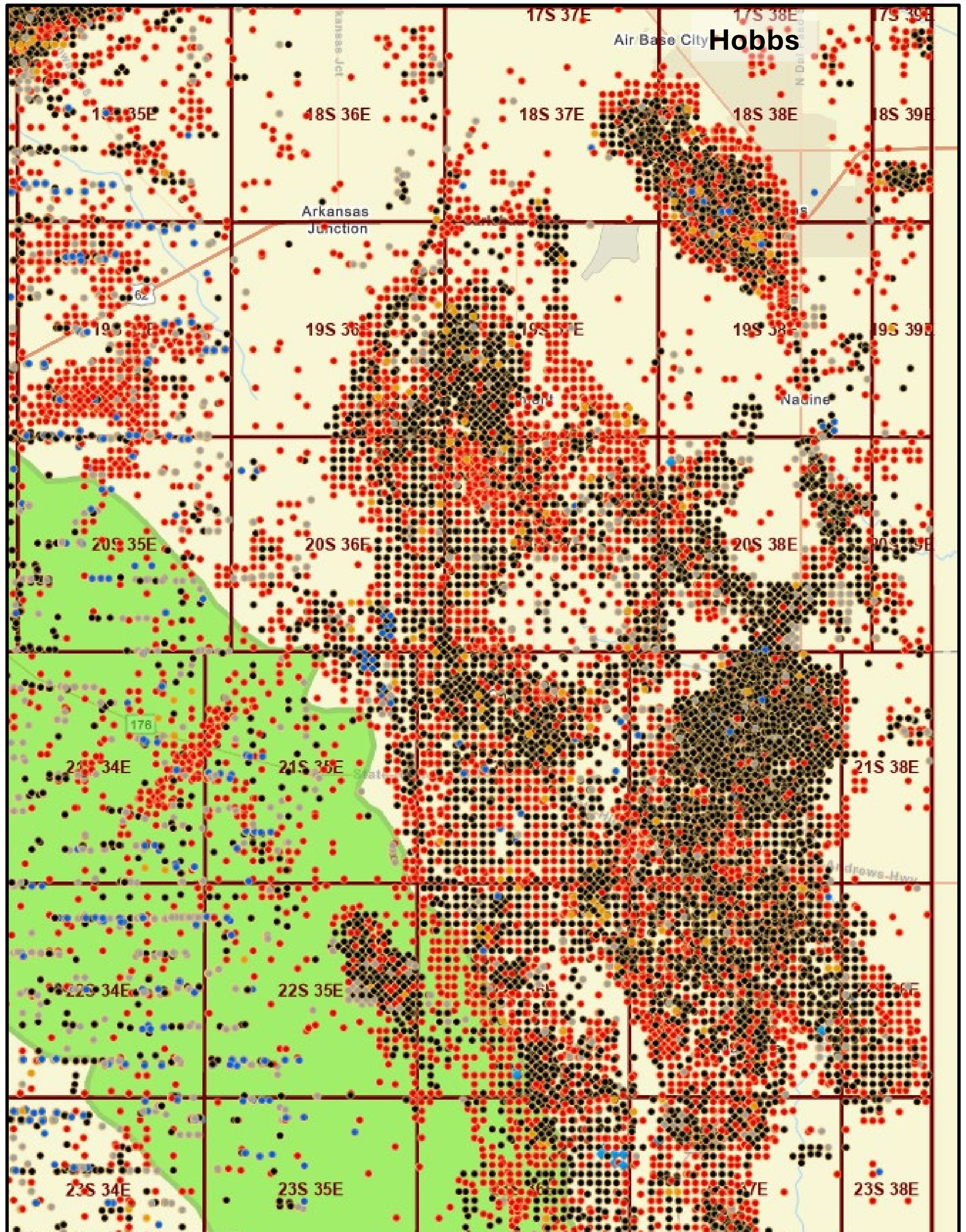
State of New Mexico
Energy, Minerals and Natural Resources Department
Oil Conservation Division

Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027
OCD Exhibit No. 1

Exhibit 1A: Map showing all well locations in the area southwest of Hobbs and the location of the Capitan Reef Aquifer.



Index Map

EXPLANATION

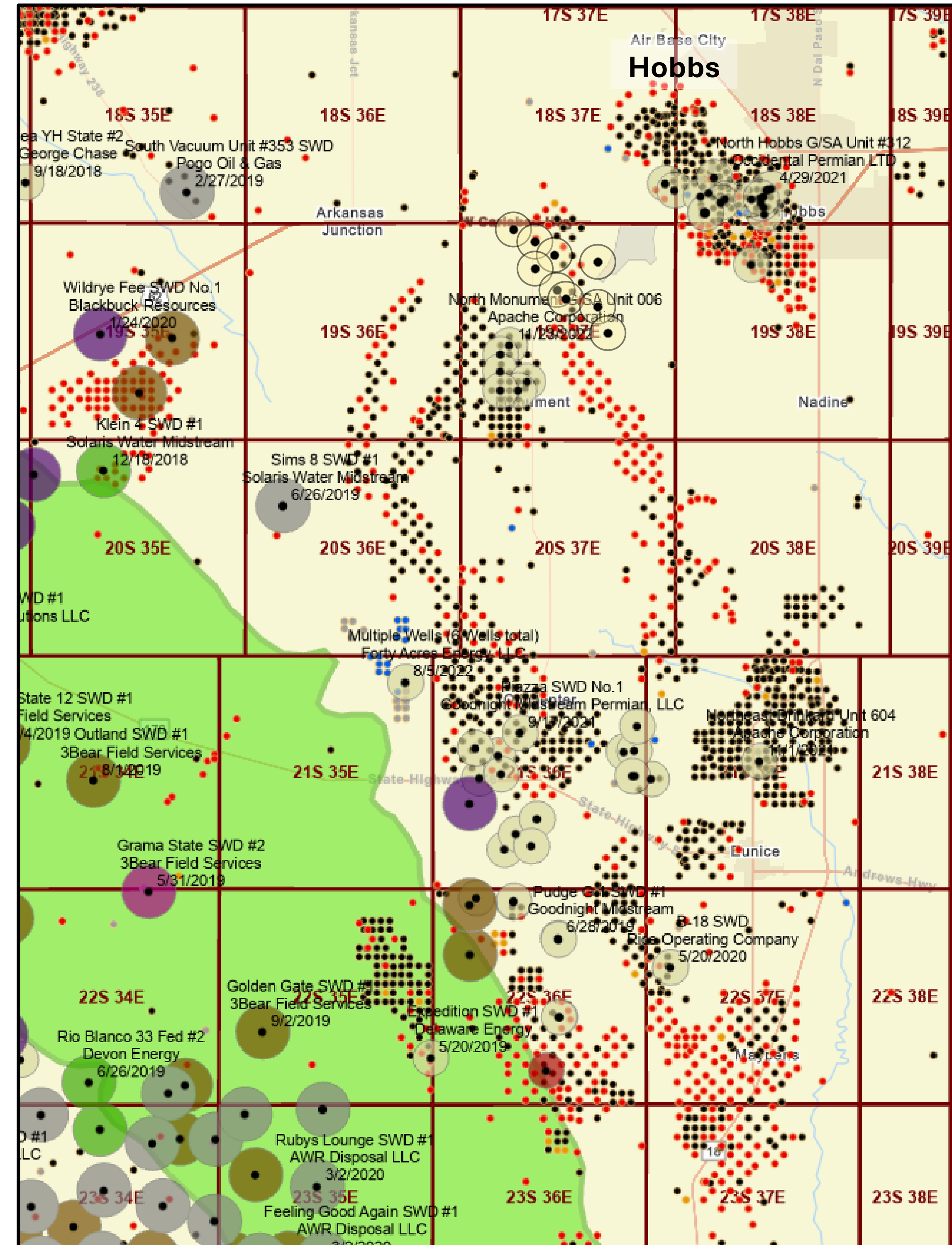
- Outline of Capitan Reef Aquifer (Hiss; 1975)
- Location of proposed well with approved APDs
- Location of producing well
- Location of plugged and abandoned well
- Location of UIC Class II permit and AOR for Non-DMG shallow applications since 2020.

Devonian Applications

- Administrative App
- Approved
- Hearing
- Protested
- Lapsed
- Dismissed / Withdrawn
- Undefined

[Others well symbols defined at OCD GIS website]
Source: NMOCD ArcGIS Database

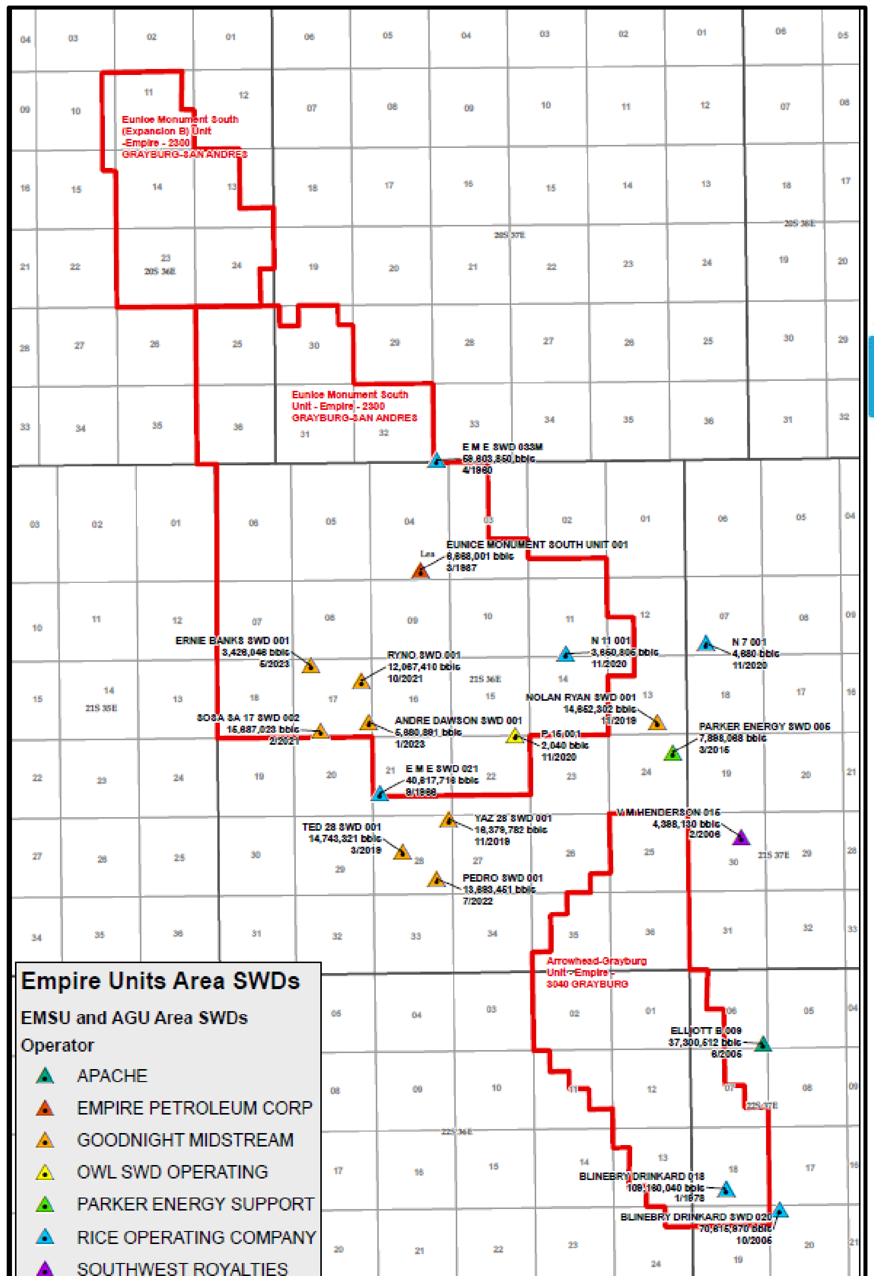
Exhibit 1B: Modified Exhibit 1A showing only UIC Class II well locations and applications for UIC Class II permits (disposal and ER).



State of New Mexico
Energy, Minerals and Natural Resources Department
Oil Conservation Division

Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027
OCD Exhibit No. 2

Exhibit 2A: Map (from Motion) Showing Goodnight's Disposal Wells in San Andres Interval and Existing Waterfloods



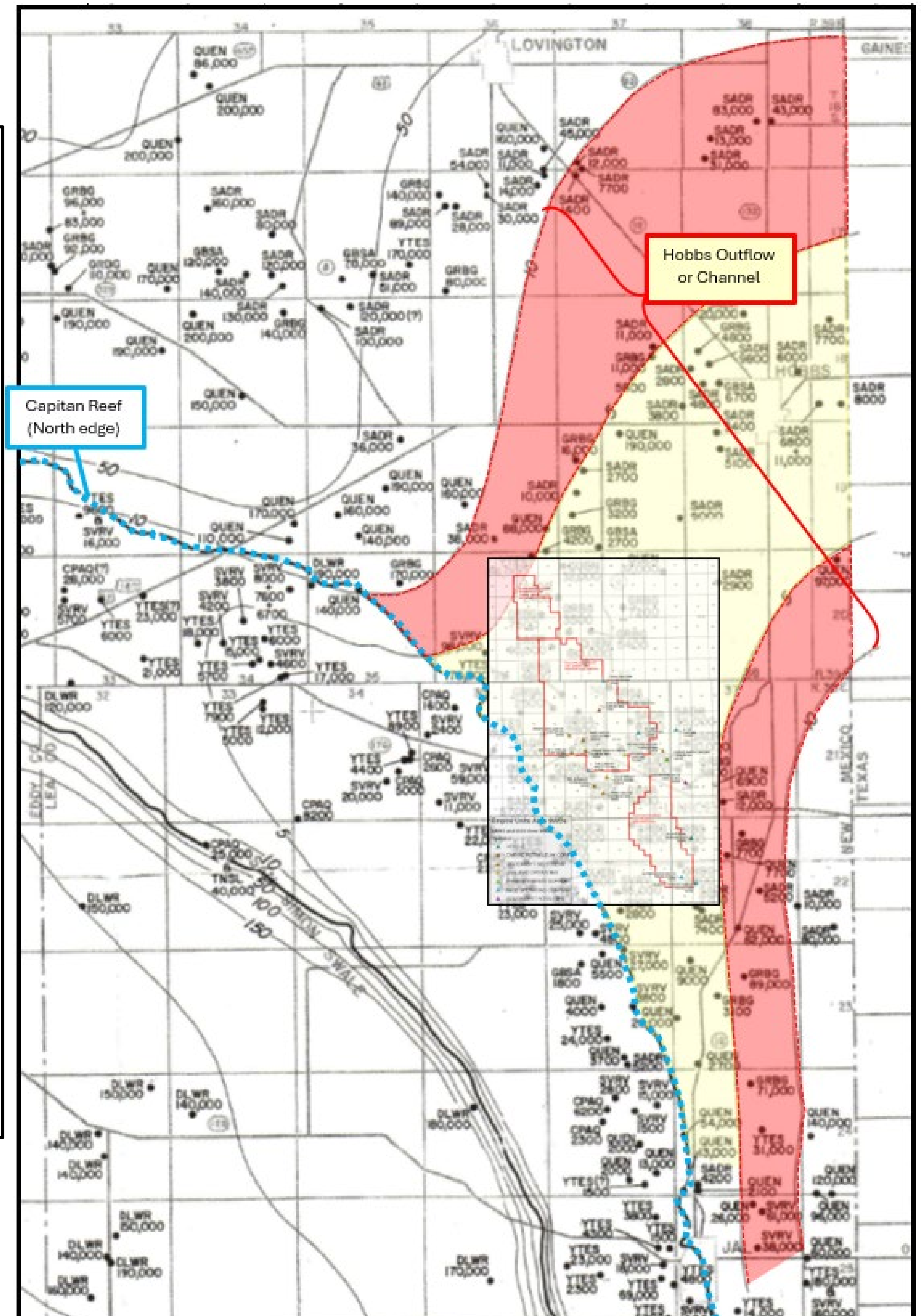


Exhibit 2C: Detail Map Showing Existing Waterfloods and Pending Applications North of the EMSU

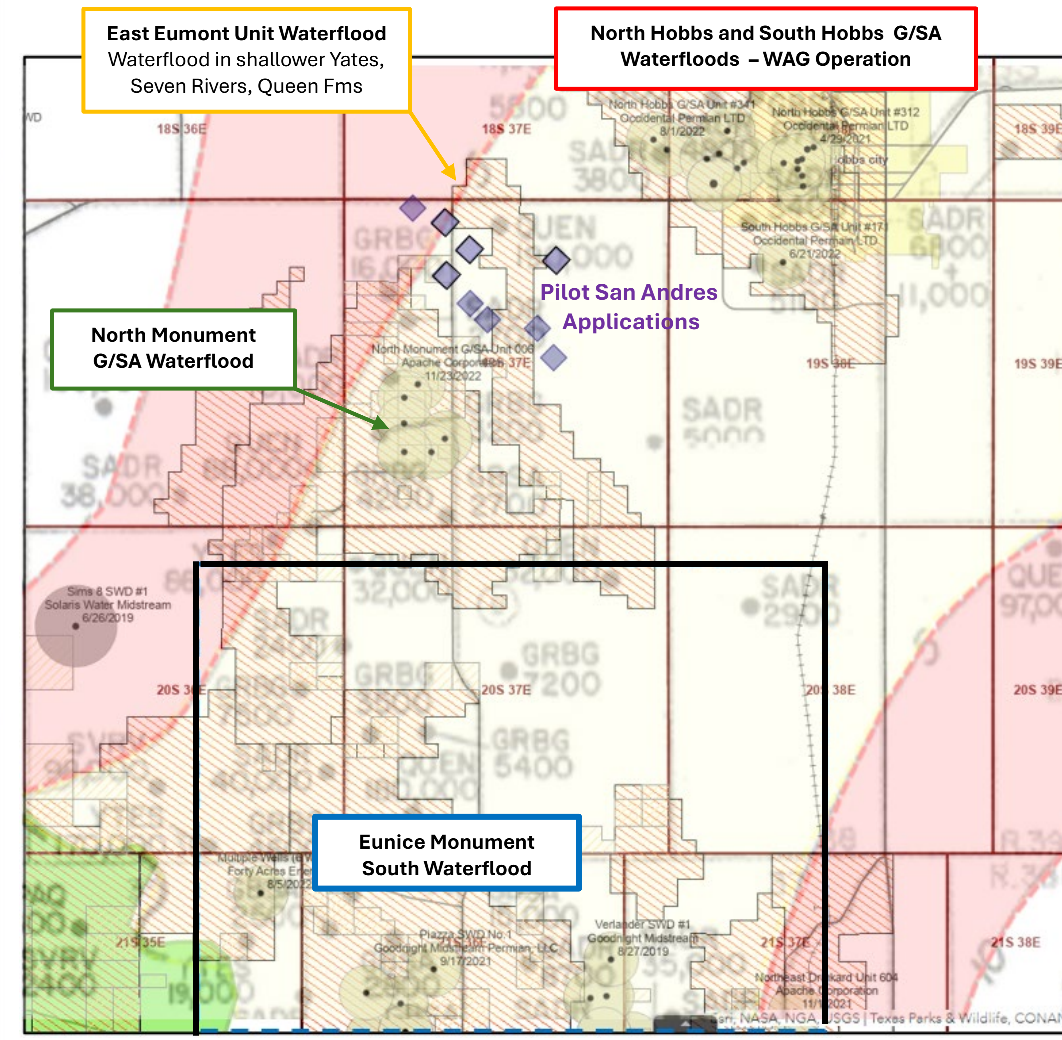


Exhibit 2B: Map Showing Goodnight's Disposal Wells in San Andres Interval and Existing Waterfloods Locations (Exhibit 2A) Relative to the Hobbs Channel and Capitan Reef

TDS values as compiled by Hiss (1975);
Map items: 10 is an inferred 10,000 mg/l contour; 5 is an inferred 5,000 mg/l contour

the new rule, so where the New Mexico oil conservation commission (commission) adopted a rule in 2013 that differed from a rule adopted in 2008, despite being based on identical evidence, the new rule was not arbitrary and capricious where the commission enumerated its reasons for adopting the 2013 rule, gave detailed explanations for the standards and requirements that it created in the 2013 rule and, in its order promulgating the rule, provided additional basis for, and reasoning behind, adopting the 2013 rule. Petitioners failed to meet their burden of demonstrating that the 2013 rule is not reasonably related to the commission's legislative purpose. *Earthworks' Oil & Gas Accountability Project v. N.M. Oil Conservation Comm'n*, 2016-NMCA-055, cert. denied.

Former act to prohibit waste. — There was no delegation to the commission of power to make law or determine what it shall be in the former Oil Conservation Act, but act was, in effect, a prohibition against waste. 1951 Op. Att'y Gen. No. 51-5397.

Law reviews. — For comment on Cont'l Oil Co. v. Oil Conservation Comm'n, 70 N.M. 310, 373 P.2d 809 (1962), see 3 Nat. Res. J. 178 (1963).

Am. Jur. 2d, A.L.R. and C.J.S. references. — 38 Am. Jur. 2d Gas and Oil §§ 145 to 148, 157.

58 C.J.S. Mines and Minerals §§ 229, 234.

70-2-12. Enumeration of powers.

A. The oil conservation division of the energy, minerals and natural resources department may:

(1) collect data;

(2) make investigations and inspections;

(3) examine properties, leases, papers, books and records;

(4) examine, check, test and gauge oil and gas wells, tanks, plants, refineries and all means and modes of transportation and equipment;

(5) hold hearings;

(6) provide for the keeping of records and the making of reports and for the checking of the accuracy of the records and reports;

(7) limit and prorate production of crude petroleum oil or natural gas or both as provided in the Oil and Gas Act; and

(8) require either generally or in particular areas certificates of clearance or tenders in connection with the transportation of crude petroleum oil or natural gas or any products of either or both oil and products or both natural gas and products.

B. The oil conservation division may make rules and orders for the purposes and with respect to the subject matter stated in this subsection:

(1) to require dry or abandoned wells to be plugged in a way so as to confine the crude petroleum oil, natural gas or water in the strata in which it is found and to prevent it from escaping into other strata; pursuant to Section 70-2-14 NMSA 1978, the division shall require financial assurance conditioned for the performance of the rules;

(2) to prevent crude petroleum oil, natural gas or water from escaping from strata in which it is found into other strata;

(3) to require reports showing locations of all oil or gas wells and for the filing of logs and drilling records or reports;

(4) to prevent the drowning by water of any stratum or part thereof capable of producing oil or gas or both oil and gas in paying quantities and to prevent the premature and irregular encroachment of water or any other kind of water encroachment that reduces or tends to reduce the total ultimate recovery of crude petroleum oil or gas or both oil and gas from any pool;

(5) to prevent fires;

(6) to prevent "blow-ups" and "caving" in the sense that the conditions indicated by such terms are generally understood in the oil and gas business;

(7) to require wells to be drilled, operated and produced in such manner as to prevent injury to neighboring leases or properties;

(8) to identify the ownership of oil or gas producing leases, properties, wells, tanks, refineries, pipelines, plants, structures and all transportation equipment and facilities;

(9) to require the operation of wells with efficient gas-oil ratios and to fix such ratios;

(10) to fix the spacing of wells;

(11) to determine whether a particular well or pool is a gas or oil well or a gas or oil pool, as the case may be, and from time to time to classify and reclassify wells and pools accordingly;

(12) to determine the limits of any pool producing crude petroleum oil or natural gas or both and from time to time redetermine the limits;

(13) to regulate the methods and devices employed for storage in this state of oil or natural gas or any product of either, including subsurface storage;

(14) to permit the injection of natural gas or of any other substance into any pool in this state for the purpose of repressuring, cycling, pressure maintenance, secondary or any other enhanced recovery operations;

(15) to regulate the disposition, handling, transport, storage, recycling, treatment and disposal of produced water during, or for reuse in, the exploration, drilling, production, treatment or refinement of oil or gas, including disposal by injection pursuant to authority delegated under the federal Safe Drinking Water Act, in a manner that protects public health, the environment and fresh water resources;

(16) to determine the limits of any area containing commercial potash deposits and from time to time redetermine the limits;

(17) to regulate and, where necessary, prohibit drilling or producing operations for oil or gas within any area containing commercial deposits of potash where the operations would have the effect unduly to reduce the total quantity of the commercial deposits of potash that may reasonably be recovered in commercial quantities or where the operations would interfere unduly with the orderly commercial development of the potash deposits;

(18) to spend the oil and gas reclamation fund and do all acts necessary and proper to plug dry and abandoned oil and gas wells and to restore and remediate abandoned well sites and associated production facilities in accordance with the provisions of the Oil and Gas Act, the rules adopted under that act and the Procurement Code [13-1-28 to 13-1-199 NMSA 1978], including disposing of salvageable equipment and material removed from oil and gas wells being plugged by the state;

(19) to make well price category determinations pursuant to the provisions of the federal Natural Gas Policy Act of 1978 or any successor act and, by regulation, to adopt fees for such determinations, which fees shall not exceed twenty-five dollars ($25.00) per filing. Such fees shall be credited to the account of the oil conservation division by the state treasurer and may be expended as authorized by the legislature;

(20) to regulate the construction and operation of oil treating plants and to require the posting of bonds for the reclamation of treating plant sites after cessation of operations;

(21) to regulate the disposition of nondomestic wastes resulting from the exploration, development, production or storage of crude oil or natural gas to protect public health and the environment; and

(22) to regulate the disposition of nondomestic wastes resulting from the oil field service industry, the transportation of crude oil or natural gas, the treatment of natural gas or the refinement of crude oil to protect public health and the environment, including administering the Water Quality Act [Chapter 74, Article 6 NMSA 1978] as provided in Subsection E of Section 74-6-4 NMSA 1978.

History: 1953 Comp., §65-3-11, enacted by Laws 1978, ch. 71, §1; 1986, ch. 76, §1; 1987, ch. 234, §61; 1989, ch. 289, §1; 1996, ch. 72, §2; 2004, ch. 87, §2; 2018, ch. 16, §1; 2019, ch. 197, §6.

ANNOTATIONS

Repeals and reenactments. — Laws 1978, ch. 71, §1, repealed 65-3-11, 1953 Comp. (former 70-2-12 NMSA 1978), relating to enumeration of powers, and enacted a new 70-2-12 NMSA 1978.

Cross references. — For filing rules and regulations, *see* 14-4-3 NMSA 1978.

For public utilities commission's lack of power to regulate sale price at wellhead, *see* 62-6-4 NMSA 1978.

For the federal Natural Gas Policy Act of 1978, *see* 15 U.S.C. §3301 et seq.

The 2019 amendment, effective July 1, 2019, authorized the oil conservation division of the energy, minerals and natural resources department to make rules and orders to regulate the disposition, handling, transport, storage, recycling, treatment and disposal of produced water; and in Subsection B, Paragraph B(15), after "regulate the disposition", deleted "of water produced or used in connection with the drilling for or producing of oil or gas or both and to direct surface or subsurface disposal of the water, including disposition by use in drilling for or production of oil or gas, in road construction or maintenance or other construction, in the generation of electricity or in other industrial processes, in a manner that will afford reasonable protection against contamination of fresh water supplies designated by the state engineer" and added the remainder of the paragraph.

Applicability. — Laws 2019, ch. 197, §12 provided that the provisions of Laws 2019, ch. 197 apply to contracts entered into on and after July 1, 2019.

The 2018 amendment, effective May 16, 2018, aligned the financial assurance requirements of this section with Section 70-2-14 NMSA 1978 for the plugging of dry or abandoned wells, and made stylistic changes throughout; in Subsection A, in the introductory clause, deleted "Included in the power given to", and after "natural resources department", deleted "is the authority to" and added "may", and added paragraph designations "(1)" through "(8)"; and in Subsection B, in the introductory clause, deleted "Apart from any authority, express or implied, elsewhere given to or existing in the oil conservation division by virtue of the Oil and Gas Act or the statutes of

History: 1953 Comp., § 65-9-7, enacted by Laws 1963, ch. 139, § 7; 1977, ch. 255, § 72; 1981, ch. 125, § 53.

ANNOTATIONS

Cross references. — For telegraph and telephone companies' right of eminent domain, *see* 42A-2-2 to 42A-2-4 NMSA 1978.

For railroads' right of eminent domain, *see* 42A-2-3 and 42A-2-4 NMSA 1978.

70-6-8. Ownership of injected gas.

All natural gas which has previously been reduced to possession, and which is subsequently injected into underground storage in any strata or formation shall at all times be deemed the property of the injector, his heirs, successors or assigns; and in no event shall such gas be subject to the right of the owner of the surface of said lands or of any mineral interest therein, under which said strata or formation lie, or of any person other than the injector, his heirs, successors and assigns, to produce, take, reduce to possession, waste or otherwise interfere with or exercise any control thereover, provided that the injector, his heirs, successors and assigns shall have no right to gas in any stratum, formation or portion thereof, in which storage rights have not been acquired pursuant to this act [70-6-1 to 70-6-8 NMSA 1978], or otherwise purchased.

History: 1953 Comp., § 65-9-8, enacted by Laws 1963, ch. 139, § 8.

ANNOTATIONS

Am. Jur. 2d, A.L.R. and C.J.S. references. — Rights and liabilities with respect to natural gas reduced to possession and subsequently stored in natural reservoir, 94 A.L.R.2d 543.

ARTICLE 7
Statutory Unitization Act

70-7-1. Purpose of act.

The legislature finds and determines that it is desirable and necessary under the circumstances and for the purposes hereinafter set out to authorize and provide for the unitized management, operation and further development of the oil and gas properties to which the Statutory Unitization Act is applicable, to the end that greater ultimate recovery may be had therefrom, waste prevented, and correlative rights protected of all owners of mineral interests in each unitized area. It is the intention of the legislature that the Statutory Unitization Act apply to any type of operation that will substantially increase the recovery of oil above the amount that would be recovered by primary recovery alone and not to what the industry understands as exploratory units.

History: 1953 Comp., 65-14-1, enacted by Laws 1975, ch. 293, 1.

ANNOTATIONS

Law reviews. — For article, "On an Institutional Arrangement for Developing Oil and Gas in the Gulf of Mexico," see 26 Nat. Res. J. 717 (1986).

70-7-2. Short title.

This act [70-7-1 to 70-7-21 NMSA 1978] may be cited as the "Statutory Unitization Act."

History: 1953 Comp., 65-14-2, enacted by Laws 1975, ch. 293, 2.

70-7-3. Additional powers and duties of the oil conservation division.

Subject to the limitations of the Statutory Unitization Act, the oil conservation division of the energy, minerals and natural resources department, hereinafter referred to as the "division", is vested with jurisdiction, power and authority and it shall be its duty to make and enforce such orders and do such things as may be necessary or proper to carry out and effectuate the purposes of the Statutory Unitization Act.

History: 1953 Comp., 65-14-3, enacted by Laws 1975, ch. 293, 3; 1977, ch. 255, 109; 1987, ch. 234, 67.

ANNOTATIONS

The 1987 amendment, effective July 1, 1987, substituted "energy, minerals and natural resources" for "energy and minerals" and made minor changes in language.

70-7-4. Definitions.

For the purposes of the Statutory Unitization Act, unless the context otherwise requires:

A. "pool" means an underground reservoir containing a common accumulation of crude petroleum oil or natural gas or both. Each zone of a general structure, which zone is completely separate from any other zone in the structure, is covered by the word pool as used herein. Pool is synonymous with "common source of supply" and with "common reservoir";

B. "oil and gas" means crude oil, natural gas, casinghead gas, condensate or any combination thereof;

C. "waste," in addition to its meaning in Section 70-2-3 NMSA 1978, shall include both economic and physical waste resulting, or that could reasonably be expected to result, from the development and operation separately of tracts that can best be developed and operated as a unit;

D. "working interest" means an interest in unitized substances by virtue of a lease, operating agreement, fee title or otherwise, excluding royalty owners, owners of overriding royalties, oil and gas payments, carried interests, mortgages and lien claimants but including a carried interest, the owner of which is primarily obligated to pay, either in cash or out of production or otherwise, a portion of the unit expense; however, oil and gas rights that are free of lease or other instrument creating a working interest shall be regarded as a working interest to the extent of seven-eighths thereof and a royalty interest to the extent of the remaining one-eighth thereof;

E. "working interest owner" or "lessee" means a person who owns a working interest;

F. "royalty interest" means a right to or interest in any portion of the unitized substances or proceeds thereof other than a working interest;

G. "royalty owner" means a person who owns a royalty interest;

H. "unit operator" means the working interest owner, designated by working interest owners under the unit operating agreement or the division to conduct unit operations, acting as operator and not as a working interest owner;

I. "basic royalty" means the royalty reserved in the lease but in no event exceeding one-eighth; and

J. "relative value" means the value of each separately owned tract for oil and gas purposes and its contributing value to the unit in relation to like values of other tracts in the unit, taking into account acreage, the quantity of oil and gas recoverable therefrom, location on structure, its probable productivity of oil and gas in the absence of unit operations, the burden of operation to which the tract will or is likely to be subjected, or so many of said factors, or such other pertinent engineering, geological, operating or pricing factors, as may be reasonably susceptible of determination.

History: 1953 Comp., 65-14-4, enacted by Laws 1975, ch. 293, 4; 1977, ch. 255, 110.

70-7-5. Requisites of application for unitization.

Any working interest owner may file an application with the division requesting an order for the unit operation of a pool or any part thereof. The application shall contain:

A. a description of the proposed unit area and the vertical limits to be included therein with a map or plat thereof attached;

B. a statement that the reservoir or portion thereof involved in the application has been reasonably defined by development;

C. a statement of the type of operations contemplated for the unit area;

D. a copy of a proposed plan of unitization which the applicant considers fair, reasonable and equitable;

E. a copy of a proposed operating plan covering the manner in which the unit will be supervised and managed and costs allocated and paid; and

F. an allegation of the facts required to be found by the division under Section 70-7-6 NMSA 1978.

History: 1953 Comp., § 65-14-5, enacted by Laws 1975, ch. 293, § 5; 1977, ch. 255, § 111.

ANNOTATIONS

Am. Jur. 2d, A.L.R. and C.J.S. references. — 38 Am. Jur. 2d Gas and Oil §§ 164, 172.

Compulsory pooling or unitization statute or ordinance requiring owners or lessees of oil and gas lands to develop their holdings as a single drilling unit and the like, 37 A.L.R.2d 434.

70-7-6. Matters to be found by the division precedent to issuance of unitization order.

A. After an application for unitization has been filed with the division and after notice and hearing, all in the form and manner and in accordance with the procedural requirements of the division, and prior to reaching a decision on the petition, the division shall determine whether or not each of the following conditions exists:

(1) that the unitized management, operation and further development of the oil or gas pool or a portion thereof is reasonably necessary in order to effectively carry on pressure maintenance or secondary or tertiary recovery operations, to substantially increase the ultimate recovery of oil and gas from the pool or the unitized portion thereof;

(2) that one or more of the said unitized methods of operations as applied to such pool or portion thereof is feasible, will prevent waste and will result with reasonable

probability in the increased recovery of substantially more oil and gas from the pool or unitized portion thereof than would otherwise be recovered;

(3) that the estimated additional costs, if any, of conducting such operations will not exceed the estimated value of the additional oil and gas so recovered plus a reasonable profit;

(4) that such unitization and adoption of one or more of such unitized methods of operation will benefit the working interest owners and royalty owners of the oil and gas rights within the pool or portion thereof directly affected;

(5) that the operator has made a good faith effort to secure voluntary unitization within the pool or portion thereof directly affected; and

(6) that the participation formula contained in the unitization agreement allocates the produced and saved unitized hydrocarbons to the separately owned tracts in the unit area on a fair, reasonable and equitable basis.

B. If the division determines that the participation formula contained in the unitization agreement does not allocate unitized hydrocarbons on a fair, reasonable and equitable basis, the division shall determine the relative value, from evidence introduced at the hearing, taking into account the separately owned tracts in the unit area, exclusive of physical equipment, for development of oil and gas by unit operations, and the production allocated to each tract shall be the proportion that the relative value of each tract so determined bears to the relative value of all tracts in the unit area.

C. When the division determines that the preceding conditions exist, it shall make findings to that effect and make an order creating the unit and providing for the unitization and unitized operation of the pool or portion thereof described in the order, all upon such terms and conditions as may be shown by the evidence to be fair, reasonable, equitable and which are necessary or proper to protect and safeguard the respective rights and obligations of the working interest owners and royalty owners.

History: 1953 Comp., § 65-14-6, enacted by Laws 1975, ch. 293, § 6; 1977, ch. 255, § 112.

70-7-7. Division orders.

The order providing for unitization and unit operation of a pool or part of a pool shall be upon terms and conditions that are fair, reasonable and equitable and shall approve or prescribe a plan or unit agreement for unit operation which shall include:

A. a legal description in terms of surface area of the pool or part of the pool to be operated as a unit and the vertical limits to be included, termed "the unit area";

B. a statement of the nature of the operations contemplated;

C. an allocation to the separately owned tracts in the unit area of all the oil and gas that is produced from the unit area and is saved, being the production that is not used in the conduct of operations on the unit area or not unavoidably lost;

D. a provision for the credits and charges to be made in the adjustment among the owners in the unit area for their respective investments in wells, tanks, pumps, machinery, materials and equipment contributed to the unit operations;

E. a provision governing how the costs of unit operations, including capital investments, shall be determined and charged to the separately owned tracts and how the costs shall be paid, including a provision providing when, how and by whom the unit production allocated to an owner who does not pay the share of the costs of unit operations charged to that owner or the interest of that owner may be sold and the proceeds applied to the payment of costs;

F. a provision for carrying any working interest owner on a limited, carried or net-profits basis, payable out of production, upon such terms and conditions determined by the division to be just and reasonable and allowing an appropriate charge for interest for such service payable out of the owner's share of production; provided that any nonconsenting working interest owner being so carried shall be deemed to have relinquished to the unit operator all of its operating rights and working interest in and to the unit until his share of the costs are repaid, plus an amount not to exceed two hundred percent of such costs as a nonconsent penalty, with maximum penalty amount in each case to be determined by the division;

G. a provision designating the unit operator and providing for the supervision and conduct of the unit operations, including the selection, removal or substitution of an operator from among the working interest owners to conduct the unit operations;

H. a provision for a voting procedure for the decision of matters to be decided by the working interest owners in respect to which each working interest owner shall have a voting interest equal to its unit participation;

I. the time when the unit operation shall commence and the manner in which and the circumstances under which the operations shall terminate and for the settlement of accounts upon termination; and

J. such additional provisions as are found to be appropriate for carrying on the unit operations and for the protection of correlative rights and the prevention of waste.

History: 1953 Comp., § 65-14-7, enacted by Laws 1975, ch. 293, § 7; 1977, ch. 255, § 113; 1986, ch. 55, § 1.

ANNOTATIONS

The 1986 amendment, effective May 21, 1986, at the end of Subsection F, added the language following "in and to the unit until" and made minor stylistic changes throughout the section.

70-7-8. Ratification or approval of plan by owners.

A. No order of the division providing for unit operations shall become effective unless and until the plan for unit operations prescribed by the division has been approved in writing by those persons who, under the division's order, will be required initially to pay at least seventy-five percent of the costs of the unit operations, and also by the owners of at least seventy-five percent of the production or proceeds thereof that will be credited to interests which are free of cost such as royalties, overriding royalties and production payments, and the division has made a finding either in the order providing for unit operations or in a supplemental order that the plan for unit operations has been so approved. Notwithstanding any other provisions of this section, if seventy-five percent or more of the unit area is owned, as to working interest, by one working interest owner, such working interest owner must be joined by at least one other working interest owner in ratifying and approving the plan of unit operations, unless such working interest owner is the owner of one hundred percent of the working interest in said unit area; provided, however, if a single owner is one who, under the division's order will be required initially to pay at least twenty-five percent, but not more than fifty percent, of the costs of unit operation, such owner must be joined by at least one other owner of the same type interest in disapproving, or failure to approve, the plan of unit operations to defeat the plan.

B. If one owner is the owner of at least twenty-five percent, but not more than fifty percent, of the production or proceeds thereof that will be credited to interests which are free of costs, such owner must be joined by at least one other owner of the same type interest in disapproving, or failure to approve, the plan of unit operations to defeat the plan.

C. If the persons owning the required percentage of interest in the unit area do not approve the plan for unit operations within a period of six months from the date on which the order providing for unit operations is made, such order shall cease to be of further force and effect and shall be revoked by the division, unless the division shall extend the time for ratification for good cause shown.

D. When the persons owning the required percentage of interest in the unit area have approved the plan for unit operations, the interests of all persons in the unit are unitized whether or not such persons have approved the plan of unitization in writing.

History: 1953 Comp., § 65-14-8, enacted by Laws 1975, ch. 293, § 8; 1977, ch. 255, § 114.

70-7-9. Amendment of plan of unitization.

An order providing for unit operations may be amended by an order made by the division in the same manner and subject to the same conditions as an original order providing for unit operations, provided:

A. if such an amendment affects only the rights and interests of the working interest owners, the approval of the amendment by the royalty owners shall not be required; and

B. no such amendment shall change the percentage for the allocation of oil and gas as established for any separately owned tract by the original order, except with the consent of all working interest owners and royalty owners in such tract, or change the percentage for the allocation of costs as established for any separately owned tract by the original order, except with the consent of all working interest owners in such tract.

History: 1953 Comp., § 65-14-9, enacted by Laws 1975, ch. 293, § 9; 1977, ch. 255, § 115.

70-7-10. Previously established units.

The division, by order, may provide for the unit operation of a pool or parts thereof that embrace a unit area established by a previous order of the division. Such order, in providing for the allocation of unit production, shall first treat the unit area previously established as a single tract, and the portion of the unit production allocated thereto shall then be allocated among the separately owned tracts included in such previously established unit area in the same proportions as those specified in the previous order.

History: 1953 Comp., § 65-14-10, enacted by Laws 1975, ch. 293, § 10; 1977, ch. 255, § 116.

70-7-11. Unit operations of less than an entire pool.

An order may provide for unit operation on less than the whole of a pool where the unit area is of such size and shape as may be reasonably suitable for that purpose, and the conduct thereof will have no adverse effect upon other portions of the pool.

History: 1953 Comp., § 65-14-11, enacted by Laws 1975, ch. 293, § 11.

ANNOTATIONS

Am. Jur. 2d, A.L.R. and C.J.S. references. — 38 Am. Jur. 2d Gas and Oil §§ 164, 172.

70-7-12. Operation; expressed or implied covenants.

All operations, including but not limited to, the commencement, drilling or operation of a well upon any portion of the unit area shall be deemed for all purposes the conduct of such operations upon each separately owned tract in the unit area by the several owners thereof. The portions of the unit production allocated to a separately owned tract in a unit area shall, when produced, be deemed, for all purposes, to have been actually produced from such tract by a well drilled thereon. Operations conducted pursuant to an order of the division providing for unit operations shall constitute a fulfillment of all the express or implied obligations for each lease or contract covering lands in the unit area to the extent that compliance with such obligations cannot be had because of the order of the division.

History: 1953 Comp., § 65-14-12, enacted by Laws 1975, ch. 293, § 12; 1977, ch. 255, § 117.

ANNOTATIONS

Communitization agreement entered into with permission of prior fee owner supports implied surface access right over land subject to that agreement but not over land that is not subject to agreement. *Kysar v. Amoco Prod. Co.*, 2004-NMSC-025, 135 N.M. 767, 93 P.3d 1272.

70-7-13. Income from unitized substances.

The portion of the unit production allocated to any tract, and the proceeds from the sale thereof, shall be the property and income of the several persons to whom, or to whose credit, the same are allocated or payable under the order providing for unit operations.

History: 1953 Comp., § 65-14-13, enacted by Laws 1975, ch. 293, § 13.

70-7-14. Lien for costs.

Subject to such reasonable limitations as may be set out in the plan of unitization, the unit shall have a first and prior lien upon the leasehold estate and other oil and gas rights (exclusive of a one-eighth royalty interest or exclusive of the interest provided in the unit operating plan which allocates costs, if it is different than one-eighth) in and to each separately owned tract, the interest of the owners thereof in and to the unit production and all equipment in the possession of the unit, to secure the payment of the amount of the unit expense charged to and assessed against such separately owned tract.

History: 1953 Comp., § 65-14-14, enacted by Laws 1975, ch. 293, § 14.

70-7-15. Liability for expenses.

The obligation or liability of each working interest owner in the several separately owned tracts in the unit for the payment of unit expense at all times shall be several and not joint or collective, and a working interest owner shall not be chargeable with, obligated or liable for, directly or indirectly, more than the amount apportioned, assessed or otherwise charged to his interest in the separately owned tract pursuant to the order of unitization.

History: 1953 Comp., § 65-14-15, enacted by Laws 1975, ch. 293, § 15.

70-7-16. Division orders.

A. No division order or other contract relating to the sale or purchase of production from a separately owned tract shall be terminated by the order providing for unit operations, but shall remain in force and apply to oil and gas allocated to such tract until terminated in accordance with the provisions thereof.

B. For purposes of this section, "division order" shall mean a contract of sale to the purchaser of oil and gas.

History: 1953 Comp., § 65-14-16, enacted by Laws 1975, ch. 293, § 16; 1977, ch. 255, § 118.

70-7-17. Property rights.

Except to the extent that the parties affected so agree, no order providing for unit operations shall be construed to result in a transfer of all or any part of the title of any person to the oil and gas rights in any tract in the unit area. All property, whether real or personal, that may be acquired in the conduct of unit operations hereunder shall be acquired for the account of the working interest owners within the unit area, and shall be the property of such working interest owners in the proportion that the costs of unit operations are charged.

History: 1953 Comp., § 65-14-17, enacted by Laws 1975, ch. 293, § 17.

70-7-18. Existing rights, rights in unleased land and royalties and lease burdens.

Property rights, leases, contracts and other rights or obligations shall be regarded as amended and modified only to the extent necessary to conform to the provisions and requirements of the Statutory Unitization Act and to any valid order of the division providing for the unit operation of a pool or a part thereof, but otherwise shall remain in full force and effect. A one-eighth part of the production allocated to each tract under an order providing for the unit operation of a pool or a part thereof shall in all events be and remain free and clear of any cost or expense of developing or operating the unit and of any lien therefor as an encumbered [unencumbered] source from which to pay the royalties or other cost-free obligations due or payable with respect to the production from such tract. If a lease or other contract pertaining to a tract or interest stipulates a royalty, overriding royalty, production payment or other obligation in excess of one-eighth of the production or proceeds therefrom, then the working interest owner subject to such excess payment or other obligation shall bear and pay the same.

History: 1953 Comp., §65-14-18, enacted by Laws 1975, ch. 293, §18; 1977, ch. 255, §119.

ANNOTATIONS

Bracketed material. — The bracketed material was inserted by the compiler and is not part of the law.

70-7-19. Agreements not violative of laws governing monopolies or restraint of trade.

No agreement between or among lessees or other owners of oil and gas rights in oil and gas properties entered into pursuant hereto or with a view or for the purpose of bringing about the unitized development or operation of such properties shall be held to violate any of the statutes of this state prohibiting monopolies or acts, arrangements, agreements, contracts, combinations or conspiracies in restraint of trade or commerce.

History: 1953 Comp., §65-14-19, enacted by Laws 1975, ch. 293, §19.

70-7-20. Evidence of unit to be recorded.

A copy of each unit agreement shall be recorded in the office of the county clerk of the county or counties in which the unit is situated.

History: 1953 Comp., §65-14-20, enacted by Laws 1975, ch. 293, §20.

70-7-21. Unlawful operation.

From and after the date designated by the division that a unit plan shall become effective, the operation of any well producing from the pool within the area subject to said unit plan, by persons other than persons acting under the authority of the unit plan, or except in the manner and to the extent provided in such unit plan, shall be unlawful and is hereby prohibited.

History: 1953 Comp., §65-14-21, enacted by Laws 1975, ch. 293, §21; 1977, ch. 255, §120.

ARTICLE 8
Emergency Petroleum Products Supplies (Recompiled.)

Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027
OCD Exhibit No. 4

AQUIFER EVALUATION FOR UIC:

SEARCH FOR A SIMPLE PROCEDURE

Submitted to:

Oil Conservation Division

Department of Energy and Minerals

State of New Mexico

Prepared by:

Mike Holland, Oil Conservation Division

Tom Parkhill, Oil Conservation Division

Lee Wilson, Lee Wilson & Associates, Inc.

Mark Logsdon, Lee Wilson & Associates, Inc.

Mike Stahl, Lee Wilson & Associates, Inc.

December 31, 1980

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INTRODUCTION

The Federal Underground Injection Control (UIC) program requires protection of existing and potential underground sources of drinking water. As part of the implementation of the UIC program, the U.S. Environmental Protection Agency (EPA) has set forth procedures for determining which underground waters require protection. Figure 1 summarizes the procedures, as they are inferred from the Federal Register (see 40 CFR Part 122.3 and 40 CFR 146.04). We term Figure 1 'the Aquifer Evaluation Process'.

Application of Figure 1 results in the classification of a rock unit as a protected aquifer if it is a present source of drinking water. It is also a protected aquifer unless it is explicitly classified into one of three other categories for which UIC protection is not required: salt-water aquifer, non-aquifer or exempted aquifer. Salt-water aquifers are rock units which contain water having a total dissolved solids content (TDS) in excess of 10,000 mg/l. Non-aquifers are rock units which are not able to yield significant amounts of water to a well or spring. Exempted aquifers are rock units which are not a source of drinking water for reason of economics, technology, gross contamination, or relationship to subsidence or collapse zones.

EPA guidance regarding the aquifer evaluation process indicates that it should be relatively thorough and detailed (Ground-Water Program Guidance No. 4.2). The agency specifically suggests the use of techniques such as: maps and cross-sections showing TDS isocons; maps showing depth to base of fresh water; maps of aquifer thickness, elevation, and saturated thickness; maps of water levels in different aquifers at different dates; and many others.

In 1979 the New Mexico Oil Conservation Division (OCD) performed a prototype study to develop and assess procedures for the evaluation of aquifers. The study involved geohydrological mapping in a lithologically complex 144 square-mile area near Artesia, Eddy County, New Mexico. Procedures used and maps produced followed EPA guidance. The results indicate that rock units can be mapped and evaluated as required by the UIC program. However, studies of the scope suggested by the EPA guidance were estimated to cost at least $10 per square mile, which would impose a considerable cost on the statewide implementation of the UIC program.

Interestingly, the in-depth analysis undertaken in the Artesia area produced the same protection of drinking water as had long been enforced by the State OCD. The results of aquifer classification from the State program and the in-depth (UIC) analysis can be compared as follows.

	State Program	UIC Program
Basis:	General geohydrologic knowledge of area	Detailed geohydrological study
Result:	Aquifers protected to base of existing drinking water aquifer; deeper units classed as salt-water aquifers	Same as State program except that some of the deeper units contain fresh water in isolated low porosity zones and are better classified as non-aquifers

In Artesia, the major benefit of a detailed geohydrologic study was to show that some rock units deemed by the State to be salt-water aquifers are in fact non-aquifers which contain fresh water. The rules for injection control are not changed by such a distinction, and consequently State regulations are correct in allowing injection below the base of the deepest existing underground source of drinking water.

On the basis of this initial prototype study, it was hypothesized that an in-depth analysis may not be required to ensure the accurate evaluation of aquifers. Rather, evaluations might be performed satisfactorily at a reconnaissance level, using procedures similar to those already applied by the State. Such an approach would reduce costs of implementing the UIC program, without endangering water supplies. In 1980 OCD performed a second study aimed at testing this hypothesis. The area chosen for study (Figure 2) was Lea County, which is the leading oil producing county in New Mexico and an area where there is considerable injection for both secondary recovery and brine disposal.

INITIAL CLASSIFICATION

The initial classification of aquifers in Lea County was based on studies of regional geohydrology published in readily available reports and supplemented by a review of the existing State regulatory program. References reviewed include: Garza and Wesselman (1959), Ash (1961a; 1961b), Nicholson and Clebsch (1961), Ash (1962), U.S. Bureau of Reclamation (1972), West and Broadhurst (1975). Appendix 1 summarizes the water-bearing characteristics of the major geologic units in the area; Figure 3 is a stratigraphic column which identifies Formation names.

The conclusion reached from the literature is that most drinking water in Lea County is obtained from shallow rock units (dominantly the Tertiary Ogallala Formation), and that there is no significant amount of fresh water in rocks older than Triassic. This concept is the basis for State regulations which have permited oil-field brines to be injected into rocks of Permian age or older.[a/] Figure 4 is a map showing the base of the Triassic (also the top of the Permian Rustler Formation). Injection below this elevation is allowed by State regulations, a policy which is supported by the most readily available reports.

IN-DEPTH STUDY

A detailed aquifer evaluation study was performed in an area in the southern portion of the County (Figure 5) to determine if the reconnaissance study provided an accurate evaluation of geohydrologic conditions. The methods

a. A possible exception is that fresh water may occur in the reef limestones of the Permian Capitan Formation. Injection into the Capitan has never been proposed and therefore the State's regulatory position toward this aquifer has not been established.

used were those developed in the Artesia study: review of technical reports and unpublished data in the files of various agencies; analysis of well logs; and analysis of borehole geophysics data.

A bibliographic form (Figure 6) was completed for dozens of published and unpublished references on the geology and hydrology of the area and those references which appeared to have the best information were reviewed in detail. Also reviewed were existing water-quality records for wells which obtain water from Paleozoic rocks. The result was a reasonably comprehensive understanding of the geohydrology of a representative portion of Lea County, as shown by: geologic maps and sections; water-table maps; and maps and sections showing water quality. This level of detail is commensurate with that suggested in the EPA guidance previously cited. Based on the bibliographic forms, the references were categorized as follows.

1. Reports or articles which discuss water resources at a regional level. These are the same references reviewed during the initial study, and were cited previously.

2. References which discuss the known aquifers of Triassic age or younger (especially the Ogallala Formation), or which discuss the water supplies of the area in a general way. Such aquifers would be protected by UIC without question, and thus while these references could be of value in review of site-specific UIC permits, they are of no value in the overall aquifer evaluation process. Examples of such references include: Nye (1930), Theis (1937),

Conover and Akin (1942), USDE (1943), Burnes, et al. (1949), Yates and Galloway (1954), Minton (1956), Dinwiddie (1963), Chen and Long (1965), Long (1965), Havens (1966), Cronin (1969), Theis (1969), Hudson (1971), Mourant (1971), Theis (1971), Brown and Signor (1972), Brown and Signor (1973), Buchnan (1973), Galloway (1975), Brutsaert, et al. (1975), N.M. Interstate Stream Commission and N.M. State Engineer Office (1975), Sorensen (1977), Brown, et al. (1978), Akin and Jones (1979).

3. Articles which provide information on the history of brine contamination incidents. All such incidents involved contamination of the Ogallala Formation, with brine ponds being the principal source of the problem. These references were useful as background information for the UIC program, but do not bear directly on the evaluation of aquifers. The references include: Rice (1958), Porter (1971), Bigbee and Taylor (1972), Bigbee (1972), Wright (1979),

4. References which provide important information on Permian aquifers. These include regional studies which focus on the oil-related brine aquifers of the Permian Basin: Nicholson (1954), Borton (1960-67), Hood (1962), McNeal (1965), Hiss (1969), Chavez (1968-1979), Hiss (1973), George (1974), Hiss (1975a; 1975b, 1975c), Lambert (1978), Hiss (1980). Also included are very localized studies of the geohydrology of an area in which the analysis of aquifers is carried well into the Paleozoic: Borton (1958), Galloway (1959), West (1961), Cooper (1962), Mercer (1977). As noted below, these references

indicate that some fresh water (TDS less than 10,000 mg/l) does occur in a few of the Permian rock units.

5. References which provide information on geologic conditions below the base of the Triassic, which do not provide information related to the geo-hydrochemistry of fresh waters and thus are not directly relevent to the evaluation process. Specific citations include: Adams (1944), Stipp et al, (1956), Stipp and Haigler (1957), Hull (1960), Sweeney, et al. (1960), Brackbill and Gaines (1964), Runyan (1965), Meyer (1966), Kinney and Schutz (1967), Jones, et al. (1973), Hiss (1976).

Water wells do not penetrate the Permian in Lea County, and well logs are not available. Oil-well logs generally contain limited information of value for an evaluation of fresh-water occurrences. However, oil-well geophysical logs are a valuable resource and can be studied to verify water quality on the basis of resistivity measurements. Resistivity estimates confirm the presence of water with less than 10,000 mg/l TDS in much of Lea County. Moreover, the good water often occurs in association with zones of good porosity in the Artesia Group and San Andres Formation. Thus, this fresh water is capable of being produced by wells. The units are neither non-aquifers nor salt-water aquifers. They must be classified as protected aquifers unless there is some basis for exemption.

The literature information, as modified by the geophysical data, allow preparation of aquifer maps and cross-sections of the type prepared for the

Artesia area. As the rough draft maps and sections developed by this study are similar in format and content to those in the previous report, they have not been developed for formal presentation and are not presented in this report except for Figures 7 and 8, presented subsequently.

The important conclusion reached from the literature study is that there is some fresh-water in rocks of Paleozoic age, and a need to pursue the aquifer evaluation process with regard to these rock units. This is the same conclusion reached in Artesia, where the additional study showed the fresh-water occurs in non-aquifers.

REVISED CLASSIFICATION

Based on the detailed literature search, analysis of logs, and interpretation of geology in the study area, it is apparent that the detailed evaluation of aquifers in Lea County pursuant to UIC guidance does produce results which differ from the existing State regulatory program which is based on less detailed information. The differences can be summarized as follows.

	State Program	UIC Program
Basis:	General geohydrologic knowledge of area	Detailed geohydrological study
Result:	Aquifers protected to base of Triassic; deeper units classed as salt-water aquifers with the possible exception of the Capitan Formation	Some Paleozoic units contain fresh water in various locations and must be considered as aquifers into which injection is prohibited unless there is a basis for exempting the aquifers from protection

while the State program is generally excellent in its protection of water, any existing regulations should not be necessarily considered as complete with regard to such protection.

DELINEATION OF FRESH WATER

Geologic controls of the distribution of fresh water were studied to provide a basis for drawing the boundary within which UIC protection may be required. The results are illustrated in Figures 7 - 9. Most of the available information is taken from Hiss (1975c, 1980). The discussion which follows is technical and assumes familiarity with the classic geology of the reef facies of the Permian Basin.

Hiss (1975c) describes strata of Permian Guadalupian age which contain three separate aquifers - shelf, basin, and the Capitan reef (Figure 7). The Capitan occurs at depth within an ancient shelf-margin reef zone which surrounds the Delaware Basin in New Mexico and Texas. Most of the Capitan aquifer has permeabilities several magnitudes higher than those found in adjacent shelf facies and overlying Ochoan age lithologies.

A major paleogeographic feature of the area is known as the Hobbs Channel (Figure 8). This channel was a bathymetric low in the Permian and connected the Delaware and Midland Basins on the northern end of the Central Basin Platform. Shelf-interior skeletal sands prograded through the channel with communication of water between the basins. Interfingered with the sands are subtidal muds which have proved more susceptible to subsequent dolomitization. These shelf-margin facies correspond to the Artesia Group and San Andres limestone.

Fresh water has been supplied to the Capitan aquifer from recharge areas in the Guadalupe Mountains within Eddy County, New Mexico and the Glass Mountains in Pecos County, Texas (Figure 9). Movement of fresh water northward from the Glass Mountains caused leaching of soluble minerals from the Capitan and from overlying rocks, increasing the permeability and hydraulic conductivity of the aquifer while also increasing the salinity of the formation fluids. A recharge area also occurs in the Guadalupe Mountains to the west, but little of the fresh water from that area reached Lea County due to the existence of intervening zones of decreased permeability caused by the presence of ancient submarine canyons which incised the reef and which were filled with less permeable silts and clays. Incision of the Pecos River in the Pleistocene (?) cut off even this small amount of recharge (Figure 9b).

When the Capitan fresh water encounters permeability barriers in the vicinity of the Lea/Eddy County line, the water then moves northward into the limestone sand facies of the Hobbs Channel. Fresh water entering these facies during the Cenozoic selectively dissolved the more soluble carbonates of the skeletal sands, creating excellent permeability yet a complex path of water flow. In contrast, the dolomitized muds retain a low permeability and seldom contain fresh water. At any one elevation, permeable and impermeable rocks are complexly related according to tidal flat drainage patterns; there simply is no single widespread unit which can be described as an aquifer.

In summary, recharge from the Glass Mountains has moved northward along selectively dissolved flow paths in the Capitan Reef and Hobbs Channel. The result is the irregular occurrence of fresh water in the Capitan reef in southern Lea County and in the San Andres Formation and Artesia Group in an arcuate shaped zone which is generally along or to the east of the Capitan Reef trend (Figure 8). Hiss (1975c) provides tabular listings of water-quality data for wells in Lea County, located to the nearest section. This listing identifies approximately 175 wells which produce or tap fresh water from Paleozoic strata (where fresh water is defined as a TDS of less than 10,000 mg/l[a]).

Today the San Andres Formation within Lea County is also a prolific oil producer and supports many enhanced recovery projects and salt water disposal wells. The Capitan aquifer is a major supply of water for oil field water-flood projects. With the exploitation of fluid reserves within these two aquifers, Hiss suggests that the effects of recharge are diminishing, reducing the hydraulic load and isolating fresher waters already in place (Figure 9c).

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a. Where only chloride data are available a graphical relationship between TDS and chloride can be used to estimate TDS. According to Hiss, on the average a chloride of 5400 mg/l is equivalent to 10,000 mg/l TDS.

The initial irregular movement of fresh water, and its subsequent isolation, make it difficult to define a boundary for a protected aquifer. One may encounter oil and water at the same depth within close lateral proximity. A plot of the 175 wells with fresh water shows that some occur in total isolation from the main trends described above. For example, a few oil wells in northern Lea County produce fresh water; almost all are in rocks older than the San Andres Formation and Artesia Group (e.g. Abo Formation). Nothing in the literature or log data accounts for this fresh water, although conceivably it has migrated northward from the Hobbs Channel. For purposes of UIC, these occurrences are so isolated that there is no basis for concluding that a fresh-water aquifer exists.

A fresh-water aquifer does exist in the Capitan Formation and associated San Andres Formation and Artesia Group. Most of the fresh water is produced from wells which occur in clusters within the trend of the Capitan Reef and Hobbs Channel. However, within such clusters there are almost always wells producing saline water from the same depth. Neither data nor geologic theories allow the delineation of a boundary for fresh water.

NEED TO CONSIDER EXEMPTIONS

The Capitan Formation, San Andres Formation and Artesia Group aquifers of Lea County contain localized fresh water and therefore are subject to UIC protection. The Artesia Group and, especially, the San Andres Formation are used for brine disposal and waterflood in the study area. Table 1 lists major salt-water disposal wells in the area which inject brines in the general area of deep fresh water. Perhaps one-fifth to one-quarter of all brine disposal in southeastern New Mexico occurs into zones which are potentially protected aquifers. If injection to these aquifers is disallowed, then all the wells listed in Table 1 would be out of compliance with UIC regulations. The alternative to injection in the San Andres (4,000 - 5,000 feet deep) would be to use Devonian strata, at depths of up to 10,000 feet. A change in injection practices will be expensive and should not be undertaken without further analysis.

The State has one obvious alternative to protecting the deep aquifers of Lea County and phasing out injection into those units. This option is to apply UIC provisions for exemptions.

EVALUATION OF EXEMPTION CRITERIA

Steps 5-8 of Figure 1 indicate the procedure for determining whether the deep aquifers of Lea County may be exempt from UIC regulations. Although EPA personnel were able to provide assistance in application of the regulations, the Agency has developed no formal guidance to assist in the interpretation of the exemption criteria. Therefore, in this study a significant effort was made to develop basic concepts which might apply to the exemption procedures. The conclusions presented are preliminary and may be revised when EPA criteria are established.

Step 5 of Figure 1 shows that injection may be allowed in a fresh-water aquifer which is 'unusable as a source of drinking water because it is mineral, hydrocarbon or geothermal energy producing'. As stated this criteria envisions the disruption of a drinking water resource by the production of other resources. In Lea County such disruption could occur only in the immediate proximity of an oil pool, where fresh water is drawn into the pool and co-produced with the hydrocarbons. Protection of such fresh water would have no benefit so long as the hydrocarbon production continues.

EPA probably intended Step 5 to apply to waterflood projects; if not then UIC would eliminate all brine waterfloods in fresh-water areas. Since the regulations contain many provisions intended to minimize adverse impacts on the oil industry, it seems improbable that there was intent to adversely affect secondary-recovery oil production in this country.

In effect, Step 5 seems to allow exemption of any portion of a fresh-water aquifer which occurs in hydrologic connection with an adjoining hydrocarbon reservoir, provided that there is a direct relationship between hydrocarbon production and conditions in the aquifer. Such an exemption would apply in much of Lea County. However, there remain a number of brine-disposal wells which inject into the San Andres Formation in areas relatively removed from the oil pools of that aquifer (see Table 1). The exemption of hydrocarbon producing areas would not in itself fully resolve the apparent conflict between UIC regulations and the current activities of the oil industry in Lea County.

Step 6 of Figure 1 shows that injection may be allowed in a fresh-water aquifer which is 'unusable as a source of drinking water because it is situated at a depth or location which makes recovery of water for drinking-water purposes economically or technologically impractical'. It is difficult to understand what is meant by 'technologically impractical'. By UIC definition, a fresh-water aquifer is capable of yielding significant quantities of water to a well. Therefore there should be no technological barrier to its production. Also the water would be of sufficiently good quality that treatment is certain to be feasible. It seems prudent to ignore this provision of the regulations, since evidently there are no circumstances to which it might apply.

The criteria of 'economic impracticality' suggests that exemption might be allowed if it made no economic sense to ever use a given aquifer as a drinking water resource. At least two situations could make it economically impractical to utilize a particular deep aquifer.

1. Economics could justify exemption if the costs of fresh water from the aquifer were not competitive with costs of alternative water supplies available to an area. For example, in regions with abundant sources of cheap drinking water there would be no reason to prohibit injection into a relatively deep aquifer containing water of marginal quality. In contrast, where drinking water is scarce, a deep aquifer containing slightly saline water might well be a potentially economic water supply deserving of UIC protection.

2. Economics could justify exemption if the value of the aquifer for brine disposal were greater than its potential value as a drinking-water source. This means that the water-supply analysis described above needs to go beyond direct costs and benefits. In the specific case of a deep aquifer it means that costs of using the aquifer for drinking water should take into account the costs of abandoning the aquifer as an injection zone.

For this study a preliminary analysis was made to see if the deep fresh-water aquifers of Lea County are an economically practical source of drinking water. The analysis is summarized in Table 2. The San Andres Formation contains the largest and freshest of the potential drinking-water resources in the Hobbs Channel; the City of Hobbs is the principal area where drinking water is needed. Therefore, the analysis assumed that the fresh water in the San Andres Formation was a potential source of drinking water for the largest city in the area, Hobbs. The need for water in Hobbs was estimated for a 100-year period, and alternatives were identified for meeting that need. The costs of each option were estimated roughly and compared to the costs of the San Andres water. As summarized in the Table, the economic analysis shows that Hobbs can obtain 1.5 million acre-feet of Ogallala water at $75 per acre-foot, much less expensive than the $900+ per acre-foot cost of San Andres water. If Ogallala water were <u>not</u> available, then the San Andres water might be a realistic source of supply for Hobbs, since its cost is of the same order of magnitude as the Eastern New Mexico Water Supply Project.

Table 2 indicates that the economics of using San Andres fresh water become even more negative when its value as an injection zone are considered; changes to existing brine disposal would cost $4000 per acre-foot of fresh water protected.

It seems reasonable to conclude that the San Andres can be exempted from UIC protection on the grounds that it is economically impractical to use this aquifer as an underground source of drinking water instead of as a brine disposal zone. The same conclusion would be reached for the smaller amounts of fresh water in other aquifers such as the Artesia Group, as well as the more distant supplies in the Capitan Formation.

It is not necessary to apply steps 7 or 8 to Lea County, since all rock units have now been classified. However, for purposes of completing this analysis it is worth noting that neither step would allow exemption of the deep aquifers in Lea County. Step 7 provides exemptions for contaminated water supplies. As with step 6, it is difficult to envision any situation in which it would be technologically impractical to render water fit for human consumption. It is possible to imagine supplies which are so contaminated as to be economically unusable. However, it is not clear why injection would be allowed into such contaminated zones, since injection would cause the area of contamination to expand into portions of the aquifer which are not now contaminated.

Step 8 provides exemptions to aquifers associated with activities such as in-situ mining; such activities are absent from Lea County.

FINAL CLASSIFICATION

The study area contains the most likely part of Lea County for protection of Paleozoic aquifers. Thus the results should be applicable elsewhere in the County. The analysis of aquifers in Lea County produced results which differ from the existing State regulatory program. The differences can be summarized as follows.

	State Program	UIC Program
Basis:	General geohydrologic knowledge of area	Detailed geohydrological study
Result:	Aquifers protected to base of Triassic; deeper units classed as salt-water aquifers with the possible exception of the Capitan Formation	Some Paleozoic units contain fresh water in various locations; they are exempted from protection on the basis of economic considerations

For practical purposes, then, the approach of the State program is in compliance with the requirements of UIC.

SUMMARY OF IN-DEPTH STUDY

A general literature search indicatees that the base of fresh water in Lea County occurs at the base of the Triassic. However, more detailed evaluations supplemented by analysis of geophysical logs demonstrate that the Permian Capitan Formation, San Andres Formation and Artesia Group contain extensive amounts of water having 5,000-10,000 mg/l total dissolved solids. This water is: intermixed with more saline fluids; occurs principally in the paleo-georaphic features known as the Capitan Reef and Hobbs Channel; and is fossil (that is, there is no recharge at present).

A review of UIC criteria for aquifer exemption indicates that the Permian aquifers of Lea County should be exempt from protection; existing injection activities need not be curtailed. The criteria indicate that waterflood wells are allowable because of their importance to hydrocarbon production. This conclusion would apply anywhere in New Mexico. Brine disposal wells are allowable because the economics of such disposal more than compensate for the economic value of the fresh water. This conclusion is limited to Lea County, where there is abundant low-cost fresh water available from the Ogallala Formation, such that the Permian water is clearly not a cost-effective source of drinking water in the area.

APPENDIX 1. SUMMARY OF GEOHYDROLOGY OF LEA COUNTY.

From the literature search a number of basic findings were reached regarding the geohydrology of the area. These are shown in the list of Formations and water-bearing characteristics at the end of the Appendix.

General Geology. The principal source of water in Lea County is the Tertiary Ogallala Formation, a fine-grained, poorly consolidated, calcareous sand which crops out at or near the surface of all but the western edge of the county. In northern Lea County, where it covers most of the High Plains, the Ogallala Formation ranges in thickness from 100-250 feet; in general, the lower half of the unit is saturated. High Plains water wells yield up to 1700 gpm. Because there are no permanent streams, all recharge in the High Plains is derived from local precipitation. Because the Ogallala dips very shallowly to the south and east, there is some ground-water movement in these directions.

The Ogallala Formation in southern Lea County thins to the west and locally is covered by Quaternary alluvium which ranges from 0-400 feet thick. In many localities the Ogallala is not saturated, but along stream valleys and over the Eunice Plain, not only the Ogallala but also some of the overlying alluvium may be saturated. Water wells completed in the Ogallala Formation of southern Lea County yield from 30-700 gpm. Recharge in the southern part of the county is from both local precipitation and through-flowing streams.

The Ogallala Formation is underlain in scattered locations by Cretaceous shales and limestones. The Cretaceous sedimentary rocks are a major source of water only in the northern part of the county where the Ogallala is very thin. They yield water which is slightly more saline than that from the Ogallala, but the water is still of good quality.

Sandstones and shales of the Triassic Dockum Group underlie the Cretaceous sedimentary rocks. The Dockum Group underlies most of Lea County, but water is produced from it primarily in the southwestern and far northwestern parts of the county where overlying sediments are thin and/or unsaturated. Wells completed in the Dockum generally yield 10-15 gpm. Dockum waters average 500 mg/l sulfate, considerably higher than the 200 mg/l average of the overlying units. Recharge of the Dockum results from precipitation on up-dip outcrops of the formations along the western side of the county and from infiltration from overlying formations.

Most data sources on Lea County ground-water depict the base of useable fresh water as the bottom of the Rustler Formation (Nicholson and Clebech, 1961). As discussed in the text, W.L. Hiss (1975c) presents evidence of ground water containing less than 10,000 mg/l TDS within aquifers at depths greater than the Rustler, although none is now being used for human consumption.

LIST OF PROBABLE AQUIFERS IN LEA COUNTY, NEW MEXICO (SPO, 1967)

SYSTEM AND STRATIGRAPHIC UNIT	WATER-BEARING CHARACTERISTICS
Quaternary alluvium	Yields small quantities of usually fresh water
Tertiary Ogallala Formation	Good aquifer where saturated thickness is adequate. Has yielded up to 1,700 gpm to wells in Lea Co. Generally yields fresh water.
Cretaceous Tucumcari shale	Sand and gravel at base yields small quantities of water. Generally yields fresh to slightly saline water.
Triassic Dockum Group	Small quantities of water pumped for stock, domestic use; not everywhere reliable aquifer. Lower unit might yield small quantities of fresh water if tested.
Permian sedimentary rocks	Permeable units predominantly contain only highly saline water.
Older Paleozoic sedimentary rocks	Permeable units predominantly contain only highly saline water.
Precambrian metamorphic and igneous rocks	Probably contain little or no water.

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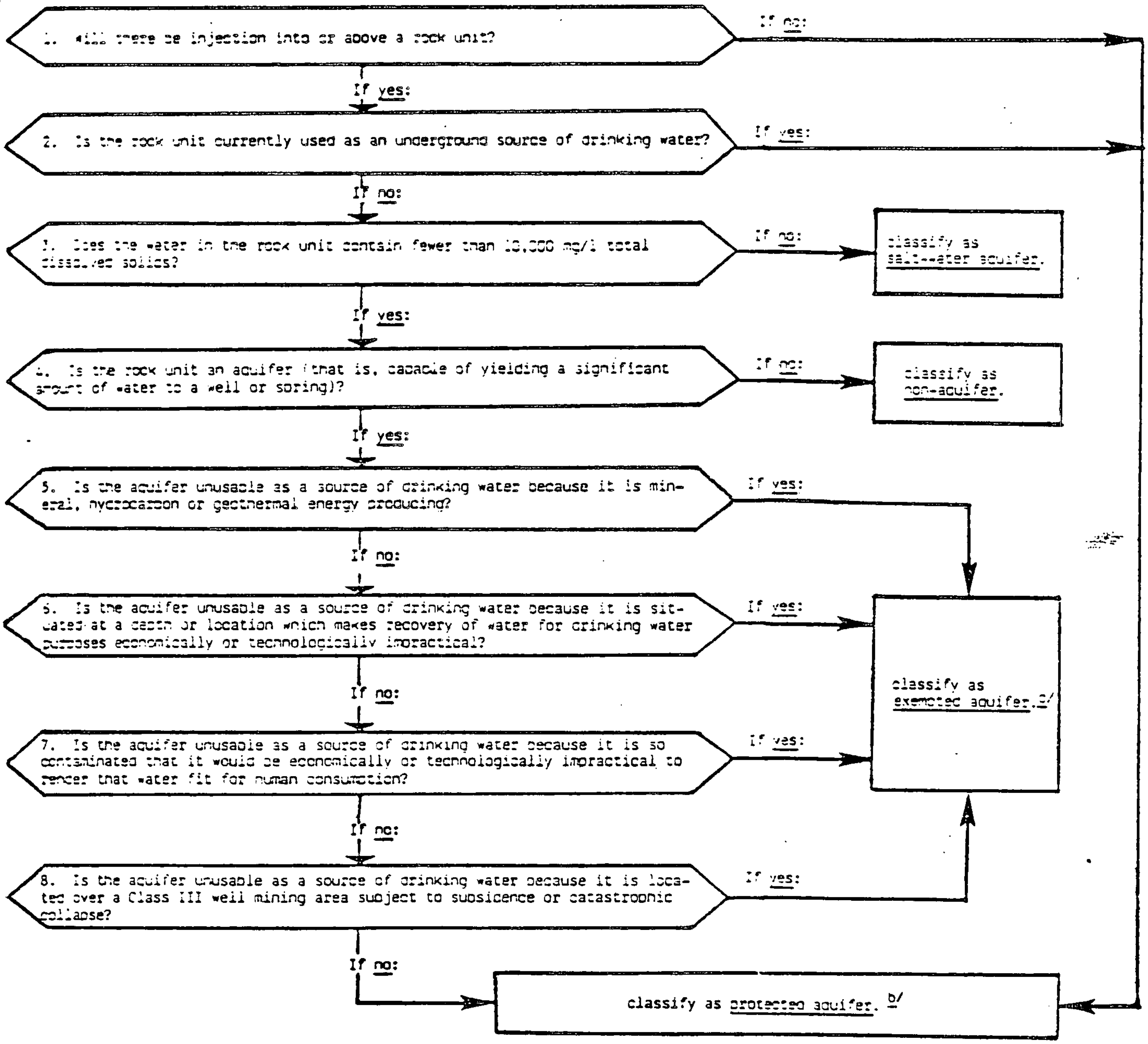
FIGURE 1. AQUIFER EVALUATION PROCESS, UNDERGROUND INJECTION CONTROL PROGRAM

Based on studies of UIC regulations in 40 CFR 122 and 146. The evaluation process involves questions about rock units a/ which can be answered by yes or no. For each question, one of the answers is shown to lead to a particular classification of the rock unit, while the other answer leads to the asking of the next question. Every rock unit must be so classified; injection by Class 1 and Class 2 wells is not allowed into any interval which is nearer to the surface than the base of the deepest protected aquifer.



a. A rock unit is a geological formation, or part thereof, which can be mapped and evaluated as to its general water-bearing and water-quality characteristics. This term is developed here because the UIC regulations contain no general term for the geological units which must be studied during aquifer classification.

b. In the case of question 1, the classification as a protected aquifer is by default, since no regulatory action is required.

c. The regulations require a public hearing prior to exemptions and explicit approval by EPA (in addition to approval by the Director of the State UIC Program). Other classifications (e.g. non-aquifer) do not appear to require a hearing and EPA approval.

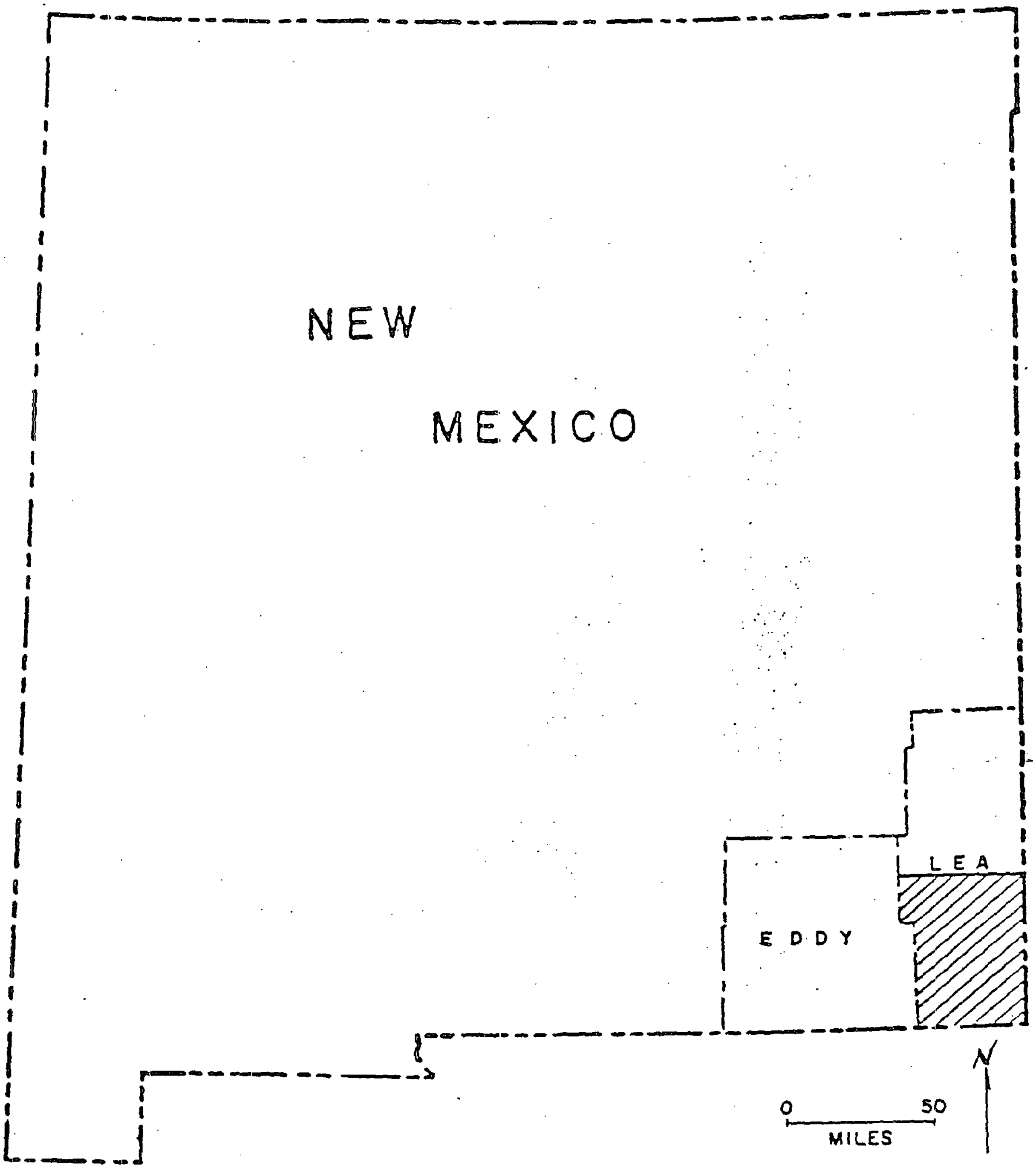


FIGURE 2. LOCATION OF STUDY AREA (LEA COUNTY, NEW MEXICO).
Slanted lines show area of intensive study.

Source: M. Holland, 1980.

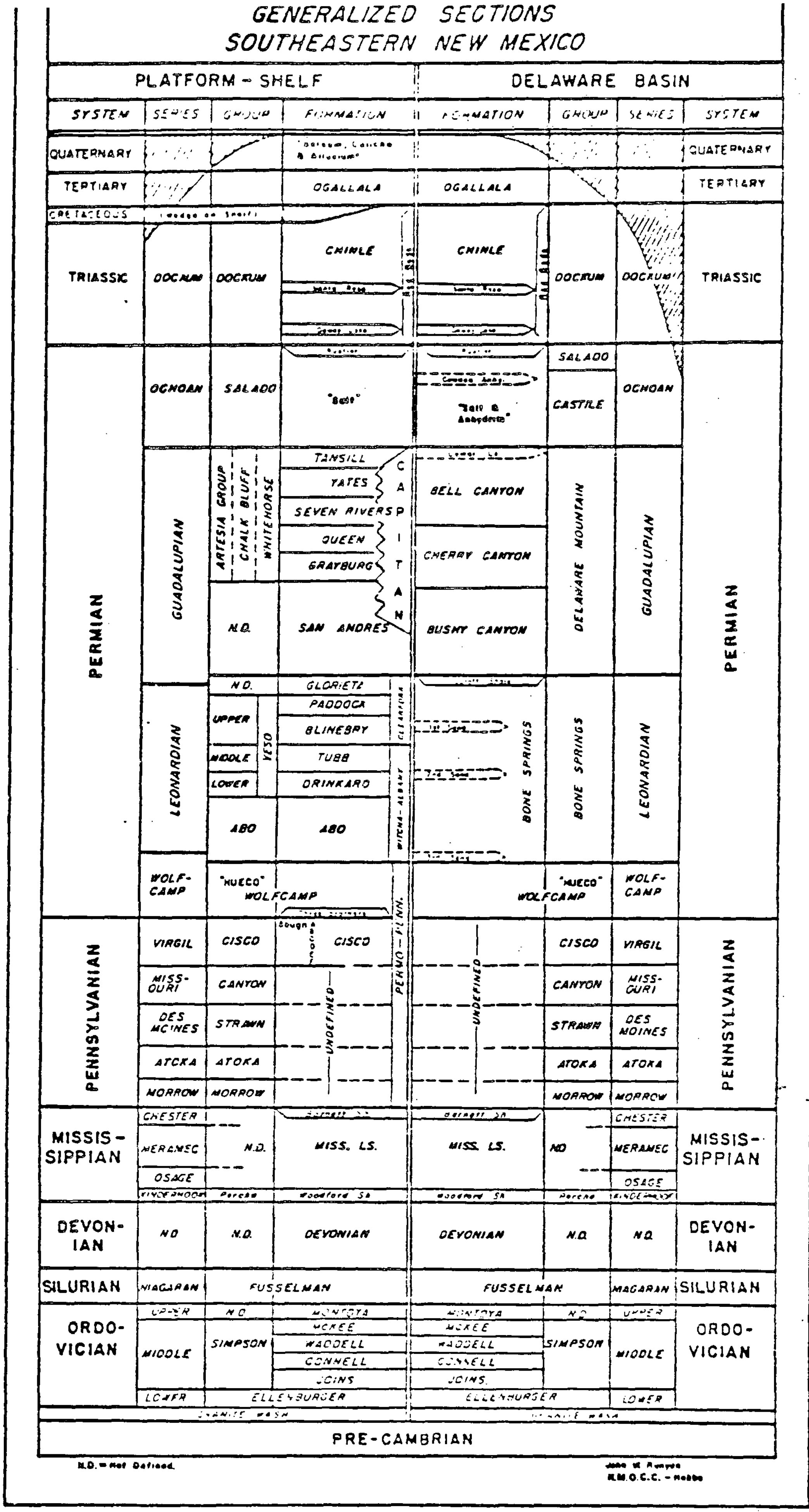
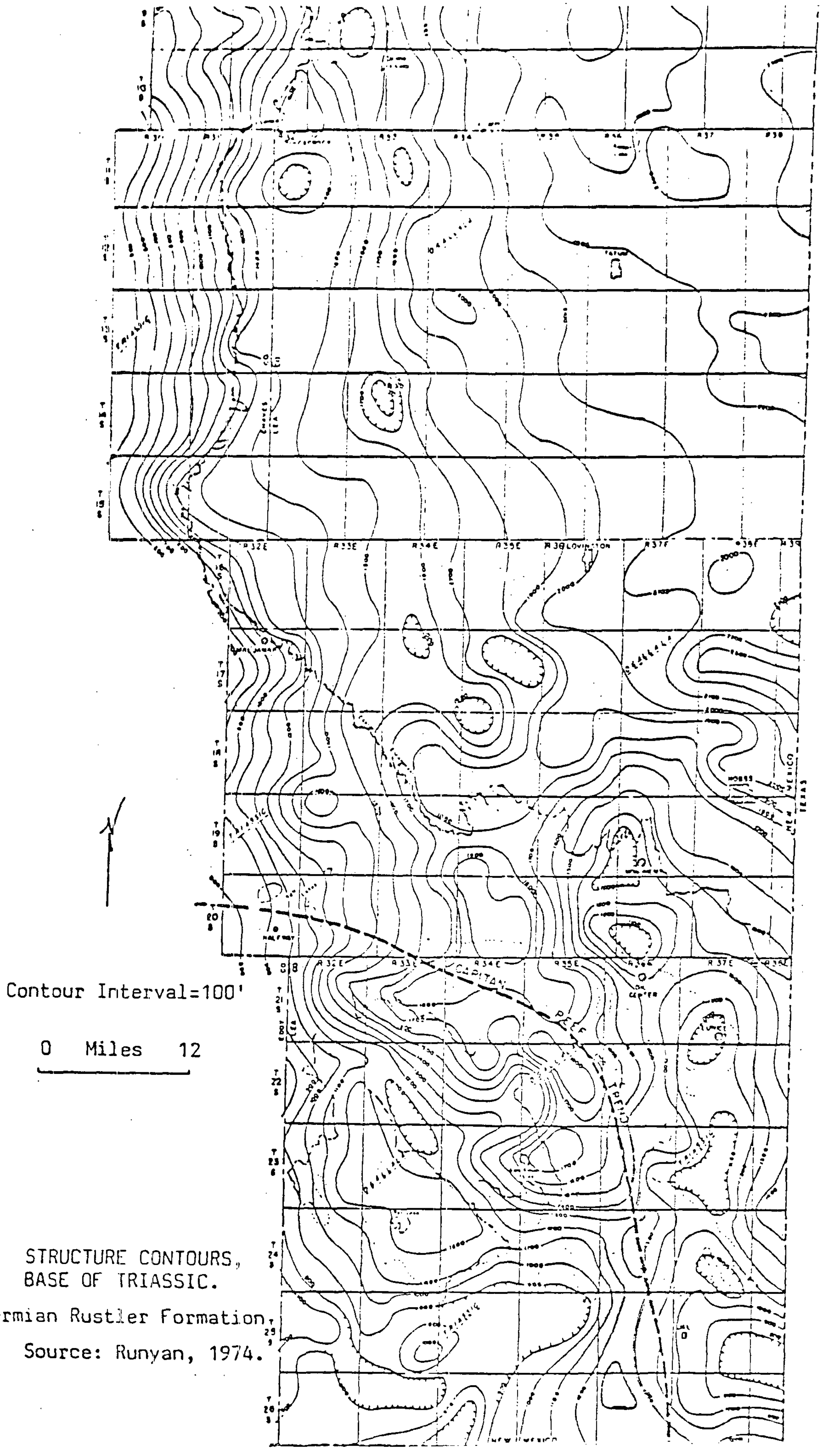


FIGURE 3. STRATIGRAPHIC COLUMN FOR THE STUDY AREA.



IGURE 4. STRUCTURE CONTOURS, BASE OF TRIASSIC.

op of Permian Rustler Formation.

Source: Runyan, 1974.

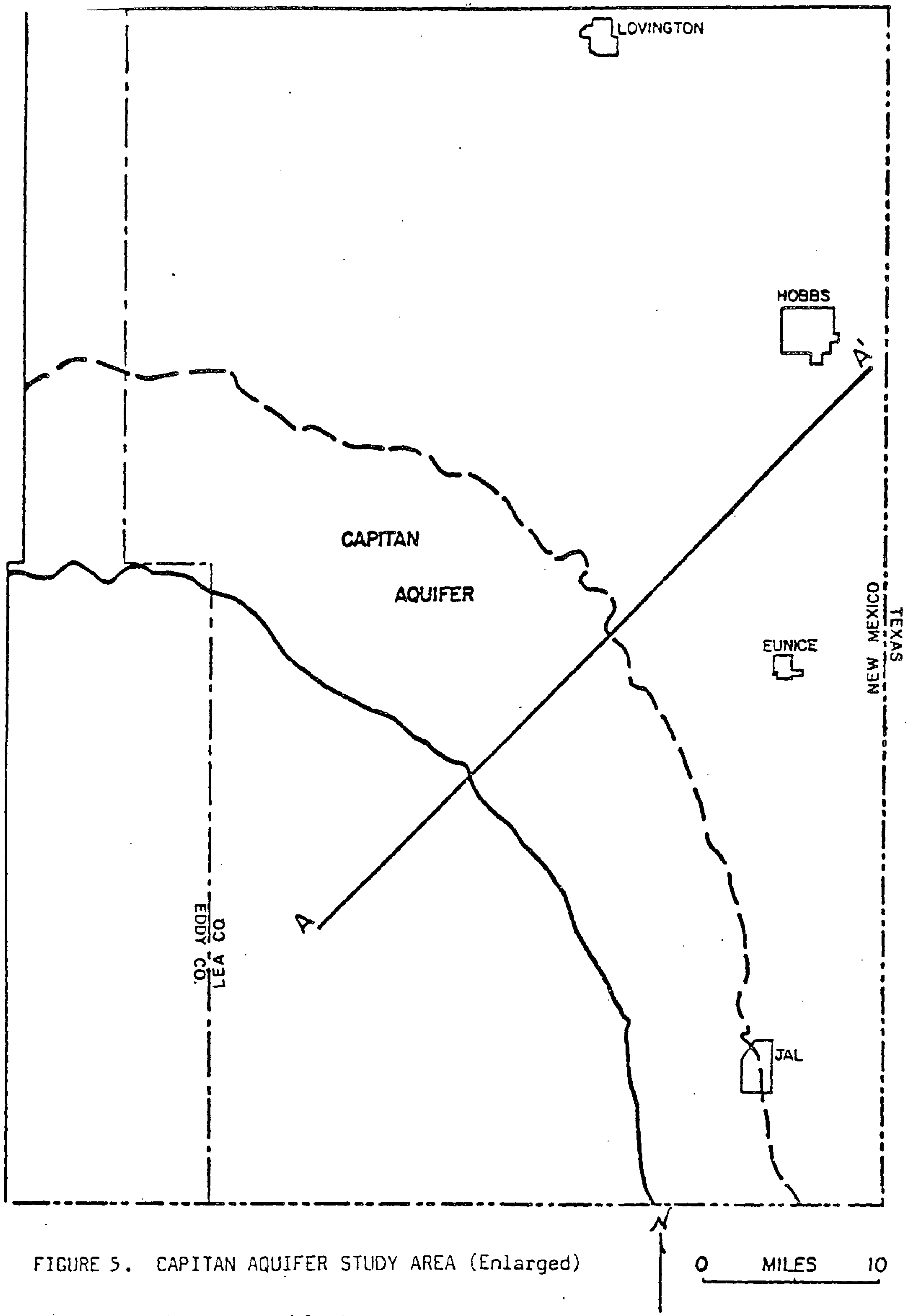


FIGURE 5. CAPITAN AQUIFER STUDY AREA (Enlarged)

Capitan shelf edge

Capitan basinal edge

Source: After W. Hiss, 1975.

FIGURE 6. AQUIFER STUDY REFERENCE FORM

Observer: ______________________ Date: ______________________

Citation:

Area:

Geologic Time:

General Subject: Geology; geohydrology; oil and gas; and other.

General level of detail/insight:

Subject	Text	Maps	X-sec	Data Tables	Quant. Anal.	Other (specify)
Lithology						
Stratigraphy						
Aquifer properties						
Water table						
Water use						
Water quality						
Salinity						
Oil and gas						
Other						

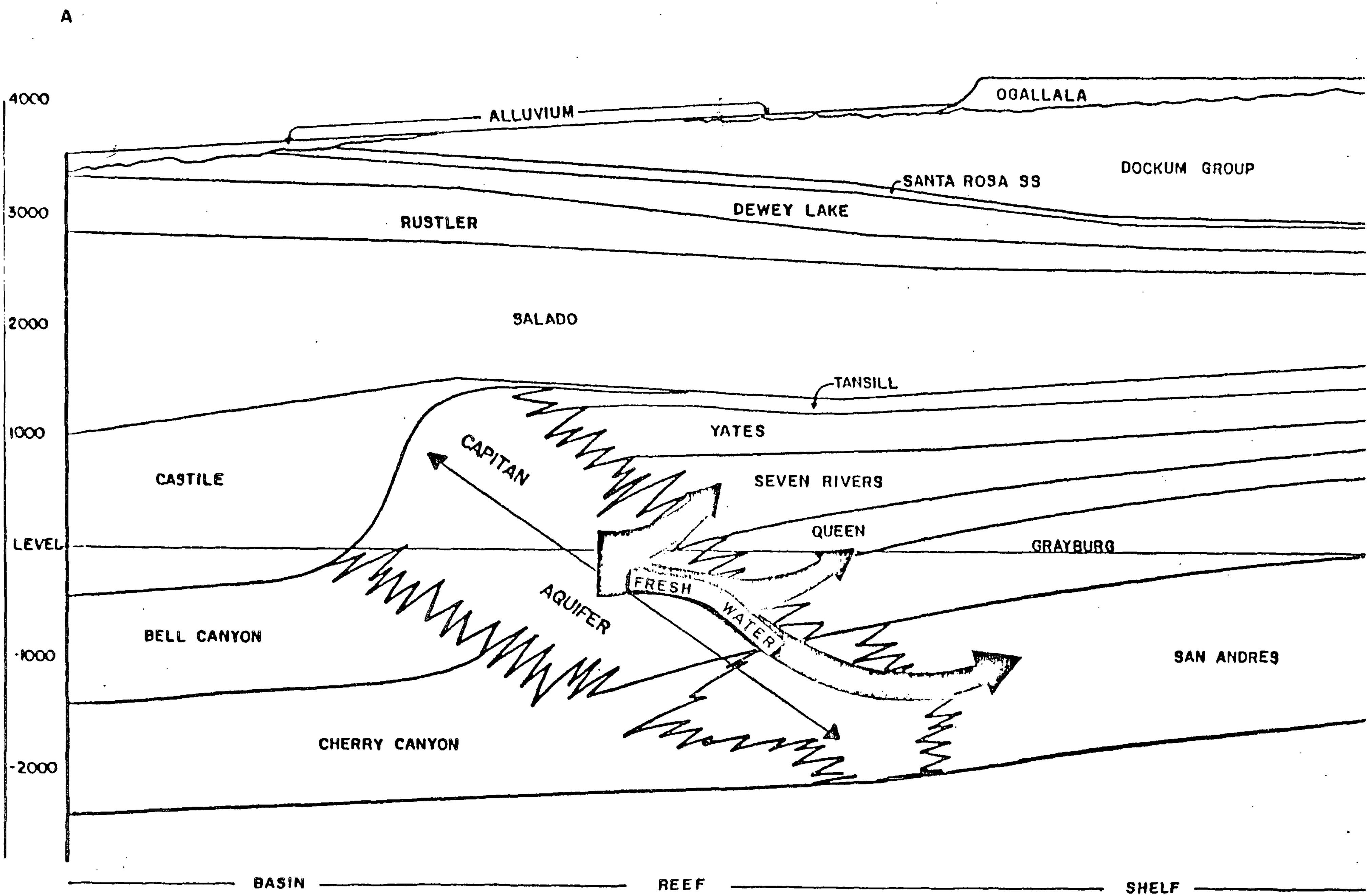


FIGURE 7. SCHEMATIC GEOLOGIC CROSS-SECTION OF THE STUDY AREA.

Source: M. Holland, 1980.

ACTUAL DATA

Parameter	Formation	Value	Units	Comments
Transmissivity				
Storage Coefficient				
Specific Storage				
Porosity				
Permeability				
Saturated Thickness				
Specific Yield				
Well Yields				
Specific Capacity				
Depth to Water				
Water-Table Elevation				
Water-Table Gradient				
Rate of Flow				
Leakance				
Diversion Rate				
Water Use				
TDS				
Other Quality				
Other Data				

Good References:

Items Xeroxed and Attached:

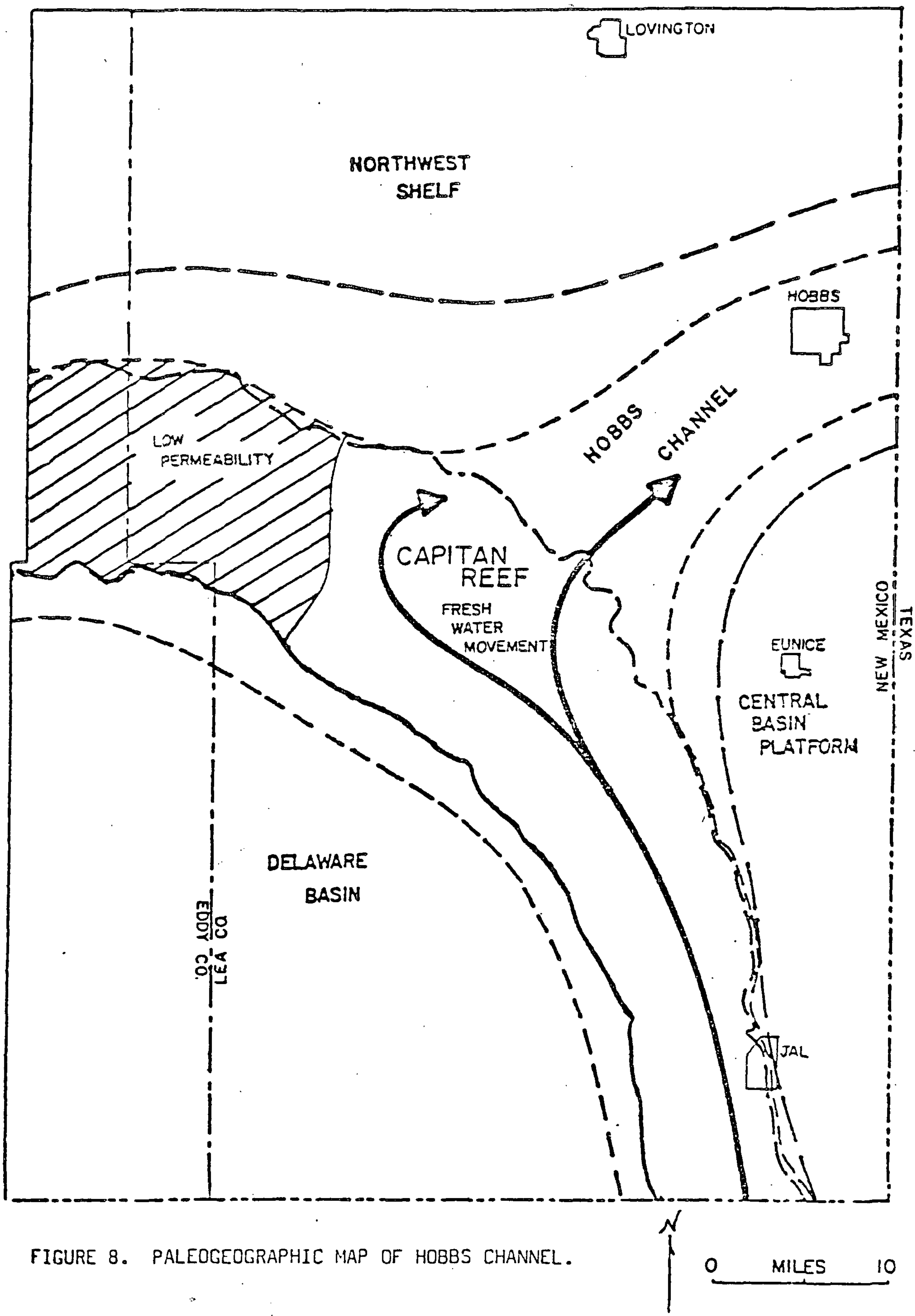
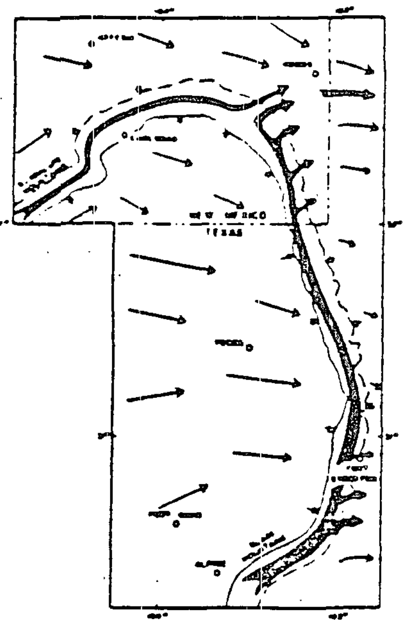
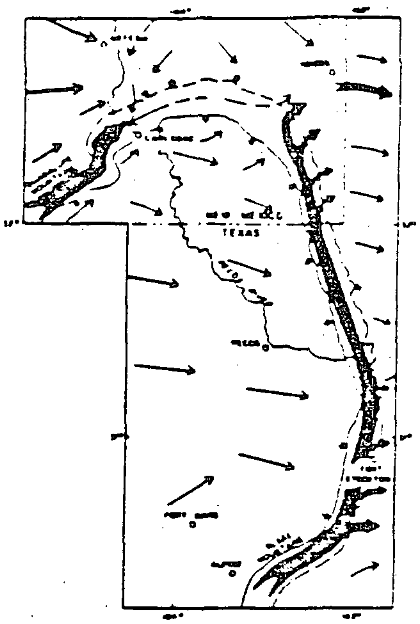


FIGURE 8. PALEOGEOGRAPHIC MAP OF HOBBS CHANNEL.

Source: Modified after W. Hiss, 1975
by M. Holland.



A. Regimen principally controlled by regional tectonics prior to development of the Pecos River.



B. Regimen influenced by erosion of Pecos River at Carlsbad downward into hydraulic communication with the Capitan aquifer.

0 50 MILES

0 50 KILOMETERS

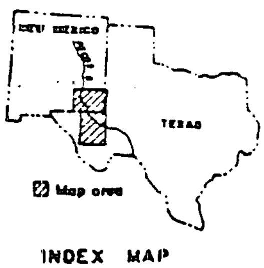
EXPLANATION

—Capitan aquifer

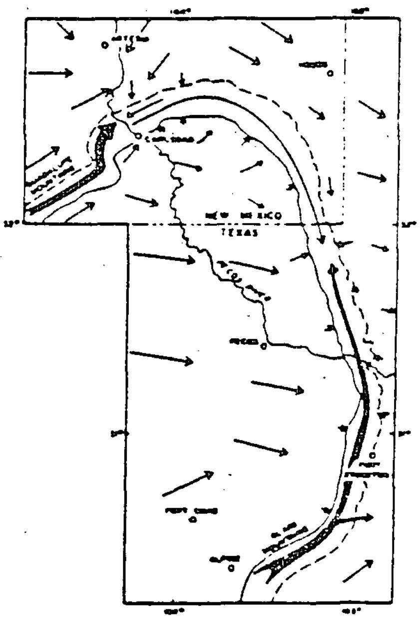
Highly diagrammatic ground-water flow vectors:

1. Vector size indicates relative volume of ground-water flow.

2. Orientation indicates direction of ground-water movement.



INDEX MAP



C. Regimen influenced by both communication with the Pecos River at Carlsbad and the exploitation of ground-water and petroleum resources.

FIGURE 9. DIAGRAMMATIC MAPS DEPICTING THE EVOLUTION OF GROUND WATER REGIMENS IN STRATA OF PERMIAN GUADALUPIAN AGE IN SOUTHEASTERN NEW MEXICO AND WESTERN TEXAS.

Source: W. Hiss, 1974.

TABLE 1.

MAJOR SALT-WATER DISPOSAL WELLS WHICH OCCUR IN FRESH-WATER AREA OF LEA COUNTY, NEW MEXICO.

Location = section, township (south), range (east).

Operator	Location	Injection Interval	Barrels Injected/month	Cumulative Injection
Rice	25-18-37	4446-4527	97,285	27,134,667
Rice	29-18-38	4469-4522	228,627	43,096,101
Rice	30-18-39	5105-5188	31,951	4,967,482
Rice	33-18-37	4500-4975	128,952	35,133,435
Rice	15-19-38	4634-4826	242,138	47,027,165
Rice	1-20-36	4300-4935	127,916	32,282,168
Rice	5-20-37	4515-4920	173,066	40,706,962
Rice	9-20-37	4396-4845	327,309	72,412,835
Rice	20-20-37	4451-4939	98,937	29,012,203
Rice	33-20-37	4500-5077	243,520	36,037,613
Rice	21-21-36		298,109	29,174,043
S & M Oil	5-18-39	5300-5854	17,390	646,793
Conoco	23-20-37	4547-4700	Disconnected	615,979
Truckers	6-21-36	4395-4435	25,170	1,086,652
McCasland	31-21-36		32,343	1,944,331
McCasland	6-22-36	3140-3295	32,343	1,805,883
Conoco	5-23-36	3710-52	Disconnected	70,444

Total injection = 2,105,056 barrels per month (for July 1980); 403,154,756 barrels cumulative in these wells. This is 18.5% of all 1979 injection in southeastern New Mexico.

TABLE 2. ECONOMIC TRADEOFFS FOR USE OF SAN ANDRES AQUIFER, HOBBS, N.M.

This summary analysis is not intended to serve as a detailed cost-benefit analysis. Estimated costs were obtained from Herkennoff (1976) and from interviews with experts at OCD, City of Hobbs and elsewhere. Baseline data are on file at Lee Wilson and Associates, Inc.

A. DRINKING WATER

1. Hobbs, New Mexico has a projected population growth as follows (Herkennoff, 1976).

1970	1980	(Census 1980/ Town Est. 1980)	2000	2020	2080
26,025	31,100	(29,200/32,900-35,000)	49,833	59,325	87,801

2. If per capita water use remains at today's value (approximately 235 gallons per day), then in the year 2080 the annual demand for water would be approximately 23,000 acre- feet per year. For the 100-year period 1980-2080, cumulative demand is approximately 1.5 million acre-feet.

3. The Ogallala Formation near and north of Hobbs contains abundant fresh water. Based on present amounts of recoverable water in storage (11,000 acre-feet per square mile; Herkenoff, 1976, p. 66) an area of 136 sq. miles would be needed to provide 1.5 million acre-feet.

4. The cost of developing the Ogallala supply (in today's dollars) is estimated at $75 per acre-foot (Herkenhoff, 1976). Less than half this is for construction.

5. An alternative water supply which has been considered for (and rejected by) Hobbs is the Eastern New Mexico Water Supply Project which would divert water from Ute Dam in east-central New Mexico. The most recent evaluations indicate a dollar cost in excess of $700/acre-foot for treated water available for storage and distribution within the City (Lloyd Calhoun, personal communication). The most optimistic estimate is that the project would supply less than 0.5 million acre-feet over its 50-year life.

6. The cost of San Andres water was roughly estimated assuming that there would be 6400 acre-feet of water available per square mile (500-foot saturated thickness; 2% specific yield) and that quality would average about 9,000 mg/l TDS. Based on Hiss (1975c) no more than half the wells in the Hobbs area would produce fresh water, so that the actual water supply would be no more than 3200 acre-feet per square mile. If so, the costs for developing supply pipelines would be similar to those for tapping the Ogallala. If we

assume that existing wells could be purchased at minimal cost, then the difference between Ogallala and San Andres water is that the latter must be pumped from depths of 1500 feet and must be treated to remove dissolved solids. (Although water is produced at 4,000 feet, artesian pressure produces a piezometric surface at 1,500 feet below the surface).) Pumping alone establishes that the San Andres will be more costly than Ogallala water. As a rough estimate, the pumping cost is about $0.50 per thousand gallons (Note 1). Desalinization would be about $2.25/thousand gallons based on estimates made for Alamogordo and El Paso (see note 2). The total cost of pumping and treatment would be about $900 per acre-foot. Transmission and storage costs would probably be similar to the same costs for the Ogallala, $25,000,000. This would add $15-20/AF, a fraction of the pumping and treatment expense. Note that while San Andres water is much more expensive than Ogallala water, it is of the same order of magnitude as Ute Reservoir water.

E. INJECTION

1. To minimize the estimated value of the San Andres as an injection zone, we assume that energy production will not be affected by a change in disposal practices. The value of injection equals any increased costs which must be borne if disposal practices are changed. A simple estimate can be made by assuming that the annual increase in costs is approximately equal to the costs associated with changing disposal practices at the 15 existing wells listed in Table 1. That is, assume that these wells are the key to disposal over the next 20 years and estimate the increased costs which occur because of UIC regulations; then assume that although different wells may be involved thereafter, the annual dollar costs will be similar through the year 2080.

2. In order to dispose of 2 million barrels (42 gallons/barrel) of brine each month at the existing wells, the water could be desalted prior to injection into the fresh aquifers. Desalinization costs of at least $2 per thousand gallons are likely, so that the total cost would amount to $168,000 per month. Over a 20 year period this would cost $40 million; over 100 years, $200 million.

3. Following EPA guidance, each of the existing wells would not be expected to influence an area greater than 1/4 mile in radius. Thus, each well would influence at most 0.2 square mile of the aquifer; at 3,200 acre-feet of fresh water per square mile this means that at most each well would damage 640 acre-feet of water containing several thousand mg/l. Using the 20-year cost of treatment, the UIC regulations would impose a dollar cost of $4,167 per acre-foot of fresh water protected. In reality, effects may occur over a much larger area, perhaps 1 square mile each; thus protection could extend to 3200 acre-feet of fresh water per well, at a cost of $835/sq. foot.

4. Instead of treatment it would be possible to deepen each of the existing wells to inject into the Devonian, at a cost of $500,000 each. For the 15 wells this amounts to a total cost of $7.5 million; discounted over a 20-year period the total cost would be about $0.7 million per year. This cost is less than the costs of treatment and results in the spending of about $1000/AF to protect the San Andres fresh water (assuming 1/4 mile effect).

NOTES TO TABLE 2.

Note 1. Assumes 23.4 horsepower per million gallons per day per 100 feet of lift; 0.45 kilowatt hours per 1000 gallons of lift per 100 feet; 8¢ per kwh.

Note 2. Treatment costs are as obtained for brine desalinization project in El Paso (Dan Knorr, Parkhill, Smith and Cooper, personal communication) and Alamogordo (Joe Pierce, EID, personal communication). Note that desalinization produces brines which require safe disposal; costs of disposal are not included in this analysis.

New Mexico Geological Society Guidebook, 31st Field Conference, Trans-Pecos Region, 1980

MOVEMENT OF GROUND WATER IN PERMIAN GUADALUPIAN AQUIFER SYSTEMS, SOUTHEASTERN NEW MEXICO AND WESTERN TEXAS

W. L. HISS
Conservation Division
U.S. Geological Survey
Menlo Park, California 94025

AQUIFER SYSTEMS

Permian Guadalupian-age strata can be divided into three aquifer systems. Hiss (1975a, p. 132) described and named them the Capitan, shelf, and basin aquifers (fig. 1). In most areas, they are readily distinguished by differences in lithology, geographic position, stratigraphic relationships, hydraulic characteristics, and quality of the contained water (Hiss, 1975b and c; 1976a).

Capitan Aquifer

The Capitan aquifer is a lithosome that includes the Capitan and Goat Seep Limestones and most or all of the Carlsbad facies of Meissner (1972). Shelf-margin carbonate banks or stratigraphic reefs in the upper part of the San Andres Limestone are included within the Capitan aquifer where they cannot be readily distinguished from the Goat Seep Limestone and Carlsbad facies (Silver and Todd, 1969, figs. 12 and 13).

Shelf Aquifers

Saturated strata yielding significant quantities of water from the San Andres Limestone and the Bernal and Chalk Bluff facies of Meissner (1972) constitute the shelf aquifers. The lithologic contact between the Capitan and shelf aquifers is gradational and is difficult to discern with accuracy in some areas. Observations of the geometry and lithologic relationships of the shelf-margin rocks in the field suggest that the width of the Capitan Limestone (reef) is considerably less than is shown in many geologic reports (Dunham, 1972, fig. I-1).

The present-day ground water regimen is strongly influenced by the Pecos River in New Mexico. As a result, the hydraulic conductivity of the shelf aquifers west of the Pecos River has been greatly enhanced by the leaching of soluble beds from the Chalk Bluff facies (Meissner, 1972; Motts, 1968). Locally and west of the Pecos River valley between Carlsbad and Roswell, the hydraulic conductivities of the shelf aquifers are quite large and may be similar to that of the Capitan aquifer. The hydraulic conductivity of the shelf aquifers in the Carlsbad and Roswell underground water basins is several orders of magnitude higher than that generally encountered in the shelf aquifers east of the Pecos River at Carlsbad. The water contained in the shelf aquifers is also much better in the shallow zones exploited in these basins than elsewhere in the same aquifers within the area studied. East of the Pecos River near Carlsbad the hydraulic conductivity of the shelf aquifers is generally one to two orders of magnitude less than that of the Capitan aquifer.

Basin Aquifers

Saturated strata yielding significant quantities of water from the Brushy Canyon, Cherry Canyon and Bell Canyon Formations of the Delaware Mountain Group are referred to as the basin aquifers. Although the Capitan aquifer abuts and overlies the Delaware Mountain Group along the margin of the Delaware Basin, the lithologic and hydrologic characteristics of the basin and Capitan aquifers are quite different. The average hydraulic conductivity of the basin aquifer ranges from one to two orders of magnitude less than that of the Capitan. Therefore, only a relatively small amount of water can be expected to move from the basin aquifers to the Capitan aquifer, or vice versa. The difference in quality of water contained in the two aquifers—relatively good in the Capitan, bad in the basin—is also a distinguishing characteristic (Hiss, 1975b).

CONSTRUCTION OF POTENTIOMETRIC SURFACES

Reliable pressure-head and water-level data were adjusted to freshwater heads to construct generalized potentiometric surfaces representative of two conditions in the three aquifer systems. Figure 2 is a map representing conditions in the aquifer systems prior to both development of water supplies for irrigation and discovery and production of oil and gas and associated waste water. Figure 3 is a similar map representing the shelf and basin aquifer for the period 1960 to 1969 and of the Capitan aquifer for the latter part of 1972.

A potentiometric surface represents hydraulic head in an aquifer; the general direction of ground-water movement is inferred to be normal to the illustrated head contours. Hiss (1975, p. 220-255) discusses the computation of ground-water head and the procedures followed in determining the heads used in these maps. The potentiometric maps support the inferred movement of water shown in figure 4.

MOVEMENT OF GROUND WATER

During the latter part of the Cenozoic Era, the movement of ground water through the rocks of Permian Guadalupian age in southeastern New Mexico and western Texas has been controlled or influenced by the following: (1) the regional and local tectonics; (2) the evolution of the landscape; (3) the relative transmissivities of the various aquifers; (4) the amount of recharge; and (5) the exploitation of the petroleum and ground-water resources in the last five decades (fig. 4).

Control by Regional Tectonics

The flow of ground water through the shelf, basin and Capitan aquifers after the uplift of the Guadalupe and Glass Mountains but prior to the excavation of the Pecos River valley at Carlsbad is shown diagrammatically in figure 4A. The three aquifer systems were recharged by water originating as rain or snowfall on the outcrops along the western margin of the Delaware Basin. Evidence of major surface drainage within the Trans-Pecos area of southeastern New Mexico and western Texas has not been reported.

Ground water moved generally eastward and southeastward through the shelf and basin aquifers under a gradient of probably only a few feet per mile toward natural discharge areas along

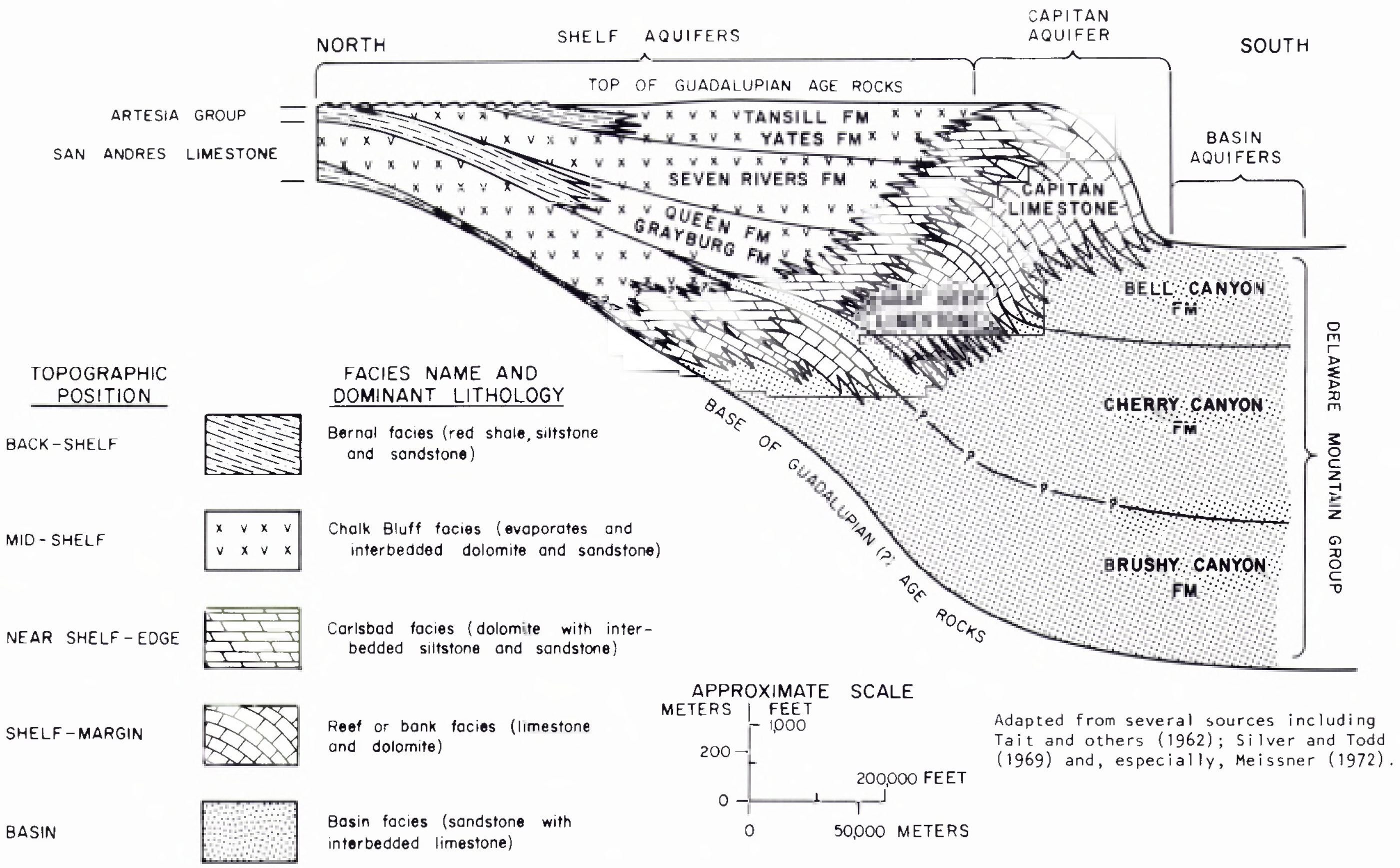


Figure 1. Highly diagrammatic north-south stratigraphic section showing the positions and relationships of the major lithofacies in the rocks of Guadalupian age, eastern New Mexico.

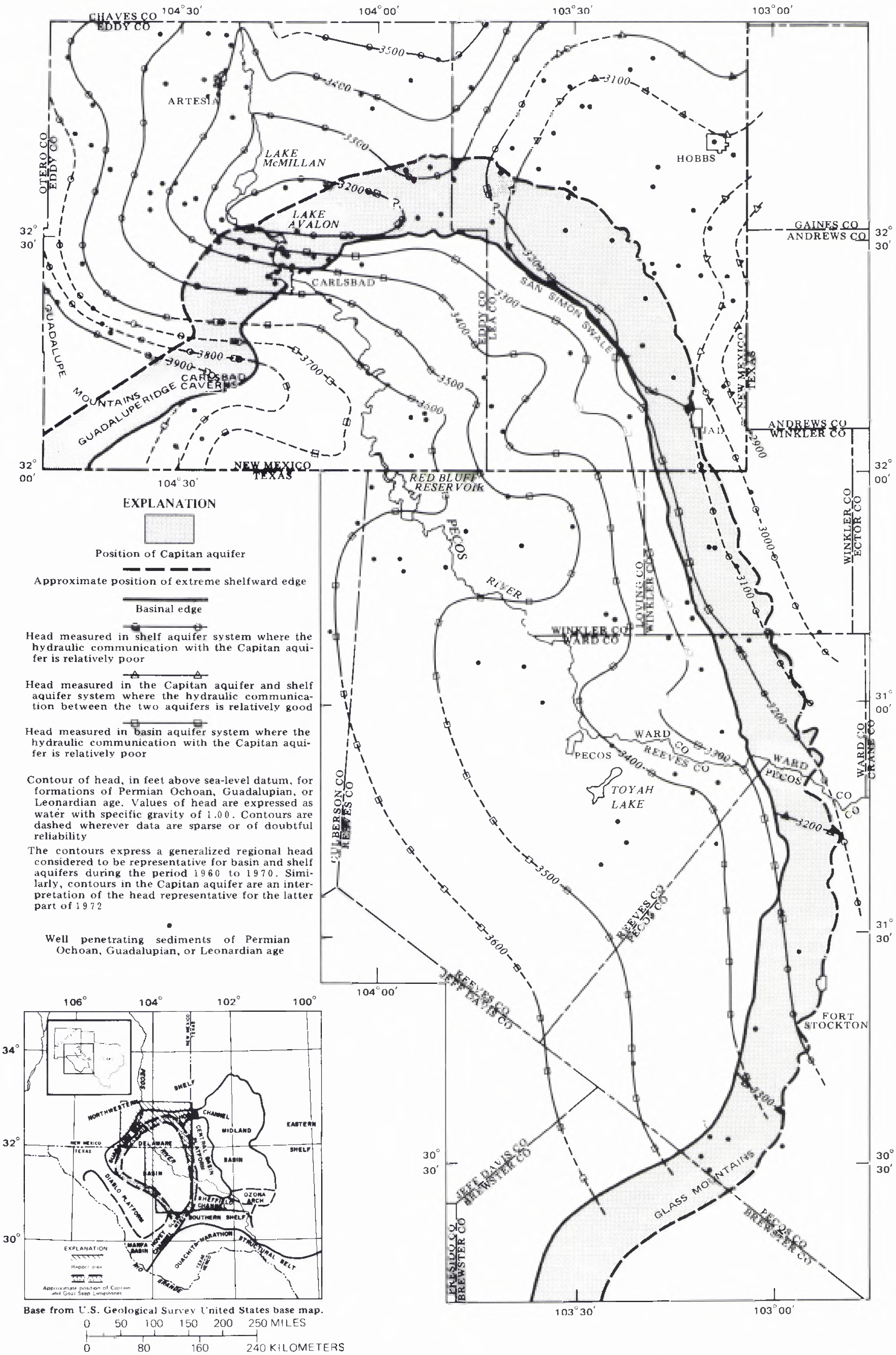


Figure 2. Pre-development potentiometric surface.

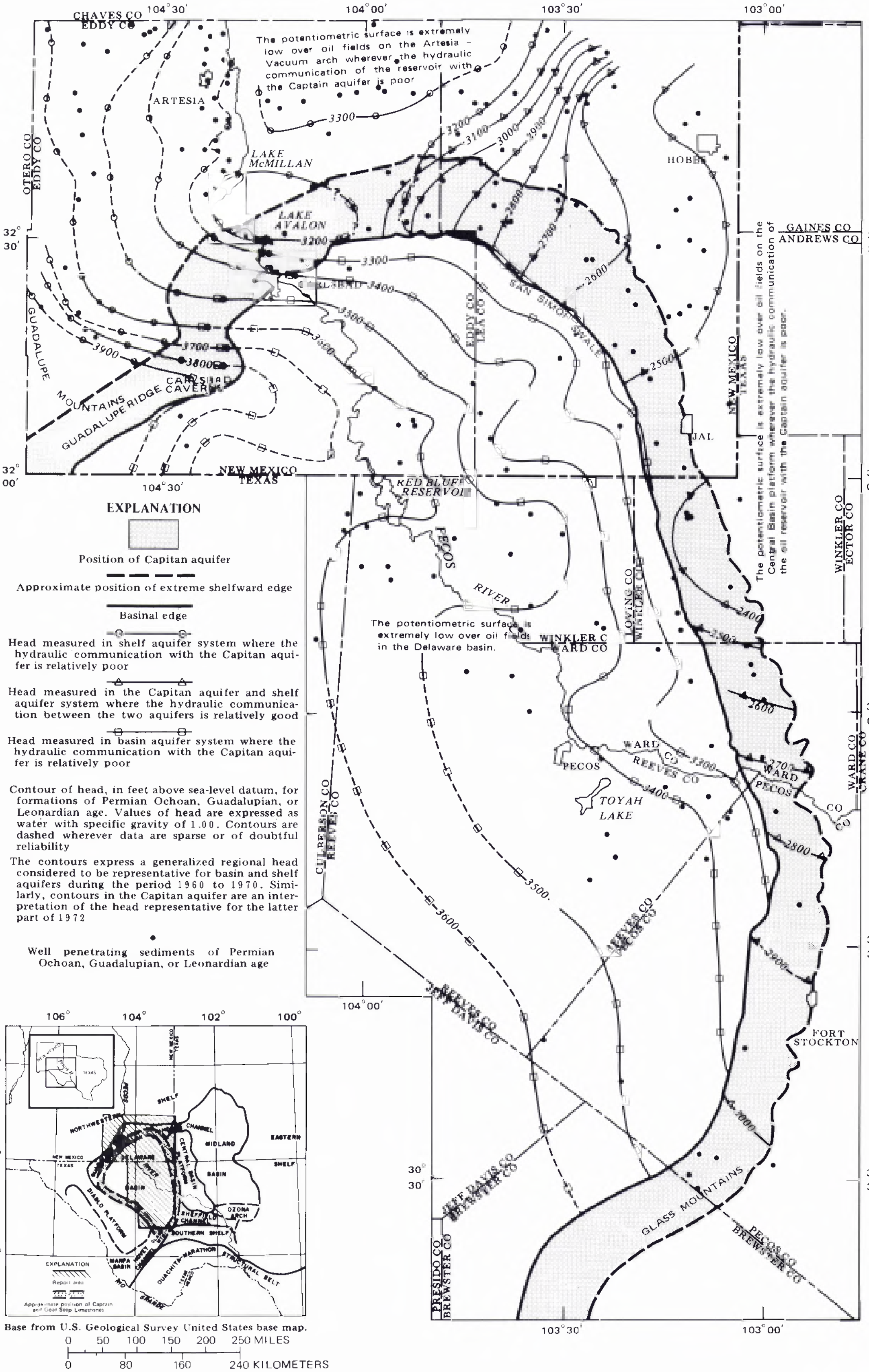


Figure 3. Post-development potentiometric surface.

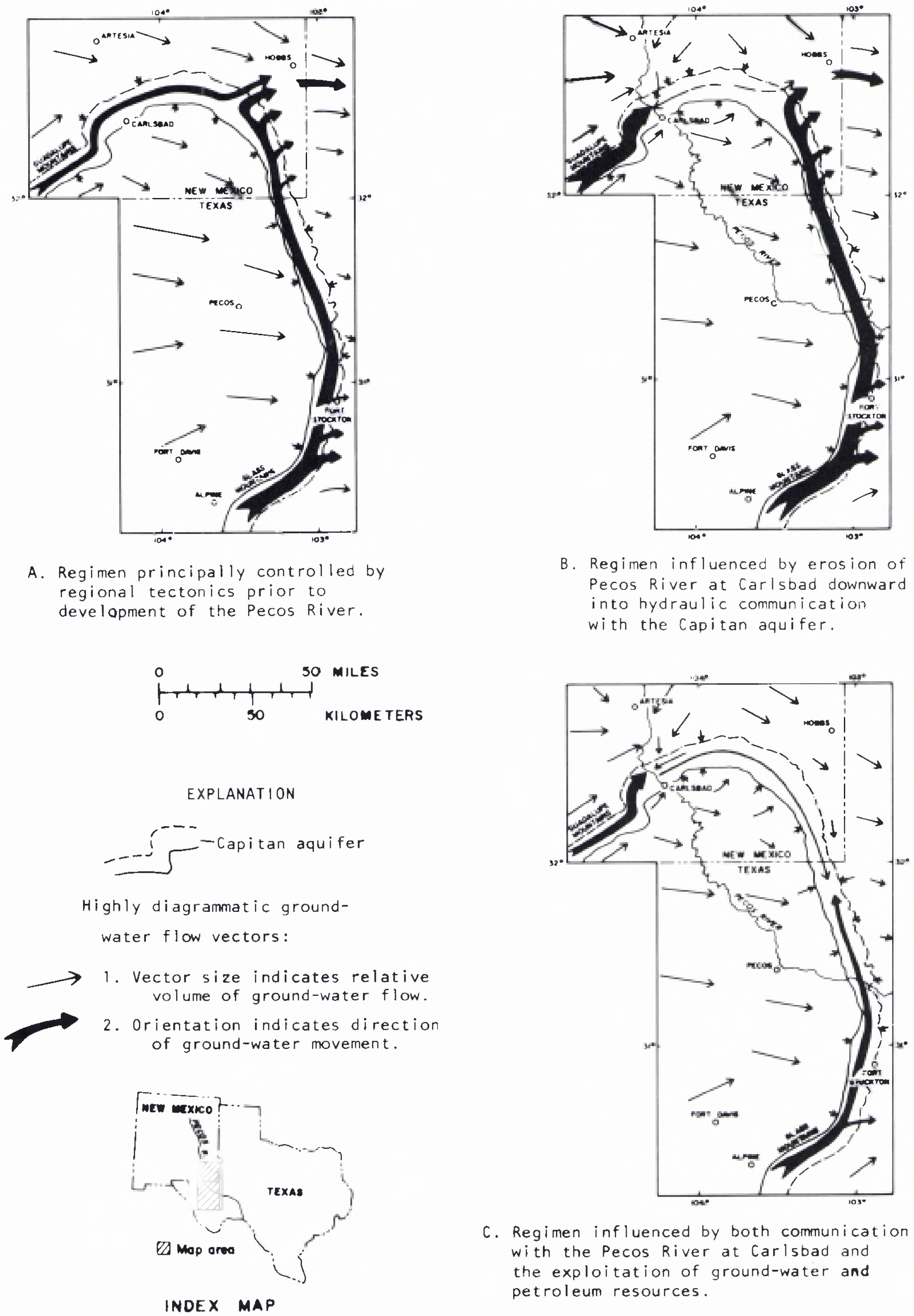


Figure 4. Diagrammatic maps depicting the evolution of ground water regimens in strata of Permian Guadalupian age in southeastern New Mexico and western Texas.

streams draining to the ancestral Gulf of Mexico. Water entering the Capitan aquifer in the Guadalupe Mountains moved slowly northeastward and then eastward along the northern margin of the Delaware Basin to a point southwest of present-day Hobbs. Here it joined and comingled with a relatively larger volume of ground water moving northward from the Glass Mountains along the eastern margin of the Delaware Basin. From this confluence, the ground water was discharged from the Capitan aquifer into the San Andres Limestone, where it then moved eastward across the Central Basin Platform and Midland Basin, eventually to discharge into streams draining to the Gulf of Mexico.

Influence of Erosion of Pecos River at Carlsbad

Some time after deposition of the Ogallala Formation, perhaps early in Pleistocene time, the headward-cutting Pecos River extended westward across the Delaware Basin to the exposed soluble Ochoan beds. It then turned northward following this natural weakness in the sedimentary rocks to pirate the streams draining to the east from the Sacramento and Guadalupe Mountains (Plummer, 1932; Bretz and Horberg, 1949b; Thornbury, 1965). As the excavation of the Pecos River valley progressed, the hydraulic communication with formations of Guadalupian age gradually increased until the Pecos River functioned as an upgradient drain. Eventually, the hydraulic gradients in the shelf, basin and Capitan aquifer were reversed along the eastern side of the Pecos River valley, and ground water that formerly flowed eastward was diverted westward as spring flow into the Pecos River (fig. 4B). Water recharged to the same aquifers in the Guadalupe Mountains began to follow the shorter path to springs in the Pecos River. Many of the solution features observed in the Guadalupian sedimentary rocks west of the Pecos River near Carlsbad probably were initiated during this period.

Movement of water eastward toward Hobbs from the Guadalupe Mountains into the Capitan aquifer was decreased by the lowering of the hydraulic head along the Pecos River. At the same time, a trough in the potentiometric surface of the shelf and basin aquifers began to develop east of Carlsbad, and water began to drain into the Capitan aquifer from the surrounding sedimentary rocks. Meanwhile, ground water continued to move northward from the Glass Mountains in the Capitan aquifer toward a point of discharge into the San Andres Limestone southwest of Hobbs. This part of the aquifer was unaffected by the cutting of the Pecos River valley across the Delaware Basin and the Central Basin Platform.

Influence of Exploitation of Ground Water and Petroleum Resources

Regionally, the movement of ground water in the shelf and basin aquifers east of the Pecos River at Carlsbad has changed very little as a result of the exploitation of ground water and petroleum during a period of approximately 50 years (fig. 4C). Locally, however, the movement of ground water within these same aquifers is controlled by the effects of the numerous producing oil fields.

The shape of the regional potentiometric surface representative of the hydraulic head in the Capitan aquifer east of the Pecos River at Carlsbad has been changed significantly in response to withdrawal of both ground water and petroleum during the past 50 years. The westward movement of saline water from the Capitan aquifer in Eddy County east of Carlsbad into the Pecos River has been greatly diminished or eliminated by a reduction in hydraulic head.

Similarly, the movement of water in the San Andres Limestone and Artesia Group eastward across the northern part of the Central Basin Platform from New Mexico into Texas has been decreased. Eventually, the movement of water probably will be reversed. Water may be diverted from the San Andres Limestone and Artesia Group westward from Texas back toward Hobbs and then into the Capitan aquifer along the western margin of the Central Basin Platform. The effects of exploitation of the ground water and petroleum resources will continue to be the dominant factor influencing the movement of ground water in the Capitan aquifer for many years into the future.

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OCD Exhibit No. 5B

STRATIGRAPHY AND GROUND-WATER HYDROLOGY OF THE CAPITAN AQUIFER, SOUTHEASTERN NEW MEXICO AND WESTERN TEXAS

by

William Louis Hiss

B.S., Kansas State University, 1953

M.S., University of Oklahoma, 1960

A thesis submitted to the Faculty of the Graduate School of the University of Colorado in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Department of Geological Sciences

1975

This Thesis for the Doctor of Philosophy degree by

William Louis Hiss

has been approved for the

Department of

Geological Sciences

By

Theodore R. Walker

Bruce F. Curtis

Date July 17, 1975

Hiss, William Louis (Ph.D., Geology)

Stratigraphy and ground-water hydrology of the Capitan aquifer, southeastern New Mexico and western Texas

Thesis directed by Professor Theodore R. Walker

The Capitan aquifer is an important source of ground water for both municipal and industrial purposes in southeastern New Mexico and western Texas. The Capitan aquifer was mapped in the subsurface as a stratigraphic reef. It extends for approximately 200 miles (320 kilometres) as a continuous arcuate unit, unbroken by faulting, parallel to the north and east margins of the Delaware basin from the Guadalupe Mountains southwest of Carlsbad, New Mexico to the Glass Mountains southwest of Fort Stockton, Texas.

At Carlsbad, where the Capitan aquifer plunges beneath the surface to the northeast away from the Guadalupe Mountains, the Pecos River is in measurable hydraulic communication with the aquifer. Large quantities of moderately to very saline water are being withdrawn from the Capitan aquifer in southeastern New Mexico and western Texas and injected into other formations to repressurize partially depleted oil fields. Water could possibly be diverted eastward from the Pecos River at Carlsbad into the Capitan aquifer in response to industrial pumping.

The cost of drilling and testing new wells precluded obtaining hydrologic data normally acquired by conventional methods. Nine abandoned deep oil and gas wells were acquired from oil companies and converted to fluid-level observation wells. Changes in head resulting from natural events and the effects of fluid production from the Capitan aquifer and other aquifers in measurable hydraulic communication were recorded.

Data, including core analyses, drill-stem tests, bottom-hole pressures, and (or) water-quality data, were obtained from oil companies for about one-third of the more than 30,000 oil and gas wells drilled within the project area. These data were coded and indexed to the Permian Basin Well Data System magnetic tape file of scout records. This approach permitted efficient and economical processing of the hydrologic data with a digital computer.

Submarine canyons and reentrants of Guadalupian and (or) earliest Ochoan age were located in the subsurface along the northern and eastern margins of the Delaware basin. These prominent features were incised into the Capitan aquifer and then filled with complexly interbedded sandstone, siltstone, and limestone with a relatively low hydraulic conductivity. The thickness and, concordantly, the transmissivity of the Capitan aquifer is reduced significantly by the more deeply incised submarine canyons that are oriented normal to the margin of the Delaware basin.

The fortuitous position of the largest submarine canyon precludes the movement of large amounts of water eastward from the Pecos River at Carlsbad into the Capitan aquifer. The water otherwise would have moved eastward in response to extensive development and production of water from this aquifer in southeastern New Mexico and western Texas.

This abstract is approved as to form and content. I recommend its publication.

Signed ______________________________
Faculty member in charge of dissertation

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ILLUSTRATIONS

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TABLES

Tables - Concluded

INTRODUCTION

Purpose of the study

This study was started during the summer of 1965 by the U.S. Geological Survey in cooperation with the New Mexico State Engineer. The primary objective was to determine the effects on the Capitan aquifer of the withdrawal of fluids from this aquifer and other aquifers in measurable hydraulic communication; and, to assess, qualitatively, the effect, if any, of continued withdrawal of fluid from this aquifer on the flow of the Pecos River at Carlsbad, N. Mex. Secondary objectives included definition of the Capitan and other associated aquifers; and determination of (1) the stratigraphic position and dimensions of the Capitan aquifer; (2) the determination of the hydraulic characteristics of the Capitan aquifer and associated formations of Permian Guadalupian age; (3) the quality of water contained in these aquifers; (4) the stratigraphic and hydrologic relationships between the Capitan aquifer and other formations; and (5) the total amount of fluids of various types produced from the Capitan aquifer and other reservoirs of Permian Guadalupian age.

The Capitan aquifer is defined elsewhere in this report but is comprised chiefly of the Capitan and Goat Seep Limestones and the Carlsbad facies of the Artesia Group. The Capitan aquifer and several stratigraphic units of equivalent age are important sources of ground water for the city of Carlsbad and for irrigation in the Pecos River basin in New Mexico and Texas. In addition to the fresh water produced for domestic, municipal, and agricultural use in New Mexico and the slightly to moderately saline water used for irrigation in Texas, large quantities of saline ground water are being withdrawn from the Capitan aquifer in Lea County, New Mexico, and Winkler and Ward Counties, Texas (Guyton and Associates, 1958; Brackbill and Gaines, 1964; and table 1). This water, along with additional saline waste water produced with oil, is transported to other areas where it is injected into several formations to repressurize partly depleted reservoirs in a number of oil fields.

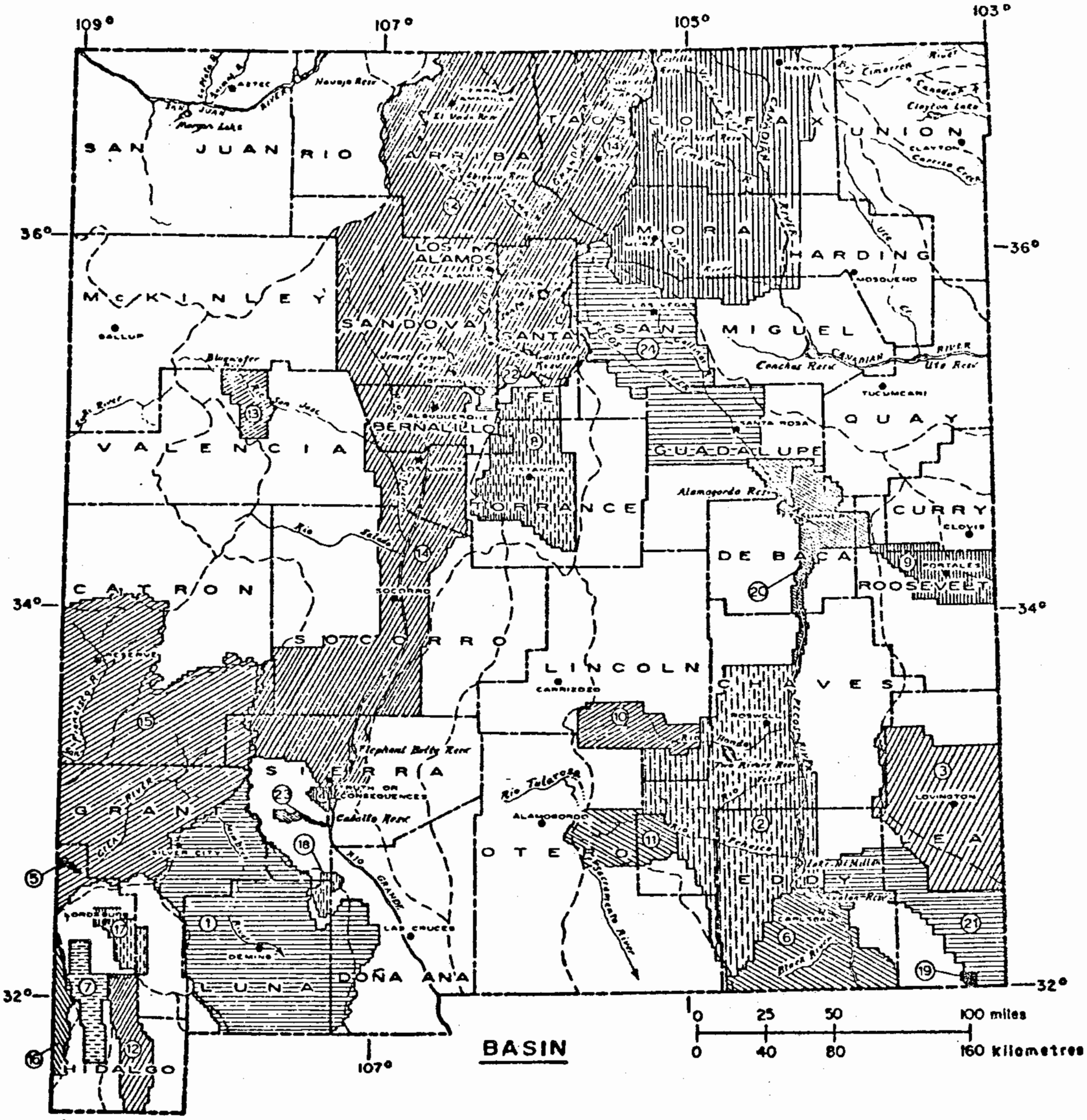
Table 1.--Classification of saline water[1/]

Description	Dissolved solids, milligrams per litre
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Brine	More than 35,000

[1/] Adapted from water-quality ranges suggested by Winslow and Kister (1956). Following the standards used by the U.S. Public Health Service (1962), the U.S. Geological Survey has defined saline water as water that contains more than 1,000 milligrams per litre of dissolved solids (Krieger and others, 1957, p. 4).

Use of surface water in the Pecos River basin is limited by an interstate stream compact between the States of New Mexico and Texas (U.S. Congress, 1949; Lingle and Linford, 1961). The use of surface water in the entire basin within New Mexico and ground water in part of the basin and adjacent areas, also within New Mexico, is administered by the New Mexico State Engineer (fig. 1; and Hutchins, 1955). In contrast, the use of ground water in adjacent areas in Texas is not controlled by State or Federal agencies. The intense competition for water within this area is reflected by the number of hearings held before the New Mexico State Engineer concerning the use of ground water from the Capitan aquifer in the vicinity of Carlsbad (New Mexico State Engineer Hearing, 1960, 1962, and 1963; New Mexico State Engineer, 1964).

The measurable hydraulic communication of the Capitan aquifer with the Pecos River at Carlsbad is an important factor considered in the administration of the right to appropriate water in New Mexico.



1. MIMBRES VALLEY
2. ROSWELL
3. LEA COUNTY
4. HOT SPRINGS
5. VIRDEN VALLEY
6. CARLSBAD
7. ANIMAS
8. ESTANCIA
9. PORTALES
10. HONDO
11. PEÑASCO
12. PLAYAS VALLEY
13. BLUEWATER
14. RIO GRANDE
15. GILA - SAN FRANCISCO
16. SAN SIMON
17. LORDSBURG VALLEY
18. NUTT - HOCKETT
19. JAL
20. FORT SUMNER
21. CAPITAN
22. SANDIA
23. LAS ANIMAS CREEK
24. UPPER PECOS
25. CANADIAN RIVER

-------BOUNDARY, SURFACE-DRAINAGE AREA

Figure 1.--Map showing underground water basins in New Mexico declared by the State Engineer as of December 31, 1973.

Disclaimer

The extensive investigation leading to the preparation of this report was funded jointly by the U.S. Geological Survey and the New Mexico State Engineer. However, the conclusions and opinions presented herein are solely those of the author and do not necessarily concur with or represent those of the sponsors. This report is subject to further review and revision by the U.S. Geological Survey.

Scope of the study

The study included the collection, compilation, and analysis of data related to ground and surface waters and to the production of water, oil, and gas within the project area. Specific items incorporated in the study included determination of (1) the location and extent of the major aquifers in the area and the relative degree of hydraulic communication between the several aquifers, (2) the chemical quality of water contained in the aquifers, (3) the quantity of ground water and oil and gas withdrawn from rocks of Permian Guadalupian age, (4) the effects of these withdrawals on aquifer head, (5) the hydraulic properties of the principal aquifers, and (6) estimates of the quantities of ground water available for use. Many procedures and techniques for handling geologic and hydrologic data with a digital computer were developed and used.

Location and extent of the area

The project area includes Eddy County and southern Lea County, New Mexico, and Winkler, Ward, Loving, Reeves, and parts of Culberson, Pecos, and Brewster Counties, Texas. This area, containing more than 16,000 sq mi (square miles) (25,700 km^2, square kilometres), is shown in figure 2. The concentration of project activities was more intensive in New Mexico than in Texas. Emphasis was placed on an arcuate strip following the trend of the Capitan aquifer along the north and east margins of the Delaware basin between the Guadalupe Mountains southwest of Carlsbad and the Glass Mountains southwest of Fort Stockton, Tex. (figs. 2 and 3).

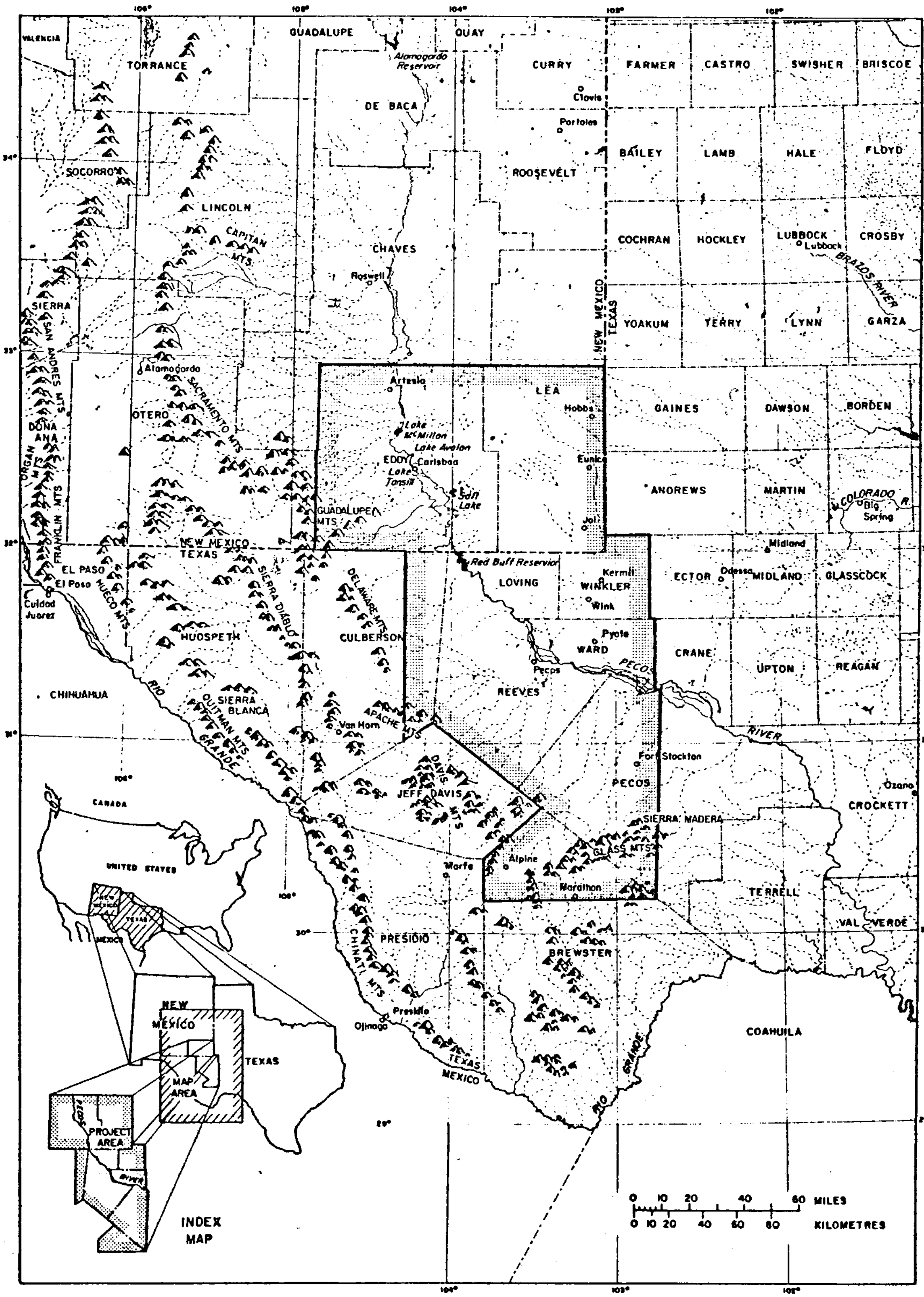


Figure 2.--Map showing location of project area.

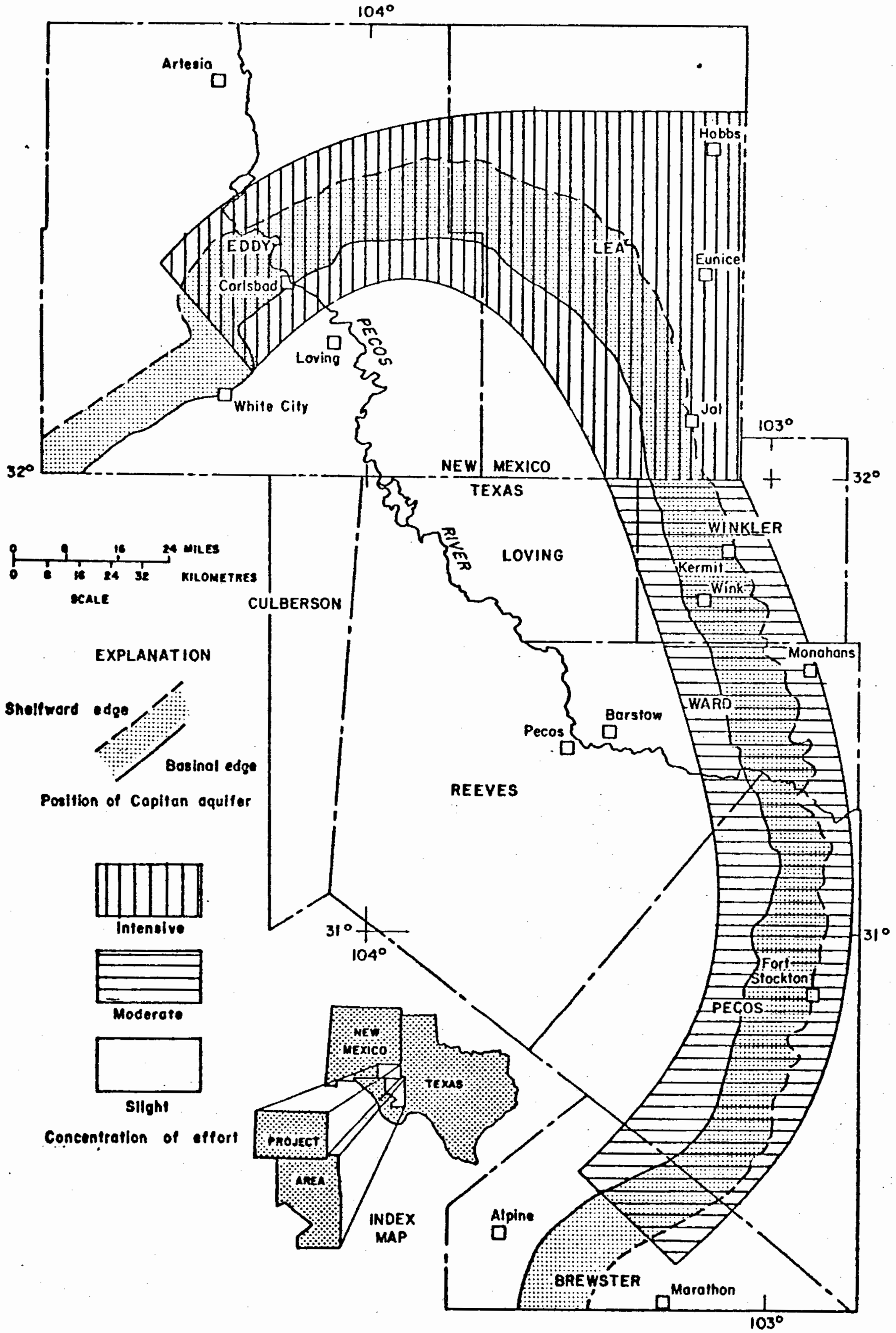


Figure 3.--Map showing concentration of effort within project area.

Conversion from English and oil-industry units to metric units

Numbers in this report are given in English units and (or) oil-industry units followed by the corresponding oil-industry or English unit and the metric equivalent in parentheses. The conversion factors used are given in tables 2 and 3.

Chemical concentrations are given only in metric units, milligrams per litre (mg/l). For concentrations less than 7,000 mg/l, the numerical value is about the same as for concentrations in the English unit, parts per million (ppm).

The altitudes, elevations, distances, depths, and volumes given in this report are often either estimated or generalized so as to be descriptive of a large area. Accordingly, the values stated are often rounded to the nearest hundred units. The values are also converted from English units to metric units and given in parentheses following the original value. The corresponding metric units are usually rounded to the nearest 5 units. However, when the magnitude of the value in English is either small or expressed with obvious precision, an attempt has been made to keep the metric conversion consistent.

Table 2.--English to metric conversion factors

English		Multiplied by	Metric	
Unit	Abbreviation		Unit	Abbreviation
Acre	acre	0.4047	Hectare	ha
Acre-foot	acre-ft	.0012335	Cubic hectometre	hm^3
Barrels (42 U.S. gallons)	bbl	.15899	Cubic metre	m^3
Do	do	.000159	Cubic hectometre	hm^3
Cubic feet	ft^3	.02832	Cubic metre	m^3
Foot	ft	.3048	Metre	m
Gallon	gal	.003785	Cubic metre	m
Do	do	3.785	letre	1
Gallons per minute	gpm	5.45	Cubic metres per day	m^3/d
Do	do	.06309	Litres per second	l/s
Gallons per day	gpd	.003785	Cubic metres per day	m^3/d
Inch	in	2.54	Centimetre	cm
Mile	mi	1.6093	Kilometre	km
Pounds per square inch	psi	703.07	Kilograms per square metre	kg/m^2
Do	do	70.307	Grams per square centimetre	gm/cm^2
Square mile	mi^2	2.59	Square kilometre	km^2

Table 3.--Relation of units of hydraulic conductivity, permeability, and transmissivity[1/]

A. Hydraulic conductivity

Hydraulic conductivity		† Field coefficient of permeability
Feet per day ($ft\ day^{-1}$)	Metres per day ($m\ day^{-1}$)	† Gallons per day per square foot ($gal\ day^{-1} ft^{-2}$)
One	00.305	7.48
3.28	One	24.5
.134	.041	One

B. Transmissivity

Square feet per day ($ft^2\ day^{-1}$)	Square metres per day ($m^2\ day^{-1}$)	† Gallons per day per foot ($gal\ day^{-1}\ ft^{-1}$)
One	0.0929	7.48
10.76	One	80.5
.134	.0124	One

C. Permeability

Intrinsic permeability $k = -\frac{q\upsilon}{d\phi/dl}$ $[(\mu m)^2 = 10^{-8} cm^2]$	$Darcy = -\frac{q\mu}{dp/dl + \rho g\ dz/dl}$ $[0.987 \times 10^{-8} cm^2]$	†Coefficient of permeability P or $Pm = -\frac{q(\text{at } 60°F.)}{dl/dl}$ $[gal\ day^{-1} ft^{-2}$ at 60°F.]
One	1.01	18.4
0.987	One	18.2
.054	.055	One

[1/] Adapted from Lohman and others (1972). Equivalent values shown in same horizontal lines. † indicates term abandoned by the U.S. Geological Survey.

Previous investigations

A number of reports describing the ground-water resources of counties and specific localities or areas for much of the Trans-Pecos region have been published. However, the saline-water resources of this region are largely unknown because most of the published reports are concerned primarily with the availability and use of the potable ground water generally found in shallow aquifers. These reports include, by county: Eddy (Hendrickson and Jones, 1952); southern Lea (Nicholson and Clebsch, 1961); Winkler (Garza and Wesselman, 1959 and 1962); Ward (White, 1971); Pecos (Armstrong and McMillion, 1961); and Reeves (Knowles and Lang, 1947; Ogilbee, Wesselman, and Irelan, 1962).

The occurrence of ground water in the Carlsbad area has been described in reports by Hale (1945a, 1945b, and 1961), Bjorklund and Motts (1959), Halpenny and Greene (1966), and Motts (1968). Some of the testimony and exhibits in three hearings before the New Mexico State Engineer were useful in this study (New Mexico State Engineer Hearing, 1960, 1962, and 1963). The information presented in the three hearings is summarized along with important interpretations in a memorandum report prepared by the staff of the New Mexico State Engineer (New Mexico State Engineer, 1964).

Brown, Rogers, and Baker (1965) have written a generalized evaluation of the ground-water conditions in the middle Rio Grande basin in Texas. The water resources of the Pecos River basin were investigated jointly by State and Federal agencies in 1939-40 (U.S. National Resources Planning Board, 1942a and 1942b). Bjorklund (1958), Cushman (1965), Akin and Slingerland (1967), and Vandertulip (1966) have analyzed the flow of the springs in the Pecos River in the vicinity of Carlsbad and Artesia, N. Mex. Cox (1967) has described the geohydrology of an area between Lake McMillan and Carlsbad.

Methods of handling saline-water chemical data and the quality of water found in rocks of Permian Guadalupian age within the project area have been described by Hiss, Peterson, and Ramsey (1969), and Hiss (1970). Hiss (1973) described the construction of an observation-well network composed of 12 wells completed in the Capitan aquifer in southeastern New Mexico. This report and another by Hiss (1971) contain hydrographs depicting the water levels recorded in these wells. The depletion of ground water and decline of the potentiometric surface in southeastern New Mexico have been described by Spiegel (1958). Dinwiddie (1963), and Broadhurst, Sundstrom, and Weaver, (1951) have described the public supplies in southeastern New Mexico and western Texas, respectively.

Spiegel (1967) has discussed the natural geohydrologic conditions controlling ground water in the Pecos River basin. Brackbill and Gaines (1964) described the production of water from the Capitan aquifer in a large water field in Winkler County, Texas, and the use of the water in oil-field secondary recovery operations. Data relating to the production of water from the Capitan aquifer in the Toyah-Monahans area of Texas for both irrigation of crops and secondary recovery of petroleum are available in a report written by the staff of Guyton and Associates (1958). The geology and ground-water resources of the Roswell artesian basin are described in reports by Fisher (1906), Fiedler (1926), Fiedler and Nye (1933), and Kinney and others (1968). Two publications of the West Texas Geological Society (Hills, 1961, and 1962) contain a number of stratigraphic sections depicting the shallow aquifers in part of the study area. Grauten (1965) and McNeal (1965) have discussed various hydrodynamic relationships and oil entrapment in the Delaware and Permian basins, respectively.

Literature on the general geology and stratigraphy of the report area is voluminous. The Delaware basin, Central Basin platform, and surrounding shelf areas within the larger Permian basin are important oil-producing provinces. The rocks of Permian age in the Delaware basin and surrounding areas are extremely complex in nature, but have been studied extensively as a result of intensive exploration for oil, gas, and other mineral resources. Conclusions and information from many of these investigations have been incorporated into this report. These articles and reports are cited individually and (or) are included in the bibliography.

The volumes of produced oil, gas, waste water, and injected water were obtained from annual reports published by the New Mexico Oil and Gas Engineering Committee (1950-1958, 1959, 1960-1970), Railroad Commission of Texas (1939-1969); Lea County Operators Committee (1935-1942 and 1943-1949); Hobbs Pool Operators Committee (1932); Lamb and Lea County Operators Committee (1948); Lamb and Macey (1947a, 1947b, and 1947c); and Kinney, Lea County Operators Committee and New Mexico Oil Conservation Commission (1949). Many of these reports also contain limited but useful reservoir-engineering data.

Methods of investigation

Location and number of wells

More than 30,000 wells that penetrate formations of Guadalupian or older age have been drilled within the project area in search of oil and gas (table 4). Relatively few wells penetrate the narrow arcuate band of the Capitan aquifer along the edge of the Delaware basin because most of the wells are concentrated in the oil fields along the Artesia-Vacuum arch and the Central Basin platform (fig. 4). A few abandoned oil-test wells have been converted to irrigation wells in Pecos County where water is produced from the Capitan aquifer and San Andres Limestone (Armstrong and McMillion, 1961, table 4, pl. 1). Water for municipal, domestic, and irrigation use is produced from wells completed in the Capitan aquifer, San Andres Limestone, and Artesia Group in the vicinity of Carlsbad west of the Pecos River (Bjorklund and Motts, 1959).

Table 4.--Number of oil and gas wells drilled, by county, to January 1, 1971

State	County	Number of wells
New Mexico		
	Eddy	7,130
	Lea	15,932
Texas		
	Brewster	85
	Culberson	1,624
	Loving	1,352
	Pecos	9,022
	Reeves	1,756
	Ward	6,573
	Winkler	7,243
Total number of wells in nine counties		50,717[1/]

[1/] More than 30,000 of the oil and gas wells are located within the project area shown in figure 2.

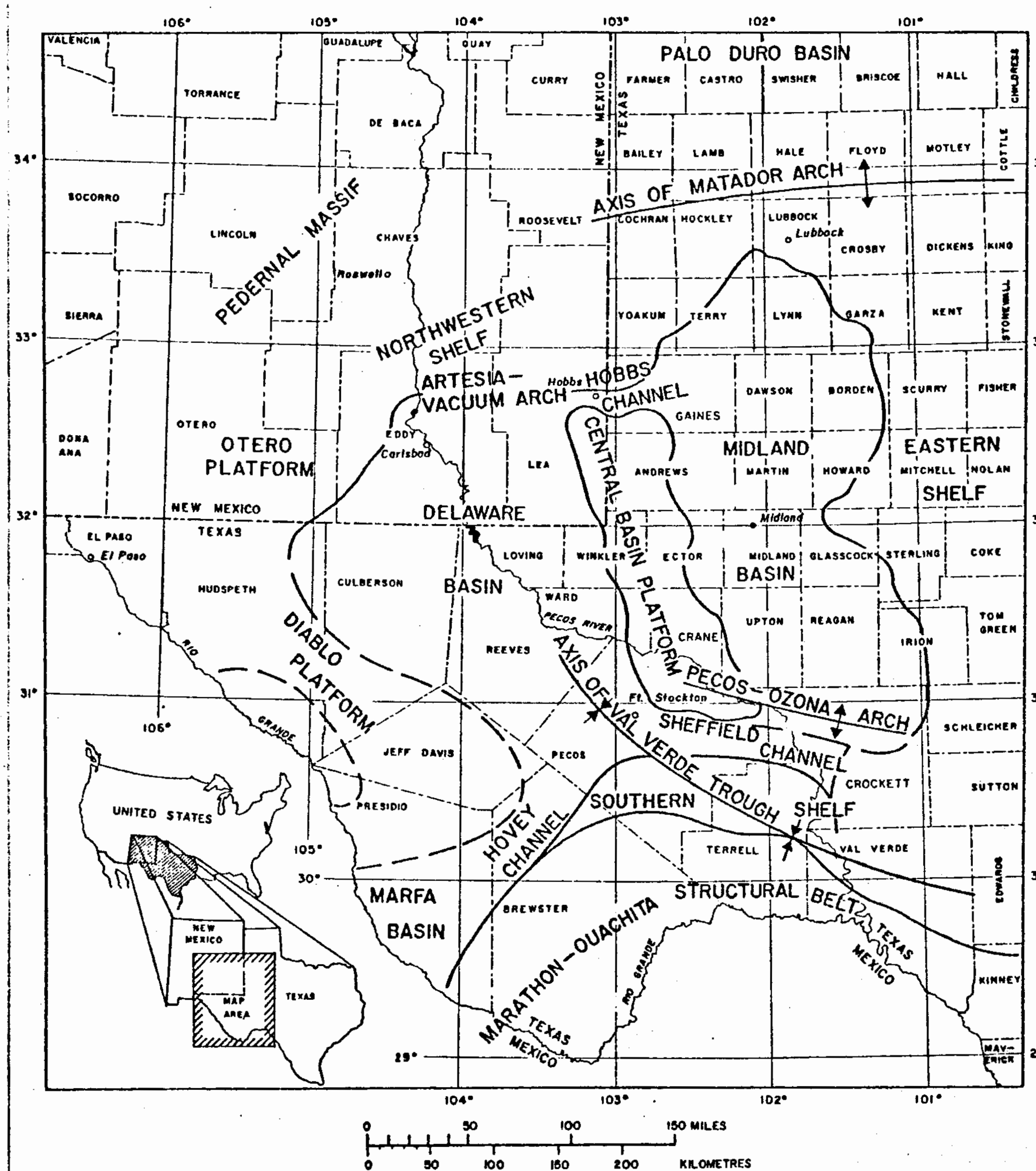


Figure 4.--Map showing position of the principal structural elements in western Texas and southeastern New Mexico during Late Paleozoic time.

Types of information available

Nearly all the information availalbe for interpretation in this study was originally collected by oil companies for industrial purposes during the drilling, evaluation, and production of the oil and gas wells. These data include: pressures measured during drill-stem or bottom-hole pressure tests; chemical analyses of water samples; permeability and porosity analyses of rock cores; aquifer or reservoir performance tests; statistical tabulations of the volume of the oil, gas, and water produced and (or) injected; lithologic and electrical logs; and fluid-level measurements. A small amount of aquifer-test and water-level data were available from published reports or in the files of the U.S. Geological Survey.

Source and ownership of information

Limited amounts of data were obtained from published reports, including the water-rights hearings before the New Mexico State Engineer, and from the public basic-data files of the New Mexico State Engineer and the U.S. Geological Survey. Other data collected, analyzed, and interpreted by Geological Survey personnel during the course of the investigation included measurements of water levels, continuous records of water-level fluctuations in a 12-well observation-well network (Hiss, 1971, and 1973), several aquifer-performance tests, chemical analyses of water samples, and lithologic logs. Several hundred electrical logs were purchased from commercial sources. Some information, including several aquifer-performance tests, was collected in cooperation with several oil companies. However, the vast majority of the data were obtained directly from the proprietary files of oil companies, geological and hydrological consultants, and members of the oil-service industry.

Acquisition of privately owned data

Almost without exception, the many segments of the oil industry offered to cooperate freely in supplying information from their private, and often confidential, files pertaining to the oil, gas, and water wells owned by them. Nevertheless, before any of this information could be obtained, it was necessary to supply the donor company with the name and location of the well for which data were being sought. Without a data-base and some form of machine-data processing capability, the search and identifications of wells would have been an impossible task considering the myriad wells drilled and the limitless possibilities of data associations for a particular well.

Fortunately, the Permian Basin Well Data System (PBWDS) magnetic tape file of scout records was being completed just as the project started (Permian Basin Well Data System, 1964; and Cooper, 1967a, and 1967b). This data base contains both the information made available to the oil industry through regular scout checks and certain facts required by regulatory agencies. Information describing the location, ownership, depth, names of formations penetrated, drilling and development history, casing records, production tests, and the completion data for all wells drilled for oil and gas within 68 counties in the Permian basin and adjacent areas of western Texas and southeastern New Mexico is included. Data pertaining to the deeper water supply and injection wells drilled for use in secondary recovery projects can frequently be obtained from this source. The PBWDS file for the nine counties in the project area contains approximately 800,000 tabulating cards as images on magnetic tape for wells drilled through 1965.

Use of the Permian Basin Well Data System file

The Permian Basin Well Data System was used both as a framework in earlier machine-data processing efforts and as a primary source of information. Lists of wells for which core analyses and drill-stem or bottom-hole pressure measurements might be available were printed on multi-part tabulating paper after execution of a detailed search of the PBWDS file. The several thousand pages of requests printed in geographic positon order within individual operator names were screened and then mailed directly to more than 70 different oil companies.

The requests were organized in a manner allowing rapid retrieval of data from manually operated central files with a minimum of clerical help. The use of multi-part paper allowed the donor company to annotate the original request list and then return one copy as a transmittal form.

Attempts were made to locate the longest cored interval in sedimentary rocks of Guadalupian age within each township in New Mexico or similar area in Ward and Winkler Counties, Texas. Similar attempts were made to locate drill-stem tests of selected intervals within the same geographic area. Approximately four times more data than needed were requested from oil companies. The response and cooperation from the oil companies was outstanding. However, due to loss of data in consolidation of offices, company mergers, transfer of ownership, and other reasons, many of the original source documents were unobtainable, and fewer data than needed were collected by this request.

The PBWDS file was searched for bottom-hole pressures and for drill-stem tests in which any of the initial or final shut-in pressures and (or) the initial or final-flow pressures were approximately equivalent. This search yielded valuable information used in the construction of the potentiometric maps.

Cross indexes (Hiss, 1970, p. 1474) were prepared after editing the township, range, and section in New Mexico (survey, block, and section in Texas), footage measurements within a section, operator and lease names, well number, total depth, file reference number (American Petroleum Institute, 1966, and 1968), decimalized latitude-longitude coordinates, reference elevations, and the spud and completion dates from the PBWDS file. Indexes in reference number order were printed first before sorting the information into location order and then into operator order to print both location and operator indexes.

Cross indexes keyed to the operator and reference number and to the geographic location, operator, and reference number were used to great advantage in locating and identifying the oil and gas wells. The oil-industry data frequently were identified only by the location, or by operator, and by lease information, so that both indexes were necessary.

Formation tops and bases, operator and lease names, location, total depth, latitude-longitude coordinates, and the reference number were edited from the PBWDS file and were used to compute the elevations of the formation tops or bases referred to sea-level datum and the thickness of selected intervals. The computed information was later employed in constructing various thickness and structural-contour maps, and in stratigraphic correlations.

Restrictions on the use of proprietary data

Most of the larger companies placed various levels of restrictions on the use and publication of data loaned to the Geological Survey. The most common restrictions concerned identification of the source of the data. Several companies restricted identification of the exact well associated with data and limited the scale of maps exhibiting the data.

Quality of the information

Most of the data obtained from the files of petroleum companies were generally of good quality, but had been collected or prepared for purposes other than the analysis of ground-water systems. Static equilibrium pressures could not be calculated from the pressures measured in the majority of the drill-stem and bottom-hole pressure tests due to the shortness of the recovery period. Almost none of the pressures measured on the drill-stem tests prior to 1958 were usable because of the poor sensitivity of the equipment.

Water samples are collected and analyzed by the petroleum industry for a variety of industrial purposes including the determination of the effectiveness of acid treatment of reservoirs, location of casing leaks, and interpretation of the effect of water flooding of partly depleted oil-bearing reservoirs. Therefore, these chemical analyses were frequently not representative of formation water and had to be verified before they could be used to prepare maps depicting ground-water quality.

Operators of many of the deeper wells concentrate only on the more prospective deep oil and gas-bearing zones and often do not collect drill cuttings or run electrical logs in the shallower formations, including those of Guadalupian age. Samples of drill cuttings were frequently not obtainable from the Capitan aquifer because of the difficulty in maintaining circulation while drilling through this formation.

Very large volumes of data were processed during the course of the study. Much of this data was discarded because it was either nonrepresentative, unreliable, or, for other reasons, unsuitable for use in ground-water studies. In many instances, the data either were not described properly or could not be located geographically.

Machine-data processing methods

Initially, all the information processed with computer methods were encoded in fixed-field formats compatible with the PBWDS file. Gradually all of the sub-files containing oil-company data, information derived from the PBWDS file, and ground-water data were blended together in the more flexible OMNIANA data file. This data-base management system was developed for use in earth science studies in New Mexico using the experience gained by working with the PBWDS file (Hiss, Garza, and Peterson, 1969; and Peterson and Hiss, 1970).

Confidential data or proprietary information edited from restricted sub-files and included in the OMNIANA data file are identified by restriction parameter codes. All data sets in the OMNIANA data file are identified by unique-reference numbers. With a few minor exceptions, oil and gas wells are identified with unique-reference numbers identical to those used by the petroleum industry (American Petroleum Institute, 1966, and 1968).

In addition to information derived from the PBWDS file, the OMNIANA data file contains a small amount of data for oil tests drilled after 1965, pressures recorded during approximately one thousand drill-stem tests, about 5,000 chemical analyses of ground water (Hiss, 1975h), approximately 30,000 water-level measurements recorded in the 12 observation wells (Hiss, 1973), porosity and permeability data from about 40,000 feet (12,200 metres) of analyzed rock cores, and about 50 digitized sonic-gamma-ray electrical logs.

Observation-well network

Purpose

Nine oil and gas test wells, drilled to depths of 10,000 (3,050 metres) to 18,000 feet (5,500 metres) and located along the trend of the Capitan aquifer in Eddy and Lea Counties, New Mexico, were acquired from oil companies at the time of abandonment. The unsuccessful oil and gas test wells were plugged back to the base of the Capitan aquifer, perforated in the Capitan aquifer, and converted to observation wells. The nine wells and three water wells previously completed in the Capitan aquifer form an observation-well network used to monitor the changes in head in the Capitan aquifer caused by natural stresses and the effects of fluid withdrawal in Lea County, New Mexico and Ward and Winkler Counties, Texas (Hiss, 1971, and 1973).

Source and ownership of observation wells

The North Cedar Hills Unit 1, Humble State 1, Yates State 1, Hackberry Deep Unit 1, Middleton Federal B 1, South Wilson Deep Unit 1, North Custer Mountain Unit 1, Federal Davison 1, and Southwest Jal Unit 1 observation wells were obtained from cooperating oil companies at the time of abandonment and converted to observation wells. The U.S. Geological Survey owns and is responsible for the future use and disposal of these wells (fig. 5).

The city of Carlsbad Water Wells 10 and 13 are owned by the city of Carlsbad, whereas the city of Carlsbad Test Well 3 is apparently still owned by Mr. Forrest Miller of Carlsbad. The three wells were drilled, completed, and developed by the city of Carlsbad during various ground-water exploration programs and are on loan to the Geological Survey (fig. 5).

The Eugene Coates 3 well is a temporarily abandoned oil well that is completed in the Seven Rivers Formation. This well was loaned to the Geological Survey for a short period of time for use as an observation well during and after aquifer performance tests in a nearby water field.

Data recorded from a crest-stage gage located near Tansill Dam were collected and compared to the hydrographs from nearby wells completed in the Capitan aquifer. The Tansill Dam crest-stage gage was discontinued in early 1970.

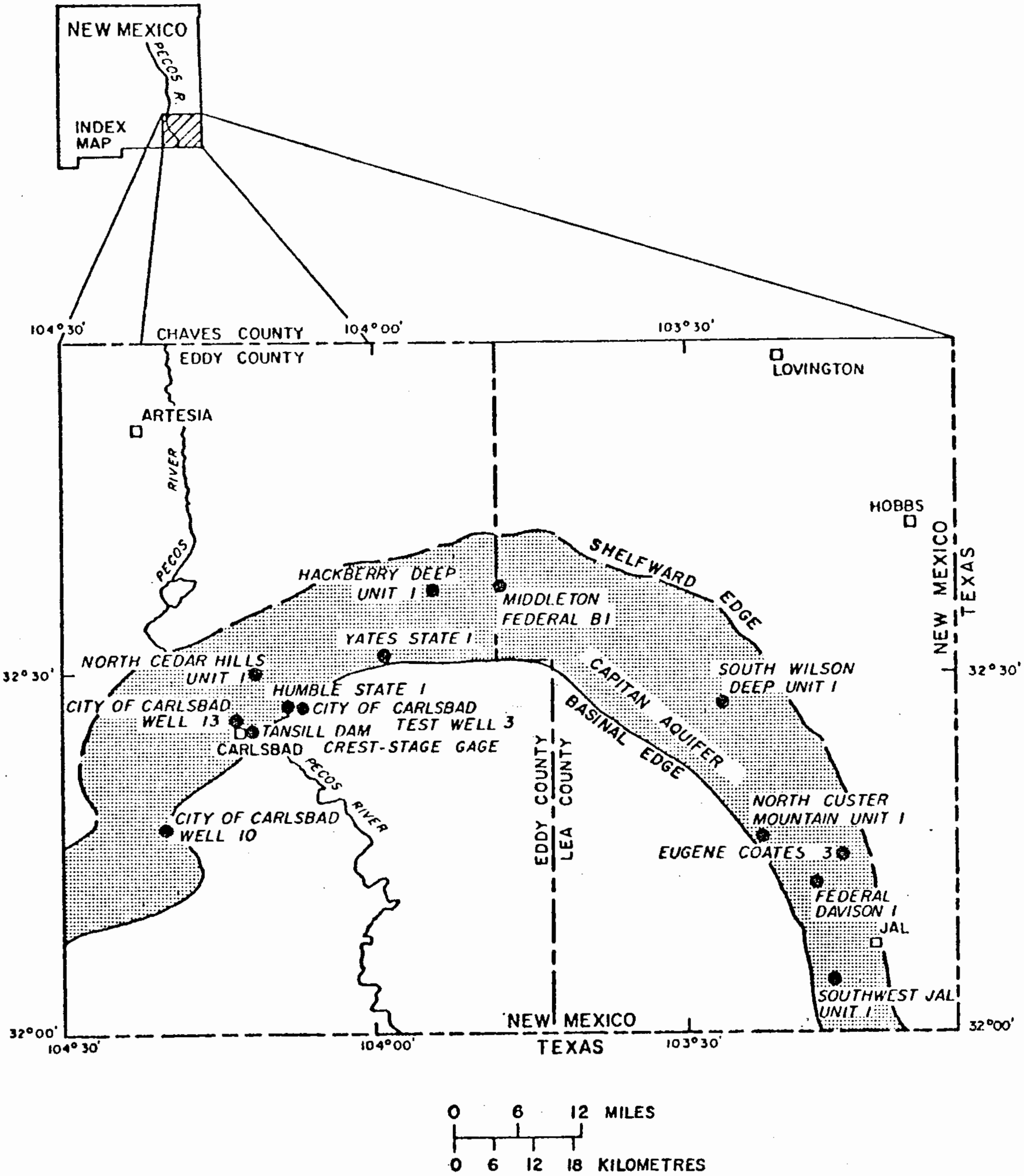


Figure 5.--Map showing location of wells in the Capitan aquifer observation-well network, southeastern New Mexico.

Well completion and development

With the exception of the North Custer Mountain Unit 1 well, a cement plug was placed by the operator at the base of the intermediate casing string that had been set through or near the base of the Capitan aquifer. The wells were then filled to the surface with either rotary drilling mud, brine, or fresh water and released to the Geological Survey. The North Custer Mountain Unit 1 well was received with the uncased interval of the borehole (12,175 to 16,000 feet; 3,711 to 4,877 metres) plugged back to 12,800 feet (3,901 metres). The well was filled with fresh water at the time of abandonment by the operator. A wire-line bridge plug was subsequently set at 5,300 feet (1,615 metres) near the base of the Capitan aquifer in this well.

The completion procedures generally followed by the Geological Survey included swabbing or bailing the mud or water from the casing, running perforating-depth control logs, perforating, swabbing to test the effectiveness of perforations, and stimulation of the well with acid as necessary to increase the well productivity. These procedures were followed by another production swab test. The position of the perforated interval in 8 of the 12 observation wells is shown in figures 6 and 7. Complete descriptions of the completion procedures and construction of the wells are given in Hiss (1973).

Acknowledgments

This study was made in cooperation with the New Mexico State Engineer. Messrs. S. E. Reynolds, State Engineer of New Mexico, and F. R. Allen, P. D. Akin, J. C. Yates, R. L. Borton, and Zane Spiegel from his staff gave encouragement and valuable technical assistance throughout the course of the study.

Much of the data, including the Permian Basin Well Data System magnetic tape file of oil-industry scout records, were furnished by various oil and oil-service companies. This study could not have been made without the generous support of the petroleum industry. Twelve wells, used in an observation-well network in southeastern New Mexico, were either assigned to the U.S. Geological Survey by oil companies or loaned by the city of Carlsbad or by private individuals.

Messrs. G. J. Gail, E. S. Hobday, and J. N. Black IV assisted with preparation and quality control of machine-processed records and supervision of data encoding. Messrs. Sergio Garza and G. J. Gail helped with tabulation of records and the preparation of several maps and stratigraphic sections. Mr. Garza also gave valuable technical assistance to the writer, including help in formulating a method used in adjusting point-water levels and bottom-hole point pressures to fresh-water heads referred to sea-level datum.

The observation wells were serviced by Messrs. E. R. Cox, J. S. Havens, C. C. Cranston, R. L. Rogers, G. E. Welder, G. E. Maddox, H. E. Lobley, J. A. Basler, J. D. Hudson, and J. D. Stevens. Messrs. E. R. Cox and J. S. Havens also assisted the author during well completion and development operations.

Computer programs were written by Messrs. J. B. Peterson, D. R. Posson, T. R. Ramsey, A. P. Trantolo, C. Z. Mitchell, Jr., J. A. Jouret, and L. E. Galyean, and Mmes. P. M. Hiss and N. R. Mitchell, Jr.

Messrs. J. N. Barbee, J. L. Kunkler, and F. C. Koopman helped with aquifer-performance tests. Dr. J. D. Bredehoeft gave valuable technical assistance and furnished one of the computer programs used in initial attempts to numerically simulate the Capitan aquifer (Peterson, Hiss, and Garza, 1969).

The New Mexico State Land Office, New Mexico State Oil Conservation Commission, Conservation Division of the U.S. Geological Survey, and the U.S. Bureau of Land Management were helpful during stages of negotiations for, and development of, the observation-well network. Latitude-longitude coordinates and elevation data for the many wells used in the study were obtained from the Permian Basin Well Data System tape file of scout records and were used with the permission of Tobin Surveys, Inc. and Laughlin-Simmons and Co. of Texas, Inc., respectively.

Computer facilities at the U.S. Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, were used for nearly all data processing. Colonel T. L. Franklin, Dr. H. F. Cooper, and Major J. T. Holland were most helpful in making the use of these facilities possible. Petroleum Information, Inc., digitized the electrical logs used in the cross sections and computed latitude-longitude coordinates for well locations not in the Permian Basin Well Data System file.

The sedimentary section and stratigraphic relationships of the Guadalupian strata were examined several times during field trips sponsored by the West Texas Geological Society and the Permian Basin Section of the Society of Economic Paleontologists and Mineralogists. The explanations and interpretations of the many obscure details to be found in these rocks by Dr. Alonza D. Jacka, Dr. Karl W. Klement, Mr. Thomas A. Bay, Jr., and many others on individual occasions in conjunction with these field trips to the Guadalupe Mountains were both highly beneficial and inspiring. It would have been most difficult to arrive at the conclusions promulgated in this report without a firm grasp of the intricate relationships of the sedimentary facies represented in the Guadalupian Series.

The base map for the Texas part of the study area was obtained from Midland Map Co., and is used with their permission. The base map for the New Mexico part of the study area was furnished by the Oil and Gas Branch, Conservation Division, U.S. Geological Survey. Messrs. W. J. LeMay and D. G. Stevens allowed the writer to use oil and gas field outlines from maps owned by them.

Messrs. W. F. Guyton, E. L. Reed, L. C. Halpenny, J. R. Barnes, E. E. Kinney, and G. A. Hill allowed the writer to use, extract, and incorporate certain proprietary data into this report.

Drs. T. R. Walker, B. F. Curtis, B. J. Chronic, W. W. Longley, and W. C. Bradley gave encouragement and counsel at many times during the study. The assistance of the many cooperating agencies, companies, and individuals is gratefully acknowledged.

STRATIGRAPHY, STRUCTURE AND GEOLOGIC HISTORY

Paleozoic Erathem

Pre-Permian Guadalupian Series

The stratigraphy, structure, and geologic history of rocks younger or older than Permian Guadalupian age is treated cursorily in this report. These rocks have very low transmissivities and are, for practical purposes, considered to be hydraulically isolated from the Capitan aquifer and San Andres Limestone, the principal aquifers of interest.

Ordovician to Mississippian Systems

A maximum thickness of approximately 7,000 feet (2,135 metres) of dolomite, limestone, sandstone, and minor shale were deposited in shallow seas in the Tobosa basin, an autogeosyncline on a broad, southward-sloping shelf developed on the craton, during the Ordovician to Mississippian Periods (Galley, 1958, p. 401-419; and Adams, 1965). Unconformities at the end of Early, Middle, and Late Ordovician time and again at the end of both the Devonian and Mississippian Periods interrupted an otherwise continuous geologic record. Some of the most important oil-producing structures in this area are located on this medial ridge. Uplift of a complex fault block, the Central Basin platform, during Late Mississippian and Early Pennsylvanian time, divided the Tobosa basin into the Delaware and Midland basins (figs. 4 and 8; and Galley, 1958, p. 401; and Adams, 1965).

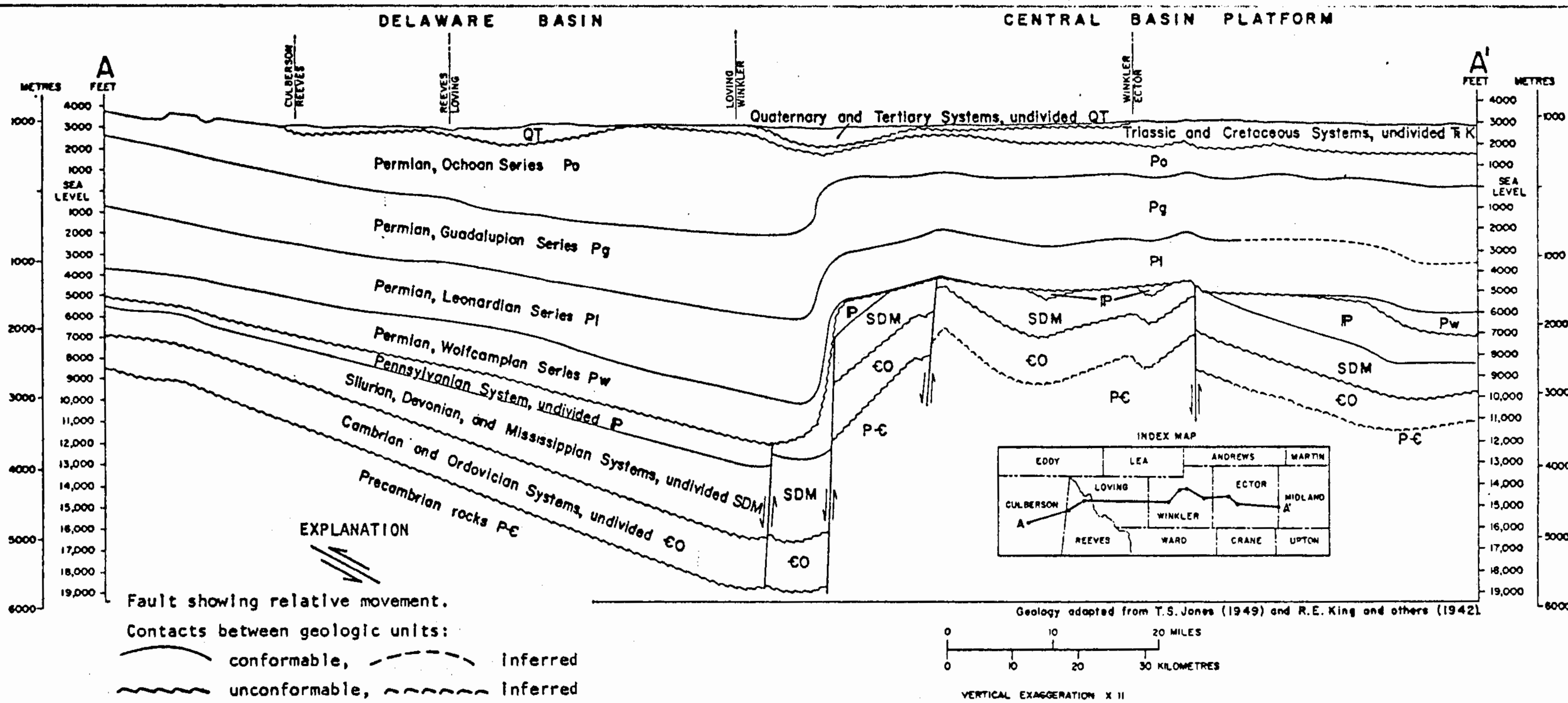


Figure 8.--Diagrammatic stratigraphic section showing structural relationship of Delaware basin and Central Basin platform.

Pennsylvanian System

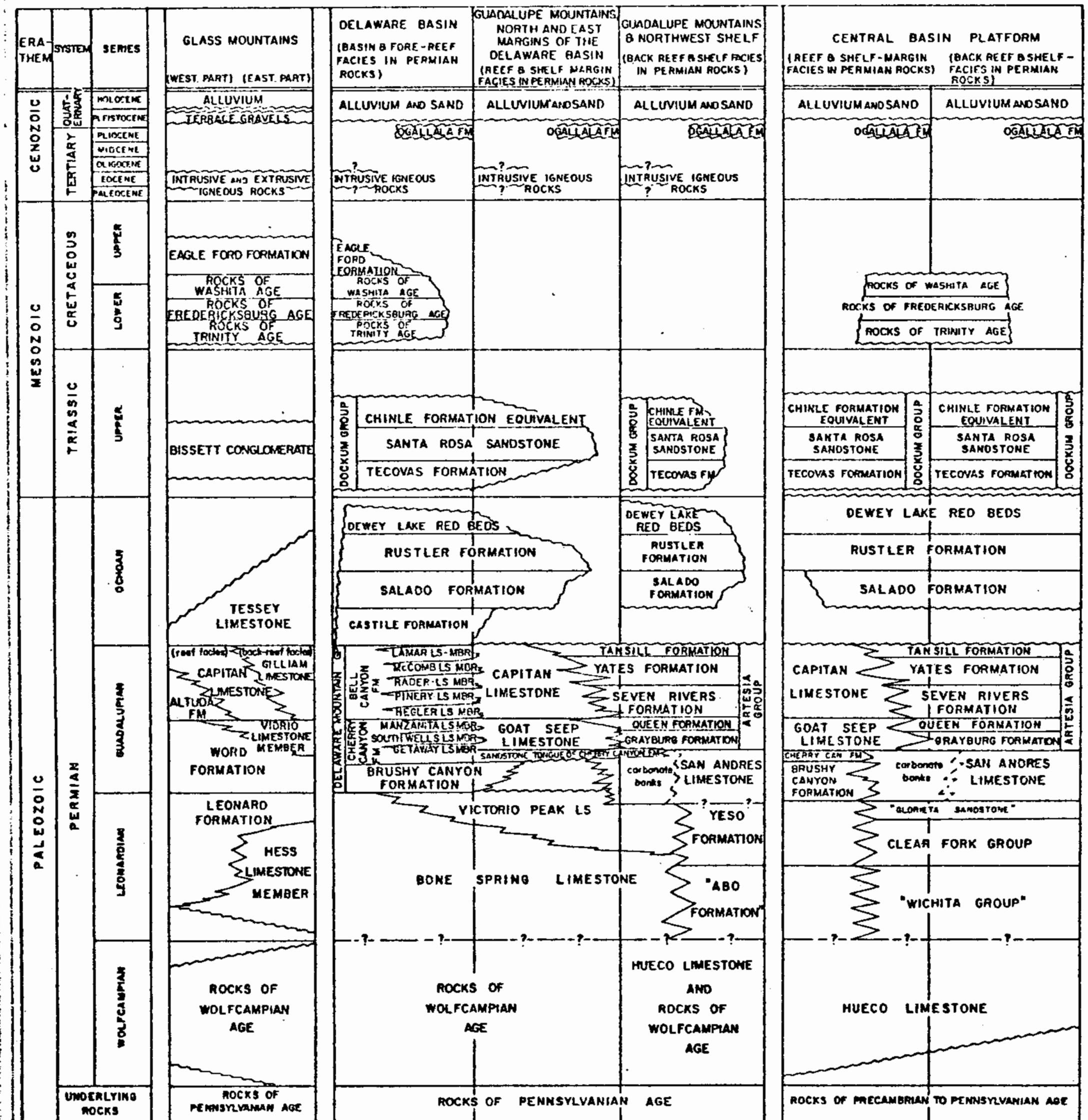
The Delaware basin subsided rapidly during the Early Pennsylvanian. Older rocks were stripped from the Central Basin platform and deposited on the flanks of this median range as clastic wedges (Vertrees, Atchison, and Evans, 1959). Material was eroded from the Pedernal massif, Diablo platform and other highlands to the north, west, and southwest of the Delaware basin, and deposited as thin sequences of sands and shales with interbedded carbonates on and along the edges of the shelves (Hills, 1963; and Galley, 1958). Carbonates are interbedded with, or take the place of, the sandstones and shales along the shelf and shelf margins but extensive, well developed limestone reefs of Pennsylvanian age have not been encountered along the shelf edge in the Delaware basin.

Sediments shed from the emerging mountains in the Marathon-Ouachita structural belt were trapped in the Val Verde trough south of the Pecos-Ozona arch until Late Pennsylvanian when sediments overflowed into the Delaware basin (Galley, 1958; Young, 1960; and Oriel, Myers, and Crosby, 1967). The maximum thickness of the Pennsylvanian System in the Delaware basin is slightly more than 2,000 feet (610 metres) west of the Central Basin platform (Galley, 1958).

Permian System

Wolfcampian Series

The Central Basin and Diablo platforms, Pedernal massif and Marathon-Ouachita belt were active uplifted areas at the beginning of the Permian Period while the Delaware basin continued to sink (Hills, 1963; and figs. 4, 8, and 9). During Wolfcampian time, more than 8,000 feet (2,440 metres) of chert, limestone, and terrigenous clastics were eroded from the Marathon-Ouachita Mountains and accumulated in the southern part of the Delaware basin where it opens into and joins the Val Verde trough. The Wolfcampian Series progressively thins to the north away from the thick section in the Val Verde trough to approximately 500 feet (150 metres) near the north and northwestern edge of the Delaware basin (Feldmen, 1962; and Vertrees, 1964). Carbonates, including some shelf-margin reefs and banks, formed the dominant facies on the Northwest shelf and the Central Basin and Diablo platforms, the more stable positive areas (figs. 4 and 8). The Val Verde trough at the southern end of the Delaware basin was filled with sediment and became less active with the close of Wolfcampian time.



[Compiled from many sources including Oriel, Myers, and Crosby (1967), Hayes (1964), McKee, and others (1959), Jones (1949 and 1953), Waldschmidt and Huffington (1949), Young, and others (1957), Young (1960), Vertrees (1964), Wilde, and others (1962), P. B. King (1930, 1937, 1942, 1948, and 1965), Newell, and others (1953), Dunbar, and others (1960), Ahlen (1958), Ahlen and Tait (1959), Roswell Geological Society (1960), Green, and others (1964), Tait, and others (1962), Society of Economic Paleontologists and Mineralogists (1957), and Hollingsworth (1955). Names enclosed in quotation marks in this table and throughout the report are used locally for rock units that are probably not the same as those of the type area.]

Figure 9.--Correlation chart showing position of Permian and younger rocks in the Delaware basin and surrounding area.

Leonardian Series

After the uplift and subsequent destruction of the Marathon and Ouachita Mountains along the southern margin of the Val Verde trough and at the southern end of the Delaware basin, orogenic activity was limited to epeirogenic movement of broad areas (Hills, 1963, p. 1719; Silver and Todd, 1969; and Meissner, 1972). In this manner, the structural framework that would control the depositional environment in the Delaware basin for the remainder of the Permian Period was firmly established at the onset of the Leonardian Epoch (Galley, 1958, p. 428; Hills, 1963, p. 1719; and Adams, 1965). Three distinctive facies are identificable in the Leonardian Series: (1) A basinal section composed of shale, siltstone, sandstone, and dark limestones, (2) shelf complexes composed of carbonates, evaporites and red beds, and (3) reef and other shelf-margin carbonates.

Dunham (1970) applied the term "stratigraphic reef" in describing the Capitan Limestone and other linear carbonate complex composed of particles wholly or largely bound with inorganically derived cement. Correspondingly, Dunham (1970) used the term "ecologic reef" to describe a similarly shaped carbonate complex built from organically bound carbonate material. Throughout this report, the work "reef" is employed in the sense of Dunham's "stratigraphic reef".

A maximum thickness of more than 4,000 feet (1,220 metres) of Leonardian age sedimentary rocks is now present in southwestern Loving County. The 2,000 to 3,500 feet (610 to 1,065 metres) of sedimentary rocks, primarily carbonates, present on and along the margin of both the Northwestern shelf and Central Basin platform are more important to the hydrology of the Capitan aquifer (Galley, 1958, p. 428 and 430).

In places, particularly along the western edge of the Central Basin platform, permeable shelf-margin carbonates of Guadalupian age are superimposed on and are probably in relatively good hydraulic communication with Leonardian sedimentary rocks having similar characteristics (Pan American Petroleum Corp. and Westbrook-Thompson Holding Corp. 1958, Defendants' Exhibit No. 47; Jones, 1949; and Silver and Todd, 1969).

Permian Guadalupian Series

Geographic distribution

Strata of Guadalupian age are present in the subsurface throughout the Permian basin. The Artesia and Delaware Mountain Groups and the San Andres Limestone and their lateral equivalents form extensive outcrops in western Texas and southeastern New Mexico (fig. 10; and Dane and Bachman, 1958, and 1965; and Goddard, 1965). Although only about 20 percent of the volume of sedimentary rocks filling the Permian basin are Guadalupian in age; reservoir rocks within these strata contain about one-half of the more than 14 billion barrels (2.2 billion cubic metres) of oil discovered within the Permian basin (Galley, 1958).

Previous investigations

The economic importance of the Guadalupian age rocks as oil reservoirs in the Permian basin has fostered numerous extensive studies of the readily accessible exposures of these rocks in the Guadalupe Mountains by many geologists.

Several contemporary investigators, including Kendall, 1969; Silver and Todd, 1969; Tyrrell, 1962, 1964, and 1969; Ball and others, 1971; Dunham, 1969, and 1972; Meissner, 1972; and Jacka and others, 1968, and 1972, have recognized sedimentary features within the Guadalupian Series in the Permian basin that are analogous to those found in the Holocene carbonate and (or) carbonate-evaporite-sandstone depositional environments located in the Bahamas, Florida, Australia, and, in particular, the Persian Gulf. Interpretations by Kendall (1969), Silver and Todd (1969), Dunham (1972), Jacka and others (1972), and Meissner (1972) were particularly useful in understanding and defining the Permian Guadalupian aquifer systems.

Structural setting

The Permian basin of western Texas and southeastern New Mexico includes the Delaware and Midland basins, the narrow elongate Central Basin platform, and the Southern shelf and relatively broad Northwestern and Eastern shelves shown in figure 4. The Diablo and Otero platforms and the Pedernal massif are positive areas that flank the western periphery of the Permian basin.

Communication between the Delaware and Midland basins was established through the Hobbs and Sheffield channels at the north and south ends of the Central Basin platform, respectively. Paleogeologic evidence suggests that seas entered the Permian basin area from an open ocean to the southwest through present-day Mexico and spread over much of western Texas and New Mexico during Late Leonardian and Early Guadalupian time (P.B. King, 1942; Hills, 1942; and Meissner, 1972).

Paleo-positions derived from fitting the morphological outlines of continents together with consideration of the paleomagnetic and other data available suggest that the North America crustal plate on which the Permian basin resides was probably located very near the equator during the latter part of the Paleozoic Era (Dietz and Holden, 1970). Presumably, a warm climate resulted in a prolific growth of calcium carbonate secreting organisms during this time.

The area covered by the epicontinental seas was gradually reduced throughout the Guadalupian Epoch until the Hovey channel remained as the principal connection to the open oceans via the Marfa basin. The Midland basin was filled by an influx of sand and mud during Late Leonardian and Early Guadalupian time and gradually converted to an evaporite shelf (Oriel, Meyers, and Crosby, 1967; Jones, 1949; Tomkins, and others 1953; and Tait, and others, 1962). However, the structural configuration of the Delaware basin with relatively deep water surrounded by broad shelves with low topographic relief, which were alternately either covered by shallow water or exposed, prevailed until the close of the Guadalupian Epoch.

Depositional environments and characteristic sediments

Major sedimentary facies

The three major time-transgressive sedimentary facies, shelf, shelf margin, and basin, representing the topographically controlled sedimentation previously recognized in the Leonardian Series are much more evident in Guadalupian strata. Silver and Todd (1969, figs. 4 to 9 inclusive), Ball and others (1971, fig. 3), and Dunham (1969, and 1972) have prepared excellent perspective diagrams of hypothetical Guadalupian landscapes in this type of geological setting. The paleotopography shown in these sedimentary models has been defined principally by relating characteristic features found in the Guadalupian sedimentary rocks to modern analogs observed in the Persian Gulf (Wells, and Illing, 1964; Illing, Wells, and Taylor, 1965; Butler, 1969; Kinsman, 1969; and Kendall, and Skipwith, 1968, 1969a, and 1969b).

Carbonate classification

Dunham (1962) has devised a method of classifying carbonate rocks according to the retained depositional texture. Rocks in which the original deposition texture is not exhibited are referred to as crystalline carbonates, e.g., "well-bedded, microcrystalline dolomite." Three textural features are evaluated in this scheme: (1) the presence or absence of carbonate mud, a factor determined largely by the amount of hydraulic energy at the depositional site; (2) the relative abundance of carbonate grains, which may be supported by mud (mud-supported), or, in the absence of sufficient mud, be self-supporting (grain-supported); and (3) the indication of organic binding during deposition.

A muddy carbonate containing fewer than 10 percent carbonate grains is a "mudstone," whereas a rock composed of more than 10 percent carbonate particles with the particles still being mud-supported is a "wackestone." A grain-supported muddy rock is a "packstone" which is differentiated from a "grainstone" in which mud is absent. Carbonate rocks characterized by organic binding are called "boundstone." The class name is usually prefixed with "lime" or "dolomite" to indicate the major chemical class of rocks, and as many other descriptive words or phrases as may be necessary to completely describe the rock, e.g., "druse-cemented, fusulinid lime grainstone."

Dunham's classification system is followed in this report whenever a particular class of carbonate rock is described, otherwise, the general terms "dolomite" and "limestone" are used.

Cyclic sedimentation

Cyclic alternations of time-synchronous carbonate, evaporite and terrigenous clastics are characteristic of the shelf and basin sediments in the Permian basin during the Leonardian and Guadalupian Epochs. The frequent and abrupt cyclic changes in lithology, both vertically and laterally, for a given time horizon, are thought to be related to alternating periods of deposition at various stages of sea level. The cyclical fluctuation in sea levels may have been controlled by the effects of glaciation superimposed upon a relatively deep basin and a broad flat shelf complex that was slowly subsiding relative to distant uplands (Meissner, 1972).

Silver and Todd (1969), Dunham (1969), Kendall (1969), and Jacka, and others (1972) have vividly described changes in environment and the corresponding sediments that might be expected to have been deposited during the cyclical rise and (or) fall of the Guadalupian sea level. The following account of the sequence of events and the sedimentary patterns expected during a substantial decline in sea level is from Silver and Todd (1969, p. 2238-2239):

> "... /during normal sea-level stand, shelf-margin reefs and banks formed near sea level. The resultant lagoon was shallow but very broad; therefore little terrigenous sand reached the distant basin. Deposition of shelf-margin carbonates was at a maximum and the main sediments in the basin were pelagic mud and micrite.

"...[At a lower sea-level stage], shelf-margin strata were partly subaerially exposed but still were forming actively at a lower elevation. Islands developed along the topographically highest parts of the shelf margin. The lagoon was constricted and was bordered landward by an extensive algal flat. Locally, barrier islands developed during this sea-level stage. Continental and sabkha environments prograded basinward from their location at normal sea-level stand. Pelagic mud and micrite were the dominant lithic types deposited in the basin.

"...[At a substantially lower stage of sea level], continental and nearshore clastic beds continued to prograde seaward. Sabkha and algal-flat deposits replaced previous lagoonal sediments. Reefs and (or) banks ceased to develop and were replaced by an extensive stable land surface dissected by canyons and tidal channels. Tidal and near-shore currents and local rivers swept land detritus into canyon heads which were formed most commonly near salient features on the shelf margin. This clastic material was transported down the canyons by traction, slow creep, or turbulent flow. Channel and overbank systems distributed clastic material in the form of prograding submarine fans along the basin floor.

"....[At maximum low-water stage of sea level], land-derived detritus, at least locally, prograded completely across the shelf. Sediment transport was at maximum, so that sheetlike sands, perhaps more correctly described as coalescing eolian and fluvial sands, prograded over the supratidal flat to the shelf edge. Lagoonal and shelf-margin environments were exposed subaerially before being covered by prograding continental-derived sediments. Base level shifted frequently during maximum low-water stand; major degradation prior to burial beneath prograding continental sediments probably did not occur on a regional scale, but was a locally important process. Detrital sediment was carried across the shelf margin by suspension or through submarine canyons by a combination of mass transport, slow creep, and tidal and nearshore currents."

Cyclic alternations of time-synchronous carbonate and terrigenous clastic units which are thought to be related to alternating periods of deposition at high and low stages of sea level are characteristic features of shelf and basin sediments. Relatively thick sequences of light colored dolomites and limestones were produced on the shelf and shelf margin during high sea-level stages while thin, dark, laminated lime mudstone "marker" beds were deposited over widespread areas within the Delaware basin. Most of the terrigenous clastics were unable to reach the basin during high sea-level stages. During intermediate and low stands of sea level, comparatively thin terrigenous sandstones and siltstones were deposited on the shelf while thick sequences of terrigenous clastics were deposited within the Delaware basin. Some of the thin, well-bedded sandstones and siltstones deposited on the shelf persist through what are otherwise regional facies changes and can be correlated over long distances. Terrigenous clastics were not deposited on the steeply sloping shelf-margin apron.

Shelf facies

The distance across the shelf between bordering continental and shelf-margin environments ranged from a few tens of miles to perhaps more than a hundred miles depending on the stand of the sea with respect to land. At normal or slightly below normal sea levels, topographically recognizable features within the comparatively low energy shelf environment included, from land seaward, broad sabkha (salt flats) and algal flats with very low relief in the supratidal zone, a broad intertidal zone, a shallow lagoon connected to the open sea by tidal channels, barrier banks or islands on the seaward side of the lagoon, and barrier flats adjacent to the landward side of the shelf-margin reefs (Kendall, 1969; Todd and Silver, 1969; Dunham, 1972; and Jacka and others, 1972).

The sabkha facies is composed of early diagenetic, bedded, nodular anhydrite and primary anhydrite interbedded with terrigenous siltstones and irregularly laminated to stromatolitic mudstone and wackestone. Lagoonal and intertidal beds consist of thinly laminated to stromatolitic dolomite mudstone and wackestone. The laminations may be destroyed locally by burrowing animals and soft sediment deformation. Pelletoidal dolomite grainstone is interbedded locally with the mudstone and wackestone. Dunham (1972) describes the porosity of the lagoonal facies as "poor to fair", and Kendall (1969, p. 2518), while not judging the relative amount of porosity, has described the nature of the pores as "interconnected vugs which are thought to be due to the movement of gas through the sediment."

The barrier island and flat province contains both pisolitic and (or) pisolitized dolomite grainstones and skeletal-lithoclastic dolomite grainstones representing a higher energy environment nearer to the seaward edge of the shelf. Dunham (1965a, 1965b, and 1969; and Thomas, 1965, and 1968) independently established that the pisolites in the Permian sedimentary rocks in the Guadalupe Mountains represent ancient vadose caliche formed at intervals when the near shelf-edge carbonates were subaerially exposed. Kendall (1969) found that two types of pisolites were present, one of primary marine origin, the other of secondary concretionary origin. Low angle crossbedding is evident on some of the carbonate mounds. Fenestral voids in these rocks are attributed by Kendall (1969) to movement of gas and trapped air as the carbonate material was subaerially desiccated in the supratidal zone. Dunham (1972) describes the porosity of the dolomite grainstones in the near shelf-edge sediments as "good."

The dolomite of the shelf facies frequently are interbedded with thin to massive-bedded well-sorted terrigenous siltstones and very fine to fine-grained sandstones.

Shelf-margin facies

The shelf-margin environment is characterized by topographically controlled banks, reefs, and forebank or forereef talus slopes located at the extreme seaward edge of a relatively deep open-marine sea. Newell, and others (1953, p. 190) estimated from work in the Guadalupe Mountains that the Delaware basin was about 1,700 feet (520 metres) deep near the close of the Guadalupian Epoch. Silver and Todd (1969, p. 2248) suggest that the Delaware basin was about 1,800 feet (550 metres) deep midway along the western margin of the Central Basin platform but only approximately 1,400 feet (425 metres) deep at the margin of the Northwest shelf near the boundary between Eddy and Lea Counties, New Mexico at the end of Capitan time. They attribute the difference in topographic relief at the end of the deposition of the Guadalupian Series to greater tectonic activity along the Central Basin platform and Guadalupe Mountains than that in the northern end of the Delaware basin. Todd and Silver (1969, p. 2247) estimate a water depth of 700 to 900 feet (215 to 275 metres) along the north and east margins of the Delaware basin at the end of Goat Seep time which is comparable to the estimate of 900 feet (275 metres) made by Newell and others (1953, p. 190) in the Guadalupe Mountains. Apparently, the amount of topographic relief between the basin and shelf edge nearly doubled during the Guadalupian Epoch.

The marine banks are principally composed of oolite bars and muddy, weakly cemented accumulations of the skeletal debris of crinoids, sponges, calcareous algae, fusulinids, brachiopods, bryozoans, and corals. Organisms found in the main reef tract include calcareous sponges and algae of several types, bryozoans, gastropods, cephalopods, and specialized brachiopods. A fierce argument rages among contemporary students of the Capitan and Goat Seep Limestones, the principal units comprising the Guadalupian shelf-margin sedimentary rocks, as to whether or not these carbonates were wave resistant at the time of deposition in the sense of the modern-day reefs as typified by the Great Barrier Reef located offshore from Northeastern Australia (Maxwell, 1968).

Solenopora and other similar calcareous algae may have bound a framework composed of larger skeletal secreting organisms together to form the locally common algal-sponge lime boundstone. However, the reef is principally composed of poorly sorted, very fine-grained lithoclasts apparently not well suited to withstand wave action. Kendall (1969) has suggested that the Capitan Limestone may have been deposited in an environment similar to the complex of sea grass banks in Shark Bay (Davies, 1970) or to the mounds in Florida Bay (Ginsburg and Lowenstam, 1958). In such an environment, the ecological position of sea grass which evolved during the Cretaceous would be filled by bryozoa, crinoids, calcareous sponges, and algae. Contemporaneous submarine cementation has been observed to bind sediments inorganically in similar recent sublittoral environments, and may well have been the most important factor in preserving the Guadalupian shelf-margin reefs (Ginsburg, and others, 1967; Kendall, 1969; Dunham, 1972; and Land, and Goreau, 1970).

The crest or reef core of the shelf-margin facies is chiefly composed of poorly but massively bedded, very fine-grained, pelletoidal-lithoclastic-skeletal lime grainstones and wackestones which grade to skeletal lime wackestones and grainstones and coarsely lithoclastic lime wackestones in the forereef. The carbonates in the shelf-margin and basin facies are nearly all limestones contrasted with a shelf suite composed almost entirely of dolomite. Dunham (1972) describes the porosity of the Capitan Limestone as "good, with exceptions." Some of the pore space originated as voids left between large fossils or formed by local slumping and settling of sediment (Newell, 1955). Porosity and permeability may have been developed or enhanced, as well as diminished, when the shelf-margin reefs and banks were exposed to subaerial processes, including desiccation and leaching, during low stands of sea level.

Fissures formed parallel to the reef trend by seaward slumping of sediment in response to over-steepening of the reef wall. The fissures may be filled with a variety of material including lithoclasts of older sediments, and (or) they may be closed with much younger laminated calcite cement (Dunham, 1972). Additional crevices were formed by structural failure of the sediment comprising the reef when the interstitial water was lost during cyclic exposure. The crevices may also be filled with penecontemporaneous or much younger eolian or fluvial terrigenous sand and silt (Kendall, 1972, p. 2507; and Hayes, P. T., 1964). A system of near-vertical joints, one set aligned parallel to the trend of the reef, the other set trending at right angles to the reef, was developed as the rigid shelf and shelf-margin sediments were subjected to regional crustal movements. The joints are incompletely filled with diagenetic calcite druse and terrigenous quartz sand (Dunham, 1972).

Many previous investigators have recognized that the forereef or apron part of the reef is volumetrically far more significant than the reef wall (King, P. B., 1948, p. 86; Newell and others, 1953; Pratt, 1964, p. 31; Hayes, P. T., 1964; and Dunham, 1972, p. III-15). One probable reason for this is that the reef wall is always subjected to maximum wave action and, therefore, the wave-resistant structures are more or less continuously eroded and destroyed concurrently with reef development (Ladd, 1950, p. 204; and Dunham, 1972, p. III-15). Fine material was probably constantly winnowed from the reef by marine currents and carried down the steep foreslope by a combination of mass transport processes including slow creep, suspension, and turbidity flows. Large blocks probably spalled off over-steepened walls and tumbled down the foreslope, perhaps triggering avalanches of other debris or turbidity flows in the process. The foreslope deposits are distinguished from the shallow-water bank and reef sediments by their darker color, presence of chert and silicified fossils, and the numerous shelf-derived lithoclasts.

The arcuate linear reef tract was incised locally by submarine canyons that extended well back into the shelf, tidal passes, and reentrants (Silver and Todd, 1969; and Jacka and others, 1968, and 1972). Occasionally a few of the submarine canyons may have cut through the entire shelf-margin facies during lower stands of sea level. Much of the carbonate material found in the forereef and basin apparently was transported through the canyons into the Delaware basin. The slope of the forereef debris commonly is 30 degrees or more. Dr. R. J. Weimer, accompanied by the author, determined an angle of repose of 45 degrees for the foreslope at excellent exposures in Carlsbad Caverns. The well-bedded sandstones and siltstones characteristic of the shelf facies are not present in the shelf-margin facies. Apparently, all, or nearly all, of the terrigenous clastics were conveyed through the shelf-margin facies from the shelf and into the basin via submarine canyons.

Basin facies

The basin facies consists of a thick sequence of well-bedded terrigenous sandstones and siltstones interbedded with thin but areally widespread, laminated, dark-lime mudstones. The dark laminated lime mudstones grade shoreward into the lighter-colored, coarsely lithoclastic lime wackestones of the forereef facies. The coarse carbonate detritus was probably transported into the basin through submarine canyons as subaqueous slides, mudflows, or turbidity flows whereas the fine silt or clay-sized carbonate particles were carried away from the shelf and shelf margin in suspension. Additional carbonate detritus entered the basin as blocks or avalanches spalling off or sliding down and away from an overly steep reef foreslope. Graded bedding is a common textural characteristic of the limestones.

Coarse lithoclastic lime wackestone including lithoclasts as large as 14 feet (4 metres) in diameter have been found as far as 10 miles (16 kilometres) from the reef front (Newell and others, 1957, p. 71 and plates 14 and 15.) Rigby (1958, p. 313) observed disturbed bedding in the Rader Limestone Member of the Bell Canyon Formation at a distance of about 28 miles (45 kilometres) seaward from the reef tract. The Lamar Limestone Member of the Bell Canyon Formation and the Manzanita Member of the Cherry Canyon Formation of the Delaware Mountain Group are the only two of the eight named limestone members in the basin facies to be mapped across the entire Delaware basin (Silver and Todd, 1969). The light-colored dolomite or dolomitic limestone in the Manzanita Limestone Member of the Cherry Canyon Formation suggests that the Delaware sea was probably comparatively shallow near the close of Goat Seep time (Silver and Todd, 1969, p. 2248).

Terrigenous sands and silts apparently prograded across the shelf onto the shelf margin during times of low sea level where they then were swept into the heads of the submarine canyons by long shore and tidal currents (Silver and Todd, 1969; and Jacka and others, 1972). Smaller quantities of eolian or deltaic quartz sands and silts entering the back-reef shelf lagoons under normal regimes could also have been transported by marine currents along the coast of the Delaware basin. Eventually the moving sediment would be intercepted by submarine canyons analogous to the processes now active along the coast of California (Ball and others, 1971).

Several major submarine canyons are located on the northwest and north margins of the Delaware basin (fig. 11) coincidental with the thick trends shown on isopach maps of the Delaware Mountain Group (Meissner, 1972, fig. 3). King, P. B. (1948), Hull (1957), and Wilde and others (1962, p. 29) indicate that the coarser grained terrigenous clastics are limited to the western part of the Delaware basin. The generally small grain size, good sorting, and high quartz composition suggests a source remote from the Delaware basin. These several lines of evidence suggests that much of the terrigenous material was derived from uplands to the north and west of the Delaware basin.

The terrigenous clastics accumulated in the submarine canyons, often with intermixed carbonate detritus, until slides, avalanches, and (or) mud flows were triggered by overloading, storm waves or other mechanisms. The submarine canyons may have been widened and deepened during mass transport of material into the basin. Studies by Jacka and others (1968, and 1972) show that the basin facies consists almost exclusively of channel, overbank, and fringe deposits. The sediments were deposited by a variety of bottom-flow processes including inertia flows, viscous mudflows, submarine avalanches, and turbulent suspensions. Submarine fans developed in the deep seas at the mouths of the submarine canyons and gradually coalesced to form a compound submarine apron or bajada. The thickness of the deep-sea fans and component sediment grain size both decrease seaward.

As described by Jacka and others (1972), deposits in a typical single fan in the proximity of the mouth of the submarine canyon are composed "predominantly of deeply incised channels which are filled with thin, laminated, and small current-rippled flow units and thick avalanche and mudflow deposits." At an intermediate distance from the mouth, "the fan channels contain thick, clean, well-sorted, current-rippled crossbedded sandstones deposited as major flow units 3 to 10 feet (1 to 3 metres) thick." The sedimentary units in both intermediate and distal positions consist of aggradational channel, levee, and overbank deposits. The units deposited in a distal position are similar to the intermediate deposits but thinner. Laminated and small current-rippled siltstones were deposited in the overbank facies. Finely laminated, silty shales form a fringe around the typical fan (Jacka, and others, 1972).

Submarine canyons

The margins of the Delaware basin were incised by numerous submarine canyons, contemporary in age to the shelf, shelf-margin, and basin facies. Much of the sediment in the Delaware basin was transported through canyons that extended (several miles) back onto the shelf. No one has located a completely exposed submarine canyon in the field. The exact nature of the material filling the canyons on the shelf margin remains unknown (Thomas A. Bay, Jr., 1973, oral commun.). The geometry and lithology interpreted from studies of electrical logs suggest that the submarinel canyons are almost completely filled with a mixture of carbonate debris, sandstones, and siltstones resembling the basin facies near the shelf margin but may be partly filled with Ochoan evaporites.

The material in the submarine canyons has a significantly lower transmissivity than that of the adjacent and underlying Capitan aquifer. The location, depth of incision, and general dimensions of the submarine canyons are, therefore, of considerable importance because they restrict the flow of ground water through the Capitan aquifer.

Jacka and others (1968, and 1972) have mapped the position of two major submarine canyons from limited exposures in the Guadalupe Mountains on the northwest margin of the Delaware basin. Last Chance-Sitting Bull submarine canyon is in southwestern Eddy County, New Mexico (fig. 11). The other unnamed submarine canyon is partly exposed in the vicinity of the West Dog, Shumard, and Bone Canyons at the extreme southwestern end of the Guadalupe Mountains in northwestern Culberson County, Texas and southeastern Otero County, New Mexico (Jacka, 1972, p. 154-157). Silver and Todd (1969) also indicate that terrigenous clastics were transported into the Delaware basin through submarine canyons incised into the margin of the basin, but do not reveal positions of any of the canyons.

The positions of large submarine canyons and reentrants incised into the Capitan aquifer along the north and east margins of the Delaware basin were delineated as thin transverse linear zones on a thickness map of the Capitan aquifer (fig. 11). The validity of this technique was confirmed by constructing structural maps contoured on the base and top of the Capitan aquifer and by examining stratigraphic sections in areas where submarine canyons might be present (figs. 6, 7, and 12). The submarine canyons appear to be located in areas where the top of the Capitan aquifer is structurally low. Futhermore, sandstone lenses appear to become more numerous in the Capitan aquifer in some of the submarine canyons, e.g., Shell Oil Co. Federal 4-1, sec. 4, T.22 S., R.34 E., Lea County (fig. 7). The Humble State 1, sec. 23, T.21 S., R.27 E., Eddy County, one of the poorest of the wells in the Capitan aquifer observation-well network, is located on the eastern bank of one of the larger canyons.

The profiles and shape of the submarine canyons outlined by the contours of the thickness of the Capitan aquifer resemble the form of recent submarine canyons shown by Shepard and Dill (1966) and Uchupi (1965).

The features identified as submarine canyons on figure 11 are of considerable importance to the interpretation of the ground-water hydrology of the Capitan aquifer. For purposes of this report, they have been located and named as shown in table 5. The submarine canyons outlined in figure 11 will become more sharply defined and others will undoubtedly be revealed by the drilling of additional deep wells through the Capitan aquifer in this area.

Table 5.--Names and locations of the most prominent submarine canyons incised into the Capitan aquifer in Eddy and Lea Counties, New Mexico

New Mexico

Name	Location	Derivation of name
1. North Alacran	sec. 31, T.20 S., R.27 E.1/ sec. 33, T.21 S., R.27 E.2/	From the overlying Alacran hills, a topographic feature located north of Carlsbad.
2. South Alacran	sec. 24, T.21 S., R.24 E.1/ sec. 13, T.22 S., R.26 E.2/	Do.
3. Quahada	sec. 9, T.20 S., R.28 E.1/ sec. 16, T.21 S., R.28 E.2/	From the overlying Quahada ridge, a local topographic feature.
4. West Laguna	sec. 18, T.19 S., R.31 E.1/ sec. 3, T.21 S., R.30 E.2/	From the several lakes ("Lagunas" on the topographic maps) formed in closed depressions at the surface overlying this area.
5. Middle Laguna	sec. 18, T.19 S., R.33 E.1/ sec. 5, T.21 S., R.31 E.2/	Do.
6. East Laguna	sec. 26, T.19 S., R.33 E.1/ sec. 1, T.21 S., R.31 E.2/	Do.
7. Eunice	sec. 23 & 36' T.21 S., R.35 E.1/ sec. 28, T.22 S., R.34 E.2/	From the town of Eunice located a few miles to the east.
8. Teague	sec. 14, T.23 S., R.36 E.1/ sec. 33, T.23 S., R.35 E.2/	From the railroad siding of Teague located approximately above the haed of the canyon.
9. North Jal	sec. 6, T.25 S., R.37 E.1/ sec. 12, T.25 S., R.35 E.2/	From the town of Jal located near the head of the canyon.
10. South Jal	sec. 18, T.25 S., R.37 E.1/ sec. 31, T.25 S., R.36 E.2/	Do.

1/ Head
2/ Mouth

Comparison of time-diachronous with time-synchronous units

As shown diagrammatically in figure 13, continental shales, sandstones, and siltstones; supratidal, and lagoonal evaporites; supratidal, lagoonal, and barrier island and flat dolomites; shelf-margin limestones and basinal sandstones, siltstones and limestones successively replaced the preceding seaward facies during the Guadalupian Epoch. The entire sedimentary sequence prograded basinward as a series of belts paralleling the shoreline. The approximate position of the change in facies from near shelf-edge dolomites to mid-shelf evaporites in the five formations of the Artesia Group is shown in figure 14.

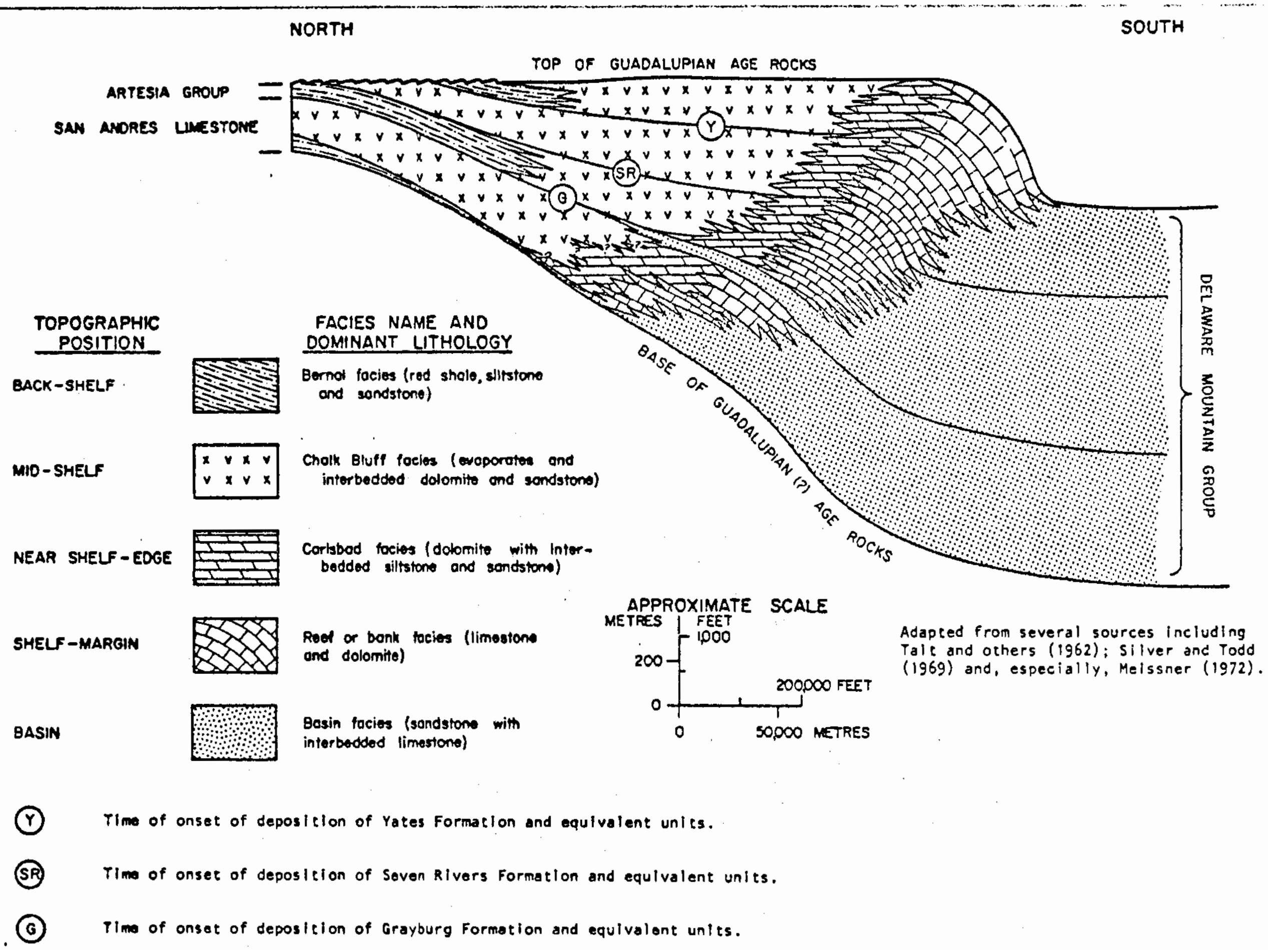


Figure 13.--Highly diagrammatic north-south stratigraphic section showing the position and relationship of the major lithofacies in the rocks of Guadalupian age in eastern New Mexico.

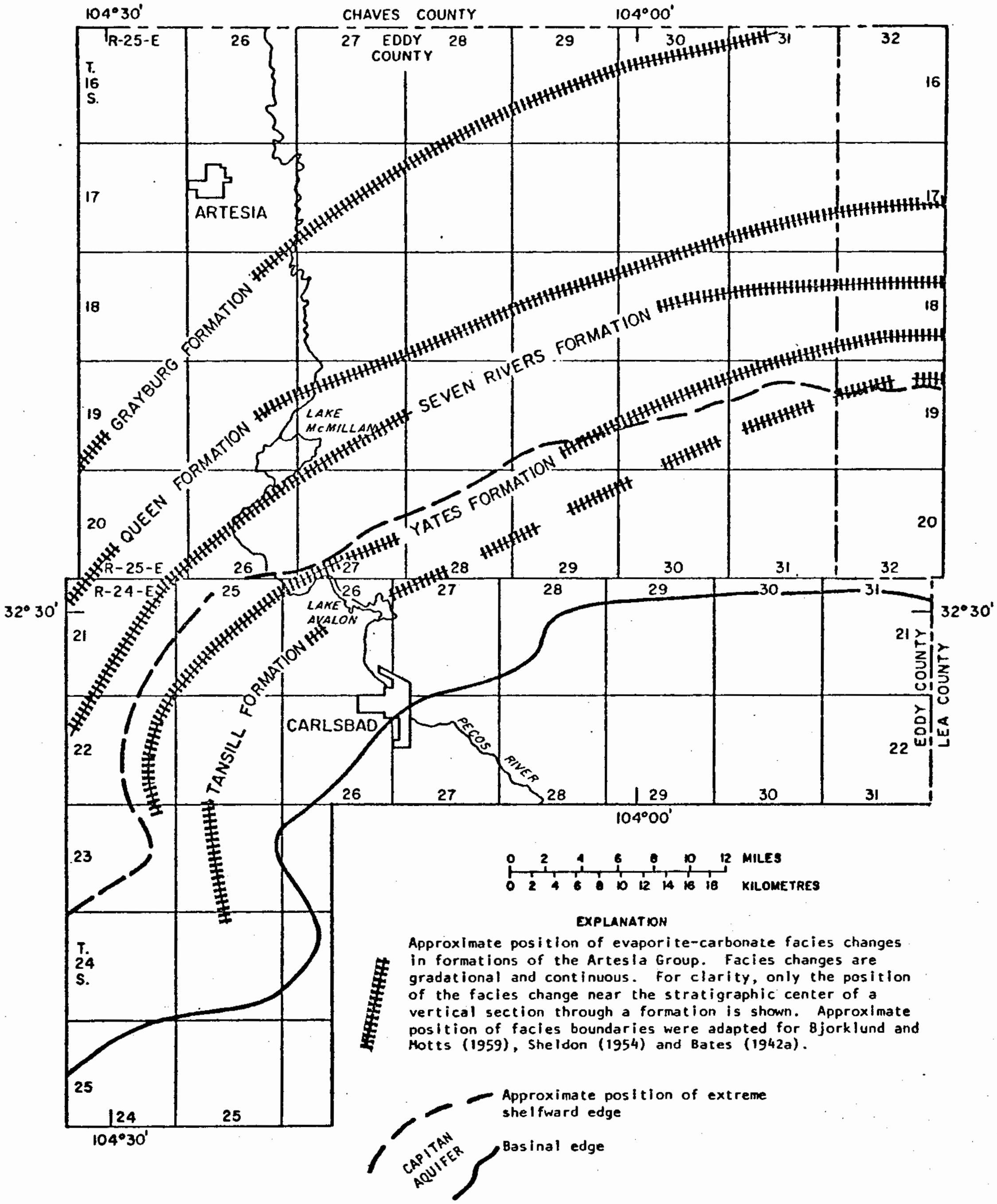


Figure 14.--Map showing evaporite-carbonate facies changes in the Artesia Group, southeastern New Mexico.

Several of the original stratigraphic units defined by geologists working on the Permian outcrops in the vicinity of Carlsbad closely followed time-transgressive lithologic boundaries between different facies in the Guadalupian Series. Lang (1937) defined the Chalk Bluff Formation to include the mid-shelf evaporites between the top of the Carlsbad Limestone and the base of the Dog Canyon Limestone (Morgan and Sayre, 1942, fig. 4). All three names were subsequently abandoned from the nomenclature by the U.S. Geological Survey. The Carlsbad Limestone was defined by Meinzer, Renick, and Bryan (1926) and subsequently modified by Lang (1937) to include the near shelf-edge dolomites and thinner interbedded sandstones above the Queen Formation and below the Castile Formation. Bachman (1953) applied the name "Bernal Formation" to a thin back-shelf section of red shales, siltstones, and sandstones. The formational names Bernal, Chalk Bluff, and Carlsbad were abandoned in the area and soon fell into disuse when the Artesia Group and the five component formations, Grayburg, Queen, Seven Rivers, Yates, and Tansill Formations, were defined and (or) redescribed and formally adopted (Tait, and others, 1962). The Bernal Formation, however, remains in good usage in north-central New Mexico but includes only a part of the red bed and evaporite sequence of the Artesia Group herein called the Bernal facies.

The position of important carbonate or clastic marker beds or zones with characteristically carbonate or clastic facies, both cyclical in nature, are employed to define the upper and lower surfaces of members, formations, and groups in the shelf section in the Permian basin. The cyclical marker beds or zones can be correlated laterally through facies changes over long distances in the subsurface and are believed by Meissner (1972) to be essentially time-synchronous (fig. 13). The lithologic character of rocks within the Artesia Group and the formations within the Artesia Group cannot be ascertained from the name of the unit because of the prominent facies changes that occur in this sequence of sedimentary rocks.

Meissner (1972, p. 206) urges that the names Bernal, Chalk Bluff, and Carlsbad be retained as a means of designating lithotopes within the Artesia Group, e.g., Carlsbad facies of the Artesia Group or simply Carlsbad facies whenever the meaning is clear within the context of the statement. The author endorses this practice as it seems much more feasible and meaningful to speak of the Chalk Bluff facies than, for example, to state "the supratidal and lagoonal evaporite facies" of the Artesia Group. The flow of ground water is often controlled by lithofacies and, therefore, the convenience and simplicity with which an aquifer can be defined and described becomes relatively important. The names Bernal, Chalk Bluff, and Carlsbad are used in this report to describe lithofacies within the Artesia Group as proposed by Meissner (1972).

Formational subdivision

San Andres Limestone

The lower part of the shelf facies in the project area is represented by the San Andres Limestone (Lee, 1909; and Needham, and Bates, 1943). The age of the San Andres Limestone is in question (Oriel, Myers, and Crosby, 1967). Lewis (1941) and Silver, and Todd (1969) assign the entire unit to the Guadalupian Epoch on the basis of physical stratigraphy and fusulinids; whereas Hills (1942), Jacka, and others (1972), and Meissner (1972), using the same approach, have assigned the upper part to the Guadalupian Epoch and the lower part to the Leonardian Epoch.

Regardless of the disputed differences in age, the upper part of the San Andres Limestone on the north and south end of the Central Basin platform is in measurable hydraulic communication with the Capitan aquifer and, therefore, is of some importance to this study.

The San Andres Limestone is composed of a lower cherty member and a thinner upper dolomite member (Hayes, 1964, p. 24; and Meissner, 1972, p. 221). Except for the Lovington Sandstone of local usage near the top of the upper member, the persistent terrigenous clastics so prevalent in the Artesia Group are absent from the San Andres Limestone. Meissner (1972) suggests that the San Andres Limestone was deposited during one major cycle of transgression and regression followed by one minor cycle near the close of San Andres time as comparedd to the numerous depositional cycles required to deposit the Artesia Group. The upper dolomite member becomes anhydritic to the north away from the shelf edge and eventually is replaced by evaporites in east-central New Mexico.

Discontinuous to continuous reefs or banks have been mapped along the margin of the Delaware basin and along the north and south ends of the Central Basin platform. Carbonate banks in the upper member of the San Andres Limestone are referred to by Silver and Todd (1969, figs. 12 and 13) as the Getaway Bank but are probably equivalent in age to the Getaway Limestone Member of the Cherry Canyon Formation (fig. 7).

Sandstone tongues of the Cherry Canyon Formation of the Delaware Mountain Group extend into the upper part of the San Andres Limestone in many localities (Boyd, 1958; and Hayes, P. T., 1964, p. 26). Most of the intertonguing relationships have been mapped using information obtained from scattered wells penetrating the section. Correlations made under these circumstances are subject to generalizations that will be improved upon as more wells are drilled. The tongues of sandstone may be related to submarine canyons as Jacka, and others (1972) have observed in the Guadalupe Mountains and probably occur at many different horizons.

The San Andres Limestone averages about 1,500 feet (455 metres) in thickness throughout much of the project area and thins irregularly to zero along a depositional facies change on the margin of the Delaware basin (Meissner, 1972, fig. 14).

Artesia Group

The upper part of the shelf facies in the Permian basin is represented by the Artesia Group (Tait and others, 1962; and Meissner, 1972, p. 221). The five formations in the Artesia Group are, in ascending order, the Grayburg Formation (Dickey, 1940; Hayes and Koogle, 1958; and Moran, 1962); the Queen Formation (Crandall, 1929; and Moran, 1954a, 1954b, and 1962); the Seven Rivers Formation (Meinzer, Renick, and Bryan, 1926; and Hayes and Koogle, 1958); the Yates Formation (Gester and Hawley, 1929; Bjorklund and Motts, 1959; and Mear and Yarbrough, 1961); and the Tansill Formation (DeFord and Riggs, 1941).

The lithology of the Artesia Group depends upon the location with respect to the shelf-margin at a specified time-synchronous horizon. Tait and others (1962) designated a reference well located in sec. 30, T.16 S., R.30 E., Eddy County, New Mexico, in which all the formations are described. The Artesia Group in the reference well is 1,710 feet (521 metres) thick and is composed of anhydrite, dolomite, sandstone, siltstone, and red shale. At this locality, the Tansill Formation is 105 feet (32 metres) thick and is dominantly anhydrite but contains a thin silt marker bed. The Yates Formation in the reference well is 261 feet (80 metres) thick and consists of interbedded sandstone, siltstone, and anhydrite. The sandstone is characterized by large, rounded, frosted, quartz grains scattered within a matrix of fine to very fine-grained sand. Tait and others (1962) indicate that the Yates Formation in the reference well can be correlated with the surface section described by Bjorklund and Motts (1959).

The Seven Rivers Formation is 565 feet (172 metres) thick and is principally composed of anhydrite but contains thin interbedded shale, dolomite, siltstone, and sandstone. Tait and others (1962, p. 514) state that some of the individual sandstones in the Seven Rivers Formation can be correlated over a wide area, and that, despite the change from anhydrite to dolomite, the thickness and lithologic character is correlative with the exposed section in the Guadalupe Mountains measured by Hayes and Koogle (1958).

The Queen Formation in the reference well is 420 feet (128 metres) thick and mainly consists of sandstone and anhydrite with thin interbedded dolomite and shale. A bed of sandstone about 30 feet (9 metres) thick near the top of the unit can be correlated over long distances in the subsurface. Tait and others (1962) indicate the section in the reference well can be correlated with the surface section of the Queen Formation measured by Hayes and Koogle (1958) in spite of the change in lithologic character from anhydrite and sandstone to dolomite and sandstone. The Grayburg Formation in the reference well is composed of dolomite with thin interbedded sandy dolomite, sandstone, and anhydrite. The basal sand in the Grayburg Formation is regionally correlative.

Meissner (1972) has described the shelf section as consisting of alternating thick carbonate and thin clastic units--each being nearly time-synchronous. The Tansill and Seven Rivers Formations of the Artesia Group and San Andres Limestone comprise the carbonate units and the Yates Formation and Queen-Grayburg Formations undivided are the clastic units. The persistent sandstones and thick carbonate-anhydrite beds permit regional correlation of the formations within the Artesia Group to be made with confidence.

The Carlsbad or carbonate facies of the Artesia Group ranges in width from 15 to 30 miles (24 to 48 kilometres) in a relatively narrow belt paralleling the margin of the Delaware basin (Meissner, 1972, fig. 3). The width of the Chalk Bluff or evaporite facies averages only 40 miles (64 kilometres) in a belt centered along the eastern edge of the Central Basin platform. A lobe of the Chalk Bluff facies extends far northward on the Northwest shelf into east-central New Mexico. The Chalk Bluff facies is surrounded by a belt of Bernal or clastic facies of variable width.

The average thickness of the Artesia Group within the northern part of the project area as depicted by Meissner (1972) is approximately 1,500 feet (455 metres). The Artesia Group thins to a thickness of about 1,000 feet (305 metres) on the southern end of the Central Basin platform.

The Artesia Group is the approximate equivalent of the Gilliam Limestone in the Glass Mountains (fig. 9).

Goat Seep Limestone

The Goat Seep Limestone was named by King, P. B., (1942, p. 588) and later restricted to include only the reef and forereef facies of the shelf margin by Newell and others (1953, p. 42-43). Hayes, P. T. (1964, p. 18) described the Goat Seep as a "light-gray, massive, fine crystalline to saccharoidal dolomite," a much different lithology than that observed in the overlying Capitan Limestone.

The Goat Seep Limestone occupies the same relative position with respect to the shelf margin as does the overlying Capitan Limestone. It is the lateral equivalent of the Grayburg and Queen Formations in the Artesia Group, and is approximately equivalent to the upper part of the Cherry Canyon Formation of the Delaware Mountain Group (figs. 9 and 13).

Capitan Limestone

The Capitan Limestone was deposited along the margin of the Delaware basin in a continuous, narrow, arcuate trending belt. Except for the narrow opening to the Hovey channel, the southern inlet to the Delaware basin, the Capitan Limestone completely encircles the basin. The Capitan Limestone crops out in the Apache, Guadalupe, and Glass Mountains and is present in the subsurface in the Salt Flat graben west of the Delaware Mountains (Reed, written commun. 1966) and along the north and east margins of the Delaware basin (fig. 6). The Capitan Limestone was named by Richardson (1904) from outcrops at the southern end of the Guadalupe Mountains and has since been the subject of many studies by geologists and the focal point of numerous discussions.

The vertical limits of the Capitan Limestone are now firmly fixed with the base at the apparently disconformable contact with the underlying Goat Seep strata (Hayes, P. T., 1964, p. 18-19) and the top at the overlying contact with evaporites of the Ochoan Series. The forereef limits are established by the rapid facies change from limestone debris into the terrigenous sandstones of the Delaware Mountain Group. However, many investigators extend the backreef limit of the Capitan Limestone shelfward more than 10 miles (16 kilometres) from the reef front and include much or all of the Carlsbad f16 kilometres) from the reef front and include much or all of the Carlsbad facies of the Artesia Group (Silver and Todd, 1969, figs. 12 and 13). The author favors restricting the Capitan Limestone to the massive and poorly bedded, lime wackestone and grainstone lithologies as shown by Dunham (1972).

Maximum overall width of the Capitan Limestone appears to be less than 5 miles (8 Kilometres) and the width at a single time-synchronous horizon is probably not more than 2 miles (3 kilometres). Thickness of the Capitan Limestone varies greatly from less than a few hundred feet in some of the incised submarine canyons to perhaps as much as 2,000 feet (610 metres) locally in some of the intercanyon areas. The Capitan Limestone is the lateral equivalent of the Tansill, Yates, and Seven Rivers Formations and the Bell Canyon Formation (figs. 9 and 13).

Delaware Mountain Group

The Delaware Mountain Group (Richardson, 1904) includes, in ascending order, the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations (King, 1948), and comprises the basin facies of the Delaware basin (Hull, 1957). The Delaware Mountain Group is present in the subsurface throughout all except the extreme southern part of the Delaware basin, and is exposed in the Delaware and Guadalupe Mountains along the western side of the basin. Beds within the Delaware Mountain Group appear to stratigraphically underlie coeval shelf-margin deposits because of the original difference in depositional topography--a spatial relationship that has been preserved (fig. 13).

The Brushy Canyon and Bell Canyon Formations are generally restricted to within the encircling wall of shelf-margin carbonates on the periphery of the Delaware basin. Discontinuous beds of the Cherry Canyon Formation, the middle unit of the Delaware Mountain Group, do, however, extend north and westward onto the Northwestern shelf beyond the shelfward or back reef limit of the Capitan and Goat Seep Limestones where they intertongue with the upper part of the San Andres Limestone. Sandstone tongues of the Cherry Canyon Formation seem to occur at different stratigraphic intervals near the top of the San Andres Limestone and may represent a series of submarine canyon deposits that may not be laterally connected (Wilde and Todd, 1968, p. 18; and Jacka and others, 1972).

The Word and Altuda Formations in the Glass Mountains section are approximately equivalent to the Delaware Mountain Group (fig. 9; and King, P.B., 1930, and 1937; and Jones, 1949).

The thickness of the Delaware Mountain Group ranges from less than 2,000 feet (610 metres) in the southern part of the Delaware basin to more than 4,000 feet (1,220 metres) in southwestern Lea and eastern Eddy Counties, New Mexico.

Permian Ochoan Series

Structural setting

The Permian basin area was elevated above sea level and tectonically stable at the onset of the Ochoan Epoch. Adams (1944, p. 1598) described the Delaware basin as a deep geosynclinal bowl encircled by high, steep-faced, cliff-like carbonate reefs. Sea water entered the Castile lagoon (Adams, 1972) through a connecting channel on the southwest side of the Delaware basin.

Near the end of Castile time, regional subsidence permitted the sea to encroach beyond the Delaware basin onto the shelf where it eventually spread over a large part of the southern Permian basin (Hills, 1942, figs. 11 and 12).

Formations of Ochoan age and their importance as aquifers

The Ochoan series is represented, in ascending order, by the Castile, Salado, and Rustler Formations, and the Dewey Lake Red Beds (fig. 9; and King, P. B., 1942; Adams, 1944; and Oriel, Myers, and Crosby, 1967). The Tessey Limestone in the Glass Mountains section is approximately equivalent to the Salado and Rustler Formations elsewhere in the study area (King, 1937). The approximate position of this facies change between the Tessey Limestone and the Salado and Rustler Formations is shown on figs. 6 and 11.

The Tessey Limestone and Rustler Formation are the only units in the Ochoan that can be considered to be of importance as aquifers. The production of water from the Rustler Formation and the general water-bearing properties of this aquifer have been described in numerous publications including Hendrickson and Jones (1952), Guyton and Associates (1958), Garza and Wesselman (1959 and 1962), Armstrong and McMillion (1961), Nicholson and Clebsch (1961), and White (1971).

Although a small amount of water for ranch use may be produced from the Tessey Limestone on the north side of the Glass Mountains, virtually nothing is known about the water-bearing properties of this aquifer. Hydraulic continuity of the Tessey Limestone and the Capitan aquifer is assured by the similarity in lithology and the numerous faults and well developed joint pattern in vicinity of the Glass Mountains.

Castile Formation

Unlike younger units of the Ochoan Series, the Castile Formation is confined to the Delaware basin where it rests conformably on the sandstones of the Bell Canyon Formation. This unit consists of a dense basal limestone near the margins of the basin, a lower banded anhydrite composed of interlaminated white anhydrite and thinner brown bituminous calcite layers, halite, and an upper massive anhydrite and small amounts of terrigenous clastics (Kroenlein, 1939; Adams, 1944; Jones, 1954; Pierce and Rich, 1962; Snider, 1965; Anderson and Kirkland, 1966; and Anderson and others, 1972). The basal limestone wedge may be coeval with the upper part of the Tansill Formation (Newell and others, 1953, p. 47). The thickness of the Castile Formation ranges from approximately 1,200 feet (365 metres) in the western part of the Delaware basin to more than 2,100 feet (640 metres) in the northern and eastern part of the basin (Snider, 1965, fig. 14).

Several mappable beds of halite within the Castile Formation attain a maximum aggregate thickness of more than 1,300 feet (395 metres) in the northern part of the Ochoan trough of Snider (1965, p. 47) in the northeast part of the Delaware basin (Snider, 1965, fig. 15). The interbedded halite has been dissolved and removed from the Castile Formation along the western and southwestern part of the Delaware basin (Maley and Huffington, 1953). The beds of halite in the Castile Formation are also either absent or thin along the northern and eastern margins of the Delaware basin in a trend adjacent to, and parallel with, the Capitan aquifer (fig. 7; and Adams, 1944, figs. 2-4; Hills, 1968, pl. 1; Pierce and Rich, 1962, fig. 12; Jones, 1949; and Vertrees, 1964).

Salado Formation

The Salado Formation underlies an area of approximately 25,000 square miles (64,750 square kilometres) in southeastern New Mexico and western Texas and extends more than 100 miles (160 kilometres) to the north and east of the Delaware basin (Pierce and Rich, 1962, fig. 13; Frenzel, 1963; and Adams, 1963). The Salado Formation is composed of halite, anhydrite, and minor amounts of dolomite and terrigenous clastics. Potassium minerals occur in the Salado Formation in the northern part of the Delaware basin where they are of considerable economic importance (Jones, 1954; and Pierce and Rich, 1962, fig. 13).

The contact between the Salado Formation and the underlying Castile Formation within the Delaware basin and Guadalupian age beds on the surrounding shelf areas is unconformable (Adams, 1944, p. 1608). The exact contact between the Castile and Salado Formations is, however, difficult to pick despite the unconformable relationships, differences in lithology, and vastly different geographic distribution (Pierce and Rich, 1962, p. 32; and Snider, 1965, p. 38).

With the exception of areas where the soluble minerals have been removed by solution, the thickness of the Salado Formation varies from about 500 feet (150 metres) in the western part of the Delaware basin to more than 2,500 feet (760 metres) as noted by Snider (1965) in one well in northwestern Pecos County, Texas. Thicknesses of more than 2,200 feet (670 metres) prevail in the Ochoan trough parallel to the Central Basin platform in the eastern part of the Delaware basin (Snider, 1965, fig. 23).

Halite in the Salado Formation has either been anomalously thinned or removed in a narrow band trending above or adjacent to the Capitan aquifer along the north and eastern margins of the Delaware basin (fig 7 D-D' and E-E'; and Adams, 1944; Maley and Huffington, 1953; Jones, 1949; Vertrees, 1964; Pierce and Rich, 1962, fig. 12; and Hills, 1968, pl. 1). The thickness of the Salado Formation varies from 800 to 1,200 feet (245 to 365 metres) on the Northwest shelf and Central Basin platform near the margin of the Delaware basin. The Salado Formation thins gradually and wedges out in both northerly and easterly directions.

Rustler Formation

The Rustler is the youngest unit in the Ochoan evaporite sequence in western Texas and southeastern New Mexico and is a record of the final incursion of the Permian sea into the Permian basin. The Salado Formation was uplifted and eroded along the western margin of the Delaware basin prior to the deposition of the overlying Rustler Formation (King, P. B., 1942; and Adams, 1944). The contact between the Salado and Rustler Formations within the Delaware basin is, however, gradational and appears to be conformable (Kroenlein, 1939; and Pierce and Rich, 1962). Nevertheless, the contact between the top of the Salado Formation and the base of the Rustler Formation in the subsurface within the Delaware basin is difficult to pick and is usually placed arbitrarily at the top of the youngest prominent halite bed in the Salado Formation. The Rustler Formation extends beyond the limits of the Salado Formation and is a well-defined marker bed throughout much of the Permian basin (figs. 6 and 7; and Vertres, 1964; Jones, 1949; Scobey, 1951; Davies, 1953; Hills, 1961, and 1962; Feldman, 1962; Roswell Geological Society, 1960; Stipp, and others, 1956; Ahlen, 1958; Ahlen, and Tait, 1959; and Tait, and others, 1962).

The Rustler Formation consists of interbedded anhydrite, gypsum, red shales, mudstones and silstones, dolomite, limestone, halite, and sandstone. Potassium minerals have been found within the Rustler Formation in the northern part of the Delaware basin (Jones, 1954). Thickness of the Rustler Formation ranges from less than 200 feet (60 metres) in the western part of the Delaware basin to more than 600 feet (185 metres) in south central Reeves County, Texas (Snider, 1965, fig. 24). The content of dolomite and limestone in the Rustler Formation increases southward and southwestward in the southern part of the Delaware basin until the Rustler becomes indistinguishable from the upper part of the Tessey Limestone in the Glass Mountains.

The Rustler Formation is a major source of the water used to flood partly depleted oil fields in southern Lea County, New Mexico, and Winkler, Ward, and Pecos Counties, Texas. Water produced from the Rustler is generally highly mineralized. However, in southern Ward and western Pecos Counties, Texas, the salinity decreases progressively toward the south and water from the Rustler is used to irrigate salt-tolerant crops.

Dewey Lake Red Beds

The Dewey Lake Red Beds, the youngest formation in the Ochoan Series, consist of orange-red siltstone with some mudstone and sandstone. This formation has been removed from the western and southern parts of the Delaware basin by post-Permian erosion but is present in the subsurface throughout most of the principal area of interest outlined in figure 3. The thickness of the Dewey Lake Red Beds varies from about 200 feet (60 metres) to as much as 600 feet (185 metres). The Dewey Lake Red Beds are separated from rocks of similar lithology in the basal part of the overlying Dockum Group primarily on a contrast in color (the Dockum Group is darker red) and a significant decrease in natural radioactivity in a thin zone immediately below the contact between the two units (Adams, 1944, p. 1615; and Garza and Wesselman, 1959, p. 18). The end of deposition of the Dewey Lake Red Beds marks the close of the Permian Period in the Permian basin and the commencement of a long period of erosion or non-depositon in western Texas and southeastern New Mexico.

Tessey Limestone

King, P. B., (1930, and 1937) has described the Tessey Limestone as a massive dolomite about 1,000 feet (305 metres) thick at sections measured in the Glass Mountains. The change from the carbonate lithology in the Tessey Limestone to the evaporites in the Rustler Formation is a very narrow band in the subsurface parallel to the southern margin of the Delaware basin a short distance to the north of the Glass Mountains. A paleogeographic map by King, P. B. (1942, p. 752) suggests that the carbonate facies of the Tessey Limestone was developed across the narrow Hovey channel that connected the Delaware evaporite basin to the more normal marine waters to the southwest.

Mesozoic Erathem

Structural movements

The Delaware basin and the other tectonic features shown in figure 4 were no longer active and had been topographically obliterated by the close of the Permian Period. The region now known as western Texas and eastern New Mexico became a low, monotonous plain with outcrops of red shale and sand and some exposures of limestone, dolomite, and gypsum. The landscape might have resembled the surface as some would describe it today (McKee, and others, 1959; and Hills, 1963). In Late Triassic time, a broad interior basin draining toward other interior basins to the northwest formed above the ancestral Permian basin. This basin was filled with continental red beds and sandstones. At the close of the Triassic, the region was gradually elevated without significant local tectonic activity. Triassic continental deposits were eroded from the western part of the project area as the region remained above sea level throughout the Jurassic (McKee and others, 1959, pl. 9).

A fundamental change in the paleogeography occurred in Early Cretaceous time when the interior basins with highlands to the east and south gave way to a gentle slope toward what is now the Gulf of Mexico. Shallow marine seas gradually and progressively invaded the area from the south and eventually overlapped beds ranging in age from Precambrian to Triassic in western Texas and southeastern New Mexico. Before withdrawing near the end of the Mesozoic, the Cretaceous seas from the Gulf had joined with seas encroaching from the Arctic to form a seaway through the western interior of the North American continent.

Stratigraphy

Triassic System

Dockum Group

Rocks assigned to the Dockum Group of Late Triassic age overlie Permian sedimentary rocks throughout much of southeastern New Mexico and western Texas where they are locally exposed at the surface (fig. 10; and Oriel, Myers, and Crosby, 1967, fig. 18). The Dockum Group gradually increases in thickness from an erosional wedge-edge along the western and southern part of the study area to more than 2,000 feet (610 metres) at a thick-center point located about 50 miles (80 Kilometres) north northeast of Hobbs (McKee and others, 1959). The Tecovas Formation, the oldest unit in the Dockum Group, consists of from 0 to approximately 300 feet (90 metres) of red shale, siltstone, and fine-grained sandstone.

The Santa Rosa Sandstone, the middle unit in the Dockum Group, is composed of from less than 100 (30 metres) to as much as 650 feet (200 metres) of red, brown, and gray sandstone. The Santa Rosa Sandstone is one of the principal aquifers in Winkler and Ward Counties, Texas, where it is a source of both fresh and saline water (Garza and Wesselman, 1959, and 1962; and White, 1971).

The Chinle Formation equivalent, the youngest unit in the Dockum Group, varies from 0 to as much as 1,300 feet (395 metres) in eastern Lea County, New Mexico, and is composed of red, maroon, and purple shales and siltstones, and lenticular beds of fine-grained red-to-gray sandstone.

A small amount of water of generally poor quality is produced from sandstones in the Chinle Formation equivalent at scattered localities. The Chinle becomes anomalously thin over the western part of the Central Basin platform in Winkler County, Texas, and southern Lea County, New Mexico, suggesting that the Central Basin platform was uplifted again after the close of the Triassic (Garza and Wesselman, 1962, pl. 2 and 3).

Bissett Conglomerate

The Bissett Conglomerate, crops out in and is geographically restricted to the vicinity of the Glass Mountains. It is approximately equivalent in age to the Dockum Group in the remainder of the western Permian basin. The Bissett Conglomerate is composed of rounded fragments of dolomite and limestone derived from the underlying Permian beds. Some interbedded layers of sandstone and limestone and lenticular beds of red shale have also been observed in the Bissett Conglomerate. King, P. B. (1930) measured a maximum thickness of 720 feet (220 metres) of Bissett Conglomerate on the north flank of the southwestern terminus of the Glass Mountains. This unit is of no hydrologic significance.

Cretaceous System

Rocks of Jurassic age are not present in this part of western Texas and southeastern New Mexico (McKee and others, 1956). Rocks of Cretaceous age are geographically restricted to the southern and southwestern part of the project area where the Cretaceous is separated from the underlying Permian or Triassic by an angular unconformity (figs. 8 and 9). Although interrupted by several regressive phases, Cretaceous seas advanced progressively from the southeast and apparently eventually inundated all of the project area (Lang, 1947; Sloss, Dapples, and Krumbein, 1960; and Hendricks and Wilson, 1967). Approximately 1,500 feet (455 metres) of lower and lowermost Upper Cretaceous limestone, sandstone, shale, and claystone are present in most of Pecos County, the southern part of Reeves County, and the northern part of Brewster County, Texas.

Large quantities of ground water are produced from the Cretaceous limestone wherever the transmissivity has been enhanced by solution and fracturing, and from the sandstone of Trinity age in Pecos and Reeves Counties (Armstrong and McMillion, 1961; Ogilbee, Wesselman, and Irelan, 1962; and Brown, Rogers, and Baker, 1965). With the exception of isolated remnants, Cretaceous rocks have been eroded from the remainder of the project area. Hydraulic communication between the Capitan aquifer and rocks of Cretaceous age in southern Pecos County, Texas, is probably good wherever joints, fractures or faults are well developed.

Cenozoic Erathem

Structural movements

Late in the Cretaceous Period or very early in the Tertiary Period, western Texas and southeastern New Mexico was elevated by a broad epeirogenic uplift and tilted slightly to the east and northeast. Laramide folding comparable to that in the Rocky Mountains did not take place in the Permian basin. Hills (1963) suggests that the Laramide stresses were absorbed and distributed by the massifs of northeastern New Mexico and the Texas Panhandle, and the tightly folded Paleozoic rocks of the Marathon-Ouachita belt and associated tectonic elements along the southern edge of the basin. In this manner, the buried structural framework established in Late Wolfcampian and Early Leonardian time was preserved and remained intact until the Guadalupe, Delaware, Apache, and Glass Mountains were formed by basin and range block faulting late in the Cenozoic.

Sediment eroded from emerging highlands in central New Mexico and in Texas west of the Pecos River, accumulated, and was spread across eastern New Mexico and western Texas by eastward-draining streams during the Middle and Late Tertiary Period. Several scattered intrusions and extrusions in the fault block mountains along the southern and western margins of the Delaware basin are the only record of igneous activity in the Permian basin during the Cenozoic Era.

Most of the faulting and the main uplift of the Guadalupe, Delaware, Apache, and Glass Mountains probably started late in the Pliocene and continued on into the Pleistocene. The major block faulting quite likely was preceded by slight warping or folding and other minor adjustments as noted in the Glass Mountains by King, P. B. (1937). Whether or not the Guadalupe and other block fault mountains along the western margin of the Delaware basin were covered by the Pliocene Ogallala Formation at an earlier stage is a matter of conjecture. Thin remnants of terrigenous siliceous sandstone and conglomerate on top of the Guadalupe Mountains were considered to be Cretaceous in age by Hayes, P. T. (1964) but may be Pliocene. Sandstone dikes and crevice fillings exposed in Jurnigan Draw in the Guadalupe Mountains southwest of Carlsbad seem to more closely resemble the Ogallala Formation than any of the sandstones of Cretaceous age observed by the author in western Texas.

Structural configuration of the Guadalupian Series

As shown in figure 15, strata of Late Guadalupian age on the Northwestern shelf dip gently southeastward away from the Sangre de Cristo Mountains toward the Central Basin platform and Midland basin at an average of about 100 feet per mile (19 metres per kilometre). Rocks in the Delaware Mountain Group dip gently eastward from the Delaware and Guadalupe Mountains, northeast from the Apache Mountains, and northward from the Glass Mountains, toward the center of basin in eastern Reeves and northern Pecos Counties, Texas, at about the same rate. The Central Basin platform appears as a complex anticlinorium with local closures trending south-southeastward from Hobbs toward Fort Stockton. The Central Basin platform was actively uplifted by block faulting through Wolfcampian time (fig. 4). However, outside the faulting associated with late Cenozoic mountain building along the southern and western margins of the Delaware basin, the Guadalupian strata within the project area do not appear to have been displaced by faulting of any magnitude.

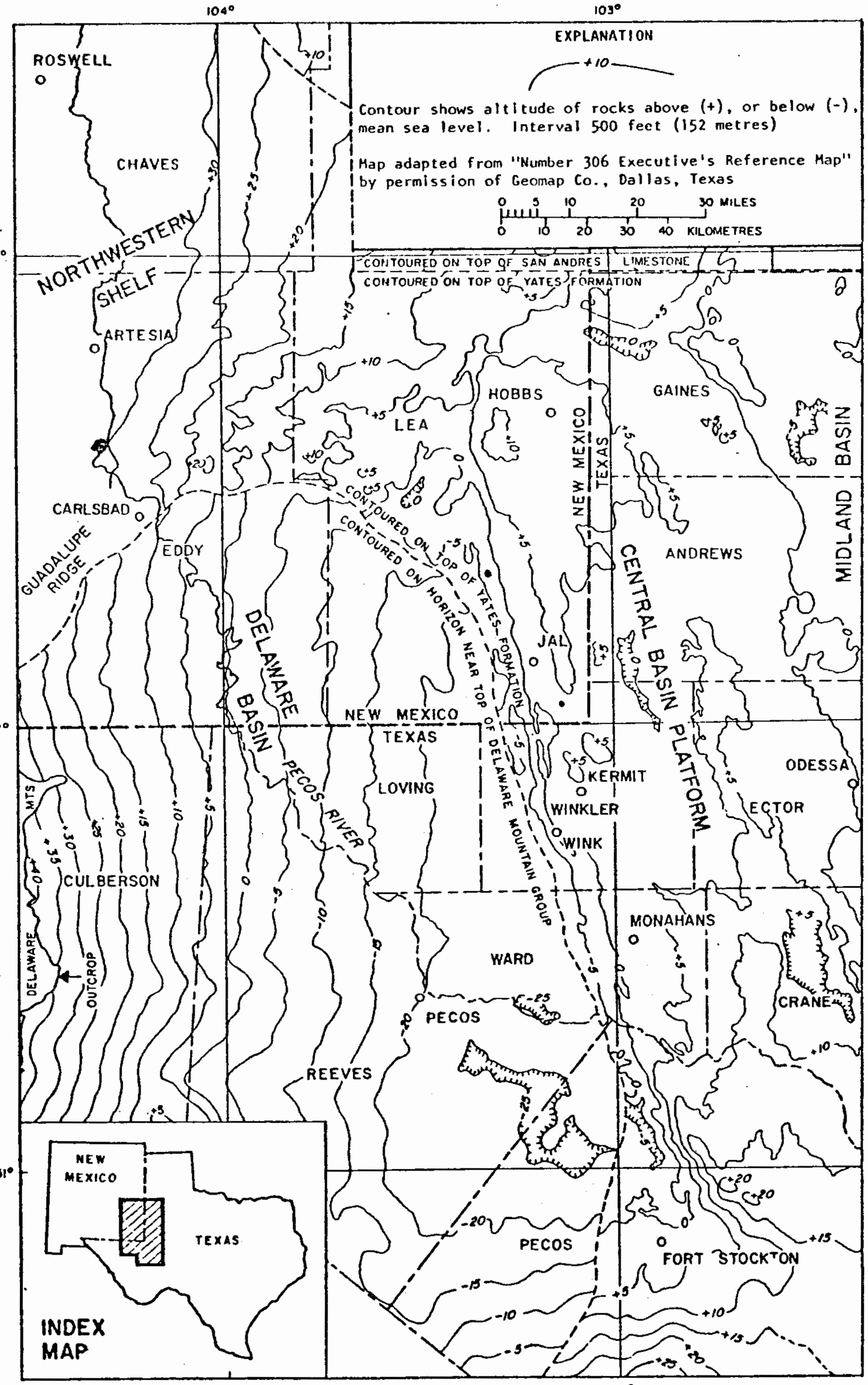
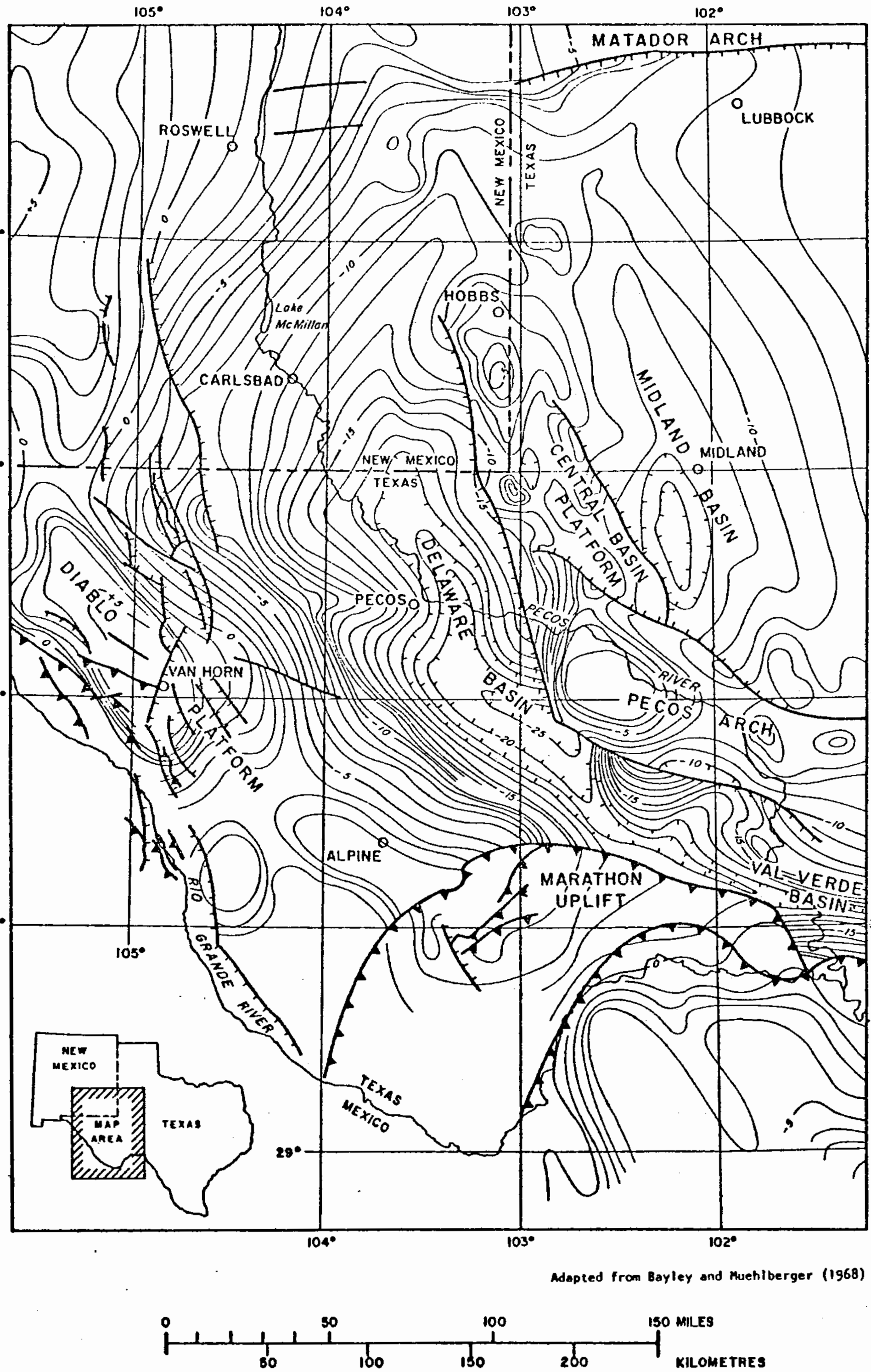


Figure 15.--Map showing structural configuration of the Delaware basin, Northwestern shelf, and Central Basin platform near the top of rocks of Permian Guadalupian age.

Structural configuration of the Precambrian basement

The generalized position of the surface of the Precambrian basement in the Delaware basin and surrounding areas is shown in figure 16. The axis of the Delaware basin trends south-southeastward from a point approximately midway between Carlsbad and Hobbs to the deepest part of the basin near Fort Stockton. At the southern end of the Central Basin platform, the axis of the Delaware basin is aligned to coincide with the axis of the southeastward-trending Val Verde basin. The more than 25,000 feet (7,620 metres) of sedimentary rocks that have accumulated in the deeper part of the Delaware basin reflects the relatively stable position of the dominant structural elements in this area during the Paleozoic Era. The Delaware basin is flanked on the east by the Central Basin platform, on the south by the complexly deformed Marathon uplift, and on the west by the Diablo platform and other smaller fault blocks.



Contour interval of 1,000 feet (305 metres) above (+), or below (-), mean sea level

Figure 16.--Map showing structural configuration of Precambrian basement rocks in the Delaware basin and surrounding areas.

Lower Paleozoic sedimentary rocks have been displaced more than 20,000 feet (6,095 metres) by faulting along the Central Basin platform in the vicinity of Fort Stockton. Displacement along the faulted western edge of the Central Basin platform becomes progressively less toward the north, but is still more than 5,000 feet (1525 metres) at the southeast corner of New Mexico. The Capitan aquifer overlies, but postdates, the faulted western margin of the Central Basin platform. The Capitan aquifer undoubtedly has been fractured by minor movements along this older fault system as the Central Basin platform and Delaware basin were adjusted to the burden and position of the large volume of overlying sedimentary rocks.

Structure of the Rustler Formation

Map preparation

The widespread occurrence, distinctive lithology, and relatively uniform thickness of the Rustler Formation over the Delaware basin, Northwest shelf, and Central Basin platform make it an ideal marker bed that can be readily distinguished in drill cutting samples and on electric logs. The structural map contoured on top of the Rustler Formation (fig. 17) was prepared using data obtained from a number of sources. Tops were taken directly from the Permian Basin Well Data System data file and stratigraphic sections prepared by the Roswell and West Texas Geological Societies, from electrical lithological logs, and from maps prepared by Guyton and Associates (1958), Garza and Wesselman (1962), White (1971), Armstrong and McMillion (1961), and Ogilbee, Wesselman and Irelan (1962).

Regional structure

Regionally, the surface of the Rustler slopes irregularly to the east reflecting the late Mesozoic and Cenozoic uplift and eastward tilting of the western part of the Permian basin. Several of the many anomalous local features superimposed on the larger regional trend coincide with the structural configuration of the older Permian strata shown in figure 15. The Hobbs, Eumont, Langlie-Mattix, Hendrick and many other oil fields are located within structural closures (figs. 15 and 17). The low centered in T.25 S., R.33 E., Lee County, New Mexico, is probably due to regional subsidence rather than solution of underlying evaporites.

Salt-solution troughs

Maley and Huffington (1953), Olive (1957), Garza and Wesselman (1959), and White (1971) have demonstrated that some of the structural features represented by the configuration of the Rustler Formation accurately depict both the location and amount of solution of the older Ochoan evaporites and the accumulation of alluvium that filled the resulting depressions.

Salt-solution troughs are located along the eastern margin of the Delaware basin and at the westernmost extension of the soluble salts of the Ochoan Series in the west and west-central part of the Delaware basin. The two troughs are filled with a variety of sedimentary rocks ranging in age from Triassic to Holocene that form excellent ground-water reservoirs. The troughs probably were formed contemporaneously with the Pliocene-Pleistocene uplift of the Delware basin and the emplacement of the Pecos River.

A series of irregular lens-shaped coalescing troughs extends northward from Balmorhea near the boundary between Reeves and Jeff Davis Counties, Texas, to Pecos, Texas where the trough then extends north along the Pecos River to near Loving in Eddy County, New Mexico. The Ochoan evaporite section was elevated and probably exposed to at least some extent as the Delaware basin was uplifted and tilted to the east. Soluble minerals, particularly halite, were consequently removed by action of surface and ground water and the western limit of the halite beds gradually retreated to a position now coincidental with the Balmorhea-Pecos-Loving trough herein named for purposes of this report (fig. 17).

Another series of linear lens-shaped depressions form a trough 8 to 12 miles (13 to 19 kilometres) wide extending northward from near Belding in southwestern Pecos County, Texas, in an arcuate trend above and parallel to the Capitan aquifer to T.22 S., R.35 E., in the vicinity of the San Simon swale in southern Lea County, New Mexico (fig. 17). Halite and other soluble minerals also have been removed from both the Castile and Salado Formations underlying the Belding-San Simon trough, herein named for purposes of this report (fig 17; and Maley and Huffington, 1953, pl. 2). Non-soluble beds in the Ochoan Series and Triassic and Cretaceous Systems have collapsed into the void left by the solution and removal of the soluble minerals.

Coincident with subsidence of the surface, a network of streams developed as a surface manifestation of the Belding-San Simon trough. As a result, more than 1,000 feet (305 metres) of alluvium is now present in some of the depressions. Garza and Wesselman (1962, p. 14) have mapped some of the southward-draining ancient stream channels in Winkler County. The Monument Draw in Ward and Winkler Counties, Texas, and a small lake formerly used by oil companies for communal waste-water disposal about 1.5 miles (2.4 kilometres) northwest of Wink, Texas, are the present-day remnants of this drainage system.

A complimentary stream system undoubtedly originated in the vicinity of the ancestral Glass Mountains and flowed to the north, although no similar surface expression of such a system is evident today. Cretaceous sediments were partially stripped from the surface above the Belding-San Simon trough prior to burial by alluvium in Pecos County (Armstrong, and McMillion, 1961). Cenozoic alluvium rests directly on the Triassic Dockum Group farther to the north in Ward and Winkler Counties, Texas, and Lea County, New Mexico.

The Capitan acquifer and overlying competent sandstones and carbonates within the Artesia Group were apparently strongly jointed and perhaps even fractured by movements in the western Permian basin during the Laramide orogeny (Adams, 1944, p. 1623; and Adams and Frenzel, 1950, p. 301). Ground water from the Capitan acquifer was able to move through the factures and joints in the overlying Artesia Group and attack the soluble beds in the Castile and Salado Formations. The orginial relatively high hydraulic conductivity of the Capitan aquifer was also enhanced by the fracturing and jointing.

Soluble beds in the adjacent Castile and overlying Salado Formations along the western edge of the Central Basin platform were dissolved during late Cenozoic time and removed by undersaturated ground water. The ground water flowed northward through the Capitan aquifer as a consequence of uplift of the Glass Mountains. The rate of movement and solution undoubtedly varied greatly and depended in part upon the amount of precipitation, the relief of the Glass Mountains, and the hydraulic gradient imposed upon the water in the Capitan aquifer. Historical records of subsidence in the San Simon swale suggest that solution and collapse processes are still operative (Nicholson and Clebsch, 1961, p. 13-17). The route of ground-water movement is recorded by the quality of water in the Capitan aquifer and other Guadalupian age sedimentary rocks and is substantiated by maps of the potentiometric surface.

The Pecos River, the dominant factor in controlling the movement of the ground water in the northwestern part of the project area, very obviously is younger than the Pliocene Ogallala Formation. The present drainage system and landscape was probably established in very late Pliocene or early Pleistocene time (Plummer, 1932; Motts, 1968; Hayes, P. T., 1964; and Thornbury, 1965).

The depressions in the surface of the Rustler Formation above the Capitan aquifer east of Carlsbad are undoubtedly also due to the solution and removal of the underlying halite. The Pecos River at Carlsbad has been in good hydraulic communication with the Capitan aquifer and has functioned as an upgradient drain for a long period of time. Therefore, these solution-collapse features were probably caused by eastward-moving ground water prior to the excavation of the Pecos River valley in Eddy County. The solution-collapse features above the Capitan aquifer east of Carlsbad are fewer in number and smaller in size than those formed along the western margin of the Central Basin platform. This is a probable consequence of both the less extensive system of joints or fractures and the smaller amount of ground water that has moved through the Capitan aquifer.

Stratigraphy

Tertiary System

Ogallala Formation

The Ogallala Formation of Pliocene age underlies the High Plains or Llano Estacado of eastern New Mexico and the panhandle of Texas and forms many of the prominent ridges in southern Lea County, New Mexico (Dane and Bachman, 1965; and Nicholson and Clebsch, 1961). This widespread formation is a heterogeneous complex of terrestrial sediments that cover an irregular erosion surface cut by eastward-draining streams into the underlying Cretaceous and Triassic sedimentary rocks. The thickness of the Ogallala Formation ranges from a few inches to more than 300 feet (90 metres). It is predominantly composed of calcareous, unconsolidated sand, but contains beds of clay, silt, and gravel and is generally capped by a dense layer of caliche. The Ogallala Formation is an excellent source of potable ground water.

Prior to the cutting of the present-day Pecos River valley, the Ogallala Formation probably extended westward to source areas in the ancestral Sandía-Manzano, Sangre de Cristo, and San Juan uplifts (Plummer, 1932; Kelley, 1972; and Thomas, 1972). Dikes filled with sandstone similar to that in the Ogallala have been observed to cut across beds of Permian age in the Guadalupe Mountains. These sandstone dikes are probably Pliocene deposits (King, P. B., 1948; and Horberg, 1949, p. 466) but may be Cretaceous (Hayes, P. T., 1957, and 1964, fig. 22. p. 37).

Igneous rocks

A northeasterly trending dike or system of relatively thin, steeply dipping basaltic and lamprophyric dikes in the northern Delaware basin has been reported by Jones and Madsen (1959). Igneous rocks have been penetrated in three oil test wells located 1,980 feet (604 metres) from the south line and 2,302 feet (702 metres) from the east line, sec. 12, T.18 S., R.34 E., and 1,980 feet (604 metres) from the south and east lines, sec. 21, T.20 S., R.33 E., Lea County, New Mexico, and 660 feet (201 metres) from the south and east lines, sec. 9. T.22 S., R.32 E., Eddy County, New Mexico, and in potash mines located in sec. 31, T.20 S., R.32 E., Lea County, and sec. 36, T.21 S., R.29 E., Eddy County (C. L. Jones, oral commun., 1972).

The thickness of the dike(s) varies from less than 4 to 15 feet (1.2 to 4.5 metres) in the exposures in the potash mines (John M. Swales and David Rice, oral commun., 1972). A well developed system of joints is present in the dikes where exposed in the potash mines. The projected trend of the dike(s) passes through the Capitan aquifer along a line extending from sec. 1, T.21 S., R.30 E., immediately west of the boundary between Eddy and Lea Counties, New Mexico, to sec. 21, T.19 S., R.33 E. (fig. 11).

Pratt (1954) described the occurrence of several subparallel north-northeast trending alkali trachyte dikes in secs. 11, 12, 13, 14, and 15, T.26 S., R.24 E., Eddy County, New Mexico (Dane and Bachman, 1965). These dikes are on trend with the dikes reported by Jones and Madsen (1959). Other minor occurrences of Tertiary igneous intrusive rocks in the vicinity of the southern Guadalupe Mountains are described in Pratt (1964) and Hayes, P. T. (1964, p. 40). Tertiary igneous rocks are exposed in the Glass Mountains in a few scattered areas west of the boundary between Pecos and Brewster Counties, Texas. Extrusive and intrusive Tertiary igneous rocks crop out over a large area in Jeff Davis, Brewster, Reeves, and Pecos Counties to the west and northwest of the Glass Mountains (fig. 10). No other occurrence of igneous rocks, especially those that might penetrate the Capitan aquifer in the subsurface along the north and east margins of the Delaware basin, has been described.

Tertiary(?) and Quaternary Systems, undivided

Alluvium of probable latest Tertiary and Quaternary age unconformably overlies rocks of Permian, Triassic, and Cretaceous age throughout much of the area (fig 10). The alluvium consists of unconsolidated sand, silt, gravel, and clay and is often capped with a layer of caliche. The greatest thicknesses of the alluvium are found in the north-south trending Balmorhea-Pecos-Loving and Belding-San Simon slumpage troughs that have developed as a result of solution of underlying evaporities (fig. 17). Thicknesses of alluvium of 600 to 700 feet (180 to 215 metres) are common and may exceed 1,500 feet (455 metres) in local areas within the troughs (Brown, Rogers, and Baker, 1965, p. M-31 and pl. M-5). Elsewhere the thickness of the alluvium is highly variable but is seldom more than a few hundred feet thick. Large supplies of water of generally good quality have been developed from wells tapping the alluvium in many areas (White, Gale, and Nye, 1941).

Quaternary System

A few inches to about 250 feet (75 metres) of windblown sands mantle the older alluvium, Ogallala Formation, and other exposures of older sediments in part of the area. Except locally, the water table is generally below the base of the dune deposits. Although small quantities of fresh water are pumped from shallow wells in the sand in a few places, the windblown deposits are more important as a site of recharge for the underlying aquifers.

GROUND-WATER HYDROLOGY

Aquifer systems

Strata of Permian Guadalupian age have been divided into three aquifers that, for purposes of this report, are referred to as the shelf, basin, and Capitan aquifers. The shelf and basin aquifers were not studied as thoroughly as the Capitan aquifer.

Shelf aquifers

Saturated strata yielding significant quantities of water from the San Andres Limestone and the Bernal and Chalk Bluff facies of the Artesia Group comprise the shelf aquifers. The contact between the Capitan and shelf aquifers is gradational and is difficult to discern with accuracy in some areas.

The present-day ground-water regimen is strongly influenced by the Pecos River in New Mexico. As a result, the hydraulic conductivity of the shelf aquifers west of the Pecos River has been greatly enhanced by the leaching of soluble beds from the Chalk Bluff facies (Meissner, 1972). In and west of the Pecos River valley between Carlsbad and Roswell, the hydraulic conductivities of the shelf aquifers, locally, are quite large and may be similar to that of the Capitan aquifer. The hydraulic conductivity of the shelf aquifers in the Carlsbad and Roswell underground water basins (fig. 1) is several orders of magnitude higher than that generally encountered for the shelf aquifer within the project area. The water contained in the shelf aquifers is also much better in the shallow zones exploited in these basins than elsewhere in the same aquifers within the project area.

However, in most areas, the shelf aquifers are readily distinguished from the Capitan aquifer by differences in the lithology, the geographic position, and the stratigraphic relationships. East of the Pecos River valley in New Mexico, the two aquifers can also be identified by the differences in hydraulic characteristics and the quality of the water.

Basin aquifers

Saturated strata yielding significant quantities of water, herein defined as the basin aquifers, are present in the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations in the Delaware Mountain Group. Although the Capitan aquifer abuts and overlies the Delaware Mountain Group along the margin of the Delaware Basin, the lithologic and hydrologic characteristics of the basin and Capitan aquifers are quite different. The average hydraulic conductivity of the basin aquifer is much less than that of the Capitan. Therefore, a relatively small amount of water can be expected to move from the basin to the Capitan aquifer, or vice versa, over a relatively short period of several decades.

Some of the sandstones of the Delaware Mountain Group, particularly those in the Cherry Canyon Formation, intertongue with the shelf carbonates within a narrow band parallel to the margin of the Delaware basin. Irregardless of the juxtaposition of the two aquifers, the relatively low transmissivities of both aquifers limits the amount of water transferred. The basin aquifer can be readily identified as a distinct aquifer system on the basis of lithology, geographic position, and stratigraphic relationships with other strata.

Capitan aquifer

In general, the position and dimensions of the Capitan aquifer closely agree with the Capitan and Goat Seep Limestones and carbonate banks in the upper part of the San Andres Limestone (Silver and Todd, 1969, figs. 12 and 13). However, observations of the geometry and lithologic relationships of the shelf-margin and shelf-sedimentary rocks in the field suggest that the width of the Capitan Limestone (reef) is considerably less than is usually shown. The relationships between the now obsolete Carlsbad Limestone and Capitan Limestone mapped by Dunham (1972, fig. I-1) appear to closely match the field relationships observed in the vicinity of Carlsbad and White City, N. Mex.

For all practical purposes, the Capitan aquifer is a lithosome that includes the Capitan and Goat Seep Limestones and most or all of the Carlsbad facies of the Artesia Group (Meissner, 1972). Some of the shelf-margin carbonate banks or stratigraphic reefs in the upper part of the San Andres Limestones are included within the Capitan aquifer whenever they cannot be readily distinguished from the Goat Seep Limestone and Carlsbad facies.

The Capitan aquifer is generally composed of a relatively "clean" carbonate, especially near the fore-reef edge. The radio-activity recorded on a gamma-ray electrical log of the Capitan and (or) Goat Seep Limestones is characteristically very low as shown in figures 6 and 7. Notable exceptions include the Capitan aquifer penetrated in the Shell Oil Co. Federal 4-1, sec. 4, T.22 S., R.34 E., Lea County, New Mexico (fig. 7 C-C'); and, in Pecos County, Texas (fig. 7 F-F'), the Aaron, Linehan, and Stoltenberg Grieson 1, sec. 72, block OW, M. J. Hawkins Survey; the Pan American Petroleum Corp. Butz Gas Unit 1, sec. 9, block 106, T + STL Survey; and the Skelly Oil Co. South Gomez Unit, sec. 1, block 106, T + STL Survey.

The tops and bases of the Capitan aquifer were determined primarily on the basis of the vertical extent of the relatively "clean" carbonate as indicated by the low gamma-ray activity levels shown on the electrical logs and the general stratigraphic position. Lithologic logs, oil field scout tops, reports of lost circulation, and other information were used whenever available to confirm these picks. Zones containing 50 percent or less of interbedded back or fore-reef lithofacies were arbitrarily included with the Capitan aquifer as a matter of convenience. Therefore, the net aggregate thickness of the Capitan aquifer may have been increased slightly.

It is often difficult or impossible to distinguish between other reefs and carbonate mounds in the back-reef sedimentary rocks and the Capitan and Goat Seep Limestones solely on the basis of the responses recorded on gamma-ray, sonic, and neutron electrical logs. Shelf and shelf-margin strata in the Carlsbad facies of the Artesia Group adjacent to the Capitan and Goat Seep Limestones are included whenever (1) the chemical composition of water in the back-reef sedimentary rocks is similar to the water produced from the Capitan Limestone, (2) the changes in water-levels in response to withdrawal of fluids is similar to the changes in hydraulic head measured in wells completed in the Capitan Limestone, and (3) the level of natural radioactivity measured in the formations adjacent to the Capitan or Goat Seep Limestone is low, suggesting a clean carbonate without significant clay, sand, silt, or shale.

Units previously referred to as reefs of Yates and Seven Rivers age, part of the Grayburg Formation, and the shelf-margin carbonate banks in the upper part of the San Andres Limestone are considered to be part of the Capitan aquifer if they cannot be distinguished as separate entities, and whenever the water quality, electrical log characteristics, or hydraulic responses justify inclusion.

The locations of nearly 400 deep wells that have been drilled within the project area are plotted on figures 11 and 12. Gamma-ray-neutron, or other combinations of electrical logs of the Capitan aquifer interval were obtained for nearly all these wells. Electrical logs were not available for (1) a few wells that were drilled before the invention of these tool and (2) many deep wells drilled to explore deeper formations where the shallower Permian Guadalupian strata were not logged due to efforts to reduce costs. Lithologic logs were available for approximately 15 percent of the wells.

Dimensions of the Capitan aquifer

Lateral extent

The Capitan aquifer parallels the northern and eastern margins of the Delaware basin in an arcuate strip extending from the Guadalupe Mountains southwest of Carlsbad to the Glass Mountains southwest of Fort Stockton (fig. 11). Exposures of the Capitan aquifer may be found in the Glass, Guadalupe, Apache, and Delaware Mountains. The Capitan aquifer undoubtedly is present elsewhere in the subsurface along the western and southwestern margins of the Delaware basin (fig. 10; and Darton, Stephenson, and Gardner, 1937; Dane and Bachman, 1965; and Barnes, 1968).

As shown in figures 6 and 11, the Capitan aquifer is one continuous unit along the north and east margins of the Delaware basin. Major displacements of the Capitan aquifer by faulting appear to be limited to the mountainous areas along the western and southern margin of the Delaware basin, because faults have not been observed in the subsurface along the western edge of the Central Basin platform and the southern edge of the Northwestern shelf. The irregular top and bottom surfaces and the lobate fore and back-reef edges are depositional forms (figs. 11 and 12).

The abrupt change in alignment of the Capitan aquifer in the vicinity of T.23 S., R.25 E., approximately 15 miles (24 kilometres) southwest of Carlsbad, is not due to post-Capitan age faulting (fig. 11). The change in alignment of the Capitan reef and increase in width and thickness of the Capitan aquifer in this area probably is due to growth of the Capitan reef along pre-Guadalupian age fault-controlled alignment and structural attitude of the margin of Delaware basin (Hills, 1963, p. 1715, fig. 4).

The width of the Capitan aquifer varies from 10 to more than 14 miles (16 to 23 kilometres) along the edge of the Northwestern shelf from the vicinity of Carlsbad to the central part of southern Lea County, New Mexico. The Capitan aquifer is much more restricted along the western edge of the Central Basin platform, where it seldom exceeds 11 miles (18 kilometres) in width.

The fore-reef edge of the Capitan aquifer in the subsurface appears to be relatively abrupt throughout the area and if exposed, would probably resemble the reef escarpment southwest of Carlsbad in the Guadalupe Mountains (Green, and others, 1964; and Newell, and others, 1953). Well control is adequate for definition of the subsurface fore-reef slope of the Capitan aquifer in several locations. Approximately 1,200 feet (365 metres) of vertical relief along the fore-reef edge of the Capitan aquifer was detected in two oil tests drilled within a few hundred feet of horizontal distance in secs. 5 and 9, T.22 S., R.33 E., Lea County (fig 18; and Meissner, 1972, pl. II). Similar evidence of the steepness of the fore-reef slope is found where deep drilling is concentrated in the ROC and Block 16 oil fields in the vicinity of Pyote, Texas; the Block 21, Mag-Sealy and South Wink oil fields, southwest of Wink, Texas; and in the Coyonosa, Gomez, and Oates N.E. oil fields located about 20 miles (32 kilometres) northwest, 8 miles (13 kilometres) northwest, and 15 miles (24 kilometres) southwest of Fort Stockton, Texas, respectively (fig. 19).

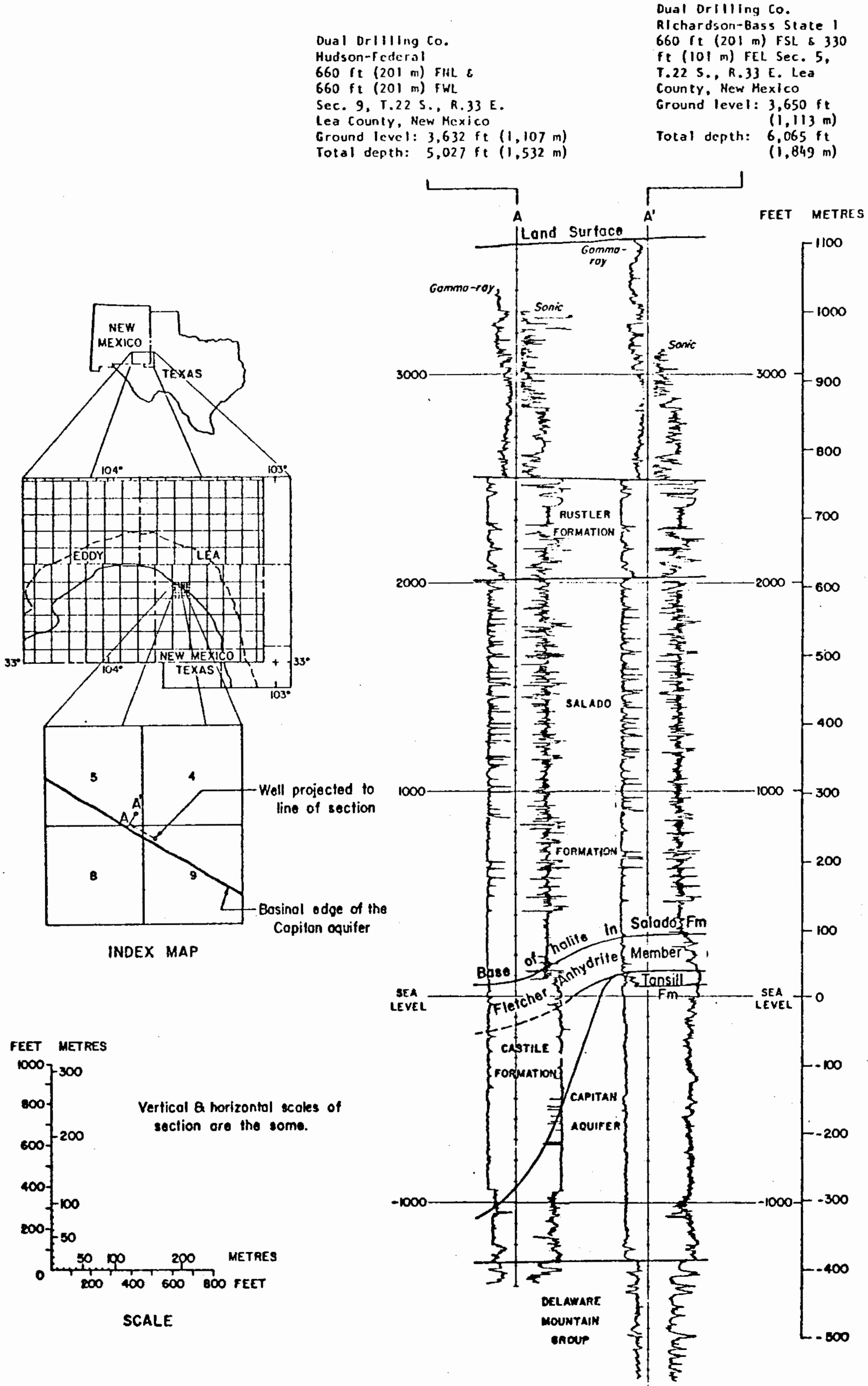


Figure 18.--Oblique stratigraphic section showing steepness of basinal edge of Capitan aquifer.

The back-reef edge of the Capitan aquifer is much more irregular than the fore-reef edge and is gradational in nature (fig 7). In some areas, especially along the western edge of the northern part of the Central Basin platform, it is difficult to distinguish the Capitan aquifer from the upper part of the San Andres Limestone. In this area the Capitan aquifer has been extended to include the carbonate banks developed in the upper part of the San Andres Limestone because of the proximity, and the similar lithology and hydraulic behavior of the two units (fig. 7 E-E').

Thickness

The thickness of the Capitan aquifer is quite variable (fig. 11). The Capitan aquifer appears to be composed of irregularly shaped and spaced, alternating thick and thin accumulations of carbonate rock. Many of the locally thick areas are well behind the reef front and may represent carbonate banks, islands, or mounds that flourished behind the protection of the reef crest (Kendall, 1969, p. 2509, and pls. 2 and 3). Motts (1962, and 1972) has mapped and described both current-oriented and irregularly oriented "shelf dome" carbonate mounds in the vicinity of Dark Canyon southwest of Carlsbad.

A number of small oil fields located along the trend of the Capitan aquifer are apparently localized on carbonate "buildups" that have been referred to by Stipp and Haigler (1956) as "reef knobs" interspersed between "surge channels." The majority of these carbonate mounds or "buildups" are also located within the thick areas shown in the Capitan aquifer thickness map (fig. 11). The Capitan aquifer attains a maximum thickness of 2,357 feet (718 metres) in the Odessa Natural Gas Federal Dooley well located on one of these mounds in sec. 24, T.20 S., R.29 E., about 13 miles (21 kilometres) northeast of Carlsbad . figs. 6 and 11).

The Capitan aquifer is slightly thicker along the edge of the Northwestern shelf in New Mexico than in Texas. In addition, the areal extent of the individual thick areas is correspondingly larger (fig. 11). A statistical summary of the thickness of the Capitan aquifer is illustrated graphically by county and State in figure 20.

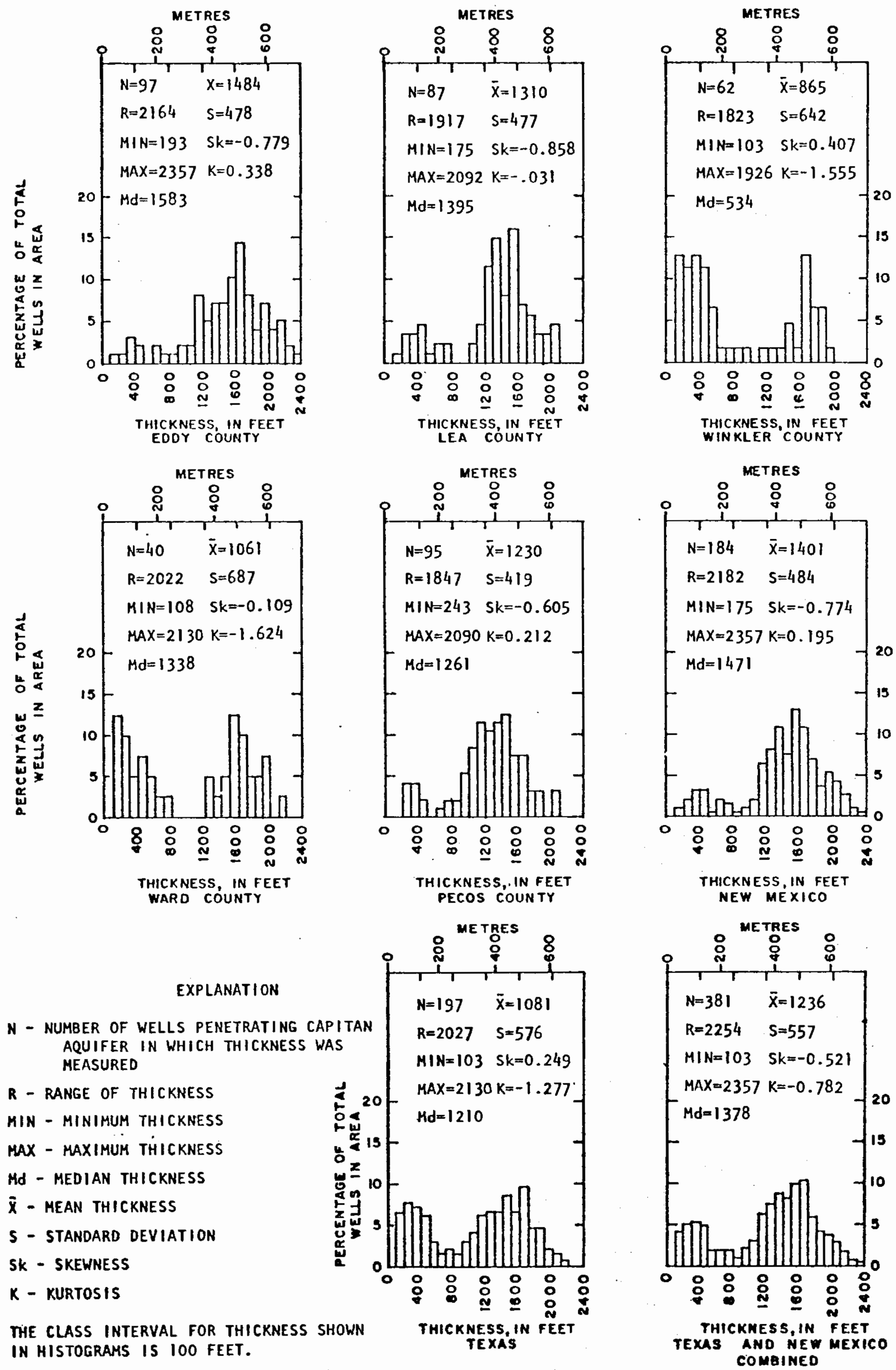


Figure 20.--Graph showing statistical summary of the thickness of the Capitan aquifer.

Thicknesses greater than 1,500 feet (455 metres) have been observed in approximately 49 and 29 percent of the wells that have penetrated the Capitan aquifer in New Mexico and Texas, respectively. More than 56 percent of the wells that have been drilled through the Capitan aquifer in Eddy County penetrated thicknesses greater than 1,500 feet (455 metres). About 12 percent of the wells drilled through the Capitan aquifer in Eddy County penetrated thicknesses of more than 2,000 feet (610 metres). Fewer than 5 percent of the wells in all other counties combined penetrated this great a thickness.

The bimodal distribution of thickness of the Capitan aquifer in Winkler and Ward Counties, as shown in figure 20, is primarily due to the bias resulting from the many wells, in comparison to other areas, that penetrate relatively thin sections of the Goat Seep Limestone and the carbonate banks in the San Andres Limestone on the extreme shelfward limit of the Capitan aquifer.

The Alacran, Quahada, Laguna, Eunice, Teague, Jal, and other submarine canyons have been cut into the Capitan aquifer in eastern Eddy and southern Lea Counties (fig. 11). The submarine canyons are oriented transversely to the arcuate main trend of this aquifer. In places, the thickness of the aquifer is reduced by one half or more. The significance of this thinning of the Capitan aquifer is not recognizable in the statistical summary.

Structural position of the Capitan aquifer

The structural position of the Capitan aquifer is shown in a longitudinal section and in a structural map with contours of the top of the Capitan aquifer (figs. 6 and 12, respectively). At first glance, an impression of a series of closed structural highs alternating with plunging synclines may be conveyed to the viewer by the pattern of structural contours of the top of the Capitan aquifer. However, when the configurations of the contours of the structural position and thickness of the Capitan aquifer are compared, the striking resemblance becomes obvious. Apparently, most of the features contoured as structural lows on figure 12 are depressions in the surface of the Capitan aquifer and are due to nondeposition or erosion in surge channels and submarine canyons of Permian Guadalupian age rather than warping of the Capitan aquifer.

In a similar manner, most of the features resembling structural highs are not due to structural uplift but are probably carbonate mounds. The Hendrick, Monument, and other fields along the western margin of the Central Basin platform produce from closed highs depicted on structural maps with contours of the top of the Yates Formation (fig. 15). The carbonate mounds described by Stipp and Haigler (1956), and Motts (1972) that form the traps for the small fields east of Carlsbad are probably not primarily due to structural deformation. Apparently, very few closed structures in the Capitan have been found along the northern margin of the Delaware basin.

The Capitan aquifer plunges to the northeast away from the Guadalupe Mountains and passes beneath the surface about 10 miles (16 kilometres) southwest of Carlsbad. The crest of the Capitan aquifer is at an altitude of approximately 3,000 feet (915 metres) at Carlsbad. At this point the Capitan aquifer turns eastward and continues to plunge in the subsurface, until altitudes of 500 to 750 feet (150 to 230 metres) below sea level are reached along the Central Basin platform west of Eunice, N. Mex. The crest of the Capitan aquifer generally remains at altitudes between 500 and 750 feet (150 and 230 metres) below sea level along the western margin of the Central Basin platform from the vicinity of Jal, N. Mex., southward to near Belding, southwest of Fort Stockton, Texas. The Capitan aquifer rises steeply southward from Belding to exposures in the Glass Mountains, where altitudes exceed 4,000 feet (1,220 metres) above sea level.

Depths to the top of the Capitan aquifer from the land surface in New Mexico vary from not more than a few hundred feet in the Pecos River valley at Carlsbad to more than 4,300 feet (1,310 metres) in the western part of southern Lea County (fig. 6). Depths to the Capitan aquifer in Ward, Winkler, and northern Pecos Counties range from less than 2,500 to more than 3,300 feet (760 and 1,005 metres, respectively).

Hydraulic characteristics of the aquifer systems

Sources of data

Wells completed in the Capitan aquifer were not generally available for evaluation of the aquifer characteristics. New wells could not be drilled for this purpose due to economic limitations. Normal pumping tests could not be run on the wells in the observation-well network due to both the high operating costs and anticipated large well losses that would occur as a consequence of the limited capacity of the wells.

A small amount of permeability and porosity data have been published in reports describing individual fields in publications of the West Texas and Roswell Geological Societies, the Texas Petroleum Research Committee, and the Texas Bureau of Economic Geology. Hogan and Sipes (1966) compiled a statistical summary of reservoir-engineering data for formations of several geologic ages in the Texas part of the Permian basin with the aid of a computer-based data bank containing information relative to approximately 500,000 samples. Unfortunately, the data are not tabulated by individual county and the number of core analyses available are not specified for each formation.

Very little information relating to the hydraulic characteristics of Permian Guadalupian age aquifers is available in the ground-water reports prepared for individual counties, because only the shallow aquifers containing potable ground-waer supplies are emphasized in these publications.

Table 6.--Permeability and porosity information obtained from oil industry rock core analyses[1/]

EDDY COUNTY

Geologic unit	Number of feet (metres) of core analyzed		Average permeability	Average porosity	Number of samples analyzed	
	Permeability	Porosity			Permeability	Porosity
Yates Formation	567.2 (172.9)	567.2 (172.9)	11.29 (0.028; 0.008)	10.21	543	543
Seven Rivers Formation	59.0 (18.0)	59.0 (18.0)	2.47 (.0060; .002)	10.65	58	58
Queen Formation	384.8 (117.3)	386.8 (117.9)	1.98 (.0048; .002)	9.21	315	317
Grayburg Formation	302.5 (92.2)	302.5 (92.2)	1.73 (.0042; .001)	6.00	161	161
Grayburg Formation-San Andres Limestone, undivided	1,763.5 (537.5)	1,944.4 (592.6)	3.46 (.0084; .003)	5.80	1,404	1,525
Delaware Mountain Group	1,097.2 (334.4)	1,114.2 (339.6)	4.25 (.010; .003)	14.44	927	944
Average for county	4,174.2 (1,272.3)	4,374.1 (1,333.2)	4.45 (.011; .003)	8.96	3,408	3,548

Table 6.--Permeability and porosity information obtained from oil industry rock core analyses - Continued

LEA COUNTY

Geologic unit	Number of feet (metres) of core analyzed		Average permeability	Average porosity	Number of samples analyzed	
	Permeability	Porosity			Permeability	Porosity
Tansill Formation	440.9 (134.4)	423.9 (129.2)	1.76 (0.0043; 0.001)	4.00	325	308
Yates Formation	7,696.3 (2,345.8)	7,738.3 (2,358.6)	11.56 (.028; .008)	9.12	7,140	7,183
Seven Rivers Formation	4,251.7 (1,295.9)	4,442.9 (1,354.2)	58.98 (.140; .043)	6.50	3,902	4,020
Queen Formation	4,933.3 (1,503.7)	5,404.1 (1,647.2)	16.29 (.040; .012)	7.30	4,281	4,614
Grayburg Formation	1,925.2 (586.8)	1,956.6 (596.4)	15.04 (.037; .011)	7.32	1,780	1,812
Grayburg Formation-San Andres Limestone, undivided	7,026.1 (2,141.6)	7,148.1 (2,178.7)	16.03 (.039; .012)	5.71	5,589	5,719
"Glorieta Sandstone"	1,362.6 (415.3)	1,331.9 (406.0)	10.28 (.025; .008)	8.44	1,057	1,038
Delaware Mountain Group	1,148.7 (350.1)	1,149.7 (350.4)	10.75 (.026; .008)	19.81	997	998
Average for county	28,784.8 (8,773.6)	29,595.5 (9,020.7)	20.45 (.050; .015)	7.76	25,071	25,692

Table 6.--Permeability and porosity information obtained from oil industry rock core analyses - Continued

WINKLER COUNTY

Geologic unit	Number of feet (metres) of core analyzed		Average permeability	Average porosity	Number of samples analyzed	
	Permeability	Porosity			Permeability	Porosity
Tansill Formation	74.0 (22.6)	72.0 (21.9)	6.98 (0.017; 0.005)	5.58	74	73
Yates Formation	2,348.8 (715.9)	2,585.3 (788.0)	9.96 (.024; .007)	11.29	2,224	2,453
Seven Rivers Formation	323.5 (98.6)	327.5 (99.8)	2.13 (.005; .002)	7.13	319	323
Queen Formation	2,416.2 (736.5)	2,405.2 (733.1)	6.12 (.015; .005)	8.19	2,098	2,087
Grayburg Formation-San Andres Limestone, undivided	61.1 (18.6)	61.1 (18.6)	4.27 (.010; .003)	10.16	62	62
"Glorieta Sandstone"	1,711.5 (521.7)	1,712.8 (522.0)	12.31 (.030; .009)	9.99	1,999	2,005
Delaware Mountain Group	221.5 (67.5)	222.5 (67.8)	14.41 (.035; .011)	17.80	216	217
Average for county	7,156.6 (2,181.3)	7,386.4 (2,251.4)	8.93 (.022; .007)	9.92	6,992	7,226

Table 6.--Permeability and porosity information obtained from oil industry rock core analyses - Continued

WARD COUNTY

Geologic unit	Number of feet (metres) of core analyzed				Average permeability	Average porosity	Number of samples analyzed	
	Permeability		Porosity				Permeability	Porosity
Yates Formation	1,537.6	(468.7)	1,301.6	(396.7)	8.02 (0.020; 0.006)	10.12	1,380	1,199
Seven Rivers Formation	113.7	(34.7)	113.7	(34.7)	117.85 (.290; .088)	5.04	85	85
Queen Formation	739.4	(225.4)	739.4	(225.4)	7.96 (.019; .006)	9.34	630	630
Grayburg Formation-San Andres Limestone, undivided	9.1	(2.8)	9.1	(2.8)	6.35 (.015; .005)	7.60	7	7
"Glorieta Sandstone"	100.6	(30.7)	100.6	(30.7)	2.17 (.005; .002)	4.70	72	72
Delaware Mountain Group	2,394.4	(729.8)	2,319.4	(707.0)	5.06 (.012; .004)	13.79	2,227	2,262
Average for county	4,894.8	(1,491.9)	4,583.8	(1,397.1)	8.99 (.022; .007)	11.60	4,511	4,255

Table 6.--Permeability and porosity information obtained from oil industry rock core analyses - Continued

Data for Eddy and Lea Counties, N. Mex. and Winkler and Ward Counties, Tex. combined

Geologic unit	Number of feet (metres) of core analyzed		Average permeability	Average porosity	Number of samples analyzed	
	Permeability	Porosity			Permeability	Porosity
Tansill Formation	514.9 (156.9)	495.9 (151.2)	2.51 (0.006; 0.002)	4.23	399	381
Yates Formation	12,149.9 (3,703.3)	12,192.4 (3,716.2)	10.79 (.026; .008)	9.74	11,287	11,384
Seven Rivers Formation	4,747.9 (1,447.2)	4,943.1 (1,506.7)	55.81 (.140; .043)	6.56	4,364	4,485
Queen Formation	8,473.7 (2,582.8)	8,935.5 (2,723.5)	12.01 (.029; .088)	7.79	7.324	7.648
Grayburg Formation	2,227.7 (679.0)	2,259.1 (688.6)	13.24 (.032; .010)	7.15	1,941	1,973
Grayburg Formation-San Andres Limestone, undivided	8,859.8 (2,700.5)	9,162.7 (2,792.8)	13.44 (.033; .010)	5.76	7,062	7,313
"Glorieta Sandstone"	3,174.7 (967.6)	3,145.3 (958.7)	11.12 (.027; .008)	9.16	3,128	3,115
Delaware Mountain Group	4,932.7 (1,503.5)	4,876.7 (1,486.4)	6.70 (.016; .005)	15.65	4,549	4,493
Average for all four counties	45,010.4 (13,719.2)	45,939.8 (14,002.5)	15.88 (.039; .012)	8.63	39,982	40,721

Table 6.--Permeability and porosity information obtained from oil industry rock core analyses - Concluded

Geologic unit	Number of feet (metres) of core analyzed: Permeability	Number of feet (metres) of core analyzed: Porosity	Average permeability	Average porosity	Number of samples analyzed: Permeability	Number of samples analyzed: Porosity
Data for shelf sedimentary rocks for Eddy and Lea Counties, N. Mex. and Winkler and Ward Counties, Tex.						
Tansill, Yates, Seven Rivers, Queen, and Grayburg Formations, "Glorieta Sandstone", and San Andres Limestone combined	36,939.5 (11,259.2)	37,954.3 (11,568.5)	17.53 (0.043; 0.013)	7.69	32,360	33,168
Data for shelf sedimentary rocks for Lea County, N. Mex. in area bounded by 103.06 and 103.50 degrees east longitude and 32.00 and 32.75 degrees north latitude, Lea County, N. Mex. on the northern end of the Central Basin platform.						
Tansill, Yates, Seven Rivers, Queen, and Grayburg Formations, and San Andres Limestone combined	20,996.6 (6,399.8)	21,875.2 (6,667.6)	24.47 (0.060; 0.018)	7.44	18,697	19,365
Data for Grayburg Formation and San Andres Limestone in area bounded by 103.06 and 103.50 degrees east longitude and 32.00 and 32.75 degrees north latitude, Lea County, N. Mex. on the northern end of the Central Basin platform.						
Grayburg Formation-San Andres Limestone, undivided	3,364.1 (1,025.4)	3,513.6 (1,070.9)	27.85 (0.068; 0.021)	6.96	2,792	2,941
Grayburg Formation	2,973.6 (906.4)	3,010.6 (917.6)	19.47 (.048; .015)	6.72	2,417	2,452
San Andres Limestone	219.5 (66.9)	219.5 (66.9)	68.68 (.17; .052)	10.01	188	188

1/ Permeability given in millidarcies with approximate equivalent hydraulic conductivity in ft/day (m/day). Porosity is effective porosity as percent of rock volume.

Table 7.--Hydraulic characteristics of the Capitan and San Andres aquifers

Location of aquifer test[1]	Aquifer	Date of completion of test	Interval tested Depth, in feet (metres), below land surface or other reference datum		Hydraulic conductivity determined from interval tested		Remarks
			Top	Bottom	ft/day	(m/day)	
2,310 ft (704 m) FNL and 2,970 ft (905 m) FEL, sec. 7, T.20 S., R.38 E., Lea County, N. Mex.	San Andres	7-26-66	4,200 (1,280)	4,550 (1,387)	0.2	0.06	Drawdown test. Effects measured in pumped well. Well produced through open-hole completion. Well pumped at rate of 92 gpm (501 m^3/d) for 96 hours.
Do.	do.	7-27-66	4,200 (1,280)	4,550 (1,387)	.2	.06	Recovery test. Effects measured in pumped well. Well recovery measured for 24 hours.
1,993 ft (607 m) FEL and 3,060 ft (934 m) FNL, sec. 5, T.21 S., R.27 E., Eddy County, N. Mex.	Capitan	8-12-69	1,007 (306.7) 1,024 (312.1) 1,042 (317.6) 1,059 (322.8 1,167 (355.7	1,014 (309.1) 1,025 (312.4) 1,044 (318.2) 1,060 (323.1) 1,170 (356.6)	2.4	.73	Recovery test. Effects measured in pumped well. Well produced through 14 ft (4 m) net of perforations in casing. Well was acidized with 6,000 gal (22.7 m^3) of 15 percent hydrochloric acid. Well was swabbed at an estimated 85 gpm (463 m^3/d) for 3 1/3 hrs prior to shut in for test. Recovery measured for 140 hours.
1,650 ft (503 m) FNL and 1,650 ft (503 m) FWL, sec.30, T.21 S., R.28 E., Eddy County, N. Mex.	do.	8- 9-61	640 (195.1)	1,060 (323.1)	16	4.98	Recovery test. Effects measured in pumped well. Well produced through open-hole completion. Aquifer was not treated with acid. Water produced with air lift at estimated rate of 100 gpm (545 m^3/d) for 4 hours. Recovery period of only 28 minutes. Driller reported lost circulation zone during penetration of Capitan Limestone. A similar hydraulic conductivity was estimated from specific capacity.
1,650 ft (503 m) FSL and 330 ft (101 m) FWL, sec.24, T.21 S., R.34 E., Lea County, N. Mex.	do.	1-14-65	3,547 (1,081.1)	5,020 (1,530.1)	3.0	.92	Hydraulic conductivity estimated from specific capacity of well. Specific capacity was determined after well pumped at rate of approximately 240 gpm (1,308 m^3/d) over a period of about 207 hours. Well produced from open-hole completion after acidizing with 15,000 gal (57 m^3) of 15 percent hydrochloric acid.

Table 7.--Hydraulic characteristics of the Capitan and San Andres aquifers - Continued

Location of aquifer test[1]	Aquifer	Date of completion of test	Interval tested Depth, in feet (metres), below land surface or other reference datum		Hydraulic conductivity determined from interval tested		Remarks
			Top	Bottom	ft/day	(m/day)	
1,650 ft (503 m) FWL and 660 ft (201 m) FNL, sec.14, T.21 S., R.35 E., Lea County, N. Mex.	Capitan	7- 8-62	4,178 (1,273.5)	4,663 (1,421.3)	1.7	.52	Hydraulic conductivity estimated from specific capacity of well. Specific capacity was determined after well pumped at rate of approximately 270 gpm (1,472 m^3/d) over a period of about 90 hours. Well produced from open-hole completion.
Do.	do.	10-15-66	4,178 (1,273.5)	4,663 (1,421.3)	3.5	1.07	Drawdown test. Effects measured in pumped well. Well pumped only 28 minutes before equipment failure. Open-hole completion. Aquifer treated with 5,000 gal(19 m^3) of 15 percent hydrochloric acid on March 3, 1965. Periodic cleaning of "silt"[2] from borehole required to maintain production.
Do.	do.	12-14-66	4,178 (1,273.5)	4,663 (1,421.3)	1.9	.58	Drawdown test. Effects measured in pumped well. Well pumped for approximately 26 hrs. Average discharge rate of 328 gpm (1,788 m^3/d) during test.
Do.	do.	12-15-66	4,178 (1,273.5)	4,663 (1,421.3)	1.4	.43	Recovery test. Effects measured in production well. Well recovery measured for approximately 4 hours.
660 ft (201 m) FNL and 200 ft (61 m) FWL, sec.29, T.22 S., R.37 E. Lea County, N. Mex.	San Andres	11-22-66	3,922 (1,216.8)	4,985 (1,519.4)	.3	.09	Drawdown test. Drawdown measured in observation well 2,216 ft (675 m) from pumped well. Well drawdown measured for 120 hours with well pumped at constant rate of 190 gpm (1,036 m^3/d). Well shut in for 48 hrs prior to start of test. Well produced through 291 casing perforations. Well acidized with 65,000 gal (246 m^3) of hydrochloric acid. Storage coefficient of 1.5×10^{-5} determined.

Table 7.--Hydraulic characteristics of the Capitan and San Andres aquifers - Concluded

Location of aquifer test[1/]	Aquifer	Date of completion of test	Interval tested Depth, in feet (metres), below land surface or other reference datum		Hydraulic conductivity determined from interval tested		Remarks
			Top	Bottom	ft/day	(m/day)	
1,313 ft (400 m) FSL and 1,327 ft (404 m) FWL, sec. 4 T.24 S., R.36 E., Lea County, N. Mex.	Capitan	2-28-68	3,875 (1,181.1)	4,500 (1,371.6)	24	7.32	Drawdown test. Effects measured in pumped well. Well produced through open-hole completion. Well pumped at rate of 550 gpm (2,998 m^3/d) for 10 hours after being shut in for more than 24 hours. Open-hole completion without acid treatment. Driller reported two lost circulation zones while drilling through the Capitan Limestone.
Do.	do.	2-28-68	3,875 (1,181.1)	4,500 (1,371.6)	25	7.62	Hydraulic conductivity estimated from specific capacity of well as determined during drawdown test above.
1,313 ft (400 m) FSL and 1,310 ft (399 m) FWL, sec.16, T.24 S., R.36 E., Lea County, N. Mex.	do.	10- 4-67	3,955 (1,205.5)	4,500 (1,371.6)	4.4	1.34	Hydraulic conductivity estimated from specific capacity of well. Specific capacity was determined after well pumped approximately 47 hours at rate of 504 gpm (2,747 m^3/d). Well was not treated with acid. Driller reported that tools dropped from 2 to 6 ft (0.6 to 1.8 m) several times while drilling in Capitan Limestone. Lower 200 ft (61 m) of hole caved in after rotary tools were removed. Sand pump and boiler was used to remove rock fragments. The largest pieces recovered were 2 to 3 in (5 to 8 cm) in diameter. Open-hole completion.

1/ Location of well site from nearest section lines are expressed by an acronym composed of 3 letters. "F" and "L" represent "from" and "line", respectively. The middle letter represents the compass direction, N-north; E-east; S-south; and W-west.

2/ "silt" recovered from well was determined to be calcium sulphate that was presumably precipitated from water during pumping (L. S. Land, personal communication, 1972).

Oil companies supplies core analyses from oil and gas test wells in response to requests made after searching the Permian Basin Well Data System scout records. Data extracted from these core analyses appear to provide a representative coverage of the hydraulic characteristics of the basin and shelf aquifers in Lea and Eddy Counties, New Mexico and Winkler and Ward Counties, Texas (table 6). Several aquifer performance tests of the Capitan and San Andres aquifers were conducted in cooperation with oil companies, and a limited amount of additional information was obtained from private sources (table 7). The aerial distribution of these data are shown by individual well in figure 21.

The values of hydraulic conductivity and porosity given in tables 6 and 7 are in good agreement with those reported by Hogan and Sipes (1966) and with the generalized information provided in studies or statistical summaries of individual fields published by the Texas Petroleum Research Committee, the Roswell and West Texas Geological Societies, and the Texas University Bureau of Economic Geology.

Sections of anhydrite, shale, gypsum, halite, and other "dense" or "tight" beds recovered from a cored interval are frequently discarded prior to determining the permeability and porosity. Also, cores are normally cut only in the most prospective part of the geologic section in exploratory wells and in the producing reservoir in development wells. Therefore, the values of permeability and porosity determined from cores and given in reports may be, and quite likely are, larger than values representative of the entire shelf and basin sections.

A pulse-type aquifer-performance test of very short duration was attempted on five of the observation wells east of the Pecos River in Eddy County. The tests were accomplished by pumping compressed air into the previously enclosed casing and slowly depressing the water surface in the well column. After a sufficiently long stabilization period, the air was suddenly released and the rise in water level measured very accurately with a transducer and strip chart recorder. Unfortunately, the results of these aquiferpulse tests proved to be inconclusive.

Capitan aquifer system

Quantitative information

Single well aquifer-performance tests were accomplished in cooperation with an oil company during October 1966 and again in December 1966 on a well completed in the Capitan aquifer in sec. 14, T.21 S., R.35 E., Lea County. A similar performance test had been conducted previously by another oil company on the same well. Values of hydraulic conductivity determined from recovery and drawdown tests and estimated from measurements of the specific capacity range from 1.4 to 3.5 ft/day (0.43 to 1.07 m/day) for this well (table 7).

A multiple-well performance test was attempted on wells completed in the Capitan aquifer in cooperation with an oil company during October 1967. The pumped well was located in sec. 16, T.24 S., R.36 E., approximately 3,800 feet from the USGS Federal Davison 1 observation well in sec. 20, T.24 S., R.36 E., Lea County. Unfortunately, pressure fluctuations caused by the passage of an intense cold front during the test prevented accurate measurements of the drawdown and recovery in the observation well. However, a hydraulic conductivity of 4.4 ft/day (1.34 m/day) was estimated from the specific capacity of the pumped well.

Hydraulic conductivities of 24 and 25 ft/day (7.3 and 7.6 m/day) were determined from measurements of the drawdown and estimated from the specific capacity, respectively, in another well with a similar open-hole completion in the Capitan aquifer located about 2 miles (3 kilometres) to the north in sec. 4, T.24 S., R.36 E., in the same well field.

Records maintained during the prolonged testing of a well completed in the Capitan aquifer in sec. 24, T.21 S., R.34 E., Lea County, near the USGS South Wilson Deep Unit 1 observation well, were made available by an oil company. A hydraulic conductivity of 3.0 ft/day (0.92 m/day) was determined from the specific capacity of this well.

A crude single well recovery test was conducted in the USGS North Cedar Hills Unit 1 well, sec. 5, T.21 S., R.27 E., Eddy County, during August 1969. A hydraulic conductivity of 2.4 ft/day (0.73 m/day) was determined from the data collected during this test.

A single well recovery test of the Capitan aquifer was accomplished during August 1961 by consultants for the city of Carlsbad in the city of Carlsbad Test Well 3 (Miller Nix-Yates Federal 1) in sec. 30, T.21 S., R.28 E., Eddy County. This well is now in the USGS Capitan aquifer observation-well network. A hydraulic conductivity of approximately 16 ft/day (4.9m/day) was determined from re-interpretation of the short recovery test data and the specific capacity of the well. This value is about one-fifth as large as that given in the New Mexico State Engineer Hearing (1962) by Mr. J. R. Barnes, expert witness for the city of Carlsbad.

Brackbill and Gaines (1964) report permeabilities of 1 to 6 darcies (0.73 to 4.5 m/day) for the El Capitan water field in northern Winkler County, Texas (fig. 19). However, subsequent discussions with oil company employees suggest that a permeability of 1 darcy (0.73 m/day) would be more representative for this large water field and the general area.

Hydraulic conductivities of 5.2 and 2.4 ft/day (1.6 and 0.73 m/day) were estimated from specific capacities of two wells completed in the lower part of the Capitan aquifer in the O'Brien water field in northern Ward County, Texas (figs. 7 C-C', and 19; and White, 1971).

Qualitative information

Development of secondary porosity and permeability

The solution, removal, recrystallization, and redeposition of carbonate material by the selective action of moving ground water during two major periods of time has unquestionably enhanced the porosity and permeability of the Capitan aquifer.

Ground-water action during the Late Permian

Vadose solution and cementation features, including caliche pisolites, floored cavities, collapse breccia, clastic dikes, and teepee structures, indicate that the shelf and shelf-margin sediments were apparently repeatedly exposed and subjected to subaerial erosion during the Guadalupian Epoch and the initial (Castile) part of the Ochoan Epoch (Dunham, 1965a, 1965b, 1969, and 1972; Thomas, 1965 and 1968; and Meissner, 1972). Feldspar in the terrigenous sandstones within the Capitan aquifer has been altered to koalinite by the intense leaching action of percolating ground water (Dunham, 1972).

Ground water moving through the shelf and shelf-margin carbonates in the phreatic zone during the cyclic low stands of sea level also undoubtedly contributed to the development of solution porosity. Collapse features typical of a karst topography were formed during the Guadalupian Epoch within beds in the Carlsbad facies of the Artesia Group. This is evident in at least one surface exposure in Walnut Canyon west of White City on the road to Carlsbad Caverns (A. D. Jacka, oral commun.).

Much of the secondary porosity and permeability that originated during the Late Permian apparently has not been reduced by later cementation and infilling. The original hydraulic characteristics were, and still are, an important factor in influencing the flow of ground water through the aquifer.

Ground-water solution during the Late Cenozoic Uplift of the Guadalupe and Glass Mountains

According to Hayes (1964, p. 54), the majority of the faulting and the principal uplift of the Guadalupe Mountains probably occurred late in the Pliocene and early in the Pleistocene. The age of the block faulting in the Glass Mountains is not as well known, but it probably was more or less contemporaneous with the uplift of the Guadalupe, Delaware, and Apache Mountains along the western margin of the Delaware basin. The present drainage system, landscape, colluvium, alluvium, and other sedimentary deposits have formed since the uplift of these mountains and are still being modified.

The joints and fractures resulting from mountain building activity are most extensive in the Capitan aquifer in the Glass and Guadalupe Mountains but are also apparently well developed along the western margin of the Central Basin platform.

A large amount of fractured limestone and dolomite were reported to have been bailed from the Skelly Oil Co. Jal Water Supply Well 1, sec. 16, T.24 S., R.36 E., Lea County after an open-hole section in the Capitan aquifer caved during completion of this well. Angular pieces of limestone ranging in size from less than an inch to several inches were observed at the well site after completion of this water well. Abnormally high rates of production from some of the oil wells located on the Central Basin platform have been attributed to increased hydraulic conductivities resulting from fractured reservoir rock.

Caves in the Guadalupe Mountains

Relatively good hydraulic communication between the Pecos River and the Capitan aquifer probably was first established late in the Pliocene Epoch or early in the Pleistocene after deposition of the Ogallala Formation. From that time, the movement of ground water through the Capitan aquifer in the Guadalupe Mountains has been controlled principally by the stage of the Pecos River at Carlsbad. (Dark Canyon and some of the other northeastward or eastward oriented drainage cutting across the Capitan aquifer in the Guadalupe Mountains may predate the Pecos River. If so, formation of the prominent caves and other late Cenozoic solution features may have been initiated earlier in the Pliocene Epoch.) The several well-defined levels of cave development that have been mapped in the Guadalupe Mountains are attributed to long periods of stability in the level of the water table (Gale, 1957; and Hayes, 1964, p. 50). The distinct changes in the altitude of the water table may have resulted from eposodic uplift of the Guadalupe Mountains and (or) periodic changes in the local base level of the Pecos River drainage system.

Carlsbad Caverns are the largest and, by far, the most famous of numerous caves carved into the Capitan, Goat Seep, and San Andres Limestones and the Artesia Group in the Guadalupe Mountains southwest of Carlsbad (Bretz, 1949; Gale, 1957; and Hayes, 1964). The solution of limestone in the strata comprising the Guadalupe Mountains fault block probably commenced along joints, because these and other fractures were the conduits through which ground water could move most easily. Consequently, the patterns of individual caves now closely parallel the regional joint system. In addition to the tectonic control, all the caves are localized in the more soluble limestone in preference to the dolomites in the carbonate lithofacies of the Guadalupian age strata (J. S. McLean, personal commun., 1973). Caves and other large-scale ground-water solution features are either absent or rarely observed in the basin and shelf aquifer in the vicinity of the Guadalupe Mountains although they are abundant in the Roswell basin in the vicinity of Roswell and Artesia. Cave development in Guadalupian strata in New Mexico is restricted to areas west of the Pecos River valley at Carlsbad.

Rauch and White (1970) have studied the development of solution porosity in Ordovician and Cambrian carbonate aquifers in Pennsylvania extensively and have determined that most of the caves were developed entirely within limestones. Caves developed in dolomite were rarely found. Furthermore, the largest caves were associated with limestones containing relatively low fractions of dolomite, clay, and other impurities. The caves were also associated with fine-grained limestones (lime mudstones?) rather than the coarser grained limestones and dolomites.

Motts (1968) found that the greatest amount of solution in the Guadalupian shelf-carbonate facies southwest of Carlsbad occurred along joints in the coarser textured carbonates. However, he also observed that the limestones were much more readily dissolved by the action of moving ground water than were the dolomites or dolomitic limestones.

Kendall (1969, p. 2517) in a discussion of the diagenetic changes that have occurred in the barrier island and flat facies of the Carlsbad facies (former Carlsbad Group) in the Guadalupe Mountains has described a process involving the selective leaching of calcite from some of the dolomites, thus "leaving an insoluble residue of unconsolidated powdery dolomite and some quartz." Kendall attributed the residue of dolomite to relatively recent solution of the calcite by downward precolation of fresh ground water.

Caves in the Glass Mountains

The "blowing and sucking of air," a phenomenon typical of the interchange of air between caverns and the atmosphere in response to seasonal or daily variations in barometric pressure and air temperature, has been observed to be associated with wells penetrating the Capitan aquifer in the Glass Mountains (Dr. D. J. Sibley, Jr., personal commun., 1972). Drillers also have reported the penetration of small caverns during the drilling of water wells in the Glass Mountains. However, extensive interconnected systems of caverns similar to those found in the Guadalupe Mountains have not been found in the Glass Mountains, nor have they been delineated in the Capitan aquifer in the subsurface along the margin of the Delaware basin east of Carlsbad or north of the Glass Mountains.

Water entering the Guadalupe Mountains as rain or snowmelt flows relatively rapidly through the Capitan aquifer, dissolving some of the calcareous sediments through which it moves, and then discharges into the Pecos River at Carlsbad as spring flow. The Glass Mountains are not drained by nearby deeply-incised streams. Water entering the Glass Mountains as precipitation must move comparatively slowly northward and eastward following tortuous paths toward points of natural discharge into adjacent aquifers. In comparison with the Guadalupe Mountains, much less water has moved through the aquifer system in the Glass Mountains and, consequently, fewer and smaller caverns have been excavated in the carbonate rocks.

Anomalously high porosity in the subsurface

Relatively thin zones of very high porosity have been detected occasionally in the Capitan aquifer along the northern and eastern margins of the Delaware basin east of the Pecos River valley at Carlsbad. The porous zones often can be located through interpretation of the "breaks" encountered by operators during the drilling of oil and gas wells and from examination of sonic or acoustic velocity types of electrical logs to locate intervals with "cycle skipping."

Typical examples of the "cavernous" zones with high porosity have been found at intervals described in the following wells: In Eddy County--Barton Mobil Federal 1, sec. 24, T.21 S., R.26 E., from 518 to 530 feet (158 to 162 metres) and from 1,792 to 1,829 feet (546 to 557 metres); Pan American Petroleum Corp., Big Eddy Unit 18, sec. 3, T.21 S., R.29 E., from 2,600 to 2,660 feet (792 to 811 metres); E. C. Hale Federal 2, sec. 22, T.20 S., R.30 E., from 2,387 to 2,411 feet (728 to 735 metres); and in Lea County--Bass Brothers Enterprises, Inc. (USGS) North Custer Mountain Unit 1, sec. 28, T.23 S., R.35 E., from 4,485 to 4,518 feet (1,367 to 1,377 metres) (fig. 6). Gail (1974) has defined several of the porous zones within the Capitan aquifer in eastern Eddy County.

Information obtained from an oil company drill-cuttings log indicated that a section composed almost entirely of limestone was penetrated in the Barton Mobil Federal 1 well, sec. 24, T.20 S., R.26 E. Lithologic information was not available for the other wells described above. All the wells described above are located near the forereef edge of the shelf-margin facies and probably penetrate a section composed of limestone rather than the less soluble dolomite of the Carlsbad facies.

Most of the thin zones of high porosity noted on electrical logs or from drillers' records probably are not true caverns in the sense of the numerous large caves in the Guadalupe Mountains. Probably they represent limestones with either original highly porous textures, e.g., the poorly cemented algal lime grainstone recovered from the Skelly Oil Co. Jal Water Supply 1, sec. 16, T.24 S., R.36 E., or secondary "honeycomb" solution structures.

Preferential solution of carbonates by moving ground water

The hydraulic conductivity of the Capitan aquifer has been markedly enhanced by the selective solution and removal of carbonate material. The amount of rock dissolved appears very clearly to be primarily a function of (1) the total amount of ground water that has moved through the aquifer, (2) the lithology of the aquifer, with limestones being dissolved in preference to dolomites, (3) the jointing and fracturing of the aquifer---mainly due to small-scale crustal movements except for that due to the regional tilting and block faulting of the Glass and Guadalupe Mountains, and (4) the texture of the rock.

The original depositional textures appear to have been of critical importance in controlling the flow of ground water and, in turn, influencing the solution of carbonate material in the vadose and phreatic zones during the Guadalupian Epoch. However, the fractures and joints apparently were more important factors in controlling the movement of ground water during the late Cenozoic solution phase.

The hydraulic conductivity of the Capitan aquifer southwest of Carlsbad is extremely high due to the development of an extensive system of caverns, caves, and other voids by ground-water solution of the calcareous strata within the aquifer (Bretz, 1949; Hale, 1945a, and 1945b; and Motts, 1968). For similar reasons, the hydraulic conductivity of the Capitan aquifer in the Glass Mountains, while not nearly as high as that observed in the Guadalupe Mountains, is apparently much greater than it is in the subsurface farther to the north along the western margin of the Central Basin platform.

An analysis of the reconstructed late Cenozoic hydrogeologic history of the region suggests that much more ground water has moved through the Capitan aquifer along the eastern margin of the Delaware basin and for a longer period of geologic time than has moved through the aquifer along the northern margin of the Delaware basin between the Pecos River at Carlsbad and the middle of southern Lea County. Therefore, the increase in the hydraulic conductivity of the Capitan aquifer in the subsurface due to solution of calcareous rocks along the eastern margin of the Delaware basin is probably relatively greater than it is along the northern margin.

The location of the caverns and other ground-water solution structures in the Guadalupe Mountains is certainly controlled to a large extent by the relatively high solubility of limestone in comparison with that of dolomite. Similarly, the effects of ground-water solution in the Capitan aquifer along the north and east margins of the Delaware basin also seem to be restricted to the calcareous strata. Therefore, in any randomly selected transverse section of the Capitan aquifer, the highest hydraulic conductivities should be localized within the poorly bedded lime grainstone and wackestone of the Capitan and Goat Seep Limestones along the extreme seaward edge of the shelf margin, as defined by Dunham (1972).

Restricted movement of ground water in eastern Eddy County, New Mexico

Several lines of evidence point to an area with relatively low transmissivity in the vicinity of the boundary between Eddy and Lea Counties, New Mexico. The most important are: (1) the shape and configuration of the present-day potentiometric surface, (2) the fluctuation of water levels in the observation wells in the area, (3) interpretations of the cause for existing differences in the salinity of ground water, and (4) geologic evidence for the restriction of ground-water movement.

Shape of the potentiometric surface

Figures 22 and 23 are maps showing the pre and postdevelopment potentiometric surfaces representing the three systems of aquifers. These will be discussed more completely in a later section. Reference is made to the maps in relation to the area of restricted circulation of ground water in the Capitan aquifer.

The potentiometric surface developed in extreme eastern Eddy and western Lea Counties resembles the typical configuration expected to form as pressure declines reach an area with reduced transmissivity (figs. 22, 23, 24, and 25 and tables 8 and 9). Eastward gradients of about 25 feet per mile (5 m/km) have been developed in the Capitan aquifer in the vicinity of T.19-20 S., east one-half of R.30 E., and R.31 E., Eddy County. The gradient decreases rapidly to about 15 feet per mile (3 m/km) in the vicinity of T.20 S., R.33-34 E., Lea County. A much lower gradient of about 6 feet per mile (1 m/km) is present over the remainder of southern Lea County. The steepest gradients are located across the inferred restriction in the Capitan aquifer and are approximately 75 miles (120 kilometres) from the regional center of pumping just west of Kermit, Tex. The gradient across and to the east of the inferred restriction will continue to increase as indicated by the consistently large declines in water levels observed in the Middleton Federal B 1 well, sec. 31, T.19 S., R.32 E., Lea County, New Mexico (figs. 24 and 25).

Table 8.--Average monthly changes in water levels observed in the Capitan aquifer, southeastern New Mexico

Name of well	Location of well[1/]	Date of start and end of period used in computing average changes	Number of months	Total change in water level, feet (metres) (-) - decline (+) - rise	Average change in water level, feet (metres) per month (-) - decline (+) - rise
City of Carlsbad Well 10 (Dark Canyon Well 1)	SW¼NW¼NE¼ sec. 24, T. 23 S., R. 25 E., Eddy County, New Mexico	Jan. 1, 1967 to Jan. 1, 1973	72	- 0.08 (0.024)	-0.001 (0.0003)
City of Carlsbad Well 13 (La Huerta East Well)	NW¼NE¼NE¼ sec. 36, T. 21 S., R. 26 E., Eddy County, New Mexico	Jan. 1, 1967 to Jan. 1, 1973	72	+ .68 (.207)	+ .009 (.0027)
Pecos River above Tansill dam at Carlsbad, N. Mex.[2/]	NW¼NW¼NW¼ sec. 5, T. 22 S., R. 27 E., Eddy County, New Mexico	Jan. 1, 1967 to Jan. 1, 1970	36	+ .12 (.0366)	+ .003 (.0009)
North Cedar Hills Unit 1	1,993 feet (607 metres) FEL, 3,060 feet (934 metres) FNL, sec. 5. T. 21 S., R. 27 E., Eddy County, New Mexico	Jan. 1, 1967 to Jan. 1, 1973	72	+ .27 (.082)	+ .004 (.0012)
Humble State 1	660 feet (201 metres) FSL, 660 feet (201 metres) FWL, sec. 23, T. 21 S., R. 27 E., Eddy County, New Mexico	Feb. 1, 1968 to Jan. 1, 1973	59	+ 9.74 (2.97)	+ .165 (.050)
City of Carlsbad Test Well 3 (Miller Nix-Yates Federal 1)	1,650 feet (503 metres) FNL, 1,650 feet (503 metres) FWL, sec. 30, T. 21 S., R. 28 E., Eddy County, New Mexico	Jan. 1, 1967 to Jan. 1., 1973	72	- 2.05 (.625)	- .028 (.0085)
Yates State 1[3/]	660 feet (201 metres) FSL, 1,650 feet (503 metres) FWL, sec. 32, T. 20 S., R. 30 E., Eddy County, New Mexico	Jan. 1, 1968 to Dec. 1, 1971 and Jan. 1, 1972 to Jan. 1, 1973	59	+ 7.01 (2.14)	+ .119 (.036)
Hackberry Deep Unit 1[3/]	1,650 feet (503 metres) FNL, 990 feet (302 metres) FWL, sec. 31, T. 19 S., R. 31 E., Eddy County, New Mexico	Jan. 1, 1967 to Jan. 1, 1973	72	-22.90 (6.98)	- .318 (.097)

Table 8.--Average monthly changes in water levels observed in the Capitan aquifer, southeastern New Mexico - Concluded

Name of well	Location of well[1]	Date of start and end of period used in computing average changes	Number of months	Total change in water level, feet (metres) (-) - decline (+) - rise	Average change in water level, feet (metres) per month (-) - decline (+) - rise
Middleton Federal B 1	660 feet (201 metres) FNL, 660 feet (201 metres) FWL, sec. 31, T. 19 S., R. 32 E., Lea County, New Mexico	Jan. 1, 1967 to Jan. 1, 1973	72	-119.90 (36.5)	-1.67 (.509)
South Wilson Deep Unit 1	1,980 feet (604 metres) FSL, 660 feet (201 metres) FWL, sec. 23, T. 21 S. R. 34 E., Lea County, New Mexico	Feb. 1, 1967 to Jan. 1, 1973	71	-93.48 (28.5)	-1.32 (.402)
North Custer Mountain Unit 1	660 feet (201 metres) FNL, 1,980 feet (604 metres) FWL, sec. 28, T. 23 S., R. 35 E., Lea County, New Mexico	Feb. 1, 1967 to Jan. 1, 1973	71	-88.58 (27.0)	-1.25 (.381)
Eugene Coates 3	660 feet (201 metres) FSL, 660 feet (201 metres) FWL, sec. 3, T. 24 S., R. 36 E., Lea County, New Mexico	Jan. 1, 1968 to Mar. 13, 1968 and Mar. 15, 1968 to Jan. 1, 1969	12	-16.80 (5.12)	-1.40 (.427)
Federal Davison 1	660 feet (201 metres) FNL, 1,980 feet (604 metres) FEL, sec. 20, T. 24 S., R. 36 E., Lea County, New Mexico	Jan. 1, 1967 to Jan 1, 1973	72	-126.13 (38.4)	-1.75 (.533)
Southwest Jal Unit 1	1,980 feet (604 metres) FNL, 1,980 feet (604 metres) FEL, sec. 4, T. 26 S., R. 36 E., Lea County, New Mexico	Jan. 1, 1967 to Jan. 1, 1973	72	-91.93 (28.0)	-1.28 (.390)

1/ Location of well site from nearest section lines are expressed by an acronym composed of 3 letters. "F" and "L" represent "from" and "line", respectively. The middle letter represents the compass direction, N=north; E=east; S=south; and W=west.
2/ Crest-stage gage.
3/ Change calculated from water levels adjusted for oil influx.

Table 9.--Narrative remarks referenced to hydrographs from observation-well network

City of Carlsbad Well 10:

1. Daily high water-level readings used through 12-31-65. Recorder installed.
2. Recorder not operating correctly from 8-7-66 to 8-10-66 due to flooding in nearby Dark Canyon.
3. Noon water-level readings begin.
4. Clock replaced and reset.
5. Records influenced by rain or flood from 6-30-67 to 7-2-67.
6. Records influenced by rain or flood from 8-30-68 to 9-1-68.
7. Records missing between 9-7-69 and 9-17-69. Paper supply depleted.
8. Records influenced by rain or flood from 9-17-69 to 9-19-69.
9. Records influenced by rain or flood from 10-20-69 to 10-24-69.
10. Records influenced by rain or flood from 9-17-70 to 9-22-70.
11. Records influenced by rain or flood from 10-5-70 to 10-10-70.
12. Clock stopped from 9-16-71 to 10-15-71. Counterweight hung on float wheel.
13. Records influenced by rain or flood from 9-2-72 to 9-19-72.

City of Carlsbad Well 13:

1. Daily high water-level readings used through 12-31-65. Recorder installed.
2. Noon water-level readings begin.
3. Weight came off. Float line loose from 6-15-67 to 6-27-67.
4. New clock installed.
5. Records influenced by rain or flood from 9-2-72 to 9-16-72.

Table 9.--Narrative remarks referenced to hydrographs from observation-well network - Continued

Tansill Dam Crest-Stage Gage:

1. Records influenced by rain or flood from 8-22-66 to 9-8-66.
2. Record missing between 12-4-66 and 1-11-67. Lake level lowered for city repairs.
3. Crest-stage gage discontinued.

North Cedar Hills Unit 1:

1. Acidized well.
2. Swabbed well.
3. Installed recorder.
4. Swabbed and acidized well.
5. Swabbed well.
6. Recorder reinstalled.
7. Tape measurement.
8. Tape measurement.
9. Clock replaced.
10. Swabbing completed. Tape measurement taken 139 minutes after pumping ceased.
11. Tape measurement.
12. Chart paper roll changed.
13. Started to add float line and lost it down well.
14. Records influenced by rain or flood from 9-1-72 to 9-25-72.

Table 9.--Narrative remarks referenced to hydrographs from observation-well network - Continued

Humble State 1:

1. Swabbed and acidized well.
2. Swabbed well.
3. Swabbed well.
4. Swabbed and acidized well.
5. Recorder installed.
6. Tape measurement.
7. Tape measurement.
8. Pen reset. Screws in clock had come off, and float was pulled up.
9. Tape measurement.
10. Tape measurement.
11. Tape measurement.
12. Recorder and shelter removed on 12-29-71. Fluid column sampled on 12-30-71. Recorder reinstalled on 1-6-72. 1.2 feet (0.037 metres) of oil on top of fluid.
13. 3.3 feet (1.0 metres) of oil on top of fluid column on 2-28-72.
14. New float and clock weight installed.
15. Records influenced by rain or flood from 9-15-72 to 9-27-72.

City of Carlsbad Test Well 3:

1. Digital recorder installed.
2. Daily high water-level readings used.
3. Data from 11-25-68 to 12-19-68 omitted because of unreliability.
4. Records influenced by rain or flood from 8-27-72 to 9-24-72.

Table 9.--Narrative remarks referenced to hydrographs from observation-well network - Continued

Yates State 1:

1. Swabbed from 8-29-67 to 9-1-67.
2. Recorder installed.
3. Chart roll changed and pen inked.
4. Pen removed to check for oil in well.
5. Clock stopped from 4-21-69 to 5-21-69. Negator spring was binding.
6. Recorder replaced 6-18-69.
7. Pulse test. Recorder was not operating from 9-3-69 to 10-15-69.
8. Recorder replaced 11-18-69.
9. Recorder and shelter removed on 10-20-71. Length of oil column was 77.4 feet (23.6 metres). Oil bailed from well on 10-22-71. Recorder reinstalled on 10-27-71.
10. Recorder and shelter removed on 12-27-71. Cast iron bridge plug set at 2,550 feet (777 metres) (KB) and well swabbed on 12-28-71 and 12-29-71. Recorder reinstalled on 1-6-72.
11. No oil present at top of water on 2-28-72.
12. Records influenced by rain or flood from 9-3-72 to 9-25-72.
13. Float line replaced with a line of a smaller diameter on 11-2-72.

Table 9.--Narrative remarks referenced to hydrographs from observation-well network - Continued

Hackberry Deep Unit 1:

1. Treated with acid and swabbed. Ran aquifer performance test.
2. Recorder installed.
3. Swabbed and acidized well.
4. Wire line measurement.
5. Poured 1 gallon (3.8 litres) of motor oil down well to free the line from the casing. Wire line measurement.
6. Wire line measurement used to make a correction to subsequent water-level data.
7. Measurement with logger.
8. Continual bubbling noise heard from well due to leakage of gas into borehole.
9. Can still hear bubbling noise.
10. Can hear only faint bubbling noise.
11. No audible bubbling noise.
12. Chart roll changed.
13. Clock stopped from 8-15-69 to 9-4-69 for pulse test.
14. Recorder and shelter removed. Length of oil column was 95.7 feet (29.2 metres) on 10-20-71. Oil bailed from well on 10-21-7. Recorder reinstalled on 10-27-71
15. Tape parted in hole on second measurement, jamming float.
16. Float reinstalled and recorder in operation on 12-14-71.
17. Poured 1 gallon (3.8 litres) of motor oil down well to free the line from the casing.
18. Float tape parted on the counterweight side of the recorder. Float line removed from well and replaced on 1-22-73.

Table 9.--Narrative remarks referenced to hydrographs from observation-well network - Continued

Middleton Federal B 1:

1. Installed recorder.
2. Swabbed 245 barrels (39 cubic metres) of water in 5 hours.
3. Pen skipping from 4-3-67 to 5-2-67.
4. Wire line measurement ignored.
5. Measurement with logger.
6. Conterweight caught on shelf from 9-9-68 to 9-19-68.
7. Added 12.13 feet (3.7 metres) of wire to float line. Water-level reading measured after unhooking counterweight.
8. Chart roll changed.
9. Wire added to float line.

South Wilson Deep Unit 1:

1. Recorder installed.
2. Wire line measurement.
3. Measurement with logger. Water-level reading missing from 5-18-68 to 5-19-68. New float line installed.
4. Cattle rubbing against shelter. Unreliable readings from 6-27-68 to 7-17-68.
5. Pen reset. Beads on float wheel slipped.
6. Wire added.

Table 9.--Narrative remarks referenced to hydrographs from observation-well network - Continued

North Custer Mountain Unit 1:

1. Swabbed approximately 330 barrels (52.5 cubic metres) of water
2. Depthometer measurement.
3. Approximately 330 barrels (52.5 cubic metres) of water swabbed and bailed.
4. Acidized with 1,000 gallons (3.8 cubic metres) regular 15 percent acid.
5. Swabbed approximately 540 barrels of (85.9 cubic metres) of water at 42 gallons per minute (229 cubic metres per day).
6. Static level after swabbing.
7. Recorder installed. Tape measurement.
8. Wire line measurement.
9. Measurement made but not used.
10. Logger and steel-tape measurement.
11. Beads out of holes on float wheel. Counterweight 0.3 feet (0.09 metre) from float wheel. Added 8.93 feet (2.72 metres) of float cable. Pen reset at 865.64 feet (263.85 metres).
12. Wire added.
13. Float line slightly hung from 9-12-69 to 9-17-69.
14. Weight hung on wheel. Added 10 feet (3 metres) of float line.

Eugene Coates 3:

1. Recorder installed.
2. Wire line measurement ignored.
3. Measurement with logger.
4. Beads out of holes on float wheel. Float line slightly hung from 8-2-68 to 8-14-68.

Table 9.--Narrative remarks referenced to hydrographs from observation-well network - Continued

Eugene Coates 3 - Concluded

5. Float line added.
6. Records missing from 1-23-69 to 2-20-69. Pen left in "up" position.
7. Recorder and shelter removed and well records discontinued on 5-6-69.

Federal Davison 1:

1. Recorder installed.
2. Clock replaced.
3. Added 20 feet (6 metres) of wire.
4. Wire line measurement.
5. Wire line measurement.
6. Large rise in water level. Duration of rise was 9 hours.
7. New clock installed.
8. Correction from logger measurement added to water-level readings from 4-17-68 to 5-16-68.
9. Float counterweight ran out of wire; weight hanging on float wheel. Wire spliced and added.
10. Float line added.
11. Cable added to float line.
12. Float line slightly hung from 7-18-69 to 8-19-69.
13. Recorder and shelter removed and water column sampled for the New Mexico State Engineer on 11-15-72.

Table 9.--Narrative remarks referenced to hydrographs from observation-well network - Concluded

Southwest Jal Unit 1:

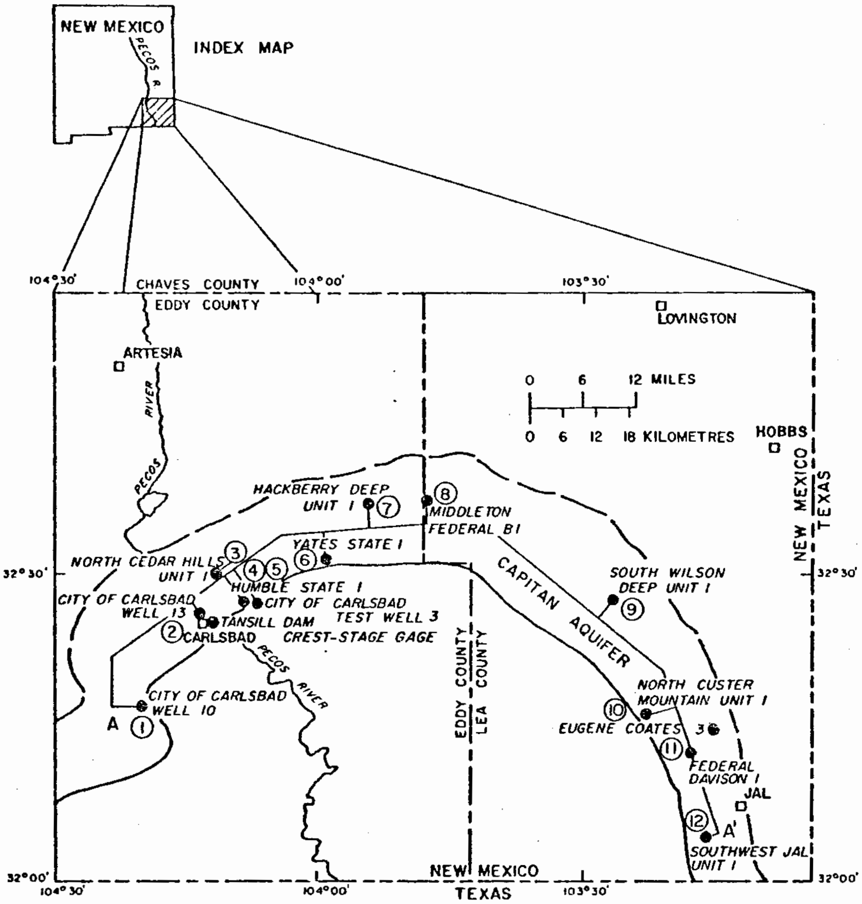
1. Swabbed and acidized.
2. Measurement with logger.
3. Water-level recorder installed.
4. Wire line measurement ignored in preference to logger measurement of 5-16-68.
5. Wire line measurement ignored in preference to logger measurement.
6. Measurement with logger.
7. Float counterweight hung on float wheel between 10-9-68 and 10-17-68. Float line lengthened.
8. Float line lengthened.
9. Float line slightly hung.

Effects of long and short-term stresses

The water levels measured in the westernmost 6 of the 7 observation wells in Eddy County appear to respond to climatic conditions and the use of water in the Pecos River valley at Carlsbad but not recognizably to the withdrawal of water from the aquifer farther to the southeast. However, the water levels recorded in one well in extreme eastern Eddy County and five wells scattered throughout the Capitan aquifer in southern Lea County are obviously declining in response to withdrawal of water from the Capitan aquifer and other formations in measurable hydraulic communication with it in Lea County, New Mexico, and Ward and Winkler Counties, Texas (figs. 24 and 25).

Pulses in the potentiometric surface generated by floods on the Pecos River at Carlsbad and changes in the rate of pumping in the water fields located between Jal, N. Mex. and Monahans, Tex. do not appear to be transmitted, in a detectable magnitude, through the Capitan aquifer in either direction beyond the Eddy-Lea County boundary.

Comparison of the predevelopment and postdevelopment potentiometric surfaces (figs. 22 and 23, respectively) suggests that over a period of about 40 years, the head in the Capitan aquifer has been reduced approximately 200 feet (61 metres) in the vicinity of the Eddy-Lea County boundary. Declines of a similar magnitude have not occurred elsewhere in eastern Eddy County east of the Pecos River.



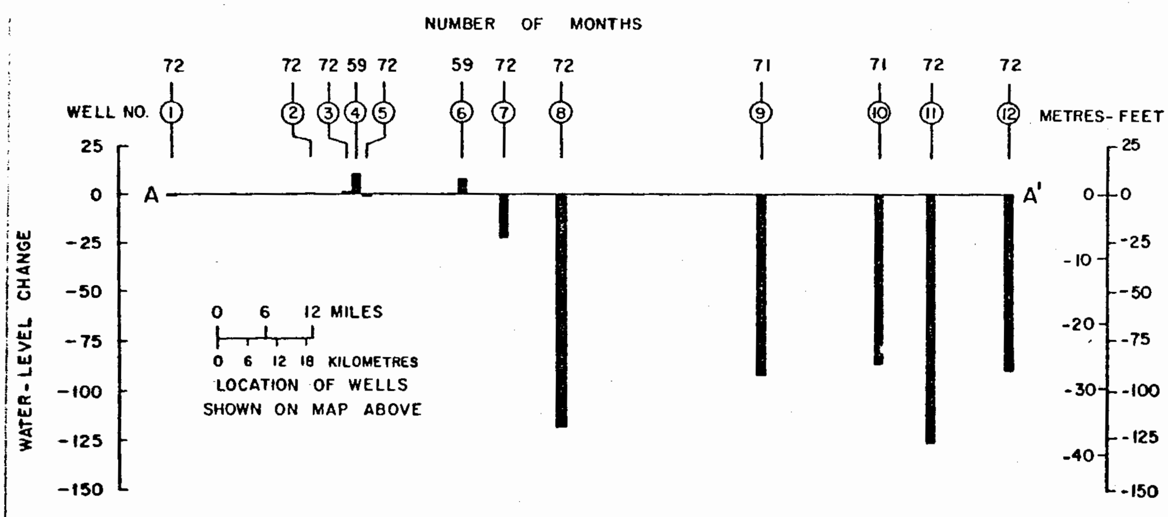


Figure 25.--Graph showing cumulative changes of water level in the Capitan aquifer observation wells, southeastern New Mexico.

Inferences from relative salinity of water

Relatively good water was emplaced in the Capitan aquifer east of Carlsbad prior to the excavation of the Pecos River at Carlsbad. Subsequently, highly mineralized water has leaked into the Capitan aquifer from the shelf and basin aquifers. The mixing of the two waters has taken place for an unknown time during the Pleistocene and Holocene Epochs. However, the available data suggest that the salinity of the water in the Capitan aquifer east of Carlsbad in New Mexico was never as low as the salinity of the water produced from this aquifer in Brewster, Pecos, Ward, and Winkler Counties, Texas (fig. 26). Apparently, the volume of fresh water that flowed eastward from the Guadalupe Mountains was not adequate to flush the original brines from the Capitan aquifer in Eddy and the northern part of southern Lea Counties.

The comparatively higher salinity of the water in the Capitan aquifer east of Carlsbad can be attributed to three factors: (1) an inadequate volume of water moving eastward due to lower transmissivity of the aquifer, (2) the establishment of hydraulic communication between the aquifer and the Pecos River very early in the geomorphic evolution of the Carlsbad area and consequent reduction in the total amount of water that flowed eastward from the Guadalupe Mountains, and (3) the subsequent leakage of higher salinity water into the Capitan aquifer from adjacent aquifers.

Geologic nature of the restriction

The igneous dike or dikes noted in the discussion of Tertiary igneous activity cut the Capitan aquifer east of the Middleton Federal B-1 observation well located in sec. 31, T.19 S., R.32 E. Lea County (figs. 11 and 21). Water levels in this well have declined consistently at the rate of approximately 1.7 feet (0.5 metres) per month over a period of 72 months, in contrast to the relatively small declines or rises in the water levels recorded in wells located farther to the west in Eddy County (table 8). Therefore, the dike or dikes do not appear to act as restrictions or barriers to movement of ground water.

The thickness of the Capitan aquifer is reduced to several hundred feet by the West Laguna submarine canyon in eastern Eddy County (fig. 11). The most prominent transverse linear thins, the West, Middle, and East Laguna submarine canyons, are located in the vicinity of the boundary between Eddy and Lea Counties where they coincide with both the position of the large increase in the eastward gradient in the potentiometric surface and the point where the largest declines in the hydraulic head commence. The transmissivity in this area has undoubtedly been reduced to a minor fraction of the average transmissivity of the Capitan aquifer by the Laguna submarine canyons, thereby restricting the movement of water eastward.

Regional hydraulic conductivity

Meager data of often-questionable reliability, in conjunction with an interpretation of the geohydrological history of the region, suggest that the hydraulic conductivity of the Capitan aquifer along the western margin of the Central Basin platform in Texas and New Mexico ranges from 1 to 25 ft/day (.3 to 7.6 m/day) (table 7). The hydraulic conductivity of the Capitan aquifer probably averages 5.0 ft/day (1.5 m/day) in most of southern Lea County, New Mexico, but appears to increase progressively southward to an estimated 10.0 ft/day (3.0 m/day) near the Pecos-Brewster County boundary in Texas. The hydraulic conductivity of the Capitan aquifer in the Glass Mountains is probably very high because of the numerous small caverns developed in this area (D. J. Sibley, Jr., personal commun.).

An average hydraulic conductivity of 5.0 ft/day (1.5 m/day) also would seem to be reasonable for the Capitan aquifer over a span of approximately 15 miles (24 kilometres) immediately east of the Pecos River valley at Carlsbad. Values of hydraulic conductivity in the Capitan aquifer west of the Pecos River at Carlsbad are apparently larger by as much as several orders of magnitude (Hale, 1945a and 1945b).

Local variations in transmissivity

The transmissivity of the Capitan aquifer in a small area near the boundary between Eddy and Lea Counties, New Mexico, in the vicinity of the deeply incised Laguna submarine canyons appears to be the lowest enocuntered anywhere within the project area.

A representative transmissivity for this major restriction has not yet been determined. However, the general response to stresses placed on the aquifer by (1) withdrawal of water in the water fields to the east, (2) recharge by floods in the Pecos River valley, and (3) precipitation in the Guadalupe Mountains to the west, suggest that the transmissivity must be at least one and perhaps two orders of magnitude lower than the average transmissivity of the Capitan aquifer.

Values of transmissivity for the Capitan aquifer in the area extending east of the Pecos River at Carlsbad around the northern and eastern margins of the Delaware basin to the Pecos-Brewster County boundary in Texas are estimated to range from approximately 10,000 ft^2/day (900 m^2/day) in the thicker intercanyon nodes to less than 500 ft^2/day (450 m^2/day) in the vicinity of the more deeply incised submarine canyons.

Shelf aquifers

Artesia Group

Aquifer-performance tests were not available for any of the formations in the Artesia Group on the Northwestern shelf east of the Pecos River between Carlsbad and Artesia, or on the Central Basin platform. The average hydraulic conductivities and porosities of the Grayburg, Queen, Seven Rivers, Yates, and Tansill Formations within the Artesia Group, the Grayburg Formation-San Andres Limestone, undivided, and the "Glorieta Sandstone" are shown on figure 21 and given in summary form in table 6 for Eddy and Lea Counties, New Mexico, and Ward and Winkler Counties, Texas. The average hydraulic conductivity and porosity of the shelf aquifers were determined to be 0.043 ft/day (0.013 m/day) and 7.69 percent, respectively. More than 32,000 measurements representing approximately 37,000 feet (11,300 metres) of core cut in wells scattered throughout the four-county area were statistically examined.

The hydraulic conductivity of the Seven Rivers Formation is significantly higher in Lea County, New Mexico, and Ward County, Texas than in the other two counties. This difference is apparently due to the more favorable location of some of the cored sections in the shelf-margin facies of the Seven Rivers Formation in Lea County and to the statistically small sample in Ward County rather than to a regional change in the lithology.

Values of permeability and porosity given by Hogan and Sipes (1966) for the Grayburg, Queen, Seven Rivers, and Yates Formations in a statistical summary representing an unknown number of analyzed cores from wells drilled in many of the counties in western Texas tend to be slightly larger than those shown in table 6, but, overall, are in general agreement.

An average hydraulic conductivity of .073 ft/day (.002 m/day) was computed from 26 typical productivity indexes measured by several oil companies in 14 oil wells producing from various pay zones within the Artesia Group. The wells were randomly located within the Premier field, Eddy County, and the Eumont, Eunice South, Jalmat, and Langlie-Mattix fields, Lea County. Little variation was noted between the computed values, the lowest value being .004 ft/day (.001 m/day) in the Jalmat field and the highest value being .167 ft/day (.05 m/day) in the Eumont field.

San Andres Limestone on the northern end of the Central Basin platform

A multiple-well test of the San Andres Limestone was accomplished during November 1966 in cooperation with an oil company. The pumped well was located in sec. 29, T.22 S., R.37 E., Lea County, approximately 2,200 feet (670 metres) from the observation well in the Langlie-Mattix oil field. A hydraulic conductivity of 0.3 ft/day (.09 m/day) and a storage coefficient of 1.5×10^{-5} was determined from the 120-hour drawdown test (table 7). Vertical leakage between the San Andres and adjacent aquifers was also indicated during the test.

Information recorded during the drawdown and recovery periods of 96 and 24 hours, respectively, for a single well test of the San Andres Limestone located in sec. 7, T.20 S., R.38 E., in the Warren-McKee oil field on the northern edge of the Central Basin platform in southern Lea County was made available to the USGS through the cooperation of both an oil company and a consultant. A hydraulic conductivity of 0.2 ft/day (.06 m/day) was computed from analysis of these data (table 7).

A limited amount of permeability data for the San Andres Limestone on the north end of the Central Basin platform was obtained during the search for core analyses. The hydraulic conductivity of approximately 0.17 ft/day (.05 m/day) computed from these data confirms the relatively high permeability of the San Andres Limestone on the northern end of the Central Basin platform in comparison with the permeabilities determined from core analyses of the San Andres elsewhere and for other formations in the shelf aquifers (table 6, and fig. 21).

Stratigraphic reefs and carbonate mounds or banks have been reported to occur in the San Andres Limestone along both the northern and western margins of the Central Basin platform. A zone of relatively high transmissivity in the San Andres Limestone on the northern part of the Central Basin platform is inferred from a map of the chloride-ion concentration in water in rocks of Guadalupian age (fig. 26). Limited hydraulic conductivity data combined with stratigraphic and water-quality information, suggest that the hydraulic conductivity of the San Andres Limestone on the northern end of the Central Basin platform is significantly higher than the hydraulic conductivities of the Artesia Group and the San Andres Limestone in the remainder of the project area east of the Pecos River valley between Carlsbad and Artesia. Similar relatively high hydraulic conductivities are also probably present in the San Andres Limestone at the southern end of the Central Basin platform.

San Andres Limestone on the Northwest shelf
and Central Basin platform

Cores cut in the lower part of the Artesia Group and upper part of the San Andres Limestone are most often identified by the operator as Grayburg Formation-San Andres Limestone, undivided, and it was impossible to distinguish between the two formations when the data were processed. However, as shown on figure 21 and in table 6, the hydraulic conductivities of the Grayburg Formation and the Grayburg Formation-San Andres Limestone, undivided, on the northern end of the Central Basin platform, are only 0.048 and 0.068 ft/day (.015 and .02 m/day), respectively. These values are almost an order of magnitude lower than the hydraulic conductivities of the San Andres aquifer determined from the two aquifer performance tests (table 7). Similarly, the average hydraulic conductivity of the Grayburg Formation-San Andres Limestone, undivided, in Ward and Winkler Counties, Texas, and Eddy and Lea Counties, New Mexico, was determined from statistical analyses of the core data to be only 0.033 ft/day (.01 m/day).

Permeabilities reported by Kinney (1969) for the San Andres Limestone in southeastern New Mexico range generally from 0.1 to 5 millidarcies (hydraulic conductivities of approximately 0.00024 to 0.0122 ft/day or 0.000073 to 0.0037 m/day). Hogan and Sipes (1966) report an average permeability of 6.9 millidarcies (approximately 0.017 ft/day or 0.005 m/day) for an area including Ward, Winkler, Ector, Andrews, Gains, Yoakum, and Terry Counties, Texas, and an average permeability of 9.7 millidarcies (about 0.024 ft/day or 0.0073 m/day) for a large area in western Texas that does not include these seven counties.

An average porosity of about 10 percent was determined from core analyses from the San Andres aquifer on the northern end of the Central Basin platform. Kinney (1969) gives a general range of 3 to 5 percent for the porosity of the San Andres Limestone in southeastern New Mexico. The average porosity of the Grayburg Formation and San Andres Limestone, undivided, in Eddy and southern Lea Counties was determined from core analyses to be about 6 percent. Hogan and Sipes (1966) report porosities of 7 percent for Ward, Winkler, Ector, Andrews, Gaines, Terry, and Yoakum Counties and 15.5 percent for a large area in western Texas excluding the previously mentioned counties.

The hydraulic conductivity and porosity data given above are representative of the oil and saline water-bearing rocks outside of the Roswell and Carlsbad underground water basins (fig. 1) where much higher values for these parameters have been determined.

Basin aquifers

Delaware Mountain Group

An average hydraulic conductivity and porosity of 0.016 ft/day (0.0049 m/day) and 15.65 percent, respectively, were determined from approximately 4,500 samples of rock core cut from the Delaware Mountain Group in Eddy and Lea Counties, New Mexico and Ward and Winkler Counties, Texas (fig. 21, and table 6). An approximate hydraulic conductivity of 0.015 ft/day (0.0046 m/day) was computed from productivity indexes (approximately equivalent to specific capacities) obtained from an oil company for two wells in the El Mar field located on the boundary between Lea County, New Mexico, and Loving County, Texas.

Hogan and Sipes (1966) report permeability values of 12.9 to 24.5 millidarcies (hydraulic conductivities of approximately 0.031 to 0.060 ft/day or 0.0095 to 0.018 m/day), and porosities of 17.9 to 21.0 percent for much of the same part of the Delaware basin.

The values of hydraulic conductivity and porosity of the Delaware Mountain Group are in the same general range as those of the Artesia Group and the San Andres Limestone.

Comparative hydraulic characteristics of the aquifers

Except for a small area in eastern Eddy County, the average hydraulic conductivity of the Capitan aquifer is apparently a minimum of two orders of magnitude larger than the average hydraulic conductivity of the adjacent and partially enclosing shelf and basin aquifers, and one order of magnitude larger than the average hydraulic conductivity of the San Andres aquifer on the northern end of the Central Basin platform.

The transmissivity of the Capitan aquifer in extreme eastern Eddy County in the vicinity of the Laguna submarine canyons is apparently much less than the average for this aquifer and may be similar to the transmissivity of the shelf and basin aquifers.

Salinity of the water in rocks of Guadalupian age

Regional salinity

Water containing relatively low chloride-ion concentration is produced from the Capitan aquifer throughout the region, from the San Andres Limestone and Artesia Group where these units are in close association with the Capitan aquifer along the margin of the Northwestern shelf and Central Basin platform, and from the San Andres Limestone and the lower part of the Artesia Group at both ends of the Central Basin platform (fig. 26).

Fingers of the less mineralized water extend into the Capitan aquifer from potential fresh-water recharge areas in the Guadalupe and Glass Mountains. The 5,000 mg/l (milligrams per litre) isochlore in the Capitan aquifer extends only a few miles east of Carlsbad, whereas the same isochlore extends northward from the Glass Mountains to north of Hobbs. This indicates that relatively good water containing 1,000 to 5,000 mg/l chloride ion may be found in the Capitan aquifer on the northeastern and eastern edge of the Delaware basin and the northern and southern ends of the Central Basin platform. Water containing less than 1,000 mg/l chloride ion concentration is present in the Capitan aquifer in a tongue extending northward from the Glass Mountains to just north of the New Mexico-Texas border in southernmost Lea County.

In sharp contrast to the water of relatively good quality that is found in the Capitan aquifer, the rocks of Guadalupian age on the Northwestern shelf northwest of Hobbs, on the Central Basin platform, and in the Delaware basin, contain water with relatively high concentrations of chloride ion (fig. 26). Chloride-ion concentrations greater than 150,000 mg/l are present over large areas in the San Andres Limestone and Artesia Group on the Northwestern shelf and in the Delaware Mountain Group in the Delaware basin. Similarly, water containing chloride-ion concentrations of more than 100,000 mg/l is found in the San Andres Limestone and Artesia Group over much of the central part of the Central Basin platform.

Emplacement of the relatively better quality water

The water of better quality is found in rocks with the highest permeability and, conversely, the water of poorest quality is found in rocks with the lowest permeability. The water of relatively low salinity found in the Capitan aquifer, the Artesia Group, and San Andres Limestone in southeastern New Mexico and western Texas is most probably a result of selective displacement of original brines by movement of fresh water from the Glass and Guadalupe Mountains into the formations with regionally highest transmissivities.

Water entering the Capitan aquifer in the Guadalupe and Glass Mountains apparently moved toward a point southwest of present-day Hobbs, where it then entered the San Andres Limestone and formations in the lower part of the Artesia Group. The water then flowed eastward via a northeast-trending zone of relatively higher transmissivity in the shelf-margin rocks. The water moved into Andrews and Gaines Counties, Texas from the vicinity of Hobbs and eventually discharged into streams draining toward the Gulf of Mexico (Stevens, and others, 1965). The configuration of the isochlores in figure 26 suggests that the bulk of the water now in the Capitan aquifer in Lea County, New Mexico and Winkler, Ward, and Pecos Counties, Texas, came from the Glass Mountains.

Halite has been wholly or partially dissolved and removed from the Salado and Castile Formations wherever they are in juxtaposition with the Capitan aquifer along the northeast and eastern margins of the Delaware basin (figs. 7, D-D' and E-E', and 17; and Maley and Huffington, 1953; and Pierce and Rich, 1962). The anomalous thinning of the Salado and Castile Formations coincides with the location of the water of low salinity in the Capitan aquifer. Apparently, relatively fresh ground water has moved through the Capitan aquifer and dissolved the halite in adjacent formations. The tongues of water of better quality and anomalously thin areas in the Salado and Castile Formations are clues that aid in the explanation of the pattern of flow through the Guadalupian age strata.

The present-day potentiometric surface has adjusted to the Pecos River, which either incises or is in measurable hydraulic communication with the Capitan aquifer at Carlsbad and acts as an ungradient drain for the Permian formations. Discharge from the Permian rocks into the Pecos River appears to preclude the movement of large quantities of water toward the vicinity of Hobbs under present-day natural conditions (Spiegel, 1967). Therefore, most of the water of relatively low salinity in the Capitan aquifer in eastern Eddy and western Lea Counties east of Carlsbad probably was emplaced during Cenozoic time prior to the post-Pliocene cutting of the Pecos River.

Because of the incision of the Pecos River, the eastward gradient in the potentiometric surface east of Carlsbad was decreased and eventually reversed in part of the aquifer. The heads in the Capitan aquifer adjusted more rapidly to the new regimen in the Pecos River valley than the surrounding shelf and basin aquifer system because of the relatively higher hydraulic conductivity of the Capitan aquifer. The highly mineralized water in the shelf and basin aquifers east of Carlsbad then began leaking into the Capitan aquifer and, over a long period of time, commingled with the previously emplaced water of relatively better quality to produce the present moderately saline water found in the Capitan aquifer in eastern Eddy County. The water within the 5,000 mg/l isochlore that bends westward to T.20 S., R.34 E. in southern Lea County, New Mexico is probably a remnant of the better quality water that once filled the Capitan aquifer from this point westward to Carlsbad (fig. 26).

Waste water produced from the Cedar Hills, Getty, Barber, and PCA oil fields in Eddy County, New Mexico; Halfway, Teas, Lynch, Wilson, and San Simone oil fields in Lea County, New Mexico; and Hendrick field in Winkler County, Texas, is similar in chemical composition to the water in the adjacent and underlying Capitan aquifer (figs. 19 and 26; and Stripp and Haigler, 1956). Large volumes of water, in relation to the oil production, have been produced from the Yates Formation in these fields. Water quality and other reservoir data suggest that oil has been produced from all these fields under water-drive reservoir conditions. Water produced from the San Andres Limestone and Grayburg Formations in the Hobbs field and from other fields on the northern end of the Central Basin platform also is similar in chemical composition to the water produced from the Capitan aquifer in Lea County, New Mexico (figs. 19 and 26).

The quality of water and reservoir engineering data suggest that the hydraulic communication between the Capitan and shelf aquifers is relatively good at both ends of the Central Basin platform and where the two aquifers are juxtaposed along the margin of the Delaware basin.

Fresh-saline water interface near Carlsbad

The chloride-ion content and specific conductance of the circulated drilling fluid composed of a mixture of air and water was monitored in three wells drilled into the Capitan aquifer near Carlsbad. One well is located approximately 6 miles (10 kilometres) southwest of the city of Carlsbad, another is about 4 miles (6 kilometres) southwest of the city of Carlsbad water field, and the other is located in Happy Valley immediately to the west of Carlsbad. The specific conductivity data was plotted against well depth in figure 27.

The well drilled in sec. 34, T.21 S., R.26 E. was started in dolomite and sandstones in the Tansill Formation and bottomed in the Capitan Limestone. Water with an odor of sulfur was detected in the circulated drilling fluid commencing at a depth of about 760 feet (231 metres). A slight increase in the salinity of the drilling fluid was noted at a depth of 793 feet (242 metres). Comments made by the driller regarding the small amount of water being produced while drilling suggest that the permeability of the section penetrated in this well was very low. A conductivity of 35,850 micromhos per centimeter was measured in a sample of drilling fluid taken while drilling at a depth of 1,217 feet (371 metres).

The saline-fresh water interface was apparently encountered at an unknown distance below a depth of 760 feet (231 metres) and above 1,217 feet (371 metres). The saline-fresh water interface was inferred to be at an altitude of approximately 2,300 feet (700 metres) above sea level from the graph of conductivity versus depth (fig. 27).

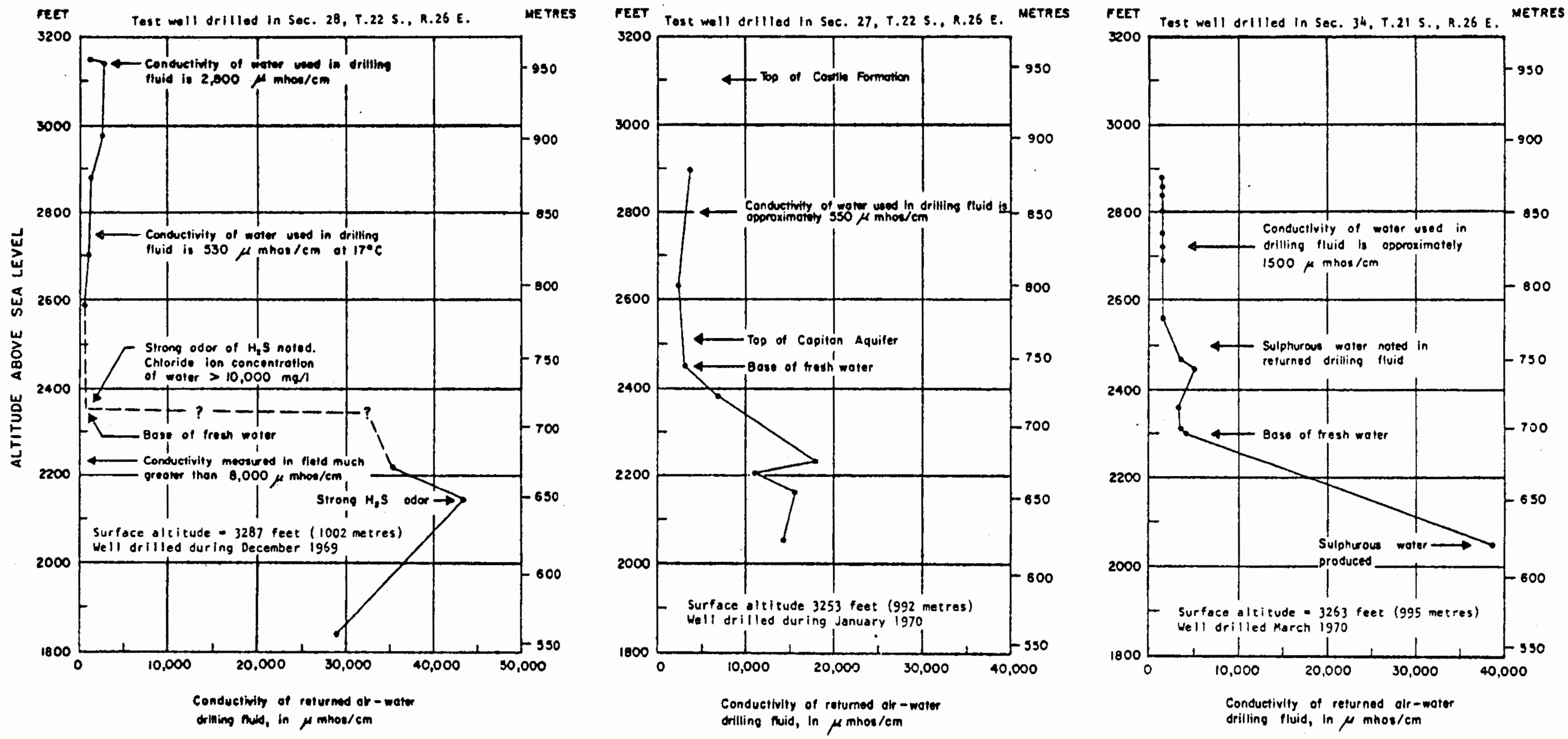


Figure 27.--Diagram showing altitude of the fresh-saline water interface in the vicinity of Carlsbad, New Mexico.

The Capitan Limestone was penetrated at a depth of 745 feet (227 metres) in the well drilled in sec. 27, T.22 S., R.26 E. very near the extreme basinward edge of the Capitan Limestone in Eddy County. A gradual but persistent increase in the conductivity of the returned drilling fluid was noted at a depth of 804 feet (245 metres) suggesting that the base of the fresh water is near an altitude of 2,449 feet (746 metres) at this locality.

Approximately 25 feet (7.6 metres) of alluvium was penetrated before the Capitan Limestone was encountered in the well drilled in sec. 28, T.22 S., R.26 E., a short distance east of the position of the depositional reef crest of the Capitan Limestone. The records from this well are incomplete; however, water containing more than 10,000 mg/l chloride ion was sampled from the returned drilling fluid starting at a depth of 937 feet (286 metres) and continuing to the total depth of 1,455 feet (443 metres). The saline-fresh water interface at this locality is probably just below an altitude of 2,354 feet (718 metres).

The depth to water in the new municipal water field for the city of Carlsbad, located about 4 miles (6 kilometres) southwest of this well (fig. 19), is about 400 feet (122 metres). The altitude of the water table in the city of Carlsbad well field is about 3,100 feet (945 metres). Comparison of the altitudes of the saline-fresh water interface in the well located in sec. 28, T.22 S., R.26 E. with the altitude of the water table in the same area suggests that there is approximately 750 feet (229 metres) of fresh water on top of the saline water in the vicinity of the city of Carlsbad well field.

The volume of water that has moved through the Capitan aquifer during the Cenozoic Era either has been inadequate to completely flush the original saline water from this system, or brines from the lower part of the adjacent shelf and underlying basin aquifers are leaking into the lower part of the Capitan aquifer and mixing with fresh water.

Hydraulic head in aquifers of Guadalupian age

Collection and preparation of data

Efforts were made to locate and collect hydraulic-head data representative of the aquifer head at the time of the discovery or early stages of exploitation of petroleum and the development of water supplies for irrigation in southeastern New Mexico and western Texas.

Water levels for the Roswell Artesian basin were obtained from Fiedler (1926) and Fiedler and Nye (1933) and other records maintained by the U.S. Geological Survey and the New Mexico State Engineer. Water-level measurements in the Carlsbad area were taken from reports published by Hendrickson and Jones (1952) and Bjorklund and Motts (1959). Very few reliable water-level measurements representative of the Permian Guadalupian aquifers during the period 1920 to 1930 were available for the remainder of the project area. In some instances, it was possible to compute reasonable values of head for this period by extrapolating backward from current water-level or pressure measurements by assuming average rates of decline.

Original bottom-hole pressures measured in some of the oil fields on the Central Basin platform and Artesia-Vacuum arch were obtained from the literature (Lea County Operators Committee, 1935-1942; Stipp and others, 1956; Sweeney and others, 1960; Ackers, DeChicchis and Smith, 1930; DeFord and Wahlstrom, 1932; Winchester, 1933; Carpenter and Hill, 1936; and Bates, 1942b). A search of the records kept by the Railroad Commission of Texas in Austin yielded a small amount of information for the southern part of the Central Basin platform. Unfortunately, many of the pressures cited in various reports, particularly those written by geologists, have no reference datum and are therefore virtually meaningless. A few original bottomhole pressure measurements were obtained through the cooperation of individual oil companies. Bottom-hole measurements were not available for many of the oil fields producing from Upper Permian rocks in Eddy County. The shallow wells in these oil fields were often drilled and completed by small operators with cable tool rigs and placed on production without apparent regard to sound engineering practices.

A list of wells in which drill-stem tests had been run in Upper Permian formations was prepared by searching the Permian Basin Well Data System data file. Copies of pressure build-up charts and other data recorded during drill-stem tests were then requested from individual oil companies. Copies of additional drill-stem test charts and records were obtained on microfilm from Petroleum Research Corp., Denver, Colo. Several thousand drill-stem test charts were reviewed during the course of more than a year. The undisturbed reservoir pressure could not be determined by extrapolation from an analysis of the build-up curve in most of the tests because the shut-in time was too brief. Unfortunately, most of the drill-stem test records were examined and discarded as unusable due to either the brief recovery period, borehole damage, or other mechanical malfunctions.

Data from several hundred drill-stem tests were encoded and punched into tabulating cards. The recovery curve was then plotted with the aid of a computer program, and the test evaluated following methods described by Bredehoeft (1965), Johnston Testers (no date), Halliburton Co. (1968), Murphy (1967), Matthews and Russell (1967), and Lynch (1962). A computer program was written to statistically fit the plot of the pressure recovery versus the logarithm of the ratio of the total test time divided by the shut-in period. A large number of drill-stem tests were evaluated in a short amount of time in this manner.

The practice of lengthening the shut-in or recovery period became more common during the late 1950's and early 1960's (Odeh and Selig, 1963). About this same time, the technique of utilizing the drill-stem tool to record the results of two production and recovery periods was adopted. The first brief test period is referred to as "initial" the other test period is relatively long in duration and is referred to as "final." Both tests are accomplished during the same trip into the well with the drill string. Consequently, the percentage of usable reservoir pressure information obtained by the drill-stem test increased enormously. However, by this time, most of the drilling was directed toward evaluation of deeper and older formations and not many of the improved tests were run in reservoirs of Guadalupian age that had not been partially depleted.

The Permian Basin Well Data System file of scout records contains some information describing drill-stem tests that were performed during the drilling and evaluation of an oil or gas test well. Initial and final flow, initial and final hydrostatic, and initial and final shut-in pressures, time periods corresponding to the flow and shut-in phases, and fluid recovery information are generally available. Incremental pressures necessary to evaluate the recovery curve are not available in the scout records.

If pressure equilibrium is reached during the course of a drill-stem test, the final flow and shut-in pressures or initial flow and initial shut-in pressures may be very nearly the same value. A computer program was written to search the drill-stem pressures in the PBWDS file and to detect this condition of repetitive pressures. Initial and final shut-in pressures were compared to one another and to all corresponding flow pressures, and, if the difference between the pressures was less than plus or minus 2 percent of either or both the initial or final shut-in pressures, the complete data set was retrieved from the PBWDS file for further inspection.

More than 2,700 sets of records representing successful drill-stem tests of formations of several geologic ages were retrieved, but only about 10 percent were found to be suitable and applicable to the Permian formations of interest. Most of these pressures were not used in the construction of the potentiometric maps because the tests were taken at times when the oil and gas-bearing reservoirs were partially depleted. This technique does appear to merit the attention of those who may have similar problems but are investigating areas that have not yet been as thoroughly exploited.

Accuracy and reliability of data

Pressure data obtained from drill-stem and bottom-hole reservoir tests are either computed and reported by oil and related service companies or may be calculated from the available pressure-recovery charts. Errors may result from mistakes made in reading and interpreting the records or from inherent mechanical limitations of the equipment, or both. A Bourdon-tube pressure recording device is commonly used in drill-stem tests and also in bottom-hole pressure surveys. Bredehoeft (1965) reports that frequent calibration of this device, plus the use of a microscopic micrometre chart reader, will reduce the gage error to ±1 to ±2 psi (pounds per square inch) (±70 to ±140 gm/cm^2) at pressures as high as 4,000 to 5,000 psi (281,000 to 352,000 gm/cm^2). Manufacturers and service companies claim an accuracy of much less than one percent of the full-scale range of the gage for pressure recorders used after the middle 1950's (Johnston Testers, personal commun., 1967). Prior to this time, a one percent accuracy is claimed for most good tests in the field. Pressures recorded for the aquifers studied in the project area generally range from about 1,500 (105,000 gm/cm^2) to several thousand psi. Errors due to inaccuracies of the relatively modern pressure-recording instruments used in the project area may amount to only a few psi, but an average error for the older instruments may be approximately 25 psi (1,760 gm/cm^2).

Bottom-hole pressure surveys are special pressure tests normally conducted at regular intervals to determine the performance of a reservoir during the production of oil and gas. Some of these tests are associated with proration activities. Many are published or filed with regulating agencies, such as the New Mexico Oil and Gas Conservation Commission and the Railroad Commission of Texas, while others are made and retained by oil companies for internal use. The duration of the normal bottom-hole pressure recovery survey made in the oil fields on the Artesia Vacuum arch and Central Basin platform is generally only 24 to 72 hours. Static equilibrium reservoir pressures apparently are seldom attained during this length of time, and, therefore, the resulting pressure measurements are frequently too low to be even remotely representative of the true formation pressures in this area. In addition, the datum for the reservoir pressure obtained in a bottom-hole pressure survey is often not given, thus negating the possible usefulness of the pressure measured.

Water levels are measured by the U.S. Geological Survey to hundredths of feet. The accuracy of these measurements is probably within a few tenths of feet, and errors due to mechanical difficulties are small, relative to those made with pressure-recording devices.

In view of the type of pressure and hydraulic head data available in the study area, and also in view of the care exercised in the selection and adjustment of this data, it is believed that a contour interval of 100 feet (30 metres) is applicable in the construction of generalized potentiometric maps. This interval is most acceptable in areas encompassing the Capitan aquifer and parts of the San Andres Limestone and the Artesia Group. It is generally acceptable for most of the remaining areas in the study area, and only in a few areas in the Delaware Mountain Group is it considered marginal.

Computation of ground-water head

Complications due to variations in density

The Capitan aquifer and associated formations of Guadalupian age contain water of variable density and quality (fig. 26). Values of head measured in an aquifer must be adjusted to a common datum and corrected for variations in density before relative comparisons between the magnitude of the hydraulic heads can be made (Lusczynski, 1961; Bond, 1972, and 1973; and Bond and Cartwright, 1970). The procedures followed in adjusting the ground-water heads in the aquifers studied are described below.

Review of basic concepts

Ground-water head at a point, such as in a well, is the height of the water column above or below some reference level (commonly mean sea level). This head will vary with the chosen reference level and the type of water in the well and in the aquifer. The relation between ground-water head and the pressure at a point in a well is illustrated in figure 28 and expressed by the hydrostatic equation (Hubbert, 1953, and 1969) as follows:

$$H = p/\gamma + Z$$

where H = ground-water head above (+), or below (-), mean sea level, or other datum, in feet,

p = pressure at a point in a well, in pounds per square foot,

γ = specific weight of the water; it is the weight per unit volume, in pounds per cubic foot, that takes into account the magnitude of the local gravitational force. It is also equal to the product of the fluid density, ρ, and the local gravitational acceleration, g,

Z = distance above (+), or below (-), mean sea level of the point where the pressure is measured; it is the altitude of the pressure point.

This equation shows that the ground-water head is dependent on the point pressure, the reference datum, and the type of water in the well column. The point pressure reflects the internal changes in a ground-water system or aquifer. Heads are adjusted to a horizontal reference level, mean sea level, in this report, so that heads at different wells can be compared in order to determine hydraulic gradient. The height of the column of water above the pressure point is equivalent to p/γ, which is dependent on the type of water in the column.

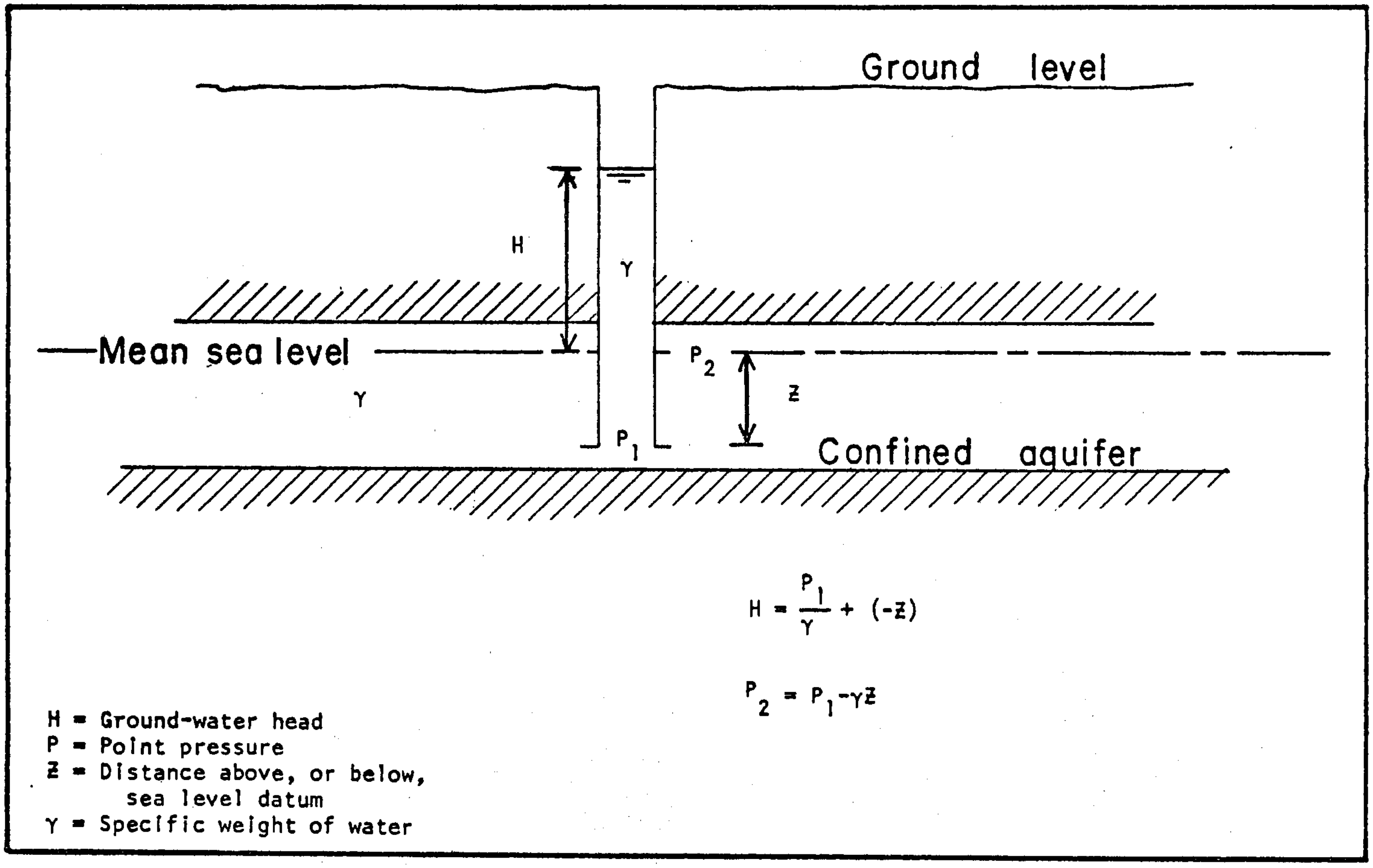


Figure 28.--Diagram showing computation of pressure at a datum.

Point-water head

Pressure at a point in a well tapping an aquifer containing water of variable density may be expressed as a ground-water head which reflects the type of water in the well column. Lusczynski (1961, p. 4247) defined point-water head as the water level, referred to mean sea level or other datum, in a well filled sufficiently with the water of the type at the point to balance the existing pressure at the point. In figure 29 which shows three wells tapping a confined aquifer, H_1 and H_2 are both point-water heads. If γ_1 represents the specific weight of fresh water, then H_1 is a fresh-water head.

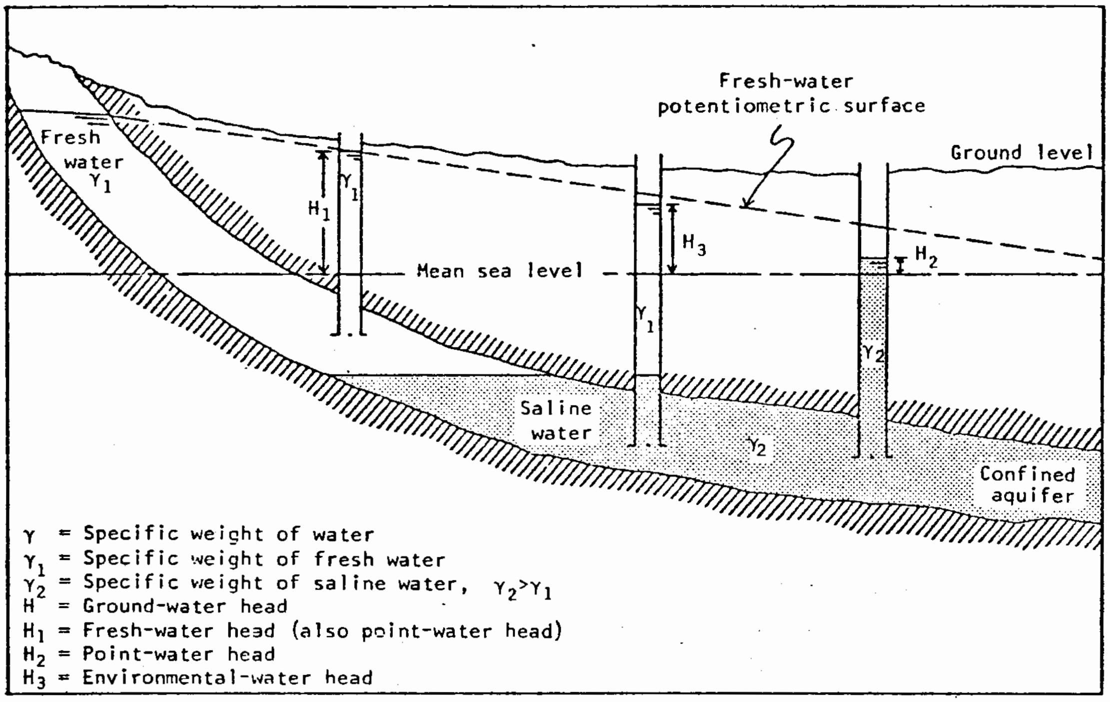


Figure 29.--Diagram showing heads and fresh-water potentiometric surface for confined aquifer containing water of variable density.

Environmental-water head

Environmental water was defined by Lusczynski (1961, p. 4248) as that water between a given point in an aquifer and the top of the zone of saturation. The water may be of constant or variable density and occurs in the environment along a vertical between the given point and the top of the zone of saturation. For confined aquifers the environmental zones may be projected to the vertical well column from points along the aquifer section (fig. 30).

The environmental water head was then defined by Lusczynski as a fresh-water head reduced by an amount corresponding to the difference of salt mass in fresh water and that in the environmental water. The well column of the middle well of figure 29 is filled with the equivalent of the environmental water found in the aquifer at this point. The environmental-water head, H_3, of the middle well in figure 29 is less than the fresh-water head would be at this location.

The fresh-water potentiometric surface shown in figure 29 represents ground-water head as it would be if the aquifer system were full of fresh water only. In later sections of this report the concept of environmental water is used in connection with adjustments of pressure and water-level data for use as fresh-water heads in potentiometric maps (fig. 30). Environmental-water head, which defines gradient along a vertical, i.e., in a well column, was not used.

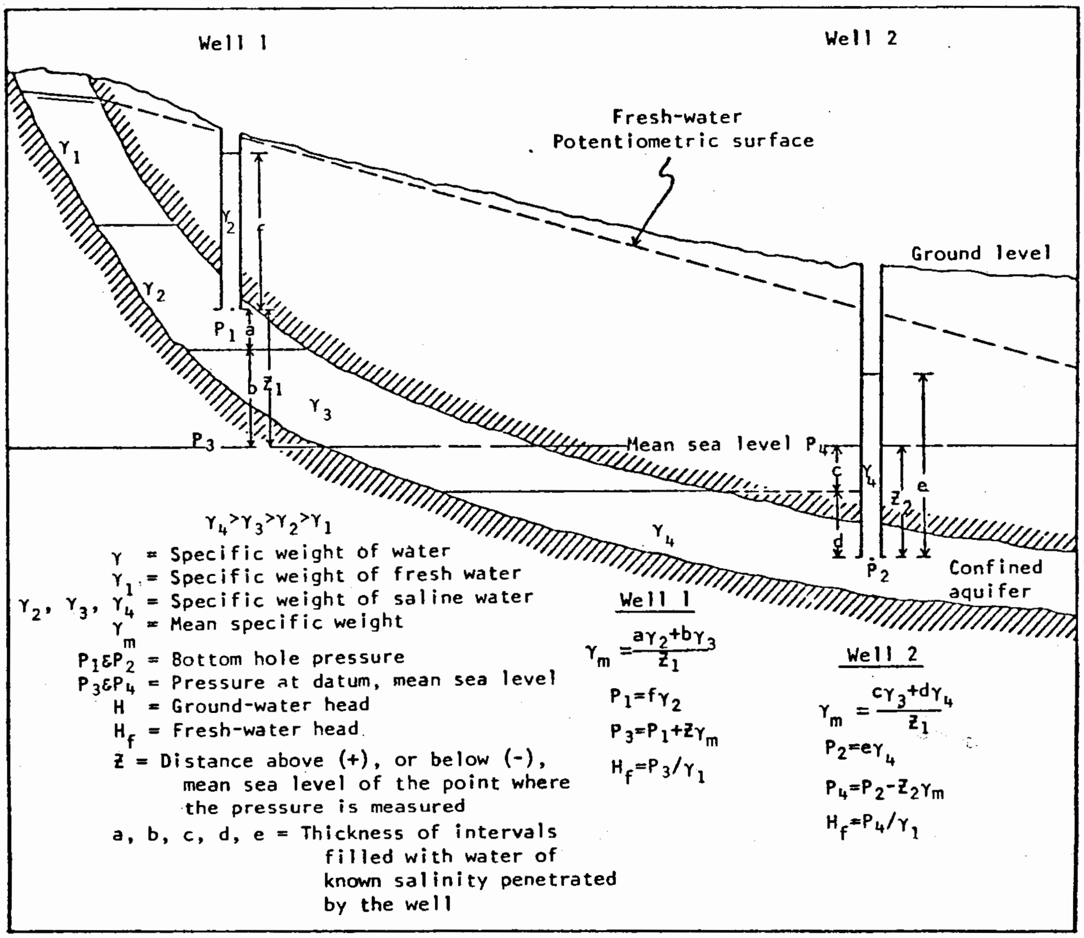


Figure 30.--Diagram showing computation of fresh-water head for wells tapping a confined aquifer containing water of variable density.

Determination of fresh-water head

The head relationship between two hydraulically connected wells tapping the same confined aquifer containing water of variable density is shown in figure 31. The example is simplified by assuming that the point pressures in each well are the same and are located at mean sea level, $Z = 0$. The specific weight, γ_1, of the water in well 1 is assumed to be that of fresh water, and the specific weight of the water in well 2 is assumed to be greater. The ground-water head, H_1 and H_2, in each well is a point-water head. H_1 is also a fresh-water head. If γ_2 is greater that γ_1, then H_1 is greater than H_2. Measurement of water levels in each well, without consideration of the density variations, would result in an erroneous indication of water moving from left to right. Because the pressures at sea level in each well are equal, no movement of water should occur in this illustration. Conversion of the pressure head in the well on the right in figure 31 to a fresh-water head should give a ground-water head equal to H_1. Ground-water heads in aquifers containing water of variable density must be adjusted so they represent ground water of a common density, such as fresh water, before the hydraulic gradient can be determined.

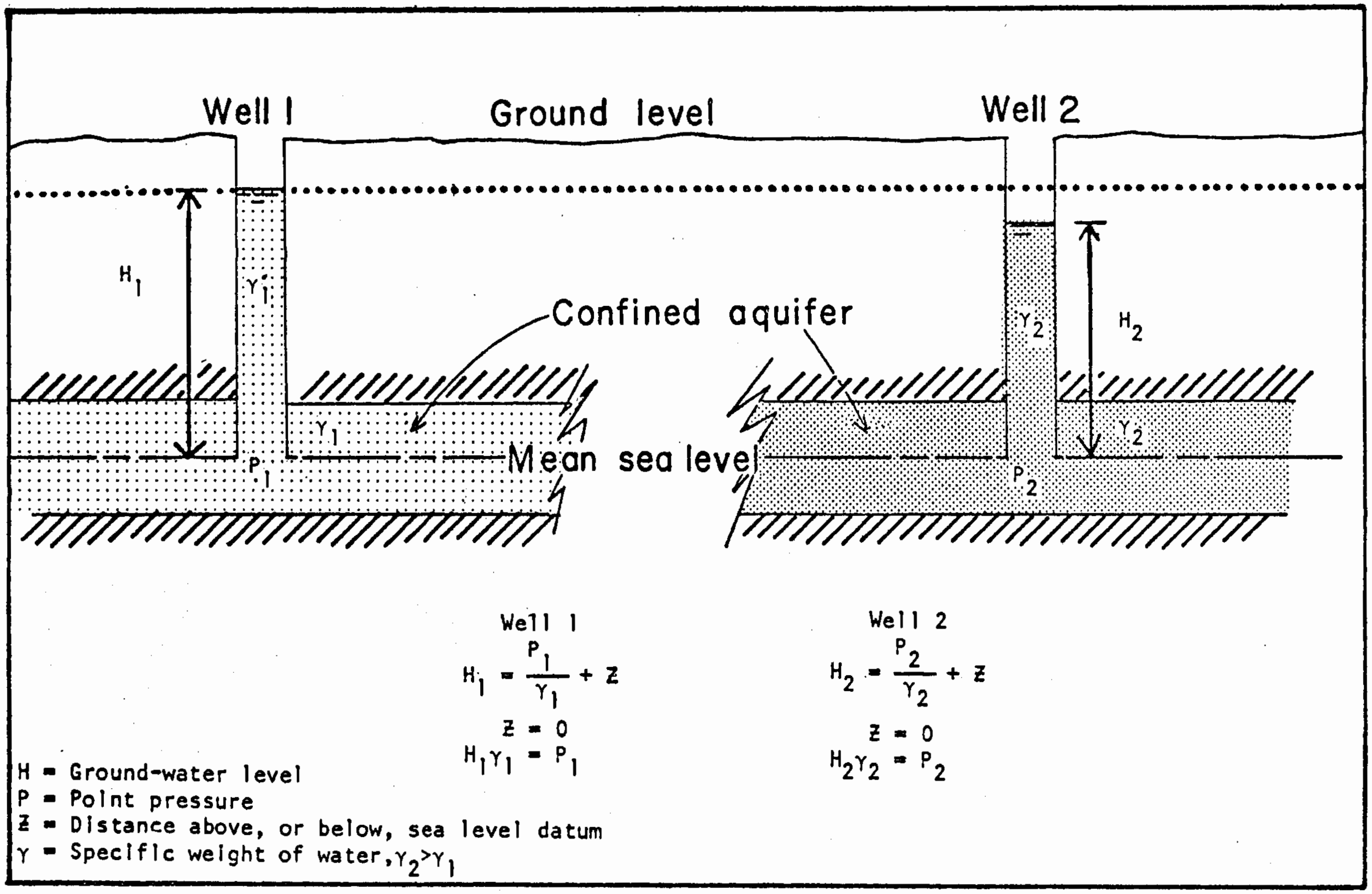


Figure 31.--Diagram showing head relationships in wells tapping a confined aquifer containing water of variable density.

When only water levels in the wells of an example similar to that of figure 31 are available, the average density of the water in each well column must be known before fresh-water head and hydraulic gradient can be computed. The possibility of error in comparison of ground-water heads without an adjustment for density becomes greater with increased variation of density. If the pressure at a horizontal level common to each well is known, no density data are needed for hydraulic gradient computations, provided that the density of the water in the interval between the level common to the wells and the datum does not vary. However, this is a condition which rarely occurs over wide areas in the field.

The condition illustrated in figure 28 is encountered more often. In this case, the pressure at sea level, p_2, must be computed using the bottom-hole pressure, p_1, and the average density of the environmental water in a vertical column, Z. Once p_2 is known, a fresh-water head from the common datum may be computed. If only the water level in the well is known, the average density of the water in the well column from the water level to uppermost perforation and the environmental-water density from column Z must be known in order to compute the fresh-water head with reference to sea level. This example has been simplified by making the specific weight of the water in the well column and the environmental water in the Z column the same. In many cases, this is not so. Frequently, an approximation of the average specific weight of water must be made, because vertical variations in density in the environmental water are complex and sometimes may preclude assignment of a valid average density from the available data.

In the example of figure 28, consideration of the environmental water is limited to within the confined aquifer, because the Z factor is similarly limited. This section of water is only a fraction of the total environmental water, which extends in the aquifer to the top of the zone of saturation in the outcrop area in one direction and to other levels in the opposite direction until it discharges from the aquifer. In some field cases, the datum (and resulting distance, Z) may be above the top or below the bottom of the confined aquifer, and the environmental water which should be considered may extend laterally for great distances. Extensive variations in the water density may further complicate the problem.

A simplified example where variations in density extend laterally is shown in figure 30. The computation of fresh-water head will depend on several factors which may be difficult to determine in the field. If the values of γ_1, γ_2, γ_3, γ_4, a, b, c, d, e, p_1, and p_2, are considered known or determinable, the values for the sea-level pressures, p_3 and p_4, can be computed and with these, the fresh-water heads. The determination of the average density (γ_m) for the environmental water within each distance, Z, is an intermediate step. Determination of the sea-level pressure depends on γ_m, the average density of the environmental water and p_1 or p_2, the bottom-hole pressure. The pressures p_1 and p_2 may be determined from a bottom-hole pressure gage or from the water level and density of the water in the well column ($p_1 = f\gamma_2$ and $p_2 = e\gamma_4$). Geologic and quality-of-water information may be available to make approximations of the other factors, but complex variations in both density and space distribution of density zones may be difficult to treat. In general, the larger the distance, Z, and the greater the magnitude of density variation, the greater the errors will be in the computation of fresh-water head in this and similar examples.

The computation of hydraulic gradient in a system of variable density is valid only if there is a viable hydraulic communication throughout an aquifer system. Hydraulic communication may exist between two of more characteristically dissimilar aquifers, and it may be possible to treat a series of aquifers as one. If such is the case, the preceding principles concerning adjustment of head data should apply to a multiaquifer system containing water of variable density. However, hydraulic communication between aquifers is largely a matter of degree, which is a function of the diffusivity and the transmissivity in an unsteady state. Correct interpretation of this degree of communication is essential before valid comparison of ground-water head in different aquifers can be made. Fortunately, because the hydraulic conductivities in the shelf and basin aquifers are much smaller than is the Capitan aquifer, the hydraulic communication is relatively slight and, for this reason, the Capitan aquifer could be regarded as a single entity.

The examples given above illustrate the head relationship in confined aquifers containing water of variable density. The same general principles relating head, pressure, and density of water apply to unncconfined or water-table systems.

Adjustment of head

The Capitan basin, and shelf aquifers of Permian Guadalupian age contain water of variable density. Most of these aquifers within the project area generally are confined by extensive thicknesses of relatively impermeable material such as shale, sandstones, salt, and anhydrite. The outcrops or recharge regions of the Guadalupian age aquifers are generally northwest, west, and south of the Delaware basin. Because of the density variation in the water contained in these aquifers, the procedures described previously were adopted in adjusting all the head data that was used in constructing potentiometric maps.

Variation in the density of water

Several thousand analyses of the water produced from formations of Permian Guadalupian age throughout the area were collected from oil and related service companies and from producing wells whenever possible. The chloride-ion concentrations of representative analyses have been plotted and interpreted in a map depicting the lowest chloride-ion concentration expected to be found in the water produced from an area (fig. 26). The relationship between the chloride-ion concentration and density of the water was determined statistically and found to be almost linear. Therefore, a map showing the variation in density of the ground water in the same strata was not prepared. A close approximation of the variation in density is given by relating the chloride-ion concentration shown in figure 26 to density. The densities used in adjusting the point-water heads to fresh-water heads were obtained by first visually selecting the representative chemical quality of the environmental water from figure 26. The relationship between chloride ion and density was then used to estimate the average density.

Typical ranges of density found in the strata of Permian Guadalupian age are illustrated in two simplified and diagrammatic stratigraphic profiles (figs. 32 and 33). The section shown in figure 32 extends from the outcrops of the Delaware Mountain Group in the Delaware Mountains of Culberson County, Texas, across the Delaware basin through the Capitan aquifer into the shelf sedimentary rocks near the middle of the Central Basin platform in Ector County, Texas. The largest contrast in the densities of water in these strata is encountered along the western margin of the Central Basin platform where the relatively dense brines of the Delaware Mountain Group are in juxtaposition with the relatively low salinity water in the Capitan aquifer.

A highly diagrammatic longitudinal profile of the Capitan aquifer, as it extends from the Guadalupe Mountains southwest of Carlsbad, around the northern and eastern margins of the Delaware basin to outcrops in the Glass Mountains southwest of Fort Stockton, is illustrated in figure 33. Fresh water rests on saline water in the Capitan aquifer in the vicinity of the Guadalupe and Glass Mountains. The water with the greatest density in the Capitan aquifer is found in eastern Eddy County. However, the density of the poorest quality water found in the Capitan aquifer is less than the density of the water in all the adjacent surrounding rocks with the exception of the water in the San Andres Limestone on the northern and southern ends of the Central Basin platform.

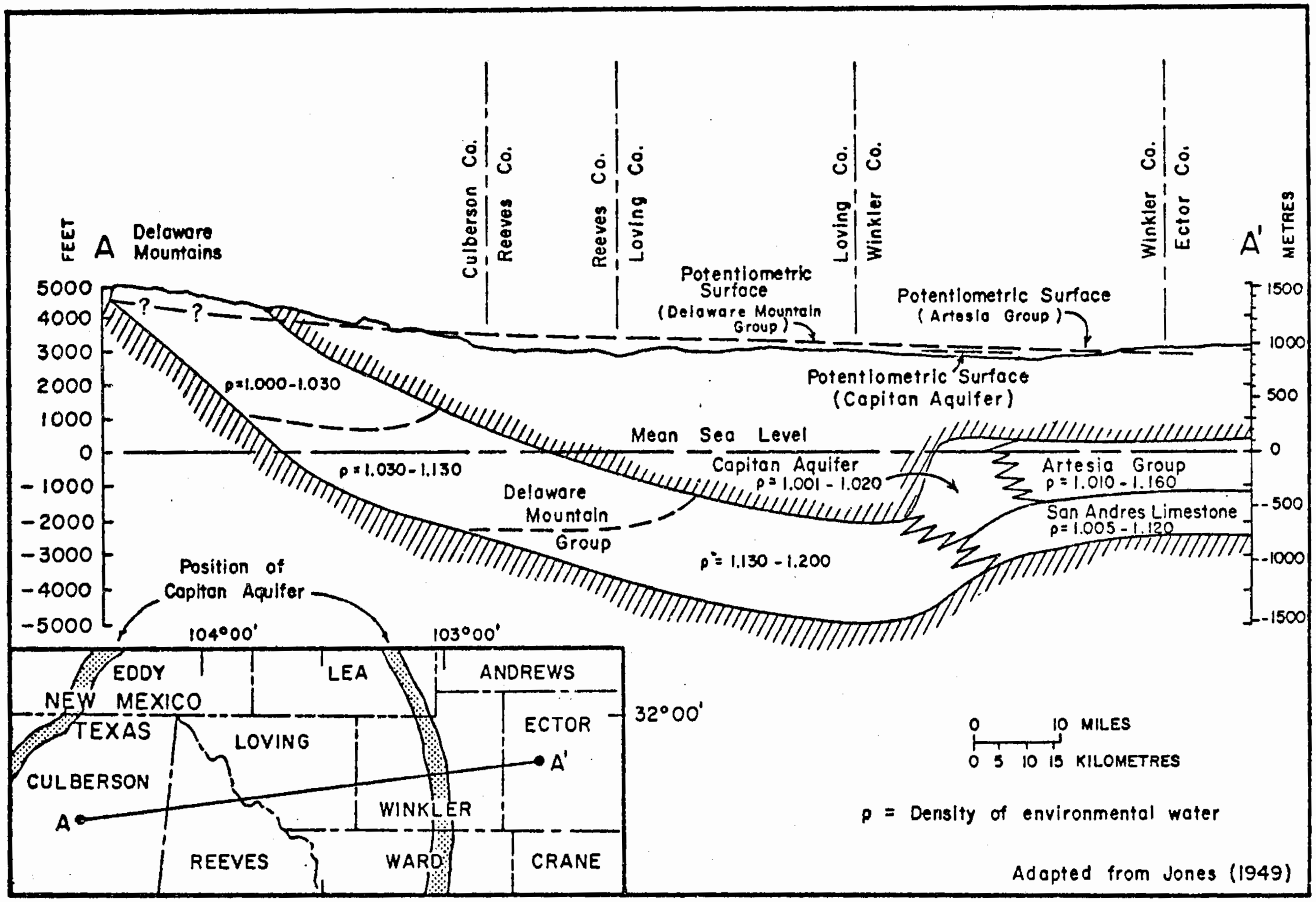


Figure 32.--Diagrammatic profile of Capitan and associated aquifers across western Texas showing pre-oil-discovery potentiometric surfaces and variation in the density of the ground water.

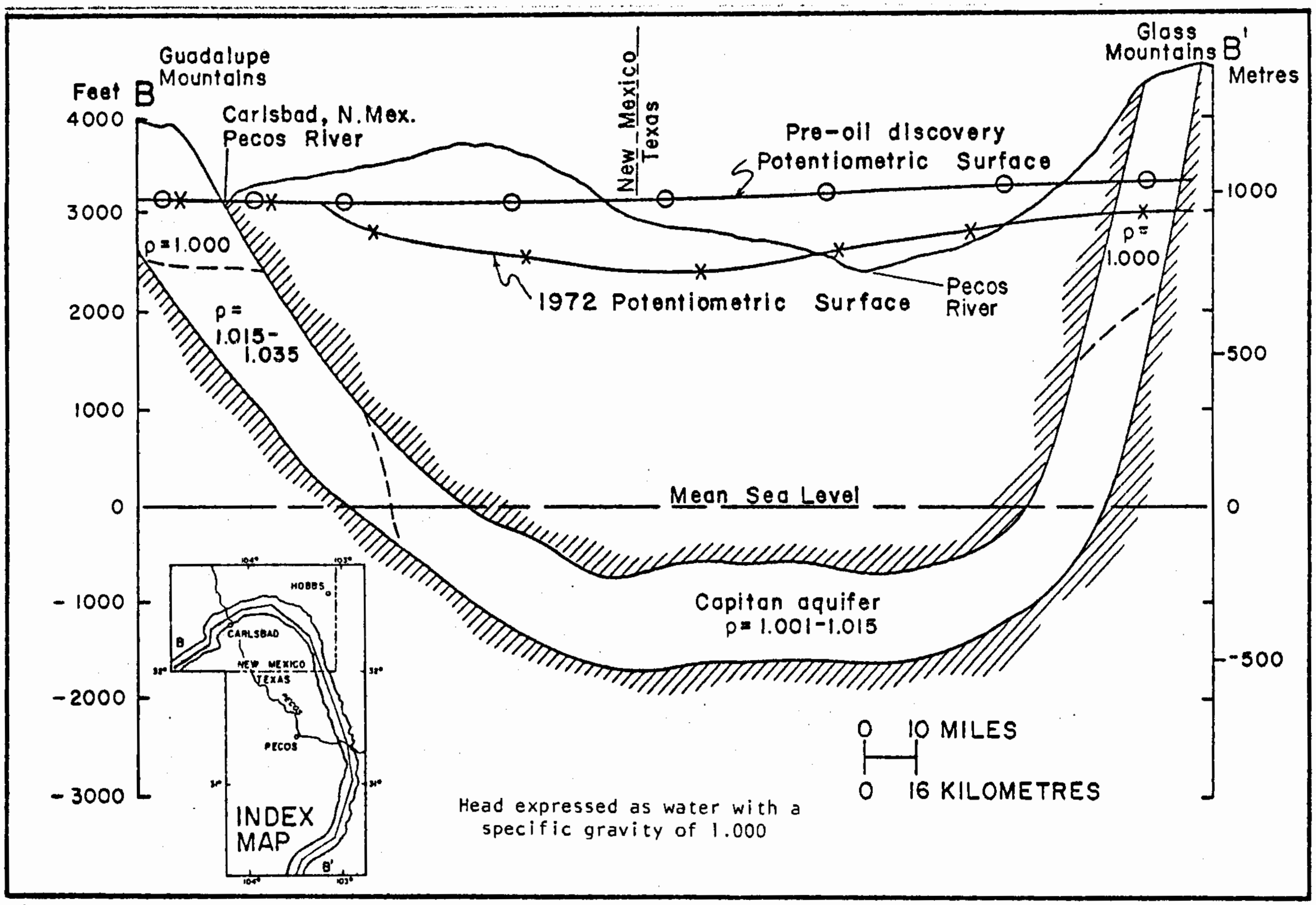


Figure 33.--Diagrammatic profile of Capitan aquifer showing potentiometric surface and variation in density of the ground water.

Adjustment of pressure data

Within the study area, most of the important head data were obtained from oil companies as unadjusted bottom-hole and drill-stem test pressures. This type of pressure-head data is convenient to work with because it can be expressed in terms of the desired density of water. For purposes of computing hydraulic gradient, the available point pressures were first adjusted to pressures at a sea level datum, and then expressed as fresh-water heads. The following precedure was adopted for handling point pressures within the project area.

(1) The altitude of the pressure point within the well column was determined. Essentially, the distance, Z, between the pressure point and sea level was determined.

(2) An average specific weight, γ_m, of the environmental water within the aquifer section equivalent to the distance, Z, is determined from the distribution of the chemical quality of the water in the various aquifers.

(3) The sea-level pressure, p_2, is computed from the point pressure, p_1, by:

$$p_2 = p_1 + [\gamma_m(\pm Z)]$$

Z is negative if the pressure point is below sea level and positive if the pressure point is above sea level.

(4) The fresh-water head, h_f, is then computed using p_2 and the specific weight of fresh water, γ_f

$$h_f = p_2/\gamma_f$$

Adjustment of water-level data

During the course of the study, several abandoned oil and gas test wells completed in the Capitan aquifer were secured for use as observation wells. Depth to water in these wells is measured and recorded continuously by water-level sensing instruments. The water in the fluid column in some of the wells is not representative of the environmental water in the aquifer. For example, the specific gravity of the water in the fluid column of one observation well is 1.115 but the specific gravity of the environmental water is 1.018. The following equation from Hiss (1973) was used to compute fresh-water head from water-level measurements in the observation wells:

$$h_f = r_1 (E_{1s} - D_p) + r_2 (D_p - D_w)$$

where

h_f = fresh-water head, in feet, above mean sea level

r_1 = specific gravity of the environmental water in the aquifer (dimensionless)

r_2 = specific gravity of the water in the well column (dimensionless)

E_{1s} = altitude of land surface, in feet, above mean sea level

D_p = depth to top of perforated well section, in feet, below land surface

D_w = depth to the non-representative water in well, in feet, below land surface

This equation relates fresh-water head directly to the parameters associated with observation-well data. It is also possible to determine the bottom-hole point pressure, p, at the perforated interval with the equation, $p = [(r_2)\ (62.5)\ (D_p - D_w)]$. This pressure then may be adjusted to sea-level pressure and converted to fresh-water head as outlined previously.

Fresh-water heads computed for water levels measured on January 1, 1973, for eachh of the observation wells completed in the Capitan aquifer, are shown in table 10 along with the supporting data. The location of the wells is shown in figures 5, 24, and 25. The maximum difference in fresh-water head between the five observation wells located in the immediate vicinity of Carlsbad, and the Pecos River is only 5 feet (1.5 metres).

The fresh-water head computed for the Yates State 1 observation well, located in sec. 32, T.20 S., R.30 E., approximately 15 miles east of Carlsbad, is 3,133 feet (955 metres) above sea level and ranges from 8 to 12 feet (2.4 to 3.7 metres) lower than the heads computed for the five wells nearer to Carlsbad. This difference in head suggests that a slight eastward hydraulic gradient of less than a foot per mile exists east of Carlsbad. However, errors made in estimating the density of the environmental water in the aquifer could easily account for these differences in head. Differences in head determined over a relatively long period of time, i.e., several decades, would appear to be a better indicator to use to definine changes to the gradient in the potentiometric surface for the Capitan aquifer in the vicinity of and immediately east of Carlsbad where the differences in head are small.

Table 10.--<u>Fresh-water head in Capitan aquifer observation wells</u>

Symbols	r_2	D_p	D_w	E_{ls}	a	r_1	h_f
Observation wells	Average specific gravity of water in fluid column	Depth to uppermost perforation adjusted to the land surface datum, feet (metres)	Depth to water Jan. 1, 1973, feet (metres)	Altitude of land surface, feet (metres)	Distance of point-pressure or equivalent above (+) or below (-) sea level datum, feet (metres)	Average specific gravity of representative environmental water in the aquifer	Fresh-water head on Jan. 1, 1973 above mean sea level feet (metres)
City of Carlsbad Well 10	1.000[a/]	Open-hole completion	400 (122)	3,502 (1,067)	+3,102 (+945)	1.014	3,145 (959)
City of Carlsbad Well 13	1.000	289 (88)	21 (6)	3,122 (952)	+2,833 (+863)	1.014	3,141 (957)
North Cedar Hills Unit 1	1.020	990 (302)	196 (60)	3,280 (1,000)	+2,290 (+698)	1.018	3,141 (957)
Humble State 1	1.032	1,538 (469)	160 (49)	3,230 (984)	+1,692 (+516)	1.018	3,145 (959)
City of Carlsbad Test Well 3	1.012	630 (192)	94 (29)	3,182 (970)	+2,552 (+778)	1.020	3,145 (959)
Yates State 1	1.030	2,223 (678)	323 (98)	3,365 (1,026)	+1,142 (+348)	1.030	3,133 (955)
Hackberry Deep Unit 1	1.115	3,726 (1,136)	639[b/] (195)	3,397 (1,035)	- 329 (-100)	1,030	3,103 (946)
Middleton Federal B 1	1.020	2,913 (888)	614 (187)	3,518 (1,072)	+ 605 (+184)	1.016	2,960 (902)
South Wilson Deep Unit 1	1.010	4,169 (1,271)	1,124 (343)	3,717 (1,133)	- 452 (-138)	1.010	2,619 (798)
North Custer Mountain Unit 1	1.030	4,451 (1,357)	936 (285)	3,387 (1,032)	-1,064 (-324)	1.008	2,548 (777)
Federal Davison 1	1.109	4,252 (1,296)	1,198 (365)	3,355 (1,023)	- 897 (-273)	1.005	2,485 (757)
Southwest Jal Unit 1	1.106	4,199 (1,280)	844 (257)	2,985 (910)	-1,214 (-370)	1.005	2,491 (759)

a/ estimated

b/ adjusted for oil at top of water column

Reliability of computed fresh-water head

The fresh-water heads computed for the Capitan and associated aquifers depend largely on the determination of a representative value for the average specific gravity of the environmental water that encompasses an aquifer section equivalent to Z, the distance of the pressure point above or below the sea-level datum. The larger the distance, Z, the greater the need for a more precise determination of the average specific gravity of the environmental water.

The magnitudes of the errors that may be introduced into the computation of fresh-water heads for various aquifers due to erroneous estimates of specific gravities of environmental water are tabulated in table 11. Sets of Z factors for each aquifer group have been selected to represent the averages for the low and high ranges found in the field.

For each set of Z factors, three possible magnitudes of error in assigning specific gravity have been computed. The first represents the maximum error expected if the environmental water is erroneously considered to be fresh and adjustments for variation in specific gravity are not made; the second represents what can be considered to be a large error that could result from the incorrect determination of an average specific gravity from the environmental water data available for this study area; and the third value represents an average error, certainly not the minimum possible, but an error in computation of head believed to be consistent with the type, quantity, and quality of information available for the three aquifers.

Table 11.--Magnitude of possible errors in computing fresh-water head for the Capitan and associated aquifers due to incorrect estimates of the specific gravity of environmental water

Aquifer	Z factor, the distance of the pressure point above, or below, sea level, in feet (metres)	Error in estimating specific gravity of environmental water	Error in computed[1/] fresh-water head, in feet (metres)
Capitan aquifer	400 (122)	0.03	12 (3.7) E
	400 (122)	.01	4 (1.2) L
	400 (122)	.005	2 (.6) A
	1,000 (305)	.03	30 (9.1) E
	1,000 (305)	.01	10 (3.0) L
	1,000 (305)	.005	5 (1.5) A
	2,000 (610)	.03	60 (18.3) E
	2,000 (610)	.01	20 (6.1) L
	2,000 (610)	.005	10 (3.0) A
	3,000 (915)	.03	90 (27.4) E
	3,000 (915)	.01	30 (9.1) L
	3,000 (915)	.005	15 (4.6) A
Basin aquifer (Delaware Mountain Group)	1,500 (457)	0.16	240 (73.2) E
	1,500 (457)	.05	75 (22.9) L
	1,500 (457)	.02	30 (9.1) A
	2,500 (762)	.16	400 (121.9) E
	2,500 (762)	.05	125 (38.1) L
	2,500 (762)	.02	50 (15.2) A
Shelf aquifer (Chalk Bluff and Bernal facies of the Artesia Group and San Andres Limestone)	300 (91)	0.16	48 (14.6) E
	300 (91)	.03	9 (2.7) L
	300 (91)	.01	3 (.9) A
	1,000 (305)	.16	160 (48.8) E
	1,000 (305)	.03	30 (9.1) L
	1,000 (305)	.01	10 (3.0) A
	2,000 (610)	.16	320 (97.5) E
	2,000 (610)	.03	60 (18.3) L
	2,000 (610)	.01	20 (6.1) A

1/ General magnitude of error indicated by E=extreme, L=large, and A=average

The potential for error in the fresh-water heads computed for the Capitan aquifer is greatest in the vicinity of Carlsbad because of the large distance of the point pressures above sea level (Z factor) and the very rapid change in the specific gravity of the environmental water in the Capitan aquifer. Within a span of approximately 25 miles (40 kilometres) extending westward from the eastern boundary of Eddy County, New Mexico, the Z factor increases from about 300 feet (91 metres) below to approximately 3,000 feet (915 metres) above sea level. Approximately 750 feet (230 metres) of fresh-water overlies saline water in the Capitan aquifer southwest of Carlsbad.

As shown in figures 26 and 33, the water in the Capitan aquifer becomes progressively more saline east of the Pecos River near Carlsbad until a maximum salinity is reached in eastern Eddy County. The average specific gravity of the environmental water in the Capitan aquifer changes from 1.014 southwest of Carlsbad and the Pecos River valley to at least 1.035 in eastern Eddy County. Errors of 10 to 30 feet (3 to 9 metres) can be expected in the values of the computed fresh-water heads in this area. Larger errors of 30 to 90 feet (9 to 27 metres) would result if the heads were unadjusted for the variation in specific gravity. Errors made in computing the fresh-water head for the Capitan aquifer elsewhere should be relatively small due to the small Z factor, the generally small amount of variation in the specific gravity of the water in the aquifer, and the relatively low specific gravity of the water.

The water in the shelf and basin aquifers is much more saline and correspondingly denser than water in the Capitan aquifer. Errors of several hundred feet would result if the heads in the Delaware Mountain and Artesia Groups and the San Andres Limestone were to be compared to heads in the Capitan aquifer without adjusting for the differences in the specific gravity of the environmental water. The potential for large errors is greatest along the northern and eastern margins of the Delaware basin and in other areas where both the Z factor and the contrast in specific gravity between the waters in the different aquifers are large (fig. 32 and table 11). Errors in the value of fresh-water head computed for the shelf and basin aquifers can be expected to range from 10 to 50 feet (3 to 15 metres) where data are adequate for control of interpretations and from 30 to 125 feet (9 to 38 metres) where data are sparse.

The density of the water in the San Andres Limestone at both ends of the Central Basin platform is similar to that in the Capitan aquifer. The magnitude of the errors made in computing fresh-water heads for the San Andres Limestone in these areas should be quite small.

Movement of water in aquifers of Guadalupian age

Construction of potentiometric surface maps

Reliable pressure-head and water-level data were adjusted to fresh-water heads for the purpose of constructing potentiometric surface maps representing the early and late-development conditions in the aquifer systems (figs. 22 and 23). A potentiometric surface represents hydraulic head in an aquifer, and the general direction of ground-water movement is inferred to be normal to the illustrated head contours.

A considerable amount of subjective judgment was used in contouring the data. In general, two factors, (1) the year in which the head was measured, and (2) and the reliability of the data, were weighed in considering each data point. The pressures and water levels were measured at various dates scattered over a period of about 40 years. The earliest available data were used in the construction of the predevelopment potentiometric surface, and the latest data were used for the postdevelopment potentiometric surface. Fluid levels measured in water wells were generally considered to be more reliable than pressure data. Initial oil field bottom-hole pressures were usually considered to be more reliable than pressure determined from the analysis of drill-stem tests.

In many instances, where data representing values of the head under natural conditions forty to fifty years ago were unavailable; a value of a head was computed by extrapolating backward from the available head data using assumed rates of decline. Values of head determined for Leonardian and Ochoan age aquifers were occasionally used as supplementary information in areas where data for the Guadalupian age aquifers were inadequate or unavailable. The relatively large differences in hydraulic conductivities of the shelf, Capitan, and basin aquifers were a factor that was considered when contouring the potentiometric surface maps.

Predevelopment potentiometric surface

Definition

The regional potentiometric surface, representing hydraulic head prior to the extensive development of oil, gas, and water in the Capitan and associated aquifers, is shown in figure 22. The contours on this map depict the approximate values of head during the early 1920's and are highly interpretative in areas where there is little control. A longitudinal profile of the potentiometric surface for the Capitan aquifer also is shown on figure 6.

Basin aquifers

Aquifers in the Delaware Mountain Group are naturally recharged at outcrops in the Delaware, Guadalupe, Apache, and Glass Mountains and from leakage downward through younger rocks in areas where the soluble Ochoan evaporites have been removed in the western and southern parts of the Delaware basin (Brown, Rogers, and Baker, 1965, pl. M-7 and M-9).

The hydraulic head in the basin aquifers is in excess of 3,900 feet (1,190 metres) above sea level in the southern part of the Guadalupe Mountains and the Delaware Mountains, but declines to less than 3,200 feet (975 metres) along the northeastern, eastern, and northern margins of the Delaware basin. Water in the basin aquifers flows very slowly northward and northeastward under a gradient of 25 to 40 feet per miles (1 to 5 m/km) from the vicinity of White City along the Guadalupe Mountains toward a potential trough or low northeast of Carlsbad where the water slowly discharges upward into the overlying Capitan and shelf aquifers and laterally into the intertonguing San Andres Limestone. Water entering the Capitan aquifer moves southwestward and eventually is discharged into the Pecos River through Carlsbad Springs. Some of the water that enters the shelf aquifers may move eastward toward Hobbs.

The head differential between the basin aquifers and the Capitan aquifer ranges from more than 800 feet (245 metres) at White City to less than 100 feet (30 metres) at Carlsbad. The head in the basin aquifers is always greater than the corresponding head in the Capitan aquifer at any location along the margin of the Delaware basin. The large differences in head reflect the great differences in the hydraulic conductivities of the two aquifer systems.

The fresh-water heads computed from drill-stem pressures measured in the shelf and basin aquifers during 1956-1960 in the vicinity of the Eddy-Lea County boundary reflect some of the head loss resulting from production of oil, gas, and waste water during the preceding 30 years. Isopotentials for the basin aquifer in this area are based solely on the known relationships between the shelf and basin aquifers, the relatively recent head measurements, and the assumed rates of head loss, because no other information is available. A sharply defined ground-water divide appears to have been present in both the basin and shelf aquifers in the vicinity of the Eddy-Lea County boundary prior to the exploitation of the oil and gas reserves in this area (fig. 22). The shelf and basin aquifers are separated into two distinct ground water regimens by this divide, one controlled by the Pecos River at Carlsbad, the other by the regional drainage to the Gulf of Mexico.

Elsewhere, water in the basin aquifer moves very slowly across the Delaware basin to the northeast and east under gradients ranging from less than 4 to as much as 15 feet per mile (1 to 3 m/km) and discharges into the laterally equivalent San Andres Limestone and Artesia Group along the margins of the Delaware basin or upward into the overlying Capitan aquifer. Beds of the Delaware Mountain Group extend shelfward and intertongue with the San Andres Limestone and the lower part of the Artesia Group shelfward of the Capitan aquifer. The hydraulic characteristics of the shelf and basin aquifers are very similar and the two aquifer systems appear to respond to stresses in a like manner. Along the margins of the Delaware basin, the heads in both the shelf and basin aquifers are represented by the same isopotential contours on figure 22 because differences in head between the two aquifer systems cannot be distinguished with the control available.

The basin aquifers in the western part of the Delaware basin contain water of relatively better quality due to the replacement of original brines by relatively less saline water over a long period of geologic time (fig. 26). Most of the oil fields with production from the Delaware Mountain Group are located in the northeastern two-thirds of the Delaware basin in areas where the produced water is relatively saline compared to other areas upgradient. Migration and entrapment of petroleum in the Delaware Mountain Group also may have been influenced by the slow movement of water through the basin aquifers within the Delaware basin (Hiss, 1975a).

Movement of substantial quantities of water from the basin aquifers upward into the younger Cretaceous and Cenozoic aquifers in the Balmorhea-Pecos-Loving trough is impeded by the beds of anhydrite in the Castile Formation.

Shelf aquifers

Over a long period of years, gypsum and anhydrite have been dissolved and removed from the Chalk Bluff facies of the Artesia Group west of the Pecos River at Carlsbad by circulating ground water. The hydraulic conductivity of these sedimentary rocks was originally very low but has been greatly increased by dissolution of the evaporites.

Bjorklund and Motts (1959) and Motts (1968) have mapped the potentiometric surfaces of two perched water-bearing zones formed by relatively impermeable sandstones in the evaporite facies of the Yates and Queen-Grayburg Formations of the Artesia Group in the foot-hills of the Guadalupe Mountains southwest of Carlsbad. These surfaces are several hundred feet higher than the potentiometric surface for the San Andres Limestone, the principal aquifer in the same area. Water perched above sandstones in the Queen-Grayburg Formations discharges as springs into arroyos that are tributaries of the Pecos River. The water perched above sandstones in the Yates Formation moves to the northeast and apparently either discharges into the Pecos River or flows into the potentiometric low northeast of Carlsbad. Water reaching the potential low eventually moves downward into the Capitan aquifer and flows toward discharge points on the Pecos River near Carlsbad.

According to Bjorklund and Motts (1959) and Motts (1968), water in the San Andres Limestone southwest of Carlsbad moves northeastward and drains into the Roswell basin. However, contours of the potentiometric surface of the same shelf aquifer prepared for a larger area (fig. 22) suggest that most of this water moved generally northeastward and eastward toward the low in the potentiometric surface northeast of Carlsbad. Water moving into this low must commingle with water contributed by the intertonguing basin aquifers and then move upward into the Capitan aquifer to eventually be discharged as spring flow into the Pecos River at Carlsbad.

The head in the San Andres Limestone west of White City is approximately 800 feet (245 metres) higher than the head in the Capitan aquifer. The head differential illustrates the relatively poor communication between the shelf and Capitan aquifers.

Data obtained from Fiedler and Nye (1933), Fisher (1906), and others suggest that water in the San Andres and Grayburg aquifers west of Artesia moved eastward under a gradient that ranged from 8 to 25 feet (1.5 to 5 m/km). The evaporites and some of the carbonate material in both the Chalk Bluff facies of the Artesia Group and the evaporite facies of the San Andres Limestone have been dissolved and removed by circulating ground water that moved the relatively short distance from the surface exposures west of Artesia and Carlsbad to the vicinity of the Pecos River. Consequently, the original saline water in the San Andres and Grayburg aquifers everywhere west of the Pecos River has been flushed to an unknown depth and replaced with potable water (Hood, Mower, and Grogin, 1960). Simultaneously, the hydraulic conductivity of the San Andres and Grayburg aquifers has been greatly increased.

The regional flow of water in the shelf aquifers east of the Pecos River between Carlsbad and Roswell is probably toward the east and southeast, similar to that shown by Spiegel (1967). A similar conclusion is not so readily apparent from a potentiometric-surface map of the San Andres Limestone prepared by McNeal (1965, fig. 6). The contours of head depicted by McNeal appear to be influenced by declines caused by the production of petroleum and associated waste water from many oil fields on the Central Basin platform and Artesia-Vacuum arch. Water in the shelf aquifer in the area between the Pecos River and the boundary between Lea and Eddy Counties moves slowly toward the southwest. Some of this highly mineralized water probably flowed into the Pecos River between Artesia and Lake McMillan prior to the lowering of the potentiometric surface by large withdrawals of water for irrigation. Most of the water moves toward the potentiometric low northeast of Carlsbad under an average gradient of about 15 feet per mile (3 m/km). Water moving in response to the gradient developed by the potentiometric low eventually flows upward or laterally into the Capitan aquifer and then discharges into the Pecos River at Carlsbad.

The potentiometric surface slopes eastward with a gradient of about 25 feet per mile (5 m/km) from the axis of the ground-water divide located a few miles west of the Eddy-Lea County boundary. Control for the ground-water divide in the basin and shelf aquifers is provided by several values of head greater than 3,200 feet (975 metres) above sea level determined in relatively recent drill-stem tests. These pressures initially may have been somewhat higher because they have probably been influenced by head losses resulting from the production of oil, gas and water from oil fields and the withdrawal of water from the Capitan aquifer during the forty years preceding the measurements.

Water moving northward in the Capitan aquifer from the Glass Mountains apparently was discharged into the shelf aquifer along the juxtaposition of the two aquifers between Jal and a point northwest of Eunice, N. Mex. (figs. 22 and 26). Most of the water flowed into the San Andres Limestone, in preference to other strata, because of the higher hydraulic conductivity of this aquifer. Water in the shelf aquifers probably moved generally southeastward across the northern part of the Central Basin platform between Eunice and Hobbs. The water moved northeastward from the Capitan aquifer into the shelf aquifers, then east and south within the shelf aquifers to a central area located about 15 miles (24 kilometres) southwest of Hobbs. The water then apparently moved eastward from Hobbs and Eunice under a regional gradient of about 25 feet per mile (5 m/km). The widely spaced contours southwest of Hobbs (fig. 22) also suggest that the transmissivity of the rocks comprising the shelf aquifers in this area is much higher than in the surrounding areas.

Water in the shelf aquifer on the Central Basin platform in Texas appears to move generally eastward under a gradient ranging from 8 to 25 feet per mile (1.5 to 5 m/km). The wider spacing of the head contours in the vicinity of Fort Stockton suggests that the transmissivity of the shelf aquifer is relatively high on the southern end of the Central Basin platform (fig. 4). The relatively good water in the shelf aquifer and, in particular, the San Andres Limestone, supports this conclusion (fig. 26).

Capitan aquifer

Stratigraphically, the Capitan aquifer is adjacent to, and partly enclosed by, the basin and shelf aquifers. Because of the position and the relatively higher transmissivity, it functions either as a drain or as a source of water for the shelf and basin aquifers, depending on the relative differences in head between the aquifers.

The Capitan aquifer crops out in the Guadalupe Mountains southwest of Carlsbad and in the Glass Mountains southwest of Fort Stockton. Water in the Capitan aquifer is under water-table conditions southwest of the Pecos River at Carlsbad. Artesian conditions prevail from the pecos River at Carlsbad around the northern and eastern margins of the Delaware basin to the vicinity of the Glass Mountains southwest of Fort Stockton. Northeast of the Glass Mountains, the change from artesian to water-table conditions probably takes place near the border between Pecos and Brewster Counties, but the exact location is not known.

Water entering the Capitan aquifer in the Guadalupe Mountains moved northeastward under a gradient of about 1 to 2 feet per mile (1.2 to .4 m/km) toward Carlsbad. After reaching Carlsbad, most of this water then discharged through Carlsbad Springs into the Pecos River.

Head data representative of the period prior to development, and production of water from the Capitan aquifer, are not available for a large area east of Carlsbad. The ground-water heads in this regimen are controlled by the Pecos River, which acts as a drain for the Permian aquifers in hydraulic communication. A slight westward gradient of a few feet per mile on the potentiometric surface has been interpreted as representative for the early 1920's (fig. 22). Heads developed in the Carlsbad area shortly after relatively good hydraulic communication between the Pecos River and the Capitan aquifer established during the headward erosion of the Pecos River are probably also represented by the interpretation.

The magnitude of the ground-water divide, representative of the predevelopment period in the Capitan aquifer in the vicinity of the Eddy-Lea County boundary, is unknown. However, the rate of decline of head in the Capitan aquifer has been determined with a high degree of precision for a 6-year period (figs. 24 and 25; and table 8). Crude but useful estimates of original heads can be made by extrapolating backward in time using assumed rates of head decline based on the recent observations and other fragmentary records gathered over a period of about 40 years.

A rate of decline of 20 feet per year (6 m/yr) has been recorded in the Middleton Federal B 1 observation well, sec. 31, T.19 S., R.32 E. Using this rate of decline, a head of about 3,300 feet (1,005 metres) was computed for the Capitan aquifer at the Eddy-Lea County boundary during 1956. This is comparable to heads measured in the shelf and basin aquifer systems in the same vicinity. The water level in the Hackberry Deep Unit 1 observation well, sec. 31, T.19 S., R.31 E., has declined at a relatively consistent rate of 0.318 feet per month (.097 m/month) over a 6 year period. A head of about 3,175 feet (968 metres) can be projected back to 1956 by assuming that this rate of head decline in this well is valid for the preceding 10-year period.

Leakage from both the shelf and basin aquifers is a source of the water required to maintain the ground-water divide in the Capitan aquifer. The ground-water regimen west of the divide is completely different from that to the east. Evidence suggesting these differences are provided by the recorded behavior of head in the aquifer (figs. 24 and 25) and the chemical quality of water in the aquifer (fig. 26). Leakage into the Capitan aquifer west of the ground-water divide is quickly released to the nearby Pecos River. The magnitude of the extrapolated possible hydraulic head for the predevelopment period in the Capitan aquifer in the vicinity of the Eddy-Lea County boundary is additional evidence that suggests that the Capitan aquifer in this area has an extremely low transmissivity compared to the aquifer characteristics on either side of the divide.

Water in the Capitan aquifer on the east side of the ground-water divide moved eastward toward a point northwest of Eunice, where it then flowed into the San Andres Limestone and other formations in the Artesia Group as noted above. The eastward flow of water in the Capitan aquifer, after the establishment of the Pecos River at Carlsbad, could have been maintained only by leakage from the shelf and basin aquifers.

Projections based on rates of decline, computed from water levels measured in a few wells in southwestern Pecos County, Texas suggest that the head in the Glass Mountains was more than 3,300 feet (1,005 metres)--probably near 3,400 feet (1,035 metres)-above sea level in the 1920's. Prior to development of production of water for industrial purposes, water in the Capitan aquifer moved northward from the Glass Mountains toward New Mexico under an average gradient of 2.5 feet per mile (.5 m/km) or less. Some of this water moved eastward from the Capitan aquifer into the San Andres Limestone and Artesia Group before reaching a point west of Fort Stockton. The remainder of the water in the Capitan aquifer appears to have moved to the north end of the Central Basin platform without significant losses to the adjacent shelf aquifers. In New Mexico, water moved from the Capitan aquifer into the San Andres Limestone, primarily, but also into other formations within the Artesia Group, and then flowed eastward into Texas.

The predevelopment potentiometric and chloride-ion concentration maps (figs. 22 and 26, respectively) suggest that the majority of the water found in the Capitan aquifer along the western margin of the Central Basin platform originated in the Glass Mountains. Only a small amount of the water in the Capitan aquifer in Lea County appears to have been derived from the Carlsbad area after the Pecos River cut down into a position where it was in hydraulic communication with the Capitan aquifer.

Postdevelopment potentiometric surface

Definition

The regional potentiometric surface, representative for the Capitan, basin, and shelf aquifers, after extensive development of oil, gas, and water within the project area, is shown in figure 23. The contours depicting a generalized regional fresh-water head for the basin and shelf aquifers are considered representative of the period 1960-70. The generalized head contours for the Capitan aquifer are considered representative of the latter part of 1972. A longitudinal profile of the postdevelopment potentiometric surface in the Capitan aquifer is also shown on figure 6.

Basin aquifers

The regional potentiometric surface for the basin aquifers apparently has changed only slightly during the period 1920 to 1970. Heads in the Delaware Mountain Gronup have been reduced by a small amount in the vicinity of Carlsbad, probably due to continued upward leakage into the Capitan and shelf aquifers.

The potentiometric surface has probably been lowered by an unknown amount along the eastern margin of the Delaware basin in response to the increased head differential between both the Capitan and shelf aquifers and the basin aquifers. In addition, the potentiometric surface of the basin aquifers has been depressed very sharply over the local areas surrounding oil fields completed in the Delaware Mountain Group. Heads are often below sea level in the local depressions and are not shown on this generalized regional potentiometric surface.

Interpretation of the data shown on the pre and postdevelopment potentiometric maps (fig. 22 and 23) suggests that the head in the basin aquifers has declined approximately 100 feet (30 metres) during the period 1920 to 1970 in the vicinity of the ground-water divide immediately west of the Eddy-Lea County boundary. The decline in head is probably due to the increased leakage upward into the Capitan aquifer in response to the lowering of the potential in that aquifer and the general regional head loss in the basin and shelf aquifers caused by the production of oil, gas, and water from these reservoirs.

Shelf aquifers

The potentiometric surface west and south of Artesia has been lowered generally less than 100 feet (30 metres) as a result of the withdrawal of water from the Roswell artesian basin for irrigation purposes during the period 1906 to 1969 (Fisher, 1906; Fiedler, 1926; and Fiedler and Nye, 1933). The potentiometric surface for the shelf aquifers west and southwest of Carlsbad probably has not changed significantly, although information is inadequate for any exact determination of the changes.

Reservoir pressures in several of the shelf aquifers on the Artesia-Vacuum arch east of the Pecos River have been reduced to minor fractions of the original pressures as a result of the exploitation of the petroleum. Head data representative of a regional potentiometric surface for the shelf aquifers in this area were generally unavailable because of the complex reservoir conditions created by the production of oil, gas, and water simultaneous with the injection of water. The problem is further complicated by the varying degree of hydraulic communication between the many different reservoirs and zones in this area from which oil and gas are produced.

Nearly all the oil on the Artesia-Vacuum arch is produced from reservoirs under solution gas drives. Therefore, the pressures in nearly all of the exploited reservoirs have declined very rapidly and are now extremely low. However, there are several areas where pressures have been artifically increased by injection of water in secondary recovery programs (New Mexico Oil and Gas Association, 1966; and New Mexico Oil and Gas Engineering Committee, 1950-1958, 1959, and 1960-1970). The regional potentiometric surface east and southeast of Artesia, but west of the ground water divide near the Eddy-Lea County boundary is estimated to have been lowered by approximately 150 feet (45 metres) due to withdrawal of oil, gas, and water during the 45-year period from 1925 to 1970 (fig. 23).

The hydraulic head in the shelf aquifers in the vicinity of the ground-water divide near the Eddy-Lea County boundary has declined approximately 100 feet (30 metres) over a period of about 45 years (figs. 22 and 23). Part of this decline in head may be attributed to the increased leakage downward and laterally into the Capitan aquifer, where the potential has been lowered due to production. The regional head loss in the basin and shelf aquifers also has been caused by the production of oil, gas, and associated waste water from these reservoirs.

No attempt has been made to map the complex potentiometric surface of those units of the shelf aquifers not in measurable hydraulic communication with the Capitan aquifer on the eastern part of the Artesia-Vacuum arch in Lea County. The potentiometric surface representative of the reservoirs within the shelf aquifers that appear to be in reasonably good hydraulic communication with the Capitan aquifer has been lowered from 100 to more than 600 feet (30 to 180 metres) in an area north and west of Eunice in southern Lea County.

Hydraulic gradients east of the axis of the predevelopment ground-water divide at the Eddy-Lea County boundary have been increased from about 25 feet per mile to about 40 feet per mile (5 to 8 m/km) by the withdrawal of fluids from the many oil and water fields in this area and in Texas downgradient to the east. A slight westward shift in the ground-water divide is suggested by comparing the predevelopment potentiometric surface map to the post-development map (figs. 22 and 23). An eastward gradient of about 2.5 feet per mile (0.5 m/km) has been induced in an area southwest of Hobbs, where the predevelopment potentiometric-surface gradients (fig. 22) were formerly ill-defined.

The direction of water movement in the shelf aquifers west and south of Eunice has changed from east to southeast. The direction of movement in the shelf aquifers on the northern part of the Central Basin platform may eventually be reversed in response to continual and (or) increased withdrawal of water from the Capitan aquifer. Water will then move westward from the shelf aquifers into the Capitan aquifer.

The regional postdevelopment potentiometric surface of the shelf aquifers has not been mapped south of Jal due to the complex nature of the system. Bottom-hole pressure data were available from various engineering reports describing the oil fields on the Central Basin platform. However, very few of the pressures reported were measured in a reservoir under near equilibrium conditions. The aquifer head in some of the oil field reservoirs has apparently been lowered below sea level. These effects have not spread very far into surrounding areas due to the very low transmissivity of the shelf aquifers.

Capitan aquifer

Aquifer head in the Capitan aquifer in the vicinity of Carlsbad is principally controlled by the Pecos River. Other than small head fluctuations due to variations in climatic conditions, the general configuration of the potentiometric surface in the Capitan aquifer between Carlsbad and White City has not changed from 1920 to 1972.

Under present-day conditions, a small amount of water moves east of Carlsbad during short periods of heavy rainfall in the Guadalupe Mountains or high streamflow-stages of the Pecos River. However, any water moving eastward into the Capitan aquifer under these conditions of increased head at Carlsbad behaves as bank storage and appears to return to the Pecos River as spring flow within a period of a few months (fig. 24).

A comparison of the postdevelopment and predevelopment potentiometric surfaces indicates that the aquifer head has been lowered approximately 150 feet at the predevelopment ground-water divide located in the vicinity of the Eddy-Lea County boundary. The head in the Capitan aquifer has declined in response to the withdrawal of water from the Capitan aquifer in southern Lea County, New Mexico, and Winkler and Ward Counties, Texas. The production of oil, gas, and water from reservoirs in measurable hydraulic communication with the Capitan aquifer also has contributed to the total decline in head.

The westward hydraulic gradient between the Pecos River at Carlsbad and the Eddy-Lea County boundary has been progressively reduced and, in places, reversed during the 45-year period preceding 1973. The ground-water divide inferred at the Eddy-Lea County boundary in the predevelopment potentiometric surface map has been removed. An apparent westward gradient of about 0.7 foot per mile (0.13 m/km) between the City of Carlsbad Well 13, on the east bank of the Pecos River, and the City of Carlsbad Test Well 3, about 6 miles (10 kilometres) east of the Pecos River, was computed for heads measured on January 1, 1973 (fig. 24 and table 10). Eastward hydraulic gradients for the same period have been computed between other observation wells as follows: between the City of Carlsbad Test Well 3 and the Yates State 1, 1.3 feet per mile (0.25 m/km); between the Yates State 1 and a point 6 miles (10 kilometres) south of the Hackberry Deep Unit 1, 6 feet per mile (1.1 m/km); and between the Hackberry Deep Unit 1 and the Middleton Federal B 1, 24 feet per mile (4.5 m/km) (fig. 24 and table 10).

These gradients were computed using relative differences between the fresh-water heads in the observation wells. Errors made in estimating the density of the environmental water in the Capitan aquifer could easily account for the difference of 12 feet of head (3.7 metres) over the 15 mile (24 kilometre) distance between the Pecos River and the Yates State 1 observation well. The average eastward gradient of less than 1 foot per mile (0.189 m/km) between the Pecos River and the Yates State 1 observation well is not supported by declines in the water level in the Yates State 1 well for the period of record.

Therefore, it appears that the hydraulic gradient in the Capitan aquifer for a distance of at least 15 miles (24 kilometres) east of Carlsbad cannot be defined with accuracy sufficient to permit calculation of the movement of ground water in the aquifer. Diversion of significant quantities of water from the Pecos River at Carlsbad into the Capitan aquifer should be indicated more reliably by (1) sustained declines in the water levels in the Yates State 1 and City of Carlsbad Test Well 3 observation wells, and (2) an increase in the rate of decline in the water level now being observed in the Hackberry Deep Unit 1 well (fig. 24).

A small amount of saline water probably was discharged from the Capitan aquifer in eastern Eddy County westward into the Pecos River at Carlsbad prior to exploitation of water and petroleum in southeastern New Mexico and western Texas. The reduction or reversal of the westward hydraulic gradient has probably decreased or eliminated any contribution of saline water to the flow of the Pecos River from the Capitan aquifer east of Carlsbad.

Although the data are inadequate for accurate control, the head in the Capitan aquifer in the vicinity of the Eddy-Lea County boundary appears to have been reduced slightly more than the heads representative of the shelf and basin aquifers. Leakage from the shelf and basin aquifers is not sufficient to maintain a comparable head in the Capitan aquifer, primarily because of the relatively low hydraulic conductivities in the shelf and basin aquifers. The head differential between the shelf and basin aquifers and the Capitan aquifer can be expected to increase rapidly because of the continued withdrawal of water from water fields in New Mexico and Texas, and the production of oil, gas, and waste water from reservoirs in measurable hydraulic communication with the Capitan aquifer. The differences between the heads on both sides of the zone of restricted transmissivity in the vicinity of the Eddy-Lea County boundary can also be expected to increase (fig. 24).

Approximately 90 percent of the total water produced from the Capitan aquifer east of the Pecos River at Carlsbad was withdrawn from water fields in Winkler and northern Ward Counties, Texas. Very large volumes of waste water are also produced from reservoirs that are in good hydraulic communication with the Capitan aquifer in the Hendrick oil field near Kermit, Texas. During a 45-year period more than twice as much water has been produced from the Hendrick field as a waste by-product as has been produced from the water fields supplying water to secondary recovery projects. The regional center of pumping for the entire Capitan aquifer system east of the Pecos River at Carlsbad is located a few miles west of Kermit, Tex. (fig. 23), where the potentiometric surface for the Capitan aquifer has been lowered about 700 feet (215 metres) during a period of approximately 45 years. The effects of pumping have spread from this center southward through the Capitan aquifer to the Glass Mountains, where the potentiometric surface has declined an estimated 300 feet (90 metres) and northward to the vicinity of the boundary between Eddy and Lea Counties, New Mexico, where the potentiometric surface has declined an estimated 150 feet (90 metres) (figs. 22 and 23).

The relationship of the withdrawal of fluid from oil and water fields in Winkler County and vicinity to the decline in head in the Capitan aquifer is shown in figure 34. The several increases in the rate of decline suggested by the limited data probably coincide with increases in production of water for use in secondary recovery projects.

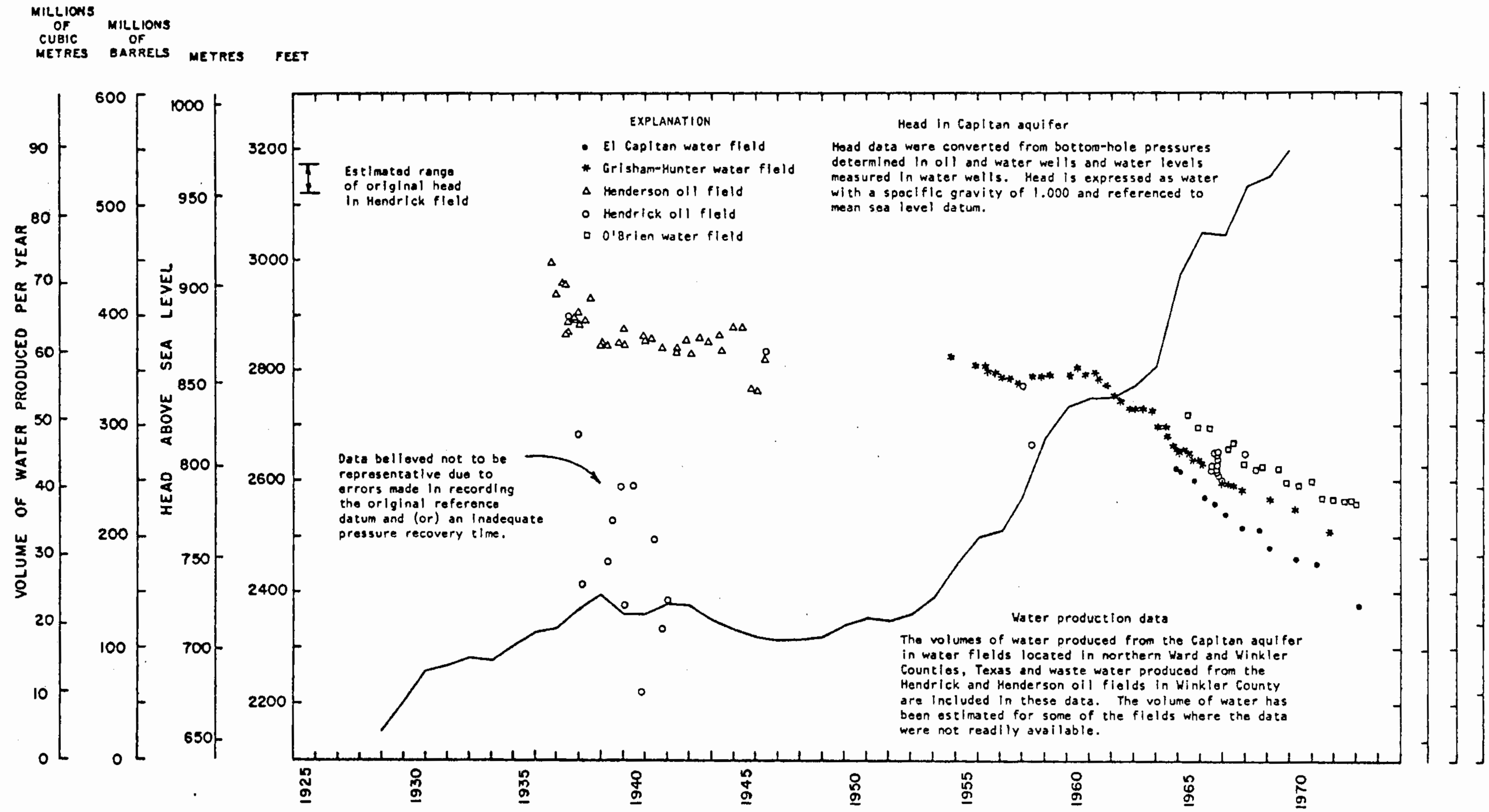


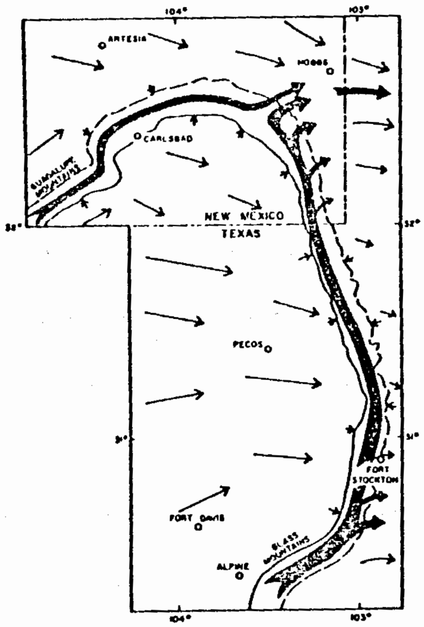
Figure 34.--Graph showing relationships between head and the production of ground water in Ward and Winkler Counties, Texas.

An average hydraulic gradient of approximately 10 feet per mile (2 m/km) has been induced in the potentiometric surface of the Capitan aquifer between Kermit and the boundary between Eddy and Lea Counties. The gradient is about 25 feet per mile (5 m/km) near the Eddy-Lea County boundary but diminishes very rapidly to about 6 feet per mile (1.2 m/km) along the western margin of the Central Basin platform in southern Lea County, New Mexico. The average hydraulic gradient between Kermit and the Pecos-Brewster County boundary is about 7.5 feet per mile (1.4 m/km).

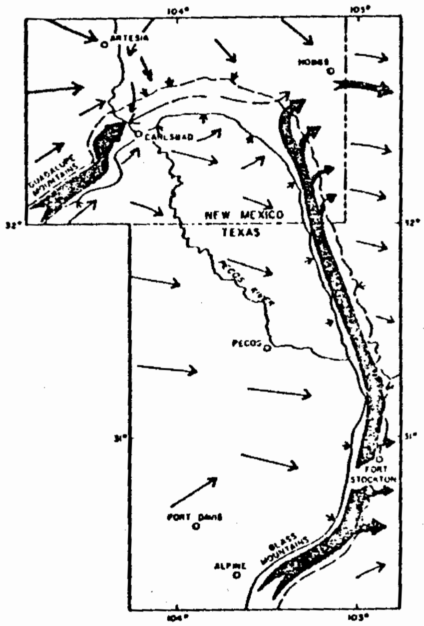
The water produced from the Capitan aquifer probably was derived primarily from storage under water-table conditions in the Glass Mountains and, secondarily, from a decrease in artesian pressure in Pecos, Ward, and Winkler Counties, Texas, and southern Lea County, New Mexico.

Evolution of ground-water regimens

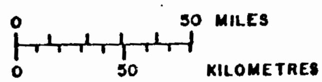
During the latter part of the Cenozoic Era the movement of ground water through the rocks of Permian Guadalupian age in southeastern New Mexico and western Texas has been controlled or influenced by the following: (1) the regional and local tectonics; (2) the evolution of the landscape; (3) the relative transmissivities of the various aquifers; (4) the amount of recharge; and (5) the exploitation of the petroleum and ground-water resources in the last 5 decades (fig. 35).



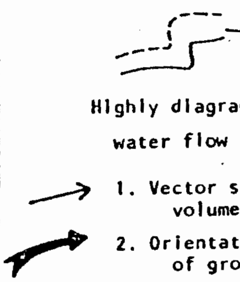
A. Regimen principally controlled by regional tectonics prior to development of the Pecos River.



B. Regimen influenced by erosion of Pecos River at Carlsbad downward into hydraulic communication with the Capitan aquifer.



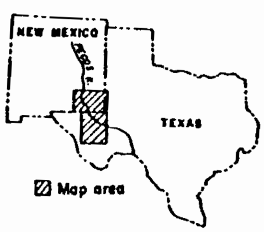
EXPLANATION



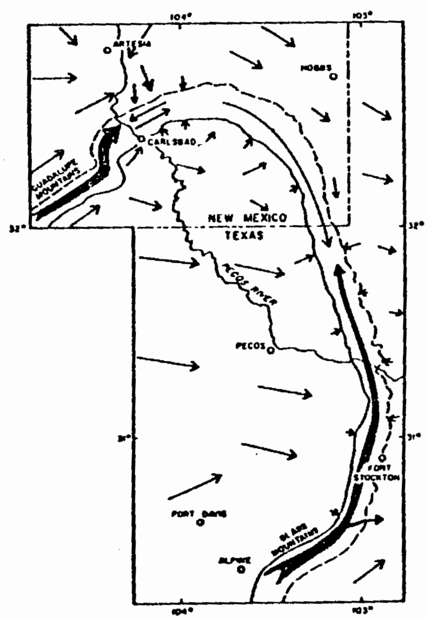
Capitan aquifer

Highly diagrammatic ground-water flow vectors:

1. Vector size indicates relative volume of ground-water flow.
2. Orientation indicates direction of ground-water movement.



INDEX MAP



C. Regimen influenced by both communication with the Pecos River at Carlsbad and the exploitation of ground-water and petroleum resources.

Figure 35.--Diagrammatic maps depicting the evolution of ground-water regimens in strata of Permian Guadalupian age in south-eastern New Mexico and western Texas.

Regimen principally controlled by regional tectonics

The flow of ground water through the shelf, basin, and Capitan aquifers after the uplift of the Guadalupe and Glass Mountains but prior to the excavation of the Pecos River valley at Carlsbad is shown diagrammatically in figure 35 "A". The three aquifer systems were recharged by water originating as rain or snowfall on the outcrops along the western margin of the Delaware basin. Evidence of major surface drainage within the Trans-Pecos area of southeastern New Mexico and western Texas has not been reported.

Ground water moved generally eastward and southeastward through the shelf and basin aquifers under a gradient of probably only a few feet per mile toward natural discharge areas along streams draining to the ancestral Gulf of Mexico. Water entering the Capitan aquifer in the Guadalupe Mountains moved slowly northeastward and then eastward along the northern margin of the Delaware basin to a point southwest of present day Hobbs. Here it joined and commingled with a relatively larger volume of ground water moving northward from the Glass Mountains along the eastern margin of the Delaware basin. From this confluence, the ground water was discharged from the Capitan aquifer into the San Andres Limestone, where it then moved eastward across the Central Basin platform and Midland basin eventually to discharge into streams draining to the Gulf of Mexico.

Regimen influenced by erosion of Pecos River at Carlsbad

Some time after deposition of the Pliocene Ogallala Formation, perhaps early in Pleistocene time, the headward cutting of Pecos River extended westward across the Delaware basin to the exposed soluble Ochoan beds. It then turned northward following this natural weakness in the sedimentary rocks to pirate the streams draining to the east from the Sacramento and Guadalupe Mountains (Plummer, 1932; Bretz and Horberg, 1949b; and Thornbury, 1965). As the excavation of the Pecos River valley progressed, the hydraulic comunication with formations of Guadalupian age gradually increased until the Pecos River functioned as an upgradient drain. Eventually, the hydraulic gradients in the shelf, basin, and Capitan aquifer were reversed along the eastern side of the Pecos River valley, and ground water that formerly flowed eastward was diverted westward as spring flow into the Pecos River (fig. 35 "B"). Water recharged to the same aquifers in the Guadalupe Mountains began to follow the shorter path to springs in the Pecos River. Many of the solution features observed in the Guadalupian age sedimentary rocks west of the Pecos River near Carlsbad probably were initiated during this period.

Movement of water eastward into the Capitan aquifer from the Guadalupe Mountains toward Hobbs was decreased by the lowering of the hydraulic head along the Pecos River. At the same time, a trough in the potentiometric surface of the shelf and basin aquifers began to develop east of Carlsbad, and water began to drain into the Capitan from the surrounding sedimentary rocks. Meanwhile, ground water continued to move northward from the Glass Mountains in the Capitan aquifer toward a point of discharge into the San Andres Limestone southwest of Hobbs. This part of the aquifer was unaffected by the cutting of the Pecos River valley across the Delaware basin and the Central Basin platform.

Regimen influenced by exploitation of ground-water and petroleum resources

Regionally, the movement of ground water in the shelf and basin aquifers east of the Pecos River at Carlsbad has changed very little as a result of the exploitation of ground water and petroleum during a period of approximately 50 years (fig. 35, "C"). Locally, however, the movement of ground water within these same aquifers is controlled by the effects of the numerous producing oil fields in the area.

The shape of the regional potentiometric surface representative of the hydraulic head in the Capitan aquifer east of the Pecos River at Carlsbad has been changed significantly in response to withdrawal of both ground water and petroleum during the past 50 years. The westward movement of saline water from the Capitan aquifer in Eddy County east of Carlsbad into the Pecos River has been greatly diminished or eliminated by a reduction in hydraulic head.

Similarly, the movement of water in the San Andres Limestone and Artesia Group eastward across the northern part of the Central Basin platform from New Mexico into Texas has been decreased. Eventually, the movement of water probably will be reversed. Water may be diverted from the San Andres Limestone and Artesia Group westward from Texas back toward Hobbs and then into the Capitan aquifer along the western margin of the Central Basin platform. The effects of exploitation of the ground-water and petroleum resources will continue to be the dominant factor influencing the movement of ground water in the Capitan aquifer for many years into the future.

Response of the Capitan aquifer to stresses

Water-level records

Water-level instrumentation

The 12 observation wells located on figure 24 are equipped with float-operated recorders. Eleven of the observation wells are equipped with graphic recorders. A continuous record of the water level is available on paper-strip charts for these wells. One water-level measurement per day is read from the strip chart, recorded for each of these wells, and encoded on forms from which tabulating cards are punched. City of Carlsbad Test Well 3 is equipped with a digital recorder. Values representing the level of the water in this well are punched into a paper tape at 15-minute intervals. The water-level data contained on the punched paper tape are then transferred to magnetic tape for further processing by digital computer.

The depth to water from the land surface at the observation wells varies from approximately 20 to 1,200 feet (6 to 365 metres). Crooked holes in several of the wells cause the float line to foul on the casing. The "stair steps" on the hydrographs recorded on Southwest Jal Unit 1, Hackberry Deep Unit 1, and occasionally on other wells, are due to fouling of the float line (fig. 24; and table 9).

Oil influx into observation wells

Oil from much deeper reservoirs began to seep through the cement plugs and to accumulate at the top of the water in the Yates State 1 well shortly after the well was completed in the Capitan aquifer. A wire-line bridge plug was set at the base of the intermediate casing during December 1971 and it effectively controlled the influx of oil (fig. 24 and table 9).

Oil began to flow into the well column of the Hackberry Deep Unit 1 during the summer of 1969. A wire-line bridge plug has not been installed in this well to control the influx of oil. Water-level measurements and hydrographs plotted from these data have been adjusted for the accumulation of oil at the top of the well column following a procedure developed by Hiss (1973).

Hydrographs

As discussed previously in this report, the water levels in observation wells must be adjusted to represent head measurements for a fluid of a common density and referenced to a common datum before head comparisons can be made. These adjustments of head data are made to account for the variation of the density of the water found in both the aquifer and the well-fluid columns. However, the changes in the unadjusted water levels can be used for general comparison of trends established in the aquifer.

Water levels measured for each of the 12 observation wells, plus one additional well temporarily loaned to the USGS and the stage of Lake Tansill (Tansill Dam), are plotted in figure 24. Abrupt changes in the hydrograph traces (as shown during 1967 in the Middleton Federal B 1 observation well, for example,) are the result of (1) corrections for original errors in measurement; (2) measurements made with different instruments that do not provide a common reading; (3) changes in the fluid-column density caused by swabbing or bailing the well; and (4) fouling of the float line. Descriptions of the adjustments, mechanical failures, and other events are described in narrative comments and by well-status designations keyed by numerical and alphabetical codes or indexes, respectively, to tables (fig. 24; and table 9).

None of the changes made to the measurements recorded in the observation wells have affected the major long-term trends shown in the hydrographs.

Response of the Capitan aquifer to seasonal variations in the Pecos River valley at Carlsbad

The demand for water for irrigation and municipal use is highest in the spring and summer seasons in the Pecos River valley near Carlsbad. Much of the water available to recharge the Capitan aquifer and replenish the flow of the Pecos River occurs as precipitation from thunderstorms during the late summer and early fall. Significant periodic declines in the potentiometric surface during the spring and summer, and rises in late summer, fall, and winter result from the two nonsynchronous events as shown in the hydrographs from the six observation wells located nearest to the Pecos River at Carlsbad (fig. 24). The magnitude of fluctuations appear to be closely related to the amount of precipitation received in the Carlsbad area, the stage of the Pecos River, and the general demand for water. Rainfall in the Pecos River watershed was particularly heavy during August 1966, early July 1967, late August and early September 1968, September and October of 1969 and 1970, and September 1972.

A major flood on the Pecos River occurred at Carlsbad coincidental with the prolonged period of heavy rainfall during August 1966 (Denis, 1968). The response of the potentiometric surface to this event is illustrated in the hydrographs of the water levels measured in the City of Carlsbad Wells 10 and 13, North Cedar Hills Unit 1, and City of Carlsbad Test Well 3. The flood is also strikingly recorded by the crest-stage gage at Tansill Dam.

The seasonal variations in the potentiometric surface of the Capitan aquifer in the Carlsbad area are transmitted to all the Capitan aquifer observation wells in Eddy County. The magnitude of the seasonal variations in head observed in the Hackberry Deep Unit 1 well located approximately 23 miles northeast of Carlsbad is much smaller than the head changes noted in the wells nearer to the Pecos River (figs. 24 and 25; table 8).

Response of the Capitan aquifer to pumpage in Lea County, New Mexico, and Ward and Winkler Counties, Texas

The head of the Capitan aquifer in each of 5 observation wells in southern Lea County has decreased at a remarkably consistent rate of 1.25 to 1.75 feet per month (0.38 to 0.53 m/month) over a period of about 6 years (figs. 24 and 25; and table 8).

A decrease in the rate of decline of water levels starting in the early part of 1969 was observed in the Southwest Jal Unit 1, Federal Davison 1, Eugene Coates 3, North Custer Mountain 1, and South Wilson Deep Unit 1 wells in Lea County. This change in the rate of decline was sensed first in March and April 1969 in the three southernmost wells in the observation-well network, and subsequently, a few months later in the two wells farther to the north. This change in the rate of decline is not perceptible in the Middleton Federal B 1 well on the western boundary of southern Lea County or in any of the wells in Eddy County (fig. 24).

An increase in the rate of decline was observed in the water levels beginning in October and November 1969 in the Southwest Jal Unit 1 and Federal Davison 1 wells, in February 1970 in the North Custer Mountain Unit 1 well, and in January 1970 in the South Wilson Deep Unit 1 well.

Conversations with oil industry personnel suggested that the changes in the rate of decline corresponded to a decrease and a subsequent increase in the rate of withdrawal of water from the Capitan aquifer in several of the large water fields in southeastern New Mexico and Ward and Winkler Counties, Texas. However, production data received from the same sources do not confirm this inferred cause of the fluctuations in head.

Comparison of the hydrographs for the Eugene Coates 3 well, completed in the Seven Rivers Formation, and the nearby Federal Davison 1 well, completed in the Capitan aquifer, confirms the measurable hydraulic communication between these formations in this area.

The long-term effect of withdrawal of oil, gas, and water from the Capitan aquifer and other associated reservoirs in measurable hydraulic communication on the potentiometric surface over a period of several decades can be seen by comparing the predevelopment potentiometric surface map to the postdevelopment map (figs. 22 and 23). The cause and effect relationships between the production of fluids and decline in head are substantiated by (1) the changes in head observed over a period of about six years in the wells in the Capitan aquifer observation-well network and (2) the relationships between volume of water produced and the decline in head over a period of about 45 years in the vicinity of the Hendrick field, Winkler County, Texas (figs. 24, 25, and 34).

Significance of the differences in response

The hydrographs may be separated into two groups with distinctly different trends. One group is composed of six of the observation wells located in Eddy County, where the water levels appear to respond primarily to climatic conditions and the withdrawal of water for municipal, industrial, agricultural, and other uses in the Pecos River valley. Net changes of less than 10 feet (3 metres) have been observed in these wells during a period of 6 years. The average monthly rate of change during the period of record is less than 0.05 foot (0.015 metre) per month (fig. 24; and table 8).

The other group includes one well in eastern Eddy County and five wells in southern Lea County, where water levels in individual wells have declined from 80 to 126 feet (24 to 38 metres). Decline rates of about 1 to 2 feet (0.3 to 0.6 metres) per month have been observed during the 6-year period, 1967-72, inclusive (fig. 24). The average rate of decline of about 2.5 feet (0.8 metres) per month in the Eugene Coates 3 well is not included in these computations. The water levels in the observation wells located in Lea County are declining primarily in response to withdrawal of water from the Capitan aquifer in Lea County, New Mexico, and Ward and Winkler Counties, Texas. The production of fluids from adjacent formations of Guadalupian age that are in measurable hydraulic communication with the Capitan aquifer also contributes to the decline in water levels.

The two distinct groups of wells, although completed in the same aquifer, appear to be separated by a hydraulic discontinuity in the vicinity of the Eddy-Lea County boundary. The degree of the apparent discontinuity is unknown. The effects of natural and artifically induced stresses recorded in the observation wells are among the geologic and hydrologic evidence pointing to a sharp reduction in the transmissivity in this area.

Withdrawal of fluids from aquifers of Guadalupian age

Oil and gas production

History

Descriptions of the exploration for oil and gas and the development of individual oil and gas fields in southeastern New Mexico and western Texas are available in Warner, 1939, p. 310-339; Ackers, DeChicchis, and Smith, 1930; DeFord and Wahlstrom, 1932; Winchester, 1933; Carpenter and Hill, 1936; Bates, 1942b; Fancher, Whiting, and Cretsinger, 1954; Helmig, 1956; Nutter, 1965; and in many other publications of the American Association of Petroleum Geologists, Roswell and West Texas Geological Societies, Lea County Operators Committee, New Mexico Oil and Gas Engineering Committee, New Mexico State Bureau of Mines and Mineral Resources, the Bureau of Economic Geology of the University of Texas, and the U.S. Bureau of Mines.

A few oil seeps and shows of oil encountered while drilling water wells indicated the presence of oil and gas in western Texas and southeastern New Mexico prior to the end of the nineteenth century. About 1900, an oil well was completed at a depth of 1,200 feet (365 metres) approximately 13 miles (21 kilometres) northwest of Fort Stockton, Tex. One well drilled to a depth of about 900 feet (275 metres) in Permian rocks in the Pecos River valley near Artesia, N. Mex. in 1909 apparently yielded a few barrels of oil per day for more than a decade (Nutter, 1965).

These were significant and encouraging finds, nevertheless, a number of test wells were drilled sporadically within the study area without commercial success until the discovery of the Artesia field located east of Carlsbad in 1923. Subsequently, the Wheat field in Loving County, Texas was discovered in 1925, and the Hendrick field near Kermit, Texas was found shortly thereafter in the summer of 1926.

After these prolific discoveries, interest in the exploration and development of the oil and gas reserves intensified rapidly. As a result, most of the major oil fields producing from rocks of Permian Guadalupian age were discovered prior to 1940. The majority of the pool extensions and development wells were completed and some of the secondary recovery projects were initiated by 1950. Several of the older oil fields of importance within the project area are listed in table 12, along with the year the field was discovered (Nutter, 1965; and Herald, 1957). The vast majority of the fields are located on either the western margin of the Central Basin platform or the Artesia-Vacuum arch on the Northwestern shelf (fig. 19).

Table 12.--Some of the first significant oil and gas fields discovered in southeastern New Mexico and western Texas

State	County	Field	Year of discovery
New Mexico	Eddy	Artesia	1923
		Getty	1927
	Lea	Maljamar	1926
		Rhodes	1927
		Hobbs	1928
		Wilson (West Eunice)	1928
		Eaves	1928
		Jal	1929
		Eunice	1929
		Vacuum	1929
		Langlie	1929
		Cooper	1929
Texas	Loving	Wheat	1925
	Winkler	Hendrick	1926
		Scarborough	1927
		Kermit (Bolin)	1928
		Leck	1928
	Ward	Shipley	1928
		North Ward	1929
		South Ward	1929
	Pecos	Yates	1926
		Pecos Valley (Low gravity)	1927
		Pecos Valley (High gravity)	1928

Sources of production data

New Mexico

The first records of the production of oil, gas, and waste water in Lea County were assembled for proration purposes and were made available to the public by the Hobbs Pool Operators Committee in 1932. This committee was succeeded by the Lea County Operators Committee in 1935 and the New Mexico Oil and Gas Engineering Committee in 1950. Statistical information supplied by oil companies are now tabulated by the New Mexico Oil Conservation Commission and published and distributed by the New Mexico Oil and Gas Engineering Committee in monthly and annual reports.

Complete statistical summaries containing the volume of oil, gas, waste water, and injected water have been available for Lea County since 1935. Similar records for Eddy County were first made available to the public in 1942 and are difficult to obtain prior to that date. Accurate volumes of the petroleum produced are determined by either gauging the oil stock tanks or by measuring the oil or gas as it passes through meters into a pipeline. Until the enactment of stringent laws to control pollution in recent years, waste water produced with oil was most often separated from the oil and gas and then disposed of in pits without volumetric determination.

Many operators reportedly calculate the volume of produced waste water from water to oil ratios determined by frequent sampling of the oil-water mixture. However, the volume of waste water reported by the operators to the regulatory agencies may be based only on visual estimates and may be unreliable. Gas flared or released at the wellhead may also be estimated or determined from gas-oil ratios.

The volume of water injected into underground reservoirs for waste disposal or pressure maintenance is reported to the regulatory agencies and published in monthly reports. The water produced from aquifers within the Lea County and Capitan underground water basins and the water injected into reservoirs in partially depleted oil-bearing reservoirs for pressure maintenance purposes is reported to the New Mexico State Engineer.

Texas

The volume of oil, gas, and condensate produced in Loving, Pecos, Reeves, Ward, Winkler, and other counties in Texas are compiled by the Oil and Gas Division of the Railroad Commission of Texas and published annually. This information is also available from private companies that specialize in the collection, tabulation, publication, and distribution of oil field scout reports and statistical data.

The volume of waste water produced as a by-product of oil production is not assembled by the Railroad Commission of Texas. Surveys of oil field brine production and disposal were made during 1961 and 1967 by the Texas Water Commission and the Texas Water Pollution Control Board (1963 and 1969). Some information describing the volumes of waste water produced in individual fields or oil-water ratios have been published in areal studies (Garza and Wesselman, 1959; White, 1971; Armstrong and McMillion, 1961; and Carpenter and Hill, 1936). Production statistics for a large part of the Hendrick field were obtained from private sources.

In order to supplement the meager information available concerning the volume of produced waste water, individual oil companies were canvassed by mail and asked to supply historical oil-water ratios for a number of fields in which they operated producing leases. The oil-water trends established from data obtained in this survey were then combined with published oil-production data and used to compute the amount of waste water produced from oil fields in the five Texas counties.

Large volumes of ground water are being produced from the Cenozoic, Rustler, Santa Rosa, and Capitan aquifers and used as injection water (Guyton, 1965). Some of the statistical data needed to determine the total amount of water produced from these water fields was derived from the biennial reports published by the Texas Petroleum Research Committee (1952-1968). However, most of the needed information was acquired directly from the individual companies engaged in suppling water for secondary recovery projects.

Volume of oil, gas, and water removed or injected

Computation of volumes

The total volume of oil, gas, water, and condensate that had been produced or injected into an individual oil, gas, or water field each year were extracted from all the available statistical reports and encoded for further processing with a digital computer. The volume of waste water produced in each of the oil fields in Texas was computed using the oil-water ratios obtained from the oil industry. Various summary reports were then prepared using these data (figs. 36-38; and table 13).

Within each state, a number of oil fields have been combined, separate pools have been created within fields, names changed, and field boundaries altered throughout the past 45 years. Consequently, it is often difficult to compute the total volume of fluid produced from any one geographic area. The changes appear to be confined to within county boundaries, probably due to considerations of tax liabilities. Therefore, the production totals for each county should be reasonably accurate.

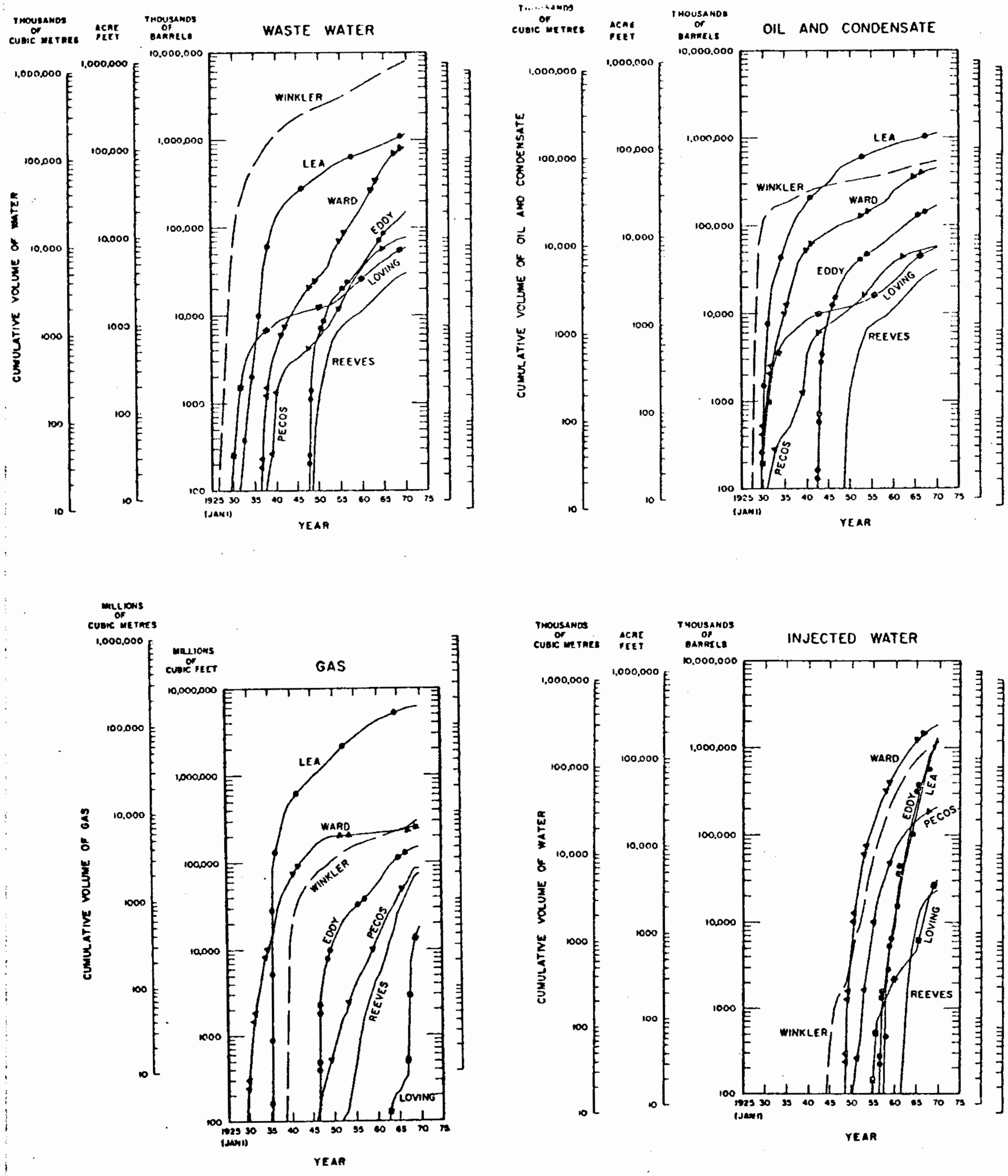


Figure 36.--Graph showing volume, by county, of fluid produced from or injected into oil fields completed in formations of Permian Guadalupian age in Eddy and Lea Counties, New Mexico, and Loving, Pecos, Reeves, Ward, and Winkler Counties, Texas. Volumes were determined under surface conditions, i.e., stock-tank barrels or cubic feet under one atmosphere of pressure.

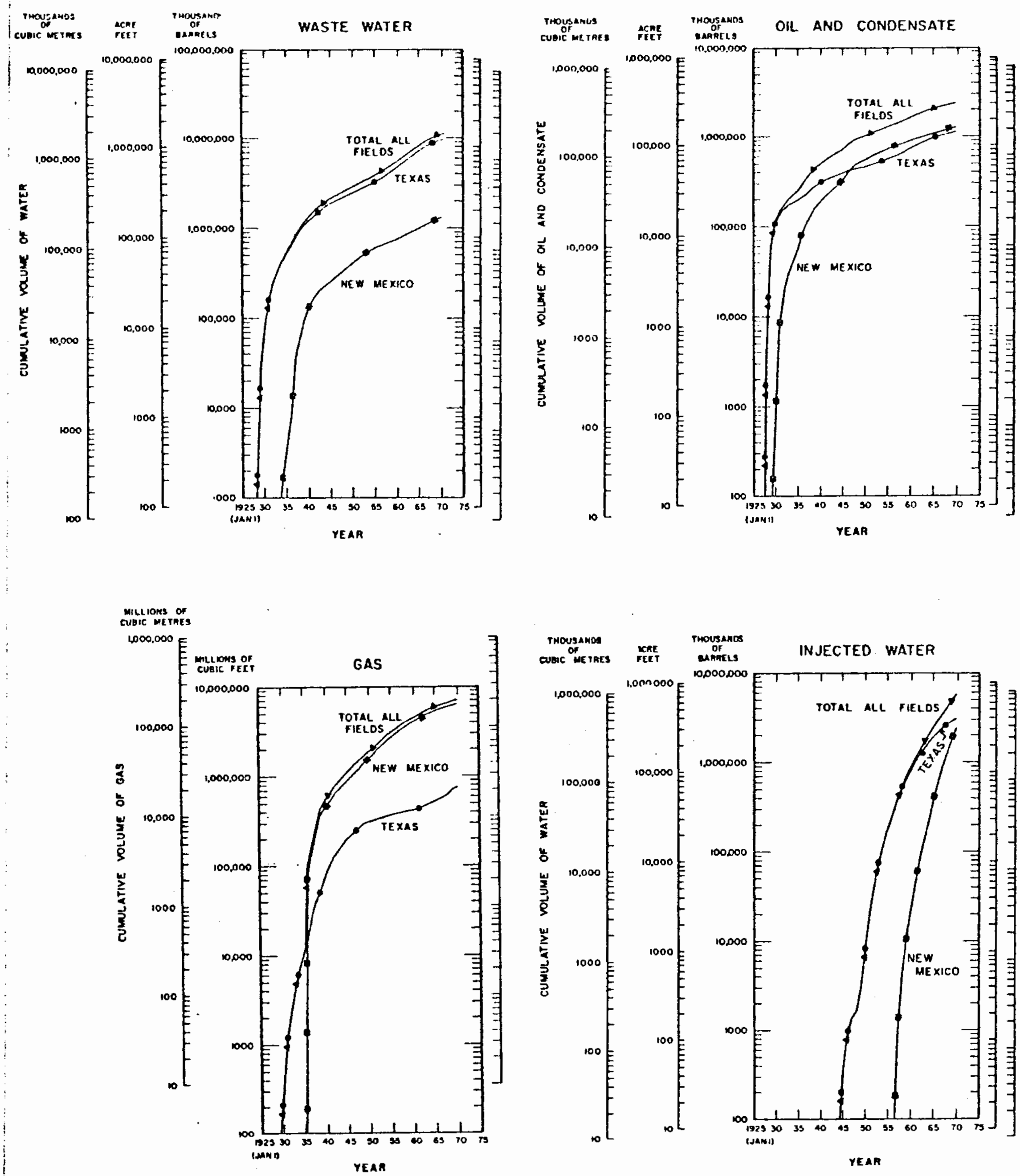


Figure 37.--Graph showing volume, by state, of fluid produced from or injected into oil fields completed in formations of Permian Guadalupian age in Eddy and Lea Counties, New Mexico, and Loving, Pecos, Reeves, Ward, and Winkler Counties, Texas. Volumes were determined under surface conditions, i.e., stock-tank barrels or cubic feet under one atmosphere of pressure.

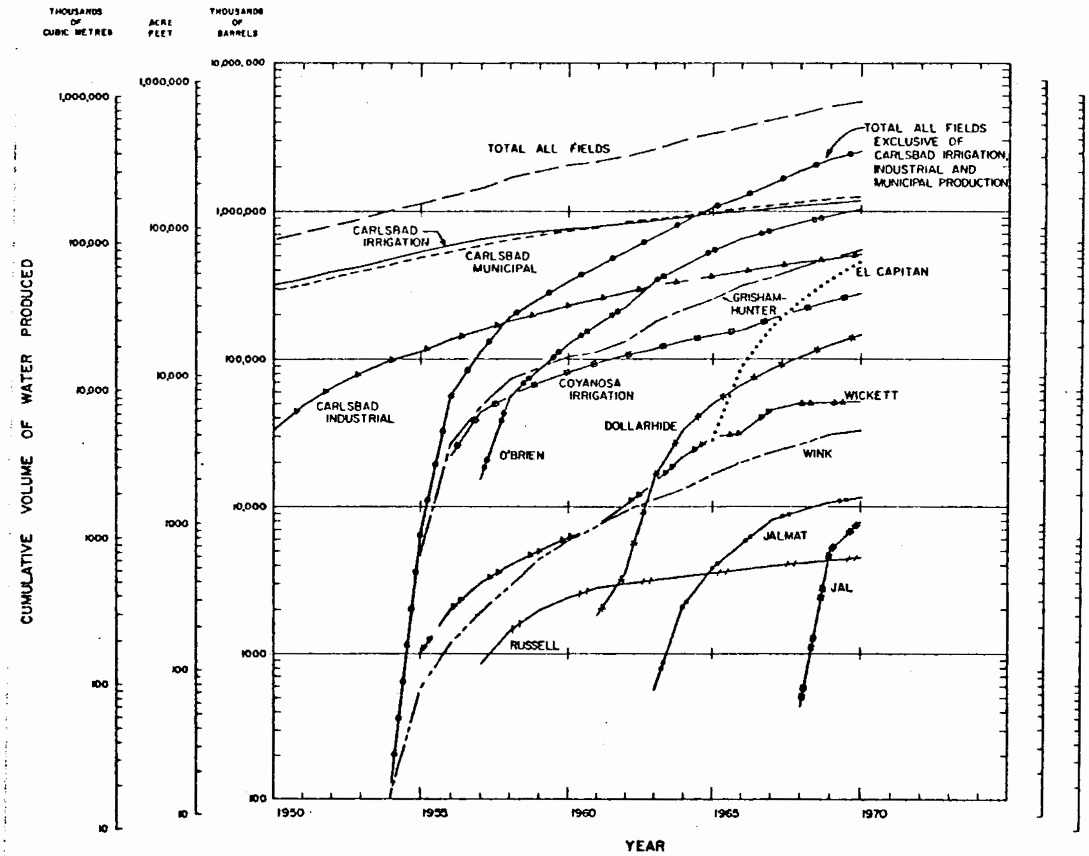


Figure 38.--Graph showing volume of water produced from principal water fields completed in the Capitan aquifer in southeastern New Mexico and western Texas.

Table 13.--Volume of fluid produced from or injected into formations of Permian Guadalupian age in Lea and Eddy Counties, New Mexico, and Loving, Pecos, Reeves, Ward, and Winkler Counties, Texas [1/]

County	1920-29 Cumulative	1930-39 Cumulative	1940-49 Cumulative	1950-59 Cumulative	1960-69 Cumulative
New Mexico					
Eddy County					
Water					
Industrial (Capitan aquifer)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	4.4 (33.8; 5.4) 4.4 (33.8; 5.4)	25.2 (196 ; 31) 29.6 (230 ; 37)	35.8 (278 ; 44) 65.4 (508 ; 81)
Irrigation (Capitan aquifer)	4.5 (34.7; 5.5) 4.5 (34.7; 5.5)	9.8 (76.3; 12) 14.3 (111 ; 18)	26.5 (206 ; 33) 40.8 (317 ; --)	57.2 (444 ; 71) 98.0 (761 ; 121)	52.7 (409 ; 65) 151 (1,170 ; 186)
Municipal (Capitan aquifer)	5.1 (39.8; 6.3) 5.1 (39.8; 6.3)	9.2 (71.2; 11) 14.3 (111 ; 18)	23.2 (180 ; 50) 37.5 (291 ; 46)	56.7 (440 ; 70) 94.2 (731 ; 116)	68.1 (529 ; 84) 162 (1,260 ; 200)
Petroleum waste	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	.8 (6.2; 1.0) .8 (6.2; 1.0)	4.2 (32.7; 5.2) 5.0 (38.9; 6.2)	14.6 (113 ; 18) 19.6 (152 ; 24)
Secondary recovery					
Produced (Capitan aquifer)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	.3 (2.4; .38) .3 (2.4; .38)	.3 (2.2; .35) .6 (4.6; .73)
Injected	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	.6 (4.0; .64) .6 (4.0; .64)	145 (1,130 ; 180) 146 (1,200 ; 191)
Petroleum	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	4.2 (32.2; 5.1) 4.2 (32.2; 5.1)	6.1 (47.2; 7.5) 10.2 (79.4; 13)	10.9 (85 ; 14) 21.1 (164 ; 26)
Gas	-- --	-- --	11.2 (0.32) 11.2 (.32)	40.1 (1.1) 51.3 (1.4)	98.9 (2.8) 150 (4.2)

Table 13.--Volume of fluid produced from or injected into formations of Permian Guadalupian age in Lea and Eddy Counties, New Mexico, and Loving, Pecos, Reeves, Ward, and Winkler Counties, Texas - Continued

County	1920-29 Cumulative	1930-39 Cumulative	1940-49 Cumulative	1950-59 Cumulative	1960-69 Cumulative
New Mexico - Continued					
Southern Lea County					
Water					
Petroleum waste	-- (-- ; --) -- (-- ; --)	17.0 (132 ; 21) 17.0 (132 ; 21)	33.9 (263 ; 42) 50.9 (395 ; 63)	41.4 (321 ; 51) 92.3 (716 ; 114)	58.7 (456 ; 72) 151 (1,170 ; 186)
Secondary recovery					
Produced (Capitan aquifer)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	2.8 (21.5; 3.4) 2.8 (21.5; 3.4)
Injected	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	1.3 (9.9; 1.6) 1.3 (9.9; 1.6)	161 (1,250 ; 199) 162 (1,260 ; 200)
Petroleum	0.13 (1.01; 0.16) .13 (1.01; .16)	23.8 (185 ; 29) 23.9 (186 ; 30)	43.6 (338 ; 54) 67.5 (524 ; 83)	38.5 (299 ; 48) 106 (823 ; 131)	38.3 (297 ; 47) 144 (1,120 ; 178)
Gas	-- --	377 (10.7) 377 (10.7)	1,180 (33.4) 1,560 (44.2)	2,380 (67.4) 3,940 (112)	2,190 (62) 6,130 (174)
Texas					
Loving County					
Water					
Petroleum waste	.03 (.25; .04) .03 (.25; .04)	1.06 (8.2; 1.3) 1.1 (8.4; 1.3)	.5 (3.7 ; .58) 1.6 (12.1 ; 1.9)	1.9 (14.9; 2.4) 3.5 (27.0; 4.3)	4.1 (32.1; 5.1) 7.6 (59.1; 9.4)
Secondary recovery					
Produced (Capitan aquifer)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)

Table 13.--Volume of fluid produced from or injected into formations of Permian Guadalupian age in Lea and Eddy Counties, New Mexico, and Loving, Pecos, Reeves, Ward, and Winkler Counties, Texas - Continued

County	1920-29 Cumulative	1930-39 Cumulative	1940-49 Cumulative	1950-59 Cumulative	1960-69 Cumulative
Texas - Continued					
Loving County - Continued					
Water - Continued					
Secondary recovery					
Injected	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	0.3 (2.2; 0.35) .3 (2.2; .35)	3.45 (26.8 ; 4.3) 3.73 (29.0 ; 4.6)
Petroleum	0.03 (0.32; 0.05) .03 (.32; .05)	1.06 (8.2; 1.3) 1.1 (8.6; 1.4)	0.5 (3.5; 0.56) 1.6 (12.1; 1.9)	1.4 (11.2: 1.8) 3.0 (23.3; 3.7)	4.12 (32.0 ; 5.0) 7.12 (55.3 ; 8.8)
Gas	-- --	-- --	-- --	.01 (.0003) .01 (.0003)	18.0 (.51) 18.0 (.51)
Pecos County					
Water					
Irrigation (Capitan aquifer)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	10.5 (81.4 ; 12.9) 10.5 (81.4 ; 12.9)	25.2 (196 ; 31.2) 35.7 (277 ; 44.0)
Irrigation (San Andres Formation)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	14.9 (116 ; 18.4) 14.9 (116 ; 18.4)	82.7 (642 ; 102) 97.6 (758 ; 121)	90.4 (702 ; 112) 188 (1,460 ; 232)
Petroleum waste	-- (-- ; --) -- (-- ; --)	.18 (1.4; .22) .18 (1.4; .22)	.56 (4.4; .69) .74 (5.8; .92)	4.0 (30.9 ; 4.9) 4.7 (36.7 ; 5.8)	5.3 (40.9 ; 6.5) 10.0 (77.6 ; 12.3)
Secondary recovery					
Produced (Capitan aquifer)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)
Injected	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	.01 (.03; .005) .01 (.03; .005)	8.2 (63.5 ; 10.1) 8.2 (63.5 ; 10.1)	18.6 (145 ; 23.0) 26.8 (208 ; 33.0)

Table 13.--Volume of fluid produced from or injected into formations of Permian Guadalupian age in Lea and Eddy Counties, New Mexico, and Loving, Pecos, Reeves, Ward, and Winkler Counties, Texas - Continued

County	1920-29 Cumulative	1930-39 Cumulative	1940-49 Cumulative	1950-59 Cumulative	1960-69 Cumulative
Texas - Continued					
Pecos County - Continued					
Petroleum	0.01 (0.04; 0.01) .01 (.04; .01)	0.44 (3.4; 0.54) .44 (3.4; .55)	1.1 (8.1; 1.2) 1.5 (11.5; 1.8)	3.5 (36.8; 4.3) 4.9 (38.3; 6.1)	2.4 (18.9 ; 3.0) 7.4 (57.2 ; 9.1)
Gas	-- --	-- --	.7 (.02) .7 (.02)	12.0 (.34) 12.7 (.36)	71.8 (2.03) 84.5 (2.39)
Reeves County					
Water					
Petroleum waste	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	.17 (1.3; .21) .17 (1.3; .21)	1.3 (10.4; 1.6) 1.5 (11.7; 1.9)	2.4 (18.5 ; 2.9) 3.9 (30.2 ; 4.8)
Secondary recovery					
Produced (Capitan aquifer)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)
Injected	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	3.0 (23.2 ; 3.7) 3.0 (23.2 ; 3.7)
Petroleum	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	.18 (1.4; .22) .18 (1.4; .22)	1.3 (9.8; 1.6) 1.4 (11.2; 1.8)	2.5 (19.6 ; 3.1) 4.0 (30.8 ; 4.9)
Gas					
Produced	-- --	-- --	.04 (.0012) .04 (.0012)	2.0 (.057) 2.0 (.057)	71.7 (2.03) 73.7 (2.09)
Injected	-- --	-- --	-- --	99 (2.8) 99 (2.8)	-- -- 99 (2.8)

Table 13.--Volume of fluid produced from or injected into formations of Permian Guadalupian age in Lea and Eddy Counties, New Mexico, and Loving, Pecos, Reeves, Ward, and Winkler Counties, Texas - Continued

County	1920-29 Cumulative	1930-39 Cumulative	1940-49 Cumulative	1950-59 Cumulative	1960-69 Cumulative
Texas					
Ward County					
Water					
Petroleum waste	-- (-- ; --) -- (-- ; --)	0.55 (4.2; 0.67) .55 (4.2; .67)	3.0 (23.5; 3.7) 3.6 (27.7; 4.4)	21.0 (163 ; 25.9) 24.6 (191 ; 30.4)	84.4 (655 ; 104) 109 (846 ; 135)
Secondary recovery					
Produced (Capitan aquifer)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	17.2 (133 ; 21.1) 17.2 (133 ; 21.1)	123 (956 ; 152) 140 (1,090 ; 173)
Injected	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	.57 (4.4; .70) .57 (4.4; .70)	64.0 (497 ; 79.0) 64.5 (501 ; 79.7)	169 (1,310 ; 208) 233 (1,810 ; 288)
Petroleum	0.06 (0.44; 0.07) .06 (.44; .07)	7.1 (55.0; 8.7) 7.1 (55.4; 8.8)	7.4 (57.6; 9.2) 14.6 (113 ; 18.0)	17.3 (134 ; 21.3) 31.8 (247 ; 39.3)	25.4 (197 ; 31.3) 57.2 (444 ; 70.6)
Gas					
Produced	.30 (.01) .30 (.01)	61.7 (1.75) 62.0 (1.76)	144 (4.1) 206 (5.8)	8.7 (.25) 215 (6.1)	46.0 (1.3) 265 (7.5)
Injected	-- --	-- --	6.1 (.17) 6.1 (.17)	1.7 (.05) 7.9 (.22)	-- 7.9 (.22)

Table 13.--Volume of fluid produced from or injected into formations of Permian Guadalupian age in Lea and Eddy Counties, New Mexico, and Loving, Pecos, Reeves, Ward, and Winkler Counties, Texas - Concluded

County	1920-29 Cumulative	1930-39 Cumulative	1940-49 Cumulative	1950-59 Cumulative	1960-69 Cumulative
Texas					
Winkler County					
Water					
Petroleum waste	9.8 (75.7 ; 12.0) 9.8 (75.7 ; 12.0)	141 (1,090 ; 173) 151 (1,170 ; 186)	156 (1,210 ; 192) 307 (2,380 ; 378)	234 (1,810; 288) 541 (4,190; 666)	357 (2,770; 440) 898 (6,970; 1,108)
Secondary recovery					
Produced (Capitan aquifer)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	14.2 (110; 17.5) 14.2 (110; 17.5)	139 (1,080; 172) 153 (1,190; 189)
Injected	-- (-- ; --) -- (-- ; --)	-- (-- ; --) -- (-- ; --)	.49 (3.8; .60) .49 (3.8; .60)	35.0 (272; 43.2) 35.5 (276; 43.9)	114 (884; 141) 149 (1,160; 184)
Petroleum	14.6 (113 ; 18.0) 14.6 (113 ; 18.0)	16.5(128 ; 20.3) 31.1(241 ; 38.3)	10.9 (85 ; 13.5) 42.0 (326 ; 51.8)	11.1 (86; 13.7) 53.1 (412; 65.5)	16.1 (125; 19.9) 69.2 (537; 85.4)
Gas					
Produced	-- --	12.7 (.36) 12.7 (.36)	93.9 (2.7) 107 (3.0)	80.7 (2.3) 188 (5.3)	116 (3.3) 304 (8.6)
Injected	-- --	-- --	.83 (.024) .83 (.024)	14.7 (.42) 15.5 (.44)	34.7 (.98) 50.2 (1.4)

1/ Water and oil in thousands of acre-feet (millions of barrels; millions of cubic metres); gas in billions of cubic feet (billions of cubic metres). All volumes were determined at surface conditions.

Volume of oil and gas produced

The cumulative volumes of oil and gas produced in the seven counties within the project area are shown graphically in figures 36 and 37, and tabulated in table 13. The volume of oil produced in all seven counties has gradually and consistently increased during the past 20 to 30 years. The rate of increase in oil production is less in Winkler County after 1933 than in the other six counties.

A substantial part of the total amount of oil produced in Winkler County came from the Hendrick field. The maximum rate of oil production was reached early in the life of this field, followed by a very rapid decline (fig. 36). A total of approximately 310,400 acre-feet (2,410,000,000 barrels; 383,000,000 cubic metres) of oil has been produced in the seven counties in southeastern New Mexico and western Texas. Of this amount, 145,500 acre-feet (1,130,000,000 barrels; 180,000,000 cubic metres) or 47 percent of the total was produced from oil fields in Loving, Pecos, Reeves, Ward, and Winkler Counties, Texas; and the remainder, 165,000 acre-feet (1,280,000,000 barrels; 204,000,000 cubic metres), or 53 percent, was produced from oil fields in Eddy and Lea Counties, New Mexico. Oil was being produced at an average annual volume of 4,380 acre-feet (34,000,000 barrels; 5,400,000 cubic metres) and 5,150 acre-feet (40,000,000 barrels; 6,360,000 cubic metres) per year in the project area in Texas and New Mexico, respectively, during the period 1965-69.

Production of oil in secondary recovery projects

Oil has been produced continually from many of the oil fields in southeastern New Mexico and western Texas for more than 45 years. The original expelling force created by expansion of the gas dissolved in oil in many of the oil fields was depleted very rapidly before more than a minor fraction of the original oil in place in the reservoir was recovered. Substantial additional oil, frequently as much as had been produced by primary methods, has been produced from many of the fields by application of secondary recovery techniques to maintain, restore, or increase the pressures in the partly depleted reservoirs.

Waterflooding, a secondary recovery method involving the injection of water to increase reservoir pressure, has been particularly successful within the project area. Water is introduced under pressure through injection wells into the oil-bearing reservoir rock. The remaining oil is then displaced, theoretically pushed as a bank through the porous medium, toward the cones of lower pressure at the producing wells. Recovery of oil is enhanced if the rock surfaces are preferentially wet by the water as it displaces oil from oil-wet surfaces (Uren, 1939, p. 444; and Levorsen, 1967). The productive life of a field is often prolonged 5 to 10 or more years by waterflooding.

Gas injection secondary recovery projects were initiated in the Shipley field, Ward County in 1930 and in the Langlie-Mattix field, Lea County in 1941 (Fancher, Whiting, and Cretsinger, 1954; and Davis, 1942). Waterfloods were started on units in the Kermit field in Winkler County in 1943, the South Ward field in Ward County and the Pecos Valley Low and High-Gravity fields in Pecos County in 1949. By 1952, three gas-injection and 23 waterflood projects were active in Loving, Pecos, Reeves, Ward, and Winkler Counties, Texas. Fifteen years later, more than 250 secondary recovery projects, most of which were waterfloods, were operating in the same area (Texas Petroleum Research Committee, 1968).

The first waterflood in the New Mexico part of the study area was started in the Shugart field in 1952 (New Mexico Oil and Gas Association, 1966, p. 6). The number of waterfloods in operation in Eddy and Lea Counties rapidly increased to 24 in 1960, to 100 in 1965, and to approximately 185 by the latter part of 1969. Fancher, Whiting, and Cretsinger (1954) estimated the remaining oil reserves in reservoirs of several geologic ages in Loving, Pecos, Reeves, Ward, and Winkler Counties, Texas, as of 1952, to be approximately 121,700 acre-feet (945,000,000 barrels; 150,000,000 cubic metres), recoverable by primary methods; and 98,700 acre-feet (766,000,000 barrels; 122,000,000 cubic metres), recoverable by secondary methods.

Water from the Capitan aquifer is being exported from Winkler County to Andrews and Ector Counties, Texas where it is injected into partly depleted reservoirs in a number of oil fields (Brackbill, and Gaines, 1964). Operators of waterfloods located in Crane and Gaines Counties reportedly are also potential users of water from the Capitan aquifer. Similar estimates of oil reserves for these four counties indicated that approximately 341,300 acre-feet (2,650,000,000 barrels; 421,000,000 cubic metres) and 304,400 acre-feet (2,363,000,000 barrels; 375,700,000 cubic metres) are recoverable by primary and secondary production methods, respectively.

Wells completed in the Capitan aquifer probably will be the source of much of the large quantity of water required for secondary recovery purposes. Other sources will be recycled waste water and new water pumped from the Santa Rosa, Rustler, San Andres, and Cenozoic aquifers. By the end of 1969, more than 416,000 acre-feet (3,230,000,000 barrels; 514,000,000 cubic metres) of water had been injected into reservoirs of several geologic ages in the five Texas counties within the project area.

The New Mexico Oil and Gas Association (1966) estimated reserves of recoverable oil in southeastern New Mexico during the next two decades to be: primary--23,200 acre-feet (180,000,000 barrels; 28,600,000 cubic metres); and secondary--77,300 acre-feet (600,000,000 barrels; 95,400,000 cubic metres). An estimated 979,000 acre-feet (7,600,000,000 barrels; 1,208,000,000 cubic metres) of water would have to be injected in waterfloods at an average rate of 45,600 acre-feet (354,000,000 barrels; 56,300,000 cubic metres) per year in order to produce the additional 600 million barrels (95,400,000 cubic metres) of oil recoverable by secondary methods. Approximately 45 percent of the required water would have to be new or "make-up" water, and the remainder would be recycled waste water.

Water is being pumped from the Ogallala, Rustler, Santa Rosa, San Andres, and Capitan aquifers in southeastern New Mexico for use in waterfloods. Yields from wells in the Ogallala, San Andres, and Capitan aquifers were considered by the New Mexico Oil and Gas Association to be adequate to support full-scale waterflood projects. More than 307,000 acre-feet (2,390,000,000 barrels; 380,000,000 cubic metres) of water have been injected into reservoirs of several different geologic ages in active waterfloods in southeastern New Mexico through the end of 1969. Approximately 73,300 acre-feet (569,000,000 barrels; 90,500,000 cubic metres) of water was injected in waterfloods during 1969. The volume of water being injected per year in Eddy and Lea Counties is increasing very rapidly (fig. 36).

Water production

Waste-water production in oil fields

Large amounts of waste water have been produced from the Artesia Group and San Andres Limestone in several of the oil fields located along the southern edge of the Northwestern shelf and western and northern margins of the Central Basin platform. Water-oil ratios during the life of production in these fields average 1.7:1 and 12:1 in Lea and Eddy Counties, respectively, and are much smaller than the water-oil ratio of 25:1 in the Hendrick field in Winkler County. The cumulative volumes of waste water and oil produced from several of these fields are given in table 14. The small fields in Eddy County and the Hobbs and Cooper-Jal (Jalmat) fields have strong water drives (Schuehle, 1942, p. 229; and Miller, and Bates, 1942, p. 201). A combination of solution gas and water-drive forces are probably active in the reservoirs in the other fields listed in table 10.

Until recently, most of the waste water was placed in earthen "evaporation" pits, where much of it seeped into the shallow aquifers (Nicholson and Clebsch, 1961, p. 102; Garza and Wesselman, 1962, p. 25; Gilkey and Stotelmeyer, 1965, p. 11-26; and White, 1971, p. 51). Nearly all of the waste water is now collected and transported by truck or pipeline systems to other storage areas, often in areas remote from the source. The waste water then is either injected into aquifers selected as waste repositories or into oil-bearing reservoirs as secondary recovery floodwater.

Table 14.--Selected oil fields in Lea and Eddy Counties, New Mexico, with relatively large water-oil ratios

County	Field and reservoir	Cumulative volume produced through 1969, in acre-feet (bbls; hm^3) oil		water		Water to oil ratio
Eddy	Benson--Yates Formation	31.6	(245,000; 0.039)	197.1	(1,530,000; 0.243)	6.2:1
	Barber--Yates Formation	153.3	(1,190,000; .189)	1,494.1	(11,600,000; 1.843)	9.7:1
	Dos Hermanos--Yates and Seven Rivers Formation	149.4	(1,160,000; .184)	1,983.5	(15,400,000; 2.447)	13.3:1
	Getty--Yates Formation	172.6	(1,340,000; .213)	5,499.8	(42,700,000; 6.784)	31.9:1
	Magruder--Yates Formation	1.3	(10,300; .002)	30.0	(233,000; .370)	22.6:1
	PCA--Yates Formation	77.9	(605,000; .096)	378.7	(2,940,000; .467)	4.9:1
	Russell--Yates Formation	284.6	(2,210,000; .351)	678.8	(5,270,000; .837)	2.4:1
Lea	Eumont--Yates, Seven Rivers, and Queen Formations	3,838.2	(29,800,000; 4.734)	5,267.9	(40,900,000; 6.498)	1.4:1
	Eunice--Grayburg Formation and San Andres Limestone	14,296.8	(111,000,000; 17.635)	12,364.8	(96,000,000; 15.252)	.9:1
	Eunice South--Seven Rivers and Queen Formations	3,155.6	(24,500,000; 3.892)	3,954.2	(30,700,000; 4.878)	1.3:1

Table 14.--Selected oil fields in Lea and Eddy Counties, New Mexico, with relatively large water-oil ratios - Concluded

County	Field and reservoir	Cumulative volume produced through 1969, in acre-feet (bbls; hm^3) oil		water		Water to oil ratio
Lea	Hobbs--Grayburg Formation and San Andres Limestone	25,760.0	(200,000,000; 31.775)	16,357.6	(127,000,000; 20.177)	0.6:1
	Jalmat--Yates, Seven Rivers and Tansill Formations (formerly Cooper--White Lime; Jal--White Lime; and Cooper-Jal--Yates and Seven Rivers Formations)	8,668.2	(67,300,000; 10.692)	51,004.8	(396,000,000; 62.914)	5.9:1
	Monument--Grayburg Formation and San Andres Limestone	10,870.7	(84,400,000; 13.409)	21,896.0	(170,000,000; 27.009)	2.0:1
	Wilson--Yates and Seven Rivers Formations	826.9	(6,420,000; 1.020)	1,841.8	(14,300,000; 2.272	2.2:1

Hendrick field

The discovery well in the Hendrick field, northeast of Wink in central Winkler County, one of the most prolific oil fields in western Texas, was completed in late 1926 (Carpenter and Hill, 1936, p. 123). Development of the field was rapid, and more than 600 wells had been drilled by early 1930 within an area encompassing approximately 10,000 acres. In May 1928, when the Hendrick field became the first field to be prorated in Texas, about 164 wells were producing more than 500,000 barrels (79,000 cubic metres) of oil and waste water per day. Sulfurous water ranging in amounts from 0.5 to 98 percent of the total fluid was produced in nearly half of these wells (Ackers, DeChicchis and Smith, 1930, p. 941). More than 130 million barrels (20,700,000 cubic metres) of oil had been produced by 1930, and water-oil ratios of as high as 16:1 were reported from estimated daily production records (Carpenter and Hill, 1936, p. 134). Data obtained from one of the largest operators in the Hendrick field indicate that waste water was being produced at sharply increasing rates and already constituted 95 percent of the total fluid produced in 1934. The ratio of water to oil gradually increased during the next ten years, until the percentage of waste water became a relatively constant 99 percent of all fluid produced from 1944 to 1960.

In 1957, only a very small fraction of the Hendrick field waste water was being recycled in waterflooding projects. Most of this waste water was placed in surface pits or in a communal disposal lake near Wink, Tex. (Garza and Wesselman, 1959, p. 45). As the number of waterflood projects increased in the sixties, more of this produced waste water was injected for secondary recovery purposes. Most of it continued to be disposed of in the usual manner, until laws were passed to preclude the disposal of brine effluent in earthen surface pits.

Extrapolation of the earliest available pressure data for the Hendrick field indicates an original bottom-hole pressure in excess of 1,350 psi (pounds per square inch), or about 3,120 feet of freshwater head above mean sea level. An original "rock pressure" of 1,300 pounds for the Hendrick field was reported in Ackers, DeChicchis, and Smith (1930 p. 923). The hydraulic head in the Hendrick field had declined to less than 2,500 feet above mean sea level by 1969. The slow but consistent decline in reservoir pressure in conjunction with the high water-oil ratio in the fluid produced indicates the field is being produced under strong water-drive reservoir conditions (fig. 34).

Approximately 32,000 acre-feet (250,000,000 barrels; 39,700,000 cubic metres) of oil and an estimated 810,000 acre-feet (6,300,000,000 barrels; 1,000,000,000 cubic metres) of water have been produced from the Hendrick field through 1969. An average of over 28,000 acre-feet (218,000,000 barrels; 34,700,000 cubic metres) of water per year was produced from the Hendrick field during the 5-year period, 1965-69. About 200 million, or about 80 percent, of the 250 million barrels (39,700,000 cubic metres) of oil recovered through 1969 had been produced by the end of 1939. More than 58 percent of the total waste water produced from Permian Guadalupian formations as a waste by-product of the exploitation of oil and gas within the project area was produced from the Hendrick field. About 10 percent of the total oil produced from the same formations in this seven-county area has been produced from the Hendrick field.

The quality of water produced from the nearby water fields completed in the Capitan aquifer is identical to that from the Hendrick field. The reservoir pressures in the same water fields and the Hendrick field are similar and are apparently declining at similar rates (fig. 34). Thus, the hydraulic communication between the reservoir in the Hendrick field and the Capitan aquifer appears to be excellent. Therefore, most of the water produced from the Seven Rivers and Yates Formations in this field, can be considered as having been produced from the Capitan aquifer.

Volume of waste water produced

A total of approximately 1,390,000 acre-feet (10,800,000,000 barrels; 1,720,000,000 cubic metres) of water has been produced as a waste by-product during the production of oil and gas in the seven-county area studied in southeastern New Mexico and western Texas. About 170,000 acre-feet (1,320,000,000 barrels; 210,000,000 cubic metres), or 12 percent, was produced in Eddy and Lea Counties and 1,220,000 acre-feet (9,440,000,000 barrels; 1,500,000,000 cubic metres), or 88 percent, was produced from oil fields in Loving, Pecos, Reeves, Ward, and Winkler Counties. Waste water was being produced at an annual average volume of 8,600 acre-feet (66,600,000 barrels; 10,600,000 cubic metres) and 54,400 acre-feet (422,000,000 barrels; 67,090,000 cubic metres) in the same counties in New Mexico and Texas, respectively, during the period 1965-69.

Production of water from the Capitan aquifer

Oil industry use

The Capitan aquifer is considered to be the prime source of the large quantities of water for the many secondary recovery projects now in operation or planned for the oil fields on the Northwestern shelf and Central Basin platform. The El Capitan, Grisham-Hunter, and O'Brien fields, largest of the nine water fields completed in the Capitan aquifer, are located in Winkler and Ward Counties (fig. 19).

Water produced from the Capitan aquifer in the Russell and Jalmat water field in New Mexico is injected into shallower reservoirs in the Artesia Group within the same local area. Water produced from the Capitan aquifer in the other seven principal water fields is transported through a network of pipelines for varying distances to other fields, where it is injected into reservoirs of several geologic ages (Brackbill and Gaines, 1964). Wells in the O'Brien field are completed in the lower part of the Capitan aquifer which, at this locality, includes carbonate banks or reefs in the upper part of the San Andres Limestone (fig. 7 E-E').

Approximately 296,200 acre-feet (2,300,000,000 barrels; 366,000,000 cubic metres) of water have been produced from the Capitan aquifer in Eddy and Lea Counties, New Mexico and Ward and Winkler Counties, Texas, during the period 1954-69 for use in oil field secondary recovery projects (table 15 and fig. 38). Nearly 264,000 acre-feet (2,050,000,000 barrels; 326,000,000 cubic metres), or more than 89 percent, was produced from wells in the Capitan, Grisham-Hunter, and O'Brien fields. Approximatley 40,700 acre-feet (316,000,000 barrels; 50,200,000 cubic metres) of water were produced from all the nine fields completed in the Capitan aquifer during 1969. About 37,400 acre-feet (290,000,000 barrels; 46,000,000 cubic metres) of water were produced from the El Capitan, Grisham-Hunter and O'Brien fields during the same period.

The demand for water from the Capitan aquifer for secondary recovery purposes has increased at a rate of about 25 percent per year during 1965-69, inclusive (fig. 38). This trend of increasing withdrawal of water from the Capitan aquifer can be expected to continue as more secondary recovery projects are placed in operation. Oil-industry sources report that the peak demand for water can be expected during the period 1970-80.

Table 15.--Volume of water produced from the Capitan aquifer for use in oil field secondary recovery projects

State	County	Water field	Volume of water produced during 1969 in acre-feet (bbls; hm^3)	Cumulative volume of water produced to January 1, 1970 in acre-feet (bbls; hm^3)
New Mexico	Eddy	Russell	40.2 (312,000; 0.05)	591.2 (4,590,000; 0.73)
	Lea	Jalmat	124.2 (964,000; .15)	1,481.2 (11,500,000; 1.83)
		Jal	363.2 (2,820,000; .45)	1,007.2 (7,820,000; 1.24)
Texas	Winkler	Dollarhide	2,717.7 (21,100,000; 3.35)	18,676.0 (145,000,000; 23.04)
		El Capitan	14,425.6 (112,000,000; 17.79)	58,604.0 (455,000,000; 72.29)
		Grisham-Hunter	8,835.7 (68,600,000; 10.90)	71,355.2 (554,000,000; 88.02)
		Wink	199.6 (1,550,000; .25)	4,147.4 (32,200,000; 5.16)
	Ward	O'Brien	14,039.2 (109,000,000; 17.32)	133,952.0 (1,040,000,000; 165.23)
		Wickett	13.8 (107,000; .02)	6,646.1 (51,600,000; 8.20)

Municipal use

The municipal water supplies for the city of Carlsbad and the community of White City are obtained from wells completed in the Capitan aquifer (fig. 19; and Bjorklund and Motts, 1959; and Halpenny and Greene, 1966). A total of approximately 162,300 acre-feet (1,260,000,000 barrels; 200,000,000 cubic metres) of water have been produced from the Capitan aquifer in the Happy Valley and Dark Canyon municipal well fields located southwest of Carlsbad during a period of about 50 years. The annual average production during the 5-year period 1965-69 was 6,830 acre-feet (53,000,000 barrels; 8,400,000 cubic metres). Water with a chemical quality suitable for human consumption can be obtained from the Capitan aquifer in only two areas; one is an extensive area southwest of the Pecos River at Carlsbad, and the other is a less well defined area in the Glass Mountains southwest of Fort Stockton.

Irrigation

Water pumped from the Capitan aquifer is used to irrigate about 2,300 acres of farmland in the Pecos River valley in the immediate vicinity of Carlsbad (Bjorklund and Motts, 1959). Approximately 5,400 acre-feet (42,000,000 barrels; 6,700,000 cubic metres) of water per year is estimated to have been used for irrigation purposes during the period 1965-69. An estimated total of 150,700 acre-feet (1,170,000,000 barrels; 186,000,000 cubic metres) has been withdrawn from the Capitan aquifer within the Carlsbad area for irrigation of croplands during the past 50 years.

Water of marginal chemical quality for irrigation of crops is produced from one flowing well near Coyanosa in northern Pecos County. This well has been used to irrigate cotton and other crops tolerant to saline water (Armstrong and McMillion, 1961; and Guyton and Associates, 1958).

Use in potash refining plants

Water pumped from the Capitan aquifer at Carlsbad is transported by pipeline to a potash refining plant located about 18 miles (29 kilometres) east of Carlsbad. Approximately 3,740 acre-feet (29,000,000 barrels; 4,600,000 cubic metres) of water per year was used to refine potash ore during the period 1965-69. An estimated total of 65,400 acre-feet (508,000,000 barrels; 80,800,000 cubic metres) of water has been pumped from the Capitan aquifer during the past 23 years and used for this purpose.

Amount of water produced from the Capitan aquifer

The cumulative volume of water produced from the principal water fields completed in the Capitan aquifer in southeastern New Mexico and western Texas is shown in figure 38. With the exception of the Wickett water field in Ward County, Texas, increasing amounts of water are being produced from all of the larger water fields.

The demand on the Capitan aquifer system within the project area has increased at an annual average rate of 54,600 acre-feet (424,000,000 barrels; 67,400,000 cubic metres) during the period 1965-69. The demand on the Capitan aquifer east of the Pecos River valley at Carlsbad has increased at an annual average rate of 38,400 acre-feet (298,000,000 barrels; 47,000,000 cubic metres) during the same period.

Approximately 711,000 acre-feet (5,520,000,000 barrels; 878,000,000 cubic metres), 378,700 acre-feet (2,940,000,000 barrels; 467,000,000 cubic metres), and 332,300 acre-feet (2,580,000,000 barrels; 410,000,000 cubic metres) of water have been produced from the entire Capitan aquifer system, the Capitan aquifer in the Pecos River valley at Carlsbad, and the Capitan aquifer east of the Pecos River valley at Carlsbad, respectively. These figures exclude the 820,000 acre-feet (6,300,000,000 barrels; 1,002,000,000 cubic metres) of water produced with oil from the Hendrick field in Winkler County, Texas.

CONCLUSIONS

Permian Guadalupian age strata can be divided into three aquifers. The Capitan aquifer is a lithosome that includes the Capitan and Goat Seep Limestones and most or all of the Carlsbad facies of Meissner (1972). Some of the shelf-margin carbonate banks or stratigraphic reefs in the upper part of San Andres Limestone are included within the Capitan aquifer whenever they cannot be readily distinguished from the Goat Seep Limestone and Carlsbad facies. Saturated strata yielding significant quantities of water from the San Andres Limestone and the Bernal and Chalk Bluff facies of Meissner (1972) comprise the shelf aquifers. The contact between the Capitan and shelf aquifers is gradational and is difficult to discern with accuracy in some areas. Similarly, saturated strata yielding significant quantities of water from the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations of the Delaware Mountain Group are referred to as the basin aquifers.

The Capitan aquifer extends approximately 200 miles (322 kilometres) in a continuous and unbroken arcuate strip parallel to the northern and eastern margins of the Delaware basin from the Guadalupe Mountains southwest of Carlsbad, N. Mex. to the Glass Mountains southwest of Fort Stockton, Tex. The width of the Capitan aquifer varies from 10 to more than 14 miles (16 to 23 kilometres) along the southern edge of the Northwestern shelf from the vicinity of Carlsbad to the central part of southern Lea County, New Mexico but seldom exceeds 11 miles (18 kilometres) along the western margin of the Central Basin platform. The thickness of the Capitan aquifer averages about 1,200 feet (365 metres) but a thickness of more than 2,300 feet (700 metres) was mapped in a small area east of Carlsbad. Depths to the top of the Capitan aquifer in New Mexico vary from not more than a few hundred feet in the Pecos River valley at Carlsbad to more than 4,300 feet (1,310 metres) in the western part of southern Lea County. Depths to the Capitan aquifer vary from less than 2,500 to more than 3,300 feet (760 to 1,005 metres) throughout Winkler, Ward and the northern part of Pecos Counties, Texas.

Submarine canyons and reentrants of Guadalupian and (or) earliest Ochoan age similar to those that have been mapped at surface exposures in the Guadalupe Mountains and Delaware basin by previous investigators have been located in the subsurface along the northern and eastern margins of the Delaware basin. The submarine canyons are filled with material with a relatively low hydraulic conductivity. The thickness, and correspondingly, the transmissivity of the Capitan aquifer are both reduced very significantly by local incision of the submarine canyons that are usually oriented transverse to the arcuate trend of the aquifer.

The location of the largest and most deeply incised submarine canyon, the West Laguna submarine canyon, coincides approximately with the positions of both the most rapid decline in the hydraulic head and the strongest eastward gradient in the present-day potentiometric surface near the boundary between Eddy and Lea Counties, New Mexico. The behavior of the hydraulic head in response to stresses and the shape of the potentiometric surface both confirm the existence of a zone with low transmissivity and restricted circulation in the Capitan aquifer.

New wells could not be drilled to evaluate the characteristics of the Capitan aquifer because of economic limitations. Aquifer performance tests were accomplished on two wells completed in the Capitan aquifer and one well producing from the San Andres Limestone in cooperation with oil companies. Limited additional information was obtained from the literature and from private sources. These data, albeit meager, suggest that the hydraulic conductivity of the Capitan aquifer along the northern margin of the Delaware basin ranges from about 1 to perhaps as much as 20 ft/day (0.3 to 7.6 m/day). Other limited information suggests that the hydraulic conductivity of the Capitan aquifer along the western margin of the Central Basin platform in Texas is similar. An average hydraulic conductivity for the Capitan aquifer of about 5 ft/day (1.5 m/day) would appear to be reasonable for most areas east of the Pecos River at Carlsbad and north of the Glass Mountains. The hydraulic conductivities of the shelf aquifers east of the Pecos River valley between Roswell and Carlsbad and the basin aquifers, are from one to two orders of magnitude lower than that of the Capitan aquifer. The transmissivity of the apparent restriction in the Capitan aquifer near the Eddy-Lea County boundary probably is similar to that of the shelf and basin aquifers.

Water containing a relatively low chloride-ion concentration is present in the Capitan aquifer throughout the region. Most of the shelf aquifers, in areas west of the Pecos River at Carlsbad, in zones near the Capitan aquifer along the margin of the Norwestern shelf and Central Basin platform, and in localities at the north and south ends of the Central Basin platform, also contain water with a relatively low chloride-ion concentration.

In sharp contrast, the rocks of Guadalupian age on the Northwestern shelf, east of Artesia, N. Mex., the medial part of the Central Basin platform, and in the Delaware basin, contain water with relatively high concentrations of chloride-ion.

Fingers of the best quality of water found in the Permian rocks extend into the Capitan aquifer from recharge areas in the Guadalupe and Glass Mountains. Isochlore patterns suggest that the bulk of the relatively good quality water found in the Capitan aquifer came from the Glass Mountains.

The saline-fresh water interface in the Capitan aquifer is located at an altitude of approximately 2,350 feet (715 metres) above sea level in the vicinity of Carlsbad, N. Mex. indicating that the fresh water in the Capitan aquifer west of the Pecos River in this area is only about 750 feet (230 metres) thick.

A series of linear lens-shaped depressions form a narrow trough extending northward from near Belding in southwestern Pecos County, Texas in an arcuate trend above and parallel to the Capitan aquifer to the vicinity of the San Simon Swale in southern Lea County, New Mexico. The trough was formed when halite was dissolved and removed from the Salado and Castile Formations by ground water moving northward from the Glass Mountains through fractures and joints in the adjacent and underlying Capitan and shelf aquifers. The Belding-San Simon trough is filled with collapsed Triassic and Cretaceous strata and younger alluvium and documents the relative age of the emplacement of water into the Capitan aquifer along the western margin of the Central Basin platform.

Twelve observation wells have been completed in the Capitan aquifer in Eddy and southern Lea Counties, New Mexico in order to monitor the effects of fluid production from this aquifer and other aquifers in measurable hydraulic communication. Very small net changes in the water levels, generally due to climatic and water-use conditions in the Pecos River valley, have been noted in six of the seven wells in Eddy County over a 3-to 6-year period. However, the water levels in one well in extreme eastern Eddy County and five wells in southern Lea County have declined from about 23 to 126 feet (7 to 38 metres) at rates of 0.32 to 1.70 feet per month (0.098 to 0.52 m/month) during the period 1967 through 1972. This decline is due to (1) the withdrawal of water from the Capitan aquifer in Lea County, New Mexico and Ward and Winkler Counties, Texas to supply water for use in the secondary recovery of oil, and (2) the production of petroleum and associated waste water from formations of Permian Guadalupian age that are in measurable hydraulic communication with the Capitan aquifer in this same area.

Ground water in the Capitan aquifer in both Texas and New Mexico is being diverted to a "regional center of pumping" just to the west of Kermit, Texas, where the potentiometric surface has been lowered approximately 700 feet (215 metres) in response to withdrawal of water and petroleum from the Capitan and associated aquifers during a period of about 45 years. The water table in the Capitan aquifer in the Glass Mountains has declined about 300 feet (90 metres) during the same period and the head has been lowered approximately 150 feet (45 metres) in the vicinity of a former ground-water divide near the boundary between Eddy and Lea Counties, New Mexico.

The deeply incised submarine canyons in eastern Eddy County, New Mexico form a hydraulic restriction that effectively controls movement of water in the aquifer from the Pecos River at Carlsbad eastward under present day conditions. However, movement of much greater volumes of water from the Pecos River into the Capitan aquifer may occur at an unknown future time if the differential in head across the restriction becomes large enough.

RECOMMENDATIONS

The following recommendations are made as a result of this study: (1) surveillance of the water-level changes in the Capitan aquifer should be continued by maintaining and operating the Capitan aquifer observation-well network indefinitely; (2) the observation-well network should be augmented by acquiring and completing one additional well in a location 5 to 8 miles (8 to 13 kilometres) west of the boundary between Eddy and Lea Counties, New Mexico, and near the south edge of the Capitan aquifer; (3) geologic and hydrologic studies should be continued in an effort to determine, quantitatively, the aquifer characteristics of the apparent restriction to movement of ground water in the Capitan aquifer in eastern Eddy County; (4) the amount of water being withdrawn from the Capitan and other aquifers in measurable hydraulic communication with this aquifer in Lea County, New Mexico and Winkler and Ward Counties, Texas, should be recorded. The reliability of the data now in the files should be evaluated to eliminate errors made by estimating production; and (5) computations should be made, preferably using a numerical model, to determine the magnitude of any significant diversion of water from the Pecos River at Carlsbad that could possibly result at some time in the future as the stresses are increased by continued withdrawal of water.

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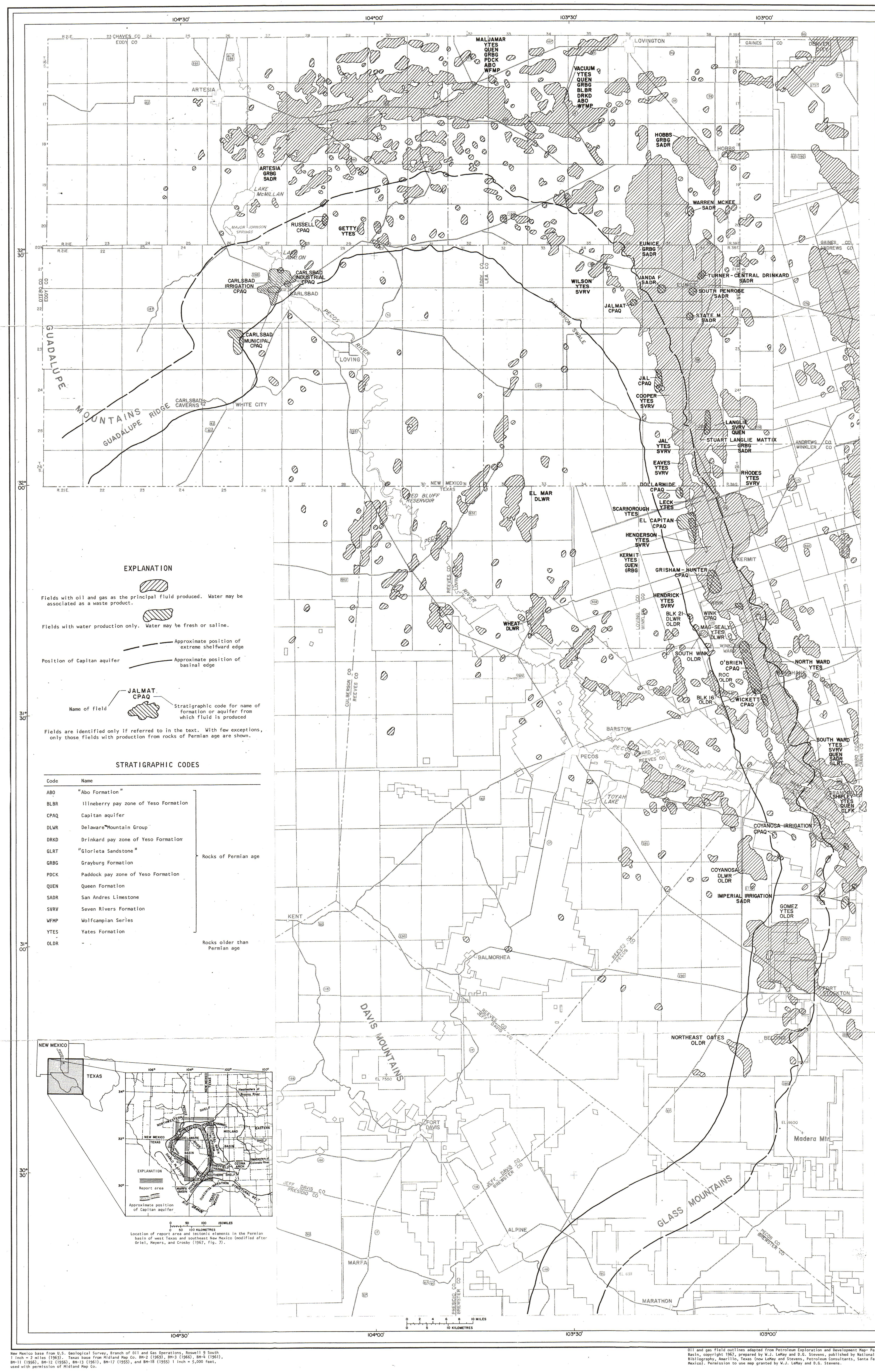

New Mexico base from U.S. Geological Survey, Branch of Oil and Gas Operations, Roswell 9 South 1 inch = 2 miles (1963). Texas base from Midland Map Co. BM-2 (1969), BM-3 (1966), BM-4 (1961), BM-11 (1956), BM-12 (1956), BM-13 (1961), BM-17 (1955), and BM-18 (1955) 1 inch = 5,000 feet, used with permission of Midland Map Co.

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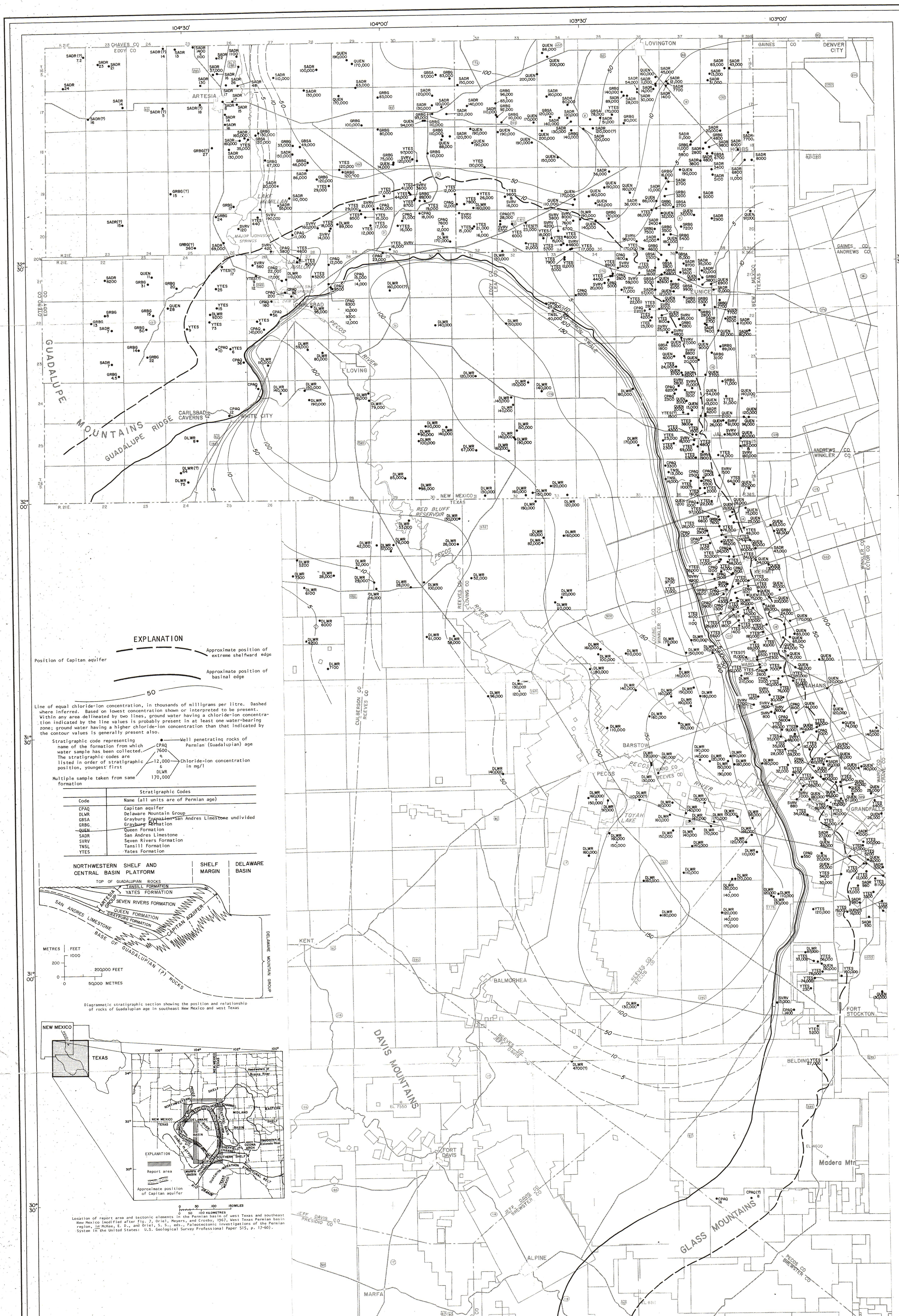
FIGURE 19-- MAP SHOWING LOCATION OF OIL, GAS, AND WATER FIELDS WITH PRODUCTION FROM ROCKS OF PERMIAN AGE IN THE DELAWARE BASIN AND SURROUNDING AREAS



New Mexico base from U.S. Geological Survey, Branch of Oil and Gas Operations, Roswell 9 South 1 inch = 2 miles (1963). Texas base from Midland Map Co. BM-2 (1969), BM-3 (1966), BM-4 (1961), BM-11 (1956), BM-12 (1956), BM-13 (1961), BM-17 (1955), and BM-18 (1955) 1 inch = 5,000 feet, used with permission of Midland Map Co.

FIGURE 26-- MAP SHOWING THE CHLORIDE-ION CONCENTRATION IN PERMIAN GUADALUPIAN AGE SEDIMENTARY ROCKS

Reasonably Foreseeable Development Scenario for Oil and Gas Activities

Carlsbad Field Office, Eddy County, Southeastern New Mexico

Principal Investigator: Dr. Thomas W. Engler

Petroleum Engineering Department, New Mexico Institute of Mining and Technology,

801 Leroy Place, Socorro, NM 87801

Final Report

submitted

to:

Dave Herrell, Project Manager
Carlsbad Field Office
U.S. Department of the Interior
Bureau of Land Management
620 E. Greene St.,
Carlsbad, NM 88220

July 10, 2023

Disclaimer

The views and conclusions contained in this document are those of the author and should not be interpreted as representing the opinions or policies of the U.S. Government. Mention of trade names or commercial products does not constitute their endorsement by the U.S. Government or New Mexico Institute of Mining and Technology.

The views and conclusions contained in this document are derived from observations and interpretations of public and non-public data and other sources of information. The author has applied best efforts to utilize scientific methods to arrive at objective conclusions but shall not be held liable for any misinterpretation or misapplication of the conclusions presented herein.

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I would like to recognize and thank Enverus™ for allowing to use their databases to develop and interpret large sets of information required on this project. Without access to this information many interpretations and conclusions could not be drawn.

I would like to acknowledge all the previous efforts by others that laid the geologic and engineering foundation that this work rests on. The geologic foundation of this work rests on the play-based analysis accomplished by Ron Broadhead of the New Mexico Bureau of Geology and Mineral Resources and many others. Without this previous work, I could not proceed.

And last, I would like to express thanks to the U. S. Bureau of Land Management for funding this important project.

Executive Summary

The proposed Reasonably Foreseeable Development (RFD) scenario is to provide the Carlsbad Field Office (CFO) a projection of the potential future oil and gas development activity for the next 20 years (starting in 2023) to assist the BLM's Resource Management Plan. Included are projections for vertical and horizontal wells drilled, future surface disturbance accompanying this development, water production and use, and oil and gas production volumes. The RFD establishes a baseline scenario that can then be used to compare the resource management plan with its alternatives and to analyze the long-term effects that could result from oil and gas activities.

The New Mexico portion of the Permian Basin is well-known for being a highly productive oil and gas region. Recently, a significant increase in production has occurred in response to technology advancements in horizontal drilling and multistage completions unlocking the hydrocarbons in the unconventional reservoirs. Past activity is cyclical, depending on a variety of factors such as commodity price, resource potential, and technology advancements. For BLM planning purposes, projections of future **oil and gas production** is needed. To accomplish, future annual oil and gas production was generated using decline curves from historical production data and then extrapolated into future years to acquire remaining production for existing wells and future production from new well development.

In the short term the trend of increasing oil production is anticipated to continue until 2025. This year (2025) was selected based on current 2022 EIA Energy Outlook reference case projections for oil price peaking in 2025 and then remaining at a relatively stable but lower value afterwards. In the long term the expectation is for new well production to reduce as the resources become less prolific, resulting in a decrease in well development. The average wells spudded on Federal-managed lands from 2011 through 2021 was 617 new spuds per year, thus a short-term prediction of 770 new spuds allow for the continued upward trend in development over the short term. In total, 12,500 wells are predicted to be drilled and completed on Federal lands managed by the BLM in the CFO. The majority (~90%) of this development will be horizontal completions and the main targets will be the unconventional Bone Spring and Wolfcamp plays. Over the 20-year forecast period, cumulative production from existing and new wells on Federal-managed lands is estimated to be 5.4 billion BO, 20.5Tcf gas, and 18 billion BW.

The Federal portion represents 60% of the total activity in the area of interest, thus the total (Federal and non-Federal) well development is projected to be 19,600 of which 90% are horizontal. The total (Federal and non-Federal) historical spuds from 2011 through 2021 average 1,031 per year. In comparison, the total new well spud count is projected to be 1,208 in the beginning of the forecast period, declining to 769 wells at the end of the twenty-year period. Over the 20-year forecast period, cumulative production from existing and new wells for Federal and non-Federal ownership is estimated to be 8.6 billion BO, 33 Tcf gas, and 30 billion BW.

As **water** is limited and thus essential in arid New Mexico for agriculture, domestic consumption, industry, and other beneficial uses, it is important to assess and predict the associated water production and the corresponding use of water in oil and gas development. Water production is estimated to be 30 billion barrels of water over the life of the plan or 1.5 billion barrels per year.

Water production has been increasing with the increasing development of oil in the area, and thus is intrinsically tied to the hydrocarbon production scenario. Water production has averaged approximately 1 billion barrels of water per year over the last twelve years, thus a 50% increase in water production is projected for the RFD time period, capturing the increasing trend observed the last several years.

Most produced water is either injected for enhanced oil recovery or disposed. However, the percent of produced water injected and disposed has been decreasing with time from >90% in 2011 through 2017 to a low of 50% in 2022. The remaining is used by oil and gas development as indirect, direct or ancillary. Gonzalez, et al, 2023 defines direct water use as water used in a wellbore to complete a well, which includes water used for drilling, cementing, stimulating, and maintaining the well during production. Indirect water use is defined as water used at or near the well site, including water used for dust abatement, equipment cleaning, materials washing, worker sanitation, and site preparation. Ancillary water use is defined as all other water used during the life cycle of oil and gas development that is not categorized as direct or indirect, such as additional local or regional water use resulting from a change (for example, population) related to oil and gas development (Valder, et al, 2021). Analysis identified stimulation, specifically hydraulic fracturing, as the major use of produced water, accounting for 99% of the direct water use. On average, 465 thousand bbls of water per well is required for stimulation of a 2-mile horizontal lateral, or a total of 8,137 million bbls will be needed for future oil and gas well development over the twenty-year span.

The additional subsurface development projected in the next twenty years will require associated **surface development** of roads, flowlines and well pads. To acquire the surface disturbance for new development and existing infrastructure was determined from surface disturbance data extrapolated from the U.S.G.S. Vegetation Data (Villarreal, et al. (2023). The total (Federal and non-Federal) existing acreage is approximately 109,000 acres, of which 60% or 65,400 acres is the Federal portion. For the twenty-year period, it is estimated an additional Federal and non-Federal 33,300 acres of disturbance is required (~ 20,000 acres - Federal portion), which includes both vertical and horizontal well development. Combining existing and new development results in the maximum potential disturbance of 142,400 acres or 85,300 acres on Federal-managed lands.

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List of Abbreviations and Acronyms

AAPG	American Association of Petroleum Geologists
AGI	Acid Gas Injection
AOI	Area of Interest
APD	Application to Permit to Drill
BEG	Bureau of Economic Geology, Texas
BLM	U.S. Bureau of Land Management
BO	Barrels of oil
BOPD	Barrels of oil per day
BSCF or BCF	Billion standard cubic feet (gas)
CO_2	Carbon Dioxide
CBP	Central Basin Platform
CFO	Carlsbad Field Office
DOE	U.S. Department of Energy
DOI	U.S. Department of Interior
EIA	U.S. Energy Information Administration
EIS	Environmental Impact Statement
EOR	Enhanced Oil Recovery
EUR	Estimated ultimate recovery
FERC	Federal Energy Regulatory Commission
ft	feet, foot
GB/SA	Grayburg/San Andres
GIS	Geographic Information System
GOR	Gas-oil Ratio, Mscf/STB
Gp	Cumulative gas production
GRI	Gas Research Institute
MBO or mstb	Thousand barrels of oil
MBOE	Thousand barrels of oil equivalent
MBBLS	Thousand barrels of liquid
MBW	Thousand barrels of water
MMSCF	Million standard cubic feet (gas)
MMBO	Million barrels of oil
MMBOPD	Million barrels of oil per day
MMBBLS	Million barrels of liquid
NMOCD	New Mexico Oil Conservation Division
ONRR	DOI Office of Natural Resources Revenue
psi	pounds per square inch (pressure)
RFD	Reasonably Foreseeable Development
RMP	Resource Management Plan
ROW	Right-of-way
SENM	Southeast New Mexico (Eddy and Lea Counties)
SPE	Society of Petroleum Engineers
Tscf	Trillion standard cubic feet of gas

U.S.	United States of America
WAG	Water-alternating-Gas
WOR	Water-oil ratio, bbl/bbl
WRRI	Water Resource Research Institute
WTI	West Texas Intermediate

Introduction

Purpose

The purpose of this update to the Reasonably Foreseeable Development (RFD) scenario is to analyze the known and potential oil and gas resources within the Carlsbad Field Office (CFO) in southeastern New Mexico, and to project the potential future oil and gas development activity for the next 20 years (starting in 2023) based on logical and technical assumptions. To accomplish the projection will require evaluation of historic and current activity to estimate future development potential (including projections for vertical and horizontal wells drilled during the life of the plan-the Carlsbad Resource Management Plan), future surface disturbance, water use for hydraulic fracturing, and oil and gas production volumes. This RFD scenario has been prepared in support of the CFO Resource Management Plan. Previous RFD scenarios for the Pecos District, which included the CFO, were completed in 2012 and 2014. The RFD is unconstrained by management-imposed conditions as it is based primarily on geology and historical exploration and development activity. It provides information to analyze long-term and/or widespread effects that could result from potential exploration and development in a defined area regardless of land ownership or jurisdiction. The RFD establishes a baseline scenario that can then be used to compare the resource management plan with its alternatives and to analyze the long-term effects that could result from oil and gas activities.

The Carlsbad Field Office administers approximately 3.0 million total acres of all Federal mineral ownership types in Eddy, Lea and portions of Chaves County, New Mexico (see Figure 1). For purposes of this work, only Eddy and Lea Counties are evaluated since no oil and gas potential is considered in Chaves County. Currently, 1.9 million acres or 63% of the total acreage is leased. Other portions of oil and gas minerals are state-owned or owned privately and are not subject to the resource management plan. All acreages presented herein are based on geographic information systems (GIS) calculations and should be considered approximate.

Draft Resource Management Plan/Environmental Impact Statement

Chapter 1: Introduction
Planning Area

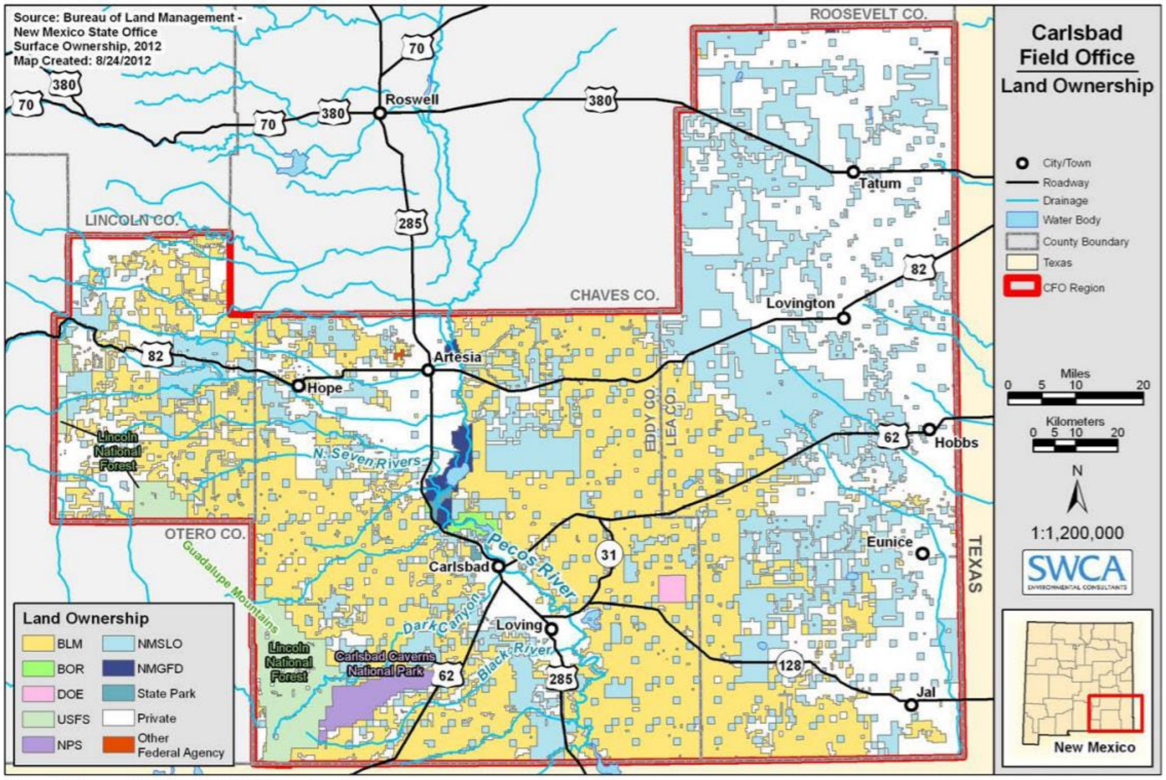

Figure 1-1. Carlsbad Field Office planning area.
(NMSLO = New Mexico State Land Office; NMDGF = New Mexico Department of Game and Fish).

BLM Carlsbad Field Office 1-4

Figure 1. BLM Carlsbad Field office land ownership map. {Map courtesy of BLM}

In analyzing historical data, production volumes are reported as a total of what the reservoir or well capacity is, independent of ownership. To acquire the federal portion, the federal volumes reported by DOI Office of Natural Resources Revenue (ONRR) were compared to the total production volumes acquired from NMOCD over an eleven-year (2011-2021) time period for Eddy and Lea Counties. Over this time, the federal portion as a percent of the total volume has been increasing for both oil and gas. This suggests more development is occurring on federal lands. To capture this trend, the latest values (Federal portion: 61% gas and 64% oil) were used for the prediction phase of this project.

Data sources

Information presented in this report was compiled from various sources. Historical and current well data (including production volumes) were acquired primarily through the GOTECH system. (http://octane.nmt.edu/gotech/) In addition, specific data was analyzed from Enverus™. Geological data were sourced from New Mexico Bureau of Geology and Mineral Resources reports and various professional publications. Information on water production and use was provided by the U.S.G.S. Water support group. The U.S.G.S. Vegetation group provided surface use associated with oil and gas development. Information regarding price commodity trends was taken from the Energy Information Administration.

Historical Activity

The New Mexico portion of the Permian Basin is well-known for being a highly productive oil and gas region. Recently, a significant increase in production has occurred in response to technology advancements in horizontal drilling and multistage completions unlocking the hydrocarbons in the unconventional reservoirs. Figure 2 shows the increase in monthly oil production for SENM (defined as Eddy and Lea Cos.) since 2011, achieving over 40 MMBO in December 2021 or approximately 1.4 MMBOPD.

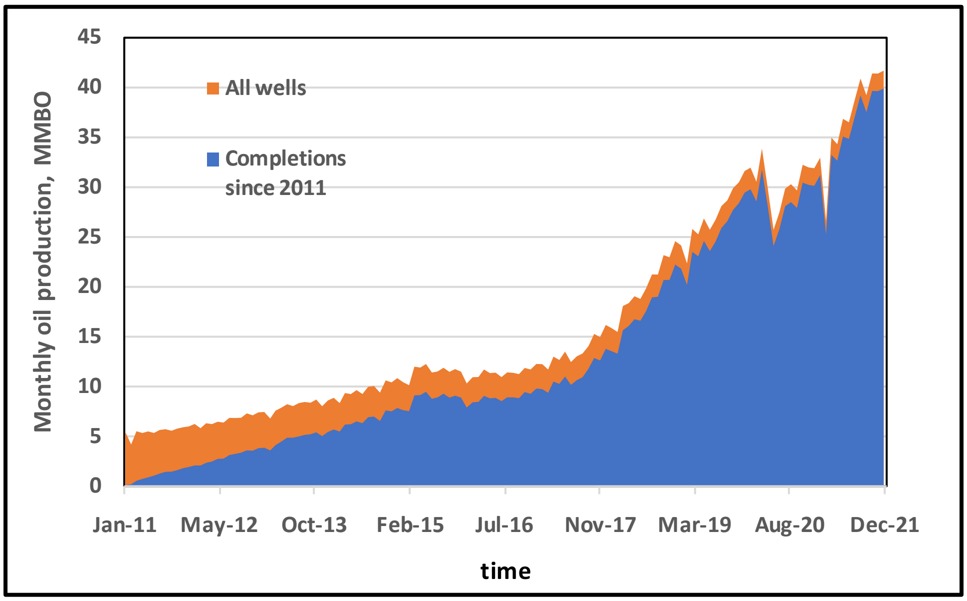

Figure 2. Monthly oil production for all plays in Eddy and Lea Co., SENM (Source: GOTECH/NMOCD)

Recent completions dominate production output, which accounted for approximately 95% of the total oil production in 2021. Remarkably, this high production volume comes from a fraction of the total well's activity. Figure 3 shows total active well count is somewhat constant at 25,000 per year over the eleven-year time period. New well completions since 2011 have steadily inclined to approximately 10,000 at the end of 2021. This increase has been balanced by wells that have been P&A, shutin, or TA and are no longer active.

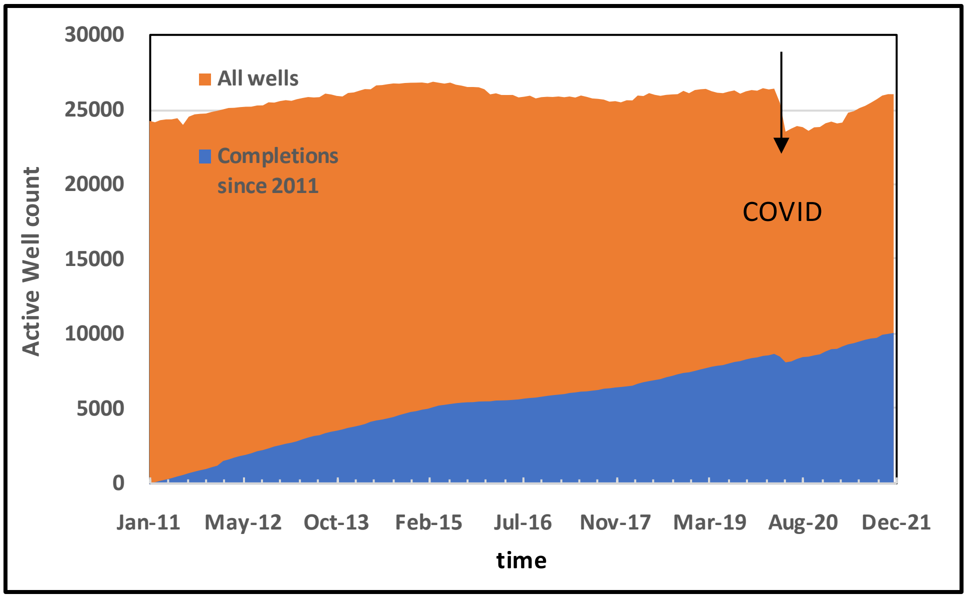

Figure 3. Active well count for all plays in the AOI (Source: GOTECH/NMOCD)

Activity is cyclical, depending on a variety of factors such as commodity price, resource potential, and technology advancements. To identify trends necessary for predictions, further analysis was performed on the recent completions. Shown in figure4 are the annual well completions shown as a bar graph from 2011 through 2021 compared to the WTI spot price (EIA,2022) represented by the solid orange line.

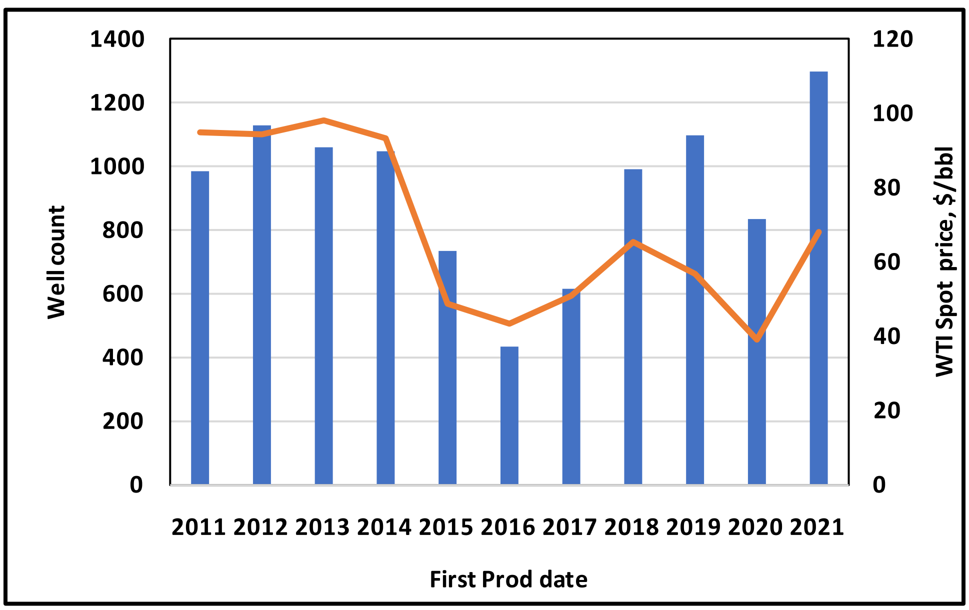

Figure 4. SENM annual well completions {Source: GOTECH/NMOCD} vs WTI Spot price {Source: EIA 2022}

Over this eleven-year time period, a total of 10,195 completions have occurred for an average of 927 completions per year. In 2015-2016, oil prices dropped below $50/bbl and the well completion count swung dramatically lower to 430. Between 2017-2018 oil prices were trending upwards at over $60/bbl resulting in a 132% increase in well completions by 2018. This cycle repeated was again between 2019-2021. The correlation of well activity with oil price is evident and suggests commodity price is a key component to development. In addition to commodity price, technological advancements in horizontal drilling and completions and a better understanding of the complex nature of unconventional reservoirs occurred during this time period. Figure 5 shows the annual well completions separated by well type, i.e., horizontal vs. vertical+ (vertical + directional + other).

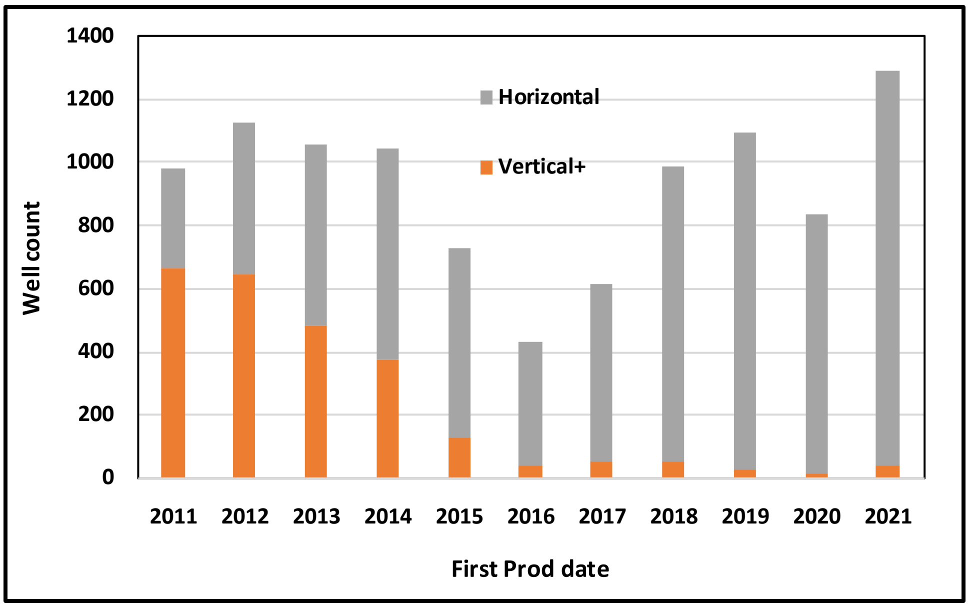

Figure 5. Annual well completions separated by well type; horizontal vs vertical+ {Source: GOTECH/NMOCD}

The increase in horizontal well completions is evident; from a third of all completions in 2011 to 97% in 2021. Horizontal completions over the last four years (2018-2021) have averaged 1000 completions per year.

Not only has the number of horizontal well completions been increasing, but also the lateral length. As shown in Figure 6, the gross perforated interval for horizontal well completions has increased to average 8,500 ft. (approximately 1 ½ miles) lateral length. In this work, the gross perforated interval is defined as the distance from the uppermost to lowermost perforation in the lateral. This distance will be less than the total lateral length and the surface-to-bottomhole distance.

In summary, the well activity and corresponding production strongly correlates with commodity pricing (Fig. 4) and advancements in horizontal drilling and completions (Figs. 5 and 6).

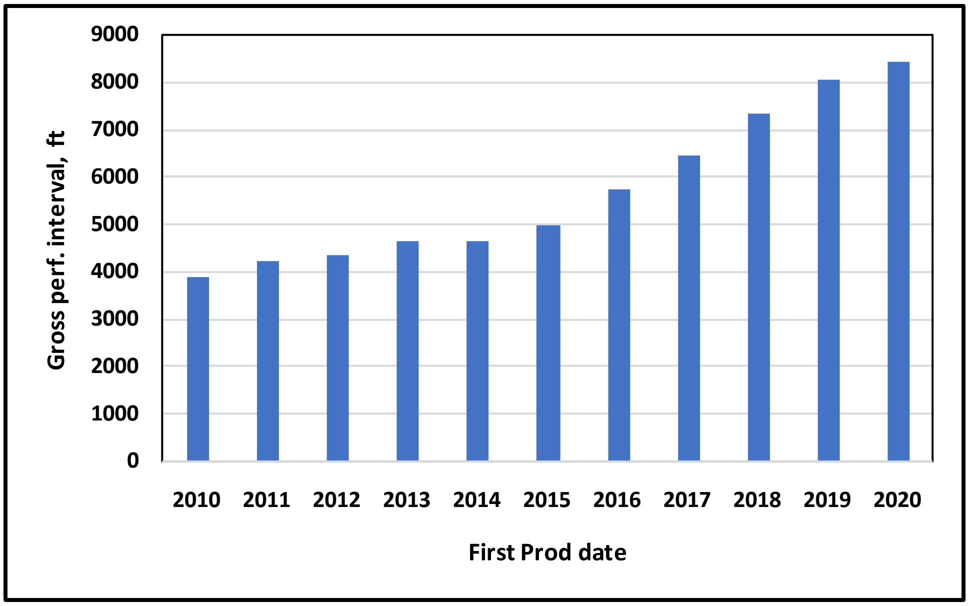

Figure 6. Gross perforated interval for horizontal well completions as a function of date of first production {Source: Enverus}

In the previous RFD and update, historical activity and predicted development was separated into defined plays (Broadhead et al, 2004). Table 1 lists the plays, the 2014 RFD results and recommendations, and the recent (2015 through 2021) activity, well type and activity trend. The scale in the bottom right corner of Table 1, defines the potential in wells per year as defined in the 2012 RFD and 2014 RFD update. The "over" and "under" in the far-right column indicates plays where the prediction overestimated or underestimated the actual activity. The most significant under-prediction was the Wolfcamp play.

	2014 RFD Results and recommendations			Statistics -2015 through 2021				
Minor Play	HC type	Potential	Comments	Average*	% Horiz	Last	Trend	
Abo Platform Carbonate	OIL	High	Additional development, horizontal, waterflooding, EOR	4	25%	2	decline	over
Artesia Sandstone Group	OIL/GAS	Moderate	Mature, shallow targets	3	4%	3	constant-low	over
Gas				2.5		1	decline	
Atoka & Atoka-Morrow	GAS	Low	Infill available, no gas price	1.5	28%	1	decline	
Morrow	GAS	Low	Infill available, no gas price	1	0%	0	decline	
Mississippian	GAS	Low	No gas price					
Woodford	OIL/GAS	Low	High risk, likely re-completions in existing wells					
Delaware Mountain Group	OIL	High	Development, waterflooding, EOR	16	73%	1	decline	over
Deep, mature oil				<1	0%	1	constant-low	
Ellenburger	OIL	Low	Limited resource, mature, deep	0	0%	0	constant-low	
Fusselman	OIL	Low	Limited resource, mature, deep	0	0%	0	constant-low	
Simpson Sandstone	OIL	Low	Limited resource, mature, deep	0	0%	0	constant-low	
Wristen	OIL	Low	Limited resource	<1	0%	1	constant-low	
Leonard	OIL	Very high	Infill and extension drilling of Yeso	66	55%	54	decline	over
Penn				5	27%	1	decline	
Penn - NW shelf	OIL/GAS	Low	Limited extent, mostly gas play					
Penn - Strawn patch reef	OIL/GAS	Low	Limited resource					
San Andres				26	24%	10	decline	
NW Shelf	OIL	Low	Mature, long term EOR-CO2 potential	6	93%	3	decline	
Artesia-Vacuum GB/SA	OIL	High	Mature, long term EOR-CO2 potential	11	5%	5	decline	over
Central Basin Platform	OIL	Moderate	Mature, long term EOR-CO2 potential	9	3%	2	decline	over
Major Play	HC type	Potential	Comments	Average*	% Horiz	Last	Trend	Trend
Bone Spring	OIL	Very high	Development of sands and Avalon, horizontal wells	391	99%	437	steady	
Wolfcamp	OIL/GAS	Moderate	Additional oil development w/horizontal wells	375	96%	595	increasing	under
		Notes				Scale	wells/yr	
		1	*Average completions per year from 2015 through 2021			Low	<25	
		2	% horizontal over the average time period			moderate	25 to 50	
		3	Last - number of wells completed in 2021			High	50 to 100	
		4	trend			Very high	> 100	

Table 1. 2014 RFD results and recent summary statistics separated by play.

In this work, the play nomenclature has been kept consistent with the previous work; however, the plays have been categorized based on their general attributes and similarities.

Major plays include the two dominant plays: Bone Spring and Wolfcamp. As will be seen, these plays are mostly oil-prone, albeit some more gassy than others, almost exclusively completed with horizontal wells, and require significant stimulation.

Minor plays include the Abo platform carbonates, Artesia Sandstone Group, Delaware Mountain Group, Leonard, and all the San Andres. These plays are similar in that all are mostly oil prone, have exhibited limited development from 2015 through 2021, and have a declining trend in development with time.

Gas plays include the Atoka and Atoka-Morrow, Morrow, Mississippian and Penn plays. Production from these plays is mostly if not all gas and as a result heavily dependent on natural gas price.

Deep, mature oil plays are the Ellenburger, Fusselman, Simpson and Wristen plays. All are very mature and depleted, with extremely limited production potential; however, these plays have been excellent candidates for saltwater disposal.

Play Analysis

Major Plays

Included in the major plays category are the Bone Spring and Wolfcamp plays. The magnitude of both plays can be observed in oil production (Figure 7) and in well count (Figure 8) from wells with a first production start date in 2011. Early in this time period, other plays, particularly the Leonard Yeso, dominated in both well count and production. Later (circa 2014-15), the Bone Spring rapidly developed while the other plays remained relatively constant. In 2016, Wolfcamp development began to spike and has continued to increase year over year in response to available acreage for spacing wells providing an opportunity in New Mexico for the increased development. Through 2021, both Bone Spring and Wolfcamp have dominated, accounting for 85% of all oil and gas production from wells completed since 2011, and approximately 65% of all wells completed.

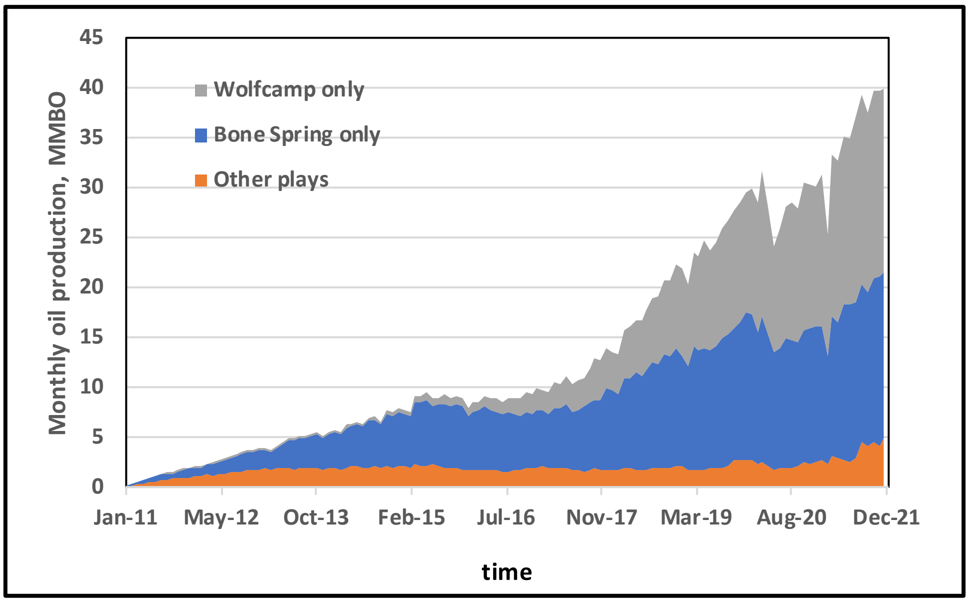

Figure 7. Monthly oil production from wells with first production date of 2011separated by Wolfcamp, Bone Spring and all other plays combined. {Source: GOTECH/NMOCD}

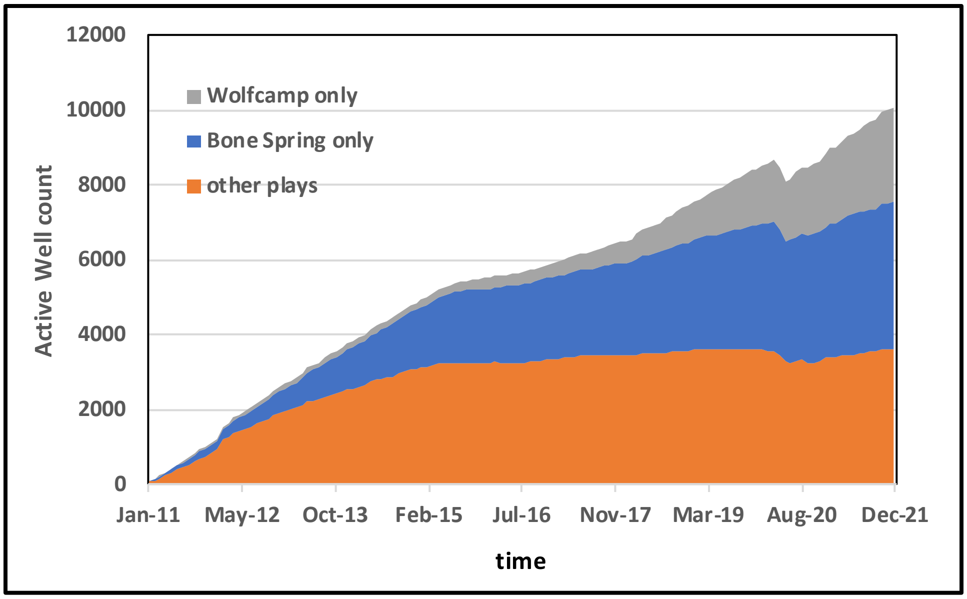

Figure 8. Monthly active well count separated by Wolfcamp, Bone Spring and all other plays combined. {Source: GOTECH/NMOCD}

<u>Minor, Gas, and Deep Mature Oil Plays</u>

Since the level of activity and corresponding production for the other three categories is extremely limited, the data has been combined and is shown in Figures 9 and 10, respectively. Within this group, the Minor plays, mostly the Leonard Yeso play, dominate production and well count.

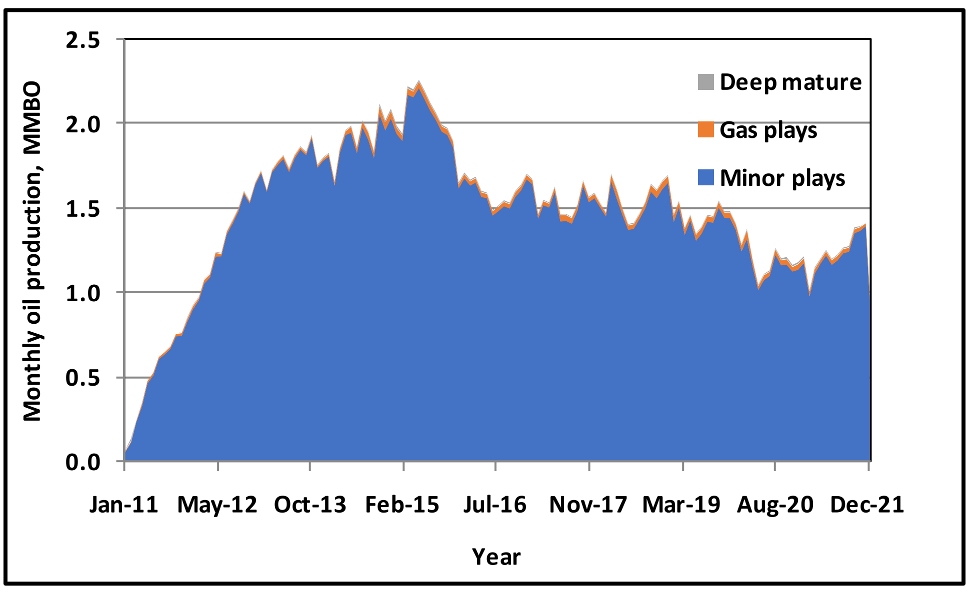

Figure 9. Monthly oil production separated by Minor, Gas, and Deep mature plays. {Source: GOTECH/NMOCD}

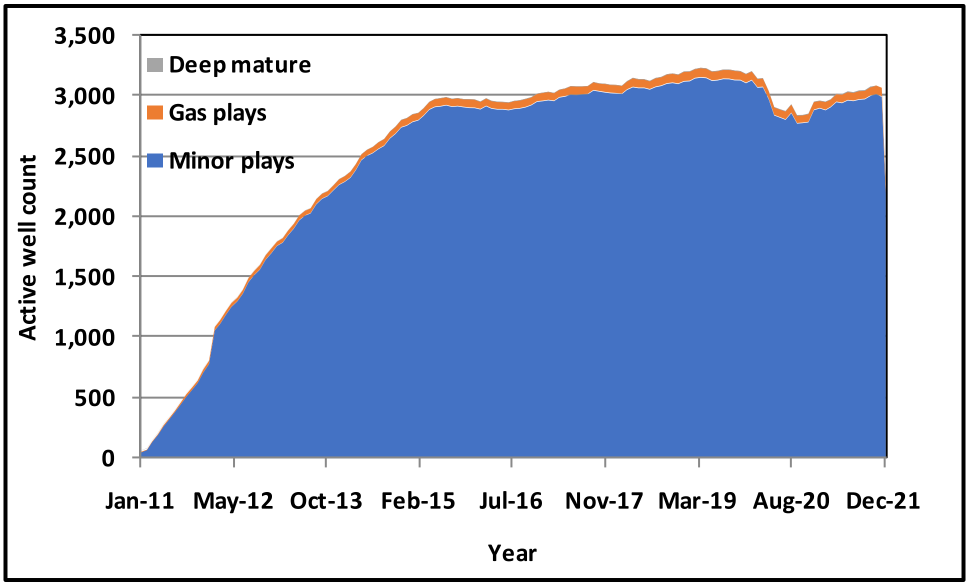

Figure 10. Monthly active well count separated by Minor, Gas, and Deep mature plays. {Source: GOTECH/NMOCD}

Further discussion and details for the plays included in the four categories listed above are presented in the Appendices A through D.

<u>Recent Activity</u>

An indicator of future interest and activity of industry is to review the submitted drilling permits. Subsequently, statistics from NMOCD were compiled and are shown in Figure 11. Unfortunately, the majority of wells (>50%) do not provide a formation on the permit. As expected, the Bone Spring and Wolfcamp dominate the known targets, but again this is not reliable given the number of wells with no formation listed. Typically, the trend of increasing and decreasing intents follow the WTI oil price, but since a significant fraction of the data is missing dependable results could not be acquired.

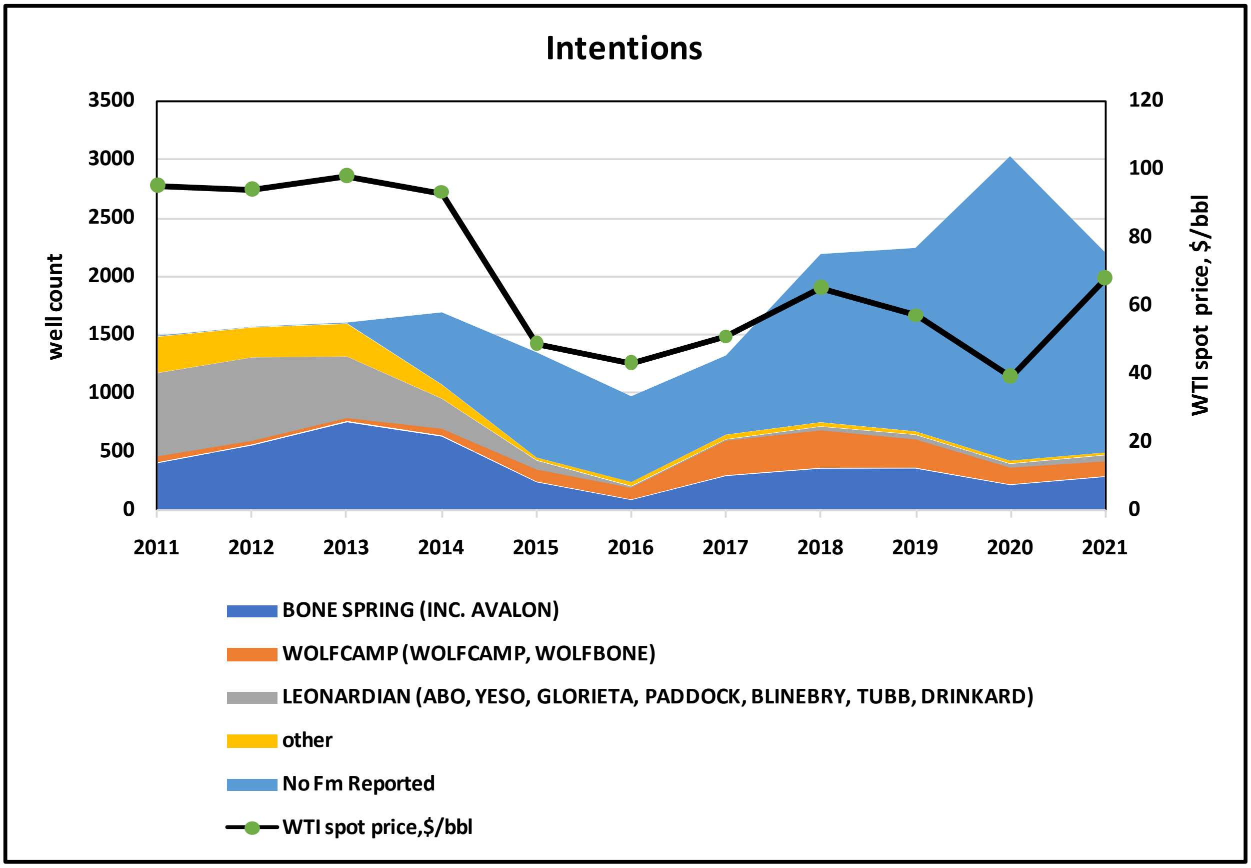

Figure 11. Intents by year and Formation type. {Source: WRRI, NMOCD}

Further analysis adjusted the drilling permits by subtracting the cancellations. Details of this evaluation can be found in (WRRI Report, 2023). Some notable findings are: 20% to 30% of APD's that are filed will eventually be cancelled, average time between the APD report and cancellation is approximately three years, and cancellations increase for plays with higher activity. A final caveat is the significant uncertainty in the data reporting of cancellations.

A comparison between intents less cancellations and completions are shown in Figure 12. Prior to 2017 the two trends were closely aligned and thus the time to completions was less. The increase difference starting in 2017 suggests industry has developed an inventory of potential locations for future development to be accounted for in the next several years.

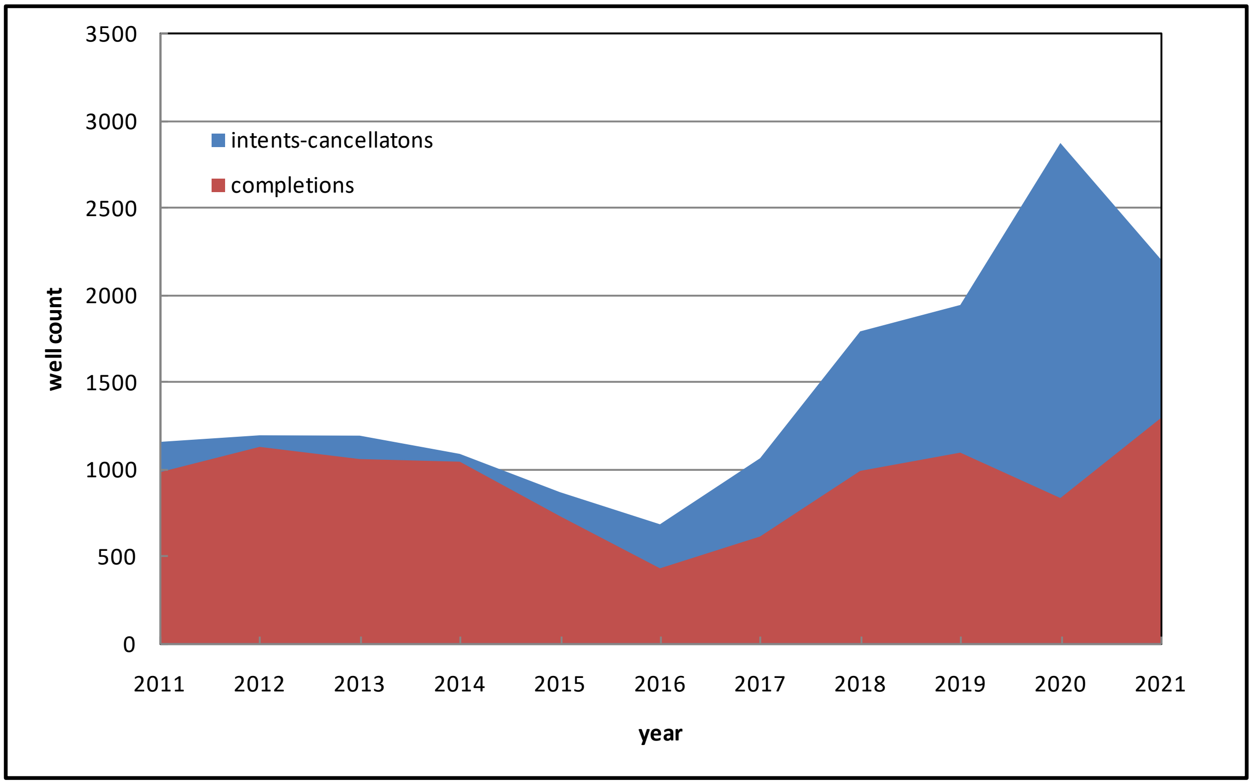

Figure 12. Well intents less cancellations compared to completions for SENM from 2011 through 2021. {Source: NMOCD/GOTECH}

Projections of Future Activity

Factors Impacting Predicted Development

The focus of this project is to predict future development in the Carlsbad Field Office area for twenty years. Specific items required are the number of new wells to be drilled and completed, the estimated ultimate recovery of this activity, the net surface disturbance created by this development and the water balance between production and use. To accomplish this estimate requires numerous assumptions and constraints. To simplify, these factors have been divided into two categories, internal and external. The geologic controls and engineering principles that control development of the resource are internal factors directly related to the resource Items such as shale content, lithology, porosity, permeability, natural fracture intensity and orientation, stress magnitude and orientation are just a few of the geologic parameters that control the extent and productivity of a given well. Engineering principles including completion effectiveness, stimulation and horizontal well design, artificial lift, and optimization also influence well productivity.

To evaluate all the factors and develop a comprehensive model is beyond the scope of this project. Instead, the approach was to use historical well data such as production volumes, number of wells, type of wells, horizontal lateral length, etc.) as a proxy for the factors listed above. That is, production type curves were created and analyzed for various subgroups (plays, reservoirs, well types, etc.). To create these type curves, sufficient subgroup data was appropriately analyzed, and meaningful results obtained. In the area of interest, applying production criteria is considered valid, since the primary activity is the development of the unconventional resources with horizontal wells while the secondary activity the continuing EOR projects.

Another internal factor is the advancement in technology that unlocks and expands the resource. Advancements such as improved reservoir characterization, extending horizontal drilling length and multistage stimulation techniques are three of the most important recent developments. Current well-established technologies are implicitly included in the production type curve analysis. However, the prediction of unknown new technologies to be employed in the future or more importantly their impact, is not feasible. It is also worth noting that undeveloped unconventional resources will require these future technologies to be productive. In the 2012 RFD, two such undeveloped resources that were mentioned as "possible" are the Woodford Shale and the San Andres Residual Oil Zone (ROZ). As of today, neither has been an active target. A third application of technology that is being investigated is EOR processes in unconventional reservoirs using horizontal wellbores. Research and pilot tests are ongoing in the Eagle Ford (Barden et al, 2020) and Bakken Formations (Rassenfoss, 2022).

External factors are defined as those items that are nationwide or global in nature. Factors in this group include commodity prices, economic growth, and market competition from other energy sources. The EIA (2022) has developed a useful and comprehensive methodology to incorporate these factors for their future predictions, and thus was relied upon in this work as the template to account for their impact on development. Details of their methodology and results can be found in EIA (2022, 2023) and thus will not be explained here. As an example of the impact of oil price on activity, Figure 4 illustrates the well-correlated trend of annual well completions to the rise and fall of oil price from 2011 through 2021.

Development Potential

The result of evaluating the activity and production from 2011 through 2021 provides the basis for projecting the reasonably foreseeable development spanning 20 years beginning in 2023. Table 2 lists the estimated potential by play using the scale shown. Also included are metrics from 2015 through 2021 for comparison.

Continued minor well development of 100 wells per year is projected for all plays except Bone Spring and Wolfcamp. These wells will mostly be replacement and infill wells in existing mature plays that are not conducive to horizontal well development. These wells are indicated by the low to very-low potential indicated in Table 2. The Bone Spring and Wolfcamp are the major plays and they each account for 554 horizontal wells per year each. This activity is due to additional development of multiple reservoirs in both plays. As noted in Table 2, both plays have very high potential as indicated.

	Results and recommendations			Statistics -2015 through 2021				
Minor Play	Potential		Comments	Average*	% Horiz	2022$	Trend	
Abo Platform Carbonate	<10	Very low	infill and extension drilling	4	<1%	3	decline	
Artesia Sandstone Group	<10	Very low	Mature, shallow targets	4	<1%		constant-low	
Gas							decline	
Atoka & Atoka-Morrow	<10	Very low	Infill available, no gas price	1	0%	2	decline	
Morrow	<10	Very low	Infill available, no gas price	1	0%	1	decline	
Mississippian			No gas price					
Penn - NW Shelf+Strawn patch reef	<10	Very low	Limited resource, mostly gas play	5	27%	6	decline	
Delaware Mountain Group	10 - 25	Low	Development, waterflooding, EOR	16	73%	7	decline	
Deep, mature oil				<1	0%	1	constant-low	
Ellenburger	<10	Very low	Limited resource, mature, deep	0	0%	0	constant-low	
Fusselman	<10	Very low	Limited resource, mature, deep	0	0%	0	constant-low	
Simpson Sandstone	<10	Very low	Limited resource, mature, deep	0	0%	0	constant-low	
Wristen	<10	Very low	Limited resource	<1	0%	1	constant-low	
Leonard				66		34		
NW Shelf Yeso Subplay	25 - 50	Moderate	Infill and extension drilling of Yeso, horizontal	57	64%	30	decline	
CBP Subplay	10 - 25	Low	Infill - vertical	9	<1%	4	decline	
San Andres				26	24%	33	decline	
NW Shelf	10 - 25	Low	horizontal well development	6	93%	10	decline	
Artesia-Vacuum GB/SA	10 - 25	Low	Mature, long term EOR-CO2 potential	11	5%	10	decline	
Central Basin Platform	10 - 25	Low	Mature, long term EOR-CO2 potential	9	3%	13	decline	
Major Play	HC type	Potential	Comments	Average*	% Horiz	2022*	Trend	Trend
Bone Spring	>100	Very high	Development of sands and Avalon, horizontal wells	393	99%	712	increasing	
Wolfcamp	>100	Very high	Additional oil development w/horizontal wells	339	99%	467	increasing	

Notes

1 *Average completions per year from 2015 through 2021
2 % horizontal over the average time period
3 $ Last - number of wells completed in 2022

Scale	wells/yr
Very low	<10
Low	10 - 25
moderate	25 to 50
High	50 to 100
Very high	> 100

Table 2. Estimation of potential by play.

Development potential maps were created to visually represent the overall potential for the area of interest. Figure 13 represents a conglomeration of these potential maps. In the high potential region outlined in Figure 13, an approximate estimate of 11 additional wells per section is projected over the RFD lifespan. Activity in this region is anticipated to be horizontal well development with an average 2-mile lateral length in the Wolfcamp and Bone Spring plays. In the moderate region, 5 new wells per section is projected and is based on a mix of Wolfcamp, Bone Spring and other plays. Again, mostly horizontal development. The low potential region is projected to have minimal development and thus less than one new well per section, composed of a mix of horizontal and vertical development. Individual play potential maps can be found in the Appendices.

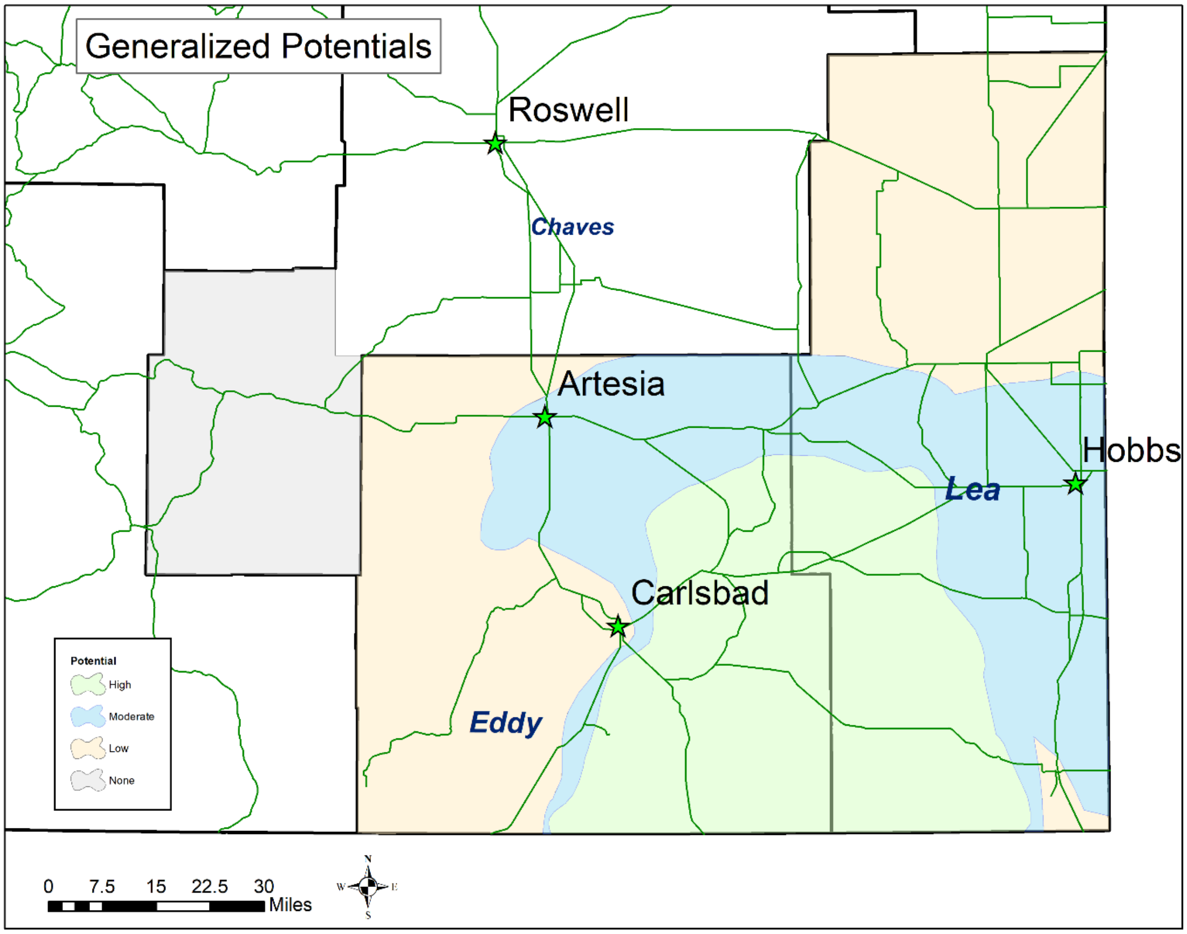

Figure 13. Conglomeration of all development potential maps for all plays. {GOTECH/NMOCD}

Estimated Future Oil and Gas Production

For BLM planning purposes, projections of future oil and gas production were created by analyzing historical production data and constructing decline curves that forecast future volumes for the next 20 years. Figure 14 shows a comparison in decline curve predictions between the RFD SE NM and the EIA's SW U.S. projections. The two trends (RFD of SENM only and the EIA estimate of Southwest U.S.) are remarkably similar until 2039 where the predictions deviate. Since the EIA estimate is for the entire Southwest region, it is hypothesized that this difference reflects an increase in development from another region outside of Southeast New Mexico.

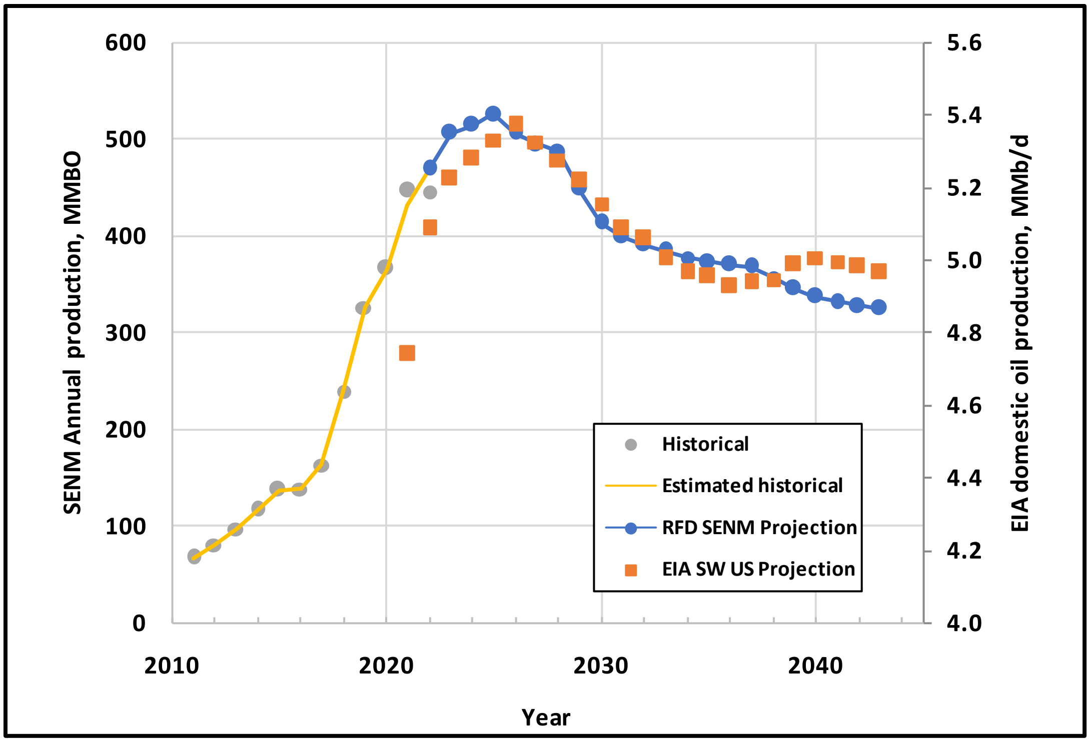

Figure 14. Historical and projected oil production for SENM {Data Sources: GOTECH/NMOCD, EIA 2022}

In the short term the trend of increasing oil production is anticipated to continue until 2025. This year (2025) was selected based on current 2022 EIA Energy Outlook projections for oil price peaking in 2025 and then remaining at a relatively stable but lower value afterwards. In the long term the expectation is for oil production to decline as reservoirs become less prolific. This also leads to a corresponding decrease in new well starts and lease development. The Federal portion of the historical number of spuds added per year from 2011 through 2022and the predicted new spuds are shown in Figure 15. Observing the dependency of the magnitude of historical spuds to commodity price, confirms the influence of price on activity level. The average from 2011 through 2021 (Note: 2022 data was ignored in this analysis) is 617 new spuds per year, and thus a short-term prediction of 770 new spuds allows for the continued upward trend in development over the short term. Over the 20-year forecast period, cumulative production from existing and new wells is estimated to be 5.4 billion BO, 20.5Tcf gas, and 18 billion BW.

The Federal portion is approximately 60% of the total spuds per year; thus, the total (Federal and non-Federal) historical spuds are 1,031 and the projected new spud count is 1,208. Over the 20-year forecast period, cumulative production from existing and new wells is estimated to be 8.6 billion BO, 33 Tcf gas, and 30 billion BW.

Footnote: Spud in this context refers to a well that is recorded as actually beginning the drilling process. This is different from the completion values provided in much of this report which is related to the actual first production of a well.

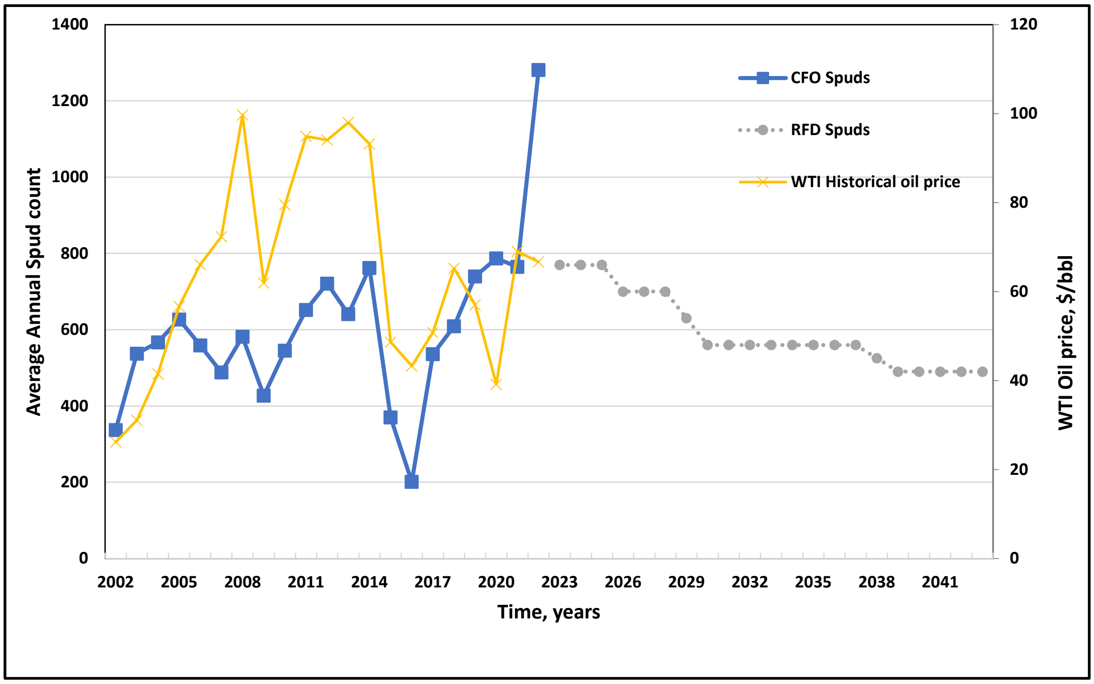

Figure 15. Historical and projected spuds on Federal lands. {Data Sources: CFO spuds from BLM, Oil price from EIA}

Estimated Surface Disturbance

Oil and gas development projected in the next twenty years will require associated surface development of roads, flowlines and well pads. To acquire the surface disturbance requirements for new development, disturbance caused by existing infrastructure was estimated and is shown in Table 3.

Surface disturbance data were extrapolated from the U.S.G.S. Vegetation Data (Villarreal, et al. (2023). The pad polygons for each of the New Mexico Oil and Gas Conservation Division well points were derived from classified 1-meter National Agriculture Imagery Program (NAIP) Imagery from 2020. The process is based on a threshold classification of the red band aimed at mapping the bright soil of the disturbed pad. The classified NAIP imagery was filtered in GIS to simplify the geometry of the polygon and fill in the gaps. Therefore, the data approximates the true size of the pad, and represents the disturbed area dominated by bright soil that is visible from aerial imagery, and not the disturbed areas that have been reclaimed or vegetated. In cases where areas around the pad were reclaimed/revegetated the true disturbance area may be underestimated. The total existing acreage is approximated to be 109,000 acres as of the end of 2020.

Year/status	Wells (n)	Pads (n)	Total pad area (ac)	Average pad size (ac)	Average area per well (ac)	Total area roads (ac)	Road area per pad (ac)	Total area disturbed (ac)
pre-2000	26,089	21,881	38,344	1.8	1.47	22,472	1.03	60,816
2001-2005	3,673	3,127	5,984	1.9	1.63	1,843	0.59	7,827
2006-2010	4,025	3,427	7,445	2.2	1.85	1,902	0.56	9,347
2011-2015	5,092	3,792	11,288	3.0	2.22	2,029	0.54	13,317
2016-2020	4,507	1,580	6,672	4.2	1.48	1,157	0.73	7,829
P&A		6,519	9,931	1.5				
Totals*	43,386	40,326	79,664	2.0	1.84	29,403	0.73	109,067

Table 3. Estimated surface disturbance at the end of 2020 from existing wells. (Federal and non-Federal combined)

*The Plugged and Abandoned pads were inferred from the data based on the SPUD year value of '9999' or '0.' The totals of surface disturbance area were included in the totals in Table 3 because the reflectance values indicate interim or unsuccessful reclamation.

Table 3 breaks down surface disturbance into summary statistics in five-year increments to include the surface disturbance associated with access roads to well pads. It includes well count, pad count, average acres per pad, average acres per well, average acres or road per pad, and total acres disturbed. The road data was interpolated based on previous work that determined that average access road width was 5 meters – thus road segment lengths were multiplied by 5 and converted to acres.

The surface disturbance for new well development is shown in Table 4. For the twenty-year period, it is estimated an additional 33,300 acres of disturbance is required, which includes both vertical and horizontal well development. Note the trend in Table 3 is an increasing number of wells per pad, with 3 wells/pad the latest value for the 2016-2020 group. Therefore, 3 wells per pad was used for the projection. Combining existing and new development results in the maximum potential disturbance of 142,400 acres.

Year/status	Wells (n)	Pads (n)	Total pad area (ac)	Average pad size (ac)	Average area per well (ac)	Total area roads (ac)	Road area per pad (ac)	Total area disturbed (ac)
Projected vertical wells	2,000	2,000	3,500	1.8	1.47	2,000	1.00	5,500
Projected horizontal wells(3 wells/pad)	17,600	5,867	23,467	4.0	1.50	4,400	0.75	27,867
Totals*	19,600	7,867	26,967	3.4	1.38	6,400	0.81	33,367

Table 4. New surface disturbance over the life of the plan (2023-2043)(Federal and non-Federal combined)

Not accounted for in the future surface disturbance is the reclamation for sites where wells are P&A. On average, from 2011 through 2021, 650 wells were plugged and abandoned each year (NMOCD, GIS database). Percent of wells plugged by formation has changed through time. A decade ago, Artesia Group wells were the biggest proportion of wells being plugged, gradually decreasing in proportion through time. Their place has been taken by Delaware and Bone Spring wells. The past two years have seen an increase of Wolfcamp wells being plugged as well.

Estimated Water Production and Use

As water is limited and thus essential in arid New Mexico for agriculture, domestic consumption, industry and other beneficial uses, it is important to assess and predict the associated water production and the corresponding use of water in oil and gas development. A holistic approach was taken with regards to the mass balance between the production of water to the end use of water. This preliminary framework is defined as the "water balance".

As a starting point, water production and injection data since 2011 were compiled and analyzed for trends. Figure 16 exhibits water production and injection combined from Eddy and Lea Counties from 2011 through 2022(note that 2022 is a partial year of data). Injection includes both water injection for enhanced oil recovery and saltwater disposal. As can be seen from the figure, most of the water is being disposed and/or injected. No attempt was made to differentiate between the two for this project.

In 2017 the difference in water production and injection/disposal begins to increase and this difference rapidly expands in subsequent years. This timing also coincides with the increase in horizontal completions for oil and gas development (see Figure 5).

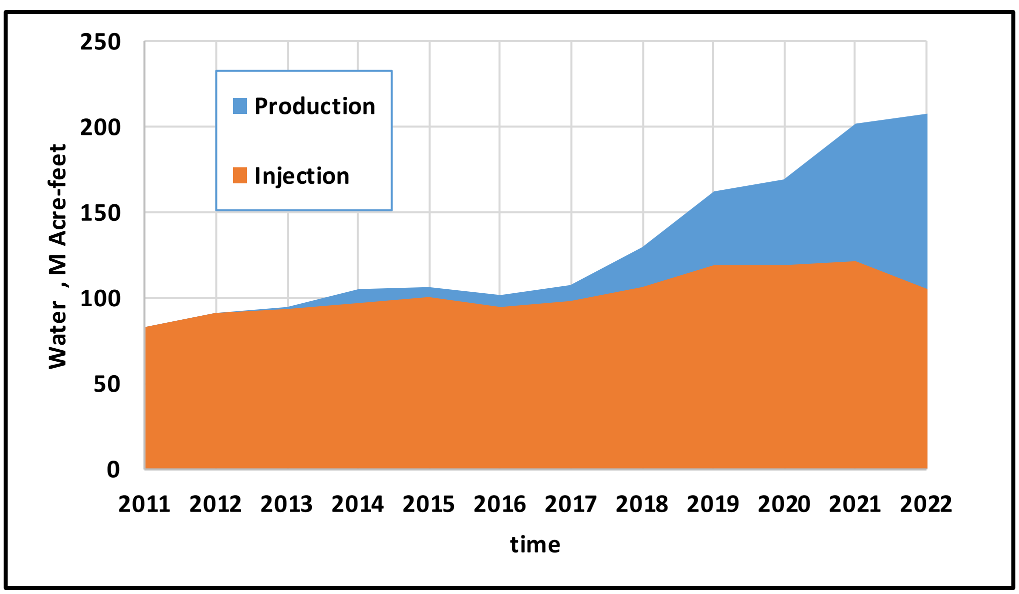

Figure 16. Water production and injection for SENM, Eddy and Lea Counties. Note: 2022 is a partial year of data. {Source: GOTECH}. 7758 bbl = 1 acre-foot

Many factors can account for this difference, from recent recycling efforts (reference) to estimates of use for oil and gas development. One such estimate by the U.S.G.S. (Gonzalez, et al, 2023) provides data for three segments of water use by oil and gas development: indirect, direct and ancillary. Direct water use is defined as water used in a wellbore to complete a well, which includes water used for drilling, cementing, stimulating, and maintaining the well during production. Indirect water use is defined as water used at or near the well site, including water used for dust abatement, equipment cleaning, materials washing, worker sanitation, and site preparation. Ancillary water use is defined as all other water used during the life cycle of oil and gas development that is not categorized as direct or indirect, such as additional local or regional water use resulting from a change (for example, population) related to oil and gas development (Valder, et al, 2021).

Data for Lea and Eddy Counties was analyzed over an eleven-year time period (2011 through 2021) for each segment and the results are shown in Figure 17. The significant rise in water use in 2017 is in response to the increase in direct water use. Data for components of direct water use (i.e. cementing, drilling, and stimulation) are provided by the U.S.G.S. data release (Gonzalez, et al, 2023) and thus were reviewed to identify the major contributor to this increase. Stimulation, specifically hydraulic fracturing, accounts for 99% of the direct water use and thus is the driver of the overall increase in water use for oil and gas development.

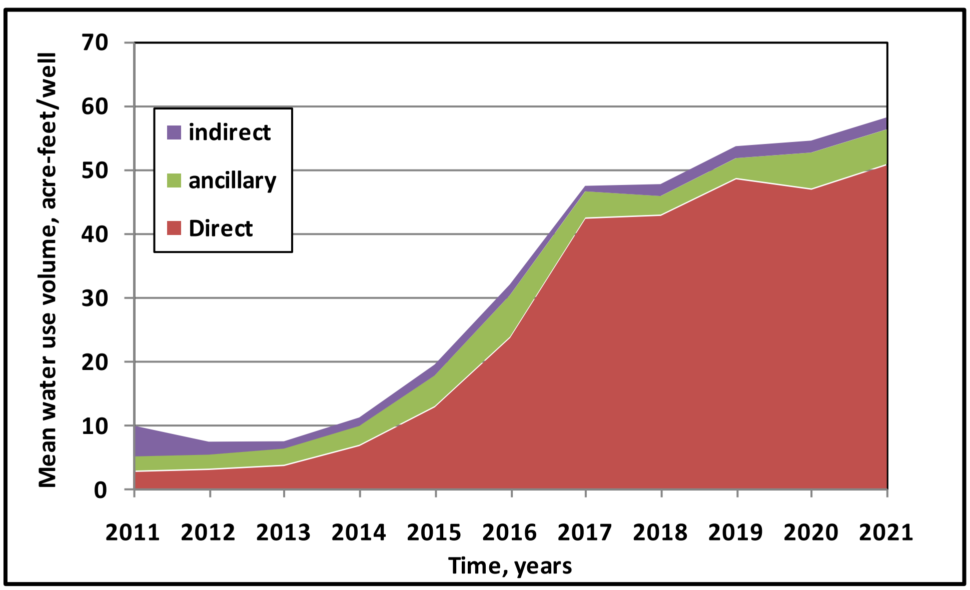

Figure 17. Indirect, direct and ancillary mean water use per well for Eddy and Lea Counties combined from 2011 through 2021. {Source: Gonzalez, et al, 2023}

Figure 16 was modified to include the estimate of water use for hydraulic fracturing in Eddy and Lea Counties combined and the results are shown in Figure 18. The difference between water production and water use by injection/disposal plus stimulation is remarkably small, except for 2022, however no stimulation volumes were available for 2022 and analyzed for that year since data is still being updated and reported. In summary, this comparison is very preliminary and requires more detailed analysis to improve our understanding of the water balance issue. However, two important trends recognized and necessary for the prediction phase are future water production and stimulation water use.

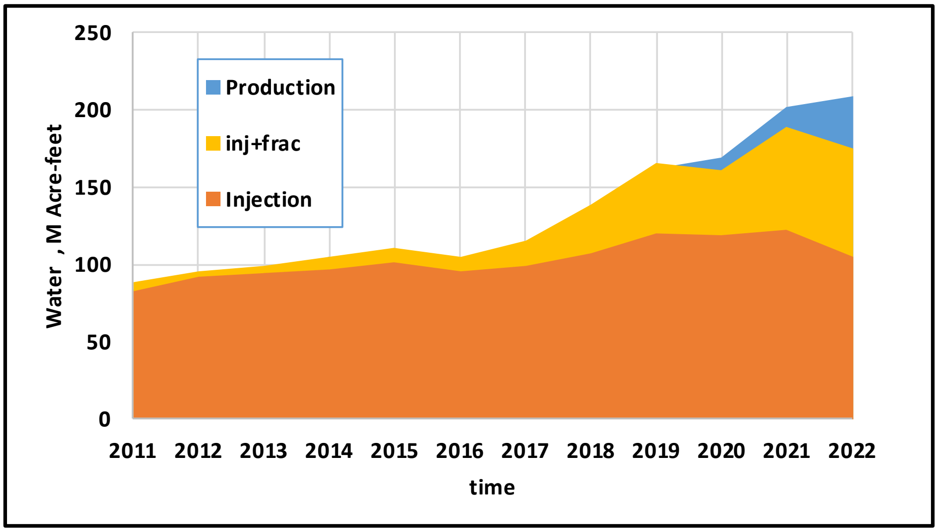

Figure 18. Water production, injection and stimulation water use for SENM, Eddy and Lea Counties. Note: 2022 is a partial year of data. {Sources: GOTECH, Gonzalez, et al, 2023}

Horizontal well completions are dominating oil and gas development, and thus this trend is expected to continue in the future prediction phase. Simultaneously, the average lateral length has been increasing since 2011 (See Figure 6) to approximately 1 ½ to 2 miles. Subsequently, the estimate for lateral length in the prediction is to average 2 miles. Data was extracted from the U.S.G.S. data release {Gonzalez, et al, 2023} to determine stimulation water use for longer laterals. The data was limited to only wells with lateral lengths greater than 10,000 ft. Results in Figure 19show an increase in stimulation water use to approximately 6 acre-feet per 1000-foot lateral length or 60 acre-feet per well. Also shown is the number of longer lateral wells has been increasing. The decreases in 2020 and 2021 are assumed to be due to limited data. Subsequently, for the purposes of future oil and gas well development, 60 acre-feet of water per well will be required for stimulation.

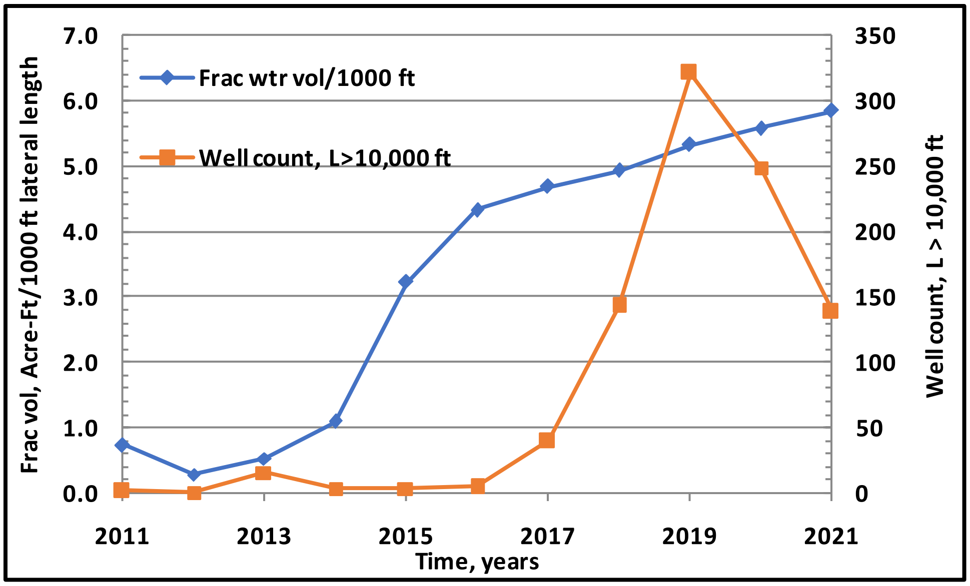

Figure 19. Stimulation water volume per 1000 ft of lateral and number of wells with lateral length greater than 10,000 ft. {Source: Gonzalez, et al, 2023}

A recent trend has shown an increase in using produced water for stimulation, replacing the use of fresh water. Water use data compiled by industry and reported on the NMOCD website began in September 2020. Figure 20 illustrates the increasing trend in using produced water as a percent of total used in hydraulic fracturing up to March 2023. Approximately 3000 wells are included in this data, with two-thirds (~2000 wells) considered to be the Federal portion.

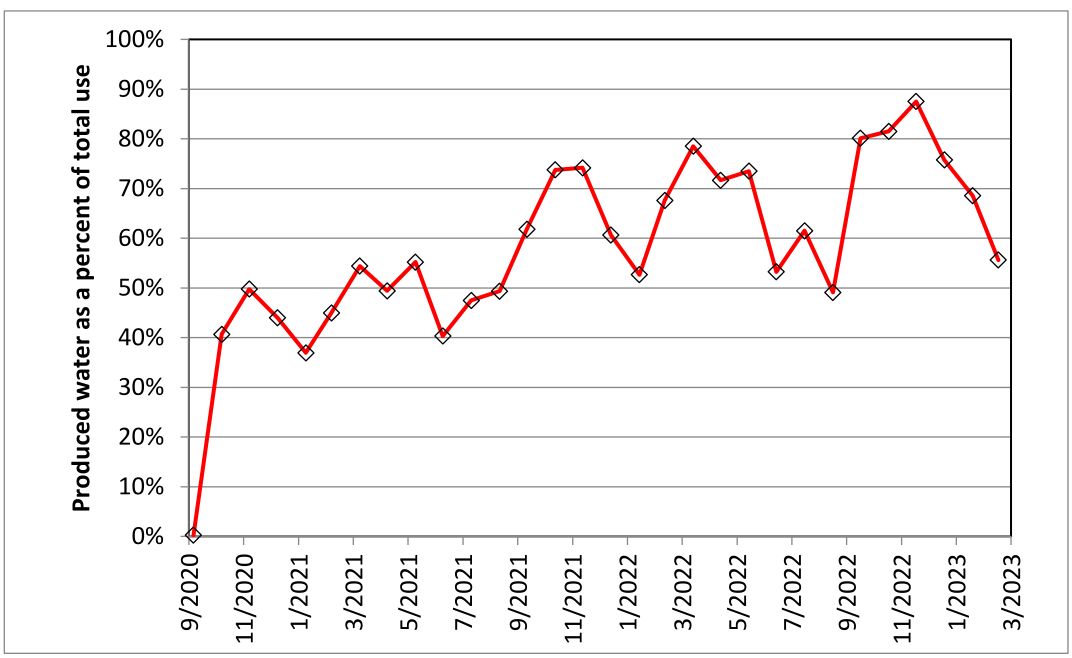

Figure 20. Percent of produced water used in hydraulic fracturing in SENM. {Data source: NMOCD}

Forecasted water production was based on historical WOR values for the Wolfcamp and Bone Spring Formations and decline analysis for the remaining plays. Furthermore, the applied WOR values varied between remaining production of existing wells and production from new wells. In all cases, the WORs were assumed constant throughout the 20 –year time period. This assumption is a simplification and should be considered as such. It is supported by observed historical trends in the Wolfcamp and Bone Spring formations, (Further discussion can be found in both plays) but a complete analysis of modeling water production was not attempted in this work.

The estimated cumulative water production for the 20-year period beginning in 2023 is 30 billion barrels of water or 1.5 billion barrels of water per year. In comparison, over the last twelve years (2011-2022), water production has averaged approximately 1 billion barrels of water per year, with an increasing trend with time. Thus a 50% increase in water production is projected for the RFD time period and captures the increasing trend observed in the last several years.

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Appendices (Attachment 1)

A. Major Plays: Bone Spring and Wolfcamp

B. Minor Plays

C. Gas Plays

D. Deep, Mature Oil Plays

E. Annual Summary of Forecast Data

Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027
OCD Exhibit No. 7A

Correlation of Disposal Wells Listed in Appendix II

API Well No.	Well Name	Well No.	UL	Sec	Twp	Rng	Feet	NS	Ft	EW	Order No.	Appendix II	Well on Table
30-025-05493	NORTH HOBBS G/SA UNIT	744	P	25	18 S	37 E	330	S	330	E	R-909	Table 1	**1**
30-025-12802	RICE SWD F	029	F	29	18 S	38 E	1880	N	1745	W	R-1574	Table 1	**2**
30-025-07950	HOBBS EAST S A	104	F	30	18 S	39 E	1980	N	2310	W	R-3500	Table 1	**3**
30-025-21496	E M E SWD	33	K	33	19S	37E	1485	S	1485	W	R-1918	Table 1	**4**
30-025-12788	HOBBS SWD	015	E	15	19 S	38 E	1650	N	840	W	R-1004	Table 1	**5**
30-025-04150	E M E SWD	001	I	1	20 S	36 E	2310	S	660	E	R-1717	Table 1	**6**
30-025-05902	E M E SWD	005	M	5	20 S	37 E	990	S	330	W	R-1277	Table 1	**7**
30-025-12801	E M E SWD	009	M	9	20 S	37 E	100	S	250	W	R-1483	Table 1	**8**
30-025-12800	E M E SWD	020	H	20	20 S	37 E	2475	N	165	E	R-1348	Table 1	**9**
30-025-12786	E M E SWD	033M	M	33	20 S	37 E	165	S	165	W	R-1647	Table 1	**10**
30-025-21852	E M E SWD	021	L	21	21 S	36 E	1520	S	440	W	R-3102	Table 1	**11**
30-025-07920	SOUTH CARTER SA UNIT	701	L	5	18 S	39 E	1650	S	990	W	R-3519	Table 1	**12**
30-025-06243	SEMU PENN	009	O	23	20 S	37 E	660	S	1980	E	SWD-37	Table 1	**13**
30-025-08703	TRUCKERS SWD	006	L	6	21 S	36 E	3300	N	660	W	SWD-161	Table 1	**14**
30-025-04861	ATHA	001	M	31	21 S	36 E	660	S	660	W	R-3694	Table 1	**15**
30-025-08815	J H DAY	001	C	6	22 S	36 E	660	N	1980	W	R-3781	Table 1	**16**
30-025-08816	J H DAY	002	D	6	22 S	36 E	660	N	990	W	R-3781	Table 1	**16**
30-025-09266	FARNEY A 5	005	G	5	23 S	36 E	1980	N	1980	E	R-4121	Table 1	**17**

TABLE 1.

MAJOR SALT-WATER DISPOSAL WELLS WHICH OCCUR IN FRESH-WATER AREA OF LEA COUNTY, NEW MEXICO.

Location = section, township (south), range (east).

Operator	Location	Injection Interval	Barrels In-jected/month	Cumulative Injection
Rice	25-18-37	4446-4527	97,285	27,134,667
Rice	29-18-38	4469-4522	228,627	43,096,101
Rice	30-18-39	5105-5188	31,951	4,967,482
Rice	33-18-37	4500-4975	128,952	35,133,435
Rice	15-19-38	4634-4826	242,138	47,027,165
Rice	1-20-36	4300-4935	127,916	32,282,168
Rice	5-20-37	4515-4920	173,066	40,706,962
Rice	9-20-37	4396-4845	327,309	72,412,835
Rice	20-20-37	4451-4939	98,937	29,012,203
Rice	33-20-37	4500-5077	243,520	36,037,613
Rice	21-21-36		298,109	29,174,043
S & M Oil	5-18-39	5300-5854	17,390	646,793
Conoco	23-20-37	4547-4700	Disconnected	615,979
Truckers	6-21-36	4395-4435	25,170	1,086,652
McCasland	31-21-36		32,343	1,944,331
McCasland	6-22-36	3140-3295	32,343	1,805,883
Conoco	5-23-36	3710-52	Disconnected	70,444

Total injection = 2,105,056 barrels per month (for July 1980); 403,154,756 barrels cumulative in these wells. This is 18.5% of all 1979 injection in southeastern New Mexico.

BEFORE THE
OIL CONSERVATION COMMISSION
SANTA FE, NEW MEXICO

IN THE MATTER OF:

Case No. 1530

TRANSCRIPT OF HEARING

October 22, 1958

DEARNLEY - MEIER & ASSOCIATES
GENERAL LAW REPORTERS
ALBUQUERQUE NEW MEXICO
Phone CHapel 3-6691

Queen formation.

Q Referring to what has been marked as Exhibit D, would you state what that shows?

A That is a tabulation of all the wells in that half mile radius that is drawn on Exhibit A, and it also shows the completion interval, subsea completion interval, and the completion zone of all the wells in that circle.

Q You are referring to the circle which appears on Exhibit A?

A Yes, sir.

Q Actually, there is no production from the San Andres formation for a considerable distance, is that correct?

A That is right. I don't know exactly how close the closest San Andres formation is produced in that area, but it is a considerable distance.

Q It would be in excess of two miles?

A Yes, sir.

Q Now, referring to what has been marked as Exhibit E, would you state what that is?

A Exhibit E is a list of all the operators with addresses that belong to this Eunice-Monument-Eumont salt water disposal system.

Q Rice Engineering and Operating, Inc., is designated as the operator of the salt water disposal system, is that correct?

A Yes, sir.

Q And you are appearing then as an operator of the salt water disposal system in this case?

A Yes, sir.

Q Now, referring to what has been marked as Exhibit F, would you state what that shows?

A Exhibit F is an agreement between Cities Service Oil Company and Rice Engineering and Operating, Inc., setting out certain things that both companies are agreed on for making that salt water disposal well on the Cities Service State B lease.

Q The well then will be drilled by Cities Service?

A Yes sir, Cities Service agreed to drill the well and then sell it to Rice Engineering for the operators in this E-M-E SWD System.

Q At the present time, do you have any log on the San Andres formation available in this area?

A No sir, I do not have a log. We will furnish the Commission with one when we drill the well.

Q What volumes of water do you propose to dispose of in this well?

A We propose to dispose of approximately 15,000 barrels a day in this well.

Q What is the source of this water?

A Well, it will be the Eumont Pool and the Eunice Pool waters, and I believe that's all, the two pools.

Q Has an analysis been run on these waters?

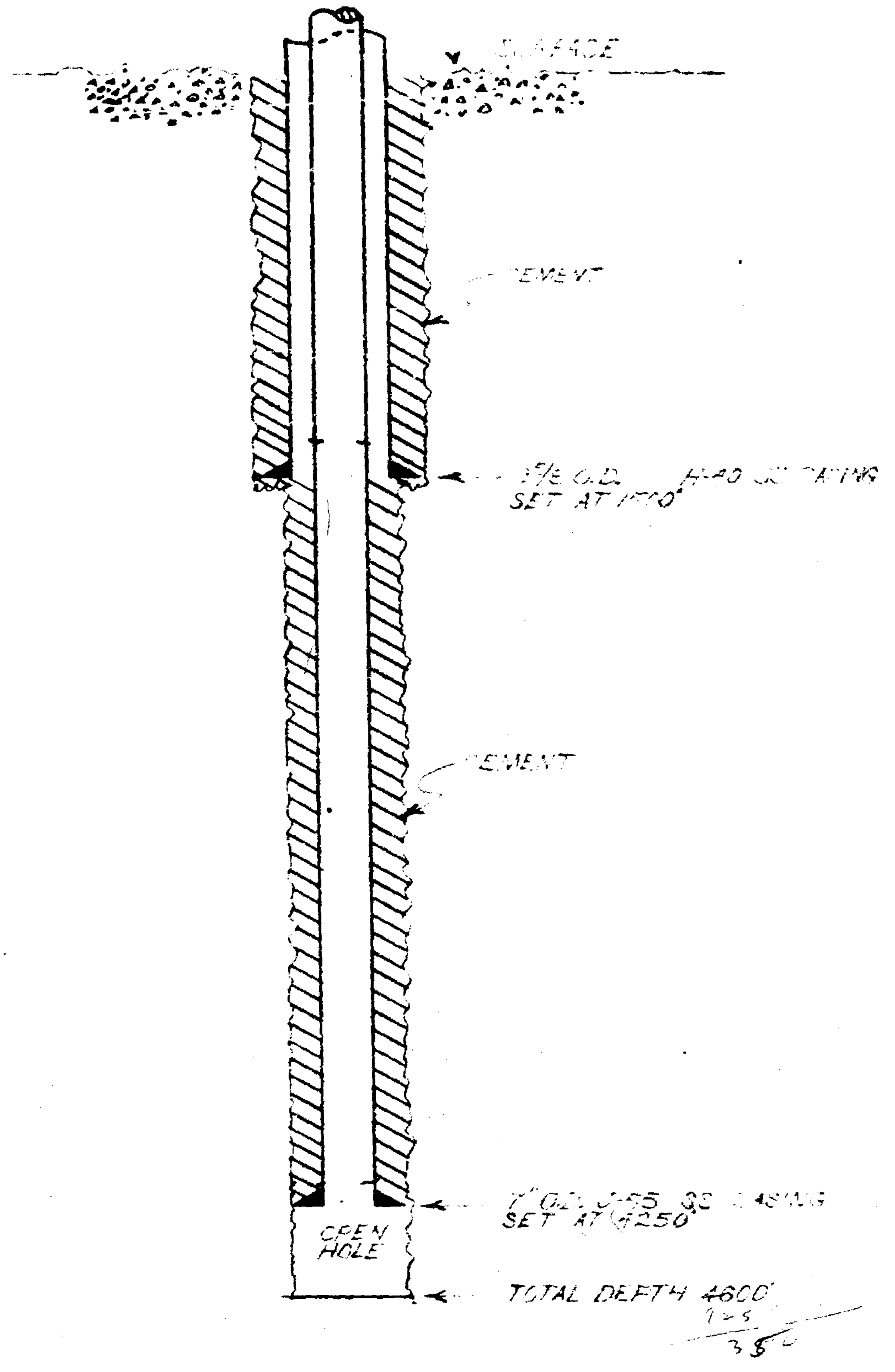


EXHIBIT B APPLICATION FOR HEARING

DWN			RICE ENGINEERING & OPERATING INC. EME NO-A-32 PROPOSED COMPLETION	SCALE NONE
			Rice Engineering & Operating, Inc. **Hobbs, New Mexico**	DWG NO. A-19

BEFORE THE
OIL CONSERVATION COMMISSION
SANTA FE, NEW MEXICO

IN THE MATTER OF:

CASE 1847: Application of Rice Engineering and Operating Inc. for an order authorizing a salt water disposal well.

TRANSCRIPT OF HEARING

JANUARY 6, 1960

A Yes, sir, we believe it is. Besides this casing program, we plan to run five and a half inch casing as tubing in the well, and this casing will be plastic lined. And then behind the five and a half and in the annular space between the five and a half inch and the seven inch we will load that annular space with sweet oil or gasoline or neptha, which should protect the outside of the tubing string and also the inside of the casing. We also do that so we'll have continual history on the disposal zone. We will put a pressure gauge on the tubing casing annulus and record that pressure daily. That way we can tell if we ever get a tubing leak or a casing leak.

Q What is the source of water that will be disposed of in this well?

A That's the Hobbs Pool.

Q Is it corrosive water?

A Mildly corrosive, yes, sir.

Q What volume do you anticipate disposing of in the well?

A We plan for future disposal to be as high as 14,000 barrels a day.

Q Are you familiar with the characteristics of the San Andres formation in this area?

A Yes, sir.

Q In your opinion, will the formation take that volume of water?

A Yes, it will take that volume by gravity.

(Thereupon, Applicant's Exhibit C was marked for identification.)

Q Now, referring to what has been marked as Exhibit C, will you discuss that?

A Exhibit C is a cross-section showing the completion of the wells in this, surrounding this proposed disposal well, and also shown on trace AA Prime of Exhibit A. It runs through the Humble Bowers "A" No. 12, which is a Bowers Well, and that's shown in red on this Exhibit; through the Bowers "A" No. 10 and Amerada "B" 1 through the proposed SWD F-29, and then the Amerada "B" 4 and the Atlantic Grimes No. 1. Those producing zones are marked there in blue for the Grayburg and San Andres zones, and red for the Bowers.

Q Do you have a list of the wells within half a mile radius of the subject well?

A Yes, sir. That's shown on Exhibit D. This shows the operator and the lease and the well number and the completion interval and also the completion zone.

(Thereupon, Applicant's Exhibit D was marked for identification.)

Q A number of those wells are San Andres producers, are they not?

A Yes, sir, a majority of them are San Andres.

Q In your opinion, will the injection of the salt water into this zone enhance the recoveries in those San Andres wells?

A We don't believe it will affect the pressure.

Q Now, do you have an easement or lease from the lease owner on this well?

A Yes, sir, we have a lease from William Grimes for two acres surrounding this well.

Q What arrangement do you have with Amerada Petroleum Corporation?

A We have a letter from Amerada where they agree to our completion and approve us -- our drilling a well on the lease.

(Thereupon, Applicant's Exhibit E was marked for identification.)

Q Exhibit E,is that a copy of the lease fee land owner?

A Yes, sir.

Q That's the surface owner?

A Yes, sir.

(Thereupon, Applicant's Exhibit F was marked for identification.)

Q Now, referring to what has been marked as Exhibit F, will you state what that is?

A Exhibit F shows all the companies that are making up the Hobbs salt water disposal system.

Q Were Exhibits A through F inclusive prepared by you or under your direction and supervision?

A Yes, sir, they were.

MR. KELLAHIN: At this time we would like to offer

STATE OF NEW MEXICO
ENERGY, MINERALS AND NATURAL RESOURCES DEPARTMENT
OIL CONSERVATION DIVISION

IN THE MATTER OF THE HEARING CALLED BY THE OIL CONSERVATION DIVISION FOR THE PURPOSE OF CONSIDERING:

APPLICATION OF GOODNIGHT MIDSTREAM PERMIAN, LLC FOR APPROVAL OF A SALTWATER DISPOSAL WELL, LEA COUNTY, NEW MEXICO.

CASE NO. 20555

REPORTER'S TRANSCRIPT OF PROCEEDINGS

EXAMINER HEARING

June 14, 2019

Santa Fe, New Mexico

BEFORE: PHILLIP GOETZE, CHIEF EXAMINER
DAVID K. BROOKS, LEGAL EXAMINER

This matter came on for hearing before the New Mexico Oil Conservation Division, Phillip Goetze, Chief Examiner; and David K. Brooks, Legal Examiner, on Friday, June 14, 2019, at the New Mexico Energy, Minerals and Natural Resources Department, Wendell Chino Building, 1220 South St. Francis Drive, Porter Hall, Room 102, Santa Fe, New Mexico.

REPORTED BY: Mary C. Hankins, CCR, RPR
New Mexico CCR #20
Paul Baca Professional Court Reporters
500 4th Street, Northwest, Suite 105
Albuquerque, New Mexico 87102
(505) 843-9241

geology, and then we'll dive into some more detail?

A. Okay. We have the Rustler and Salado Formations down to about 2,600 feet, then the Artesia group, which consists of Tansill, Yates, Seven Rivers, Queen, Grayburg. It extends down to about 3,800 feet. At that point we have the top of the San Andres Formation at about 3,980. The top of the San Andres is a dolomite that is infilled with anhydrite. It makes a very good barrier between the Grayburg and the San Andres porosity intervals. San Andres is roughly 1,000 feet thick and extends down to about 5,200, which would be the top of the Glorieta Formation.

Below the Glorieta, we would get into the carbonate intervals of the Leonard, which have -- four porosities members are identified within the Leonard. We would give those names of Paddock, Blinebry, Tubb and Drinkard.

Q. Now, have you prepared a cross section that kind of gives us a little more visual depiction of the geology and the stratigraphy in the area?

A. Yes, I have.

Q. Is that behind Tab Number 9?

A. It is. That is correct.

Q. Will you review for the examiners again the geology and why you think that this particular zone in

the San Andres is suitable for injection and will contain the fluids that you're injecting?

A. In this particular picture, we have a well to the south of the proposed location, open-hole well log, and then we have a well to the north on the left. What we see in the area is that the porosity is developed high in the section to the south and grades downward as we pass to the north.

Our reason for selecting the San Andres in Township 21 South, 36 East is we did a very long and extensive historical study of the operations in the area, and we determined that over 500 million barrels of water were pulled out of the San Andres to supply water to the Grayburg and Penrose waterfloods at the Monument Unit and at the Arrowhead Unit. We reconstructed the history of each one of those water supply wells. We know the cums that were pulled out of each area. And what we're seeing is that this large porosity interval that is at the upper part of the section and then transitions down into the middle part of the section as you move north is massively pressure depleted from extraction, and then that creates a wonderful opportunity that we can put hundreds of millions of barrels back in the ground before we ever get back to normal pressure.

CROSS-EXAMINATION

BY EXAMINER GOETZE:

Q. Welcome.

Let's see. Where do I want to start?

So have you looked at the performance of the Parker well, Parker Energy?

A. Yes.

Q. And also you're going to be sharing the same neighborhood as Rice Engineering --

A. Yes.

Q. -- who has been there for some time?

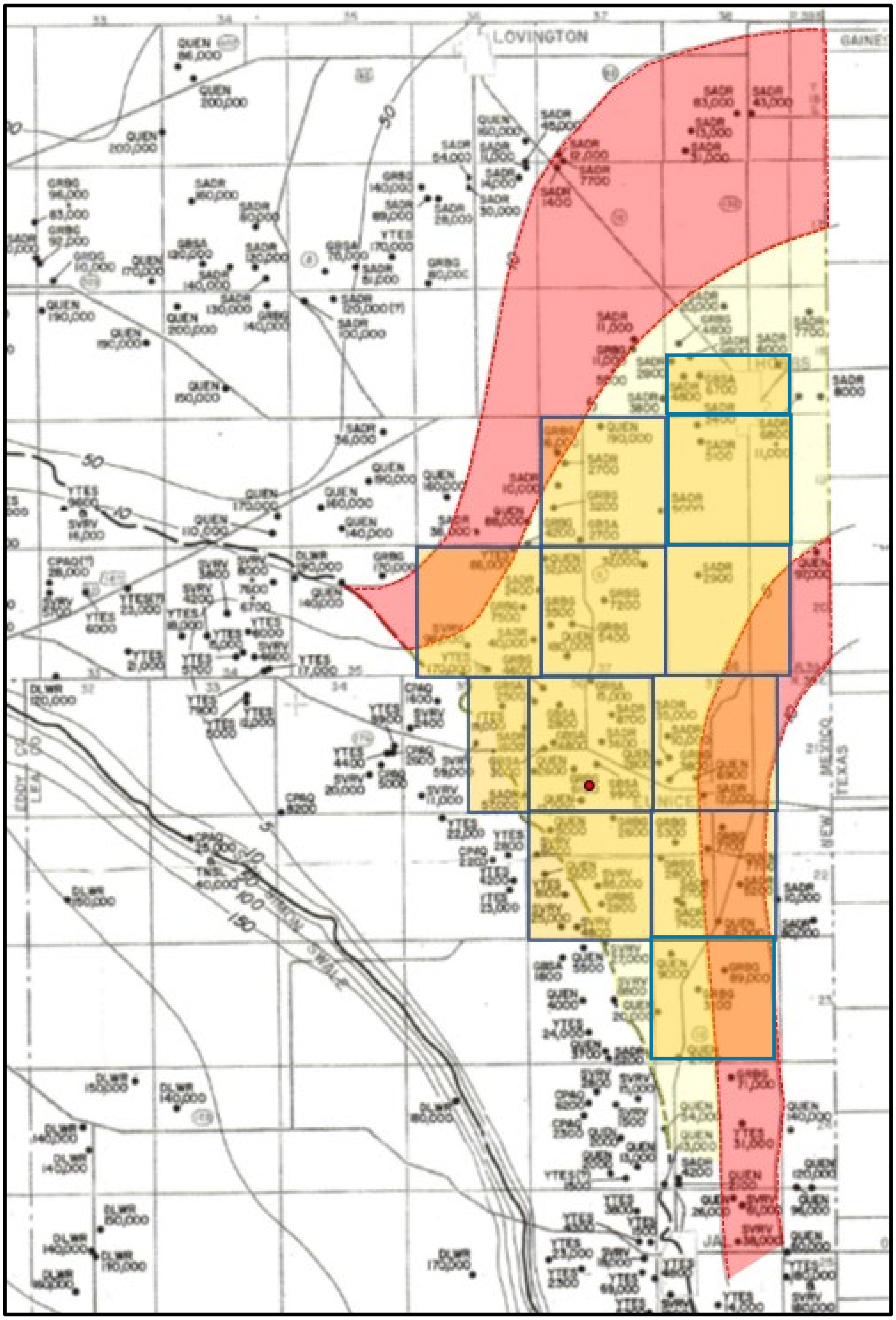
A. Correct.

Q. Do you feel that you're going to end up competing probably with Rice Engineering, or do you think there is enough capacity where we're all going to be able to cooperate and have very few issues?

A. We have a very unusual advantage here that 500 million barrels has been taken out, and I think it will be a large number of years, possibly a decade, before we will see the reservoir start to return to normal pressure. I think that everybody will be competing for pore space over time, and as a result, we would eventually see -- like every other reservoir, that we will see pressures increase some point out in the future.

State of New Mexico
Energy, Minerals and Natural Resources Department
Oil Conservation Division

Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027
OCD Exhibit No. 7C
Townships Included in Review of Disposal History



Township or half township reviewed for injection volumes by UIC Class II disposal wells

Base map from Hiss (Figure 26; 1975) with 5,000 TDS (red shading) and 10,000 TDS areas (yellow shading) highlighted

Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027
OCD Exhibit No. 7D

Summary of Form C-108 Applications for the Area of Interest

Application Tracking Number	Assigned UIC Permit Number	Well Name	Applicant / Operator	Date Received
pMSG2413551076	SWD-2618	Skywalker State SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	4/23/2024
pMSG2411457593	SWD-2611	Hank SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	3/11/2024
pMSG2314755059	SWD-2537	Seaver SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	5/15/2023
pMSG2314753442	SWD-2536	Hodges SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	5/15/2023
pMSG2314750646	SWD-2535	Hernandez SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	5/15/2023
pMSG2314749547	SWD-2534	Doc Gooden SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	5/15/2023
pBL2126055537	SWD-2458	Piazza SWD No.1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	9/17/2021
pBL2032264441	SWD-2404	Ernie Banks SWD No.1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	11/17/2020
pBL2032263200	SWD-2403	Andre Dawson SWD No.1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	11/17/2020
pBL2024439207	SWD-2392	Rocket SWD No.1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	8/19/2020
pBL2024438245	SWD-2391	Pedro SWD No.1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	8/19/2020
pKAM1928247158	SWD-2307	Ryno SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	7/2/2019
pKAM1928246669	SWD-2306	Express SA SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	6/28/2019
pKAM1928246148	SWD-2305	Piper G SWD #2	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	7/2/2019
pLEL1925948840	SWD-2280	Unitas State SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	9/10/2019
pLEL1925948540	SWD-2279	Staubach Fed SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	9/10/2019
pLEL1925948154	SWD-2278	Montana Fed SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	9/10/2019
pLEL1925947679	SWD-2277	Marino Fed SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	9/10/2019
pLEL1925947351	SWD-2276	Manning SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	9/10/2019
pLEL1925947010	SWD-2275	Favre State SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	9/10/2019
pLEL1925946560	SWD-2274	Elway SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	9/16/2019
pLEL1925946081	SWD-2273	Brees Federal SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	9/10/2019
pLEL1925945394	SWD-2272	Blanda Fed SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	9/10/2019
pDHR1924054414	SWD-2261		GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	8/27/2019
pMAM1918245008	SWD-2181	Young G SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	6/28/2019
pMAM1918243253	SWD-2180	Springer G1 SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	6/28/2019
pMAM1918238141	SWD-2179	Sosa SA 17 Well No. 2	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	6/28/2019
pMAM1918232097	SWD-2178	Pudge SWD G #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	6/28/2019
pMAM1911936697	SWD-2075	Ted 28 SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	2/15/2019
pMAM1911552448	SWD-2061	Robinson SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	4/18/2019
pMAM1911551157	SWD-2060	Scully SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	4/18/2019
pMAM1907757636	SWD-1999	Jose Altuve SWD #1	GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	3/18/2019
pMAM1907048843	SWD-1989		GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	3/11/2019
pMAM1817157933	SWD-1820		GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	6/20/2018
pMAM1811359607	SWD-1770		GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	4/23/2018
pPRG1814552176	SWD-1739		GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	5/1/2018
pMAM1724045488	SWD-1700		GOODNIGHT MIDSTREAM PERMIAN, LLC [372311]	8/28/2017
pMSG2411557345	SWD-2613	Flutie SWD State #2	Pilot Water Solutions SWD LLC [331374]	3/22/2024
pMSG2411556309	SWD-2612	JFF SWD State #1	Pilot Water Solutions SWD LLC [331374]	3/22/2024
pMSG2404540316	SWD-2602	Staubach SWD State #1	Pilot Water Solutions SWD LLC [331374]	1/25/2024
pMSG2404539121	SWD-2601	Sanders SWD State #1	Pilot Water Solutions SWD LLC [331374]	1/24/2024
pMSG2404538029	SWD-2600	Dorsett SWD State #1	Pilot Water Solutions SWD LLC [331374]	1/23/2024
pMSG2404537096	SWD-2599	Bush SWD State #1	Pilot Water Solutions SWD LLC [331374]	1/23/2024
pMSG2404536593	SWD-2598	JFF SWD State #1	Pilot Water Solutions SWD LLC [331374]	1/16/2024
pMSG2404535733	SWD-2597	Mariota State SWD #1	Pilot Water Solutions SWD LLC [331374]	1/12/2024
pMSG2404453250	SWD-2596	Lamar SWD State#1	Pilot Water Solutions SWD LLC [331374]	12/29/2023
pMSG2335441445	SWD-2587	Ricky State SWD #1	Pilot Water Solutions SWD LLC [331374]	12/11/2023
pMSG2335440753	SWD-2586	Dayne State SWD #1	Pilot Water Solutions SWD LLC [331374]	11/2/2023
pMSG2332553600	SWD-2581	Flutie State SWD #1	Pilot Water Solutions SWD LLC [331374]	11/21/2023
pAYH2329349274	SWD-2576	Burrow SWD State#1	Pilot Water Solutions SWD LLC [331374]	10/13/2023
pAYH2329339450	SWD-2575	Tebow SWD State#1	Pilot Water Solutions SWD LLC [331374]	10/13/2023
pMSG2325252627	SWD-2573	Juice SWD State #1	Pilot Water Solutions SWD LLC [331374]	9/7/2023
pMSG2325052811	SWD-2561	O'Brien SWD State #1	Pilot Water Solutions SWD LLC [331374]	8/30/2023
pMSG2325047149	SWD-2560	Toretta State SWD #1	Pilot Water Solutions SWD LLC [331374]	8/23/2023
pMSG2325045881	SWD-2559	Flutie SWD State #1	Pilot Water Solutions SWD LLC [331374]	8/31/2023
pMSG2325043933	SWD-2558	Cannon SWD State #1	Pilot Water Solutions SWD LLC [331374]	9/1/2023
pMSG2325042619	SWD-2557	O'Brien SWD State #1	Pilot Water Solutions SWD LLC [331374]	8/30/2023
pMSG2324251335	SWD-2555	Jameis SWD State #1	Pilot Water Solutions SWD LLC [331374]	8/23/2023
pBL2014230588	SWD-2383	B-18	RICE OPERATING COMPANY [19174]	5/20/2020
pMAM1836029684	SWD-1877		RICE OPERATING COMPANY [19174]	12/24/2018
pMAM1822245838	SWD-1754		RICE OPERATING COMPANY [19174]	8/9/2018
pMAM1822056380	SWD-1753	D 24 N SWD No.1	RICE OPERATING COMPANY [19174]	1/1/1900
pMAM1818433528	SWD-1752	O 34 SWD No.1	RICE OPERATING COMPANY [19174]	7/2/2018
pMAM1822950834	SWD-1751	N 7 SWD No.1	RICE OPERATING COMPANY [19174]	8/17/2018
pMAM1822950450	SWD-1750		RICE OPERATING COMPANY [19174]	8/17/2018

Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027
OCD Exhibit No. 8A

Guidon Energy's frac fleet and recycling center in the Midland Basin. *Source: Guidon Energy.*

Permian Operators Squeezed by Growing Water Pressure

Stephen Rassenfoss, *JPT* Emerging Technology Senior Editor

The rising tide of produced water in the Permian Basin is requiring operators to re-engineer how they manage water.

One big difference in the Permian is that water production from unconventional reservoirs exceeds output from most other plays, particularly in the Delaware Basin. Prolific water production has long been a given in conventional fields there, but most of that could be reinjected to maintain production, which is not an option in the ultratight rock.

Instead, billions of gallons of produced water have been pumped into saltwater disposal wells in shallow formations, such as the San Andres, significantly increasing the pressure drillers encounter, creating a hazard for drillers moving in and out of them from lower-pressure zones.

To isolate the higher-pressure zones passed on the way to the Wolfcamp, operators have increased the number of strings of casing used from three to four. The increase adds about $600,000 to the cost per well, said Andrew Hunter, drilling manager for Guidon Energy, which uses the added string to isolate two under-pressure zones.

To maximize produced water use for fracturing, Cimarex has streamlined filtration and chemical treatments of the water in the pipeline system en route to fracture sites, limiting the need for fixed facilities, said Rita Behm, Permian exploration engineering project manager for Cimarex.

Occidental Petroleum is working to manage water production while picking drilling targets. It has developed a detailed evaluation system based on a large company database that predicts production of hydrocarbons and water. High water cuts are a negative in the grading system used to choose where to spend, said John Polasek, vice president of geoscience at Occidental.

All three mentioned the water issue in their presentations at the recent AAPG Global Super Basins conference on the Permian. The comments reflected the importance of dealing with water issues for operators that need to minimize fresh water use and manage injections of produced water.

ExxonMobil's XTO Energy arm is building a system to "treat produced water and reuse it again and again" to reduce its demand for fresh or brackish water wells, said Staali Gjervik, senior vice president for Permian Integrated Development at XTO.

A Big Shift

Addressing the problem will require an industrywide shift. Even if an operator is reusing all of its water, "they can get hammered" by the injections of a nearby commercial saltwater disposal well by an operator that is not finding other uses, Hunter said. "The only way to deal with this is to work cooperatively with other operators," he said.

When drilling through higher pressures, Hunter said drillers increase mud weight to counter the higher pore pressure in that layer, and promptly adjust it back when the pressure drops.

Through drilling 48 wells in the Midland Basin, Guidon learned how to deal with the challenges associated with the higher pressure in the San Andres. Those include the risk of differentially stuck bottomhole assemblies when drilling goes below the San Andres. The sudden shift to a lower-pore-pressure zone can cause an abrupt fluid loss. That pulls the bit on to the well wall like the force of a drain when a bathtub is emptying, Hunter said.

Rather than using force, the company found that the best way to free a tool is hitting the spot with about 50 bbl of hydrochloric acid to dissolve the carbonate rock to break the seal.

"I am not happy with where this is going. On every well we drill in the future, we will have to deal with this (over-pressure) issue. It doesn't make any sense," Hunter said. "We believe the best approach is to recycle all produced water and only use deep disposal wells on a short-term basis while recycling infrastructure is being built."

Water disposal adds to the drilling issues in the Permian. The multilayered richness of the rock means drill bits travel through a century of all sorts of water-injection projects, plus the Permian Basin goes through major changes. Among those differences is a lot higher water production in the western half of the basin.

In the Delaware Basin, Cimarex wells with water cuts of 80–90% are common. For a section with 12 wells, that is 100 million bbl of water for 12 million BOE. "We will need two saltwater disposal wells to handle that peak," Behm said.

Adapting to Injection

Saltwater injection can cause overpressure in the shallow San Andres formation, requiring changes by drilling engineers going for deeper targets in the Midland Basin of the Permian. These can include:

- Increasing mud weight to more than 10 lb/gal in the higher-pressure zone, from 8 to 9 lb/gal elsewhere.
- Setting intermediate casing shallower than desired in the Clear Fork lime when the kill mud weight of the San Andres exceeds the 8.7 lb/gal fracture gradient of the Upper Spraberry.
- Using a drilling liner to achieve adequate shoe integrity in Wolfcamp targets because of the higher mud weight.
- Drilling Spraberry targets without the liner by keeping the production interval mud weight below its fracture gradient.

Source: Andrew Hunter, Guidon Energy.

Cimarex is maximizing reuse by making it as efficient as possible. Rather than building a large water recycling facility and storage pits, it is filtering the fluid and killing the bacteria in it while moving the water to the frac site. This reduces the facilities needed and the risk of pits leaking, which multiple speakers said can be an issue, even with good plastic liners.

Water reuse saves Cimarex the cost of fresh water for fracturing—from $0.60 to $2.50/bbl, depending on the county—but not the cost of injection, Behm said. With water production growing as more wells come on line, "it defers it [injection] by 30 to 60 days. They will have to put it in the ground."

Due to the problems associated with rising pressures in shallower zones, Guidon and Cimarex are among the companies that have added deepwater injection capacity into the Ellenburger Formation. Cimarex has two injection wells, each permitted to handle up to 90,000 B/D.

The Ellenburger is the same basement-level layer used for injection in Oklahoma, where a surge in seismic activity in certain areas forced the state to curtail high-volume water disposal.

Texas operators are taking steps to reduce the chance of a repeat. Behm said Cimarex has installed seismic monitoring equipment for its five injection wells. In addition, she said a group of operators is informally talking with Texas officials about how to manage injection to limit risks.

Major producers such as Occidental are taking advantage of their huge acreage position to select drilling targets with an eye toward reducing produced water.

Its reservoir analysis system predicts both oil and water production, Polasek said. When choosing which benches to develop, "we try to stay away from the high-water zones," he said.

Core Laboratories reported at the conference that it is working on rock analysis techniques it can use to model water production, suggesting other companies share their concern.

While salty water can work for fracturing, fresh water is still needed for drilling fluids. Fasken Oil and Ranch, an exploration and development company in Midland—which reuses all of its water for fracturing, injection into conventional zones, and drilling—has begun using reverse osmosis to desalinate water for drilling, said Stonie Pollock, a geologist for Fasken.

Hunter said the commitment to reuse pays off in a relatively short time, but requires a significant investment in infrastructure, manpower, and a willingness to make operational changes during the completion of the well.

Considering the costs and consequences of water disposal and fresh water use on a large scale, he pointed out that the cost of doing nothing is considerably higher. **JPT**

Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027
OCD Exhibit No. 8B

(Form C-105)

AREA 640 ACRES
LOCATE WELL CORRECTLY

DUPLICATE

NEW MEXICO OIL CONSERVATION COMMISSION

Santa Fe, New Mexico

WELL RECORD

Mail to District Office, Oil Conservation Commission, to which Form C-101 was sent not later than twenty days after completion of well. Follow instructions in Rules and Regulations of the Commission. Submit in QUINTUPLICATE.

Gulf Oil Corporation (Company or Operator) .... Bertie Whitmire (Lease)

Well No. 7, in SW 1/4 of NE 1/4, of Sec. 8, T. 20-S, R. 37-E, NMPM.

Monument-Paddock Pool, Lea County.

Well is 2310 feet from East line and 1980 feet from North line of Section 8. If State Land the Oil and Gas Lease No. is -

Drilling Commenced 11-28-53, 19 53 Drilling was Completed 1-10, 19 54

Name of Drilling Contractor Rife Drilling Co.

Address Box 9447, Fort Worth, Texas

Elevation above sea level at Top of Tubing Head 3549' The information given is to be kept confidential until ...., 19........

OIL SANDS OR ZONES

No. 1, from 5170' to 5240' No. 4, from .... to ....

No. 2, from .... to .... No. 5, from .... to ....

No. 3, from .... to .... No. 6, from .... to ....

IMPORTANT WATER SANDS

Include data on rate of water inflow and elevation to which water rose in hole.

No. 1, from .... to .... feet. ....

No. 2, from .... to .... feet. ....

No. 3, from .... to .... feet. ....

No. 4, from .... to .... feet. ....

CASING RECORD

SIZE	WEIGHT PER FOOT	NEW OR USED	AMOUNT	KIND OF SHOE	CUT AND PULLED FROM	PERFORATIONS	PURPOSE
13-3/8"	48#	New	447'	HOWCO			
9-5/8"	36#	New	2885'	HOWCO			
7"	20,23#	New	5694'	HOWCO			

MUDDING AND CEMENTING RECORD

SIZE OF HOLE	SIZE OF CASING	WHERE SET	NO. SACKS OF CEMENT	METHOD USED	MUD GRAVITY	AMOUNT OF MUD USED
17-1/2"	13-3/8"	463'	475	HOWCO		
12-1/4"	9-5/8"	2900'	1500	HOWCO		
8-3/4"	7"	5709'	735	HOWCO		

RECORD OF PRODUCTION AND STIMULATION

(Record the Process used, No. of Qts. or Gals. used, interval treated or shot.)

Acidized w/3000 gals 15% NE Acid by Chemical Process from 5660-5705'

A cidize w/1000gals 15% NE Acid by Chemical Process from 5660-5705'

Acidized w/500 gals 15% NE Acid by Chemical Process from 5655-5705'

Acidized w/2000 gals 15% NE Acid by Chemical Process from 5655-5705'

Result of Production Stimulation No oil obtained from the Hlinebry Pay - Plugged back to 5300' in the Paddock pay.

.... Depth Cleaned Out........

R ORD OF DRILL-STEM AND SPECIAL TES

If drill-stem or other special tests or deviation surveys were made, submit report on separate sheet and attach hereto

TOOLS USED

Rotary tools were used from 0 feet to 5710' feet, and from .... feet to .... feet.
Cable tools were used from .... feet to .... feet, and from .... feet to .... feet.

PRODUCTION

Put to Producing February 7, 19 54

OIL WELL: The production during the first 24 hours was 600 barrels of liquid of which 100 % was was oil; - % was emulsion; - % water; and - % was sediment. A.P.I. Gravity 40.0

GAS WELL: The production during the first 24 hours was .... M.C.F. plus .... barrels of liquid Hydrocarbon. Shut in Pressure .... lbs.

Length of Time Shut in ....

PLEASE INDICATE BELOW FORMATION TOPS (IN CONFORMANCE WITH GEOGRAPHICAL SECTION OF STATE):

Southeastern New Mexico			Northwestern New Mexico
T. Anhy 1080'	T. Devonian		T. Ojo Alamo
T. Salt	T. Silurian		T. Kirtland-Fruitland
B. Salt 2260'	T. Montoya		T. Farmington
T. Yates 2420'	T. Simpson		T. Pictured Cliffs
T. 7 Rivers	T. McKee		T. Menefee
T. Queen 3070'	T. Ellenburger		T. Point Lookout
T. Grayburg	T. Gr. Wash		T. Mancos
T. San Andres	T. Granite		T. Dakota
T. Glorieta 5080'	T.		T. Morrison
T. Drinkard Blinebry 5660'	T.		T. Penn
T. Tubbs	T.		T.
T. Abo	T.		T.
T. Penn	T.		T.
T. Miss	T.		T.

FORMATION RECORD

From	To	Thickness in Feet	Formation	From	To	Thickness in Feet	Formation
0	13		Distance from top kelly drive to top of ground				
	80 47		Sand & Caliche				
	129		Red Bed				
	190		Sand & Red Bed				
	865		Red Bed				
	1135		Anhydrite & Red Bed				
	1155		Anhydrite				
	2090		Anhydrite & Salt				
	2265		Anhydrite				
	2360		Anhydrite, Lime & Gyp				
	2415		Anhydrite				
	2607		Anhydrite & Lime				
	3091		Lime				
	3181		Lime & Sandy Lime				
	3287		Lime & Sand				
	3342		Lime & Gyp				
	5282		Lime				
	5324		Lime & Shells				
	5660		Lime				
	5680		Hard Sandy Lime				
	5710		Lime				

ATTACH SEPARATE SHEET IF ADDITIONAL SPACE IS NEEDED

I hereby swear or affirm that the information given herewith is a complete and correct record of the well and all work done on it so far as can be determined from available records.

February 24, 1954
(Date)

Company or Operator Gulf Oil Corporation
Address Box 2167, Hobbs, N.M.

Name E F Taylor
Position or Title Area Prod. Supt.

(Form C-103)
(Revised 7/1/52)

DUPLICATE

NEW MEXICO OIL CONSERVATION COMMISSION
Santa Fe, New Mexico

MISCELLANEOUS REPORTS ON WELLS

RECEIVED
JAN 20 1954
OIL CONSERVATION COMMISSION

Submit this report in TRIPLICATE to the District Office, Oil Conservation Commission, within 10 days after the work specified is completed. It should be signed and filed as a report on Beginning Drilling Operations, Results of test of casing shut-off, result of plugging of well, result of well repair, and other important operations, even though the work was witnessed by an agent of the Commission. See additional instructions in the Rules and Regulations of the Commission.

Indicate Nature of Report by Checking Below

REPORT ON BEGINNING DRILLING OPERATIONS		REPORT ON RESULT OF TEST OF CASING SHUT-OFF	X	REPORT ON REPAIRING WELL	
REPORT ON RESULT OF PLUGGING WELL		REPORT ON RECOMPLETION OPERATION		REPORT ON (Other)	

January 18, 1954 (Date) Hobbs, New Mexico (Place)

Following is a report on the work done and the results obtained under the heading noted above at the

Gulf Oil Corporation (Company or Operator) Bertie Whitmire (Lease)

Rife Drilling Co. (Contractor), Well No. 7 in the SW ¼ NE ¼ of Sec. 8,

T. 20-S, R. 37-E, NMPM., Undesignated Pool, Lea County.

The Dates of this work were as folows: January 12-14, 1954

Notice of intention to do the work (XXX) (was not) submitted on Form C-102 on ...., 19......, (Cross out incorrect words)

and approval of the proposed plan (XXX) (was not) obtained.

DETAILED ACCOUNT OF WORK DONE AND RESULTS OBTAINED

Ran 165 jts 5694' of 7" OD 8 Rnd. Thd. 23 & 20# J-55 SS casing, 1 Howco shoe, 2 Howco floats, & Howco DV tool at 3553', with 13 Weatherford centralizers and 54 scratchers from 5709' to 5009' & Weatherford petal basket at 3600', set at 5709'. Cemented in two stages with 735 sacks 4% Gel & Neat cement. 1st stage with 235 sacks 4% Gel, max pressure 1700#. Circulated approximately 40 sacks. 2nd stage thru DV tool at 3553' with 450 sacks 4% Gel & 50 sacks Neat on bottom, max pressure 500#. Howco Temperature Survey failed to find cement behind 7" casing above DV tool after 8 hours.

After waiting over 30 hours tested 7" casing with 1000# for 30 min, no drop in pressure. Drilled DV tool at 3553' & tested tool with 1500# for 30 min, no drop in pressure. Ran bit to 5628', drilled cement from 5628' to 5708'. Tested 7" casing with 1000# for 30 min, no drop in pressure. Job completed 1-14-54.

Witnessed by J. E. Snead (Name) Gulf Oil Corporation (Company) Drilling Foreman (Title)

Approved: OIL CONSERVATION COMMISSION

A. G. Stanley (Name)

Engineer District 1 (Title) JAN 25 1954 (Date)

I hereby certify that the information given above is true and complete to the best of my knowledge.

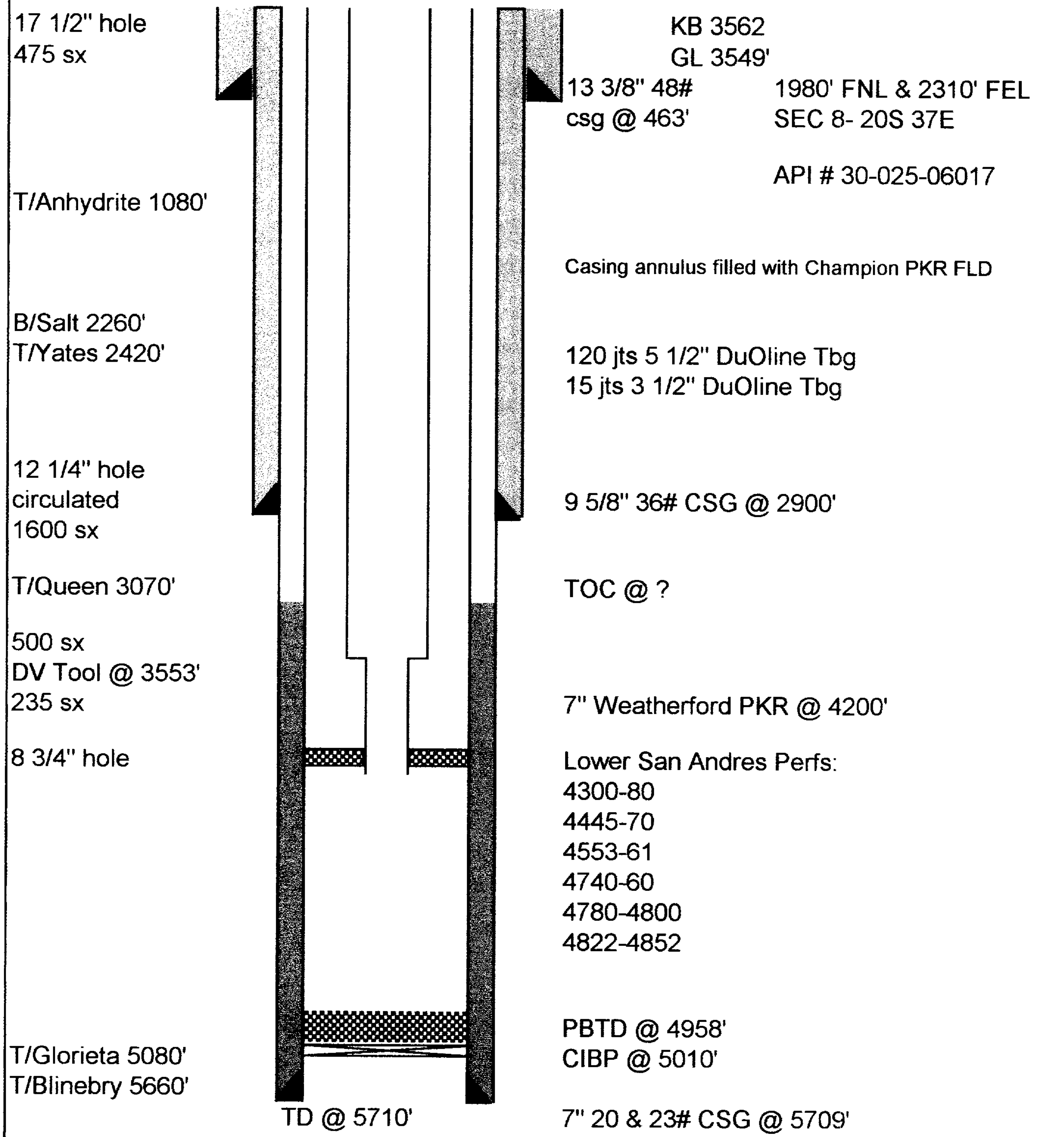
Name C. F. Taylor

Position Area Prod. Supt.

Representing Gulf Oil Corporation

Address Box 2167, Hobbs, N. Mex.

EME SWD Well G-8



Drawn	By		
9/27/00	CDH	**RICE OPERATING COMPANY** 122 WEST TAYLOR HOBBS, NM 88240	**EME G-8** 1980' FNL & 2310' FEL SEC 8- 20S 37E LEA COUNTY, NM

From: Kautz, Paul, EMNRD
To: Goetze, Phillip, EMNRD; Rose-Coss, Dylan H, EMNRD; Murphy, Kathleen A, EMNRD
Cc: Cox, Scott, EMNRD
Subject: RE: CBL Log
Date: Monday, July 13, 2020 1:31:08 PM

Hello Everyone,

Talked to Scott Curtis with Rice. The first CBL log was run at about 20 hours after running cement. They will be running another CBL tomorrow and will e-mail the second CBL for OCD review.

Paul Kautz
Hobbs District Geologist
Energy Minerals Natural Resources Dept.
Oil Conservation Division
1625 N. French Dr.
Hobbs, NM 88240
575-393-6161 ext. 104

From: Goetze, Phillip, EMNRD <Phillip.Goetze@state.nm.us>
Sent: Friday, July 10, 2020 3:45 PM
To: Kautz, Paul, EMNRD <paul.kautz@state.nm.us>; Rose-Coss, Dylan H, EMNRD <DylanH.Rose-Coss@state.nm.us>; Murphy, Kathleen A, EMNRD <KathleenA.Murphy@state.nm.us>
Cc: Cox, Scott, EMNRD <Scott.Cox@state.nm.us>
Subject: Re: CBL Log

My comment: Your call is accurate as usual - 2450 is the start of accumulation and 2550 is where the acoustics start showing cement that is sealing. Sad cementing probably due to flows in the SA from all that disposal. I concur with your recommendation to bradenhead. But you might want to warn them that the cement has to get to the shoe of the surface casing or it's perf and squeeze next. Or maybe P&A. Another future project for the group - is the SA flowing so much that a new design is necessary? Thanks Paul and have a good weekend. PRG

Get Outlook for iOS

On Fri, Jul 10, 2020 at 12:59 PM -0600, "Kautz, Paul, EMNRD" <paul.kautz@state.nm.us> wrote:

> Hello Phil, Dylan and Kathleen,
>
> Please see the attached CBL. The operator has not filed nay paperwork on this well. It is obvious that cement on the production string did not tie back into the surface casing. I would like to recommend that they do a breadenhead squeeze and running enough to cover the back side of the production casing. I believe that the top of cement at approximately 2450

to 2550.

Paul Kautz
Hobbs District Geologist
Energy Minerals Natural Resources Dept.
Oil Conservation Division
1625 N. French Dr.
Hobbs, NM 88240
575-393-6161 ext. 104

-----Original Message-----
From: Scott Curtis
Sent: Friday, July 10, 2020 9:10 AM
To: Kautz, Paul, EMNRD
Subject: [EXT] FW: CBL Log

Mr. Kautz,
Hope all is well. Here is a cbl that we ran on the N-11 swd well last night. Obviously we did not circulate cement on our production string.

We are discussing different options. I spoke with Kerry this morning and he deferred to you.

I will try to call you in a few minutes.

Thx Sir

-----Original Message-----
From: rtaylor@grandecom.net
Sent: Friday, July 10, 2020 2:27 AM
To: Scott Curtis ; Hayden Holub ; Roy Haynes
Cc: Lucas Sheward ; Nick Hines
Subject: CBL Log

scott,
attached is the CBL log for your review.

Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027
OCD Exhibit No. 8D

From:	Rose-Coss, Dylan, EMNRD
To:	Nathan Alleman; Goetze, Phillip, EMNRD
Cc:	Tom Tomastik; Nick Wofford; Steve Drake; Kautz, Paul, EMNRD; Gebremichael, Million, EMNRD
Subject:	RE: [EXTERNAL] Goodnight - Andre Dawson SWD #1 Question
Date:	Wednesday, December 21, 2022 1:59:40 PM

Nate,

After internal discussion, it was decided that it would be best if Goodnight could go ahead and perform a remedial perf and squeeze cement job. The primary objective would be to cap the contact with the Glorieta, but any additional cement up the annulus would be a benefit.

Thanks,

Dylan Rose-Coss

Petroleum Specialist
Oil Conservation Division
1220 South St. Francis Drive
Santa Fe, New Mexico 87505

C: (505) 372-8687

From: Nathan Alleman <nalleman@all-llc.com>
Sent: Tuesday, December 20, 2022 2:23 PM
To: Goetze, Phillip, EMNRD <phillip.goetze@emnrd.nm.gov>
Cc: Rose-Coss, Dylan, EMNRD <DylanH.Rose-Coss@emnrd.nm.gov>; Tom Tomastik <ttomastik@all-llc.com>; Nick Wofford <nwofford@goodnightmidstream.com>; Steve Drake <steve.drake@goodnightmidstream.com>; Kautz, Paul, EMNRD <paul.kautz@emnrd.nm.gov>
Subject: [EXTERNAL] Goodnight - Andre Dawson SWD #1 Question

links or opening attachments.

Mr. Goetze,

Thank you for joining us on the call this afternoon regarding Goodnight's Andre Dawson SWD #1. To summarize … Goodnight just finished drilling the Andre Dawson SWD #1, but wanted to get some regulatory guidance from OCD before moving forward with completing the well and setting tubing and packer.

Pertinent Details:

- **Injection Interval:** The Andre Dawson SWD #1 is a cased-hole completion using the San Andres Formation (4,287 ft – 5,590 ft) as the injection interval.
- **Well Depth:** The well was drilled to a TD of 5,743 ft. Logs ran after drilling indicated that the top of the underlying Glorieta Formation is at 5,643 ft, so the well is drilled 100 ft into the Glorieta.
- **Lower Cement:** After setting casing and pumping cement, the CBL showed there are numerous cement stringers isolating the Glorieta, but it didn't achieve complete cement bonding as expected. Based on the amplitude curve on the CBL, it is unlikely that remedial squeeze cementing could be accomplished on this section. ***See attached full CBL and snip of the CBL at the bottom of the injection interval.***
- **Upper Cement:** Based on the analysis of the radial cement bond log (attached), the top of good cement above the proposed top perforations in the San Andres Formation is at approximately 2,586 feet with proposed top perforation at 4,287 feet.
- **Remedial Cementing:** If remedial cementing is attempted, it is unlikely to succeed due to the presence of cement stringers and amplitude curve on the radial CBL. Additionally, if we perforate and squeeze cement in an attempt to remediate, we will have lost integrity of our production casing in the Glorieta since we would perforations in the Glorieta Formation. Additionally, even if remedial squeeze cementing is accomplished, squeeze perforations are notorious for leaking and not holding pressure.
- **Geologic Confinement:** There are several shale layers (total thickness of about 20 feet) between the lowest planned perforations (5,505 ft - 5,525 ft) and the top of the Glorieta (5,643 ft). These shale layers will act as lower confinement and prevent injection fluid migration downward out of the permitted San Andres injection zone. ***See attached neutron log snip***.
- **Production Casing Pressure Test:** The production casing was pressure tested to 1,000 and the test was good.

Based on the presence of shale layers below the perforations in the San Andres (and above the top of the Glorieta Formation) and the presence of cement stringers and steel casing isolating the Glorieta from injection fluids, ALL Consulting is confident that the injection will be confined to the San Andres injection zone and will not result in injectate migrating out of zone into the Glorieta. However, we wanted to get OCD's direction on how we should proceed before moving forward with running tubing and packer.

Question: What are OCD's thoughts on how Goodnight should proceed? Are they cleared to go ahead and run tubing and packer or is further discussion/data necessary?

-
As always, we're happy to jump on a call to discuss in more detail at your earliest convenience.

Thank you for your prompt attention to this matter!

Nate Alleman
Energy & Environmental Consultant
ALL Consulting
1718 South Cheyenne Avenue
Tulsa, OK 74119
Office: 918-382-7581
Cell: 918-237-0559

STATE OF NEW MEXICO
ENERGY, MINERALS AND NATURAL RESOURCES DEPARTMENT
OIL CONSERVATION DIVISION

IN THE MATTER OF THE HEARING CALLED BY THE OIL CONSERVATION DIVISION FOR THE PURPOSE OF CONSIDERING:

APPLICATION OF GOODNIGHT PERMIAN MIDSTREAM, LLC FOR APPROVAL OF A SALTWATER DISPOSAL WELL, LEA COUNTY, NEW MEXICO.

CASE NO. 22626
ORDER NO. R-22869-A

ORDER OF THE DIVISION

This case came in for hearing before the Oil Conservation Division ("OCD") at 8:15 a.m. on September 15, 2022, in Santa Fe, New Mexico.

The OCD Director, having considered the testimony, the record, the recommendations of Hearing Examiner Phillip R. Goetze, these findings of fact, and conclusions of law issues this Order.

FINDINGS

1. Due public notice has been given, and the OCD has jurisdiction of this case and the subject matter.

2. Goodnight Midstream Permian, LLC ("Applicant" or "Goodnight") seeks authority to for its proposed Piazza Well No. 1 (API No. 30-025-pending; "Proposed Well"), to be located 1847 feet from the South line and 2537 feet from the West line (Unit K) of Section 9, Township 21 South, Range 36 East, NMPM, Lea County, New Mexico, as an Underground Injection Control ("UIC") Class II well for commercial disposal of produced water into the San Andres formation from approximately 4125 feet to 5400 feet below surface.

3. Applicant submitted a Form C-108 application (Administrative Application No. pBL2126055537; designated administrative order SWD-2458) on September 17, 2021, for authority to inject into the Proposed Well.

4. The OCD received on September 22, 2021, a formal written notice by Empire New Mexico, LLC ("Protestant" or "Empire") protesting the application.

5. On March 4, 2022, Goodnight filed an application for hearing for approval of the Proposed Well for disposal of produced water. Subsequently, Empire filed an entry of appearance for this application on March 5, 2022, followed by an objection to the case being conducted by affidavit on March 31, 2022.

6. Following a status conference on April 7, 2022, the OCD Examiner [William Brancard] issued a pre-hearing order which detailed the evidentiary requirements for the hearing and set the hearing date for June 16, 2022.

7. Between the issuance of the OCD Pre-hearing Order and the final hearing on September 15, 2022, the Applicant and Protestant filed the following motions and results by the OCD:

a. OCD issued a Subpoena on May 16, 2022, requiring Empire to provide specific records and information regarding the Eunice Monument South Unit ("EMSU" or "Unit").

b. OCD issued a second Subpoena on June 6, 2022, requiring Empire to provide specific records and information identified in the first Subpoena but with a new enforcement date of June 9, 2022.

c. A motion hearing on June 16, 2022, oral arguments were presented by both parties to OCD Examiner addressing a Motion to Dismiss filed by Empire on June 7, 2022, along with an Opposed Motion for Continuance.

d. At the same hearing on June 16, 2022, oral arguments were presented by both parties addressing a Motion to Quash Subpoena filed by Empire on June 7, 2022. On July 26, 2022, the OCD issued an Order denying the motion but did modify the conditions of the Subpoena including a revised compliance date of August 25, 2022.

e. A second Pre-Hearing Order was issued following the motion hearing which scheduled an evidentiary hearing in this case for September 15, 2022.

f. On August 24, 2022, the OCD Examiner issued an order on Motion to Dismiss by Empire. The Motion to Dismiss was denied and the scheduled hearing remained in effect.

g. Protestant filed a Motion for Leave to File Late Exhibits and Testimony. On September 12, 2022, Goodnight filed a separate response in opposition to the Motion for Leave along with a Motion in Limine to Exclude Evidence and Testimony regarding the late submittal of the witness testimony and exhibits. At the evidentiary hearing on September 15, 2022, the OCD Examiner heard arguments from both parties and, though expressed disappointment with the late submittal of the exhibits by Empire, allowed the entry of the exhibits into the record while denying the Motion in Limine to Exclude.

8. On June 20, 2022, Goodnight filed a Supplemental Legal Memorandum in response to the OCD Examiner's statement that a significant issue "*is whether statutory unitization precludes the Division from authorizing injection for disposal, unrelated to unit operations, within a formation*

included within the vertical limits of a statutory unit". The Memorandum summarizes the following arguments:

a. The Statutory Unitization Act limits the Division's authority to unitize only underground hydrocarbon reservoirs or pools;

b. Order No. R-7765 must be read in harmony with the Division's authority to unitize only a pool or part of a pool;

c. Unitization of the San Andres aquifer conflicts with the New Mexico Constitution; and

d. Because the Act does not preclude injection into the San Andres formation, the Division must decide Goodnight's application on its merits.

9. On September 8, 2022, Goodnight filed a pre-hearing statement with the following conclusions based on the evidence and testimony filed concurrently:

a. That the proposed San Andres injection interval does not have a history of hydrocarbon production and is not prospective for hydrocarbon development;

b. That injection into the San Andres interval would not migrate out the approved zone which would impair correlative rights and cause waste; and

c. That approval of the San Andres injection interval would not interfere with the waterflood operations of the EMSU.

10. Empire also filed a pre-hearing statement with the following conclusions based on the evidence and testimony filed concurrently:

a. Applicant does not have a working interest or any other interest in the EMSU which would allow it to operate a commercial UIC Class II disposal well within the vertical and horizontal limits of the Unit;

b. Location and operation of the Proposed Well with respect to Empire's EMSU Well No. 200H, an active production well, will damage the damage the production of this well; and

c. Protestant is studying new oil recovery trends of the San Andres formation in this area and the potential to implement new practices for development of these trends.

11. At hearing on September 15, 2022, Goodnight, through counsel, provided exhibits and testimony at hearing in support of the approval of the injection authority for the Proposed Well.

a. Applicant proposed an injection interval within the San Andres formation between 4,125 feet and 5,400 feet with the Proposed Well operating at a maximum surface injection pressure of 825 pounds per square inch and an estimated daily injection rate of 25,000 barrels of water per day ("BWPD").

b. The Proposed Well is to be completed using a two-string casing design: 13⅜-inch surface casing set at 1,445 feet and 9⅝-inch production casing set at 5,470 feet; both casings completed with cement circulated to surface. Tubing is to be internally coated and have a diameter of 5½-inch or less set with a Baker Hornet packer at approximately 4,100 feet. Perforations for injection are to be between 4,125 feet and 5,400 feet.

c. Applicant states the proposed injection interval is defined by an upper confining layer composed of low-permeable lithologic barrier at the top of the San Andres formation and a lower confining layer defined by the Glorieta formation. Applicant states that the proposed injection interval is sufficiently isolated as not to impact either deeper producing interval or shallower intervals with development through secondary recovery.

d. The proposed injection interval is characterized as depleted reservoir requiring very low injection pressure with some disposal wells demonstrating the ability to inject 28,000 to 35,000 BWPD using only gravity as the injection pressure. Applicant attributes this reservoir condition to the withdrawal of a significant volume of San Andres formation water for use in the EMSU waterflood.

e. Applicant identified three (3) wells out of total of 24 wells that penetrated the proposed injection interval within the one-half mile Area of Review (AOR) of the surface location of the Proposed Well. Two of these wells are active The Applicant stated the completion information indicates the three wells are properly cased and cemented to prevent vertical migration of injection fluids.

f. Applicant identified nine (9) points of diversion listed in the New Mexico Water Rights Reporting System database that are in the within one mile of the surface location of the Proposed Well. Of the nine locations, two wells were sampled for this application while another four wells were sampled for other Form C-108 applications in this area.

g. The analyses of produced water samples provided by Applicant indicates that injection fluids contained significantly higher total dissolved solids concentrations than those values provided for the existing formation fluids in the proposed disposal interval.

h. Applicant stated that the Proposed Well is to be part of their "Llano system" which currently is comprised of 80 miles of pipelines, six recycling/re-use facilities, and nine approved UIC Class II disposal wells. The disposal wells were approved for injection into either the San Andres or Glorieta formations with some of the wells having a combination of these two formations as injection intervals.

i. Applicant identified the EMSU Well No. 200H (API No. 30-025-04492) as being completed only in the Grayburg formation and stated its production has not been impacted by injection operations that were closer and had been operating for a significant amount of time prior to the submittal of the application for the Proposed Well.

j. Based on its own evaluation, Applicant asserted that the potential for hydrocarbon development of the San Andres formation in this area was not supported by any significant show of hydrocarbons in the vast volume of water produced for the EMSU waterflood operation. Additionally, Applicant stated that the formation was no longer a candidate for development as a Residual Oil Zone ("ROZ") due to the effects of water production that have altered and degraded the original reservoir conditions.

12. At the same September hearing, Empire appeared through counsel and provided exhibits and testimony regarding the potential impacts on the EMSU with the approval of the Proposed Well.

a. Protestant stated the EMSU was acquired in 2021 with the intent of renewing the operation of the waterflood to increase the performance of the Unit and to assess the entire Unitized Interval for additional hydrocarbon potential. Empire did not provide a plan of development for this project at hearing.

b. Empire exhibits included a recent prospectus by the previous unit operator for renewal of the current waterflood operation and expansion. Protestant also noted that the prior unit operator required an override on production as a condition of the sale.

c. Empire stated that it was assessing the potential of ROZ occurrences which would include the San Andres formation but did not provide any specific details at hearing.

d. Empire maintained that the geologic parameters of the San Andres formation and the current reservoir conditions of the waterflood unit are not fully characterized and that disposal into the Unitized Interval would degrade any future efforts for an increased recovery of the remaining oil in place.

13. NGL Water Solutions Permian, LLC filed an entry of appearance but did not oppose the application at hearing. No other party appeared at hearing or otherwise opposed the granting of this application.

14. Following the hearing of the case in September and prior to an order being issued by the OCD Director, three additional motions were filed by the parties in this case.

a. Goodnight filed a Motion to Compel on November 3, 2022, regarding EMSU Well No. 462 and the required filing of the completion report for well. Empire did not respond to the motion.

b. On January 10, 2023, Goodnight filed a Motion to Withold Allowable for the EMSU No. 462 contending Empire was noncompliant with OCD rule on the proper filing of Form C-105 for this well thus requiring the OCD to withhold the allowable for the well.

c. The OCD issued an Order dated January 23, 2023, approving the Motion to Compel by ordering Empire to provide the well information within 15 days or provide a sworn statement that all records for this well have been provided. In the same Order, the Motion to Withhold was denied by the OCD Examiner and later became the subject matter for a separate case, Case No. 23775.

d. On August 25, 2023, Empire filed a Motion to Stay Issuance of Order citing that four pending cases involving protested disposal well applications by Goodnight in the same area should be considered in conjunction with Case No. 22626. Empire contended that the technical evaluation for the pending cases was relevant to Case No. 22626 and that a single order should be issued only after considering the evidence of the pending cases. Goodnight filed a response in opposition to the motion. Subsequently, OCD issued Order No. R-22869 dated September 8, 2023, which denied the Motion to Stay.

CONCLUSIONS OF LAW

1. Applicant provided the information required by 19.15.26 NMAC and the Form C-108 for an application to inject produced water into a Class II UIC well.

2. Applicant complied with the notice requirements of 19.15.4 NMAC.

3. Empire entered an appearance and pre-hearing statement for the case in a proper and timely manner.

4. On November 7 and 8, 1984, the Oil Conservation Commission ("OCC") heard consolidated Cases No. 8397, No. 8398 and No. 8399 which established the EMSU and the parameters under which the Unit was to operate.

a. Case No. 8397 was an application for statutory unitization of the EMSU and was approved as Commission Order No. R-7765.

b. Case No. 8398 was an application for the waterflood project and operation which was approved as Commission Order No. R-7766.

c. Case No. 8399 was an application for pool extension and contraction for the EMSU which was approved as Commission Order No. R-7767.

5. On December 27, 1984, Commission Order No. R-7765 established the EMSU with the vertical limits including the San Andres formation (Ordering Paragraph (3)). Concurrently, Commission Order No. R-7766 also included the San Andres formation as part of the Unitized Interval (or "Unitized Formation"). Finally, Ordering Paragraphs (1) and (2) of Commission Order No. R-7767 realigned the vertical limits for the shallower Eumont Gas Pool and the deeper Eunice Monument Oil pool [Eunice Monument Grayburg-San Andres pool; pool code 23000]. This

separate order on nomenclature changes also reaffirmed that the lower limit of the Eunice Monument Oil pool as the base of the San Andres formation.

6. The Commission approved the inclusion of the San Andres formation in the Unitized Interval based on the Technical Committee findings presented in the hearing for the consolidated cases. The Technical Committee Report (*Proposed Eunice Monument South Unit, Lea County, New Mexico* dated April 1983; "Report") concluded that the southern portion of the Eunice Monument Oil pool should be unitized and a waterflood initiated. The Report further recommended "*The unitized interval shall include the formations from a lower limit defined by the base of the San Andres formation, to an upper limit defined by the top of the Grayburg formation or a -100 foot subsea datum, whichever is higher.*" [Recommendations and page 43]

In the Facility Design section of the Report, the Technical Committee described the following sources of water for use in the operation of the waterflood:

> *"The total water requirement will be provided by reinjection of produced water, and from make-up water provided by nine San Andres supply wells. For this cost estimate, the assumption was made that new water supply wells would be drilled; however there is a possibility that existing wellbores may be available which could be purchased and completed in the San Andres."* [Page 29]

The economic evaluation presented in the Report for a waterflood operation in this area of the Eunice Monument Oil pool included the use of formation water of the San Andres to supplement the fluid volumes required to successfully conduct the secondary recovery project. Additionally, the testimony for the consolidated cases emphasized that the San Andres formation water were compatible for use as supplemental injection (or "make-up") water for the waterflood operation.

7. Chevron USA, Incorporated, as subsequent Unit operator of the EMSU, expanded the use of San Andres formation waters for the waterflood operation with the completion and operation of six (6) water supply wells. The volume of formation water produced from these wells for use in the waterflood was estimated at approximately 348 million barrels.

8. The same Unitized Interval (with the San Andres formation included) was later presented in the testimony for Case No. 10253 which resulted in Order No. R-9494 for the approval of the North Monument Grayburg-San Andres Unit. From the hearing transcript dated April 4, 1991 [Pages 25 and 26], the testimony of the Amerada Hess expert summarized the reasons for the inclusion of the formation:

> *Question: Now does Amerada Hess propose to interject both the Grayburg and the San Andres?*
>
> *Answer: We propose to inject into the Grayburg formation. The primary target for this injection are the lower two zones, Zones 3 and 3C.*
>
> *Question: Why is the San Andres included in this application?*

> *Answer: The San Andres is included for three reasons: Number one, the San Andres may be a source of water for the injection. Number two, there is potential for tertiary production from the San Andres. And thirdly, this interval is comparable to the unitized intervals in the Eunice Monument South.*

9. The approval of both Statutory Units with the inclusion of the San Andres formation in the Unitized Interval is consistent with the OCC recognition of this formation as critical element for a successful waterflood operation and for the potential of undeveloped hydrocarbon resources. This approval is concordant with the authority provided to the OCC under the provisions of NMSA 1978, §70-7-7(J) which states that the Division order providing for unitization and unit operation of a pool or part of a pool shall include "*such additional provisions as are found to be appropriate for carrying on the unit operations and for the protection of correlative rights and the prevention of waste*."

10. Applicant's proposed operation for the Proposed Well would expand the use of the San Andres formation as a disposal interval. Approval of the Proposed Well with the injection of UIC Class II fluids into the Unitized Interval would encroach towards the northeast and the interior of the EMSU and the use of the San Andres formation as a compatible source of make-up water for waterflood operations.

11. Empire has provided sufficient evidence for continued assessment of the Unitized Interval for potential recovery of any additional hydrocarbon resources remaining in place. Approval of the Proposed Well would contradict the responsibility of the OCD "*to prevent the drowning by water of any stratum or part thereof capable of producing oil or gas or both oil and gas in paying quantities and to prevent the premature and irregular encroachment of water or any other kind of water encroachment that reduces or tends to reduce the total ultimate recovery of crude petroleum oil or gas or both oil and gas from any pool.*"

IT IS THEREFORE ORDERED THAT:

1. The application of Goodnight Midstream Permian, LLC for authority to inject produced water into the San Andres formation using the proposed Piazza SWD Well No. 1 as a UIC Class II disposal well is hereby **denied**.

2. Empire New Mexico, LLC, as the unit operator of the Eunice Monument South Unit, shall comply with Commission Order No. R-7766, Ordering Paragraph (8) and reinstitute submitting monthly reports for the waterflood project. The unit operator shall provide these reports to OCD through the OCD Engineering e-mail (ocd.engineer@emnrd.nm.gov) with electronic copies also provided to the New Mexico State Land Office ("NMSLO") and the appropriate office of the Bureau of Land Management. OCD shall have the authority without hearing to reduce the reporting frequency to biannual two years after the approval of this order. Additionally, Empire shall provide a copy of any Plans of Operation and/or Plans of Development that are annually submitted to the NMSLO for this Unit.

3. Jurisdiction is retained by the OCD for the entry of such further orders as may be necessary for the prevention of waste and/or protection of correlative rights or upon failure of the operator to conduct operations (1) to protect fresh or protectable waters or (2) consistent with the requirements in this order; whereupon the OCD may, after notice and hearing or prior to notice and hearing in event of an emergency, terminate the disposal authority granted herein.

DYLAN M. FUGE
DIRECTOR (Acting)

Date: 11/29/23

DMF/prg

State of New Mexico
Energy, Minerals and Natural Resources Department

Michelle Lujan Grisham
Governor

Sarah Cottrell Propst
Cabinet Secretary

Todd E. Leahy, JD, PhD
Deputy Secretary

Adrienne Sandoval, Director
Oil Conservation Division

May 28, 2020

Mr. Philip Dellinger, Chief
Ms. Lisa Pham, Environmental Engineer
Ground Water/UIC Section, Region 6
United States Environment Protection Agency
1445 Ross Avenue, Suite 1200
Dallas, TX 75202-2733

RE: UPDATE OF UNDERGROUND INJECTION CONTROL CLASS II ACTIVITIES WITHIN THE STATE OF NEW MEXICO FOR POSSIBLE INJECTION INTO UNDERGROUND SOURCES OF DRINKING WATER: THE CAPITAN REEF AQUIFER SYSTEM

Dear Mr. Dellinger and Ms. Pham:

The Oil Conservation Division (OCD) of the New Mexico Energy, Mineral and Natural Resources Department (EMNRD) previously provided a review to specifically identify impacts due to Underground Injection Control (UIC) Class II operations which were potentially injecting directly into Underground Sources of Drinking Water (USDWs). The OCD submitted a comprehensive review of Class II operations within the state in a correspondence dated October 24, 2016. You have requested, on behalf of the United States Environmental Protection Agency (EPA), for an update of current oil and gas injection activities occurring in association with one specific USDW, the Capitan Reef aquifer system.

<u>Review of the Capitan Reef Aquifer System</u>
The Capitan Reef aquifer system (Capitan Reef) is the lithosome that comprises the reef complex, the Goat Seep reef, and the facies transition of the backreef area (the shelf aquifers contained in the Artesia Group as described by Hiss (1980); see Report Figure 1). The Capitan Reef in New Mexico extends from the surface exposure of the reef at the base of the Guadalupe Mountains, and extends in an arc to the southeast corner of the state south of Jal where the New Mexico-Texas state lines meet (see Report Figure 1).

Hiss describes the general ground-water movement as follows:

> *Water entering the Capitan aquifer in the Guadalupe Mountains moved slowly northeastward and then eastward along the northern margin of the Delaware Basin to a point southwest of present-day Hobbs. Here it joined and comingled with a relatively larger volume of ground water moving northward from the Glass Mountains along the eastern margin of the Delaware Basin. From this confluence, the ground water was discharged from the Capitan aquifer into the San Andres Limestone, where it then moved eastward across the Central Basin Platform and Midland Basin, eventually to discharge into stream draining to the Gulf of Mexico (Page 294; Hiss, 1980).*

Figure 22 of Attachment 1 provides the general flow directions based on Hiss' interpretation and includes more recent water data following the presentation by Hiss. Figure 18 of Attachment 1 provides a map showing the thickness of the Capitan Reef.

The quality of groundwater in the Capitan Reef is variable with location. The western segment of the Capitan Reef is recognized as a USDW and is utilized as a source for both domestic and municipal water supply wells. The eastern portion of the aquifer contains both protectable waters, based on total dissolved solids (TDS) concentrations, as well as productive oil and gas fields in formations of the Artesia Group along the facies transition in the forereef (see Report Figure 2).

Additionally, the western segment of the Capitan Reef where the reef outcrops at surface is an important recharge area mapped as Capitan Outcrop with overlying Quaternary deposits (see Figure 8 of Attachment 1). This area provides vital recharge of the Capitan Reef groundwater that flows northeast and supports water production for the Carlsbad Municipal Water System (see Report Figure 2).

<u>Review of OCD Protocols for Evaluation of UIC Class II Injection Activities</u>

As part of the prior effort to assess the Class II injection activities possibly impacting USDWs, the OCD emphasized the significant difference between Class II activities that were enhanced recovery (ER) projects and injection wells that were approved as disposal operations. The approval process for ER wells offered the following reasoning for limited application of exempted aquifers in areas with ER projects in response to 40 CFR 146.4:

> *"There seems little necessity for elaborate aquifer exemptions related to ER Projects for the following reasons:*
>
> *(1) The pressure sinks surrounding the producing wells in an ER project cause injected fluids to move inward toward producing wells rather than outward toward any other part of the formation. Such contained movement eliminates the direct potential for contamination of USWDs which may be located elsewhere in the same formation.*
>
> *(2) The Division knows of no instance in the State where drinking water is being produced and consumed by the public from an aquifer which is also an oil and/or gas reservoir at the same horizontal and vertical section. Some USDWs exist within the same vertical section but horizontally removed from*

> *the hydrocarbon zone. The San Andres formation in Eddy County provides excellent examples of both of these situations. These conditions are discussed and extensively referenced in Appendix A-1."* [Section j. Aquifer Protection, Aquifer Exemption, *Class II Demonstration*, page 51]

The approval process for produced water (or SWD) wells includes the following stipulation in response to 40 CFR 146.4:

> *"All applications for approval of SWD wells not within an oil or gas zone or within one mile thereof will contain data on water quality in the proposed disposal interval. Any SWD well proposed for disposal into a formation or zone containing water of 10,000 mg/1 TDS* [Total Dissolved Solids] *or less which is not an exempted aquifer will be set for public hearing before a Division examiner*." [Section j. Aquifer Protection, Aquifer Exemption, *Class II Demonstration*, page 52]

This criterion is incorporated in the Division's regulation under Rule 19.15.26.8(E) New Mexico Administrative Code (NMAC). Additionally, the state UIC program included specific regulation by limiting disposal by SWD wells in Lea County to formations older than the Triassic age (Rule 19.15.26.8(E)(1) NMAC).

The primacy demonstration also contained the following recommendation for future assessment for aquifer exemptions for portions of the Capitan Reef aquifer within Lea County:

> *"Based upon this study the Division proposes that the Tansil, Yates, Seven Rivers, Queen, Grayburg, and San Andres formations of Lea County be classified as exempt aquifers. Please refer to Figures 8 and 9 of the Lea County Report, Appendix A-2* [Hiss (1980)] *and Resource Map No. 6 from "Stratigraphy and Ground-Water Hydrology of the Capitan Aquifer, Southeastern New Mexico and Western Texas" by William L. Hiss (PhD Thesis, University of Colorado 1975)* [Hiss (1976)] *for the vertical and horizontal sections to be exempted. Because of the gradational nature of the back reef facies a more precise description is not proposed."* [Section j. Aquifer Protection, Aquifer Exemption, *Class II Demonstration*, page 53]

Review of Injection Wells from the RESPEC Report

In 2009, the OCD identified the need for further study of the Capitan Reef and its relationship with Class II well activities along the eastern portion in Lea County. The EPA provided funding for the evaluation which resulted in a report (Topical Report RSI-2048 by RESPEC Consulting and Services Inc.) that identified a list of wells with a higher risk of injection into the Capitan Reef.

The OCD, through the 2016 UIC Class II activities review, identified existing injection operations in proximity to the Capitan Reef that require supplemental assessment including the high-risk wells identified in the 2009 RESPEC report. The OCD compiled a list of 32 wells which required additional investigation to determine the potential or necessity for establishing exempted aquifers. The list of wells with information and current status is compiled in Table 1 of this report and locations of the wells (labelled as ReefWellsEPA) are provided in Report Figure 2.

For this report, a commercial operation is defined as a disposal well that receives multiple sources of produce water and the operation is not restricted by a daily rate, limited to a specific operator, or limited to specific production leases.

The review of the 32 wells produced the following results:

1. **Injection wells within active ER units:** The first 12 wells listed in Table 1 (Report ID No. 1 through 12) are associated with ER activities. There are three specific ER projects that are authorized to use these injection wells. All three ER projects are active with the injection wells providing the waterflood drive for production of reservoirs within the Artesia Group. The portion of the Capitan Reef where the producing formations of the Artesia Group are part of the backreef transition to the reef begins east of the city of Carlsbad and continues to the southeast corner of the state. Report Figure 2 highlights the locations of the Capitan Reef where hydrocarbon occurrences (classified as pools under OCD rules) in the backreef interact with the reef aquifer.

   These injection wells are assessed as having no impact to that portion of the Capitan Reef characterized as USDWs. Their ER operation and relationship to the Capitan Reef is discussed in a prior section of this report. The active injection wells have very low injection rates while some of the injection wells have been converted back to producing wells.

2. **Injections wells that have lost authority or are plugged:** Six injection wells from Table 1 (Report ID Nos. 16, 18, 21, 24, 27 and 29) are no longer active due to the loss of injection authority *ipso facto* through non-injection for a continuous period of 12 months or because the wells have been plugged. All six wells were originally approved for disposal associated with leases that had production from the Artesia Group. These wells were later approved for expansion into commercial operations that received produced water from multiple formations and operators.

3. **Injection well assessed as not a high-risk to impact the Capitan Reef:** One injection well was evaluated and assessed as not hydrologically connected to the Capitan Reef. The Brown No. 5 (API 30-025-09807; Report ID No. 32) was reviewed as part of OCD Case No. 15723 (see Division Exhibit No. 2 of Attachment 2). The injection pressure for this well has increased to a point where operation of the well is minimal. This increase would indicate the reservoir has reached capacity to accept fluids and shows no apparent communication with the Capitan Reef.

4. **Active injection wells that are shut-in:** Four injection wells from Table 1 (Report ID Nos. 15, 22, 23 and 30) are no longer actively injecting but still retain the authority to inject. All four wells are disposal operations that are commercial. Two of the wells were acquired by a new operator that is being actively petitioned by OCD for plugging. The two remaining wells are shut-in and are part of a bankruptcy case. The OCD is also pursuing the voluntary plugging of these wells or seek denial for renewal should the injection authority lapse.

5. **Active injection wells:** Nine injection wells (Report ID Nos. 13, 14, 17, 19, 20, 25, 26, 28 and 31) remain active and comply with required mechanical integrity testing. All of these wells are commercial disposal operations. Of the nine wells, six have reported current disposal rates of less than 400 barrels of water per day (BWD) or have no reported injection for 2020. The disposal wells were approved with the best information available regarding the delineation of the aquifer and were assessed as having low potential to impact the Capitan Reef water quality.

   The three remaining disposal wells (Report ID Nos. 25, 28, and 31) are active and are subject to continued monitoring of operation and for compliance with OCD UIC rules. It is probable that these wells will be plugged in the near future due to age and changing disposal requirements due to larger midstream participation within the Delaware Basin.

<u>Current OCD Procedures to Protect Water Quality</u>

OCD continues the effort to protect the water quality of those portions of the Capitan Reef that qualifies as an USDW. As part of this effort, four review procedures are being utilized by the OCD for both new applications and existing Class II disposal permits.

1. **Review of Existing UIC Class II Wells Though Change of Operator Applications**
   Recent fluctuations in commodity prices has increased the sale and transfer of ownership for many Class II injection wells along with active producing wells. OCD has expanded its review for change of operators through the processing of OCD Form C-145. When an operator provides this form, those wells with injection authority are reviewed for history, operation, and compliance status. This offers the ability to confirm the status of the injection authority as well as intervene to oppose the transfer of a well that the OCD finds in violation of UIC rules.

2. **Special Well Construction: Four-string Casing Requirement**
   A portion of the Capitan Reef shares the same spatial area with the Known Potash Leasing Area. The economic potash resource is found within the Salado formation which overlies the Capitan Reef where they occur along the Northwest Shelf and adjacent portion of the Delaware Basin (see Report Figure 1B). The area where the four-string casing construction is required is shown in Report Figure 2.

   Due to the salt content of the Salado formation, drilling through this interval requires a brine-saturated drilling mud. To avoid impacting the Capitan Reef below the Salado formation, the Bureau of Land Management and the OCD established a protocol to require a dedicated string of cemented casing (the second casing) to isolate the Salado before drilling into the reef. Another dedicated string (the third casing) is required for the Capitan Reef before continuing to deeper formations. This construction is required for both producing wells and Class II wells.

3. **Application of Wellhead Protection Areas Under the Safe Drinking Water Act**
   The OCD has applied components from the Wellhead Protection Program approved in the

1986 amendments to the Safe Drinking Water Act in assessing UIC applications. Two examples are provided. Attachment 3 contains exhibits for a case prepared by OCD to oppose an application for a Devonian disposal well in an area east of Carlsbad. The proposed well was to be completed in a deep Devonian interval which required drilling through the Capitan Reef. The applicant failed to recognize the protectable status of the reef in this area and address this situation with a proper casing design (see Division Exhibit No. 4 of Attachment 3). The location of the well also exhibited extreme karst geology which was demonstrated by the history of difficult well completions especially for the first casing or the casing designed to protect shallow USDWs (see Division Exhibit No. 2 of Attachment 3). This completion difficulty is further complicated by shallow domestic wells which could easily be contaminated by improper UIC well construction (see Division Exhibit No. 3 of Attachment 3).

The second example is the administrative denial of an application for a disposal well within the recharge area for the reef west of Carlsbad. The reasons for the denial are detailed in the following email content sent to the applicant:

"Denial of the application is based on the following observations:

1. *The well is proposed as a commercial operation with multiple produced water sources for disposal.*
2. *The proposed drilling program at location of the well presented in the application will result in the well penetrating the Capitan Reef aquifer [as projected from Hiss (1976) and mapped by Hayes and Gale (1957)] at shallow depth. This portion of the reef structure is the within the recharge area for the aquifer and is up-gradient of the municipal wells that provides drinking water to the city of Carlsbad. The application also does not address this transition and makes general assumptions of the stratigraphy not supported by the available geologic information as well as aerial photography of the surface geology of the area.*
3. *The application provides a water sample (assumed to be from the BLM stock water well with OSE POD No. C-03936) that demonstrates ground water with very good quality (523 mg/L TDS) at shallow depths. Similar ground water wells in the area note "artesian" conditions. The SWD well design and potential drilling program [based on the stratigraphic column included in the applications] does not address the protection of these occurrences, including the Reef aquifer, of protectable waters.*
4. *Finally, review of both BLM assessments for "Critical Karst Resource Areas" and drilling history for producing wells in this area show extremely high potential for poor well construction for the casing interval designated to protect any USDW. The daily logs for the Exxon Federal Com. No. 3 (30-015-32865), approximately 1600 feet east of the proposed SWD location, provides examples of drilling difficulties at shallow depths:*
   - *07/23/2003: Lost returns at 62'. Mix LCM sweep and pump. Regained circulation. Drill from 62' to 64' and lost returns. Drill string went from 75' to 152' with no returns.*
   - *07/24/2003: Ream from 50' – 81'. When attempting to make connection, cannot get rotary busing in table. Pick up and ream*

several times with same results. [The entry continues to describe the recovery of the drilling string, the pumping of 400 sacks of fiberglass cement into the bore hole, then continuing to ream to 80 feet with no returns].

- *07/25/2003: Reaming from 85' to 112' with no returns and hole falling in as we are attempt to make conn; keep hole open by reaming while waiting for cmt from Hall, TOH; ran 75' of fiberglass tubing, could not get past that depth, hook up Hall & pump 400 sx of cmt, cmt came up into conductor pipe & btm of cellar when hole caved in around cellar; diameter of hole appears to be 14-15' & water level is about 8' below btm of cellar, ordered 1500 sx of Hall "light" cmt for cellar; wait on Hall & monitor hole around cellar, hole still falling in, but conductor pipe still in place, so it appears that cmt job worked as planned and caving is loose sand and rock below cellar; cmt with 400 sx of Hall "light" and cmt came up into cellar, shoveling pea gravel into hole as we cmt, put 6 yards of gravel into hole along with the 400 sx of cmt; cmt did not fall back & samples set up firm in 3 hrs; PU bit & kelly, tag cmt at 35' & drill cmt down to 152' with full returns, having large amt of torque while ramming through previously drilled hole, torque should go away once we start making new hole below 224'.*
- *07/26/2003: Reaming from 152' - 155' with returns. Lost returns at 155' and ream to 175' pumping LCM sweep. Work string out of hole to 80' and pulled free. Build volume in pits. Ream up and down to 121' and attempt to make connection with no success. Trip out of hole and laydown bit and RMR. Run 2.375" Fiberglass tubing to 108' and could not get any deeper. Wait on cement from Halliburton. Cement with 400 sx of Thixatropic at 108'. Level in conductor came up from 40' to flow line and circulated 5 - 7 bbls of water to pits. Drained 10' of good cement from bottom of conductor and level did not fall any farther. Pull on fiberglass tubing and surface joint broke just below rotary table. Wait on cement to set. Mud up in slug pit and transfer to frac tank. Will go to mud after drilling cement and circulate through steel pits. Tag cement at 23' and drill hard cement to 115'. Ream on to 194' with full returns and very high torque String became stuck at 194' and lost returns. Hole appears to have fallen in on drill string. Work drill string and attempt to rotate and circulate. Pulled up 5' to 189' and have partial returns. Kelly beginning to slip in rotary bushings.*
- *07/26/2003: Work stuck pipe at 189'. Kelly bushings stripped and kelly rounded off. Rotary chain broken and sprocket teeth worn off. Replacement parts coming from Hobbs, NM yard. Replace chain and sprocket on rotary table. Wait on kelly. Filling pits with water.*

Unload kelly, Smith Driving tool, and 2.375" tubing. Cut conductor underneath floor to break out kelly. Break out kelly and change out. Make up driving tool on 6" DC and drive bit down 9'. Laydown driving tool. Trip out of hole and build 100 bbls of 100 viscosity mud. Tagged fill at 120' while going in hole to open up for cement plug. Ream in hole from 120' to 197'. Had partial returns when sweep was pumped and hole was open. Ran out of mud and hole fell in at 160' while attempting to pull out. Work stuck pipe at 160'. Ran 5 jts of fiberglass tubing and wash down to 150'. Pumped 100 bbls of mud in attempt to wash fill from around drill string. Presently working pipe.

Based on the consideration of all these elements, the Division will not support the approval of this application."

4. **Administrative Review and Hearing Process**
   The OCD continues to review existing Class II injection well operations and new applications for injection wells that are in proximity of the Capitan Reef. Attachment 2 contains the history of a case involving one proposed well for shallow injection near Jal, New Mexico. The proposed injection well was one of four applications for commercial operation within mile and half of each other. The injection interval was identified as the Yates-Seven Rivers formations and the applicant described a projected injection rate of 35,000 BWD for each well.

   The applicant stated that the injection fluid would remain within Yates-Seven Rivers formations due to the depleted characteristics of the reservoir which was a former hydrocarbon producing zone. However, the OCD contended that the proposed injection project would connect with the Capitan Reef and impact the current water quality of the aquifer in this area.

   Order No. R-14738 was issued by the Division Hearing Examiners that denied the new application and associated applications based on the insufficient information for the hydrology of the reef system in this part of the state, the potential for impact of remaining hydrocarbon potential of the proposed injection zone, and issues with improperly plugged wells within the area of review.

SUMMARY

The OCD remains attentive of the effort to maintain the water quality of the Capitan Reef and prevent further degradation. Portions of the Capitan Reef continue to attract interest as an alternative disposal interval when compared to more expensive, deeper disposal zones. ER projects associated with the backreef formations of the Capitan Reef are active and provide a steady source of hydrocarbon production with minimal capital investment. Expansion of the area of these ER projects is unlikely due to their age and declining reserves. However, modification of injection patterns to improve recovery of the remining hydrocarbons will require new applications for injection wells.

Further characterization of reef could provide a better delineation of areas that are protectable while identifying areas that qualify for exempt aquifer status. However, the scope of this investigation would be significant and would require an enormous scale of effort for proper assessment.

The content of this response was prepared by Phillip Goetze of the Engineering Bureau along with staff of the UIC Group within the Bureau. Please contact Mr. Goetze with any questions regarding the content of this document.

Sincerely,

PHILLIP R. GOETZE
Acting UIC Manager / Hydrogeologist
Email: phillip.goetze@state.nm.us

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Daniel B. Stephens and Associates, Inc., 2009, *Capitan Reef Complex Structure and Stratigraphy*, Texas Water Development Board. Contract No. 0804830794, p.75.

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Minnick, Matthew D., 2009, Capitan Reef Injection Well Study, RESPEC Consulting and Services Topical Report RSI-2048, April 2009, 14 p. Report prepared for the Oil Conservation Division, Santa Fe, NM.

Wilson, Lee, and Holland, Michael T., 1984, *Aquifer Classification for the UIC Program: Prototype Studies in New Mexico*, in Ground Water, Volume 22, Number 6, November-December Issue, p. 706-716.

FIGURES

Report Figure 1A. Map Showing the General Location of the Capitan Reef Aquifer System
Report Figure 1B. Relevant Stratigraphic Column and Relationship to Aquifer Occurrences in the Capitan Reef Lithosome
Report Figure 2. Map showing locations of Injection Wells from Summary Table 1

TABLES

Table 1. Summary Table of Active Injection Wells Requiring Further Investigation

ATTACHMENTS

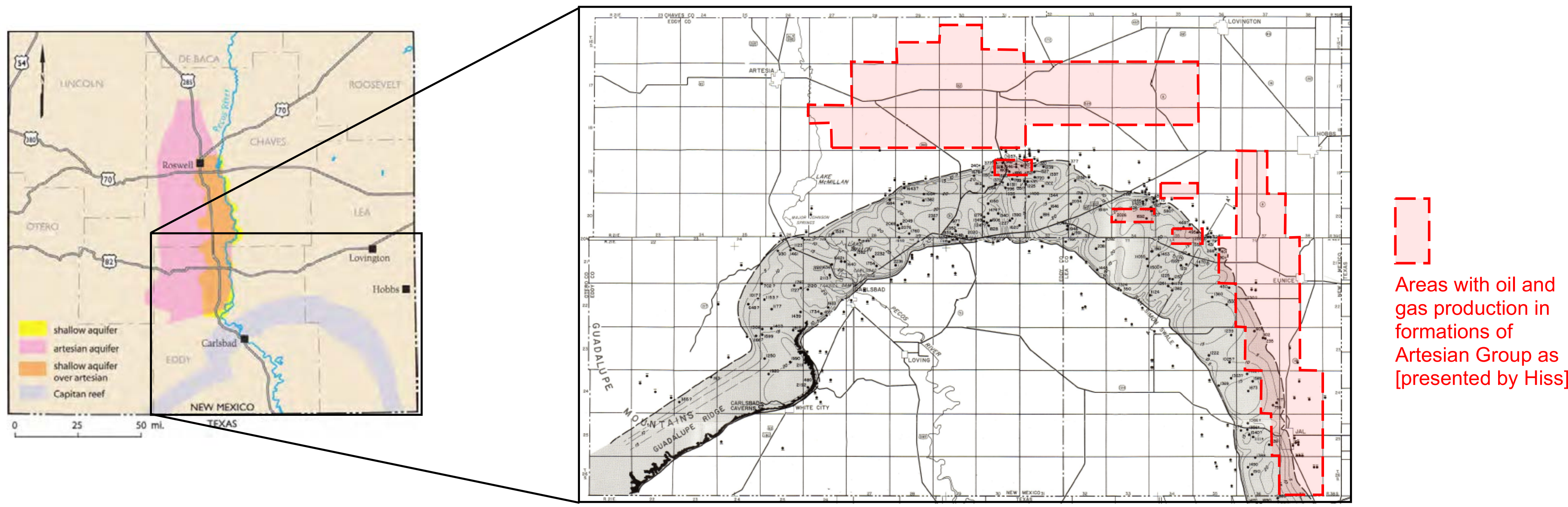
Attachment 1. Figures from *Capitan Reef Complex Structure and Stratigraphy*
Attachment 2. Exhibits from Division Case No. 15723
Attachment 3. Examples of OCD Reviews for Administrative Applications

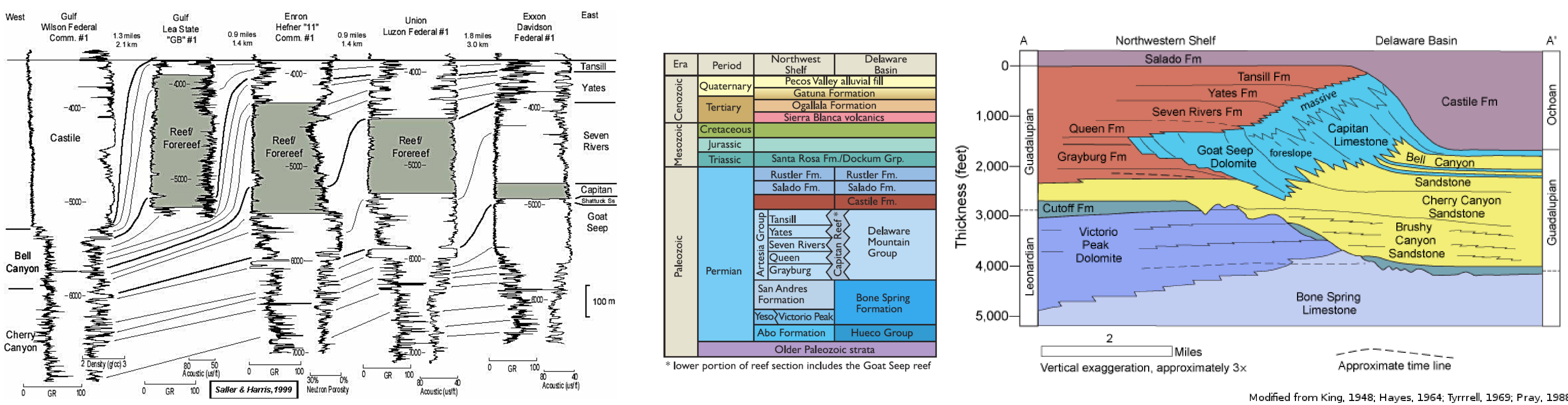
cc: UIC Class II Program Imaging File

State of New Mexico
Energy, Minerals and Natural Resources Department
Oil Conservation Division

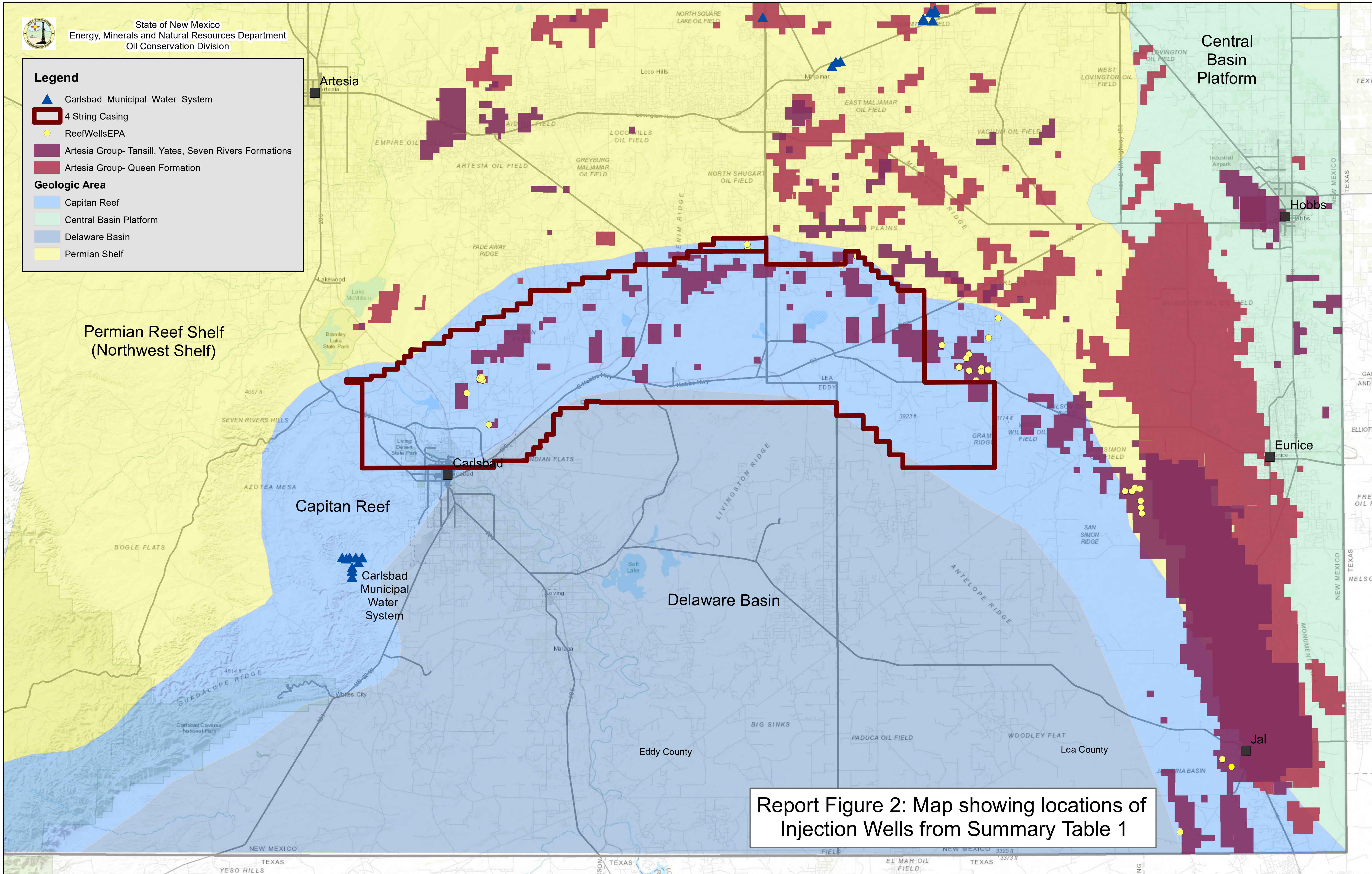
Update of UIC Class II Activities Within the State of New Mexico for Possible Injection into USDWs: the Capitan Reef Aquifer System

REPORT FIGURE 1A. Maps Showing the General Location of the Capitan Reef Aquifer System





REPORT FIGURE 1B. Relevant Stratigraphic Column and Relationship to Aquifer Occurrences in the Capitan Reef Lithosome as Shown in the Schematic and Correlation Cross Sections



Report Figure 2: Map showing locations of Injection Wells from Summary Table 1

State of New Mexico
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Update of UIC Class II Activities Within the State of New Mexico for Possible Injection into USDWs: the Capitan Reef Aquifer System

Table 1. Updated Summary Table of Active Injection Wells Requiring Further Investigation

Report ID Number	Well Identification No.	Well Name	Current Operator	Location (UL-Sec-Twn-Rge)	OCD Designated Pool	Well Type	Injection Authority	Status as of May 2020 and Comments on Injection	Recommended OCD Action
1	30-015-02446	SALADAR FEDERAL NO. 4	MNA ENTERPRISES LTD CO	K (NE¼SW□)-33-20S-28E	SALADAR;YATES	ER	WFX-869	Saladar Waterflood Unit; Order No. R-5939	Continued monitoring of operation until waterflood is complete; plug and abandon with no option for conversion to disposal operation.
2	30-015-02448	SALADAR FEDERAL NO. 6	MNA ENTERPRISES LTD CO	K (NE□SW□)-33-20S-28E	SALADAR;YATES	ER	WFX-869		
3	30-015-02449	SALADAR FEDERAL NO. 8	MNA ENTERPRISES LTD CO	N (SE□SW□)-33-20S-28E	SALADAR;YATES	ER	WFX-869		
4	30-015-02450	SALADAR B NO. 2	MNA ENTERPRISES LTD CO	L (NW□SW□)-33-20S-28E	SALADAR;YATES	ER	Shut-in		
5	30-015-24179	SALADAR FEDERAL NO. 12	MNA ENTERPRISES LTD CO	K (NE□SW□)-33-20S-28E	SALADAR;YATES	ER	WFX-869		
6	30-025-08606	CONE JALMAT YATES POOL UNIT NO. 105	BREITBURN OPERATING LP	L (NW□SW□)-13-22S-35E	JALMAT;TAN-YATES-7 RVRS (OIL)	ER	R-2495^	Cone Jalmat Yates Pool Waterflood Unit; Order No R-2495	Continued monitoring of operation until waterflood is complete; plug and abandon with no option for conversion to disposal operation.
7	30-025-08640	CONE JALMAT YATES POOL UNIT NO. 502	BREITBURN OPERATING LP	L (NW□SW□)-24-22S-35E	JALMAT;TAN-YATES-7 RVRS (OIL)	ER	WFX-206		
8	30-025-08648	CONE JALMAT YATES POOL UNIT NO. 107	BREITBURN OPERATING LP	D (NW□NW□)-24-22S-35E	JALMAT;TAN-YATES-7 RVRS (OIL)	ER	R-2495^		
9	30-025-08579	JALMAT FIELD YATES SAND UNIT NO. 123	BREITBURN OPERATING LP	P (SE□SE□)-10-22S-35E	JALMAT;TAN-YATES-7 RVRS (OIL)	ER	R-2243^	Cooper Jal Waterflood Unit; Order No. R-4020	Continued monitoring of operation until waterflood is complete; plug and abandon with no option for conversion to disposal operation.
10	30-025-08588	JALMAT FIELD YATES SAND UNIT NO. 121	BREITBURN OPERATING LP	N (SE□SW□)-11-22S-35E	JALMAT;TAN-YATES-7 RVRS (OIL)	ER	R-2243^		
11	30-025-08590	JALMAT FIELD YATES SAND UNIT NO. 114	BREITBURN OPERATING LP	J (NW□SE□)-11-22S-35E	JALMAT;TAN-YATES-7 RVRS (OIL)	ER	R-2243^		
12	30-025-08601	JALMAT FIELD YATES SAND UNIT NO. 116	BREITBURN OPERATING LP	L (NW□SW□)-12-22S-35E	JALMAT;TAN-YATES-7 RVRS (OIL)	ER	Currently producer (R-2243)		
13	30-015-26524	HADSON FEDERAL NO. 1	GRIZZLY OPERATING, LLC	O (SW□SE□)-11-19S-31E	SWD;YATES-SEVEN RIVERS	SWD	SWD-700	Active disposal well; cumulative injection for 2019 was 83,622 BW or approximately 232 BWD; total injection in 2020 reported as 7023 BW.	Continued monitoring of operation; plug and abandon with no option for new disposal operation.
14	30-015-26730	HADSON FEDERAL NO. 3	GRIZZLY OPERATING, LLC	G (SW□NE□)-11-19S-31E	SWD;YATES-SEVEN RIVERS	SWD	SWD-479	Active disposal well; cumulative injection for 2019 was 8097 BW or 22 BWD; total injection in 2020 reported as 21 BW.	Continued monitoring of operation; plug and abandon with no option for new disposal operation.
15	30-025-32735	PRONGHORN SWD NO. 1	SPUR ENERGY PARTNERS, LLC	B (NW□NE□)-24-19S-32E	SWD;YATES-SEVEN RIVERS	SWD	SWD-536	Active disposal well; new operator; no injection in Feb. 2020; no injection at time of report; well proposed for plugging by OCD.	Pursue P&A of well with current operator or limit injection through modification of existing order.
16	30-025-02431	LEA UNIT NO. 8	LEGACY RESERVES OPERATING, LP	B (NW□NE□)-12-20S-34E	SWD;SEVEN RIVERS	SWD	SWD-189^	**P□A**	
17	30-025-02459	CRUCES FEDERAL NO. 3	BURK ROYALTY CO., LTD.	N (SE□SW□)-26-20S-34E	LYNCH;YATES-SEVEN RIVERS	SWD	R-9000	Active disposal well; less than 100 BW per day.	Continued monitoring of operation; plug and abandon with no option for new disposal operation.
18	30-025-02507	W H MILNER FEDERAL NO. 4	BURK ROYALTY CO., LTD.	C (NE□NW□)-35-20S-34E	SWD;YATES	SWD	R-3779^	**P□A**	
19	30-025-02501	NEAL NO. 3	BURK ROYALTY CO., LTD.	A (NE□NE□)-35-20S-34E	LYNCH;YATES-SEVEN RIVERS	ER	R-4283-A	Active disposal well; total injection for 2019 was 2771 BW; total injection in 2020 reported as 175 BW.	Continued monitoring of operation; plug and abandon with no option for new disposal operation.
20	30-025-02476	SILVER FEDERAL NO. 4	STEVEN D RUPPERT	O (SW□SE□)-28-20S-34E	SWD;YATES-SEVEN RIVERS	SWD	R-3724^	Active disposal well; total injection for 2019 was 6000 BW (500 BW per month); no injection reported in 2020.	Continued monitoring of operation; plug and abandon with no option for new disposal operation.
21	30-025-02466	BALLARD DE FEDERAL NO. 3	BLACK MOUNTAIN OPERATING LLC	D (NW□NW□)-27-20S-34E	SWD;SEVEN RIVERS	SWD	SWD-354	**P□A**	
22	30-025-02494	B V LYNCH A FEDERAL NO. 2	MAS OPERATING CO.	P (SE□SE□)-34-20S-34E	SWD;YATES-SEVEN RIVERS	SWD	R-7971	Active disposal well; last injection Sept 2019; no injection at time of report; operator in bankruptcy.	Pursue P&A of well with current operator or limit injection through modification of existing order.
23	30-025-12580	B V LYNCH A FEDERAL NO. 10	MAS OPERATING CO.	C (NE□NW□)-34-20S-34E	SWD;YATES-SEVEN RIVERS	SWD	R-4612	Active disposal well; last injection Sept 2019; no injection at time of report; operator in bankruptcy.	Pursue P&A of well with current operator or limit injection through modification of existing order.
24	30-025-02448	D AND E FEDERAL NO. 1	CHESTNUT EXPLORATION AND PRODUCTION, INC.	N (SE□SW□)-22-20S-34E	SWD;SEVEN RIVERS	SWD	SWD-326	**Lost injection authority; P□A authority with BLM**	
25	30-025-20386	WHITTEN NO. 1	NEW MEXICO SALT WATER DISPOSAL COMPANY	I (NE□SE□)-14-20S-34E	SWD;SEVEN RIVERS	SWD	SWD-525	Active disposal well; cumulative injection for 2019 was 1,508,689 BW; total injection in 2020 reported as 6550 BW.	Continued monitoring of operation; plug and abandon with no option for new disposal operation.
26	30-025-23985	WALLEN FEDERAL NO. 2	DAKOTA RESOURCES INC (I)	C (NE□NW□)-20-20S-34E	SWD;YATES-SEVEN RIVERS	SWD	SWD-249	Active disposal well; cumulative injection for 2019 was 5076 BW; total injection in 2020 reported as 1331 BW (approximately 400 BW per month).	Continued monitoring of operation; plug and abandon with no option for new disposal operation.
27	30-015-26710	WELCH FEDERAL NO. 7	BILL G TAYLOR AND HARVEY R TAYLOR	P (SE□SE□)-5-21S-27E	CEDAR HILLS;YATES	SWD	SWD-425	**Lost injection authority; P□A authority with BLM**	
28	30-015-22055	EXXON STATE NO. 8	PERMIAN WATER SOLUTIONS, LLC	O (SW□SE□)-15-21S27E	SWD;YATES	SWD	R-13043	Active disposal well; current injection of 2500 BWD; operator in bankruptcy; cumulative 32,092,877 BW.	Continued monitoring of operation; plug and abandon with no option for new disposal operation.
29	30-025-25957	7406 JV-S LEA 20 NO. 1	CHANCES PROPERTIES COMPANY	P (SE□SE□)-20-26S-36E	SWD; CAPITAN REEF	SWD	SWD-210^	**Lost injection authority; NMSLO business lease expired and not renewed; well to be P□A**	
30	30-025-01671	FEDERAL 18 B NO. 4	SPUR ENERGY PARTNERS, LLC	H (SE□NW□)-18-19S-33E	SWD; SEVEN RIVERS	SWD	SWD-589	Active disposal well; average injection in 2020 of 1410 BWD; no injection at time of report.	Pursue P&A of well with current operator or limit injection through modification of existing order.
31	30-025-09806	MARALO SHOLES B NO. 2	OWL SWD OPERATING, LLC	P (SE□SE□)-25-25S-36E	SWD;YATES-SEVEN RIVERS	SWD	SWD-1127	Active disposal well; see Order No. R-14737; last reported dispsoal rate of 27,000 BWD.	Continued monitoring of operation; plug and abandon with no option for new disposal operation.
32	30-025-09807	BROWN NO. 5	OWL SWD OPERATING, LLC	E (SW□NW□)-25-25S-36E	SWD;YATES-SEVEN RIVERS	SWD	R-5196^	Active disposal well; MSIP pressure limits injection rate with pressure increase in the reservoir; cumulative injection for 2019 was 120 BW; no injection reported in 2020.	Continued monitoring; current information indicates no hydrologic connection with Capitan Reef aquifer; pursue P&A of well with current operator.

BWD: barrels of water per day; **BW:** barrels of water; **P□A:** plugged and abandoned

^Indicates injection authority predates primacy approval date of March 7, 1982.

Explanation of Color Code

(yellow)	Disposal wells that have either been plugged and abandoned or have lost their injection authority.
(cyan)	Active disposal well that is currently shut-in; OCD effort to plug or limit injection through modification of existing order.
13	Active disposal wells.
(light orange)	Five injection wells within single waterflood unit.
(salmon)	Three injection wells within single waterflood unit.
(green)	Four injection wells within single waterflood unit.

State of New Mexico
Energy, Minerals and Natural Resources Department
Oil Conservation Division

Update of Underground Injection Control Class II Activities Within the State of New Mexico for Possible Injection into Underground Sources of Drinking Water: the Capitan Reef Aquifer System

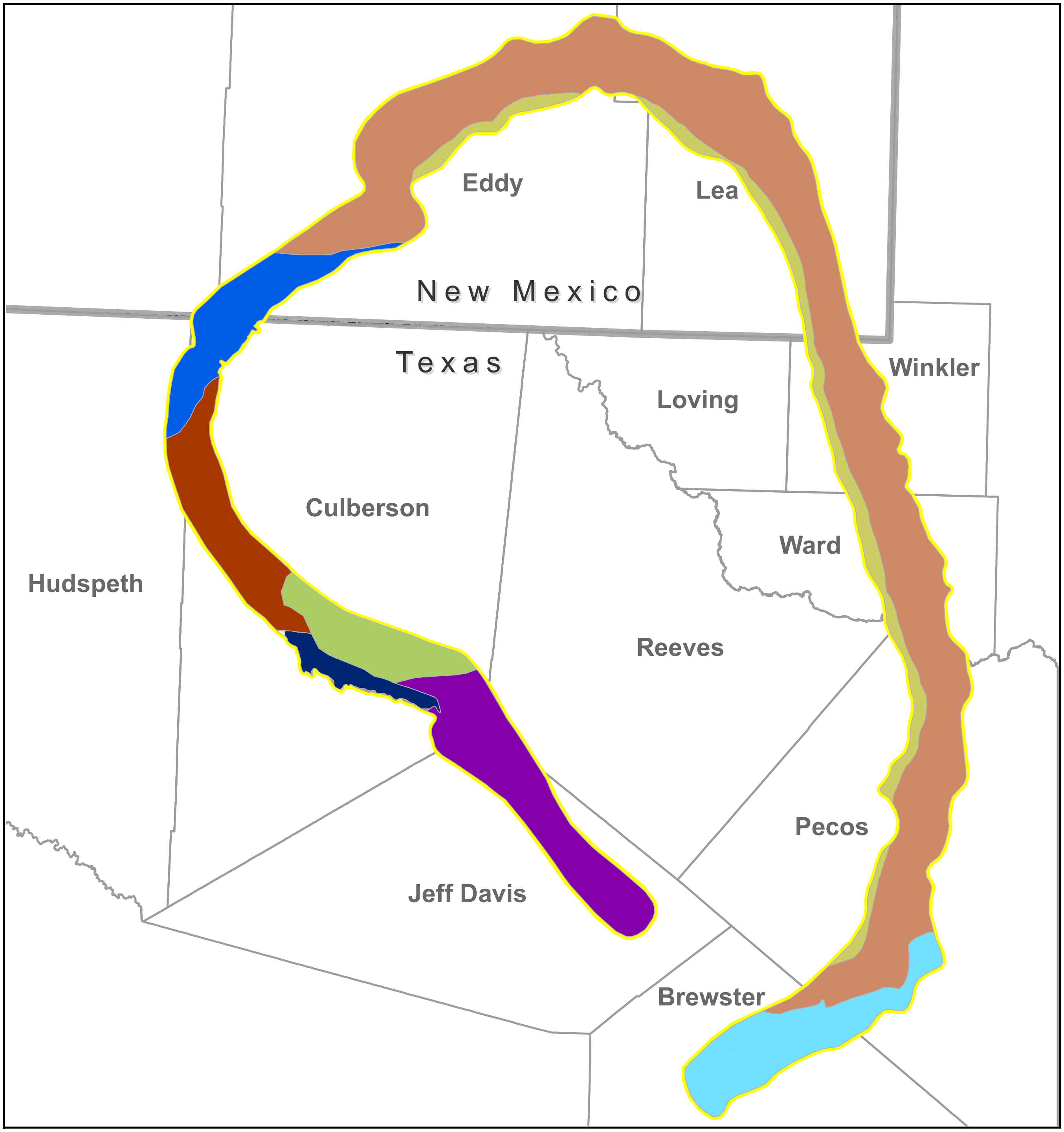
ATTACHMENT 1

Source: Daniel B. Stephens and Associates, Inc., 2009, *Capitan Reef Complex Structure and Stratigraphy*, Texas Water Development Board

Figure 8: Geologic Formations Overlying the Reef Complex

Figure 18: Capitan Reef Complex Thickness Contours

Figure 22: Regional Groundwater Flow



Explanation

- Capitan Reef Complex outline (revised)
- Texas/New Mexico border

Overlying units

- Salt Basin sediments
- Quaternary deposits and Cretaceous formations
- Artesia Group
- Castile and Salado formations
- Castile or Salado formations
- Capitan Outcrop with overlying Permian, Triassic, Cretaceous, and Quaternary deposits
- Capitan Outcrop with overlying Quaternary deposits
- Capitan Outcrop, with overlying Artesia and Quaternary deposits
- Erosional Base of Capitan Reef Complex

0 10 20 30 Miles

N

Source: Modified after King, 1937, 1948; Woods, 1968; Hiss, 1975.

CAPITAN REEF COMPLEX

Geologic Formations Overlying the Capitan Reef Complex

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Daniel B. Stephens & Associates, Inc.
08/28/2009 JN WR08.0039

Figure 8

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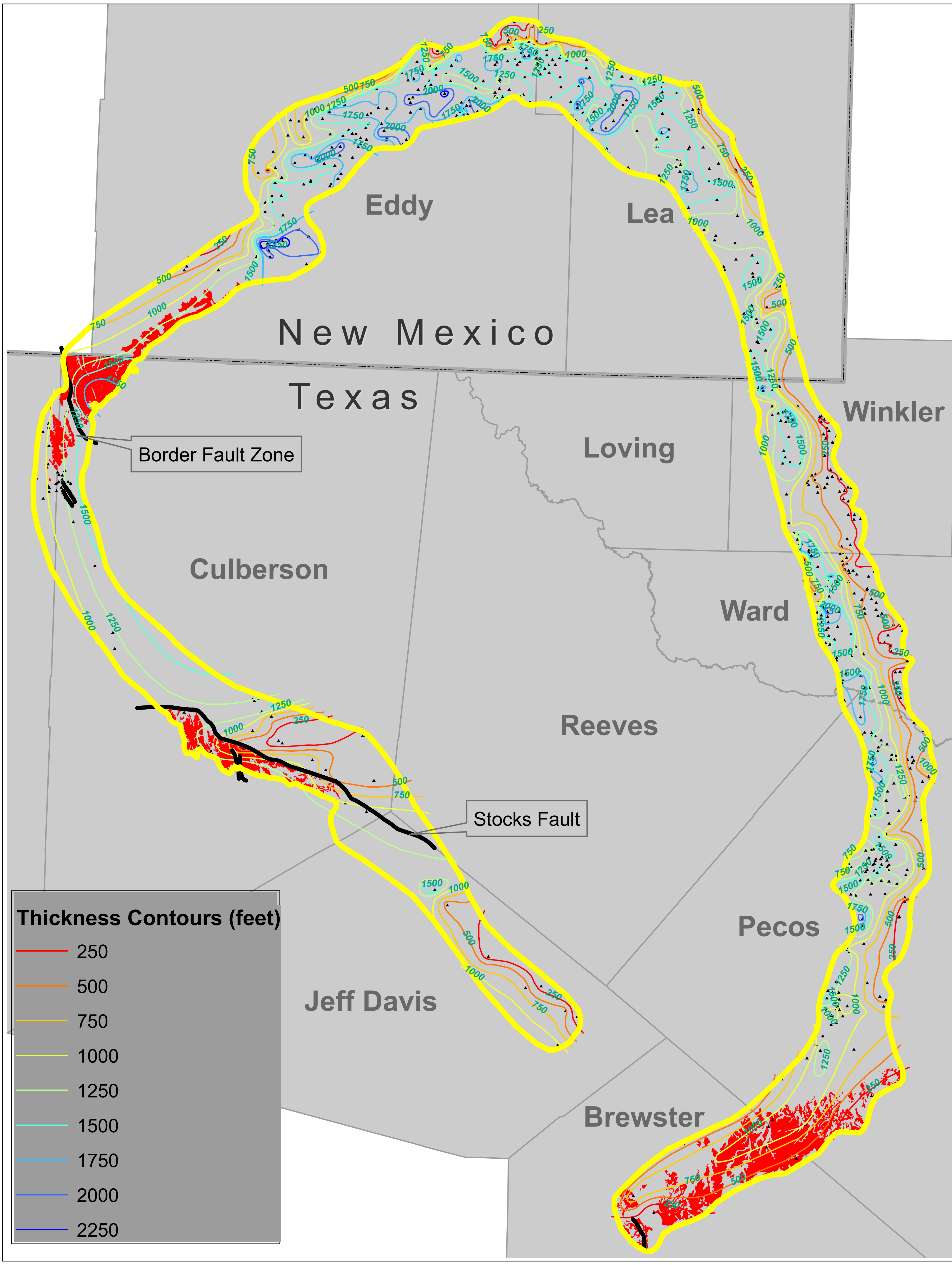


Explanation

- Capitan Reef Complex outline (revised)
- Capitan Reef Complex outcrop
- Mapped faults
- Texas/New Mexico border
- Counties

Control Points

N

0 10 20 30 Miles

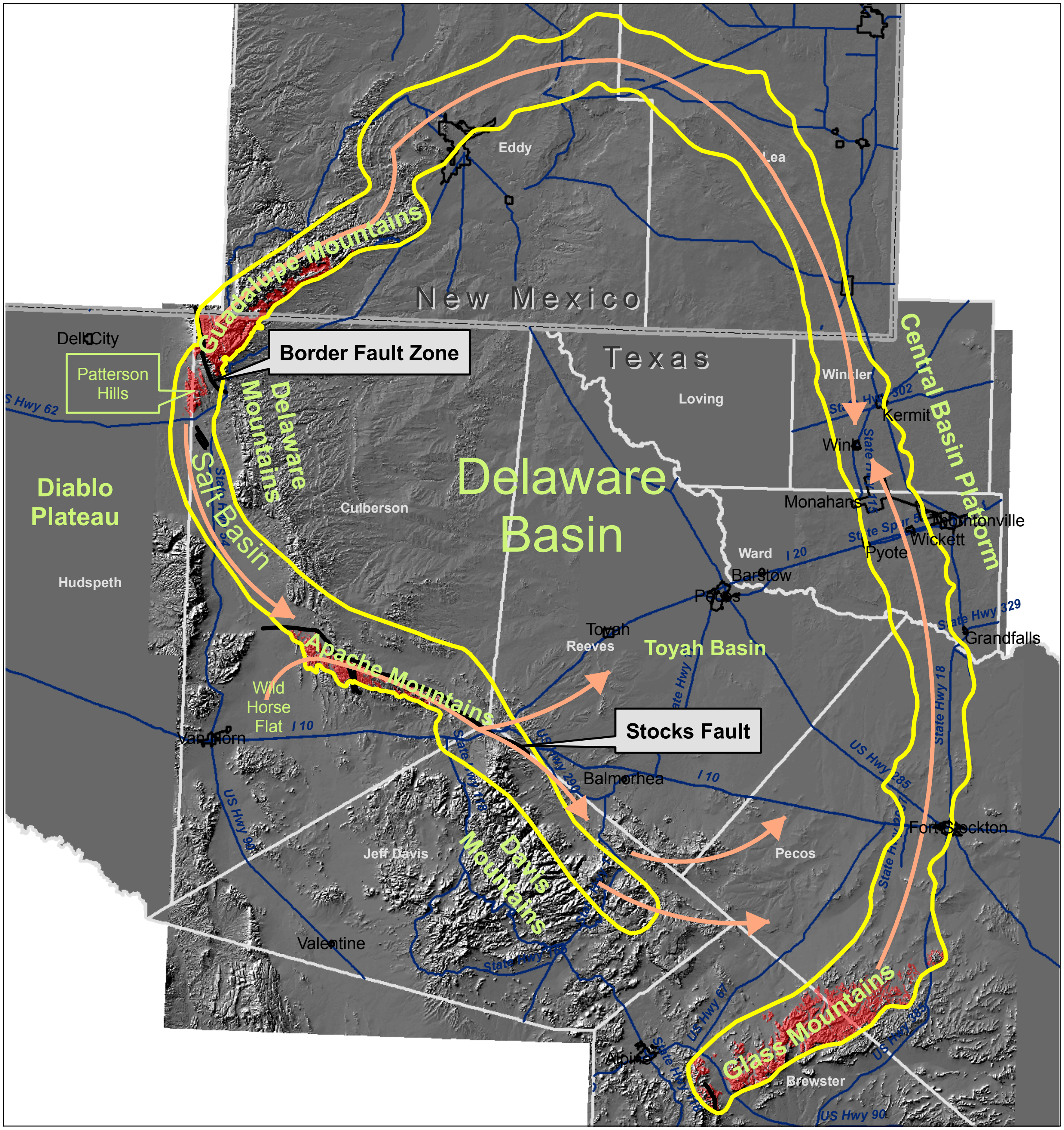
CAPITAN REEF COMPLEX

Capitan Reef Complex Thickness Contours

Daniel B. Stephens & Associates, Inc.

08/28/2009 JN WR08.0039

Figure 18



Explanation

- Regional groundwater flow
- Capitan Reef Complex outline (revised)
- Capitan Reef Complex outcrop
- Mapped faults
- Cities
- Major roads
- Texas/New Mexico border
- County boundary

Source: After Sharp, 2001; Hiss, 1976, 1980; Uliana, 2001.

CAPITAN REEF COMPLEX

Regional Groundwater Flow

N:/Client/Water Resources/Capitan Aquifer/GIS/MXDs/New figures_082509/Figure 22.mxd

Daniel B. Stephens & Associates, Inc.

08/28/2009

JN WR08.0039

Figure 22

State of New Mexico
Energy, Minerals and Natural Resources Department
Oil Conservation Division

Update of Underground Injection Control Class II Activities Within the State of New Mexico for Possible Injection into Underground Sources of Drinking Water: the Capitan Reef Aquifer System

ATTACHMENT 2

Source: OCD Case No. 15723; Hearing Order No. R-14738; Division Exhibits
http://ocdimage.emnrd.state.nm.us/imaging/CaseFileView.aspx?CaseNo=15723

Division Exhibit No. 1: Map Showing Location of Proposed Bobcat SWD Well No. 1

Division Exhibit No. 2: Aerial Photograph Map Showing Major Features and Wells Near the Bobcat SWD Well No. 1 Location

Division Exhibit No. 3: Relevant Excerpts from Referenced Reports on the Capitan Reef Aquifer

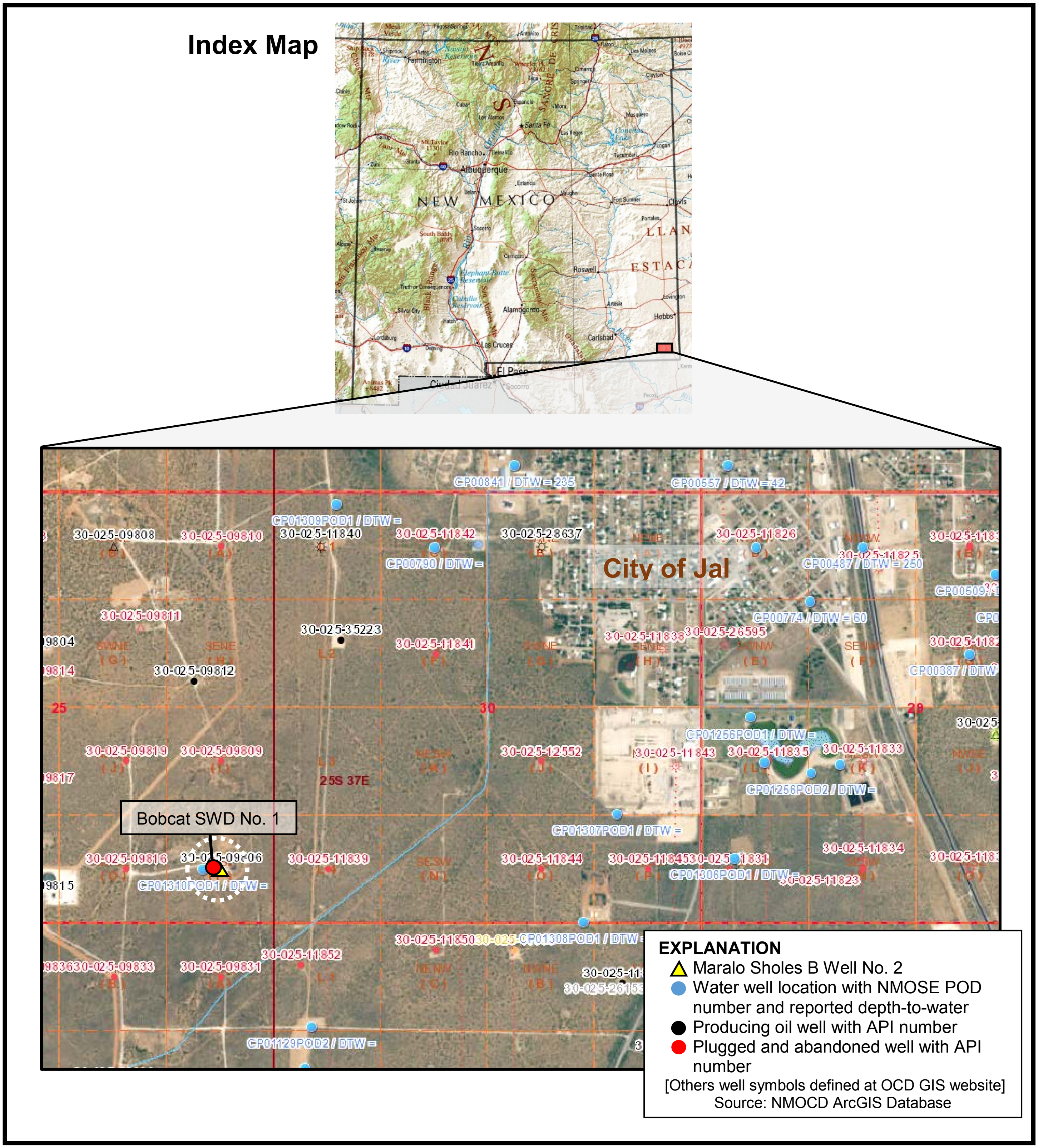
Division Exhibit No. 4: Map Showing Capitan Reef Aquifer Monitoring Wells and Water Production Wells Near Jal, New Mexico

Division Exhibit No. 5: Graph Showing Water Production of Sholes B 25 Well No. 1 and Water Injection of Maralo B Sholes Well No. 2 vs. Time

Copy of Division Order No. R-14738

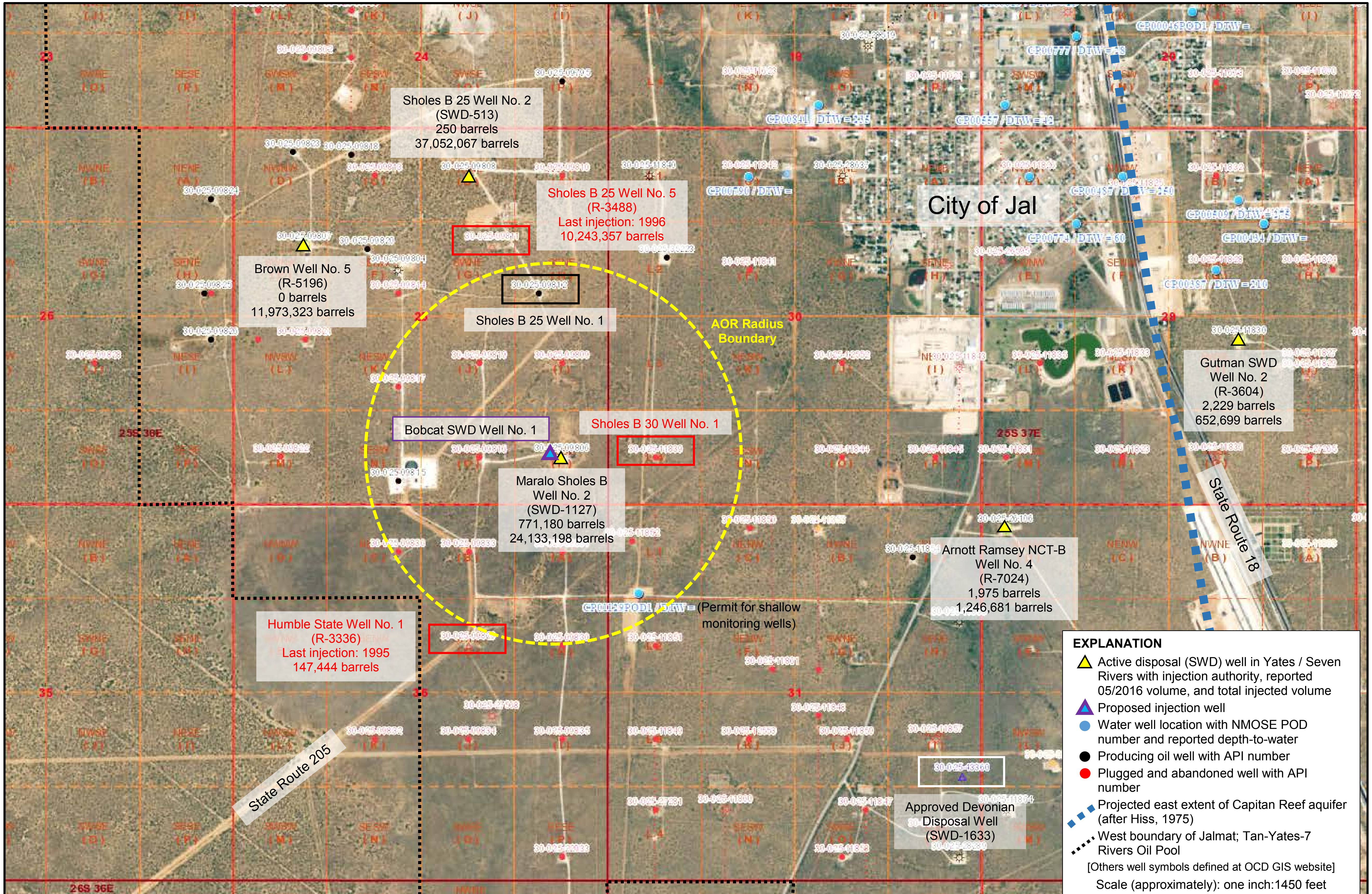
Oil Conservation Division
Energy, Minerals and Natural Resources Department
State of New Mexico

CASE NO. 15723 Division Exhibit No. 1:
Map Showing Location of Proposed Bobcat SWD No. 1



Oil Conservation Division
Energy, Minerals and Natural Resources Department
State of New Mexico

CASE NO. 15723 Division Exhibit No. 2: Aerial Photograph Map Showing Major Features and Wells Near the Bobcat SWD Well No. 1 Location



Oil Conservation Division
Energy, Minerals and Natural Resources Department
State of New Mexico

CASE NO. 15723 Division Exhibit No. 3: Relevant Excerpts from Referenced Reports on the Capitan Reef Aquifer

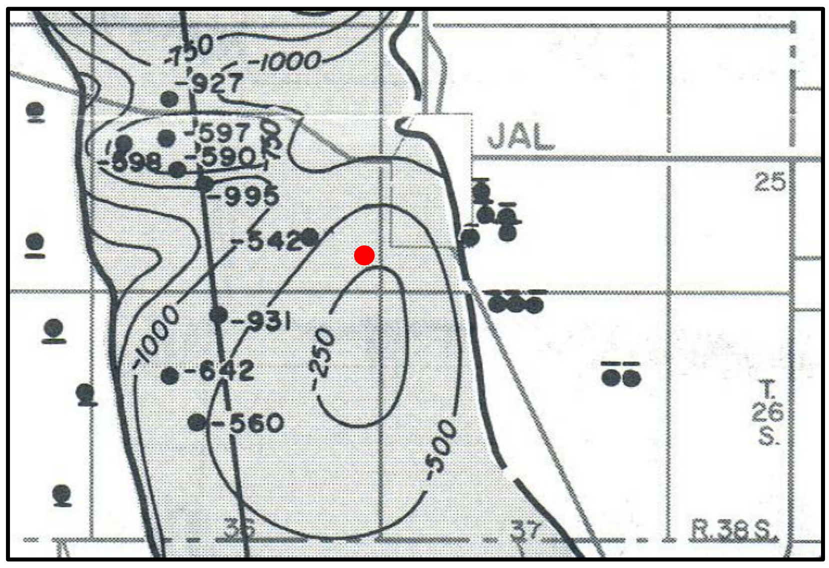


Figure 3A: Map Showing Structure of the Capitan Aquifer
Contour indicates the altitude of the top of the Capitan aquifer; in feet; datum is mean sea level. Source: NMBGMR Resource Map 6; Hiss (1976)

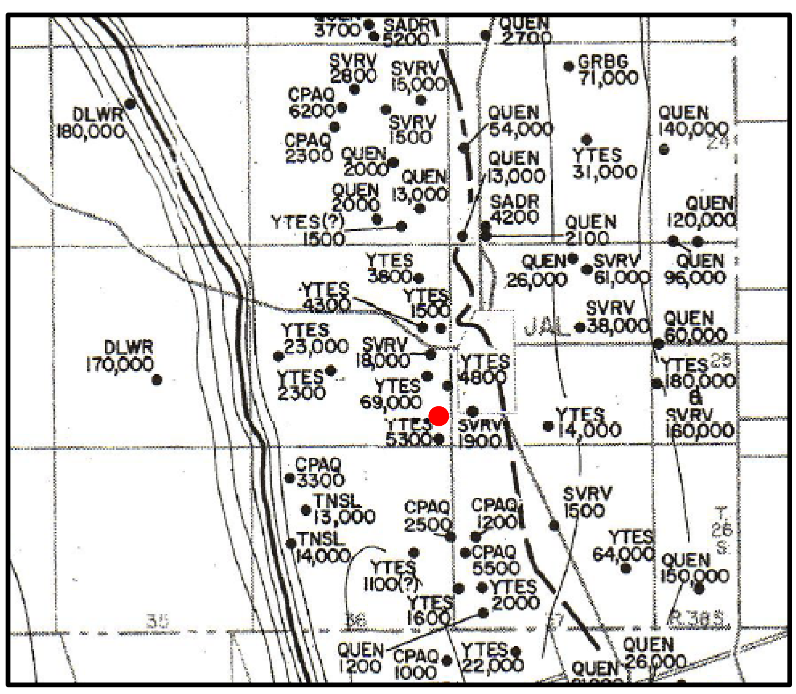


Figure 3B: Map Showing Chloride-Ion Concentration in Permian Age Sedimentary Rocks
Number represents chloride-ion concentration in milligrams per liter; Relevant unit codes: CPAQ – Capitan aquifer; QUEN – Queen formation; SVSR – Seven Rivers formation; YTES – Yates formation. Source: Figure 26; Hiss (1975)

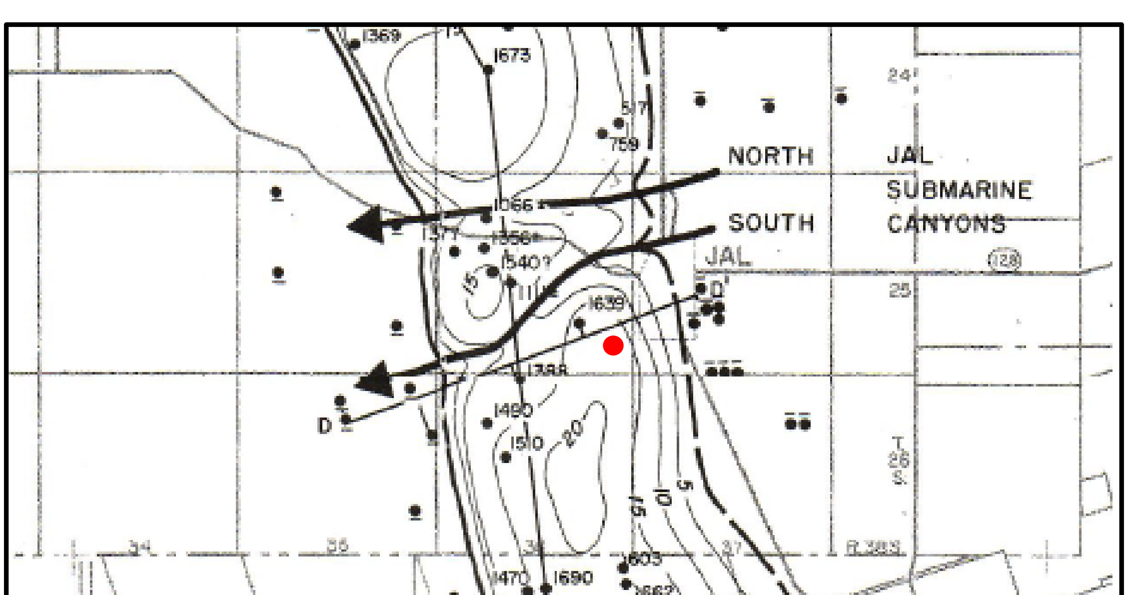
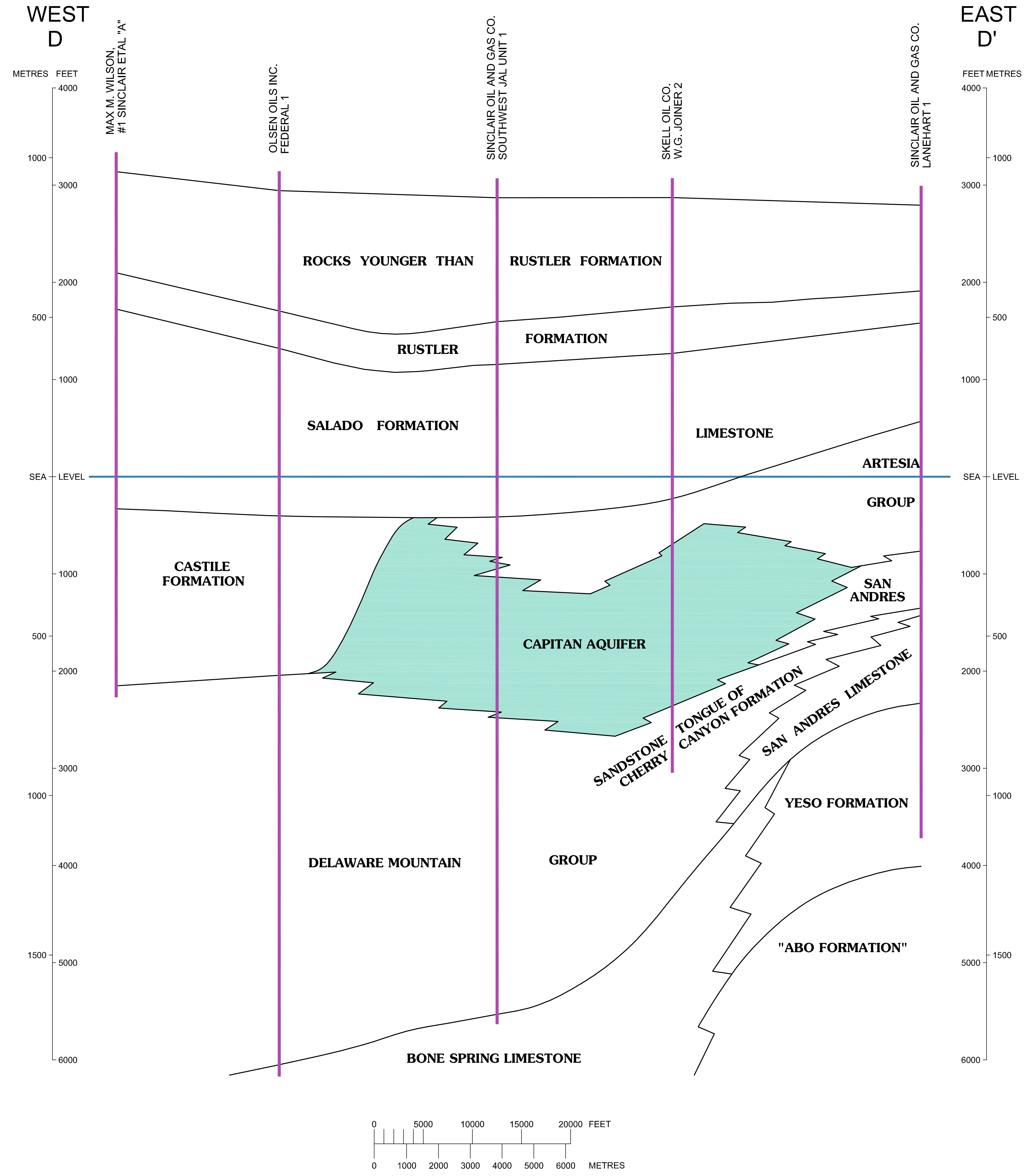


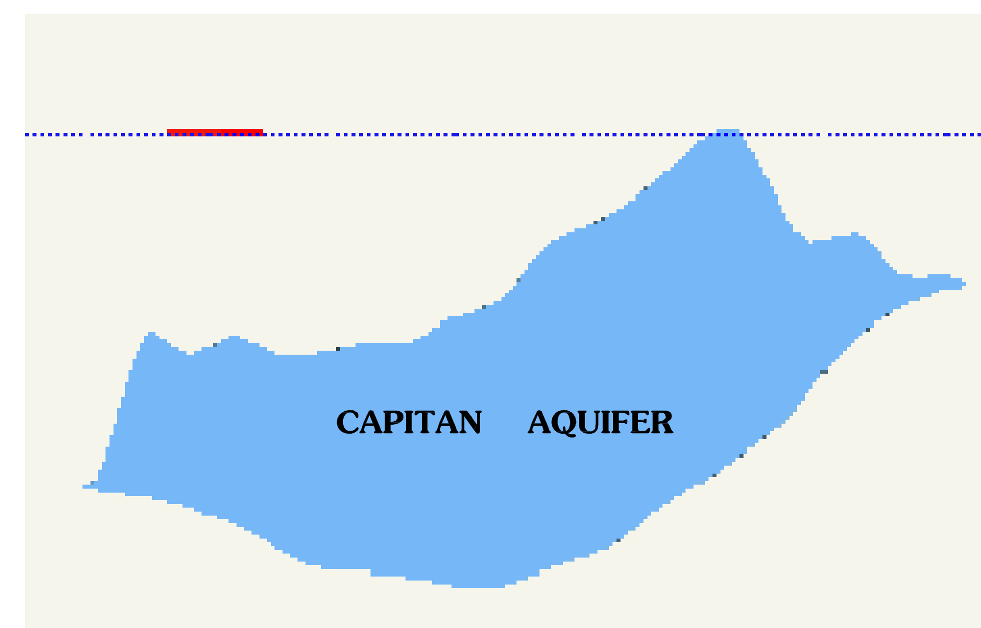
Figure 3C: Map Showing the Thickness of the Capitan Aquifer
Lines of equal thickness; in hundreds of feet and interval is 500 feet; wells: ● wells penetrating reef and (or) shelf margin facies; wells penetrating shelf facies; wells penetrating basinal facies. (Note: well symbols also used in Figure 3A). Source: Figure 11; Hiss (1975)

EXPLANATION
● Approximate location of Maralo Sholes B Well No. 2

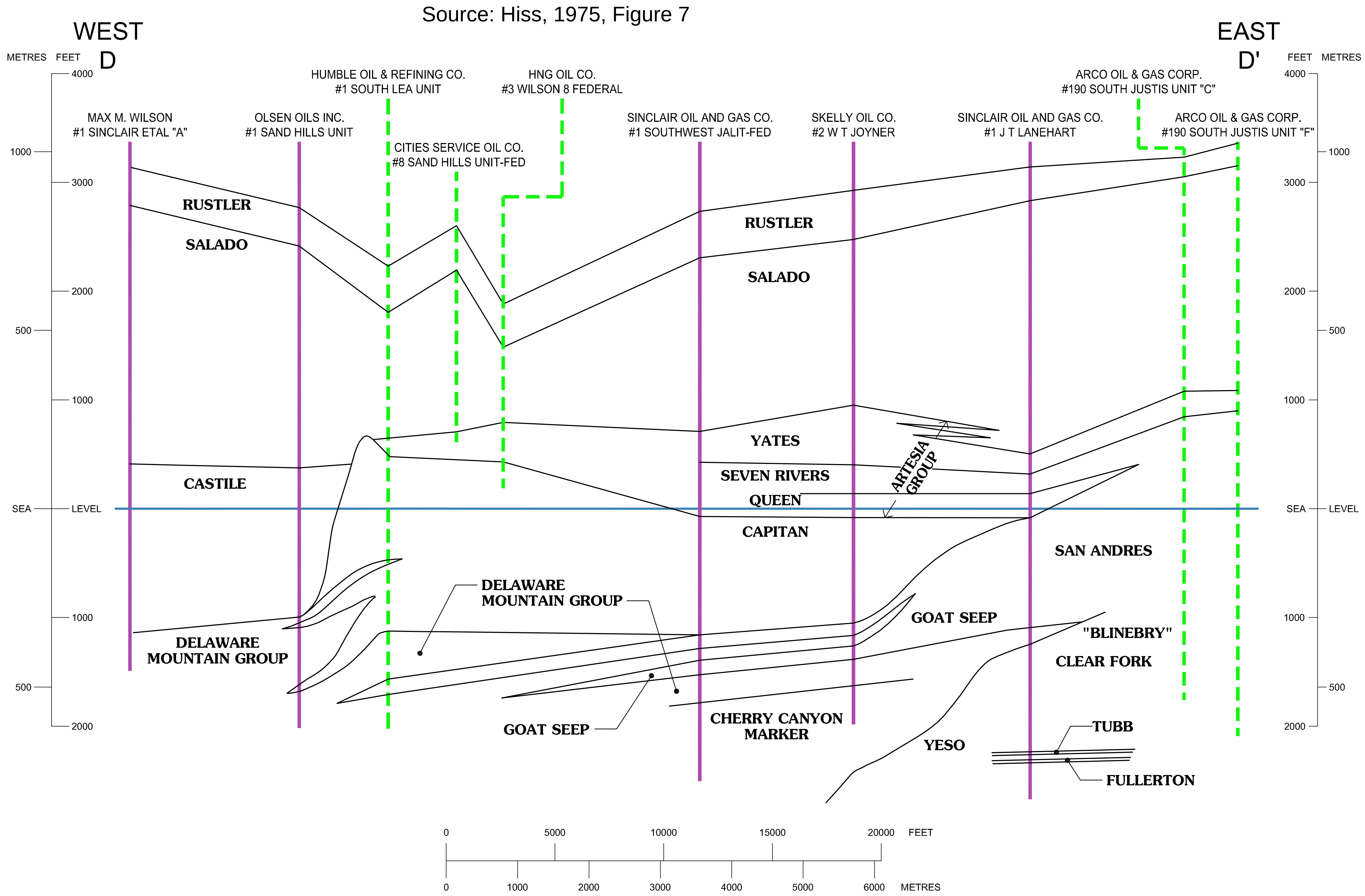
CASE NO. 15723
Division Exhibit No. 3:
Figure 3D: Stratigraphic Section D - D'
Source: Water Resources Monitoring Plan, Ochoa Mine Project (INTERA, 2004)



HISS SECTION
Source: Hiss, 1975, Figure 7



INTERA Model
NOT TO SCALE
(1H : 10V)



LAMB SECTION

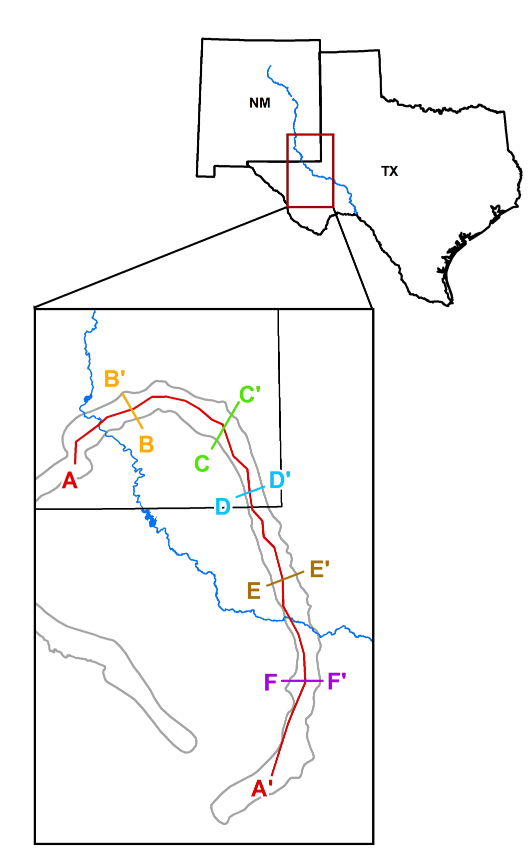


Figure 14
Stratigraphic Section D-D'
Across the Capitan Reef Complex and Aquifer
Ochoa Mine Water Resources Monitoring Plan

INTERA

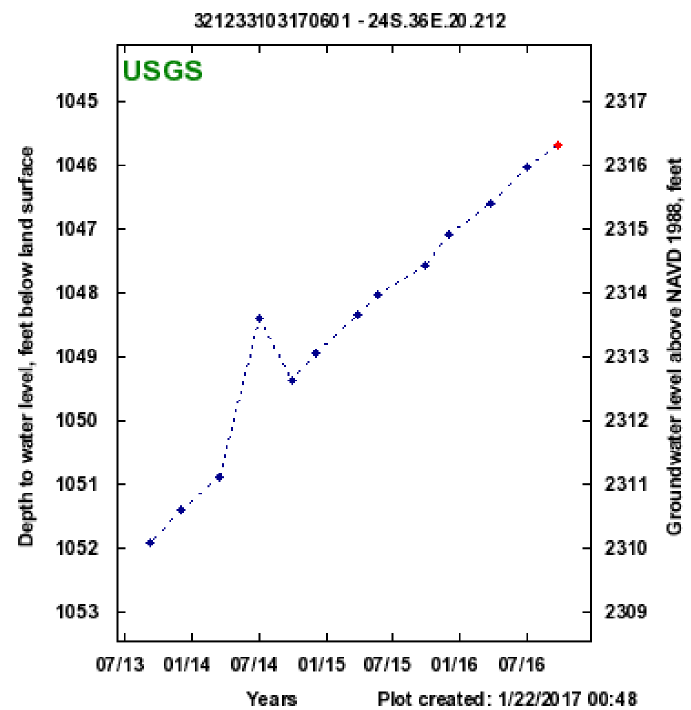
Oil Conservation Division
Energy, Minerals and Natural Resources Department
State of New Mexico

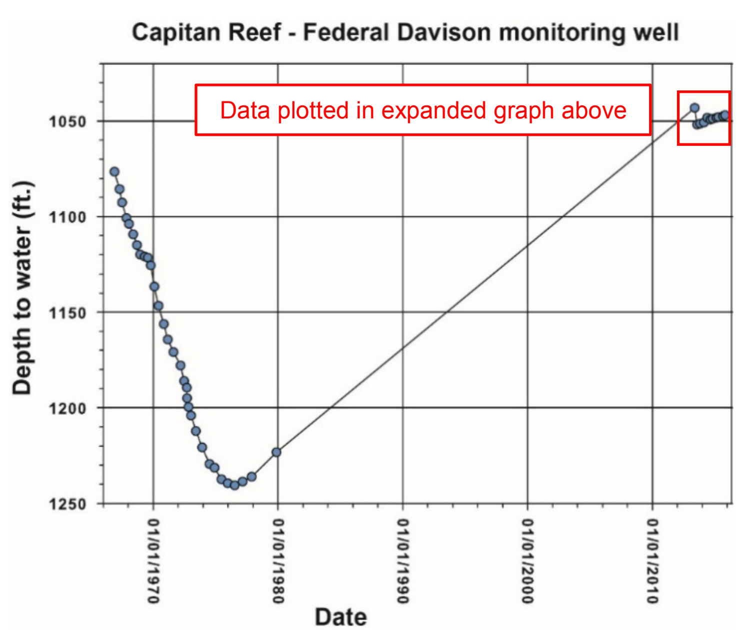
CASE NO. 15732 Division Exhibit No. 4: Map Showing Capitan Reef Aquifer Monitoring Wells and Water Production Wells Near Jal, New Mexico

MONITORING WELL DESCRIPTION

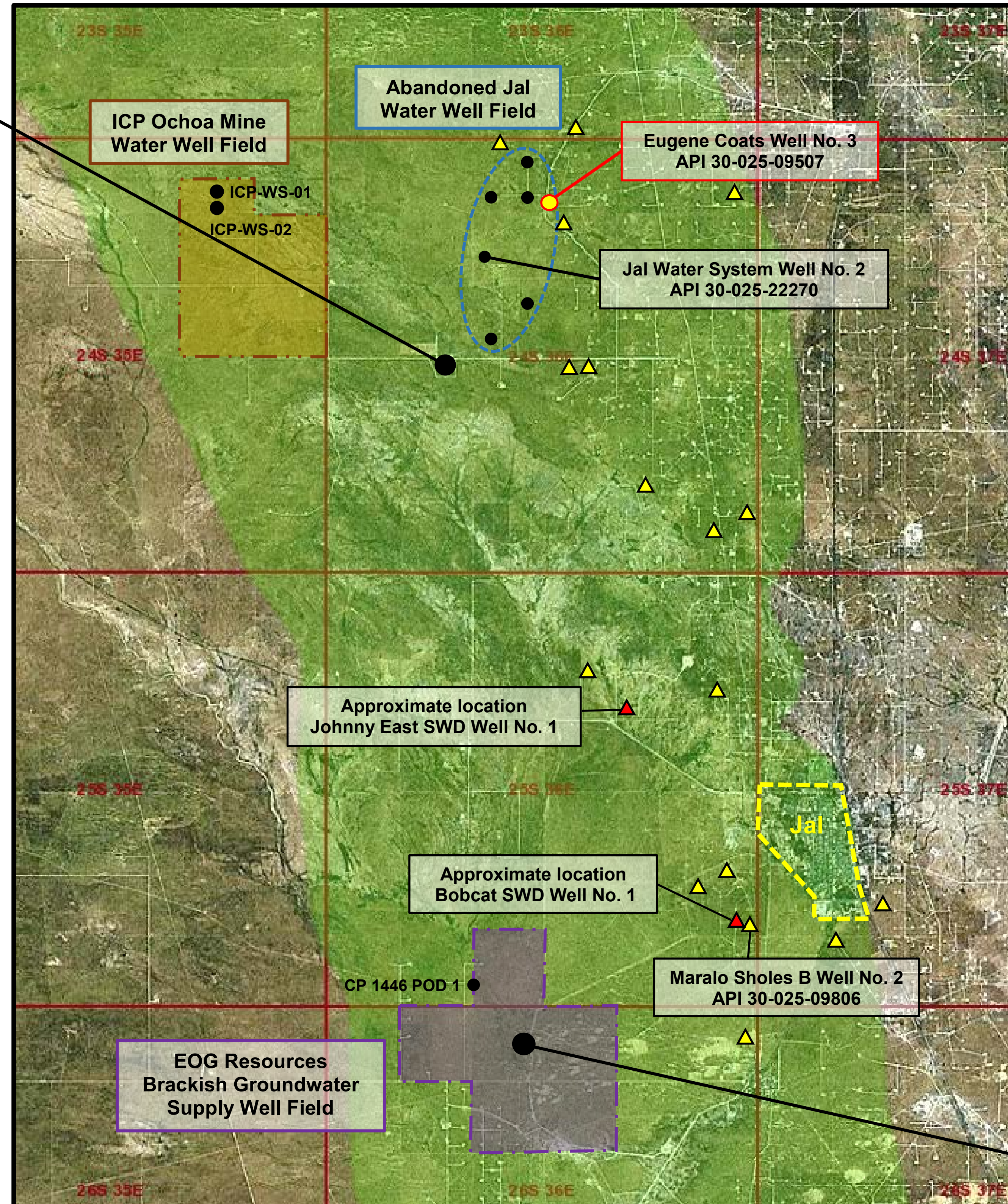
USGS Well Identification: 321233103170601

Location: 660 ft FNL / 1980 ft FEL; Sec 20, T24S, R36E, NMPM
Lat: 32° 12'33.3" Long: 103° 17'5.9" NAD83
Original completion information:
Davison Federal No. 1 (30-025-21725)
Spud: 07/22/1965 P&A: 09/30/1966
TD: 17,691 feet PBTD: 5,713 feet
Relinquished to the USGS WRD for monitoring use on 12/08/1967.

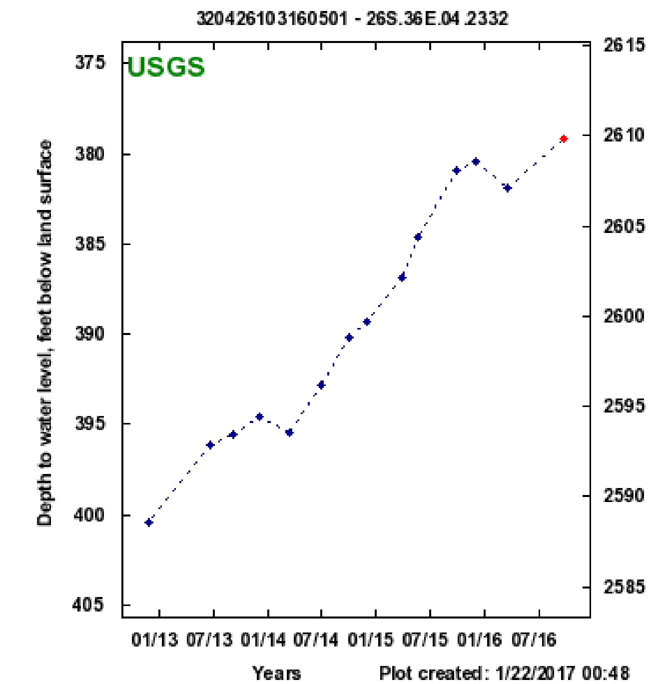


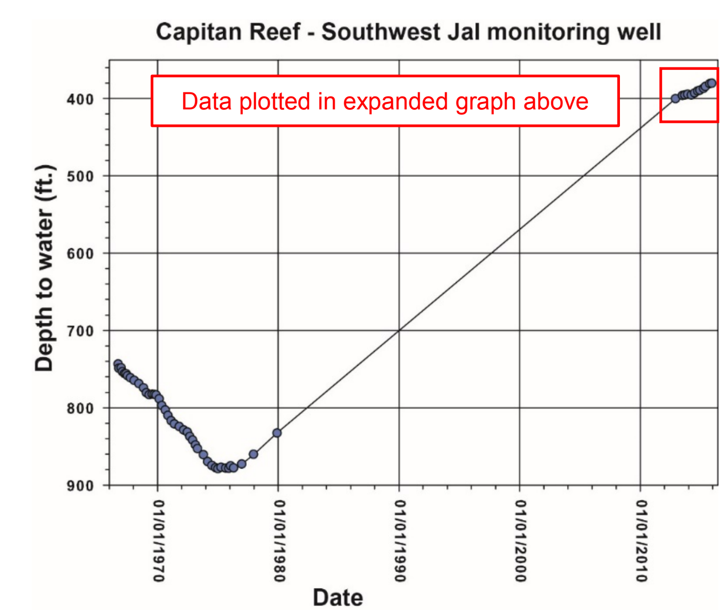


Graph Data Sources: USGS Groundwater Watch database (2016) and Land (2016)
Aerial photobase from OCD GIS map database



EXPLANATION:
- Active salt water disposal wells in Seven Rivers, Yates, or Queen formations (or combination)
- Water wells or monitoring wells in Capitan Reef associated with commercial or municipal projects
- Green shading represents projected lateral extent of Capitan Reef aquifer (after Hiss,1975)





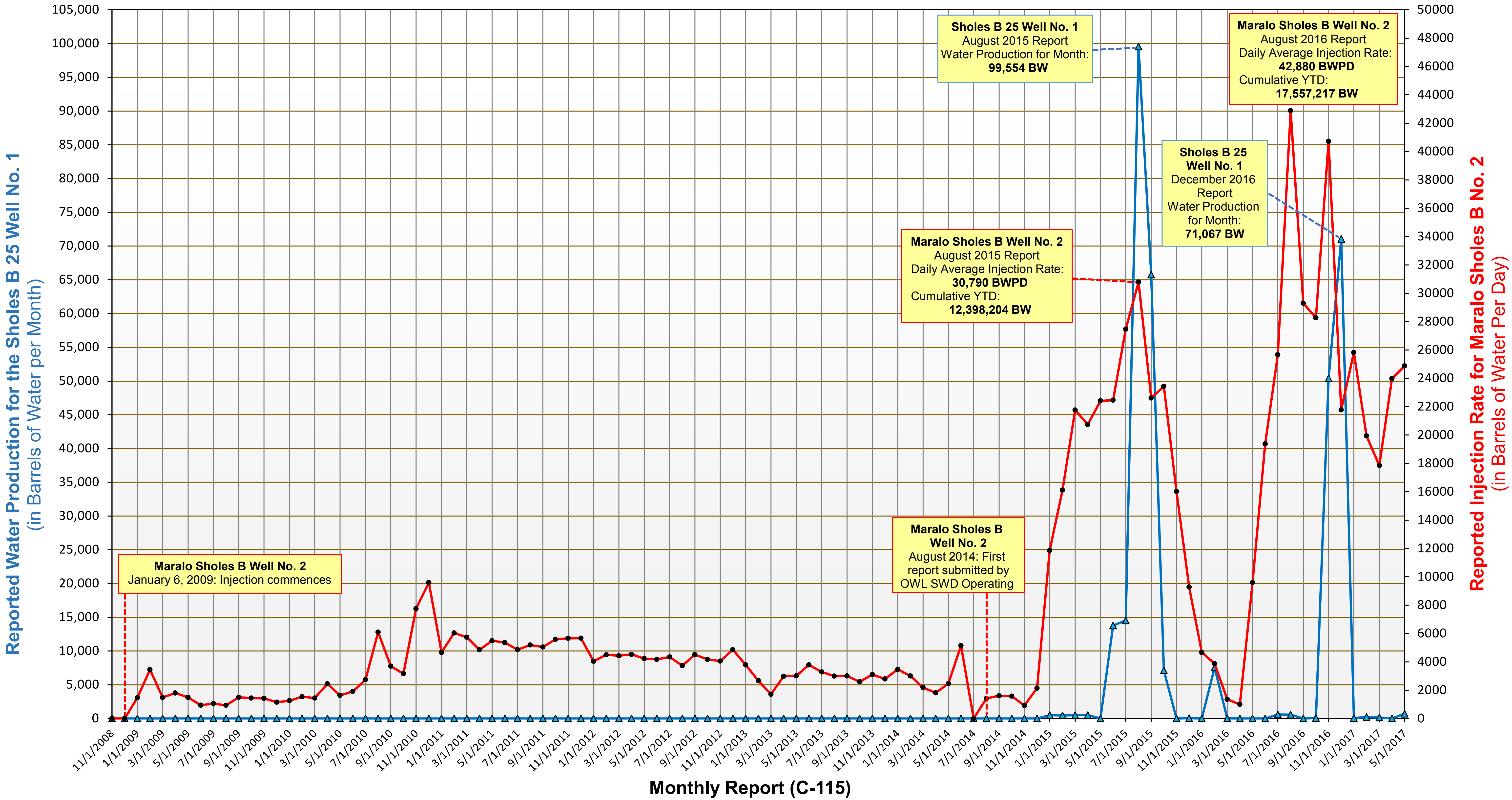
MONITORING WELL DESCRIPTION

USGS Well Identification: 320426103160501

Location: 1980 ft FNL / 1980 ft FEL; Sec 4, T26S, R36E, NMPM
Lat: 32° 4'25.8" Long: 103° 16'4.7" NAD83
Original completion information:
Southwest Jal Unit No. 1 (30-025-20843)
Spud: 04/21/1964 P&A: 03/05/1966
TD: 13,505 feet PBTD: 5,300 feet
Relinquished to the USGS WRD for monitoring use on 03/15/1966.

CASE NO. 15723 Division Exhibit No. 5:

Graph Showing Water Production of Sholes B 25 Well No. 1 and Water Injection of Maralo B Sholes Well No. 2 vs. Time



STATE OF NEW MEXICO
ENERGY, MINERALS, AND NATURAL RESOURCES DEPARTMENT
OIL CONSERVATION DIVISION

IN THE MATTER OF THE HEARING CALLED BY THE OIL CONSERVATION DIVISION TO CONSIDER:

CASE NO. 15723
ORDER NO. R-14738

THE APPLICATION OF OWL SWD OPERATING, LLC FOR AUTHORIZATION TO INJECT, LEA COUNTY, NEW MEXICO.

ORDER OF THE DIVISION

BY THE DIVISION:

This case came on for hearing at 9:00 a.m. on August 1st, 2nd, and 4th, 2017, at Santa Fe, New Mexico and again on August 31st, 2017, before Examiner William V. Jones.

NOW, on this 15th day of June 2018, the Division Director, having considered the testimony, the record, and the recommendations of the Examiners,

FINDS THAT

(1) Due public notice has been given, and the Division has jurisdiction of this case and its subject matter.

(2) The applicant, OWL SWD Operating, LLC (OGRID 308339) ("OWL"), seeks authorization to use the proposed Bobcat SWD Well No. 1 (API No. 30-025-Pending, "Proposed Well") as a disposal well, replacing its existing, nearby disposal well, the Maralo Sholes B Well No. 2 (API No. 30-025-09806). The Bobcat SWD Well No. 1 will be located 740 feet from the South line and 705 feet from the East line, Unit P of Section 25, Township 25 South, Range 36 East, NMPM, Lea County, New Mexico.

(3) The Oil Conservation Division ("OCD") entered an appearance in opposition to the permit for the Proposed Well and presented one technical witness. The State Land Office ("SLO") also entered an appearance and presented one technical witness.

(4) By letter to the Division dated April 28, 2016, the City of Jal ("Jal") had expressed concerns that the high disposal rates into this well would endanger its potential to exploit its proposed water rights in this Section 25. The City of Jal appeared at the hearing through counsel, questioning witnesses and presenting briefs.

(5) OWL provided notice of the proposed disposal well and the hearing to all affected parties and operators of record within the ½ mile Area of Review as required in Rule 19.15.26.12 NMAC. During the hearing, the hearing examiner required the area of review for notice purposes to be extended from one half mile to a one-mile radius from the

proposed disposal well. The case was continued to August 31, 2017 to provide adequate time for the additional notice.

(6) The Division subsequently received a letter from Special Energy Corporation dated August 30, 2017 as one of the noticed (affected) parties stating there was no objection to the application, so long as only one of the wells [subject wells of Cases No. 15723 and 15753] is allowed by the Division to be used for disposal.

(7) No other party entered appearance or otherwise opposed this application.

(8) Case No. 15753, "Application of the New Mexico Oil Conservation Division Compliance and Enforcement OCD for a Compliance Order Against OWL SWD Operating, LLC for the Maralo Sholes B Well No. 2 Operated in Lea County New Mexico." was heard September 15, 2017. The competence of this existing well and its tubulars for use as a high rate commercial disposal well was the subject in Case No. 15753. Case No. 15753 could be considered a companion case because the disposal well permit being proposed in Case No. 15723 would replace the permit for disposal into the Maralo Sholes B Well No. 2; which well is also located in Unit P of Section 25, Township 25 South, Range 36 East, NMPM, Lea County, New Mexico. The parties considered whether to combine the two cases for purposes of testimony but agreed to present the cases separately. A separate order will be issued in Case No. 15753.

(9) OWL had proposed this application administratively by submittal of Form C-108 on May 1 of 2017. The matter was evaluated and referred to an Examiner hearing by the OCD Engineering Bureau.

(10) OWL appeared at the hearing through counsel and presented the following by testimony and exhibits.

a. The Proposed Well would replace the existing Maralo Sholes B Well No. 2 disposal well which would be plugged and abandoned.

b. The Proposed Well would have two casing strings. The 9-5/8-inch casing would be set to the top of the Salado formation at 1325 feet and cemented to surface, covering all potential fresh water sources. The 7-inch casing is proposed to be set in the Yates formation, just above the top of the proposed disposal interval at 2915 feet. A 5-7/8-inch open hole would be drilled to 3060 feet and the open hole interval used for disposal through 4-1/2-inch duo-lined tubing set in a 7-inch packer at no higher than 2815 feet.

c. OWL anticipates a maximum injection rate of 30,000 barrels of water per day. The waste water would be sourced from locally produced water in the Delaware, Bone Spring, Devonian, and Yates-Seven Rivers formations. The maximum anticipated injection pressure would be 580 psi at surface.

d. The closest fresh water well is located 2328 feet and one other well may be located within one mile. OWL will attempt to supply a fresh water analysis to the Division from these wells.

e. The affirmative statement in the application says, "Based on the available engineering and geologic data we find no evidence of open faults or any other hydrologic connection between the disposal zone and any underground sources of drinking water." The form C-108 application was signed by a consulting engineer and agent for OWL.

f. The Proposed Well would be part of a series of wells permitted for disposal into either the Yates Seven Rivers or the Devonian formations.

g. The disposal wells will support a water handling system intended to reliably recycle and dispose of oil field waste water for many years to come. The system is designed to consist of a landfill, two 500,000-barrel water ponds, and be fed from oil field operations located to the west through a 16-inch fiberglass lined water pipeline. The pipeline system is necessary to largely eliminate truck traffic and wear on existing roads and will be much more reliable and much larger in size than a system based on trucking. The system has over a dozen clients and is necessary to the drilling, completion, and production operations near the Red Hills area. OWL intends to continue to scale up the recycling of oil field waste water.

h. The proposed disposal interval is located geologically in the backreef facies. The well is laterally several miles east of the Capitan Reef. The earlier, older portion of the Capitan Reef extends under the proposed disposal interval below the Seven Rivers formation.

i. Within the nine-township area surrounding the Proposed Well are three or four hundred Yates-Seven Rivers injection wells within the Langlie Mattix; 7Rvrs-Q-Grayburg Pool (Pool code 37240). There have been numerous other SWD wells permitted by the Division in this area and some in this same Section 25 – all within the same Yates and Seven Rivers formations.

j. OWL presented an analysis of the Hiss water quality data [report published in 1975] from wells in the surrounding nine-township area of the Proposed Well. Most of the Hiss wells were located to the east of the Proposed Well. The analysis indicated that the waters in the Yates-Seven Rivers formations average above 10,000 TDS of total salinity with a median of 14,650.

k. Injection into the Proposed Well would be filling up depleted pore space in this reservoir and not harming correlative rights. The Yates and Seven Rivers formations in this area have been produced since the 1920's and by the 1950's had been severely depleted by primary production. In the 1960's injection projects were put in to recover additional oil in place.

l. The oil reservoir is within the lower Yates and upper Seven Rivers formations which trend roughly north/south and dip gently to the east. Beginning in the west and moving east, the reservoir grades from a free gas phase to oil and then to water in the east. The western edge of Section 25 is near the line at which the phase changes from gas to oil. The current disposal and the Proposed Well would be disposing just below this contact. There has been significant gas produced from the gas cap of this reservoir.

m. Original reservoir pressure in the 1920's is estimated to have been 1400 psi or near the bubble point. By the 1950's the gas cap had increased in size and the reservoir pressure had decreased to about 200 psi. The gas cap helped in oil recovery until it was blown down by recompletions up-hole.

n. The productive rock in this reservoir has been the clean sands with an estimated permeability of at least 350 millidarcies as measured in a core from an adjacent well. The carbonates contain anhydrites which have reduced the permeability. Therefore, the proposed disposal is expected to be contained in the sands and not migrate vertically through the rock.

o. In the Maralo Sholes B Well No. 2, the initially completed pay interval was above the oil to water contact, therefore the well did not produce any water and only began producing some water after pressure depletion.

p. Near the Proposed Well, the Yates or Seven Rivers formations would not be a valid source of water for the City of Jal not only due to higher salinity but also due to the initial pay interval not having water.

q. Within this immediate project area, there is 85 to 90 million barrels of pore space that must be filled before a waterflood would be successful. Other waterflood attempts in this portion of the reservoir have not been successful.

r. Waterflood operations would not be successful until this reservoir was again restored to original pressures. Small waterfloods have been tried without success. High rate water disposal into the Proposed Well may be positive to surrounding producers and should not be detrimental or cause waste.

s. The Capitan Reef exists both laterally from and vertically below the Proposed Well. The Capitan Reef trends north/south and the youngest aged, highest portion of the Reef is located several miles to the west where the proposed disposal interval grades into the reef. Older, lower portions of the Capitan Reef are located vertically below the proposed disposal interval anywhere from 250 to 700 feet depending on which estimate was provided.

t. There are nearby water supply wells and observation wells in the Capitan Reef. The reported water analysis from this area in the Reef indicates waters higher than the 10,000 TDS fresh water limit and dangerous levels of hydrogen sulfide, with a black, corrosive quality.

u. Disposed waters are not expected to move vertically down due to low permeable dolomites in the lower Seven Rivers formation and the low reservoir pressures in the depleted sand disposal intervals, as compared with the lower intervals.

v. Disposed waters are not expected to move vertically upward due to the impermeable Salado formation overlying the stratified target disposal interval. The injection survey run in December of 2016 on the Maralo Sholes B Well No. 2 shows that waters are not moving up-hole around the packer and injection water is staying in the permitted disposal interval.

w. The target disposal interval has been depleted of pressure after years of production; therefore, injected fluids should remain in this interval and not move laterally out of this interval. Any horizontal movement of waste water should be preferentially in an easterly direction because of the lower pressures existing in the east from all the prior oil production. Movement to the west towards the reef is up dip but should not happen due to the higher pressures in the Reef.

x. The City of Jal currently gets its water from the Pecos Alluvium, the shallowest aquifer in the area. Jal would most likely find additional waters first in the Santa Rosa formation and then in the Rustler formation. The Capitan Aquifer waters would be the third choice and would be expensive to pump and purify.

y. The State Engineer defines the "Capitan Underground Water Basin" for purposes of administering water rights within that defined extent. This basin includes the Capitan Reef Aquifer and water sources above the Reef but the two sources are not identical in lateral extent.

z. The Capitan Reef Aquifer is a poor choice for the City of Jal because of its depth and the higher salinity and contaminates in southern Lea County. The newest installed wells in the Capitan Reef in this area were for the Ochoa Mine project. Those wells were pumped for seven days and the final water salinity measured was 70,000 mg/l of TDS.

aa. The multilayer hydrologic model presented by a hydrologist showed that disposed waste waters would most likely never reach the Capitan Reef. Currently the Capitan water pressures are higher than the pressures in the target disposal interval. In addition, there are layers of low permeability rocks vertically below the target disposal interval. Both factors would prevent or limit movement of injected waters into the Reef.

bb. The reported rebound in water column in the Capitan monitor wells could be explained by the cessation of large water supply projects both to the north and to the south of this location.

cc. There has been no evidence of pressure communication or water movement from the higher-pressure Capitan Reef and the depleted Yates-Seven Rivers target disposal reservoir. Therefore, it can be concluded that the two are not in communication and waters introduced back into the depleted reservoir would not contaminate the Capitan Reef Aquifer.

dd. The flowline installed to this location along with the planned ponds will even-out any injection surges into the Proposed Well. The surface facilities for the Proposed Well are new and designed to Division requirements. The well would be equipped with a SCADA system which monitors rates and pressures and can be used to remotely control the well.

ee. The injection operation into the Proposed Well can be conducted in a safe and responsible manner without causing waste, impairing correlative rights or endangering fresh water, public health or the environment.

(11) The OCD appeared at the hearing through counsel and presented the following.

a. The OCD administratively reviewed the permit for disposal in the Proposed Well and referred it to hearing where the matter of commercial disposal into this depleted, low salinity reservoir could be considered. The OCD also reviewed and denied three other proposals for commercial disposal in this area.

b. The OCD presented maps and a large volume of available data relating to water quality, water availability, water head (or pressure) in the nearby Capitan Reef, and water production in surrounding Area of Review wells.

c. This reservoir is still producing oil and gas. There are few wells located to the west of the Maralo Sholes B Well No. 2. There are many wells to the east and these are mostly plugged. The remaining producing wells seem to be located to the north or south. Because of the presence of many wells in this same disposal interval, the OCD recommends the one-half mile area of review be expanded to a larger area.

d. There is a concern that high rate disposal will cause waste in this reservoir. Within the one-half mile area of review is the Fulfer Oil & Cattle, LLC operated Sholes B 25 Well No. 1 (API No. 30-025-09812) located in Unit H of Section 25, Township 25 South, Range 36 East, NMPM, Lea County, New Mexico. This well has reported spikes in water production that may be correlated with injection of high rates of waters into the Maralo Sholes B Well No. 2.

e. There may be an uncemented well located in the "area of review" that could provide a conduit for high rate disposal waters to move up hole. Within the one-half mile area of review is the Continental Oil Company, Sholes B 30 (API No. 30-025-11839) located in Unit M of Section 30, Township 25 South, Range 37 East, NMPM, Lea County, New Mexico. The well is reported as plugged and abandoned but there are no logs of well file records available in public records to verify depth or plugging method.

f. The Maralo Sholes B Well No. 2 was originally permitted for handling local waters, but after being taken over for commercial disposal has reported a peak disposal rate of 42,880 barrels of water per day.

g. Order No's R-14034 and R-9913 were presented by the OCD as examples of proposals for disposal in this area over the years that were denied after notice and hearing. The reason for denial has been cited as a concern over waste of oil and gas and adverse impact on the relatively low salinity waters in the target interval or adverse impact on the Capitan Reef.

h. The OCD and the Division have received letters from the City of Jal expressing concern over the effects on fresh water supplies of disposal at high rates into the Maralo Sholes B Well No. 2.

i. The water analysis submitted with the original disposal application for the Maralo Sholes B Well No. 2 reported 8,200 mg/l of TDS. That application was not for commercial disposal of outside waters and the applicant indicated an intention to re-inject those same waters or local waters from local operations back into the Yates and Seven Rivers formations.

j. The water analysis recently submitted for the application for the Proposed Well is much higher than that submitted with the original application for the Maralo Sholes B Well No. 2.

(12) The State Land Office ("SLO") appeared at the hearing through counsel and presented the following.

a. SLO explained that the Hiss data confirms a hydrologic model of movement of fresh waters through and near the Capitan Reef. The Artesia group formations near the Proposed Well have clearly been flushed from waters within the Capitan Reef below the original sea water concentrations and are at or below the protectable concentrations.

b. There has been contamination occurring in this area. The older salt water disposal wells have increased the salt level in waters from surrounding producing wells. This is evidence that disposal waters were being brought into those disposal wells from higher salt yielding formations.

c. The waters in this Yates, Seven Rivers, Queen formation aquifer to the north of the Proposed Well range from good drinking water to much higher salt content, a complete range of salinities, but many samples are below the 10,000 mg/l of TDS.

d. There is a well on located to the south of the Proposed Well that had 5800 TDS at one point in time. The salinity in that well degraded over time which has been a pattern for wells in this area.

e. Looking at the samples taken over time in this back-reef area, it is evident that the waters were clearly fresh and in places have been contaminated by drilling or disposal.

f. In 2009, the Texas Water Development Board issued a complete report about the waters in this area, updating and expanding on the Hiss work.

g. From examination of thickness of the Seven Rivers, the Capitan Reef may be within 100 to 300 feet vertically from the open hole, total depth of the Maralo Sholes B Well No. 2. From correlations, the Seven Rivers formation may range in thickness from 100 to 400 feet thick at this location. The lack of deeper wells in this area prevents knowing this thickness precisely.

h. The permeability in the Capitan Reef can be three to ten times as much as the permeability in the back-reef facies. There is sometimes a low ratio of horizontal to vertical permeability in the Artesia group formations. Therefore, vertical migration can and does occur.

i. There is some indication of a fault within one mile of the Proposed Well. The faults in the Reef may have resulted in cavernous porosity and points of recharge in the Reef. This cavernous porosity sometimes extends upward into the rocks of the Artesia group overlying the Capitan Reef, as it does above the entrance to the Carlsbad Caverns.

j. The SLO does not want poor quality water which would be injected into the Proposed Well to migrate under State Trust lands. The SLO has easements for both fresh and naturally brackish water for use by mining companies and oil and gas companies.

k. The SLO is also concerned about waste and believes there is a residual oil saturation in this reservoir even after depletion. Wells set up to dispose of salt water instead of wells set up in a pattern for injection and waterflooding will result in a waste of State Trust oil resources.

l. The SLO stated that oil companies are reluctant to install a waterflood or CO2 flood in this area because of the large liability from poorly plugged wells.

(13) Additional technical details in OWL's submitted form C-108 (application for disposal) and in Division records concerning the Maralo Sholes B Well No. 2 and disposal in this area are pertinent to this case and listed below.

a. The Maralo Sholes B Well No. 2 (as it is now called) was originally drilled in 1947 for production of oil. The oil pay interval (Yates or Seven Rivers formation dolomite) was initially reported to extend from 2945 feet to 2950 feet. In 1961, the operator reported that the oil interval had "watered out" and applied to recomplete the well up hole as a gas well in the Yates formation. On October 6, 1961 the well tested at 780 Mcf per day from upper Yates formation sands at 2871 feet to 2910 feet. These perforations were cement squeezed and a thicker gas pay interval from 2824 feet to 2933 feet was perforated and fractured on October 21, 1981.

b. By 1986, the well had reached its economic limit for production of oil and gas and was deepened at least 50 feet and used as a water supply well for the Jalmat Waterflood. The well continued to produce and sell some gas.

c. After administrative application, on June 1, 2008, the Maralo Sholes B Well No. 2 was permitted by the Division with administrative order SWD-1127 for use as a disposal well into an open hole from 2938 to 3055 in the Lower Yates and Upper Seven Rivers formations. The application for disposal stated the operator's intention to dispose of a maximum of 5,000 barrels of water per day from the same formation and from the operator's own production in the area.

d. OWL took over as operator of record on July 16, 2014, cleaned out the disposal well, and changed the injection tubing from 3-1/2 inch to 4-1/2 inch in diameter, and connected a produced water flowline to the well. The well has since been used for commercial disposal at rates of approximately 25,000 barrels of water per day ("bwpd"), sometimes peaking at much higher rates.

e. The Proposed Well would be a new disposal well to be located near and to replace the Maralo Sholes B Well No. 2.

f. Division records indicate that within one half mile of the Proposed Well are nine (9) plugged and abandoned wells and two (2) other wells that have not yet been plugged, both operated by Fulfer Oil & Cattle, LLC. The producing wells are in the Jalmat; Tansill Yates Seven Rivers (Oil) Pool with Pool Code 33820. All wells located within one-half (½) mile of the Proposed Well are reported in the C-108 application submitted by OWL to be cased and cemented adequately to prevent movement of disposal water up-hole and out of interval.

g. Partially as a check on whether waste will occur, the form C-108 asks for all wells within two miles to be listed in any application for disposal. OWL intends to dispose at relatively high rates over many years into the Proposed Well; therefore, during the hearing the Examiner asked for the radius of notice to be extended from the rule-required one-half mile radius to a one-mile radius, which radius was amended to include all lands in the surrounding four Sections. OWL has done that additional notice. The data indicates that many of the active wells in those Sections are operated by Fulfer Oil & Cattle, LLC and some are operated by Herman L. Loeb, LLC.

h. Two of the active wells in Section 25 are permitted for disposal and being used for salt water disposal into the same proposed interval as the Proposed Well. Division records for these two disposal wells can be summarized as follows:

- The Sholes B 25 Well No. 2 (API No. 30-025-09809)

Located in Unit B of Section 25 and currently operated by Fulfer Oil & Cattle, LLC. This well was permitted by SWD-513 on May 20, 1993 for disposal into the Seven Rivers (open hole) from 3061 feet to 3290 feet. The application stated the intention "to inject water from our wells from the

Yates and Seven Rivers formations" at no more than 7000 barrels of water per day.

- The Brown Well No. 5 (API No. 30-025-09807)

Located in Unit E of Section 25 is now operated by OWL SWD Operating, LLC. This well was permitted by Division Order No. R-5196 issued in Case No. 5655 on April 20, 1976 for disposal into the lower Yates and Seven Rivers formations through an open hole from approximately 3289 feet to 3363 feet.

The testimony in this Case No. 5655 presented in 1976 indicated that water from the producing interval of the Yates formation in surrounding wells would be injected in this well into the (lower) Seven Rivers open hole. *The applicant submitted a water analysis of these Yates waters (Exhibit No. 5 of Case No. 5655) which showed a TDS of 7302 mg/l with (a lot of) H2S.*

The case file also contains a request submitted relatively recently asking to convert the disposal well from lease-only to Commercial Disposal. The request letter included a water analysis sampled in March of 2000 (titled: Project Owner Fulfer and Project Name Brown SWD near Jal New Mexico) showing waters to be disposed into the well. *The Seven Rivers formation water was listed at 8200 TDS and the Queen formation water at 5000 TDS.*

The Case file did not contain a reply from the Division granting or denying permission to convert to commercial disposal.

Issues and Conclusions

(14) Waste of Oil or Gas due to Disposal

a. It was proper that the OCD not approve this disposal application administratively and prudent to require a hearing where the possibility of waste of oil and gas could be further explored.

b. OWL presented an expert opinion from a Petroleum Engineer that this reservoir cannot be waterflooded until the reservoir pressure is restored, previous waterflood attempts have failed, and disposal into this reservoir will not harm oil reserves but may even help recover additional oil. Prior to the production from gas higher in the reservoir, this reservoir may have had a combination of solution gas and pressure depletion from the gas cap. That may have yielded a higher oil recovery or a faster recovery of the same percent of original oil in place.

c. Oil reservoirs producing under a pure solution gas drive have a residual oil saturation that can be significant. OWL did talk about reservoir pressures and about permeability as measured on a core and inferred by the rate of disposal, but did not specifically list other reservoir, rock, or fluid parameters that would support the conclusion about waterflooding.

d. It does ring true that the reservoir pressure must be restored, and the depleted gas cap would hamper recovery, but waterfloods are often started under depleted conditions where logical patterns of injection and production wells are used to re-pressure and direct the sweep direction.

e. This application is for commercial disposal into a depleted oil and gas reservoir and was not presented as an application for creation of a pressure maintenance project as is commonly done. The choice to qualify the well as disposal and not injection may be logical considering the large number of plugged wells and the small number of remaining production wells in this vicinity.

f. Except for the SLO, owners or operators of the minerals did not attend the hearing or otherwise indicate a concern as to waste of oil and gas. The SLO mentioned that waste of oil and gas could occur due to this proposed disposal well but acknowledged that oil companies have been reluctant to install an enhanced recovery project in this area.

g. The Division has selectively allowed disposal wells into oil productive reservoirs in the past to inexpensively test the waterflooding concept and observe the effect on offsetting production wells. This should not be done administratively, but only after identifying separately owned tracts surrounding the well and providing adequate notice to ALL mineral estate owners of those tracts, and only after convincing testimony from a petroleum engineer. OWL has identified tracts and provided disposal notice to tract owners and presented testimony from a petroleum engineer.

h. There was no waterflooding study or reservoir simulation and therefore, there is still a question as to the effect of commercial disposal, whether this reservoir has recoverable oil, or whether recoverable oil would be profitable.

(15) Influence of Disposal on the Reef

a. There was conflicting testimony as to the distance to the reef. It seems there is a lack of well data available to the witnesses as to exactly where the Reef rocks begin vertically underneath the Maralo Sholes B Well No. 2 and even a question as to exactly how far the reef is offsetting to the west.

b. The low reservoir pressure in the target Yates-Seven Rivers formations is evident by observing the extremely high rate of injection at low surface pressures into the Maralo Sholes B Well No. 2 and the need to use CO2 foam to clean out the fill from the Maralo Sholes B Well No. 2 prior to running the latest injection survey.

c. The current low reservoir pressure indicates that any strong hydrodynamic connection with the Capitan Reef Aquifer (or waters) does not exist. The area has been essentially depleted since the 1950's, which was 50 to 60 years ago, and reservoir pressures are still extremely low and dramatically lower than the pressures in the Capitan Reef. If there were a strong connection from the reef, then it seems that pressures would have equalized or shown signs of equalizing.

d. It is likely that the planned large disposal volumes into this depleted reservoir will eventually fill up the reservoir. At the estimated disposal rate in the C-108 application of 30,000 barrels of water per day, the well will fill up the 90 million barrels of depleted pore space in this project area within less than nine years. These numbers can be considered as estimates, since OWL did not clearly define the project area or estimated area of invasion and as shown above, the vertical injection interval thickness is not precisely known.

e. As the local reservoir fills up and the pressures rise, injected waters that may be corrosive will migrate somewhere. OWL maintains the waters will migrate to the east where the major depletion has occurred. This is logical; however, there was a slight downward movement of water in the injection survey that was run at only one fifth of the rate that disposal is happening.

f. There is a lack of well data in this area on the lower Seven Rivers formation and the pore pressures existing vertically below the Proposed Well. Therefore, it is prudent to gather more data and until OWL can provide enough data to show the Division differently, it should consider that fluids may more downward and have an interaction with the Capitan Reef as this reservoir achieves fill up.

(16) The Presence of Water in the Target Interval

a. OWL's focus in its testimony was on the oil and gas reservoir and concluded that little water was present in this interval or available for use. A specific look at the well records indicates that the target disposal interval or interval slightly deeper in the Seven Rivers formation does have water present. From the SLO presentation, it could be concluded that the connection to the reef and the brackish near reef waters is not too much deeper than the target disposal interval.

b. The Maralo Sholes B Well No. 2 had produced oil and then reported to have "watered out" prior to recompletion in the gas interval. The well had also been deepened into the water leg of the reservoir [it is not clear as to how far it was deepened] and used as a water supply well for a waterflood.

c. The question remains as to whether a weak bottom water drive existed and what thickness of interval would be effective for disposal. The thickness, or net pay, of the formation taking water from disposal may not be accurately known and is a critical factor in estimating the invasion radius after many years of injection.

d. The recently run injection survey on the existing Maralo Sholes B Well No. 2 was run at 6500 barrels of water per day to obtain usable data from the tracer survey. This survey did not show waters exiting the well and moving down out of the permitted open hole interval, but the survey was not run at the representative rate of 25,000 barrels of water per day, so that is still a possibility.

e. The conclusion that the sands in the Yates and upper Seven Rivers formations (as those formations are in this backreef lagoonal depositional environment) have dramatically more permeability than the dolomites (which may be filled with anhydrite) would likely still apply to rocks deeper in the water leg.

(17) Yates-Seven Rivers Waters for the City of Jal

a. The State Engineer did not enter an appearance or otherwise express any support or opposition to this application.

b. OWL presented testimony that the State Engineer defines the "Capitan Underground Water Basin" for purposes of administering water rights within a defined extent and this basin includes water sources above the Capitan Reef Aquifer so is not laterally limited to the Capitan Reef Aquifer.

c. OWL opined that the City of Jal would seek waters from many other sources before it would drill wells and produce water from the Capitan Reef Aquifer.

(18) In-Situ Water Quality

a. This is a reservoir with insitu water salinity considerably lower than the salinity of the proposed disposal waters and therefore has been a consideration for use by business and local municipalities.

b. As stated by the City of Jal, it is interested in procuring additional water supplies and interested in protecting waters that may someday be of interest. The City of Jal has applied for water rights in this Section 25 and is concerned about the proposed commercial disposal in this area and what effect it would have on fresh waters.

c. The State Land Office is concerned about waste of oil and gas but also about dilution of potentially valuable waters in the Capitan Reef Aquifer. The State Land Office seems to be taking the position that waters in and around the Capitan Reef even if higher than the protectable limit should be protected from further dilution of waters under State Trust lands by oil field water disposal wells.

(19) Underground Injection Control Program

a. The State of New Mexico was granted primacy on March 7, 1982 by the US Environmental Protection Agency ("EPA") for administering the federal Underground Injection Control ("UIC") Class II well program within most of the lands in New Mexico. The Oil Conservation Division is the lead agency for administering the program.

b. The Division is responsible for permitting, inspecting, and monitoring oil field related disposal wells such as the Proposed Well and for reporting such activity quarterly and annually to the EPA.

c. The following federal definitions are integral with the UIC program:

40 CFR 144.3 - Definitions.

- Aquifer means a geological "formation," group of formations, or part of a formation that is capable of yielding a significant amount of water to a well or spring.

- Total dissolved solids means the total dissolved (filterable) solids as determined by use of the method specified in 40 CFR part 136.

- Underground source of drinking water (USDW) means an aquifer or its portion:

  (a) Which supplies any public water system; or
  Which contains a sufficient quantity of ground water to supply a public water system; and
  (i) Currently supplies drinking water for human consumption; or
  (ii) Contains fewer than 10,000 mg/l total dissolved solids; and

  (b) Which is not an exempted aquifer.

- Even if an aquifer has not been specifically identified by the Director, it is an underground source of drinking water if it meets the definition in § 144.3.

(20) Protectable Waters

a. The proposal for injection is into a specific well at a specific location and depth, but the presented facts were of a statistical nature over this generally large area. It is evident that the formations, waters, phases of production, and well data change rapidly in an East to West direction and less rapidly from North to South. The available data gets sparse only a short distance to the West because there were less wells drilled for oil and gas. Both sides presented statistics of water salinity showing much variation.

b. OWL has done a statistical analysis over a nine-township area surrounding this well showing that the median and average water salinities as reported in the 1975 paper by Hiss are both above the protectable level.

c. The OCD and the SLO cited many examples of water samples showing low, sometimes protectable salinities in Yates, Seven Rivers, and Queen formation wells in this north to south trending reservoir. The SLO showed how salinities have trended over time in selected wells, with many water samples beginning at protectable levels of salinity and some contamination occurring from vertically mixing reservoirs [drilling] or from outside disposal of waters [salt water disposal].

d. The specific, local water analysis already present in the Division files for previously issued disposal permits in Section 25 [*see* Brown Well No. 5, API No. 30-025-09807] indicates that the native waters in the Yates, Seven Rivers, and Queen formations are in fact protectable. The Queen formation being equivalent in age to the Capitan Reef, did show lower salinity than the Yates and Seven Rivers formations.

e. Disposal permits in this area have previously been approved for re-injection of local waters <u>from the same formations</u>. This is allowed under the provisions of Division Rule 19.15.26.8 E(3) NMAC which says, *"...the director may authorize disposal into such zones administratively if the waters to be disposed of are of higher quality than the native water in the disposal zone"*.

f. However, the Division must consider the disposal of outside waters of higher salinity as is being proposed in this case under a higher standard of consideration under Division Rule 19.15.26.8E(2) NMAC which states that *"The division shall not permit disposal into zones containing waters having total dissolved solids concentrations of 10,000 mg/l or less except after public notice and hearing, provided that the division may, by order issued after public notice and hearing, establish exempted aquifers for such zones where the division may administratively approve the injection"*.

<u>Summary of Findings</u>

(27) This application for permit to inject should be denied without prejudice to further proceedings. The following facts, conclusions, and remaining questions support this conclusion:

a. The in-situ waters in this proposed disposal interval of the Yates and Seven Rivers formations within and around Section 25 are protectable and a defined area around the Proposed Well has not yet been declared as an "exempted aquifer" by the Oil Conservation Division and by the US EPA.

b. The Proposed Well may cause waste of oil or gas. The reservoir is largely depleted, yet there remain active producing wells in the target formation in this immediate area. A rigorous analysis or reservoir simulation or waterflood study has not yet been done to determine the additional recovery capability of this reservoir.

c. If additional recovery capability exists, then the applicant must further justify the waste of oil with the overreaching need to use this reservoir for commercial disposal. This would involve both facts and legal arguments.

d. There is a lack of critical data necessary to understand the characteristics of the Yates, Seven Rivers, Capitan Reef, and Queen formations. This data can only come from the drilling, logging, and testing of a nearby well designed to penetrate at least the top of the Capitan Reef. The test well and the location of the test well should be proposed by geologists and engineers and permitted under guidance of the Division.

e. The Continental Oil Company, Sholes B 30 (API No. 30-025-11839) located in Unit M of Section 30, Township 25 South, Range 37 East, NMPM, Lea County, New Mexico, was reported by the OCD as having no well records, no logs, and no plugging records. Records on offsetting wells indicate wells were plugged with small amounts of cement, but placed at adequate locations. The plugging program used on this well may or may not be similar. Most importantly, because there is likely an open hole through the Salado formation, any attempt to re-enter this well would likely fail and during the work over, would expose shallow fresh water intervals to invasion by salts. Despite these assumptions, OWL should attempt to locate records for this well and supply those records to the Division for further review and guidance.

f. The extended pressure radius of influence must be determined and presented to the Division. The well construction of all wells within this agreed upon extended radius must then be examined and presented to the Division with a plan for repair of any cementing or casing concerns.

g. A plan for the periodic monitoring of static reservoir pressures [not just well head injection pressures] near any proposed commercial disposal well must be presented and approved by the Division. Reservoir pressures should rise predictably as disposed water volume increases and the static reservoir pressure should be limited to a pressure that would not cause preferential flow towards the Capitan Reef. And if pressures do NOT rise predictably as water volumes increase, then the confining reservoir and rock assumptions are incorrect, and waste water may be migrating downward and into the Capitan Reef.

IT IS THEREFORE ORDERED THAT

(1) The application of OWL SWD Operating, LLC for permit to inject into the proposed Bobcat SWD Well No. 1 to be located 740 feet from the South line and 705 feet from the East line, Unit P of Section 25, Township 25 South, Range 36 East, NMPM, Lea County, New Mexico, is denied without prejudice.

(2) Jurisdiction is hereby retained for the entry of such further orders as the Division may deem necessary.

DONE at Santa Fe, New Mexico, on the day and year hereinabove designated.

STATE OF NEW MEXICO
OIL CONSERVATION DIVISION

HEATHER RILEY
Director

S E A L

State of New Mexico
Energy, Minerals and Natural Resources Department
Oil Conservation Division

Update of Underground Injection Control Class II Activities Within the State of New Mexico for Possible Injection into Underground Sources of Drinking Water: the Capitan Reef Aquifer System

ATTACHMENT 3

Source: OCD Case No. 20474; Division Exhibits

Division Exhibit No. 1: Figure 1: Map Showing Locations for the Proposed Texas Ranger SWD No. 1 and Existing Disposal Wells in Area

Division Exhibit No. 2: Figure 2: Map Showing Adjacent Production Wells with Sundry Cement Histories for Surface Casing

Division Exhibit No. 3: Figure 3: Map Showing Shallow Drinking Water Sources in Proximity of the Proposed Texas Ranger SWD No. 1

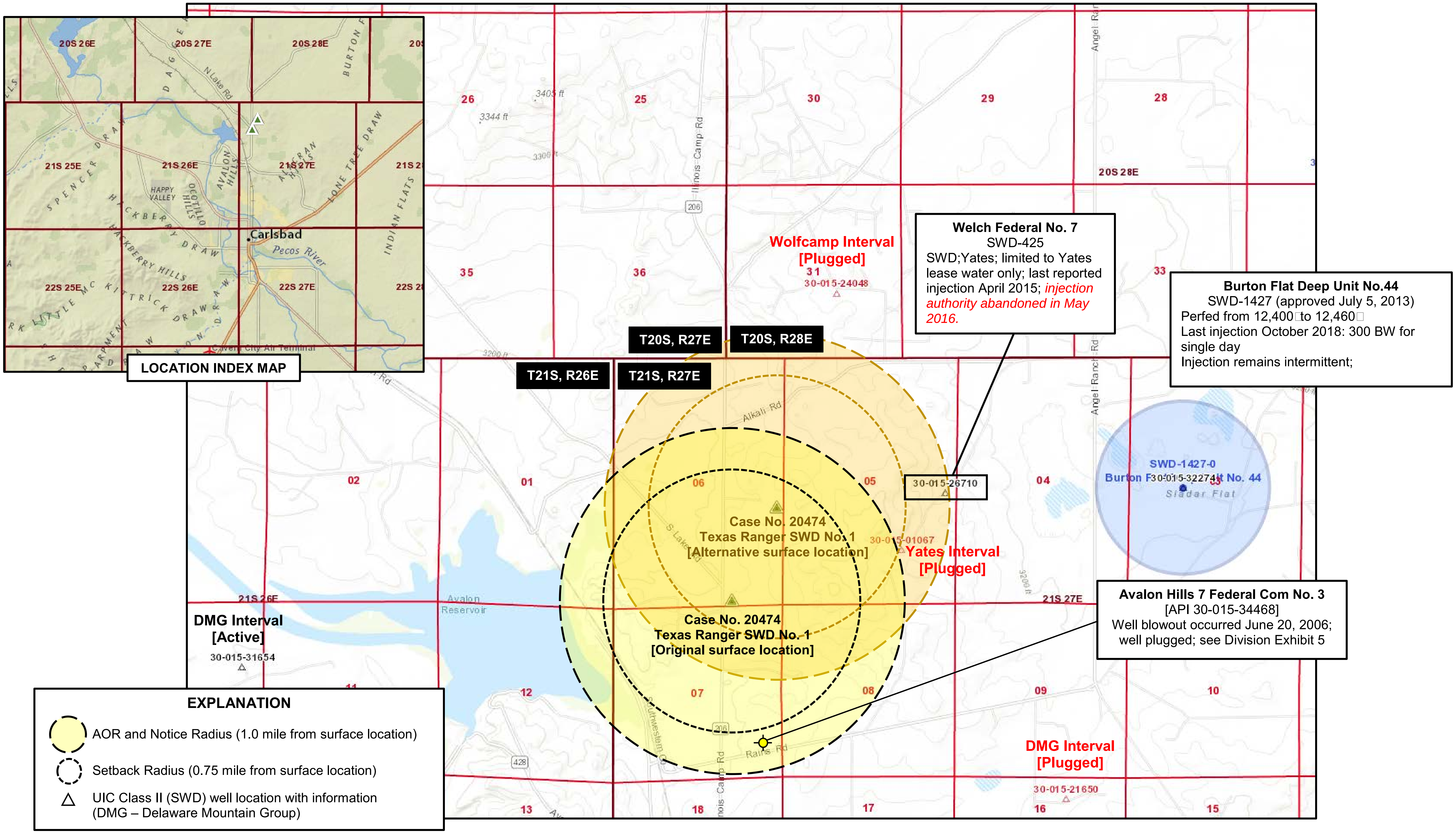
Division Exhibit No. 4: Figure 4: Excerpt from NMBGMR Resource Map No. 5 and Resource Map No. 6

Division Exhibit No. 5

Oil Conservation Division
Energy, Minerals and Natural Resources Department
State of New Mexico

CASE NO. 20474 DIVISION EXHIBIT NO. 1

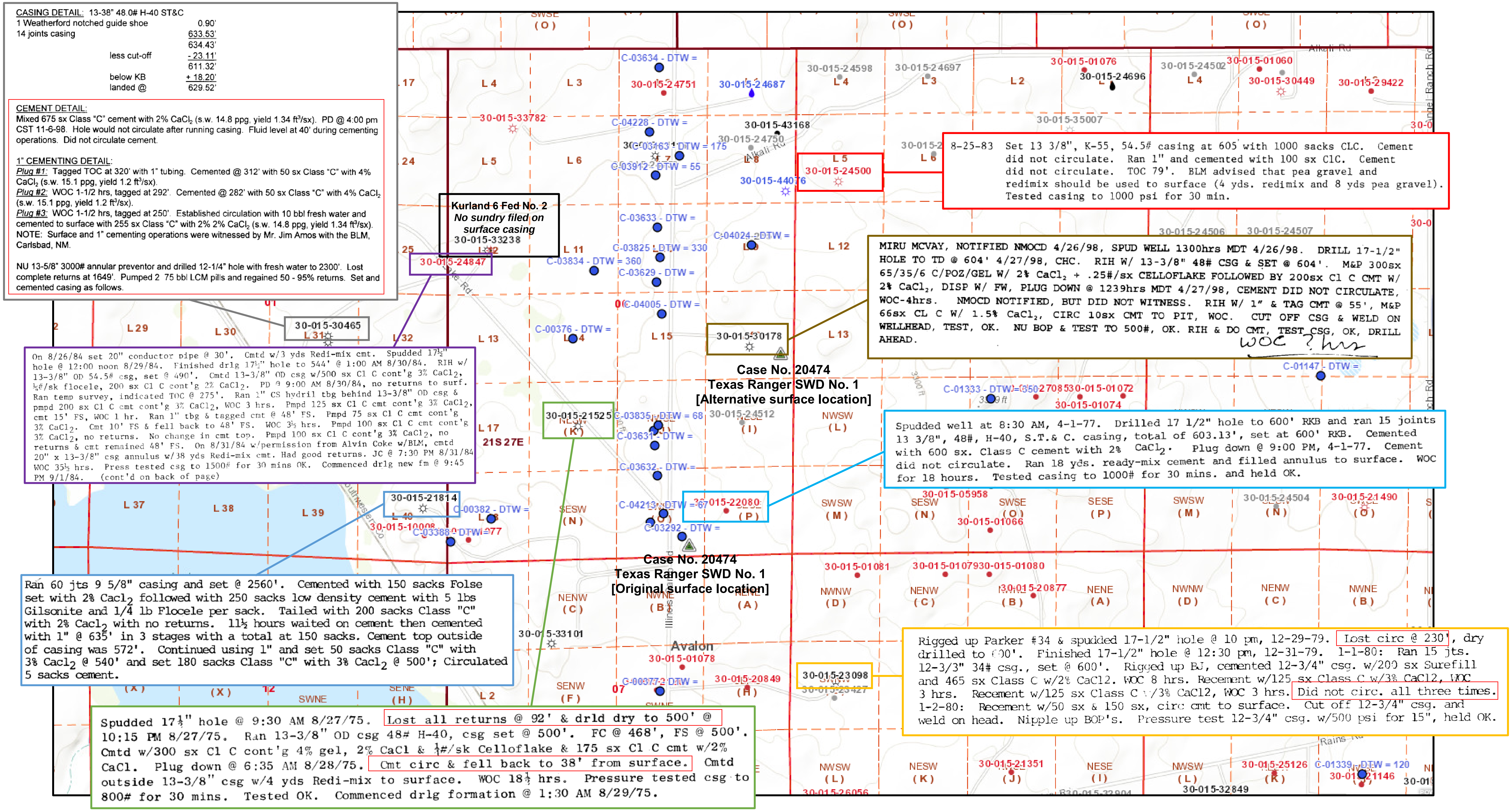
Figure 1: Map Showing Locations for the Proposed Texas Ranger SWD No. 1 and Existing Disposal Wells in Area



Oil Conservation Division
Energy, Minerals and Natural Resources Department
State of New Mexico

CASE NO. 20474 DIVISION EXHIBIT NO. 2

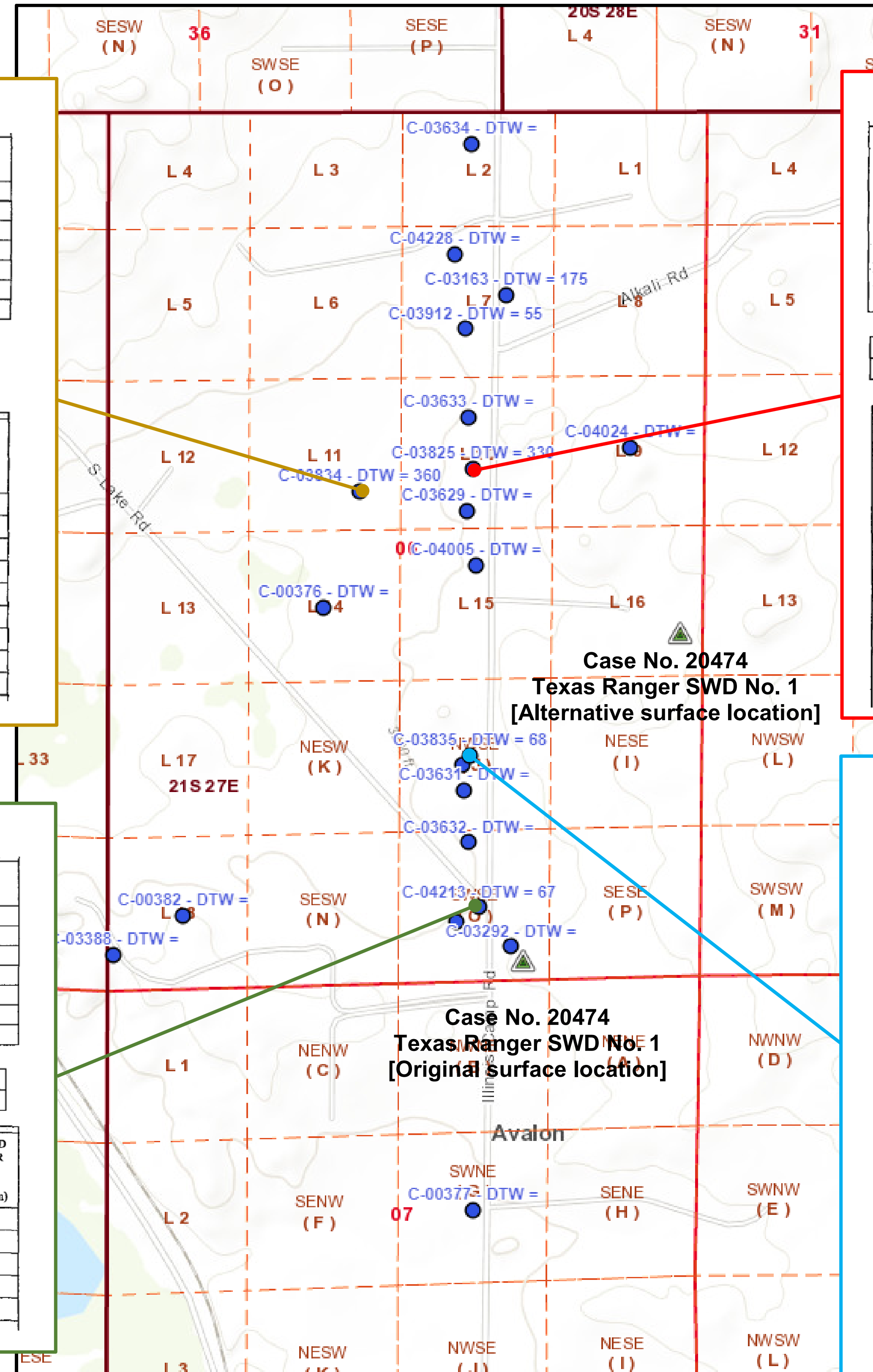
Figure 2: Map Showing Adjacent Production Wells with Sundry Cement Histories for Surface Casing



Oil Conservation Division
Energy, Minerals and Natural Resources Department
State of New Mexico

CASE NO. 20474 DIVISION EXHIBIT NO. 3

Figure 3: Map Showing Shallow Drinking Water Sources in Proximity of the Proposed Texas Ranger SWD No. 1



Point of Diversion C-3834 – Well Record Log

3. ANNULAR MATERIAL

DEPTH (feet bgl) FROM	TO	BORE HOLE DIAM. (inches)	LIST ANNULAR SEAL MATERIAL AND GRAVEL PACK SIZE-RANGE BY INTERVAL	AMOUNT (cubic feet)	METHOD OF PLACEMENT
0	20	9	Concrete	18	Down Hole
20	370	9	1/4 Pea Gravel	90	Down Hole

FOR OSE INTERNAL USE — WR-20 WELL RECORD & LOG (Version 06/08/2012)

FILE NUMBER C-3834 — POD NUMBER 1 — TRN NUMBER 561016

LOCATION 1-2-4 21S,27E,06 — PAGE 1 OF 2

LOG OF WELL

DEPTH (feet bgl) FROM	TO	THICKNESS (feet)	COLOR AND TYPE OF MATERIAL ENCOUNTERED - INCLUDE WATER-BEARING CAVITIES OR FRACTURE ZONES (attach supplemental sheets to fully describe all units)	WATER BEARING? (YES / NO)	ESTIMATED YIELD FOR WATER-BEARING ZONES (gpm)
0	4	4	Topsoil	N	
4	50	46	Limestone	N	
50	125	75	Brownish Clay & Sandstone	N	
125	200	75	Yellowish Sandstone	N	
200	290	90	Redish/Brown Clay	N	
290	325	35	Brown Sandstone	N	
325	355	30	Red Clay	N	
355	370	15	Fractured Limestone	Y	20+

Point of Diversion C-3825 – Well Record Log

3. ANNULAR MATERIAL

DEPTH (feet bgl) FROM	TO	BORE HOLE DIAM. (inches)	LIST ANNULAR SEAL MATERIAL AND GRAVEL PACK SIZE-RANGE BY INTERVAL	AMOUNT (cubic feet)	METHOD OF PLACEMENT
0	20	9	Concrete	18	Down Hole
20	390	9	1/4" Pea Gravel	108	Down Hole

FOR OSE INTERNAL USE — WR-20 WELL RECORD & LOG (Version 06/08/2012)

FILE NUMBER C-3825 — POD NUMBER 1 — TRN NUMBER 559270

LOCATION 2,1,3 21S,27E,03 — PAGE 1 OF 2

LOG OF WELL

DEPTH (feet bgl) FROM	TO	THICKNESS (feet)	COLOR AND TYPE OF MATERIAL ENCOUNTERED - INCLUDE WATER-BEARING CAVITIES OR FRACTURE ZONES (attach supplemental sheets to fully describe all units)	WATER BEARING? (YES / NO)	ESTIMATED YIELD FOR WATER-BEARING ZONES (gpm)
0	3	3	Topsoil	N	
3	50	47	Limestone	N	
50	100	50	Brownish Clay	N	
100	135	35	Brown Sandstone	N	
135	175	40	Redish Clay	N	
175	275	100	Yellow and Brown Sandstone	N	
275	315	40	Redish Clay	N	
315	390	75	Fractured Limestone	Y	20+

Point of Diversion C-4213 – Well Record Log

3. ANNULAR MATERIAL

DEPTH (feet bgl) FROM	TO	BORE HOLE DIAM. (inches)	LIST ANNULAR SEAL MATERIAL AND GRAVEL PACK SIZE-RANGE BY INTERVAL	AMOUNT (cubic feet)	METHOD OF PLACEMENT
0	20	9.875	Cement	7.619	Poured
20	105	9.875	3/8 Pea Gravel	30.47	Poured

FOR OSE INTERNAL USE — WR-20 WELL RECORD & LOG (Version 06/30/17)

FILE NO. C-4213 — POD NO. 1 — TRN NO. 621884

LOCATION 21S-27E-06 4-3-4 — WELL TAG ID NO. 2GCC4 — PAGE 1 OF 2

DEPTH (feet bgl) FROM	TO	THICKNESS (feet)	COLOR AND TYPE OF MATERIAL ENCOUNTERED - INCLUDE WATER-BEARING CAVITIES OR FRACTURE ZONES (attach supplemental sheets to fully describe all units)	WATER BEARING? (YES / NO)	ESTIMATED YIELD FOR WATER-BEARING ZONES (gpm)
0	5		Top soil		
5	60	55	Sand		
60	70		Sand Gravel	Y	15
70	105		Sand		

Point of Diversion C-3825 – Well Record Log

3. ANNULAR MATERIAL

DEPTH (feet bgl) FROM	TO	BORE HOLE DIAM. (inches)	LIST ANNULAR SEAL MATERIAL AND GRAVEL PACK SIZE-RANGE BY INTERVAL	AMOUNT (cubic feet)	METHOD OF PLACEMENT
0	20	10	Cement	20	Hand
20	120	10	Pea Gravel	100	Hand

FOR OSE INTERNAL USE — WR-20 WELL RECORD & LOG (Version 06/08/2012)

FILE NUMBER C-3835 — POD NUMBER 1 — TRN NUMBER 561180

LOCATION 21S.27E.6 314 — PAGE 1 OF 2

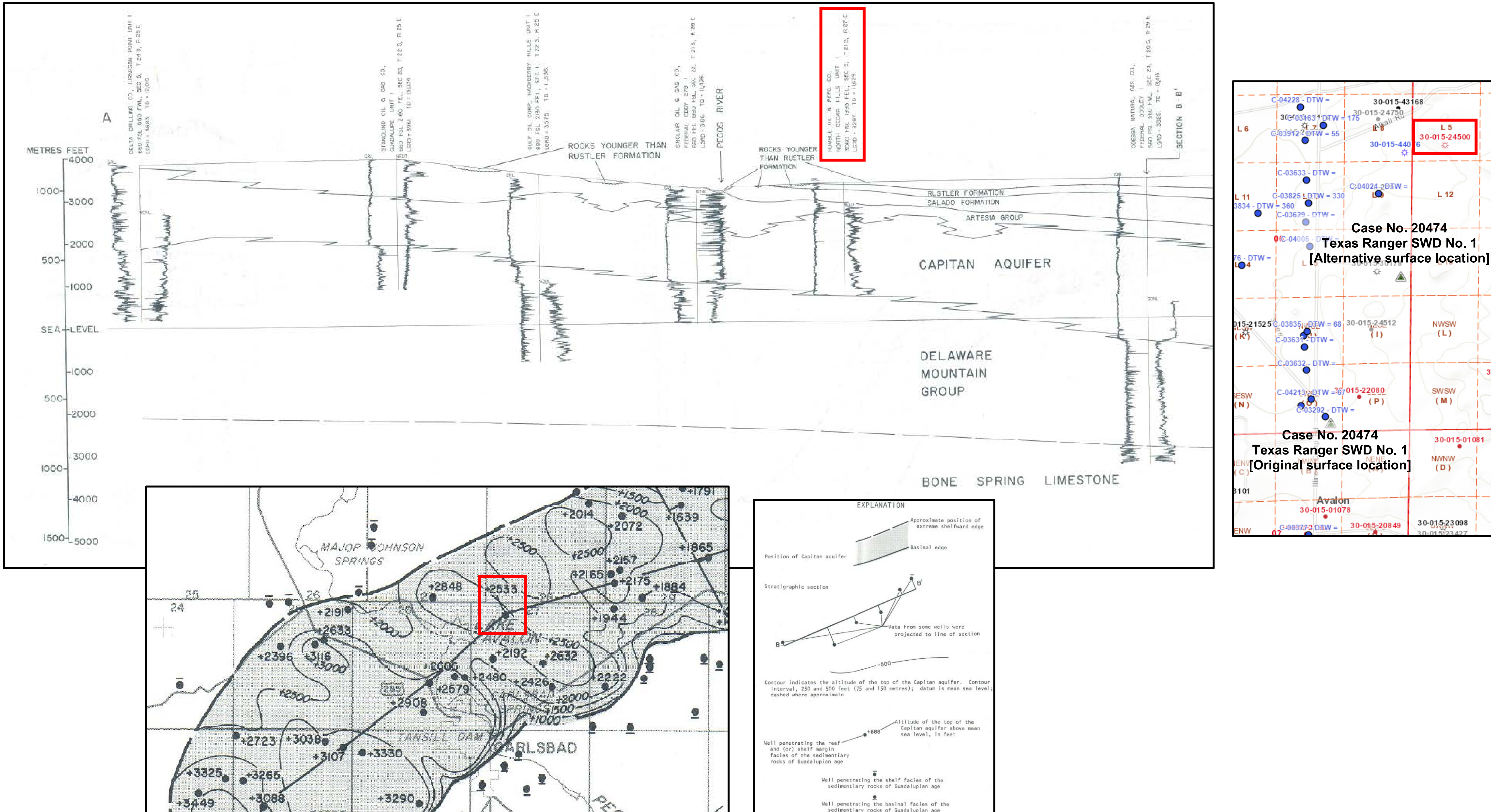
LOG OF WELL

DEPTH (feet bgl) FROM	TO	THICKNESS (feet)	COLOR AND TYPE OF MATERIAL ENCOUNTERED - INCLUDE WATER-BEARING CAVITIES OR FRACTURE ZONES (attach supplemental sheets to fully describe all units)	WATER BEARING? (YES / NO)	ESTIMATED YIELD FOR WATER-BEARING ZONES (gpm)
0	2	2	Topsoil	N	
2	10	8	Caliche and Rock	N	
10	23	13	Limestone	N	
23	55	32	Sand & Clay Mix	N	
55	110	87	Brown Sand	Y	20+
110	120	10	Red Clay	N	

Oil Conservation Division
Energy, Minerals and Natural Resources Department
State of New Mexico

CASE NO. 20474 DIVISION EXHIBIT NO. 4

Figure 4: Excerpt from NMBGMR Resource Map No. 5 and Resource Map No. 6



CASE NO. 20474 DIVISION EXHIBIT NO. 5

Form 3160-5
(August 1999)

NMOCD

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
SUNDRY NOTICES AND REPORTS ON WELLS

Do not use this form for proposals to drill or to re-enter an abandoned well. Use Form 3160-3 (APD) for such proposals

SUBMIT IN TRIPLICATE

FORM APROVED
OMB NO. 1004-0135
EXPIRES: NOVEMBER 30, 2000

5. Lease Serial No.
NM-0375257-A

6. If Indian, Allottee or Tribe Name

7. Unit or CA Agreement Name and No.

8 Well Name and No.
Avalon Hills 7 Fed Com 3

9. API Well No.
30-015-34468

10. Field and Pool, or Exploratory
Burton Flat; Morrow

12. County or Parish: Eddy 13. State: NM

1a. Type of Well ☐ Oil Well ☑ Gas Well ☐ Other

2. Name of Operator
Devon Energy Production Company, LP

3. Address and Telephone No.
20 North Broadway, Ste 1500, Oklahoma City, OK 73102 405-552-7802

4. Location of Well (Report location clearly and in accordance with Federal requirements)*
SESE Lot P 1010' FSL & 660' FEL
Sec 7 T21S, R27E

RECEIVED
JUL 1 4 2006

CHECK APPROPRIATE BOX(s) TO INDICATE NATURE OF NOTICE, REPORT, OR OTHER DATA

TYPE OS SUBMISSION	TYPE OF ACTION			
☑ Notice of Intent	☐ Acidize	☐ Deepen	☐ Production (Start/Resume)	☐ Water Shut-Off
☐ Subsequent Report	☐ Alter Casing	☐ Fracture Treat	☐ Reclamation	☐ Well Integrity
☐ Final Abandonment Notice	☐ Casing Repair	☐ New Construction	☐ Recomplete	☐ Other
	☑ Change Plans	☐ Plug and Abandon	☐ Temporarily Abandon	
	☐ Convert to Injection	☐ Plug Back	☐ Water Disposal	

13. . Describe Proposed or Completed Operations (Clearly state all pertinent details, and give pertinent dates, including estimated date of starting any proposed work and approximate duration thereof. If the proposal deepen directionally or recomplete horizontally, give subsurface location and measured and true vertical depths of all pertinent markers and zones. Attach the Bond under which the work will be performed or provide the Bond No. on file with BLM/BIA. Required subsequent reports shall be filed within 30 days following completion of the involved operations. If the operation results in a multiple completion or recompletion in a new interval, a Form 3160-4 shall be filed once testing has been completed. Final Abandonment Notices shall be filed only after all requirement, including reclamation, have been completed, and the operator has determined that the site is ready for final inspection)

Devon Energy Production Company, L.P. respectfully requests approval to change plans from initial APD:

Alexis, as a follow-up to telephone conversation on Thursday, June 22nd with Gerald Brockman, Drilling Engineer; the following are the events that have occurred on this well and what we are proposing to do:

While drilling the 8 3/4" hole at 10,427' the well had an influx of gas. The well was shut-in and the gas was being circulated out of the well when gas and water began blowing out of the ground around the rig. The rig was shut down and the well shut in. All personnel were evacuated from the well site with no injuries. The well was subsequently killed with 11.2 ppg mud. It is not known at this time if the 9 5/8" casing failed or if the gas channeled around the 9 5/8" shoe. It is our plan to set a 200' cement plug from 9100' to 8900' that should isolate any gas shows that we had while drilling the well. We will then proceed with inspection of the 9 5/8" casing for a hole in the casing and if so repair the hole. We will then after drilling out the cement plug that was set, with YOUR APPROVAL, proceed to set a string of 7"26# HCP110 LTC casing at our present total depth of 10,427'. The 7" casing will be cemented in 3 stages cemented to the surface. We will then drill a 6 1/8" hole to the original intended TD and set a 4 1/2" 13.5# HCP110 Liner with 250' of overlap cemented to the top of the liner.

Verbal and written approval given June 22nd by Alexis Swaboda (see attached e-mail.) Sundry Notice filed as a follow-up to this.

14. I hereby certify that the foregoing is true and correct

Signed [signature] Name Stephanie A. Ysasaga Title Sr. Staff Engineering Technician Date 6/30/2006

(This space for Federal or State Office use)

Approved by (ORIG. SGD.) ALEXIS C. SWOBODA Title PETROLEUM ENGINEER Date JUL 1 1 2006

Conditions of approval, if any:

Title 18 U.S.C Section 1001, makes it a crime for any person knowingly and willfully to make any department or agency of the United States any false, fictitious or fraudulent statements or representations to any matter within its jurisdiction.

*See Instruction on Reverse Side

NEW MEXICO ENERGY, MINERALS and NATURAL RESOURCES DEPARTMENT

BILL RICHARDSON
Governor
Joanna Prukop
Cabinet Secretary

NEWS RELEASE

For release: June 20, 2006

Contact: Jodi McGinnis Porter, Public Information Officer, 505-476-3226
Mark Fesmire, Director, Oil Conservation Division, 505-476-3460

Oil Well Blowout Near Carlsbad's Avalon Lake

No One Injured and No Evacuations Necessary

SANTA FE, NM – The Oil Conservation Division (OCD) Artesia District Office of the New Mexico Energy, Minerals and Natural Resources Department is investigating a gas well blowout that occurred early this morning north of Carlsbad near Avalon Lake. Work crews were immediately evacuated and no one was injured in the incident. State officials and well control specialists from Wild Well Control, Inc. of Houston, TX. are on location for safety concerns and are working to control the blowout.

"State, local government and company officials are working to stop the flow of gas from this well and there does not appear to be any threat to local residents at this time," said Mark Fesmire, OCD Director. "Once this problem is fixed, we will launch a full investigation and take enforcement action as necessary to ensure that this does not happen again."

Devon Energy Production was drilling a gas well at the Avalon Hills 7 (Federal Com #30-15-34458, P-7-21S-27E) location when the blowout occurred. At approximately 1:30 a.m. Tuesday, June 20, the drilling rig crew was in the process of replacing the drill bit, when the crew noted a large mud flow from the formation. The crew noticed high pressure gas escaping from the ground surface strong enough to penetrate asphalt in the surrounding area

200 yards away. The rupture is believed to have occurred in the casing pipe at a very shallow depth.

The cause of the piping failure is unknown at this time. OCD will require an investigation to determine the cause of the incident and require the company to perform an investigation to determine if fresh water was impacted. The Devon Energy Production Company had reached an approximate depth of 10,427 ft.

# # #

The Energy, Minerals and Natural Resources Department provides resource protection and resource development services to the public and other state agencies.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUL 2 1 2014

MEMORANDUM

OFFICE OF WATER

SUBJECT: **Enhancing Coordination and Communication with States on Review and Approval of Aquifer Exemption Requests Under SDWA**

FROM: Peter Grevatt, Director
Office of Ground Water and Drinking Water (OGWDW)

TO: Water Division Directors Regions I – X

I. Introduction

More than four thousand aquifer exemptions have been approved over the history of the UIC program, and the vast majority of these have been straightforward actions that have been completed in a timely manner. There are some aquifer exemption decisions, however, where review of the aquifer exemption request has been considerably more complex, due to specific conditions associated with the proposed exemption. In some cases, these issues have led to protracted discussions between EPA and the states, without a clear path for resolution.

The purpose of this memorandum is to promote a consistent and predictable process for the review of Aquifer Exemption requests under the Safe Drinking Water Act (SDWA).[1] EPA has both a direct implementation role and a state partnership role in reviewing and approving aquifer exemption requests. Over the course of the past year, EPA has participated in discussions with a number of states through a Ground Water Protection Council (GWPC) workgroup to review issues associated with more complex aquifer exemption requests and to make recommendations on steps to improve the review process. Based on these discussions, EPA and the participating states agreed on a number of steps to enhance coordination and communication between EPA Regions and state UIC programs regarding proposed aquifer exemptions, as discussed below.

II. Roles and Responsibilities

EPA is responsible for the final review and approval of all aquifer exemption requests, based on the regulatory criteria in 40 CFR 146.4 [attached]. UIC permit applicants that need an aquifer exemption in order to conduct injection activities typically delineate the proposed exempted area and submit the delineation to the primacy agency, along with information to support a determination under 40 CFR 146.4 that the proposed exemption is appropriate. States or tribes with primacy review the application and, if the information submitted supports a determination that an aquifer exemption is warranted, make a designation, provide for public participation, and submit a request for approval of the exemption to the

[1] The substantive and procedural requirements for aquifer exemptions in connection with Class VI wells are not addressed in this memo.

appropriate EPA regional office. Primacy states and tribes are also responsible for issuing the UIC permit that goes with the aquifer exemption request and are the direct point of contact for the owners or operators requesting the permit and exemption. Where EPA directly implements the UIC program, the applicant submits the request directly to EPA, and EPA reviews the applicant's demonstrations and makes the final determination to approve or disapprove the exemption request.

If the aquifer exemption is a non-substantial program revision, the relevant EPA Region either responds by letter to the primacy state or tribe or, where EPA directly implements the program, to the applicant. If the aquifer exemption is a substantial program revision, notice of approval of the aquifer exemption is published in the *Federal Register* after EPA has provided public notice and an opportunity for public comment and a public hearing. Where EPA directly implements the UIC program, regional offices are also responsible for identifying and designating exempted aquifers or portions of aquifers at the request of a UIC permit applicant, issuing public notices, and issuing any related UIC permits following aquifer exemption approval. Regional Administrators are primarily responsible for approving/disapproving non-substantial aquifer exemption requests, and the Administrator is responsible for approving the request if the exemption is a substantial program revision.

III. Recommended Steps for Facilitating the Aquifer Exemption Review and Approval Process

As indicated above, most aquifer exemption requests have clearly met the regulatory criteria in 40 CFR 146.4, and reviews have been completed in a timely manner. There are some aquifer exemption requests, however, that have proven to be considerably more complex to review. These more complex aquifer exemption requests have not been limited to substantial program revisions; in some cases, non-substantial aquifer exemption requests have proved quite complex as well. Typically, these have involved situations where the proposed exempted area is located adjacent to an underground source of drinking water (USDW) that is currently in use, or where the potential future use of the USDW is unclear. The following steps are recommended to help facilitate the aquifer exemption review and approval process:

a. Each Region should adopt and share the attached aquifer exemption checklist with each of your states. OGWDW, in consultation with the Regions and states, developed the attached checklist to facilitate EPA's aquifer exemption review process and documentation. The checklist will help convey to states, tribes, and UIC permit applicants the typical information needed to facilitate EPA's review of an aquifer exemption request.

b. Regions should document their review and analysis of the information in the checklist in a Statement of Basis or decision memo that should be included in the Agency's record of its final action. The Statement of Basis should include explanations of the factual, technical, and legal bases for the determination. Information collected following the template of the checklist should inform the Statement of Basis.

c. In the case of aquifer exemption requests that are expected to be complex, EPA Regions are encouraged to schedule a discussion with the state UIC program managers as early in the process as possible. These discussions will serve to identify any potential technical issues that require additional attention even before the package has been submitted to EPA for review and approval.

d. Regional UIC program managers are encouraged to elevate significant disagreements on AE requests to senior primacy program managers rather than allowing them to persist at the staff level for extended periods of time. While HQ can offer assistance on specific Regional AE decisions, I anticipate that most technical issues can be resolved at the Regional level.

IV. Additional background for Approving and Documenting Aquifer Exemptions

The Safe Drinking Water Act (SDWA) directed EPA to establish an Underground Injection Control (UIC) program to prevent endangerment of Underground Sources of Drinking Water (Section 1421(b)(1)). EPA's regulatory approach to aquifer exemptions was promulgated in a 1980 rulemaking. EPA determined that without aquifer exemptions, certain types of energy production, solution mining, or waste disposal would be severely limited. Thus, the regulatory approach that EPA adopted—a broad definition of covered underground waters coupled with a discretionary exemption mechanism—allows the agency to prevent endangerment consistent with the statute while allowing some case-by-case consideration. This approach protects underground sources of drinking water while also allowing underground injection associated with industrial activities including the production of minerals, oil, or geothermal energy. EPA retains the final approval authority over aquifer exemption decisions regardless of state primacy status.

EPA must follow the regulatory criteria at 40 CFR 146.4 in making aquifer exemption determinations. For the EPA to approve an aquifer exemption, the Agency must first find that the state or, where EPA directly implements the UIC program, the applicant, has demonstrated that the aquifer or the portion of an aquifer identified by the state as exempt "does not currently serve as a source of drinking water" (40 CFR 146.4 (a)). EPA has determined that water that currently serves as a source of drinking water includes water that is being withdrawn in the present moment as well as water that will be withdrawn in the future by wells that are currently in existence. EPA's evaluation of this criterion ensures that water from the exempted area of the aquifer "does not currently serve as a source of drinking water" for nearby drinking water wells as required by 40 CFR 146.4(a).

The second exemption criterion requires EPA to determine either that the aquifer cannot now and will not in the future serve as a source of drinking water or that the total dissolved solids content of the ground water is more than 3,000 and less than 10,000 mg/l and it is not reasonably expected to supply a public water system.[2] The regulations at 40 CFR 146.4(b) describe four (4) potential reasons for making the determination that the aquifer cannot now and will not in the future serve as a source of drinking water. One reason (146.4(b)(1)) is that the aquifer is mineral, hydrocarbon, or geothermal energy producing, or can be demonstrated as part of a permit application to contain minerals or hydrocarbons that are expected to be commercially producible. The other reasons relate to practicality of access to water. EPA is continuing discussions with the GWPC workgroup to better define and communicate the type of data and analyses used to support those determinations. EPA Regions will need to document all reasons and factors they considered in a Statement of Basis or decision memo when making the final aquifer exemption decision. As best management practice, EPA will continue to communicate to the states the importance of documenting aquifer exemption analyses and their decision making process.

Robust recordkeeping and management of decision memos and aquifer exemption data is critically important to support informed decisions related to public and private ground water uses for drinking water. Therefore, in addition to the decision memos and records underlying EPA's approval/disapproval

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[2] EPA will fully address the criteria 146.4 (b) and 146.4(c) at a later time, after ongoing discussions with GWPC have concluded.

decisions, it is essential that regions maintain standardized, readily available data on all existing aquifer exemptions. Proper recordkeeping and data management at the regional level will help with mapping and geospatial analysis for greater accessibility and comprehension of the exemption data and ensure that potentially affected parties are made aware of the exempted areas. Additionally it will enhance HQ efforts to facilitate a national tracking mechanism for approved exemptions.

Conclusion

Recognizing that EPA's approval of an aquifer exemption request is typically required prior to issuance of a UIC permit, regional UIC programs should establish early communication with the primacy state to inform EPA's review. The Region should start its review with the information provided in the primacy program's designation and approval request. If questions arise or further information is needed to either supplement the request or clarify specific data points related to the proposed exempted aquifer, the Region should work with the primacy program to obtain this information at the earliest opportunity. The Region should also work expeditiously with the primacy program to resolve any disagreements arising from the aquifer exemption process.

While there are other technical and policy issues associated with aquifer exemptions that are not addressed by this memorandum, I hope that the clarity on the review and determination process for aquifer exemptions provided herein, will help the Agency's effort to achieve national consistency and clarify expectations from states and tribes (and potentially owners or operators) on aquifer exemptions. The Agency will continue to work in consultation with states and stakeholders to promote a consistent and predictable process for the review of aquifer exemption requests under the Safe Drinking Water Act (SDWA).

Attachments

40 CFR 146.4: Criteria for Exempted Aquifers

An aquifer or a portion thereof which meets the criteria for an "underground source of drinking water" in § 146.3 may be determined under § 144.7 of this chapter to be an "exempted aquifer" for Class I-V wells if it meets the criteria in paragraphs (a) through (c) of this section. Class VI wells must meet the criteria under paragraph (d) of this section:

(a) It does not currently serve as a source of drinking water; and

(b) It cannot now and will not in the future serve as a source of drinking water because:

(1) It is mineral, hydrocarbon or geothermal energy producing, or can be demonstrated by a permit applicant as part of a permit application for a Class II or III operation to contain minerals or hydrocarbons that considering their quantity and location are expected to be commercially producible.

(2) It is situated at a depth or location which makes recovery of water for drinking water purposes economically or technologically impractical;

(3) It is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption; or

(4) It is located over a Class III well mining area subject to subsidence or catastrophic collapse; or

(c) The total dissolved solids content of the ground water is more than 3,000 and less than 10,000 mg/l and it is not reasonably expected to supply a public water system

(d) The areal extent of an aquifer exemption for a Class II enhanced oil recovery or enhanced gas recovery well may be expanded for the exclusive purpose of Class VI injection for geologic sequestration under § 144.7(d) of this chapter if it meets the following criteria:

(1) It does not currently serve as a source of drinking water; and

(2) The total dissolved solids content of the ground water is more than 3,000 mg/l and less than 10,000 mg/l; and

(3) It is not reasonably expected to supply a public water system.

Aquifer Exemption Checklist

Reviewed by: ____________________ ***Date***________

A- Regulatory Background and Purpose

An aquifer or a portion thereof which meets the criteria for an "underground source of drinking water" in § 146.3 may be determined to be an "exempted aquifer". The aquifer exemption criteria at 146.4 must be met as follows:

- Class I-V wells must meet criteria **146.4(a) and 146.4(b)(1)**; or **146.4(a) and 146.4(b)(2)**; or **146.4(a) and 146.4(b)(3)**; or **146.4(a) and 146.4(b)(4)**; or **146.4(a) and 146.4(c)**.
- Class VI wells must meet the criteria **146.4(d)**[1].

Regardless of the AE request or the type of injection activity, in all cases, first and foremost a demonstration that the aquifer or portion thereof does not currently serve as a source of drinking water is the required first step in the process. **EPA must evaluate each AE request to ensure the criteria are met prior to approval. EPA should also document its rationale for approving or disapproving each AE request in its statement of basis and, in case of exemptions that are substantial program revisions, EPA must provide public notice and an opportunity for the public to comment and request a public hearing.**

The purpose of this checklist is to ensure that appropriate and adequate information is collected to facilitate review of AE requests, and documentation of AE decisions. Some information described here may not apply to all AE requests.

B- General Information

AE request received by EPA on ____________________

Is the aquifer exemption Substantial__________ **Non-Substantial**______________
Describe basis for substantial/non-substantial determination______________________________
Is the aquifer exemption Complex? (Existence of drinking water wells, populated area ...) ______________
Did the state or tribe provide public notice and opportunity for public hearing on the aquifer exemption request (144.7 (b)) Y/N
Were there any public comments? Y/N If yes, identify where they may be located____________________
Date(s) of notice(s) published___________, Public meeting(s) held_______________, Hearing held
_____________, any notable findings or pending litigation ______________________________
Describe the notice and comment process and the final decision______________________________
Describe the basis for the decision to exempt the aquifer or the basis for the decision to withhold or deny approval of the exemptions request______________________________
Any anticipated issues associated with EPA approval or disapproval of the AE request Y/N______________________________
Any meetings between EPA/States/Tribes/Operator to discuss issues Y/N list____________________

Is the request submitted by a primacy state or tribe? Y/N If yes name the State/Tribe/Agency _______ **Contact:**______________________________
AE identified by the Primacy State or tribe and submitted for EPA review and final determination on ______________

Name of the Owner/operator______________________________
Well/Project Name:______________________________ **Well Class** ____________________
Purpose of injection: ______________________________(mineral mining/oil and gas/other)

Where is the proposed aquifer exemption located? Township, Section, Range, Quarter Section or other method used to identify the area ____________ Latitude and longitude information _________County_________ City__________
State_________ Add information about distance to nearest Town, County ______________________________

Name of aquifer or portion of aquifer to be exempted ______________________________

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[1] Additional Class VI only requirements in 40 CFR 144.7(d)(1) and (2) apply. This checklist does not address those requirements.

Areal extent of the area proposed for exemption____________________________________

Depth and thickness of the aquifer ____

Discuss the total dissolved solid (TDS) content of the aquifer, including the TDS at the top and bottom of the exempted zone, and the locations and depths of all fluids samples taken. __________________________

C- Regulatory Criteria

An aquifer or a portion thereof may be determined to be an exempted aquifer for Class I-V wells if it meets the criteria in paragraphs (a) –(c) below. Other than EPA approved aquifer exemption expansions that meet the criteria set forth in 146.4(d), new aquifer exemptions for Class VI wells shall not be issued.

146.4: ( ) (a) ***Not currently used as a drinking water source*** **and:**

( ) **(b)(1)** It is mineral, hydrocarbon, or geothermal energy producing, or can be demonstrated by a permit applicant as part of a permit application for a Class II or Class II operation to contain minerals or hydrocarbons that considering their quantity and location are expected to be commercially producible; or

( ) **(b)(2)** It is situated at a depth or location which makes recovery of water for drinking water purposes economically or technologically impractical; or

( ) **(b)(3)** It is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption; or

( ) **(b)(4)** It is located over a Class III well mining area subject to subsidence or catastrophic collapse; or

( ) **(c)** TDS is more than 3,000 and less than 10,000 mg/l and it is not reasonably expected to supply a public water system.

( ) **(d)** *The areal extent of an aquifer exemption for a Class II enhanced oil recovery or enhanced gas recovery well may be expanded for the exclusive purpose of Class VI injection for geologic sequestration under § 144.7(d) if it does not currently serve as a source of drinking water; and the TDS is more than 3,000 mg/l and less than 10,000 mg/l; and it is not reasonably expected to supply a public water system.*

1- Demonstration that the aquifer or portion thereof does not currently serve as a source of drinking water per 146.4(a)

Describe the proposed exempted area and how it was determined:____________________________

____

TDS:__________________ Top:__________________ **Bottom:**__________________

Lithology: ____

Permeability: __________ **Porosity:** __________ **Groundwater flow direction:** __________________

Upper and Lower Confining Zone(s) and description of vertical confinement from USDWs:

____

Oil or mineral production history:____

Are there any public or private drinking water wells within and nearby the proposed exempted area for which the proposed exempted portion of the aquifer might be a source of drinking water Y/N If yes, list all those wells

____

- *Include*: pertinent map(s) visually showing the areal extent of exemption boundary, depth and thickness of the aquifer proposed for exemption, all known subsurface structures such as faults affecting the aquifer, and each of the inventoried water well locations by well # or owner name.
- *Include*: Table of all inventoried water wells showing: Well Name/#, Owner, (Private/Public), Contact information, Purpose of well (Domestic, Irrigation, Livestock, etc.), depth of source water, name of aquifer, well completion data, age of well (if known), and the primary source of well data (Applicant/State/Tribe/EPA).
- *Include*: Map showing the areal extent of exemption boundary, all domestic water wells considered potentially down gradient of the exemption and hydraulically connected to the exemption. If wells are deemed horizontally and/or vertically isolated from the exemption, this should be foot noted on the Table as well. Use arrow(s) to indicate the direction and speed of GW in the aquifer proposed for exemption.

- Describe the evidence presented in the application and/or methodology used to conclude GW direction and speed when relevant.
- *Include*: any source water assessment and/or protection areas and designated sole source aquifers located within the delineated area.

What is the appropriate area to examine for drinking water wells? Although guidance 34 says it should be a minimum of 1/4 mile, the determination of the appropriate area is on a case by case basis. Describe area and give a rationale.

Are there any public or private drinking water wells or springs capturing (or that will be capturing) or producing drinking water from the aquifer or portion thereof within the proposed exemption area? Y/N*

- Evaluate the capture zone of the well (s) in the area near the proposed project (i.e., the volume of the aquifer(s) or portion(s) thereof from within which groundwater is expected to be captured by that well).
- A drinking water well's current source of water is the volume (or portion) of an aquifer which contains water that will be produced by a well in its lifetime. What parameters were considered to determine the lifetime of the well?

- (*) If the answer to this question is Yes, therefore the aquifer currently serves as a source of drinking water.

2- Demonstration that the aquifer or portion thereof is mineral, hydrocarbon or geothermal energy producing per 146.4(b)(1)

Did the permit applicant for a Class II or III operation demonstrate as part of the permit application that the aquifer or portion thereof contains minerals or hydrocarbons that, considering their quantity and location are expected to be commercially producible? Did the permit applicant furnish the data necessary to make the demonstration as required by 40 C.F.R. 144.7(c)(1) and (2)? Summarize this demonstration and data ________________________________

- Include narrative statement, logs, maps, data and state issued permit.
- If the proposed exemption is to allow a Class II enhanced oil recovery well operation in a field or project containing aquifers from which hydrocarbon were previously produced, commercial producibility shall be presumed by the Director upon a demonstration of historical production having occurred in the project area or field. Many times it may be necessary to slightly expand an existing Class II operation to recover hydrocarbons and an aquifer exemption for the expanded area may be needed. If the expanded exemption for the Class II EOR well is for a well field or project area where hydrocarbons were previously produced, commercial producibility would be presumed.
- For new or existing Class II wells not located in a field or project containing aquifers from which hydrocarbons were previously produced, information such as logs, core data, formation description, formation depth, formation thickness and formation parameters such as permeability or porosity shall be considered by the Director, to the extent available.
- Many Class II injection well permit applicants may consider much information concerning production potential to be proprietary. As a matter of policy, some states/tribes do not allow any information submitted as part of a permit application to be confidential. In those cases where potential production information is not being submitted, EPA would need some record basis for concluding that the permit application demonstrates that the aquifer contains commercially producible minerals or hydrocarbons. For example, the permit application may include the results of any R & D pilot project. In this case, the applicant should state the reasons for believing that there are commercially producible quantities of minerals within the expanded area. Also, exemptions relating to new or existing Class II wells not located in a field or project containing aquifers from which hydrocarbons were previously produced should include the following types of information:
  - a- Production history of the well if it is a former production well which is being converted.
  - b- Description of any drill stem tests run on the horizon in question. This should include information on the amount of oil and water produced during the test
  - c- Production history of other wells in the vicinity which produce from the horizon in question.
  - d- Description of the project, if it is an enhanced recovery operation including the number of wells and there location.

For Class III wells, the Director must require an applicant to furnish data necessary to demonstrate that the aquifer is expected to be mineral or hydrocarbon producing and the Director must consider information contained in the mining plan for the proposed project, such as a map and general description of the mining zone, general information on the mineralogy and geochemistry of the mining zone, analysis of the amenability of the mining zone to the proposed mining method, and a time-table of planned development of the mining zone. Information to be provided may also include: a summary of logging which indicates that commercially producible quantities of minerals or hydrocarbons are present.

3- Demonstration that the aquifer or portion thereof is situated at a depth or location which makes recovery of water for drinking water purposes economically or technologically impractical per 146.4(b)(2)

Is the aquifer or portion thereof situated at a depth or location which makes recovery of water for drinking water purposes economically or technologically impractical? ______________________

- List evidence in the application showing how this demonstration was made.
- EPA consideration of an aquifer exemption request under this provision would include information related to: The availability of less costly and more readily available alternative supplies, the adequacy of alternatives to meet present and future needs, and costs for treatment (including cost of disposal of treatment residuals) and or development associated with the use of the aquifer.
- The economic evaluation, submitted by the applicant, should consider the above factors, and these that follow:

1. Distance from the proposed exempted aquifer to public water supplies.
2. Current sources of water supply for potential users of the proposed exempted aquifer.
3. Availability, quantity and quality of alternative water supply sources.
4. Analysis of future water supply needs within the general area.
5. Depth of proposed exempted aquifer.
6. Quality of the water in the proposed exempted aquifer.

4- Demonstration that the aquifer or portion thereof is too contaminated per 146.4(b)(3)

Is the aquifer or portion thereof proposed for exemption so contaminated that it would be economically or technologically impractical to render that water fit for human consumption ______________________

- List evidence in the application showing that the area to be exempted is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption.
- Economic considerations would also weigh heavily in EPA's decision on aquifer exemption requests under this section. Unlike the previous section, the economics involved are controlled by the cost of technology to render water fit for human consumption. Treatment methods can usually be found to render water potable. However, costs of that treatment may often be prohibitive either in absolute terms or compared to the cost to develop alternative water supplies.
- EPA's evaluation of aquifer exemption requests under this section will consider the following information submitted by the applicant:

(a) Concentrations, types, and source of contaminants in the aquifer.
(b) If contamination is a result of a release, whether contamination source has been abated.
(c) Extent of contaminated area.
(d) Probability that the contaminant plume will pass through the proposed exempted area.
(e) Ability of treatment to remove contaminants from ground water.
(f) Current and alternative water supplies in the area.
(g) Costs to develop current and future water supplies, cost to develop water supply from proposed exempted aquifer. This should include well construction costs, transportation costs, water treatment costs, etc.
(h) Projections on future use of the proposed aquifer.

5- Demonstration that the aquifer or portion thereof is located over a Class III well mining area subject to subsidence or catastrophic collapse per 146.4(b)(4)

Is the aquifer or portion thereof proposed for exemption located over a Class III well mining area subject to subsidence or catastrophic collapse?

- List evidence in the application showing that the area to be exempted is located over a Class III well mining area subject to subsidence or catastrophic collapse______________________

- Discuss the mining method and why that method necessarily causes subsidence or catastrophic collapse. The possibility that non-exempted underground sources of drinking would be contaminated due to the collapse should also be addressed in the application.

6- Demonstration that the aquifer or portion thereof has TDS more than 3,000 and less than 10,000 mg/l and it is not reasonably expected to supply a public water system per 146.4(c)

Is the TDS of the aquifer or portion thereof proposed for exemption more than 3,000 and less than 10,000 mg/l?______

Is the aquifer proposed for exemption or portion thereof not reasonably expected to supply a public water system?____

- Identify and discuss the information on which the determination that the total dissolved solids content of the ground water in the proposed exemption is more than 3,000 and less than 10,000 mg/l and the aquifer is not reasonably expected to supply a public water system.
- Include information about the quality and availability of water from the aquifer proposed for exemption. Also, the exemption request must analyze the potential for public water supply use of the aquifer. This may include: a description of current sources of public water supply in the area, a discussion of the adequacy of current water supply sources to supply future needs, population projections, economy, future technology, and a discussion of other available water supply sources within the area.

7- Demonstration that a Class II aquifer exemption may be expanded to Class VI per 146.4(d) *(Refer to additional requirements in EPA's regulations for Class VI aquifer exemptions for this demonstration)*

May the areal extent of an aquifer exemption for a Class II enhanced oil recovery or enhanced gas recovery well be expanded for the exclusive purpose of Class VI injection for geologic sequestration under § 144.7(d)?_______________

- List evidence in the application showing an existing Class II operation associated with AE that is being converted into Class VI____

State of New Mexico
Energy, Minerals and Natural Resources Department

Susana Martinez
Governor

Tony Delfin
Acting Cabinet Secretary

David R. Catanach, Division Director
Oil Conservation Division

October 24, 2016

Mr. Philip Dellinger, Chief
Ground Water/UIC Section, Region 6
United States Environment Protection Agency
1445 Ross Avenue, Suite 1200
Dallas, TX 75202-2733

RE: REVIEW OF UNDERGROUND INJECTION CONTROL CLASS II ACTIVITIES WITHIN THE STATE OF NEW MEXICO FOR POSSIBLE INJECTION INTO UNDERGROUND SOURCES OF DRINKING WATER

Dear Mr. Dellinger:

Reference is made to your request on behalf of the United States Environmental Protection Agency (EPA) for a review of current oil and gas injection activities occurring within New Mexico that may potentially impact Underground Sources of Drinking Water (USDWs) and their relationship to exempted aquifers associated with operations permitting injection into USDWs. This review was to specifically identify impacts due to Underground Injection Control (UIC) Class II operations potentially injecting directly in USDWs. This request was submitted to the New Mexico Oil Conservation Division (Division) in an EPA correspondence dated August 31, 2016.

I. State Underground Injection Control (UIC) Program General Information

The Division prepared general guidelines for the protection of USDWs as part of the *Class II Demonstration* dated September 15, 1981. The demonstration was submitted to the EPA as part of the effort by the state to obtain primacy for management of Class II wells in New Mexico. The proposed program was approved by the EPA on March 7, 1982, and recorded in Code of Federal Regulations (CFR) Title 40, Part 147, Subpart GG, Section 1600.

Section j. Aquifer Protection, Aquifer Exemption of the *Class II Demonstration* presented the argument that the original concept for the use of formal aquifer designations and aquifer exemptions, as proposed in 40 CFR 104.6, was not practical based on the common occurrences of hydrocarbon reservoirs and aquifers in the same lithologic units and the expense for formal declaration of numerous exempted aquifers not supported by budget. This concept was supported by two studies included in the demonstration (Appendices I and II) and summarized in a technical paper by Wilson and Holland (1984).

The demonstration detailed, in Appendix II, the prototype approval process for each of the three Class II well categories: Enhanced Oil Recovery (ER wells), Produced Fluid Disposal (SWD wells or Class II disposal wells), and Liquid Hydrocarbon Storage (HS wells).

Following the approval of the state UIC program, a new source of produced water became prolific: coal-bed methane (CBM) wells. This new source of hydrocarbon production was not considered in the original *Class II Demonstration* and was determined to be within the regulatory authority of the Division. The produced water from CBM wells was considered to be equivalent to produced fluids from oil and gas wells and applications for disposal were assessed using the same approval process as SWD wells.

The demonstration approval process for ER wells provided the following reasoning for limited application of exempted aquifers in areas with ER projects in response to 40 CFR 146.4:

> *There seems little necessity for elaborate aquifer exemptions related to ER Projects for the following reasons:*
>
> *(1) The pressure sinks surrounding the producing wells in an ER project cause injected fluids to move inward toward producing wells rather than outward toward any other part of the formation. Such contained movement eliminates the direct potential for contamination of USWDs which may be located elsewhere in the same formation.*
>
> *(2) The Division knows of no instance in the State where drinking water is being produced and consumed by the public from an aquifer which is also an oil and/or gas reservoir at the same horizontal and vertical section. Some USDWs exist within the same vertical section but horizontally removed from the hydrocarbon zone. The San Andres formation in Eddy County provides excellent examples of both of these situations. These conditions are discussed and extensively referenced in Appendix A-1.* [Section j. Aquifer Protection, Aquifer Exemption, *Class II Demonstration*, page 51]

The demonstration approval process for SWD wells includes the following stipulation in response to 40 CFR 146.4:

> *All applications for approval of SWD wells not within an oil or gas zone or within one mile thereof will contain data on water quality in the proposed disposal interval. Any SWD well proposed for disposal into a formation or zone containing water of 10,000 mg/l TDS* [Total Dissolved Solids] *or less which is not an exempted aquifer will be set for public hearing before a Division examiner.* [Section j. Aquifer Protection, Aquifer Exemption, *Class II Demonstration*, page 52]

This criterion is incorporated in the Division's regulation under Rule 19.15.26.8(E) New Mexico Administrative Code (NMAC). Additionally, the state UIC program included specific regulation by limiting disposal by SWD wells in Lea County to formations older than the Triassic age (Rule 19.15.26.8(E)(1) NMAC).

The demonstration also contained the following recommendation for future assessment for aquifer exemptions for portions of the Capitan Reef aquifer within Lea County:

> *Based upon this study the Division proposes that the Tansil, Yates, Seven Rivers, Queen, Grayburg, and San Andres formations of Lea County be classified as exempt aquifers. Please refer to Figures 8 and 9 of the Lea County Report, Appendix A-2* [Hiss (1980)] *and Resource Map No. 6 from "Stratigraphy and Ground-Water Hydrology of the Capitan Aquifer, Southeastern New Mexico and Western Texas" by William L. Hiss (PhD Thesis, University of Colorado 1975)* [Hiss (1976)] *for the vertical and horizontal sections to be exempted. Because of the gradational nature of the back reef facies a more precise description is not proposed.* [Section j. Aquifer Protection, Aquifer Exemption, *Class II Demonstration*, page 53]

To respond to EPA's request, the reviews of UIC Class II operations were divided and grouped based on the four major geographic areas of oil and gas activities. This separation provides the ability to discuss the corresponding Class II activities based on mutual geologic and hydrologic characteristics. These areas included the San Juan Basin, the Raton Basin, the Bravo Dome area, and the Permian Basin (see Figure 1). Of these four groups, the Permian Basin has the most Class II well activity due the significant increase in the volume of produced water associated with the recent expansion of horizontal well completions in Permian-age formations.

II. Class II Operations in the San Juan Basin

Class II activities in the San Juan Basin includes historical oil and gas operations along with recent shallow CBM production and current exploration activities of the Mancos Shale using horizontal well completions. The development of the oil potential of the Mancos Shale, as well as any new interest in further development of CBM resources, has subsided due to the decrease in commodity prices. The majority of oil and gas operations, including the recent efforts for Mancos Shale development and CBM production, is concentrated in the northern half of the San Juan Basin (see Figures 2A and 2B).

There are numerous aquifers in the San Juan Basin with the potential for classification as USDWs, but these aquifers have variable water quality characteristics relative to their location in the structural basin and the associated aquifer's recharge area (see Figure 2B). The Jurassic Morrison Formation is an example of a commonly occurring lithologic unit with potential as an USDW in the vicinity of the recharge area created by the exposure of formation outcrops along the south boundary of the basin. Groundwater occurring in this formation along the south edge of the basin contains TDS concentrations significantly below 10,000 milligrams per liter (mg/L). However, as this lithologic unit is followed to the north towards the center (axis) of the basin, the water quality degrades as the influence of recharge decreases resulting in TDS concentrations in excess of 10,000 mg/L (Kelley and others, 2014).

The volume of produced water in the San Juan Basin is relatively minor when compared to the level of production activity. This geographical area contains 99 active Class II disposal wells and represents only 12 percent of the total amount of SWD wells operating in New Mexico. Most of the Class II disposal wells have permitted intervals within the upper Cretaceous Mesaverde Group (the Menefee Formation), the lower Cretaceous Dakota Sandstone, and the Jurassic sequence of Morrison-Bluff-Entrada Formations. The SWD wells utilizing these lithologic units for disposal are frequently located over the deepest part of the structural basin where the TDS concentrations of the formation fluids exceeds 10,000 mg/L.

The Division utilized the state UIC program's process for exempted aquifers for two applications involving disposal injection into protectable waters as defined by 40 CFR 146.4. Both applications were reviewed through Division hearings and were approved for exempted aquifer status (Division Order No. R-10168-A/Case No. 11179 and Division Order No. R-10847/Case No. 11470). Of these two orders, the exempted aquifer in the Entrada Formation provides the highest probability for future hearings for exempted aquifer determination.

ER activities are also limited with only 39 active ER wells in the San Juan Basin. Of the 39 ER wells, 20 wells are associated with a single oil field (Hospah oil field) with production from a Gallup Sandstone reservoir that initiated production in the 1930s and has been determined not to be a USDW in this portion of the basin.

III. Class II Operations in the Bravo Dome Area

The development and production of carbon dioxide (CO_2) resources southeast of the Raton Basin has required a very limited number of Class II disposal wells (see Figure 3A). The interior portion of the Bravo Dome CO_2 field (the AMOCO Unit) has gas production with little water content. Recent expansion of development along the western flank of the dome has increased produced water content, but this additional volume of water has necessitated only one additional SWD well. Disposal is permitted for the Permian Glorieta Formation which, in this area, has porosity but is void of any formation water.

IV. Class II Operations in the Raton Basin

Class II operations in the Raton Basin are limited to SWD wells in support of CBM production (see Figure 4A). The development of CBM resources in the southern portion of the Raton Basin (within New Mexico) remains stagnant and the current number of Class II disposal wells associated with production is seven. ER wells and HS wells are not employed in the Raton Basin. Disposal is permitted in the deep interval from the lower Cretaceous Dakota Sandstone to the Permian Glorieta Formation. Various analytical reports of formation fluids provided in applications for injection permits have demonstrated TDS concentrations above 10,000 mg/L for the lithologic units utilized for disposal of CBM produced waters.

V. Class II Operations in the Permian Basin

The Permian Basin represents the greatest concentration of Class II wells operating in New Mexico. Approximately 89 percent of all active SWD wells and nearly 99 percent of the approximately 3,200 active ER wells operate within the New Mexico portion of the Permian Basin. There are two prominent occurrences in the Permian Basin where there are both hydrocarbon reservoirs and aquifers classified as USDWs following EPA definitions. These locations are the Roswell Artesian Basin aquifer system and the Capitan Reef aquifer system.

Shallower USDWs within the Permian Basin, such as the Ogallala aquifer (Ogallala and Blackwater Draw Formations) and aquifers within the Dockum Group (Santa Rosa Formation), are excluded from this review since they are protected under Rule 19.15.26.8(E)(1) NMAC and are not available for Class II activities.

The eastern extent of the Roswell Artesian Basin aquifer system parallels the Pecos River drainage from north of the city of Roswell to north of the city of Carlsbad (see Figure 6A). This aquifer system has both a shallow alluvial aquifer that is principally recharged by the Pecos River and a deeper, artesian aquifer that is recharged through exposures of the aquifer formation along the Sacramento Mountains which forms the western boundary of the basin (see Figure 6B).

The shallow alluvial aquifer is separated from the artesian aquifer by an aquitard composed of the formations known as the Artesia Group (Tansil Formation, Yates Formation, Seven Rivers Formation, Queen Formation, and Grayburg Formation). The artesian aquifer occurs within the San Andres Formation which is beneath the Artesia Group and contains both hydrocarbon resources as well as protectable waters. The artesian aquifer represents a significant USDW while the quality and quantity of groundwater from the shallow alluvial aquifer is variable due to discharges from surface uses (agriculture) and drought impacts to the Pecos River. A more extensive discussion is found in the two Appendices of the *Class II Demonstration* (Holland and others, 1979; and Holland and others, 1980).

Review of the Class II wells located in the Roswell Artesian Basin aquifer system revealed no issues for the portions of the San Andres Formation which is both an USDW and a hydrocarbon reservoir. Class II injection wells for support of hydrocarbon production are typically authorized for permitted intervals that are deeper than the San Andres Formation and contain TDS concentrations significantly above 10,000 mg/L.

There are occurrences of hydrocarbon resources in the Artesia Group located to the east of the Pecos River and the eastern boundary of the artesian aquifer. These shallow oil fields are very mature and a few are being operated using ER wells with no indication of impacts to either of the aquifer systems.

The Capitan Reef aquifer system is the lithosome that comprises the reef complex, the Goat Seep reef, and the facies transition of the backreef area (the shelf aquifers contained in the Artesia Group as described by Hiss (1980); see Figure 5B). The Capitan Reef aquifer system in New Mexico extends from the recharge area of the Guadalupe Mountains, west of the city of Carlsbad, and extends in an arc to the southeast corner to the state line with Texas (see Figure 5A).

Hiss describes the general ground-water movement as follows:

> *Water entering the Capitan aquifer in the Guadalupe Mountains moved slowly northeastward and then eastward along the northern margin of the Delaware Basin to a point southwest of present-day Hobbs. Here it joined and comingled with a relatively larger volume of ground water moving northward from the Glass Mountains along the eastern margin of the Delaware Basin. From this confluence, the ground water was discharged from the Capitan aquifer into the San Andres Limestone, where it then moved eastward across the Central Basin Platform and Midland Basin, eventually to discharge into stream draining to the Gulf of Mexico (Page 294; Hiss, 1980).*

The quality of groundwater in the Capitan Reef aquifer system is variable with location. The western segment of the Capitan Reef aquifer system is recognized as a USDW and is utilized as a source for both domestic and municipal water supply wells. The eastern portion of the aquifer contains both protectable waters, based on TDS concentrations, as well as productive oil and gas fields in formations of the Artesia Group along the facies transition in the forereef (see inset of Figure 5A). Due to this common occurrence, the *Class II Demonstration* identified this area of the aquifer in Lea County for future assessment.

In 2009, the Division identified the need for further study of the Capitan system and its relationship with Class II well activities along the eastern portion in Lea County. The EPA provided funding for the evaluation which resulted in a report that identified a list of 30 wells with a higher risk of injection into the Capitan Reef. A copy of the report (RESPEC Consulting and Services Topical Report RSI-2048) is attached.

As a result of this review, the 2009 consultant's report prepared for the Division, and the review of current injection applications, the Division has identified existing injection operations in proximity to the Capitan Reef that require supplemental assessment including the wells identified in the 2009 RESPEC report. The Division has compiled a list of 32 wells which require additional investigation to determine the potential or necessity for establishing exempted aquifers (see Table 1).

Though not reported as HS wells, there are two gas storage operations in the Permian Basin. Both operations utilize depleted oil and gas reservoirs that are below Permian-age rocks with no potential for USDW classification.

VI. Summary

The greatest potential for occurrences of USDWs containing injection operations is within the Permian Basin. Of the two areas with USDWs in the Permian Basin, the Capitan Reef aquifer system contains both ER wells and SWD wells that have injection activities in association with a USDW. Many of the Class II wells listed in Table 1 are associated with older ER projects along the backreef area of the Reef aquifer that include formations that transition into the reef complex.

Many of these ER wells and their original injection authority predate the Safe Drinking Water Act and the related UIC Program.

Equally, the older SWD wells (including the 7406 JV-S Lea 20 No. 1) were authorized through Division hearings that predate the UIC Program. Other SWD wells were approved with the best information available regarding the delineation of the aquifer and were assessed as having no hydrologic connection with the Reef system.
There is no indication in the Division's historical record of any Class II injection authority being approved for operation within a recognized USDW. Additionally, there is no evidence of acute impacts such as the degradation of a water supply system observed with the injection activities listed in Table 1; however, the potential for long-term effects of the listed activities and their possible association with any USDWs should be examined.

The operation of Class II wells within the remaining three areas, the San Juan Basin, the Bravo Dome area, and the Raton Basin, have not exhibited any indications of existing conflicts with potential USDWs and injection intervals that may require an exempted aquifer determination. Additionally, the use of the state's UIC application process has successfully addressed USDWs and exempted aquifer determinations for individual Class II SWD wells in the San Juan Basin.

VII. State UIC Program Proposed Efforts for Resolution

This review has identified potential USDW issues for management of the Capitan Reef aquifer system in Lea County. The Division finds this review as an opportunity to complete the initial effort outlined in the *Class II Demonstration* for addressing exempted aquifers, to assess the Class II wells identified in the 2009 RESPEC report, and establish a process for managing future applications for Class II activities in the proximity of the Capitan Reef.

The Division proposes to continue the effort to review the wells listed in Table 1 for determination of the necessity for exempted aquifer in each case. This would include detailed technical review of the well's operation, review of the original application for the injection authority, and assessment of the potentials for impacts to the Capitan Reef aquifer system using current hydrologic information and mapping tools.

The wells listed in Table 1 that are associated with ER activities will be assessed by reviewing the current operation of the ER project which is typically an older waterflood for this area of the Artesia Group. This would provide a greater scope on the impacts and identify any additional wells not included in the 2009 RESPEC report.

Once a determination for exempted aquifer status has been completed, then the Division would meet with the operator and discuss the findings and options. This may include a determination of no action, a requirement for the operator to apply for an exempted aquifer specific to the injection activity, or initiation a hearing by Division to have the injection authority either restricted or revoked.

The content of this response was prepared by Phillip Goetze of the Division's Engineering Bureau. If additional information is required or if there questions about the content of this correspondence, please contact either Mr. Goetze (phillip.goetze@state.nm.us; direct: 505.476.3466) or myself at your convenience.

Sincerely,

DANIEL SANCHEZ
Field Operations Bureau Chief / UIC Program Manager

JDS/prg

References:

Hiss, W. L., 1976, Structure of the Permian Guadalupian Capitan Aquifer, Southeast New Mexico and West Texas, Resource Map 6, New Mexico Bureau of Geology and Mineral Resources, one sheet.

Hiss, W. L., 1980, *Movement of Ground Water in Permian Guadalupian Aquifer Systems, Southeastern New Mexico and Western Texas*, in New Mexico Geological Society Guidebook, 31st Field Conference, Trans-Pecos Region, 1980, p. 289-294.

Holland, Michael T., Parkhill, T., Wilson, L., Logsdon, M., and Stahl, M., 1980, *Aquifer Evaluation for UIC: Search for a Simple Procedure*, in New Mexico State Demonstration for Class II Wells, Appendix II (referenced in Demonstration as Appendix A-2). Report prepared for the Oil Conservation Division, Santa Fe, NM.

Holland, Michael T., Wilson, L., Stahl, M., and Jenkins, D., 1979, *Aquifer Designation for UIC: Prototype Study in Southeastern New Mexico*, in New Mexico State Demonstration for Class II Wells, Appendix I (referenced in Demonstration as Appendix A-1). Report prepared for the Oil Conservation Division, Santa Fe, NM.

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Wilson, Lee, and Holland, Michael T., 1984, *Aquifer Classification for the UIC Program:*

Prototype Studies in New Mexico, in Ground Water, Volume 22, Number 6, November-December Issue, p. 706-716.

ATTACHMENTS:

Figures

Tables

Copy of Evaluation Report

Minnick, Matthew D., 2009, Capitan Reef Injection Well Study, RESPEC Consulting and Services Topical Report RSI-2048, April 2009, p. 14.

cc: UIC Class II Program File

Oil Conservation Division
Energy, Minerals and Natural Resources Department
State of New Mexico

Review of UIC Class II Activities Within the State of New Mexico for Possible Injection into USDWs

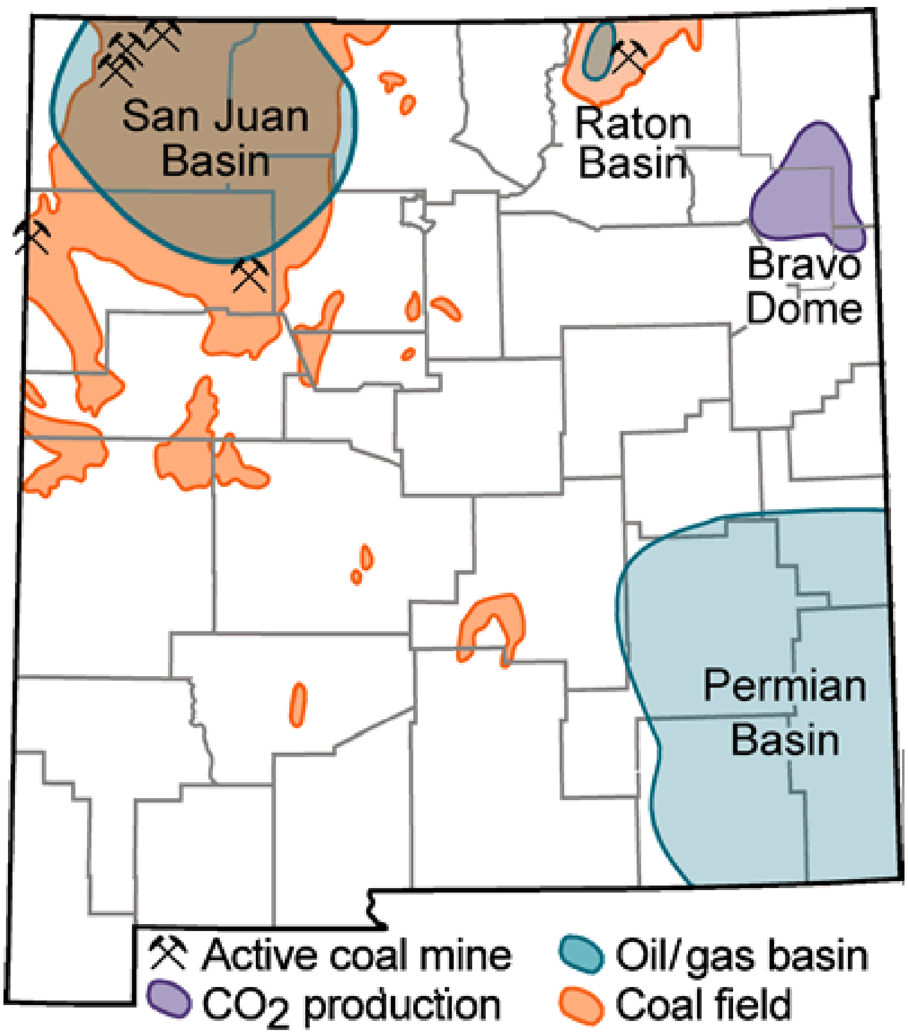

FIGURE 1. Map Showing Locations of Major Oil and Gas Activities (Including Coal-Bed Methane Production)

Oil Conservation Division
Energy, Minerals and Natural Resources Department
State of New Mexico

Review of UIC Class II Activities Within the State of New Mexico for Possible Injection into USDWs: San Juan Basin

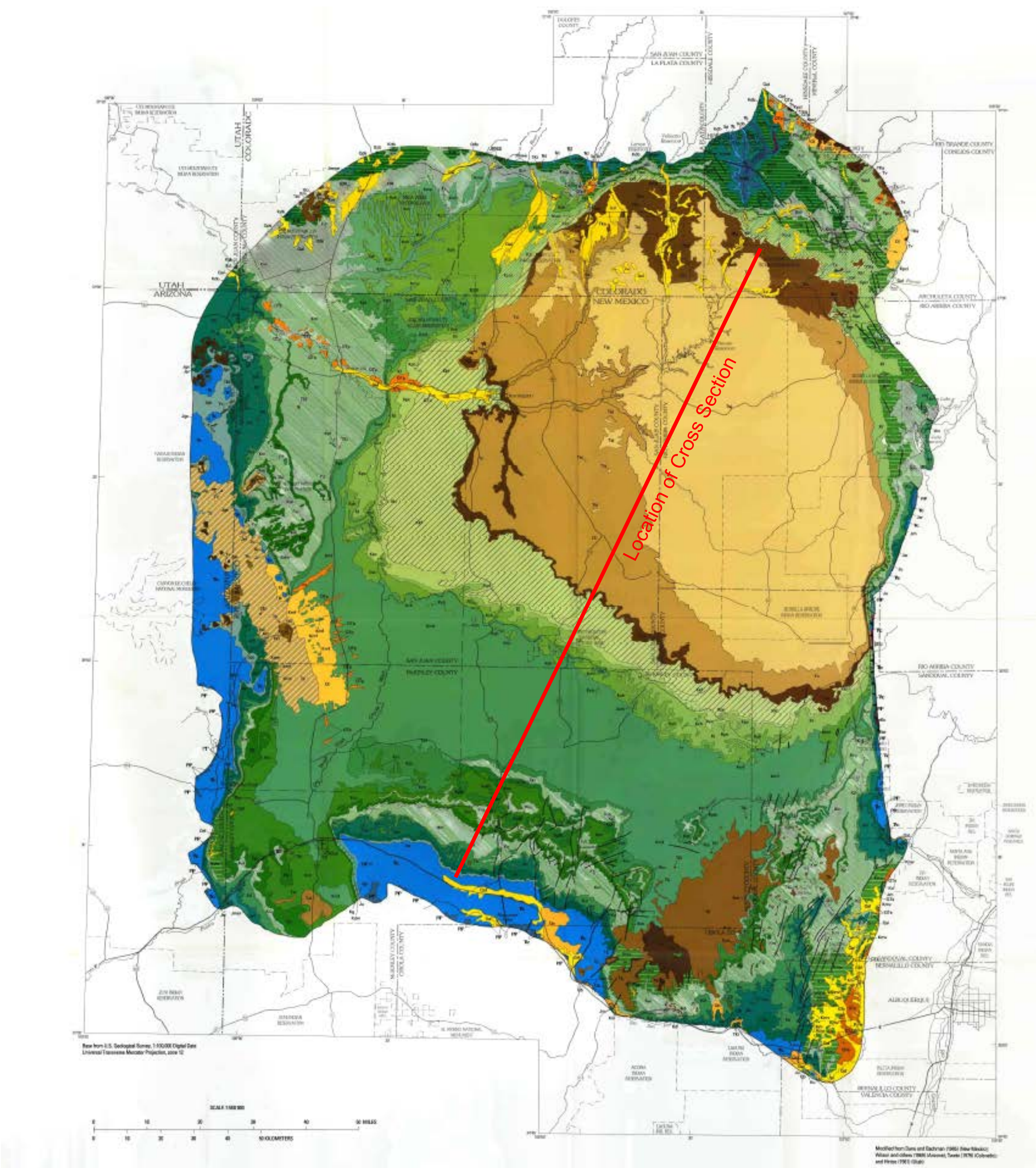

FIGURE 2A. Geologic Map of the San Juan Structural Basin

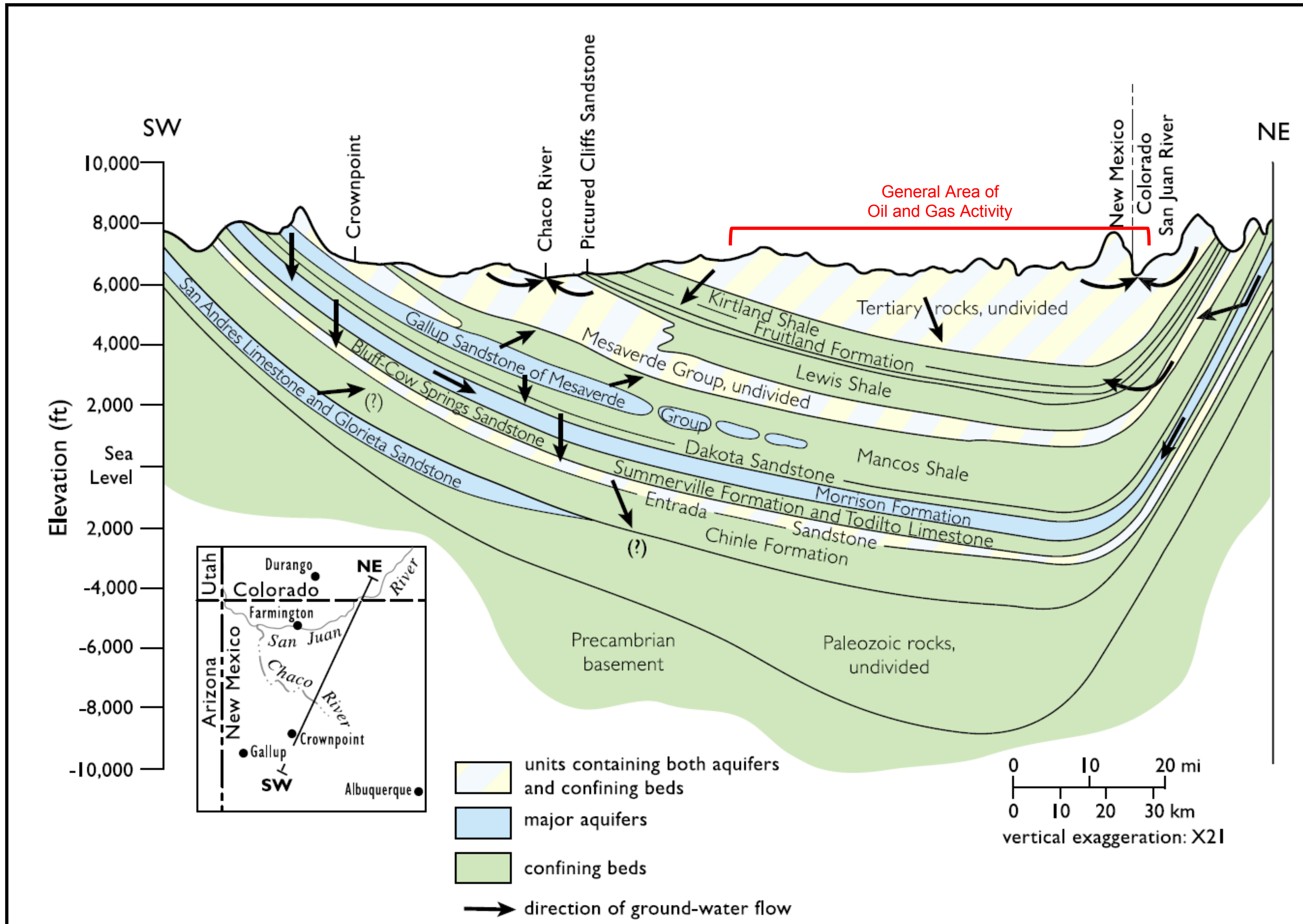

FIGURE 2B. Schematic Cross Section of the San Juan Basin Showing Potential Aquifers

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Energy, Minerals and Natural Resources Department
State of New Mexico

Review of UIC Class II Activities Within the State of New Mexico for Possible Injection into USDWs: Bravo Dome Area

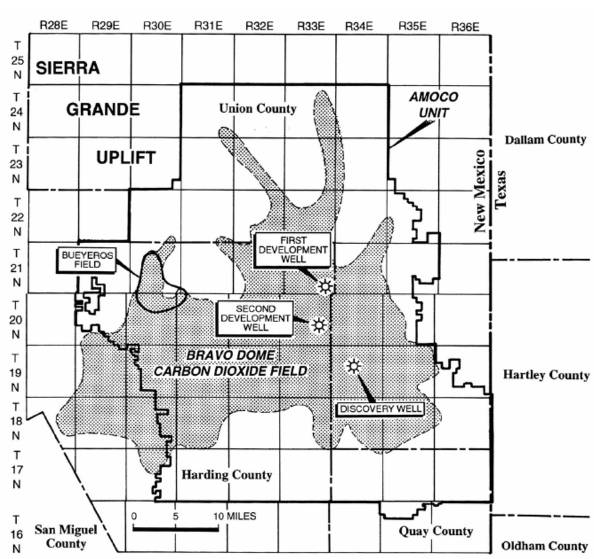


FIGURE 3A. Location Map Showing the Bravo Dome Carbon Dioxide Field

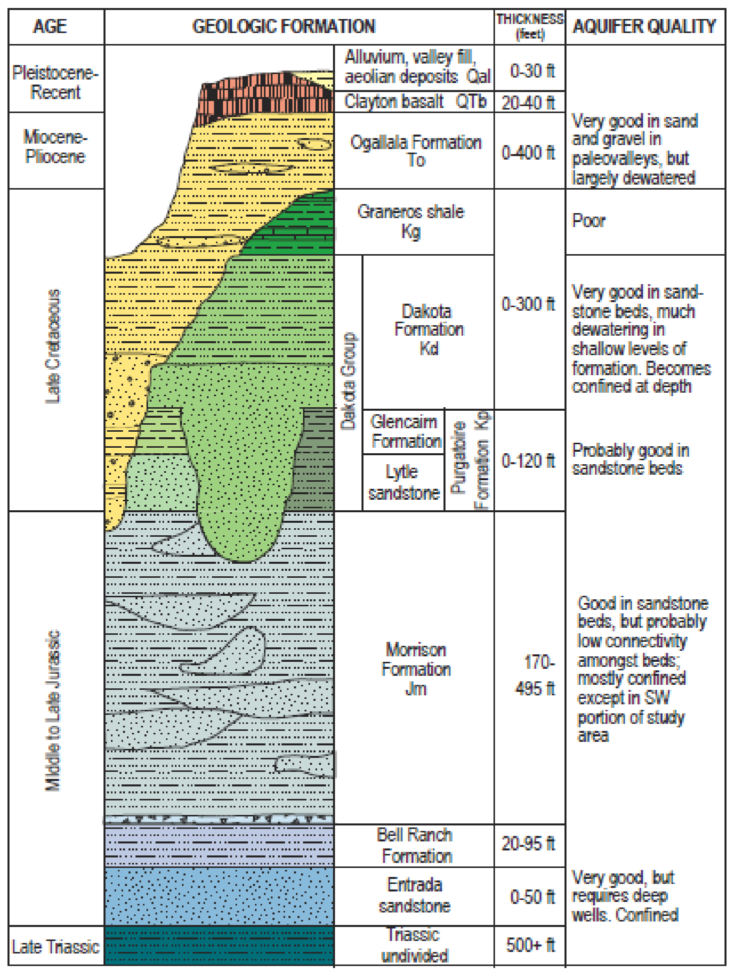


FIGURE 3B. General Stratigraphic Column in the Vicinity of the Bravo Dome Field

Review of UIC Class II Activities Within the State of New Mexico for Possible Injection into USDWs: Raton Basin

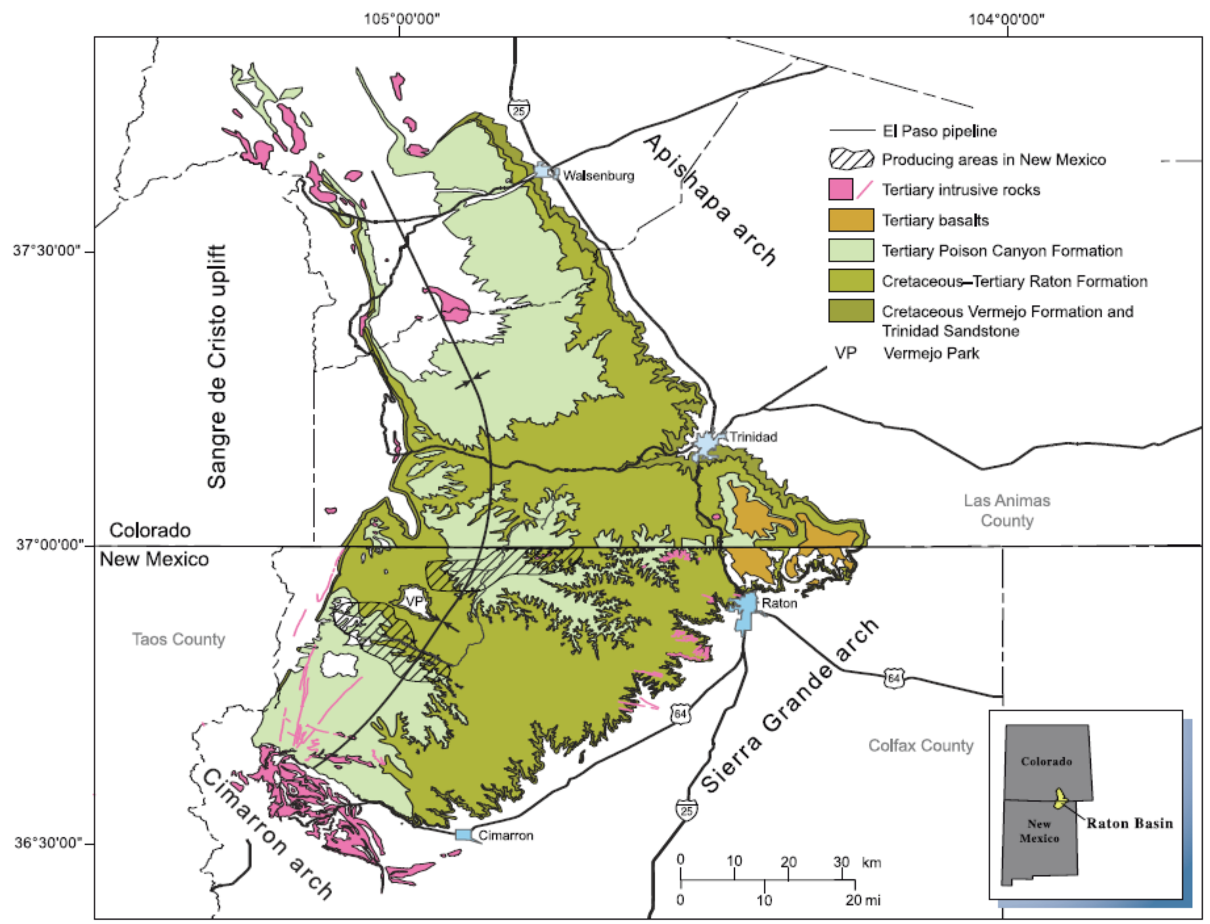
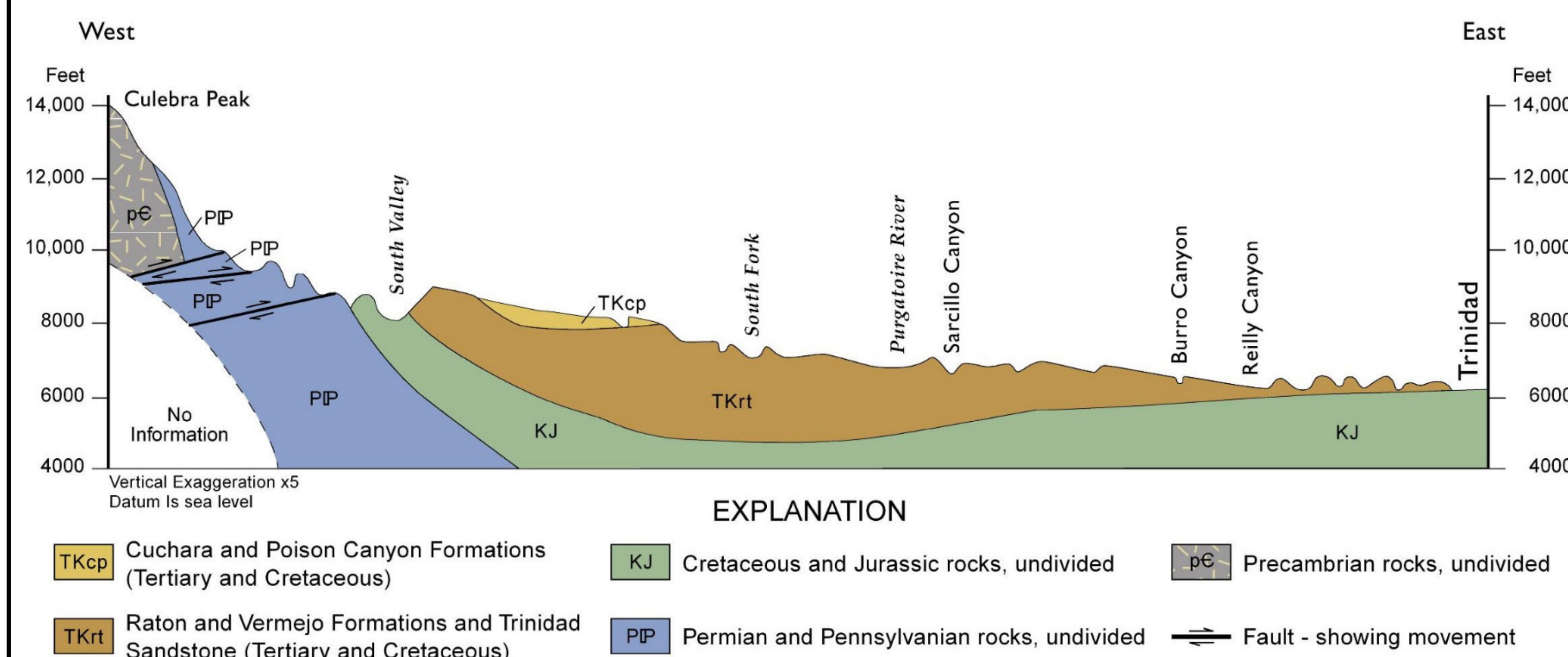


FIGURE 4A. Map Showing the General Geology of the Raton Basin

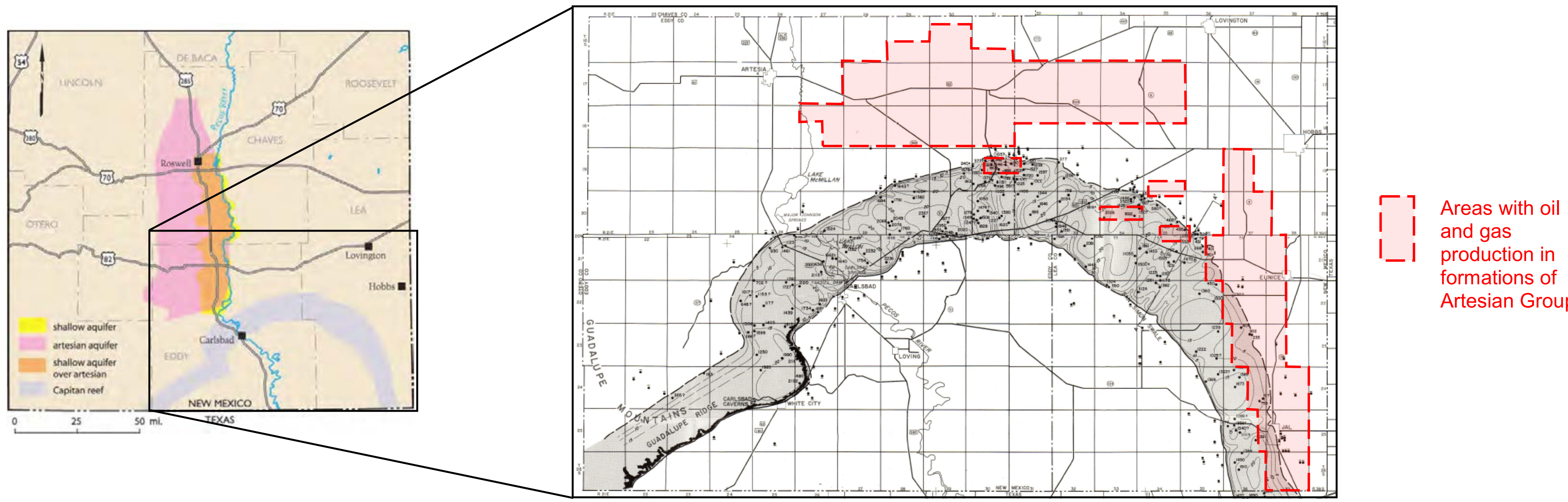
FIGURE 4B. Relevant Stratigraphic Column and Relationship to Aquifer Occurrences in the Raton Basin as Shown in the Schematic Cross Section

Era	System	Series	Strati-graphic Unit	Unit Thickness (feet)	Physical Characteristics	Hydrogeologic Unit	Hydrologic Characteristics
Cenozoic	Quaternary	Holocene	Alluvium		Silt, sand, and gravels	Alluvial aquifer	Water-table aquifer of limited extent
		Pleistocene					
	Tertiary	Oligocene	Devil's Hole Formation				
			Farisita Conglomerate				
			Intrusive igneous rocks		Granitic to gabbroic stocks, dikes, and sills		
		Eocene	Huerfano Formation	2,000	Variegated shale and limestone		
			Cuchara Formation	5,000	Pink and white sand-stone with shale	Cuchara-Poison Canyon aquifer	Transmissivities of 0.20–575 ft²/day; yields 0.07–33 gpm
		Paleocene	Poison Canyon Formation	2,500	Tan, gray and olive sandstone, conglomerate and shale		
			Raton Formation	1,000–1,600	Gray, green, and black shale, siltstone with sandstone, coal	Raton-Vermejo-Trinidad aquifer	Target formation for coalbed methane; trans-missivities of 0.02–79 ft²/day; yields 0.04–16 gpm
Mesozoic	Cretaceous	Upper Cretaceous	Vermejo Formation	80–550	Gray, green, and black shale, siltstone with sandstone, coal		
			Trinidad Sandstone	45–310	Tan and gray sandstone with shale partings		
			Pierre Shale	1,600–2,300	Shale, with interbedded sandstone in the upper 100–300 feet	Confining layer	Sandstone layers might yield limited water
			Niobrara Formation	450–570	Chalky and sandy shale with limestone in lower 50–70 feet	Ft. Hayes Limestone Member	Ft. Hayes Limestone Member supplies wells in adjacent areas
			Carlile Shale	225–290	Sandstone in upper 5–30 feet, shale below	Codell Sandstone Member	Codell Sandstone Member supplies wells in adjacent areas
			Greenhorn Limestone	25–35	Thin gray limestone interbedded with shale		Yields small quantities of water to wells in adjacent areas
			Graneros Shale	185–235	Shale and limestone	Confining layer	Not an aquifer in Raton Basin
		Lower Cretaceous	Dakota Sandstone	50–200	White and tan sandstone	Dakota aquifer	Average porosity range 10–20%; average hydraulic conductivity 0.2 ft/day



Review of UIC Class II Activities Within the State of New Mexico for Possible Injection into USDWs: Permian Basin and the Capitan Reef Aquifer System

FIGURE 5A. Maps Showing the General Location of the Capitan Reef Aquifer System



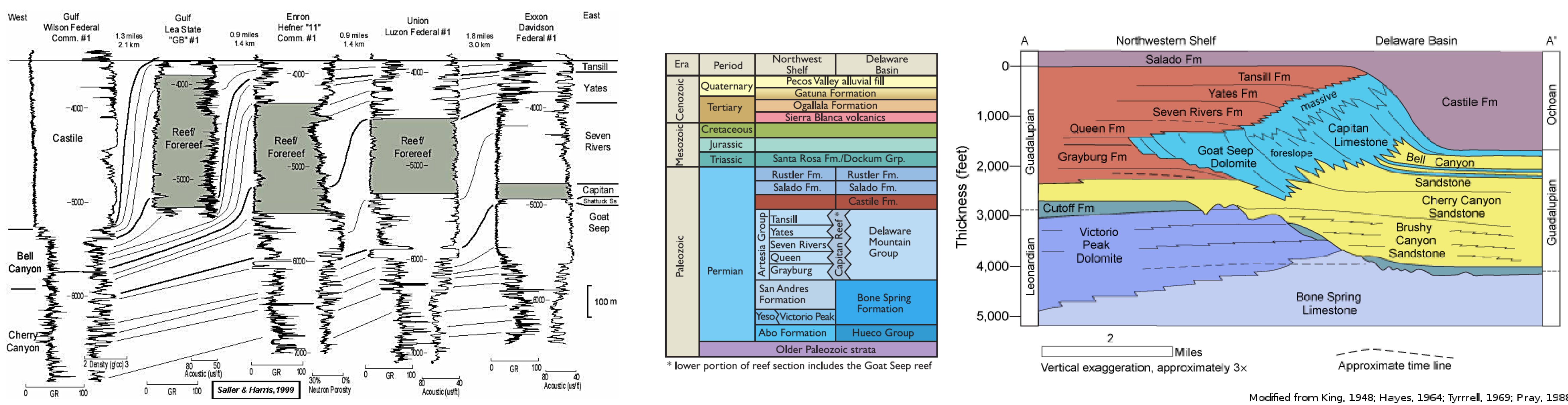
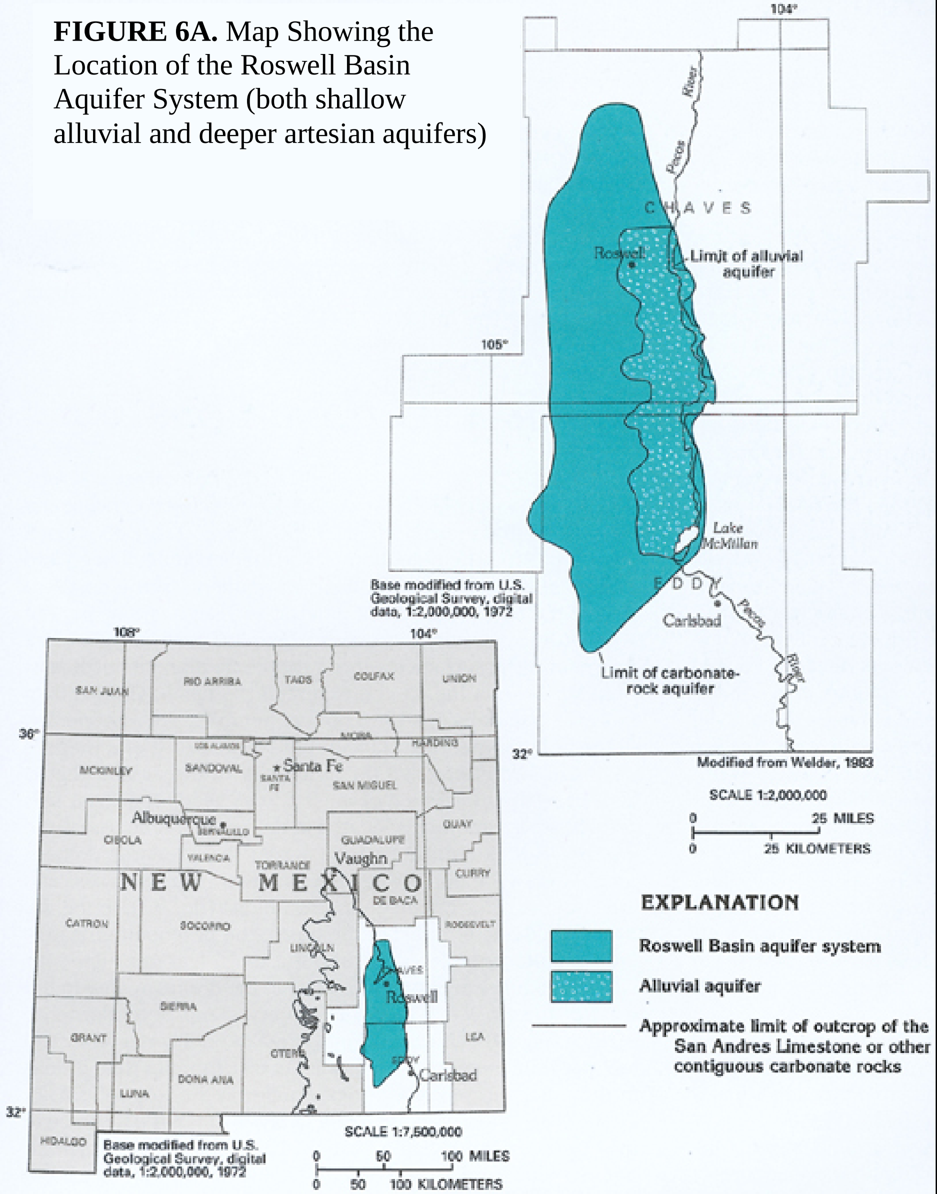


FIGURE 5B. Relevant Stratigraphic Column and Relationship to Aquifer Occurrences in the Capitan Reef Lithosome as Shown in the Schematic and Correlation Cross Sections

Review of UIC Class II Activities Within the State of New Mexico for Possible Injection into USDWs: Permian Basin and Roswell Basin Aquifer System

FIGURE 6A. Map Showing the Location of the Roswell Basin Aquifer System (both shallow alluvial and deeper artesian aquifers)



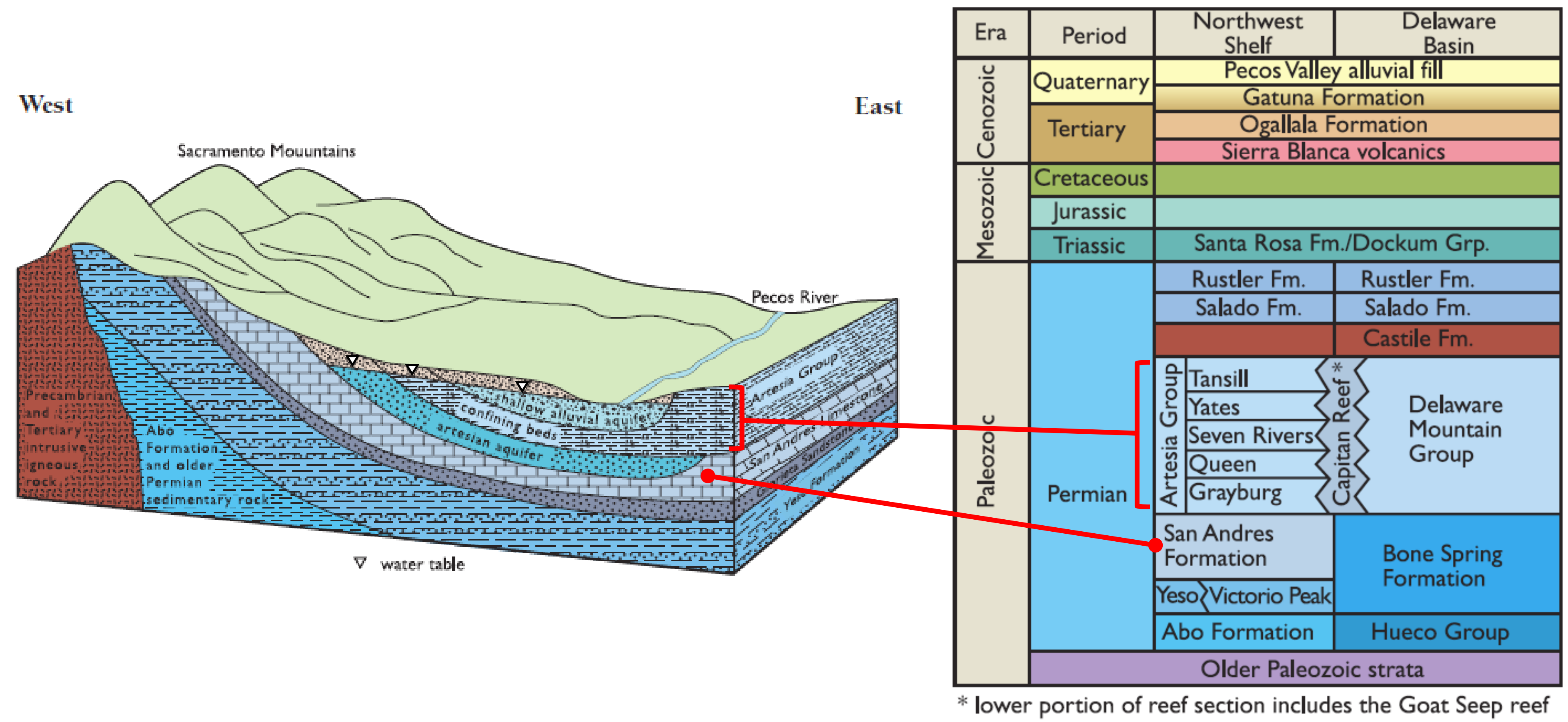


FIGURE 6B. Stratigraphic Column and Relationship to Aquifer Occurrences in the Roswell Artesian Basin as Shown in the Schematic Cross Section

Oil Conservation Division
Energy, Minerals and Natural Resources Department
State of New Mexico

Review of UIC Class II Activities Within the State of New Mexico for Possible Injection into USDWs

Table 1. Summary Table of Active Injection Wells Requiring Further Investigation

Report ID Number	Well Identification No.	Well Name	Current Operator	Location (UL-Sec-Twn-Rge)	OCD Designated Pool	Well Type	Injection Authority	Source Identifying Potential
1*	30-015-02446	SALADAR FEDERAL NO. 4	MNA ENTERPRISES LTD CO	K (NE¼SW□)-33-20S-28E	SALADAR;YATES	ER	WFX-869	RESPEC Report RSI-2048
2*	30-015-02448	SALADAR FEDERAL NO. 6	MNA ENTERPRISES LTD CO	K (NE□SW□)-33-20S-28E	SALADAR;YATES	ER	WFX-869	RESPEC Report RSI-2048
3*	30-015-02449	SALADAR FEDERAL NO. 8	MNA ENTERPRISES LTD CO	N (SE□SW□)-33-20S-28E	SALADAR;YATES	ER	WFX-869	RESPEC Report RSI-2048
4*	30-015-02450	SALADAR B NO. 2	MNA ENTERPRISES LTD CO	L (NW□SW□)-33-20S-28E	SALADAR;YATES	ER	**Shut-in** (expired authority)	RESPEC Report RSI-2048
5*	30-015-24179	SALADAR FEDERAL NO. 12	MNA ENTERPRISES LTD CO	K (NE□SW□)-33-20S-28E	SALADAR;YATES	ER	WFX-869	RESPEC Report RSI-2048
6*	30-025-08606	CONE JALMAT YATES POOL UNIT NO. 105	BREITBURN OPERATING LP	L (NW□SW□)-13-22S-35E	JALMAT;TAN-YATES-7 RVRS (OIL)	ER	**R-2495^**	RESPEC Report RSI-2048
7*	30-025-08640	CONE JALMAT YATES POOL UNIT NO. 502	BREITBURN OPERATING LP	L (NW□SW□)-24-22S-35E	JALMAT;TAN-YATES-7 RVRS (OIL)	ER	WFX-206	RESPEC Report RSI-2048
8*	30-025-08648	CONE JALMAT YATES POOL UNIT NO. 107	BREITBURN OPERATING LP	D (NW□NW□)-24-22S-35E	JALMAT;TAN-YATES-7 RVRS (OIL)	ER	**R-2495^**	RESPEC Report RSI-2048
9*	30-025-08579	JALMAT FIELD YATES SAND UNIT NO. 123	BREITBURN OPERATING LP	P (SE□SE□)-10-22S-35E	JALMAT;TAN-YATES-7 RVRS (OIL)	ER	**R-2243^**	RESPEC Report RSI-2048
10*	30-025-08588	JALMAT FIELD YATES SAND UNIT NO. 121	BREITBURN OPERATING LP	N (SE□SW□)-11-22S-35E	JALMAT;TAN-YATES-7 RVRS (OIL)	ER	**R-2243^**	RESPEC Report RSI-2048
11*	30-025-08590	JALMAT FIELD YATES SAND UNIT NO. 114	BREITBURN OPERATING LP	J (NW□SE□)-11-22S-35E	JALMAT;TAN-YATES-7 RVRS (OIL)	ER	**R-2243^**	RESPEC Report RSI-2048
12*	30-025-08601	JALMAT FIELD YATES SAND UNIT NO. 116	BREITBURN OPERATING LP	L (NW□SW□)-12-22S-35E	JALMAT;TAN-YATES-7 RVRS (OIL)	ER	**Currently producer** (R-2243)	RESPEC Report RSI-2048
13	30-015-26524	HADSON FEDERAL NO. 1	VANGUARD OPERATING, LLC	O (SW□SE□)-11-19S-31E	SWD;YATES-SEVEN RIVERS	SWD	SWD-700	RESPEC Report RSI-2048
14	30-015-26730	HADSON FEDERAL NO. 3	VANGUARD OPERATING, LLC	G (SW□NE□)-11-19S-31E	SWD;YATES-SEVEN RIVERS	SWD	SWD-479	RESPEC Report RSI-2048
15	30-025-32735	PRONGHORN SWD NO. 1	COG OPERATING LLC	B (NW□NE□)-24-19S-32E	SWD;YATES-SEVEN RIVERS	SWD	SWD-536	RESPEC Report RSI-2048
16	30-025-02431	LEA UNIT NO. 8	LEGACY RESERVES OPERATING, LP	B (NW□NE□)-12-20S-34E	SWD;SEVEN RIVERS	SWD	**SWD-189^**	RESPEC Report RSI-2048
17	30-025-02459	CRUCES FEDERAL NO. 3	BURK ROYALTY CO., LTD.	N (SE□SW□)-26-20S-34E	LYNCH;YATES-SEVEN RIVERS	SWD	R-9000	RESPEC Report RSI-2048
18	30-025-02507	W H MILNER FEDERAL NO. 4	BURK ROYALTY CO., LTD.	C (NE□NW□)-35-20S-34E	SWD;YATES	SWD	**R-3779^**	RESPEC Report RSI-2048
19	30-025-02501	NEAL NO. 3	BURK ROYALTY CO., LTD.	A (NE□NE□)-35-20S-34E	LYNCH;YATES-SEVEN RIVERS	ER	R-4283-A	RESPEC Report RSI-2048
20	30-025-02476	SILVER FEDERAL NO. 4	STEVEN D RUPPERT	O (SW□SE□)-28-20S-34E	SWD;YATES-SEVEN RIVERS	SWD	**R-3724^**	RESPEC Report RSI-2048
21	30-025-02466	BALLARD DE FEDERAL NO. 3	BLACK MOUNTAIN OPERATING LLC	D (NW□NW□)-27-20S-34E	SWD;SEVEN RIVERS	SWD	SWD-354	RESPEC Report RSI-2048
22	30-025-02494	B V LYNCH A FEDERAL NO. 2	MAS OPERATING CO.	P (SE□SE□)-34-20S-34E	SWD;YATES-SEVEN RIVERS	SWD	R-7971	RESPEC Report RSI-2048
23	30-025-12580	B V LYNCH A FEDERAL NO. 10	MAS OPERATING CO.	C (NE□NW□)-34-20S-34E	SWD;YATES-SEVEN RIVERS	SWD	R-4612	RESPEC Report RSI-2048
24	30-025-02448	D AND E FEDERAL NO. 1	CHESTNUT EXPLORATION AND PRODUCTION, INC.	N (SE□SW□)-22-20S-34E	SWD;SEVEN RIVERS	SWD	SWD-326	RESPEC Report RSI-2048
25	30-025-20386	WHITTEN NO. 1	NEW MEXICO SALT WATER DISPOSAL COMPANY	I (NE□SE□)-14-20S-34E	SWD;SEVEN RIVERS	SWD	SWD-525	RESPEC Report RSI-2048
26	30-025-23985	WALLEN FEDERAL NO. 2	DAKOTA RESOURCES INC (I)	C (NE□NW□)-20-20S-34E	SWD;YATES-SEVEN RIVERS	SWD	SWD-249	RESPEC Report RSI-2048
27	30-015-26710	WELCH FEDERAL NO. 7	BILL G TAYLOR AND HARVEY R TAYLOR	P (SE□SE□)-5-21S-27E	CEDAR HILLS;YATES	SWD	SWD-425	RESPEC Report RSI-2048
28	30-015-22055	EXXON STATE NO. 8	PYOTE WELL SERVICE, LLC	O (SW□SE□)-15-21S27E	SWD;YATES	SWD	R-13043	RESPEC Report RSI-2048
29	30-025-25957	7406 JV-S LEA 20 NO. 1	CHANCES PROPERTIES COMPANY	P (SE□SE□)-20-26S-36E	SWD; CAPITAN REEF	SWD	**SWD-210^**	Identified as result of EPA 2016 review request
30	30-025-01671	FEDERAL 18 B NO. 4	COG OPERATING LLC	H (SE□NW□)-18-19S-33E	SWD; SEVEN RIVERS	SWD	SWD-589	Identified as result of EPA 2016 review request
31	30-025-09807	MARALO SHALES B NO. 2	OWL SWD OPERATING, LLC	P (SE□SE□)-25-25S-36E	SWD;YATES-SEVEN RIVERS	SWD	SWD-1127	Identified as result of disposal application in vicinity
32	30-025-09807	BROWN NO. 5	OWL SWD OPERATING, LLC	E (SW□NW□)-25-25S-36E	SWD;YATES-SEVEN RIVERS	SWD	**R-5196^**	Identified as result of disposal application in vicinity

*Colors represent grouping of individual injection wells that are part of active waterflood units.

^Indicates injection authority predates primacy approval date of March 7, 1982.

CAPITAN REEF INJECTION WELL IMPACT STUDY

Topical Report RSI-2048

prepared for

New Mexico Oil Conservation Division
1220 South Saint Francis Drive
Santa Fe, New Mexico 87505

April 2009

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CONSULTING & SERVICES

CAPITAN REEF INJECTION WELL IMPACT STUDY

Topical Report RSI-2048

by

Matthew D. Minnick

RESPEC
P.O. Box 725
Rapid City, South Dakota 57709

prepared for

New Mexico Oil Conservation Division
1220 South Saint Francis Drive
Santa Fe, New Mexico 87505

April 2009

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1.0 OBJECTIVES

The objective of this preliminary study was to increase the New Mexico Energy, Minerals, and Natural Resources Department (NMERD), Oil Conservation Division's ability to protect the water quality in and around the Capitan Reef and to protect the Carlsbad area's drinking water source. This aquifer vulnerability study focused primarily on identifying brine injection wells that have the potential to contaminate the freshwater resource of the Capitan Reef aquifer.

2.0 TASKS

The primary task and deliverable of this study was to identify wells currently permitted to inject into or near the upper or lower portions of the Capitan Reef boundary. The wells considered consist of those within 1 mile of Capitan Reef that are injecting and/or have injected within the past 2 years. Well completion reports and electronic log (elogs) data were obtained to determine the perforation depths and subsequent formation of injection to identify wells that have potential for contaminating groundwater in the area. A Geographic Information System (GIS) layer of the wells was generated and delivered in a format compatible with the Oil Conservation Division's risk-based data management system (RBDMS).

A list of wells found to meet the criteria was generated with the following attributes:

- American Petroleum Institute (API) numbers
- Injection location (above, into, or adjacent to Capitan Reef)
- Injection formation
- Well data source.

A new table, WELLSINJECT_SENAREA, was created in the RDBMS_BASE_GIS SQL database. The table includes wells that meet the criteria and the associated attributes.

3.0 METHODS

The primary source of data used for this project was the procuring agency's wells database and catalog of electronic completion reports and elogs. The New Mexico Environmental Department was also contacted as a data source, but no wells were found to fit the criteria stipulated under the project task from this agency. Using the task criteria, wells were identified that had been injecting in the last 2 years within 1 mile of the Capitan Reef. Oil Conservation Division's wells database was queried by well type and water injected per year to narrow down the spatial search. A 1-mile buffer was created around the surface boundaries for the Capitan Reef. The boundaries used were from the Phase 1 study that was digitized from open file reports developed by the U.S. Geological Survey in the mid-1970s [Hiss, 1975]. The buffered surface boundaries of Capitan Reef were used to perform a spatial selection of the wells in ArcGIS.

For the list of wells found to match the criteria, electronic documents, including well completion reports, status changes, perforation permits, and elogs, were downloaded. Many wells did not have elogs and some had only a few supporting documents where available. The perforated or open hole injection interval was determined from the supporting documents. This was done with careful attention to the evolution of the well outlined in the documentation to pinpoint the most recent injection interval. The injection formation and other formation tops were also recorded from the completion reports and elogs where available. Subsequently, the injection location attribute was populated based on the understanding of the injection interval and formation relative to the depth and thickness of the Capitan Reef. A second interpretation of the injection location was also done comparing the injection interval from the documentation with the structure contour and isopach data of the Capitan Reef developed by Hiss [1975]. The structure interval and isopach maps were used to develop interpolated surfaces to define the subsurface structure of the Capitan Reef. Wells and associated injection intervals were visually inspected and compared with the interpolated structure to further refine injection intervals.

4.0 RESULTS

A total of 298 wells were found to fit the criteria outlined in the project task. A table of the selected wells is contained in Appendix A (included on CD). The full datatable was uploaded into the RDBMS_BASE_GIS SQL database as specified by the Oil Conservation Division. From the preliminary findings based solely on well completion data, 139 wells are injecting above, 84 wells adjacent, and 75 below the Capitan Reef. The spatial distribution of the well injection locations from the initial findings are presented in Figure 4-1.

The injection intervals were reanalyzed using the 1975 Hiss interpolation of the subsurface structure of the Capitan Reef. A three-dimensional (3D) model of the Capitan Reef was built in ESRI's **ArcScene** using Hiss' interpolation and the 298 wells and injection intervals were added to the 3D structure model in Figure 4-2. The spatial distribution of the 3D interpolated injection well locations is presented in Figure 4-3. According to Hiss' structural interpolation, a set of 30 wells was found to be injecting close to, if not into, Capitan Reef. These 30 higher risk wells are presented in Table 4-1 and Figure 4-4. From the 3D interpolation, Exxon State 08 was found to be injecting approximately 70 feet above Capitan Reef (Figure 4-5). It is therefore difficult to identify the impact of the wells identified here in this subset.

The Hiss structural interpolation is an approximation based on limited data that may not reflect exact spatial relations between Capitan Reef and well injection intervals. The close spatial proximity to the Capitan Reef of these wells does not prove these wells are impacting Capitan Reef, just that they are a potential source of vulnerability. A modern structural interpolation using all available data would help to better define the subsurface structure of Capitan Reef and the proximity to the well injection intervals. To verify whether injection either below or above the Capitan Reef is safe under various aquifer stress conditions, additional work must be done to characterize the vertical hydraulic gradients.

A plot of the chloride concentration [Hiss, 1975] reveals a trend of lower chloride concentrations on Capitan Reef with concentrations increasing basinward (Figure 4-6). Recent water-quality data was not compared to historic data or injection well locations.

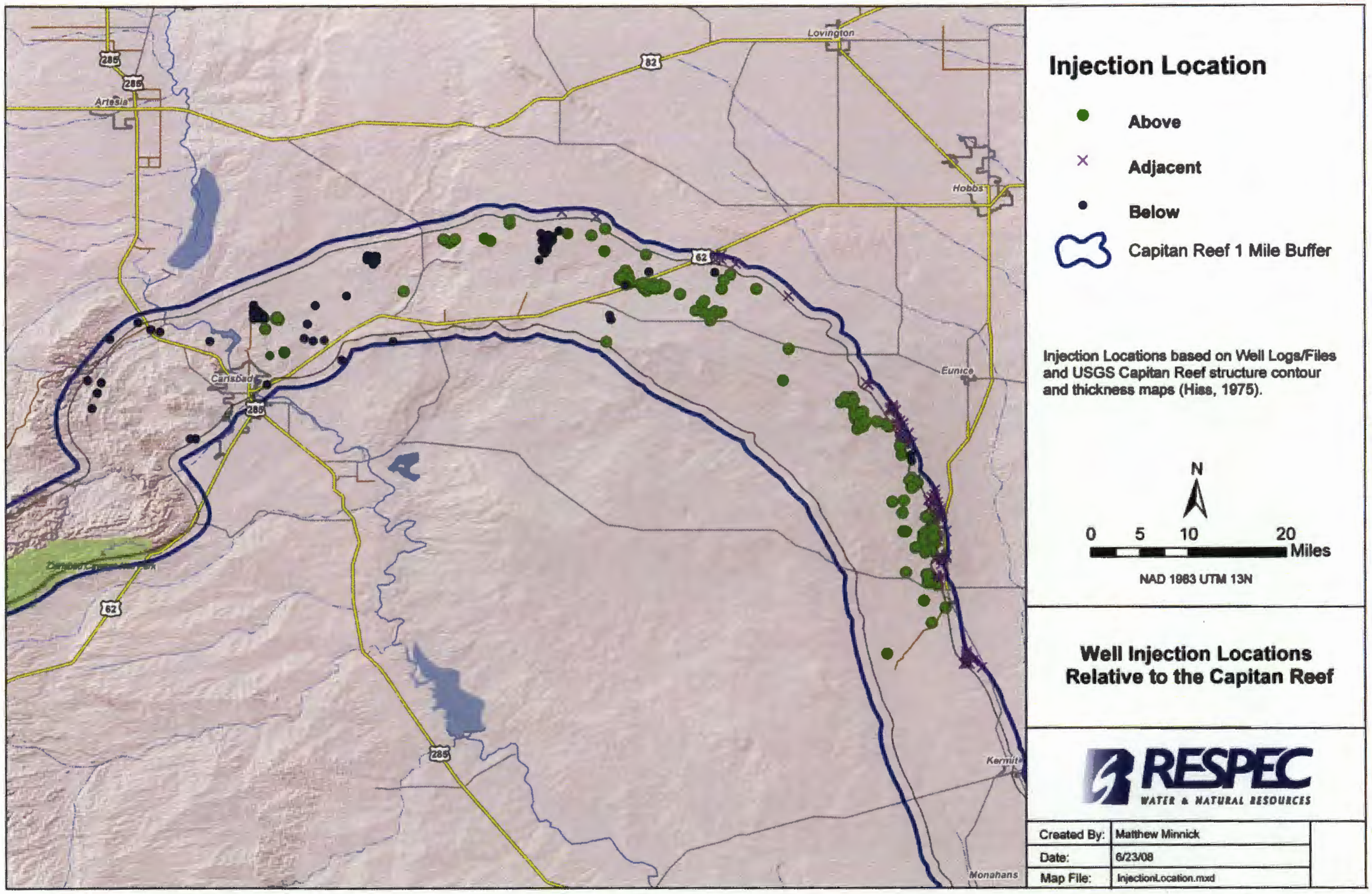


Figure 4-1. Locations of All Active Injection Wells Within 1 Mile of the Capitan Reef. Injection intervals derived from supporting well documents.

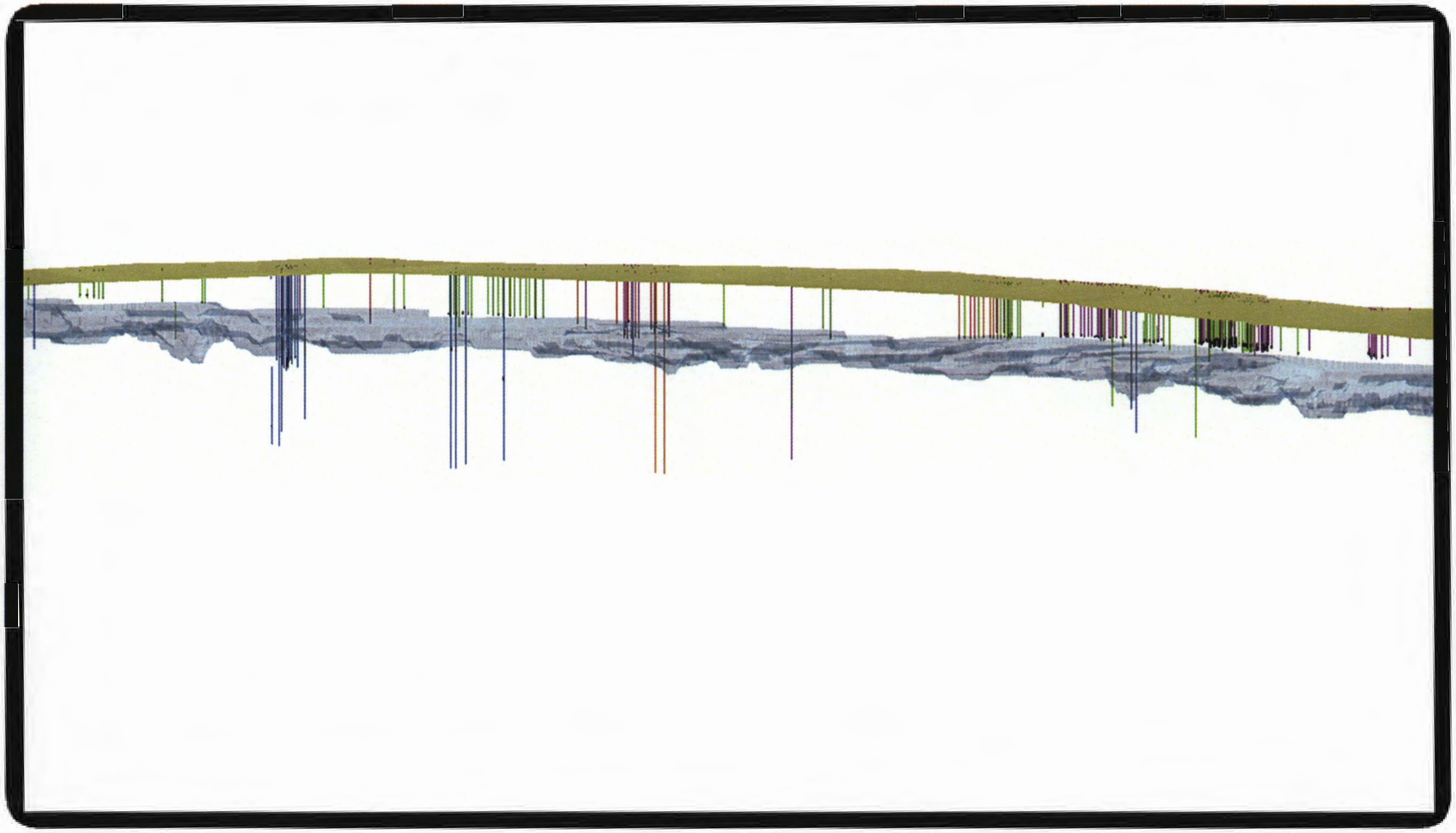


Figure 4-2. Three-Dimensional Interpolation of the Capitan Reef Created From Structure and Isopach Contours (From Hiss [1975]). Wells are colored according to injection location, green–above, blue–above, purple–adjacent, red–into. Injection intervals are colored black.

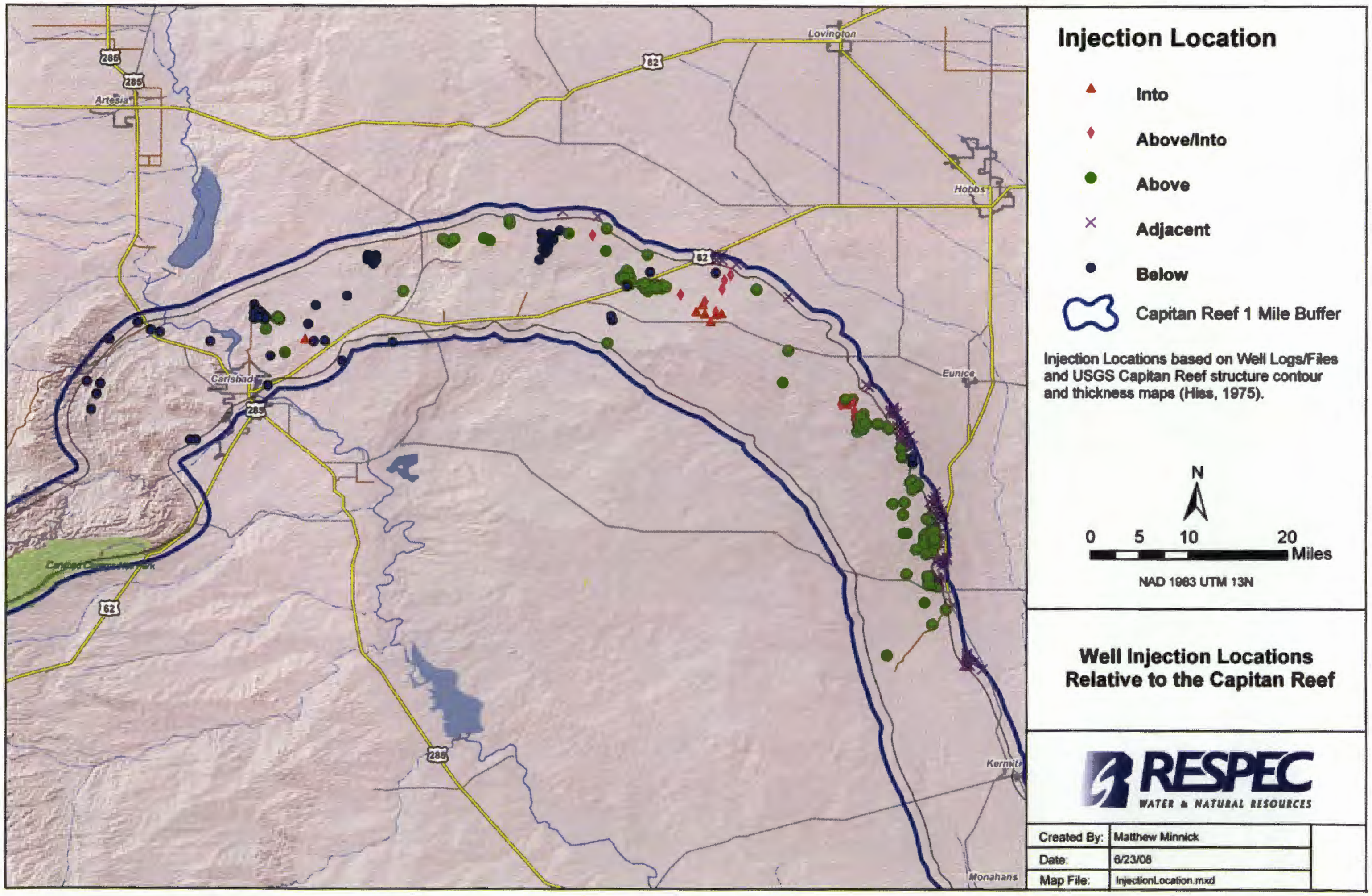


Figure 4-3. Revised Well Injection Intervals Derived From the Three-Dimensional Interpolation of the Capitan Reef.

Table 4-1. List of Higher Risk Wells Identified Using the Three-Dimensional Interpolation of the Capitan Reef (Page 1 of 2)

API No.	Well Name	Injection Location	Interpolated Injection Location	Injection Formation
3001502449	SALADAR UNIT 008	Above	Above	Yates
3001502446	SALADAR UNIT 004	Above	Above	Yates
3001502448	SALADAR UNIT 006	Above	Above	Yates
3001502450	SALADAR UNIT 002	Above	Above	Yates
3001524179	SALADAR UNIT 012	Above	Above	Yates
3002502459	CRUCES FEDERAL 003	Above	Above/Into	Yates
3002508640	CONE JALMAT YATES POOL UNIT 502	Above	Above/Into	Yates
3002508590	JALMAT FIELD YATES SAND UNIT 114	Above	Into	Yates
3002508579	JALMAT FIELD YATES SAND UNIT 123	Above	Above/Into	Yates
3002508606	CONE JALMAT YATES POOL UNIT 105	Above	Above/Into	Yates
3002508588	JALMAT FIELD YATES SAND UNIT 121	Above	Into	Yates
3002508601	JALMAT FIELD YATES SAND UNIT 116	Above	Above/Into	Yates
3002508648	CONE JALMAT YATES POOL UNIT 107	Above	Above/Into	Yates
3001526524	HADSON FEDERAL 001	Above	Above	Yates
3001526710	WELCH FEDERAL 007	Above	Above	Yates
3002502476	SILVER FEDERAL 004	Above	Into	Seven Rivers
3002502466	BALLARD DE FEDERAL 003	Above	Into	Seven Rivers
3001526730	HADSON FEDERAL 003	Above	Above	Yates/Seven Rivers
3002502507	W H MILNER FEDERAL 004	Above	Into	Seven Rivers
3002502431	LEA UNIT 008	Above	Above/Into	Yates
3002502494	B V LYNCH A FEDERAL 002	Above	Into	Yates/Seven Rivers
3002502448	D AND E FEDERAL 001	Above	Above/Into	Yates
3002502501	NEAL 003	Above	Into	Yates
3002520386	WHITTEN 001	Above	Above/Into	Seven Rivers/Queen

Table 4-1. List of Higher Risk Wells Identified Using the Three-Dimensional Interpolation of the Capitan Reef (Page 2 of 2)

API No.	Well Name	Injection Location	Interpolated Injection Location	Injection Formation
3002512580	B V LYNCH A FEDERAL 010	Above	Into	Yates
3002528528	LEA UNIT SWD 002	Above	Above/Into	Seven Rivers
3002523985	WALLEN FEDERAL 002	Above	Above/Into	Seven Rivers
3002532735	PRONGHORN SWD 001	Above	Above/Into	Yates/Seven Rivers
3001520387	GOVERNMENT D 001	Below	Into	Delaware
3001522055	EXXON STATE 008	Above	Above	Yates

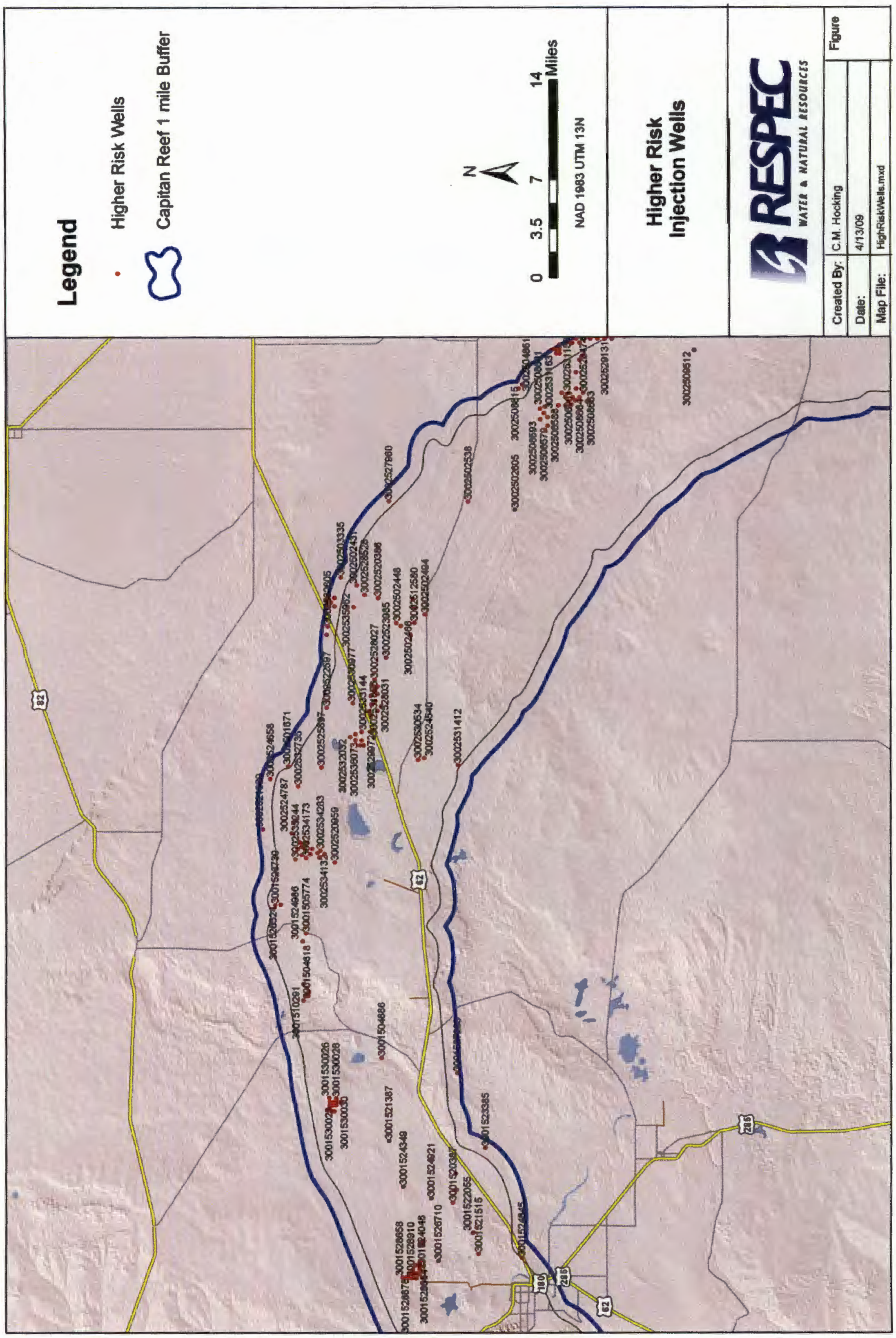


Figure 4-4. Injection Location Map of the 30 Wells Representing Higher Risk.

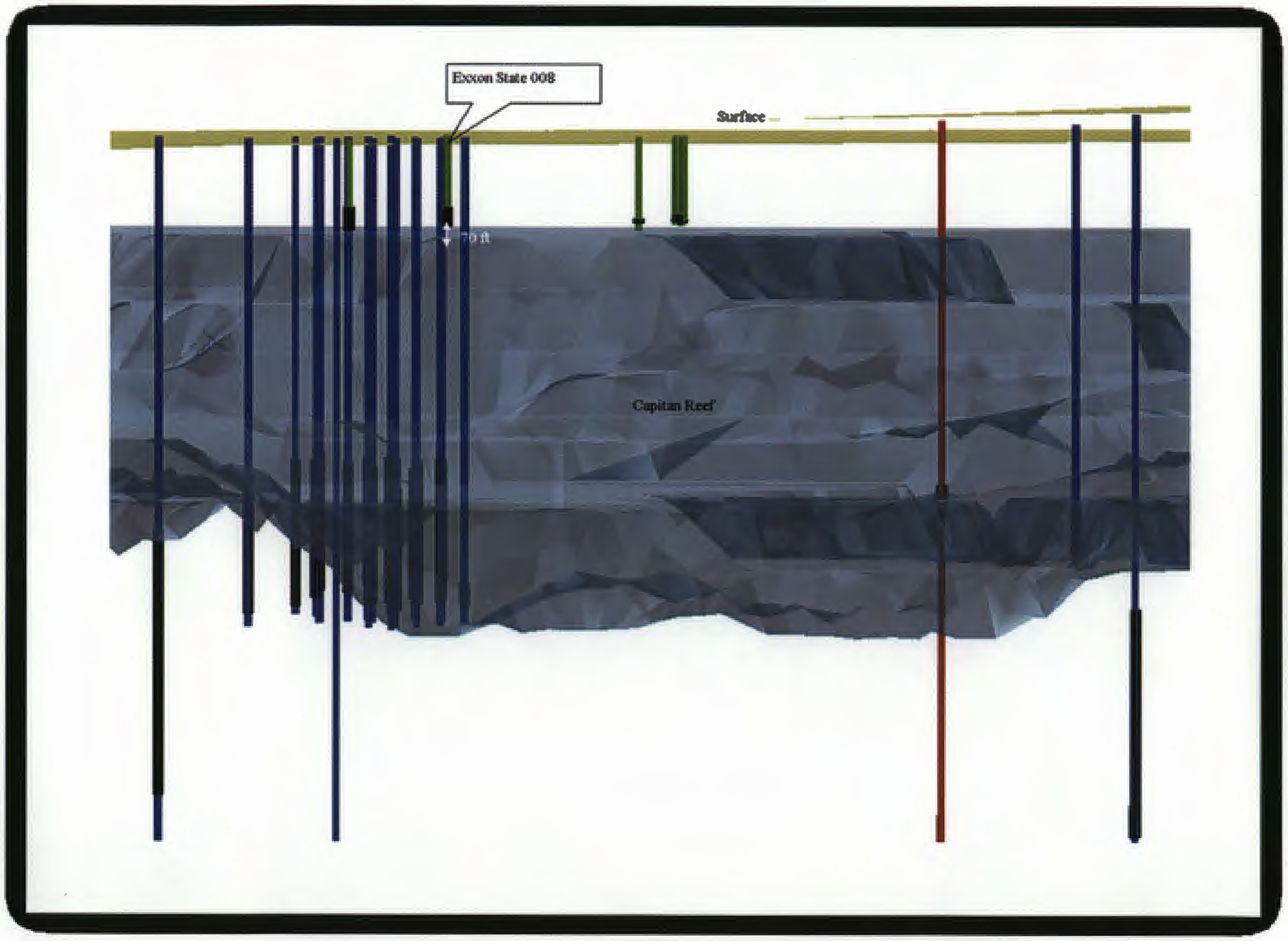


Figure 4-5. View of the Exxon State 008 Well Injection Interval in Relation to the Capitan Reef. Three-dimensional interpolation of the Capitan Reef created from structure and isopach contours (from Hiss [1975]). Wells are colored according to injection location, green–above, blue–below, purple–adjacent, and red–into. Injection intervals are colored black. In this figure, Exxon State 008 is injecting approximately 70 feet above the reef.

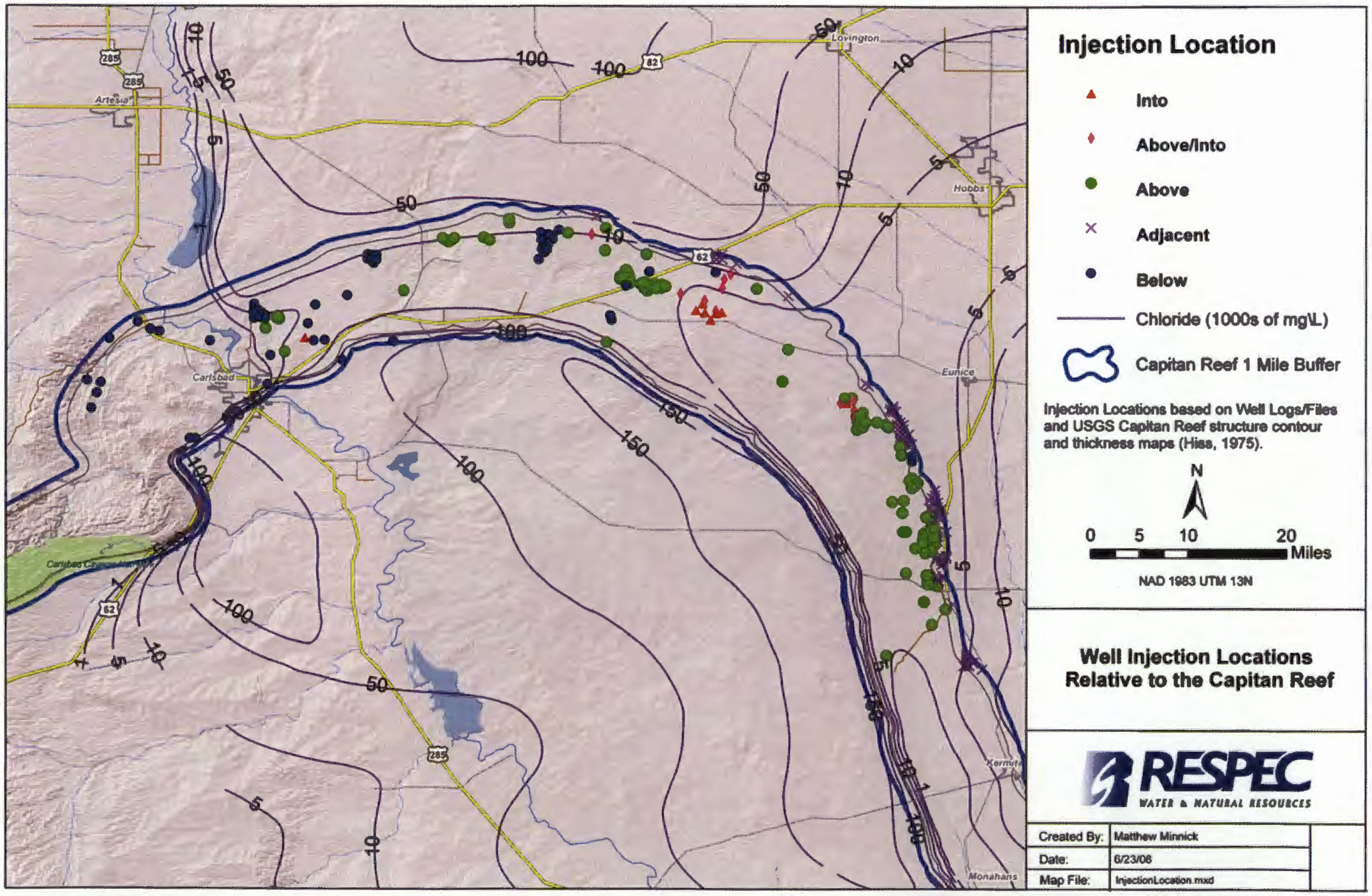


Figure 4-6. Injection Location Map Coupled With Chloride Concentrations Interpolated by Hiss [1975]. Injection locations represented here are derived from the three-dimensional interpolation of the reef.

5.0 RECOMMENDATIONS

Out of the 298 wells identified that match the task criteria, 30 wells were found to be of higher risk for potential to impact the Capitan Reef aquifer. Out of the 30 higher risk wells, 29 wells are injecting above the Capitan Reef in the Yates and Seven Rivers Formations and possibly into Capitan Reef. One well, GOVERMENT D 001, is injecting just below or possibly into the Capitan Reef. This study is a regional survey of risk potential and does not attempt to understand the local scale structural features, faults, and lithology that control interformational flow and potential impact of brine injection. Understanding these features on a local scale is important to further assessing the potential impact of these wells. Using the results from this regional study, areas of focused research may be identified around suspect wells and areas of high vulnerability, including the fresh water, saline groundwater interface and the Pecos River. A more detailed and accurate subsurface visualization using data from all available resources should be built to provide a framework for assessing the potential impact of the higher risk wells and defining vulnerable areas of the Capitan Reef. Structural features, including faults that may provide preferential flow paths for injected brine to reach the Capitan Reef, need to be identified. Highly porous lithologic units or evaporites susceptible to dissolution also need to be identified in the subsurface framework. Other data, including groundwater flow and geochemistry, can also be visualized to further support the understanding of the aquifer.

ESRI's GIS can provide the platform to store, analyze, visualize, and disseminate the geology and groundwater data. Detailed geostatistical subsurface interpolations can be built using C-Tech's **Mining Visualization Systems** (**MVS**) and imported into an **ArcHydro** groundwater geodatabase schema for analysis with groundwater flow and geochemistry data. Coupling of this data with analytical and numerical models can provide a powerful decision support tool. Products developed from this system, including visualizations and animations, provide powerful and defendable litigation support material. This system would increase the NMERD Oil Conservation Division's ability to protect the water quality in and around the Capitan Reef and protect the Carlsbad area's drinking water source.

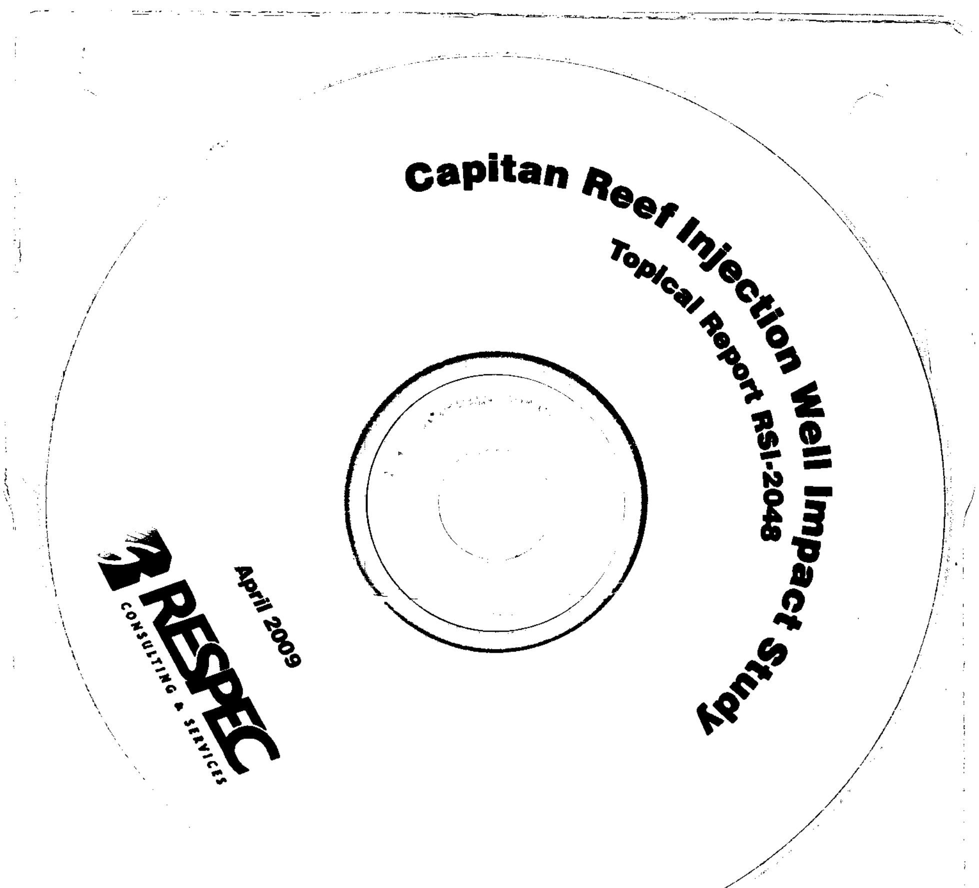
6.0 REFERENCES

Hiss, W. L. 1975. *Map Showing Thickness of the Permian (Guadalupian) Capitan Aquifer, Southeast New Mexico and West Texas*, prepared by the U.S. Geological Survey in cooperation with the New Mexico State Engineer.

APPENDIX A

TABLE OF WELLS MEETING THE TASK CRITERIA

(CD ROM)


Capitan Reef Injection Well Impact Study
Topical Report RSI-2048
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Phone: 605.394.6400 • Fax: 605.394.6456

5971 Jefferson NE, Suite 101
Albuquerque, New Mexico 87109-3413
Phone: 505.268.2261 • Fax: 505.268.0040

698 Cobblestone Trail, PO Box 485
Macedon, New York 14502-0485
Phone: 315.573.6366 • Fax: 315.986.5887

302 North Canal, Suite C, PO Box 2261
Carlsbad, New Mexico 88221-2261
Phone: 505.885.1583 • Fax: 505.885.9329

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API	WELL NAME	InjectLoc	InjectLoc3D	InjectFm	WellDataSrc	Elev	TD	Perf_T	Perf_B	T_Rustler	T_T_Salt	T_B_Salt	T_Yates	T_Seven	T_Queen	T_Penrose	T_Grayburg	T_Cap	T_Del	T_Cherry_C	T_49sand	T_BrushyCa	T_Bone_Spr	T_Wolfcamp	T_CiscoReef	T_Strawn	T_Atoka	T_Morrow	T_Dev	T_Ellenburger	water_inj_2008	water_inj_2007	water_inj_2006	LATITUDE	LONGITUDE
3001502449	SALADAR UNIT 008	Above	Above	Yates	OCD	3,199	664	628	664				604																		0	4,375	9,007	32.5254	-104.1840
3001502446	SALADAR UNIT 004	Above	Above	Yates	OCD	3,200	700	667	677				634																		0	1,337	31	32.5290	-104.1862
3001502448	SALADAR UNIT 006	Above	Above	Yates	OCD	3,200	682	666	677				636																		0	73	37	32.5272	-104.1844
3001502450	SALADAR UNIT 002	Above	Above	Yates	OCD	3,201	748	650	689				636																		0	1,312	1,174	32.5272	-104.1883
3001524179	SALADAR UNIT 012	Above	Above	Yates	OCD	3,198	711	631	696				631																		0	829	764	32.5281	-104.1851
3001504622	NORTH HACKBERRY YATES UNIT 108	Above	Above	Yates	OCD	3,257	2,000	1,749	1,851	545			1,684																		3	4	5	32.6440	-103.9331
3001504627	NORTH HACKBERRY YATES UNIT 113	Above	Above	Yates	OCD	3,268	2,000	1,789	1,901	562		1,560	1,712																		1,266	5,842	2,309	32.6412	-103.9286
3001504626	NORTH HACKBERRY YATES UNIT 110	Above	Above	Yates	OCD	3,350	2,075	1,896	1,927	600		1,664	1,823																		1,963	7,738	3,034	32.6431	-103.9246
3001504618	NORTH HACKBERRY YATES UNIT 105	Above	Above	Yates	OCD	3,285	1,993	1,762	1,820			1,510	1,716	1,947																	307	625	72	32.6467	-103.9374
3001510291	NORTH HACKBERRY YATES UNIT 101	Above	Above	Yates	OCD	3,436	2,125	2,022	2,050			1,500	1,928																		1,968	7,745	4,371	32.6467	-103.9203
3001526006	PARKWAY DELAWARE UNIT 302	Below	Below	Delaware	OCD	3,312	5,000	4,241	4,310	403	502	1,130	1,335						3,345												90	36,178	70,360	32.6182	-104.0516
3001526029	PARKWAY DELAWARE UNIT 505	Below	Below	Delaware	OCD	3,319	5,000	4,221	4,300	392	480	1,130	1,325						3,362												0	70,192	0	32.6153	-104.0517
3001526143	PARKWAY DELAWARE UNIT 204	Below	Below	Delaware	OCD	3,310	4,550	4,210	4,246			1,122	1,480	1,619					3,680												10,092	107,930	36,432	32.6216	-104.0510
3001526433	PARKWAY DELAWARE UNIT 601	Below	Below	Delaware	OCD	3,320	4,500	4,266	4,350				1,355	1,548	2,510				3,862												9,110	3,261	8,568	32.6089	-104.0425
3001527445	PARKWAY DELAWARE UNIT 303	Below	Below	Delaware	OCD	3,311	4,800	4,138	4,247	390		1,175	1,470	1,620					3,365												32,452	384,258	307,962	32.6204	-104.0459
3001527464	PARKWAY DELAWARE UNIT 506	Below	Below	Delaware	OCD	3,311	4,750	4,127	4,203	394		1,162	1,468	1,624					3,366												22,117	239,670	212,151	32.6170	-104.0456
3001527283	GOLDEN 8 FEDERAL 003	Below	Below	Delaware	OCD	3,391	4,575	4,238	4,310	902								2,064	3,044	3,854											0	99,666	60,764	32.4921	-104.0122
3001528668	AVALON DELAWARE UNIT 571	Below	Below	Delaware	OCD	3,212	3,880	2,520	3,736										2,486												0	25,220	25,433	32.5263	-104.2090
3001528667	AVALON DELAWARE UNIT 533	Below	Below	Delaware	OCD	3,216	3,880	2,546	3,706										2,500												0	28,790	30,000	32.5295	-104.2090
3001528659	AVALON DELAWARE UNIT 238	Below	Below	Delaware	OCD	3,295	3,926	3,632	3,470										2,510												0	180,619	175,681	32.5434	-104.2213
3001528683	AVALON DELAWARE UNIT 537	Below	Below	Delaware	OCD	3,236	3,800	2,544	3,656										2,508												0	82,298	91,474	32.5298	-104.2179
3001528658	AVALON DELAWARE UNIT 222	Below	Below	Delaware	OCD	3,299	3,950	2,706	3,753										2,530												0	9,768	12,354	32.5471	-104.2214
3001528665	AVALON DELAWARE UNIT 516	Below	Below	Delaware	OCD	3,232	3,850	2,576	3,670										2,484												0	127,532	131,771	32.5335	-104.2091
3001528666	AVALON DELAWARE UNIT 570	Below	Below	Delaware	OCD	3,233	3,850	2,600	3,692										2,485												0	58,939	59,887	32.5301	-104.2132
3001528660	AVALON DELAWARE UNIT 254	Below	Below	Delaware	OCD	3,291	3,870	2,584	3,632										2,480												0	41,102	40,390	32.5403	-104.2213
3001528684	AVALON DELAWARE UNIT 542	Below	Below	Delaware	OCD	3,279	3,875	2,644	3,774										2,480												0	52,312	53,742	32.5263	-104.2219
3001528661	AVALON DELAWARE UNIT 253	Below	Below	Delaware	OCD	3,297	3,820	2,552	3,728										2,480												0	54,465	56,825	32.5400	-104.2174
3001528664	AVALON DELAWARE UNIT 520	Below	Below	Delaware	OCD	3,240	3,782	2,590	3,628										2,505												0	67,789	69,119	32.5333	-104.2172
3001528662	AVALON DELAWARE UNIT 626W	Below	Below	Delaware	OCD	3,208	3,849	3,532	3,711										2,480												0	50,876	50,247	32.5299	-104.2051
3001528594	AVALON DELAWARE UNIT 503	Below	Below	Delaware	OCD	3,265	3,850	2,628	3,680										2,548												0	231,384	279,103	32.5370	-104.2136
3001528678	AVALON DELAWARE UNIT 507	Below	Below	Delaware	OCD	3,260	3,870	2,498	3,614										2,480												0	61,444	81,933	32.5368	-104.2217
3001528677	AVALON DELAWARE UNIT 505	Below	Below	Delaware	OCD	3,257	3,850	2,546	3,576										2,476												0	99,503	95,766	32.5368	-104.2175
3001528663	AVALON DELAWARE UNIT 642	Below	Below	Delaware	OCD	3,205	3,850	2,534	3,678										2,495												0	76,520	81,150	32.5263	-104.2051
3001528910	AVALON DELAWARE UNIT 523	Below	Below	Delaware	OCD	3,283	3,800	2,556	3,738										2,514												0	64,823	65,836	32.5334	-104.2219
3001529504	PARKWAY DELAWARE UNIT 507	Below	Below	Delaware	OCD	3,334	4,400	4,164	4,280																						12,997	151,877	134,179	32.6170	-104.0419
3001529503	PARKWAY DELAWARE UNIT 304	Below	Below	Delaware	OCD	3,321	4,430	4,154	4,261																						12,032	99,428	124,966	32.6202	-104.0419
3001530026	PARKWAY DELAWARE UNIT 205	Below	Below	Delaware	OCD	3,338	4,400	4,260	4,364																						22,563	259,172	192,700	32.6206	-104.0376
3001530030	PARKWAY DELAWARE UNIT 509	Below	Below	Delaware	OCD	3,333	4,400	4,204	4,324																						0	90,207	140,949	32.6131	-104.0410
3001530029	PARKWAY DELAWARE UNIT 508	Below	Below	Delaware	OCD	3,328	4,400	4,160	4,278																						26,169	242,627	256,822	32.6135	-104.0453
3001530028	PARKWAY DELAWARE UNIT 704	Below	Below	Delaware	OCD	3,327	4,400	4,219	4,344																						32,266	273,133	213,182	32.6137	-104.0381
3002501724	TEAS YATES UNIT 034	Above	Above	Yates	OCD	3,608	3,536	3,308	3,484				3,120																		0	299	1,389	32.5777	-103.6136
3002501739	TEAS YATES UNIT 121	Above	Above	Yates	OCD	3,540	3,355	3,304	3,355				3,115																		0	598	713	32.5786	-103.6447
3002501725	TEAS YATES UNIT 022	Above	Above	Yates	OCD	3,599	3,359	3,335	3,359				3,015																		0	429	826	32.5786	-103.6243
3002501722	TEAS YATES UNIT 032	Above	Above	Yates	OCD	3,611	3,540	3,335	3,366				3,130																		0	401	310	32.5722	-103.6147
3002501727	TEAS YATES UNIT 111	Above	Above	Yates	OCD	3,592	3,319	3,204	3,329																						0	406	756	32.5777	-103.6329
3002501720	TEAS YATES UNIT 021	Above	Above	Yates	OCD	3,606	3,309	3,290	3,305		1,585	3,080	3,249																		0	440	888	32.5749	-103.6189
3002501734	TEAS YATES UNIT 091	Above	Above	Yates	OCD	3,596	3,338	3,204	3,330				3,215																		0	524	533	32.5686	-103.6350
3002502459	CRUCES FEDERAL 003	Above	Above/Into	Yates	OCD	3,725	3,730	3,509	3,629	1,620			3,494	3,692																	3,100	37,500	41,030	32.5377	-103.5340
3002508640	CONE JALMAT YATES POOL UNIT 502	Above	Above/Into	Yates	OCD	3,602	3,950	3,802	3,914		1,820	3,570	3,753																		0	27,029	0	32.3763	-103.3264
3002508641	CONE JALMAT YATES POOL UNIT 503	Above	Above	Yates	OCD	3,592	3,840	3,794	3,824		1,725	3,514	3,696																		0	46,884	0	32.3727	-103.3222
3002508649	CONE JALMAT YATES POOL UNIT 110	Above	Above	Yates	OCD	3,583	4,010	3,754	3,876		1,867	3,526	3,706																		0	54,712	9,227	32.3791	-103.3232
3002508587	JALMAT FIELD YATES SAND UNIT 108	Above	Above	Yates	OCD	3,606	4,062	3,866	3,878				3,741																		0	5,708	6,644	32.4081	-103.3307
3002508590	JALMAT FIELD YATES SAND UNIT 114	Above	Into	Yates	OCD	3,612	4,076	3,868	4,004				3,868																		0	107,532	57,179	32.4045	-103.3350
3002508579	JALMAT FIELD YATES SAND UNIT 123	Above	Above/Into	Yates	OCD	3,602	4,132	3,718	3,986		2,010	3,730	3,936																		0	97,298	100,060	32.4008	-103.3478
3002508606	CONE JALMAT YATES POOL UNIT 105	Above	Above/Into	Yates	OCD	3,585	4,000	3,766	3,906		1,902	3,576	3,766																		0	31,289	20,764	32.3900	-103.3275
3002508588	JALMAT FIELD YATES SAND UNIT 121	Above	Into	Yates	OCD	3,613	4,052	3,876	4,013				3,780																		0	115,896	100,565	32.4008	-103.3393
3002508610	CONE JALMAT YATES POOL UNIT 111	Above	Above	Yates	OCD	3,587	3,921	3,647	3,862		1,790	3,461	3,628																		0	49,593	23,071	32.3864	-103.3147
3002508651	CONE JALMAT YATES POOL UNIT 602	Above	Above	Yates	OCD	3,582	3,900	3,784	3,812		2,200	3,020	3,618																		0	56,282	0	32.3755	-103.3190
3002508593	JALMAT FIELD YATES SAND UNIT 110	Above	Above	Yates	OCD	3,626	4,065	3,890	4,000				3,711																		0	66,231	28,588	32.4081	-103.3414
3002508658	CONE JALMAT YATES POOL UNIT 804	Above	Above	Yates	OCD	3,571	3,960	3,812	3,832				3,714																		0	45,941	0	32.3609	-103.3232
3002508601	JALMAT FIELD YATES SAND UNIT 116	Above	Above/Into	Yates	OCD	3,596	4,030	3,828	3,966																						0	1,094	6,643	32.4036	-103.3286
3002508648	CONE JALMAT YATES POOL UNIT 107	Above	Above/Into	Yates	OCD	3,583	4,003	3,773	3,900		1,915	3,582	3,773																		0	52,014	25,379	32.3827	-103.3275
3002508664	CONE JALMAT YATES POOL UNIT 702	Above	Above	Yates	OCD	3,536	3,900	3,696	3,815				3,647																		0	32,481	50,604	32.3682	-103.3190
3002508663	CONE JALMAT YATES POOL UNIT 701	Above	Above	Yates	OCD	3,536	3,830	3,726	3,750				3,588																		0	1,869	1,832	32.3646	-103.3147
3002508646	CONE JALMAT YATES POOL UNIT 304	Above	Above	Yates	OCD	3,563	3,824	3,593	3,722		1,759	3,351	3,598																		0	62,198	50,748	32.3791	-103.3147
3002509187	SOUTH EUNICE UNIT 033	Above	Above	Seven Rivers/Qu	OCD	3,542	3,815	3,644	3,810	1,365	1,465	3,020	3,156	3,377	3,785																0	76,735	49,739	32.3682	-103.2808
3002509142	SEVEN RIVERS QUEEN UNIT 035	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,490	3,910	3,667	3,857	1,364	1,454	3,026	3,186	3,375	3,758																0	37,417	1,085	32.3429	-103.2594
3002508986	SOUTH EUNICE UNIT 020	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,515	3,810	3,672	3,807		1,605	2,995	3,178	3,383	3,755																0	100,456	100,375	32.3755	-103.2638
3002509073	SOUTH EUNICE UNIT 041	Above	Above	Seven Rivers/Qu	OCD	3,519	3,820	3,660	3,800	1,345	1,452	2,990	3,128	3,354	3,745																0	12,123	12,107	32.3646	-103.2765
3002509070	SEVEN RIVERS QUEEN UNIT 003	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,502	3,790	3,714	3,778	1,490	1,570	3,050	3,204	3,422	3,772																0	57,970	67,851	32.3682	-103.2548
3002509076	SOUTH EUNICE UNIT 037	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,517	3,815	3,682	3,770		1,496	3,002	3,154	3,390	3,764																0	14,681	12,677	32.3682	-103.2637
3002509151	SEVEN RIVERS QUEEN UNIT 023	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,474	3,755	3,706	3,754	1,358	1,435	2,895	3,171	3,363	3,744																0	57,078	60,053	32.3501	-103.2595
3002508644	CONE JALMAT YATES POOL UNIT 202	Above	Above	Seven Rivers/Qu	OCD	3,573	3,850	3,698	3,762		1,821	3,123	3,646																		0	23,197	36,124	32.3827	-103.3190
3002508952	SOUTH EUNICE UNIT 028	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,514	3,830	3,704	3,796	1,460	1,553	3,030	3,184	3,422	3,788																0	37,574	54,127	32.3719	-103.2595
3002509137	SEVEN RIVERS QUEEN UNIT 038	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,494	3,785	3,660	3,810	1,410	1,525	2,925	3,090	3,275	3,642																0	64,312	39,953	32.3429	-103.2477
3002509068	SEVEN RIVERS QUEEN UNIT 005	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,503	3,768	3,692	3,768	1,430	1,522	2,990	3,181	3,394	3,751																0	64,600	55,035	32.3646	-103.2595
3002509064	SEVEN RIVERS QUEEN UNIT 013	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,479	3,785	3,684	3,785	1,365	1,468	3,015	3,187	3,392																	0	54,632	33,454	32.3573	-103.2595
3002509660	COOPER JAL UNIT 146	Above	Above	Seven Rivers/Qu	OCD	3,326	3,642	3,088	3,628	1,175	1,275	2,865	2,996																		14,356	159,960	35,025	32.2146	-103.2135
3002509145	SEVEN RIVERS QUEEN UNIT 021	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,476	3,750	3,664	3,745	1,385	1,495	2,985	3,158	3,360	3,736																0	62,560	36,434	32.3537	-103.2552
3002509239	SEVEN RIVERS QUEEN UNIT 052	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,476	3,866	3,654	3,772	1,349	1,509	2,878	3,026	3,230	3,664																0	17,556	945	32.3356	-103.2466
3002509063	SEVEN RIVERS QUEEN UNIT 011	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,510	3,885	3,733	3,822	1,456	1,562	3,030	3,198	3,416	3,776																0	81,944	66,396	32.3610	-103.2552
3002509150	SEVEN RIVERS QUEEN UNIT 025	Adjacent	Adjacent	Queen	OCD	3,489	3,780	3,680	3,780	1,426	1,501	2,957	3,120	3,318	3,680																0	61,283	25,197	32.3501	-103.2510
3002509489	MYERS LANGLIE MATTIX UNIT 138	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,312	3,609	3,449	3,609	1,170			2,910	3,140	3,496																0	72,697	63,383	32.2517	-103.2124
3002509245	SEVEN RIVERS QUEEN UNIT 047	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,510	3,817	3,698	3,782	1,350	1,450	3,070	3,170	3,362	3,737																0	46,274	5,022	32.3392	-103.2541
3002509136	SEVEN RIVERS QUEEN UNIT 037	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,486	3,782	3,678	3,782	1,380	1,480	2,930	3,100	3,370	3,684																0	54,136	13,506	32.3438	-103.2520
3002509620	COOPER JAL UNIT 205	Above	Above	Yates/Seven Riv	OCD	3,316	3,600	2,988	3,600	1,150	1,260	2,850	3,010																		13,908	139,836	84,609	32.2046	-103.2156
3002509148	SEVEN RIVERS QUEEN UNIT 019	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,513	3,800	3,660	3,800		1,590	2,973	3,142	3,352	3,704																0	75,288	55,640	32.3537	-103.2467
3002509389	LANGLIE LYNN QUEEN UNIT 005	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,371	3,734	3,494	3,631	1,221	1,358	2,770	2,918	3,150	3,514																0	92,146	62,934	32.2881	-103.2338
3002509554	MYERS LANGLIE MATTIX UNIT 239	Above	Above	Seven Rivers/Qu	OCD	3,318	3,570	3,400	3,570																						0	125,430	143,152	32.2300	-103.2124
3002509139	SEVEN RIVERS QUEEN UNIT 033	Adjacent	Adjacent	Queen	OCD	3,481	3,894	3,772	3,806	1,372	1,470	2,990	3,144	3,337	3,710																0	61,582	18,632	32.3465	-103.2552
3002509212	SEVEN RIVERS QUEEN UNIT 044	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,497	3,800	3,552	3,757	1,394			3,040	3,232	3,597																0	74,282	33,931	32.3392	-103.2423
3002509388	LANGLIE LYNN QUEEN UNIT 003	Above	Above	Seven Rivers/Qu	OCD	3,371	3,791	3,556	3,691	1,182	1,322	2,760	2,990	3,210	3,580																0	81,937	64,001	32.2881	-103.2423
3002509561	COOPER JAL UNIT 234	Above	Above	Yates/Seven Riv	OCD	3,315	3,228	2,985	3,228	1,165	1,270	2,860	3,002																		15,170	159,300	66,065	32.2110	-103.2156
3002509644	COOPER JAL UNIT 134	Above	Above	Yates/Seven Riv	OCD	3,310	3,570	3,031	3,570	1,170	1,280	2,840	3,030	3,250	3,416																13,521	134,483	78,477	32.1965	-103.2220
3002509646	COOPER JAL UNIT 224	Above	Above	Yates/Seven Riv	OCD	3,309	3,230	2,970	3,230	1,180	1,270	2,860	3,010																		8,398	85,568	42,525	32.1946	-103.2198
3002509482	MYERS LANGLIE MATTIX UNIT 099	Adjacent	Adjacent	Queen	OCD	3,324	3,690	3,458	3,642	1,170		2,860	2,968																		0	22,628	40,366	32.2590	-103.2124
3002509636	COOPER JAL UNIT 126	Above	Above	Seven Rivers/Qu	OCD	3,311	3,560	3,022	3,560	1,150	1,250	2,850	2,995	3,240	3,430																3,284	43,226	25,183	32.2055	-103.2178
3002509391	LANGLIE LYNN QUEEN UNIT 007	Above	Above	Seven Rivers/Qu	OCD	3,384	3,800	3,510	3,682	1,232	1,392	2,798	2,908	3,180	3,650																0	87,166	68,611	32.2845	-103.2380
3002509631	COOPER JAL UNIT 120	Above	Above	Yates/Seven Riv	OCD	3,317	3,604	3,011	3,516	1,140	1,255	2,800	3,000		3,407																10,145	122,292	76,264	32.2082	-103.2209
3002509624	COOPER JAL UNIT 218	Above	Above	Yates/Seven Riv	OCD	3,310	3,250	2,991	3,250				3,095																		7,207	86,826	43,784	32.1964	-103.2156
3002509630	COOPER JAL UNIT 203	Above	Above	Yates/Seven Riv	OCD	3,324	3,195	3,031	3,195	1,180	1,300	2,790	3,030																		2,870	47,148	29,083	32.2046	-103.2249
3002509639	COOPER JAL UNIT 132	Above	Above	Yates/Seven Riv	OCD	3,307	3,640	3,024	3,640				3,016		3,474																16,677	197,600	86,305	32.2019	-103.2135
3002509641	COOPER JAL UNIT 135	Above	Above	Yates/Seven Riv	OCD	3,312	3,650	3,019	3,650	1,120	1,260	2,850	2,995	3,300	3,419																11,798	150,386	84,086	32.1983	-103.2167
3002509653	COOPER JAL UNIT 241	Above	Above	Yates/Seven Riv	OCD	3,288	3,580	3,033	3,580	1,090	1,220	2,800	2,965	3,180																	7,245	56,551	29,831	32.1910	-103.2156
3002509634	COOPER JAL UNIT 216	Above	Above	Yates/Seven Riv	OCD	3,325	3,210	3,035	3,210				3,035																		20,542	240,522	101,822	32.1974	-103.2252
3002509628	COOPER JAL UNIT 201	Above	Above	Yates	OCD	3,308	3,237	2,994	3,160	1,190	1,290	2,850	3,005	3,235																	14,134	130,904	75,547	32.2082	-103.2114
3002509486	MYERS LANGLIE MATTIX UNIT 103	Adjacent	Adjacent	Yates/Seven Riv	OCD	3,325	3,648	3,385	3,648			2,650	2,870	3,070																	0	477,328	85,945	32.2554	-103.2167
3002509787	COOPER JAL UNIT 211	Above	Above	Seven Rivers/Qu	OCD	3,313	3,600	3,255	3,600	1,160	1,270	2,860	3,005																		10,536	127,512	66,352	32.2019	-103.2198
3002509659	COOPER JAL UNIT 238	Above	Above	Yates/Seven Riv	OCD	3,304	3,589	3,032	3,589	1,190	1,310	2,870	3,030	3,255	3,436																18,426	187,689	72,035	32.1901	-103.2263
3002509551	MYERS LANGLIE MATTIX UNIT 241	Above	Above	Seven Rivers/Qu	OCD	3,334	3,607	3,436	3,607																						0	187,761	173,572	32.2300	-103.2209
3002509748	JALMAT YATES UNIT 002	Above	Above	Yates/Seven Riv	OCD	3,162	3,064	2,885	3,049	1,117	1,292	2,778	2,940																		0	6,103	25,606	32.1439	-103.2157
3002509597	MYERS C SWD 002	Above	Above	Seven Rivers/Qu	OCD	3,340	3,510	3,344	3,510	1,408	1,640	3,140	3,260		3,452																0	1,161,462	1,310,862	32.2083	-103.2550
3002509651	COOPER JAL UNIT 226	Above	Above	Yates/Seven Riv	OCD	3,287	3,600	2,989	3,600	1,100	1,200	2,800	2,995																		9,191	102,115	42,016	32.1946	-103.2114
3002509638	COOPER JAL UNIT 122	Above	Above	Yates/Seven Riv	OCD	3,309	3,552	3,020	3,552	1,180	1,280	2,880	2,996	3,250	3,430																14,663	172,359	55,084	32.2091	-103.2135
3002510908	MYERS LANGLIE MATTIX UNIT 105	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,313	3,608	3,470	3,608	1,180	1,250	2,770	2,920		3,570																0	13,642	57,543	32.2554	-103.2081
3002511049	MYERS LANGLIE MATTIX UNIT 246	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,313	3,595	3,407	3,595	1,200	1,298	2,734	2,920		3,518																0	18,159	88,588	32.2264	-103.1999
3002511161	COOPER JAL UNIT 133	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,286	3,680	2,982	3,680	1,160	1,268	2,815	2,976		3,582																13,826	178,032	88,343	32.2010	-103.2041
3002511297	LANGLIE JAL UNIT 027	Adjacent	Adjacent	Queen	OCD	3,242	3,540	3,493	3,540	1,160	1,350		2,898																		908	10,103	9,510	32.1683	-103.1956

3002510887	MYERS LANGLIE MATTIX UNIT 039	Adjacent	Adjacent	Queen	OCD	3,333	3,650	3,541	3,650	1,205			2,940		3,540															0	27,717	9,509	32.2699	-103.2081
3002511048	MYERS LANGLIE MATTIX UNIT 244	Adjacent	Adjacent	Queen	OCD	3,314	3,666	3,472	3,617	1,185			2,960																	0	44,377	43,766	32.2264	-103.2081
3002511323	LANGLIE JAL UNIT 019	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,250	3,620	3,354	3,609	1,120	1,220	2,692	2,918	3,149	3,454															2,917	34,319	40,290	32.1720	-103.1913
3002511149	COOPER JAL UNIT 242	Adjacent	Adjacent	Yates/Seven Riv	OCD	3,303	3,190	2,962	3,190	1,150			2,855	2,985																17,334	193,121	106,867	32.2073	-103.2051
3002511036	MYERS LANGLIE MATTIX UNIT 137	Adjacent	Adjacent	Queen	OCD	3,321	3,588	3,454	3,588	1,158			2,940	3,193																0	12,966	65,970	32.2517	-103.2083
3002511019	MYERS LANGLIE MATTIX UNIT 136	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,327	3,615	3,460	3,615	1,170	1,270	2,740	2,950	3,230	3,590															0	26,764	81,753	32.2517	-103.2039
3002511322	LANGLIE JAL UNIT 026	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,239	3,560	3,397	3,560	1,175			3,000	3,220	3,481															9,245	117,335	103,124	32.1683	-103.1913
3002511301	LANGLIE JAL UNIT 017	Adjacent	Adjacent	Queen/Grayburg	OCD	3,233	4,006	3,504	3,700	1,100	1,200	2,680	2,879	3,100	3,515		3,700													6,707	74,665	106,892	32.1720	-103.1997
3002511022	MYERS LANGLIE MATTIX UNIT 173	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,328	3,620	3,464	3,620	1,165			2,922	3,215																0	6,362	45,762	32.2445	-103.2041
3002510901	MYERS LANGLIE MATTIX UNIT 071	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,325	3,650	3,459	3,647	1,165	1,255	2,740	3,090		3,495															0	41,391	48,542	32.2626	-103.2081
3002511480	LANGLIE JAL UNIT 033	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,228	3,577	3,375	3,521	1,110	1,434	2,650	2,829	3,043	3,395															8,346	102,447	97,320	32.1656	-103.1988
3002511290	COOPER JAL UNIT 228	Adjacent	Adjacent	Yates	OCD	3,267	3,134	3,040	3,120	1,105			2,957																	9,070	116,297	68,500	32.1937	-103.2041
3002511029	MYERS LANGLIE MATTIX UNIT 175	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,311	3,620	3,477	3,620	1,170			2,921	3,272	3,538															0	1,710	91,869	32.2418	-103.1988
3002511039	MYERS LANGLIE MATTIX UNIT 235	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,306	3,570	3,410	3,570																					0	49,402	48,292	32.2300	-103.1959
3002511488	SOUTH LANGLIE JAL UNIT 004	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,125	3,353	3,127	3,353	1,080	1,185	2,610	2,760	2,965	3,205															0	113,400	113,400	32.1421	-103.1965
3002511162	COOPER JAL UNIT 220	Above	Above	Seven Rivers/Qu	OCD	3,276	3,600	2,986	3,600	1,109	1,224	2,820	2,979	3,210																6,750	106,774	57,453	32.1973	-103.2082
3002511288	COOPER JAL UNIT 239	Above	Above	Yates/Seven Riv	OCD	3,268	3,180	2,828	3,180	1,089			2,869																	8,808	116,643	66,967	32.1901	-103.2081
3002511141	COOPER JAL UNIT 116	Above	Above	Yates/Seven Riv	OCD	3,326	3,641	2,980	3,641	1,100			2,980	3,215	3,598															12,286	114,459	65,712	32.2119	-103.2081
3002511476	LANGLIE JAL UNIT 055	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,241	3,511	3,370	3,511		1,251	2,650	2,846	3,070	3,460															3,605	41,221	51,669	32.1584	-103.1988
3002511173	LANGLIE JACK UNIT 006	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,287	3,641	3,334	3,641				2,830		3,467															0	350	0	32.2082	-103.1913
3002511475	LANGLIE JAL UNIT 031	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,245	3,470	3,157	3,470			2,640	2,770	2,930	3,380															7,535	94,469	196,316	32.1656	-103.2073
3002511654	JALMAT YATES UNIT 030	Adjacent	Adjacent	Yates	OCD	3,126	3,062	2,822	3,040				2,819																	0	20,770	25,546	32.1294	-103.2028
3002512075	W H RHODES B FEDERAL NCT 2 003	Adjacent	Adjacent	Seven Rivers	OCD	2,983	3,330	3,018	3,330	1,180			2,860	3,030																0	1,200	300	32.0124	-103.1614
3002512033	RHODES YATES UNIT 001	Adjacent	Adjacent	Seven Rivers	OCD	2,977	3,253	3,054	3,253	1,087			2,774																	0	600	600	32.0269	-103.1614
3002512066	RHODES YATES UNIT 011	Adjacent	Adjacent	Seven Rivers	OCD	2,988	3,327	3,130	3,327																					0	48,600	48,086	32.0133	-103.1518
3002512059	RHODES YATES UNIT 009	Adjacent	Adjacent	Seven Rivers	OCD	2,981	3,323	3,139	3,275	1,087			2,898																	0	600	0	32.0160	-103.1614
3002520052	LANGLIE LYNN QUEEN UNIT 012	Above	Above	Seven Rivers/Qu	OCD	3,368	3,750	3,446	3,682	1,203	1,295	2,796	2,926	3,193	3,596															0	76,173	55,623	32.2809	-103.2423
3002512776	MARY E WILLS A FEDERAL 008	Adjacent	Adjacent	Seven Rivers	OCD	2,973	3,324	3,256	3,297	1,130		2,805	2,956	3,247																0	720	0	32.0035	-103.1386
3002520049	LANGLIE LYNN QUEEN UNIT 009	Above	Above	Seven Rivers/Qu	OCD	3,371	3,800	3,512	3,714	1,188			2,998	3,211	3,603															0	81,771	60,132	32.2845	-103.2455
3002520191	LANGLIE LYNN QUEEN UNIT 014	Above	Above	Seven Rivers/Qu	OCD	3,373	3,720	3,408	3,586	1,188	1,289	2,731	2,893	3,148	3,490															0	81,126	57,077	32.2808	-103.2338
3002520302	MESCALERO RIDGE UNIT 351	Adjacent	Adjacent	Queen/Penrose	OCD	3,703	5,152	4,580	5,086	1,778	1,908	3,365	3,572		4,543	4,886														0	95,854	121,086	32.6150	-103.5243
3002520695	MESCALERO RIDGE UNIT 358	Adjacent	Adjacent	Queen/Penrose	OCD	3,705	5,232	4,580	5,102	1,751	1,894	3,376	3,613		4,557	4,920														0	45,714	14,023	32.6150	-103.5331
3002520693	MESCALERO RIDGE UNIT 356	Adjacent	Adjacent	Queen/Penrose	OCD	3,719	5,250	4,591	4,996	1,797	1,923	3,352	3,573		4,560	4,912														0	61,564	52,261	32.6223	-103.5331
3002520692	MESCALERO RIDGE UNIT 354	Adjacent	Adjacent	Queen/Penrose	OCD	3,715	5,200	4,562	5,190	1,792	1,918	3,356	3,564		4,543	4,885														0	19,606	24,894	32.6187	-103.5289
3002521229	LANGLIE LYNN QUEEN UNIT 016	Above	Above	Seven Rivers/Qu	OCD	3,355	3,700	3,468	3,653	1,178	1,310	2,793	2,951	3,166	3,571															0	86,654	68,819	32.2772	-103.2380
3002521244	TEAS YATES UNIT 061	Above	Above	Yates	OCD	3,579	3,429	3,180	3,310	1,370	1,510	2,990	3,166																	0	497	3,429	32.5722	-103.6393
3002521458	LANGLIE LYNN QUEEN UNIT 018	Above	Above	Seven Rivers/Qu	OCD	3,360	3,710	3,540	3,681	1,176		2,850	3,007	3,220	3,624															0	87,957	62,877	32.2736	-103.2423
3002521639	LUSK SEVEN RIVERS UNIT 004	Adjacent	Adjacent	Seven Rivers	OCD	3,662	3,860	3,816	3,820	1,265		2,752	2,932	3,812																310	1,986	217	32.6876	-103.7605
3002521683	MESCALERO RIDGE UNIT 015	Adjacent	Adjacent	Queen/Penrose	OCD	3,722	5,135	4,585	4,971	1,808	1,932	3,349	3,565		4,571	4,900														0	74,985	117,878	32.6223	-103.5246
3002523867	LANGLIE JAL UNIT 029	Adjacent	Adjacent	Queen	OCD	3,234	3,600	3,185	3,547	1,090	1,408	2,623	2,775	2,988	3,170															8,549	111,787	116,839	32.1683	-103.2038
3002524869	LUSK WEST DELAWARE UNIT 007	Below	Below	Delaware	OCD	3,581	12,814	6,446	6,467	770	1,083	2,395	2,583					2,885	4,676											0	27,453	160,011	32.6486	-103.7873
3002524575	RHODES YATES UNIT 002	Adjacent	Adjacent	Yates/Seven Riv	OCD	2,966	3,350	3,128	3,194	1,120			2,912	3,154																0	600	600	32.0233	-103.1614
3002524889	LANGLIE JAL UNIT 034	Adjacent	Adjacent	Queen	OCD	3,231	3,750	3,134	3,556	1,126			2,864	3,092	3,428															4,081	46,136	65,837	32.1647	-103.1956
3002525691	W H RHODES B FEDERAL NCT 2 004	Adjacent	Adjacent	Yates/Seven Riv	OCD	2,965	3,460	3,114	3,318	1,050	1,410	2,650	2,940	3,180																0	150	0	32.0088	-103.1614
3002525217	RHODES YATES UNIT 004	Adjacent	Adjacent	Yates/Seven Riv	OCD	2,973	3,350	3,080	3,325	1,050	1,410	2,650	2,940	3,180																0	600	0	32.0199	-103.1614
3002525682	COOPER JAL UNIT 151	Above	Above	Yates	OCD	3,304	3,650	3,296	3,608	1,188	1,298	2,860	3,020	3,294																8,565	88,488	40,585	32.1983	-103.2108
3002525897	TONTO 007	Above	Above	Yates	OCD	3,589	3,119	2,900	3,113				2,960																	0	16,391	22,579	32.6285	-103.6972
3002525693	RHODES YATES UNIT 013	Adjacent	Adjacent	Yates	OCD	2,975	3,450	3,175	3,349	1,198			3,045	3,362																0	107,643	71,872	32.0088	-103.1572
3002526405	JALMAT YATES UNIT 015	Above	Above	Yates	OCD	3,187	3,570	2,954	3,178				2,954	3,191	3,410															0	36,315	76,177	32.1346	-103.2139
3002526407	JALMAT YATES UNIT 020	Above	Above	Yates/Seven Riv	OCD	3,156	3,500	2,920	3,447				2,906	3,148	3,363															0	82,029	102,394	32.1341	-103.2101
3002526128	COOPER JAL UNIT 153	Above	Above	Yates/Seven Riv	OCD	3,291	3,700	3,003	3,696	1,128	1,240	2,834	3,003	3,276	3,616															14,288	160,000	92,936	32.1994	-103.2094
3002526403	JALMAT YATES UNIT 004	Above	Above	Yates	OCD	3,153	3,500	2,917	3,002				2,917	3,141	3,359															0	14,062	51,529	32.1415	-103.2140
3002526406	JALMAT YATES UNIT 019	Adjacent	Adjacent	Yates	OCD	3,148	3,540	2,902	3,130			2,740	2,895	3,141	3,357															0	129,046	151,846	32.1340	-103.2059
3002526408	JALMAT YATES UNIT 025	Adjacent	Adjacent	Yates	OCD	3,125	3,510	2,858	3,031			2,700	2,856	3,085	3,310															0	29,367	39,680	32.1307	-103.2053
3002526409	JALMAT YATES UNIT 031	Above	Above	Yates/Seven Riv	OCD	3,113	3,500	2,833	3,210				2,824	3,052	3,476															0	77,672	132,948	32.1276	-103.2048
3002526897	JALMAT YATES UNIT 018	Adjacent	Adjacent	Yates	OCD	3,113	3,500	2,836	3,055				2,834	3,074																0	80,830	105,956	32.1340	-103.2021
3002526404	JALMAT YATES UNIT 009	Above	Above	Yates	OCD	3,183	3,557	2,971	3,184			2,802	2,954	3,192	3,409															0	71,884	66,409	32.1386	-103.2136
3002526871	JALMAT YATES UNIT 027	Above	Above	Yates	OCD	3,152	3,501	2,885	3,127				2,883	3,129																0	25,937	43,879	32.1305	-103.2139
3002526896	JALMAT YATES UNIT 011	Adjacent	Adjacent	Yates	OCD	3,133	3,497	2,876	3,107				2,876	3,126																0	184,862	228,557	32.1372	-103.2059
3002526869	JALMAT YATES UNIT 014	Above	Above	Yates	OCD	3,133	3,525	2,916	3,186				2,916	3,186																0	238,116	147,739	32.1345	-103.2185
3002526971	MYERS LANGLIE MATTIX UNIT 204	Adjacent	Adjacent	Queen	OCD	3,311	3,750	3,355	3,503	1,178		2,798	2,858	3,110	3,446	3,574														0	109,254	108,494	32.2372	-103.2039
3002527020	JALMAT YATES UNIT 008	Above	Above	Yates	OCD	3,150	3,550	2,904	3,157				2,904																	0	144,747	101,057	32.1385	-103.2184
3002527019	JALMAT YATES UNIT 003	Above	Above	Yates	OCD	3,165	3,496	2,915	3,163				2,912	3,164																0	190,652	84,877	32.1418	-103.2184
3002527089	MYERS LANGLIE MATTIX UNIT 212	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,306	3,711	3,404	3,652	1,193		2,690	2,902	3,115	3,496															0	4,037	35,644	32.2336	-103.1992
3002527073	JALMAT YATES UNIT 010	Adjacent	Adjacent	Yates	OCD	3,135	3,497	2,873	3,106				2,871	3,116																0	121,105	0	32.1410	-103.2062
3002526872	JALMAT YATES UNIT 028	Above	Above	Yates	OCD	3,133	3,498	2,901	3,020				2,899	3,166																0	184,482	148,354	32.1306	-103.2185
3002527635	TEAS YATES UNIT 103	Above	Above	Yates/Seven Riv	OCD	3,604	3,420	3,210	3,310	950			3,100																	0	520	324	32.5742	-103.6300
3002528033	TEAS YATES UNIT 132	Above	Above	Yates	OCD	3,583	3,380	3,206	3,330	970	1,380		3,200																	0	526	281	32.5804	-103.6404
3002528031	TEAS YATES UNIT 084	Above	Above	Yates	OCD	3,610	3,433	3,280	3,420		1,400		3,200																	0	449	705	32.5721	-103.6222
3002528027	TEAS YATES UNIT 012	Above	Above	Yates	OCD	3,614	3,512	3,354	3,392	1,392	1,500		3,228																	0	706	1,283	32.5749	-103.6082
3002528911	W H RHODES B FEDERAL NCT 2 006	Adjacent	Adjacent	Yates/Seven Riv	OCD	2,966	3,450	3,168	3,324	1,195	1,230		3,020																	0	150	0	32.0088	-103.1654
3002529131	SEVEN RIVERS QUEEN UNIT 065	Above	Above	Seven Rivers/Qu	OCD	3,479	3,920	3,691	3,831	1,284	1,470	3,008	3,180	3,355	3,772															0	23,854	205	32.3353	-103.2597
3002529971	WEST TEAS YATES SEVEN RIVERS UNIT 91	Above	Above	Yates	OCD	3,555	3,400	3,138	3,270				3,025	3,275																0	6,165	4,438	32.5895	-103.6747
3002530439	LUSK WEST DELAWARE UNIT 105	Below	Below	Delaware	OCD	3,589	6,700	4,984	5,040	830		2,481	2,613	2,817					4,715											0	24,063	44,575	32.6486	-103.7787
3002529972	WEST TEAS YATES SEVEN RIVERS UNIT 91	Above	Above	Yates	OCD	3,543	3,400	3,114	3,172				3,101																	0	11,933	11,328	32.5858	-103.6747
3002530165	LUSK WEST DELAWARE UNIT 911	Below	Below	Delaware	OCD	3,553	6,850	6,431	6,446	890	1,075	2,345	2,532	2,765				2,875	4,485											0	32,847	95,441	32.6305	-103.7899
3002530572	LUSK WEST DELAWARE UNIT 103	Below	Below	Delaware	OCD	3,596	6,650	6,489	6,503			2,513	2,657	2,878					4,817											0	26,351	101,628	32.6504	-103.7744
3002530490	LUSK WEST DELAWARE UNIT 015	Below	Below	Delaware	OCD	3,564	7,200	5,025	5,394	784			2,522					2,740	4,552		5,591									0	2,167	13,123	32.6396	-103.7862
3002530524	LUSK WEST DELAWARE UNIT 009	Below	Below	Delaware	OCD	3,582	7,230	6,469	7,154	782			2,552					2,800	4,648		5,640									0	11,477	76,842	32.6450	-103.7819
3002530518	LUSK WEST DELAWARE UNIT 001	Below	Below	Brushy Canyon	OCD	3,592	7,500	6,476	6,484	823			2,688					2,870	4,590		5,610	7,174								0	51,284	129,012	32.6523	-103.7809
3002531157	MCDONALD STATE AC 1 031	Adjacent	Adjacent	Queen	OCD	3,543	4,000	3,656	3,748						3,656		3,830													0	60,196	82,446	32.3882	-103.2702
3002531158	MCDONALD STATE AC 1 032	Adjacent	Adjacent	Queen	OCD	3,545	4,000	3,691	3,790						3,689		3,854													0	93,907	132,157	32.3882	-103.2657
3002531166	MCDONALD STATE AC 1 042	Adjacent	Adjacent	Queen	OCD	3,563	4,000	3,699	3,780						3,678		3,868													0	11,685	2,213	32.3854	-103.2702
3002531162	MCDONALD STATE AC 1 036	Adjacent	Adjacent	Queen	OCD	3,553	4,000	3,699	3,780						3,678		3,868													0	2,694	236	32.3917	-103.2702
3002531156	MCDONALD STATE AC 1 030	Adjacent	Adjacent	Queen	OCD	3,538	4,000	3,606	3,690						3,606		3,771													0	79,853	24,734	32.3884	-103.2746
3002530791	LUSK WEST DELAWARE UNIT 111	Below	Below	Delaware	OCD	3,585	7,230	6,735	6,744	832		2,487	2,612	2,810					4,794											0	87,809	146,088	32.6450	-103.7744
3002531163	MCDONALD STATE AC 1 037	Adjacent	Adjacent	Queen	OCD	3,549	4,000	3,661	3,755						3,662		3,840													0	1,234,509	77,008	32.3917	-103.2744
3002531896	WEST TEAS YATES SEVEN RIVERS UNIT 92	Above	Above	Yates	OCD	3,557	3,320	3,161	3,252			2,970	3,161																	0	50,794	147,098	32.5940	-103.6694
3002532032	WEST TEAS YATES SEVEN RIVERS UNIT 43	Above	Above	Yates	OCD	3,556	3,550	3,230	3,292	1,403	1,495	3,029	3,126	3,319																0	176,595	82,433	32.5994	-103.6662
3002532217	WEST TEAS YATES SEVEN RIVERS UNIT 94	Above	Above	Yates	OCD	3,555	3,390	3,076	3,306	1,400			3,060	3,350																0	216,868	231,657	32.5940	-103.6630
3002534131	LUSK WEST DELAWARE UNIT 901	Below	Below	Brushy Canyon	OCD	3,573	6,927	6,425	6,478	810	1,130		2,620					2,765	4,590		6,472									0	16,288	29,343	32.6378	-103.7808
3002534269	LUSK WEST DELAWARE UNIT 915Y	Below	Below	Brushy Canyon	OCD	3,551	6,630	6,434	6,456	898			2,570					2,793	4,315		6,434									0	62,342	42,733	32.6254	-103.7864
3002534132	LUSK WEST DELAWARE UNIT 907	Below	Below	Brushy Canyon	OCD	2,559	6,630	6,434	6,451	898			2,570					2,793	4,315		6,434									0	8,184	67,068	32.6326	-103.7851
3002534283	LUSK WEST DELAWARE UNIT 909	Below	Below	Brushy Canyon	OCD	2,559	6,630	6,444	6,456	898			2,570					2,793	4,315		6,444									0	98,673	93,184	32.6296	-103.7828
3002534173	LUSK WEST DELAWARE UNIT 011	Below	Below	Brushy Canyon	OCD	3,574	6,630	6,443	6,451	922	1,090		2,545					2,787	4,660		6,443									0	14,132	12,322	32.6441	-103.7905
3002535962	MOBIL LEA STATE 008	Below	Below	Cherry Canyon	OCD	3,664	6,275	5,930	5,992	1,595	1,710	3,431	3,612	3,835	4,655		5,050		5,596	5,930										0	180,418	185,403	32.5959	-103.5342
3002536079	WEST TEAS YATES SEVEN RIVERS UNIT 94	Above	Above	Yates/Seven Riv	OCD	3,553	3,350	3,096	3,322	1,289	1,412	2,920	3,082	3,295																0	110,265	131,455	32.5877	-103.6608
3002536073	WEST TEAS YATES SEVEN RIVERS UNIT 92	Above	Above	Yates/Seven Riv	OCD	3,540	3,350	3,038	3,286	1,275	1,420	2,870	3,035	3,230																0	48,574	57,490	32.5879	-103.6697
3001526524	HADSON FEDERAL 001	Above	Above	Yates	OCD	3,564	2,740	2,648	2,656	644		2,194	2,388	2,603																0	115,518	121,023	32.6699	-103.8386
3001524349	LEE FEDERAL 002	Below	Below	Delaware	OCD	3,240	11,660	3,123	3,226				1,169	1,438					3,090			5,518	8,994		10,234	10,670	11,241			0	26,301	24,501	32.5464	-104.1291
3002502605	STATE AA 001	Above	Above	Yates/Seven Riv	OCD	3,620	4,250	3,822	4,150	1,662		3,547	3,851	4,223																0	66,730	54,187	32.4336	-103.4341
3001526710	WELCH FEDERAL 007	Above	Above	Yates	OCD	3,231	698	515	698				407																	0	158,896	193,236	32.5113	-104.2043
3002502476	SILVER FEDERAL 004	Above	Into	Seven Rivers	OCD	3,732	3,733	3,718	3,725			3,302	3,480	3,718																0	6,000	6,000	32.5386	-103.5631
3001524986	AMOCO FEDERAL 003	Above	Above	Yates	OCD	3,493	2,400	2,215	2,327	856		2,004	2,162																	0	43,232	13,617	32.6478	-103.8764
3002503352	APPLESEED SWD FEDERAL 002	Above	Above	Seven Rivers	OCD	3,698	4,130	3,932	4,038	1,942	2,050	3,500	3,675	3,848																0	10,581	13,846	32.5714	-103.4730
3001534833	TWO MARKS 36 STATE 004	Below	Below	Devonian	OCD	3,719	12,500	11,099	12,500												2,126	3,255	7,344			9,473	9,702	11,052	12,156	0	1,521,255	158,534	32.4301	-104.4495
3001524921	GOVERNMENT D 004	Below	Below	Delaware/Bone S	OCD	3,196	5,712	3,849	5,632									1,493	2,865			5,516								0	28,274	138,946	32.5184	-104.1409
3002502466	BALLARD DE FEDERAL 003	Above	Into	Seven Rivers	OCD	3,677	4,026	3,615	4,026	1,557	2,120	3,225	3,450	3,610																0	26,070	16,510	32.5486	-103.5534
3001533458	DRY LAND SWD 001	Below	Below	Devonian	OCD	3,272	8,875	8,400	8,620										1,762			2,822	7,600			8,184				0	1,520,840	2,653,849	32.5098	-104.3755
3001526730	HADSON FEDERAL 003	Above	Above	Yates/Seven Riv	OCD	3,586	2,744	2,613	2,717	681	900	2,238	2,448	2,664																0	10,107	10,587	32.6753	-103.8390
3001527558	BARBADOS STATE 001	Below	Below	Delaware	OCD	3,334	5,040	4,402	4,783										1,675			4,934								0	181,864	218,859	32.3465	-104.3088
3001525006	TRIGG FEDERAL 001	Below	Below	Delaware	OCD	3,155	3,366	2,926	3,315										2,712											0	34,982	41,410	32.4931	-104.1323
3002502507	W H MILNER FEDERAL 004	Above	Into	Seven Rivers	OCD	3,735	3,850	3,786	3,806				3,480	3,665																10,450	153,700	161,738	32.5341	-103.5340
3002502431	LEA UNIT 008	Above	Above/Into	Yates	OCD	3,674	14,693	3,986	4,180	1,726	1,849	3,133	3,544		4,724							8,225	11,136		12,002			14,295		0	434,723	400,397	32.5927	-103.5117
3001523385	BIG EDDY UNIT 079Y	Below	Below	Delaware	OCD	3,221	12,370	3,869	4,150										2,514			5,974	9,602		10,740	11,120	11,866			0	10,805	16,311	32.4640	-104.0895
3002502494	B V LYNCH A FEDERAL 002	Above	Into	Yates/Seven Riv	OCD	3,783	4,003	3,633	4,003																					0	576,202	488,486	32.5241	-103.5415
3002502448	D AND E FEDERAL 001	Above	Above/Into	Yates	OCD	3,675	3,693	3,478	3,693	1,563	1,695	3,230	3,428																	1,664	17,485	17,496	32.5532	-103.5502
3002503335	CACTUS FEDERAL 003	Adjacent	Adjacent	Queen	OCD	3,694	5,030	4,650	4,970	1,890	1,985	3,383	3,580		4,610	4,938														3,258	33,971	37,959	32.6087	-103.5031
3001524845	WERSELL FEDERAL 002	Below	Below	Delaware	OCD	3,172	4,650	2,832	3,794																					0	251,711	311,701	32.4273	-104.2013

3001524824	BIG EDDY FEDERAL 100	Below	Below	Delaware	OCD	3,178	9,200	3,197	3,450											5,720	8,994		10,039	10,366	10,736		30,687	360,926	312,143	32.4938	-104.1158
3001524048	AVALON DELAWARE UNIT 546	Below	Below	Wolfcamp	OCD	3,229	11,901	9,004	9,130											4,876	8,994		10,039	10,366			0	5,731	688	32.5280	-104.2152
3002504861	ATHA 001	Adjacent	Adjacent	Yates	OCD	3,615	3,872	3,715	3,872	1,755	1,935	3,335	3,487														12,879	72,666	46,590	32.4299	-103.3104
3001534529	RIGHTHAND CANYON 35 FEDERAL 007	Below	Below	Devonian	OCD	3,917	12,000	11,000	12,000											3,750	7,440			9,472	9,811	11,048	0	15,690,281	1,216,506	32.4337	-104.4697
3002502501	NEAL 003	Above	Into	Yates	OCD	3,729	3,805	3,705	3,714	1,650	1,775		3,576														1,800	6,250	35,320	32.5359	-103.5255
3001532056	ZEBRA FF FEDERAL 001	Below	Below	Atoka/Morrow	OCD	3,490	10,390	9,564	10,214						457				1,523	2,735	7,240		9,018	9,528	9,999		0	14,017	8,344	32.4960	-104.4366
3001525352	NEW MEXICO EV STATE 001	Below	Below	Delaware	OCD	3,346	11,788	2,658	4,680											4,828	8,462		9,936		11,036		0	55,831	53,713	32.3465	-104.3174
3002501671	FEDERAL 18 004	Above	Above	Yates	OCD	3,642	3,750	3,350	3,450	1,350	1,480	2,830	3,010														0	785,653	568,697	32.6621	-103.6960
3002502538	KAISER STATE 009	Above	Above	Yates	OCD	3,660	3,781	3,590	3,668	1,614	2,155		3,571														49,155	785,754	704,260	32.4809	-103.4256
3002530977	GEM 8705 JV-P 003	Below	Below	Delaware	OCD	3,579	13,700	7,743	8,022										5,486	7,898	11,174		12,234		13,050		0	127,590	108,160	32.5968	-103.6319
3002528396	STATE A A/C 1 116	Above	Above	Seven Rivers/Qu	OCD	3,480	8,400	3,740	3,842	1,230		2,968	3,117	3,323	3,740		3,937										0	1,068,485	1,773,243	32.3228	-103.2572
3002524540	CLEARY STATE 001	Below	Below	Delaware	OCD	3,626	13,860	5,413	5,682	1,345	1,485	3,115	3,185						4,750	8,315	11,500		12,287	12,635			0	230,498	216,244	32.5251	-103.6876
3002525957	LEA 20 001	Above	Above	Queen	OCD	2,920	3,420	3,323	3,420	1,932	1,988	2,416	3,210														0	9,378	6,919	32.0242	-103.2796
3002520463	STATE A A/C 1 101	Below	Below	Delaware	OCD	3,418	10,241	3,950	5,100	1,240	1,490	2,800	2,945	3,160	3,559											10,200	0	1,063,163	514,868	32.3135	-103.2423
3002509807	BROWN 005	Above	Above	Seven Rivers	OCD	3,066	3,350	3,289	3,350	1,085	1,210	2,860	3,030														0	51,640	47,133	32.1040	-103.2242
3002509839	C W SHEPHERD B FEDERAL 005	Above	Above	Seven Rivers	OCD	2,992	2,964	2,964	3,088	1,027	1,140	2,580	2,762														0	118,488	178,304	32.0705	-103.2125
3002508815	J H DAY 001	Adjacent	Adjacent	Seven Rivers	OCD	3,591	3,851	3,706	3,851	1,720	1,750		3,260														12,879	72,666	46,590	32.4263	-103.3061
3002528474	CITIES FEDERAL 002	Above	Above	Seven Rivers/Qu	OCD	3,539	3,800	3,492	3,800	1,430	1,650	3,148	3,296	3,518													4,522	19,260	79,450	32.3718	-103.2937
3002520386	WHITTEN 001	Above	Above/Into	Seven Rivers/Qu	OCD	3,649	14,495	4,040	4,165	1,700	2,130	3,360	3,550							8,268	11,282		12,128	12,252	12,766	14,394	72,434	749,944	822,116	32.5713	-103.5245
3002524787	LUSK 16 STATE 004	Below	Below	Delaware	OCD	3,616	11,000	4,918	6,535			2,379	2,790	3,133	3,925		4,375		5,510	7,280	10,478						0	135,965	98,133	32.6587	-103.7648
3002509709	MCKINNEY 001	Above	Above	Seven Rivers	OCD	3,269	3,490	3,066	3,490	1,900	2,150		2,855	3,150													0	46,545	49,560	32.1792	-103.2124
3002509753	W F HANAGAN 004	Above	Above	Yates	OCD	3,179	3,164	2,892	2,955		1,200	2,740	2,885	3,080													0	94,700	116,900	32.1435	-103.2203
3002526106	ARNOTT RAMSAY NCT-B 004	Above	Above	Seven Rivers/Qu	OCD	2,999	3,600	3,338	3,448		1,200	2,582	2,727	3,025	3,390												0	54,669	79,507	32.0931	-103.1923
3002512580	B V LYNCH A FEDERAL 010	Above	Into	Yates	OCD	3,716	3,734	3,712	3,734																		0	576,206	488,484	32.5350	-103.5502
3002509512	H WHITTEN 001	Above	Above	Yates/Seven Rive	OCD	3,422	3,761	3,645	3,761	745																	372	4,380	4,368	32.2527	-103.2711
3002520959	NEW MEXICO CR STATE 003	Below	Below	Delaware	OCD	3,533	11,500	4,578	4,624	857	987	2,354	2,530							7,254	10,558		11,290				0	40,328	44,818	32.6150	-103.7948
3002530534	HAT MESA STATE 010	Below	Below	Delaware	OCD	3,619	13,900	5,310	5,574	1,327	1,552	3,135	3,318					3,516	4,908	8,314	11,292		12,312	12,480	13,154		0	63,041	82,805	32.5314	-103.6894
3002524658	LUSK FEDERAL DISPOSAL 001	Adjacent	Adjacent	Yates/Seven Rive	OCD	3,665	4,675	3,481	4,427				3,208	3,575	4,145	4,375											0	101,810	104,273	32.6802	-103.7090
3002526676	WEST JAL DISPOSAL 001	Above	Above	Yates	OCD	3,166	9,550	3,690	3,700	1,305		3,190	3,376	3,627				3,743	5,300	7,647							0	161,456	132,942	32.1466	-103.2509
3002528210	DOUBLE SS 001	Above	Above	Yates/Seven Rive	OCD	3,302	3,275	3,207	3,238	990	1,140	2,260	2,990	3,220													0	124,898	136,194	32.1838	-103.2369
3002509531	J L COATES 004	Above	Above	Yates/Seven Rive	OCD	3,379	3,670	3,492	3,496																		18,750	231,600	216,600	32.2364	-103.2561
3002531412	UNION AJS FEDERAL 001	Above	Above	Queen	OCD	3,557	3,700	3,445	3,502			2,588	2,762	2,968	3,432												0	1,120,405	1,316,821	32.4914	-103.6947
3002528528	LEA UNIT SWD 002	Above	Above/Into	Seven Rivers	OCD	3,659	4,611	3,800	4,611					3,800													0	446,438	429,949	32.5849	-103.5213
3002523985	WALLEN FEDERAL 002	Above	Above/Into	Seven Rivers	OCD	3,637	3,847	3,660	3,847	1,480	1,580	3,200	3,403														0	9,541	9,236	32.5632	-103.5857
3002524334	ARCO CRUMP 002	Adjacent	Adjacent	Seven Rivers/Qu	OCD	3,333	3,730	3,454	3,638	1,179	1,455	2,730	2,896	3,106	3,510												3,275	35,995	38,973	32.2436	-103.2157
3002529544	STIVASON FEDERAL 003	Adjacent	Adjacent	Queen	OCD	3,692	4,630	4,527	4,556	106	1,860	3,322	3,605	3,958	4,490												0	20,805	13,237	32.6231	-103.5621
3002526965	POSSH 002	Above	Above	Queen	OCD	3,268	3,750	3,553	3,627	1,170	1,300	2,600	2,767	2,995	3,394												0	179,001	139,394	32.1765	-103.2220
3002508961	CLOSSON B FEDERAL 018	Above	Above	Seven Rivers	OCD	3,580	3,909	3,790	3,834	1,602		3,405	3,582														0	22,586	100,806	32.3718	-103.3104
3002527960	BYERS 8605 JV-P 002	Adjacent	Adjacent	Queen/Delaware	OCD	3,676	13,570	4,842	9,840					4,440	4,855				5,738	8,239					12,877		0	95,146	81,488	32.5605	-103.4251
3002509463	B DAVIS 002	Above	Above	Seven Rivers	OCD	3,382	3,607	3,278	3,418				3,034	3,246	3,516												0	173,600	179,637	32.2545	-103.2540
3002522597	BATE FEDERAL 003	Above	Above	Seven Rivers	OCD	3,600	3,514	3,484	3,514	1,304		2,918	3,118	3,402													0	120,114	255,334	32.6230	-103.6361
3002509603	A H MEYERS A 005	Above	Above	Seven Rivers	OCD	3,340	3,800	3,590	3,645																		0	7,281	7,538	32.2083	-103.2508
3002527188	JENNINGS B FEDERAL 002	Above	Above	Yates	OCD	3,621	3,100	2,986	3,060	1,003		2,606	2,824														0	168,103	179,771	32.6549	-103.7519
3002511830	GUTMAN SWD 002	Adjacent	Adjacent	Seven Rivers	OCD	3,028	3,297	2,960	3,068	950			2,565														0	16,931	48,182	32.1004	-103.1817
3002533144	WEST TEAS YATES SEVEN RIVERS UNIT 64	Above	Above	Yates	OCD	3,552	3,470	3,160	3,294				3,160	3,424													0	662	95	32.5795	-103.6608
3002535244	LUSK DEEP UNIT A 019	Below	Below	Strawn	OCD	3,584	12,754	11,358	11,410	778			2,584						4,476	10,346			11,220	11,615	12,228		0	211,211	91,527	32.6550	-103.7916
3002531856	WEST TEAS YATES SEVEN RIVERS UNIT 60	Below	Below	Delaware	OCD	3,539	13,858	5,554	5,653										5,468	8,241	11,600		12,300	12,860			0	501	2,300	32.5756	-103.6662
3002532605	MALLON 34 FEDERAL 001	Below	Below	Delaware	OCD	3,699	6,306	6,180	6,260	1,730		3,348	3,541	3,843	4,578	4,858	5,092		5,702								0	43,993	105,082	32.6222	-103.5535
3002532735	PRONGHORN SWD 001	Above	Above/Into	Yates/Seven Rive	OCD	3,620	3,500	3,300	3,500			2,835	3,068	3,348													0	912,366	1,090,577	32.6521	-103.7166
3002536098	SAPPHIRE STATE 003	Below	Below	San Andres	OCD	3,456	8,647	4,692	5,319																		0	635	978	32.3217	-103.2434
3001520387	GOVERNMENT D 001	Below	Into	Delaware	OCD	3,208	11,800	2,802	2,950											5,414	9,048		10,281	10,760	11,242		0	90,660	92,938	32.4966	-104.1454
3001521387	BURTON FLATS SWD 001	Below	Below	Queen/Delaware	OCD	3,271	12,000	3,410	5,385	720			2,083		3,150				4,300		9,383						0	116,166	197,705	32.5608	-104.0822
3001522055	EXXON STATE 008	Above	Above	Yates	OCD	3,270	700	550	700	70			338														223,342	2,470,011	1,090,105	32.4763	-104.1757
3001520963	LEVERS FEDERAL SWD 002	Below	Below	Cisco Reef	OCD	3,258	10,560	8,144	8,160											7,260		8,124	8,805		10,104		0	1,767,789	1,546,567	32.5066	-104.3624
3001521824	STATE L 001	Below	Below	Delaware	OCD	3,236	11,100	3,980	4,130											7,950	8,280		9,642	10,043	10,412		0	134,334	132,397	32.4928	-104.2872
3001522782	M H FEDERAL COM SWD 001	Below	Below	Cisco Reef	OCD	3,854	8,381	8,004	8,381										1,592	3,551	7,502	7,932					0	4,035,239	4,990,041	32.4145	-104.4552
3001505774	TENNESSEE FEDERAL 001	Above	Above	Yates	OCD	3,467	5,010	2,418	2,470																		0	129,966	99,889	32.6441	-103.8679
3001521515	MYRTLE MYRA SWD 001	Below	Below	Delaware	OCD	3,236	11,750	3,002	5,050												8,800	9,930	10,185	10,788	11,008		0	98,295	107,789	32.4709	-104.1971
3001504686	STATE 002	Above	Above	Yates	OCD	3,210	1,520	1,443	1,520				1,181														0	55,368	921,287	32.5679	-103.9965
3001500129	SPRING SWD 001	Below	Below	Cisco Reef	OCD	3,304	10,784	8,300	8,400											2,300	7,558	8,155	10,430	10,748			0	1,244,902	900,037	32.5207	-104.3944
3001521010	MCKITTRICK 14 FEDERAL SWD 001	Below	Below	Morrow	OCD	4,025	12,366	11,500	12,366												7,145	8,110	8,925	9,320	10,180		0	8,117,303	9,601,167	32.3916	-104.4633

STATE OF NEW MEXICO

ENERGY, MINERALS AND NATURAL RESOURCES DEPARTMENT

OIL CONSERVATION DIVISION

BRUCE KING
GOVERNOR

ANITA LOCKWOOD
CABINET SECRETARY

POST OFFICE BOX 2088
STATE LAND OFFICE BUILDING
SANTA FE, NEW MEXICO 87504
(505) 827-5800

April 23, 1992

Mr. Eluid L. Martinez
State Engineer
P.O. Box 25102
Santa Fe, New Mexico 87504-5102

Dear Mr. Martinez:

As you may know, the Oil Conservation Division of the Energy, Minerals and Natural Resources Department, has primacy in administering the Federal Underground Injection Control Program for the State of New Mexico. This program mandates that the Division, in reviewing applications for salt water disposal and secondary recovery injection wells, make a determination that such injection shall not pose a danger of contaminating underground sources of drinking water containing less that 10,000 parts per million total dissolved solids.

Recently, an application was filed by Anadarko Petroleum Company to utilize the Exxon Federal Well No. 3 located 660 feet from the North line and 1980 feet from the West line (Unit C) of Section 19, Township 19 South, Range 33 East, NMPM, Lea County, New Mexico, as a salt water disposal well, injection to occur into the Capitan Reef at a depth of approximately 3500 feet to 4300 feet. The produced water to be injected into this well originates from the Delaware formation at a depth of approximately 5492 feet to 6020 feet, and contains total dissolved solids of approximately 219,389 parts per million. Injection is proposed to average 1000 barrels of water per day.

Anadarko presented geologic and engineering evidence and testimony at a public hearing held in Santa Fe on February 6, 1992, which indicates that in the area of concern, the Capitan Reef contains water with total dissolved solids of 105,532 parts per million, as evidenced by a water analysis from Anadarko's Teas Yates Water Supply Well No. 1 located 1330 feet from the North and West lines (Unit F) of Section 14, Township 20 South, Range 33 East, NMPM, which is currently completed in the Capitan Reef at a depth of approximately 3660 feet to 3762 feet. Based upon the evidence presented, the Division can approve the proposed injection into the Capitan Reef.

The Division's concerns regarding the proposed injection are as follows:

1) The Division has historically not allowed injection into the Capitan Reef as per an agreement supposedly reached between Mr. Pete Porter, previous director of the Division and Mr. Steve Reynolds;

2) Allowing the proposed injection at the present time would set a precedent, and as a result, the Division would expect to see numerous similar applications filed due to the unique ability of the Capitan Reef to easily accept injected fluids;

3) The Division lacks reservoir modeling capability and hydrologic expertise to adequately predict whether or not injection into the Capitan Reef on a large scale will ultimately have a detrimental affect on those portions of the Capitan Reef containing good quality water such as that currently being used by the City of Carlsbad.

Members of my staff have been in preliminary contact with Mr. Paul Saavedra of your office. Thus far, they have been unable to locate any documentation regarding the agreement between Mr. Porter and Mr. Reynolds.

I feel that this is a very important issue because once injection into the Capitan Reef is allowed and the injection occurs, it would be very difficult to perform remediation should contamination occur. We are therefore seeking your assistance in making a hydrologic determination that large scale injection of produced salt water into the Capitan Reef will not have a detrimental affect, at some future time, on those portions of the Reef containing fresh water. A hydrologic study of this nature will provide the Division scientific data and evidence needed to make informed decisions on the effects of salt water injection into the Capitan Reef.

Any assistance you can provide the Division in this matter will be greatly appreciated. If my engineering or geologic staff can be of any assistance, please feel free to request such assistance.

Sincerely,

William J. LeMay

William J. LeMay
Division Director

Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027
OCD Exhibit No. 11D

STATE OF NEW MEXICO

ENERGY, MINERALS AND NATURAL RESOURCES DEPARTMENT

OIL CONSERVATION DIVISION

BRUCE KING
GOVERNOR

ANITA LOCKWOOD
CABINET SECRETARY

POST OFFICE BOX 2088
STATE LAND OFFICE BUILDING
SANTA FE, NEW MEXICO 87504
(505) 827-5800

March 25, 1993

Eluid Martinez
State Engineer
Bataan Memorial Building
Santa Fe, NM 87501

RE: Proposed Injection into Capitan Reef

Dear Mr. Martinez:

The Oil Conservation Division has recently received another application to inject produced salt water into a portion of the Capitan Reef, this one being from Pronghorn SWD System of Hobbs, New Mexico. We are informed that the applicant has or is submitting information to your office and soliciting your support or approval for the project.

As you may remember, there has been a previous application for the same type of operation, which the Division denied. At that time we consulted with your staff regarding a long-standing agreement between Steve Reynolds and Pete Porter under which no injection would be allowed in the Reef.

As the agency responsible for protecting fresh water as designated by your office, we are very concerned about permitting injection into the Capitan Reef. We know that there are portions of the Reef which are major sources of fresh water in the area. Our concern is that injection of produced water could at some point contaminate the fresh water.

We would very much appreciate input from the experts in your office on questions within their expertise, specifically questions about the locations of fresh water and the potential alterations of water movement within the Reef which could cause contamination. We may ask that someone from your staff provide testimony at the hearing on this application.

That hearing is currently set for April 8, 1993, in the OCD conference room in the State Land Office Building, but we plan to continue that hearing to a later docket. We would like to hear from you prior to April 8 to help us determine what input your office can provide.

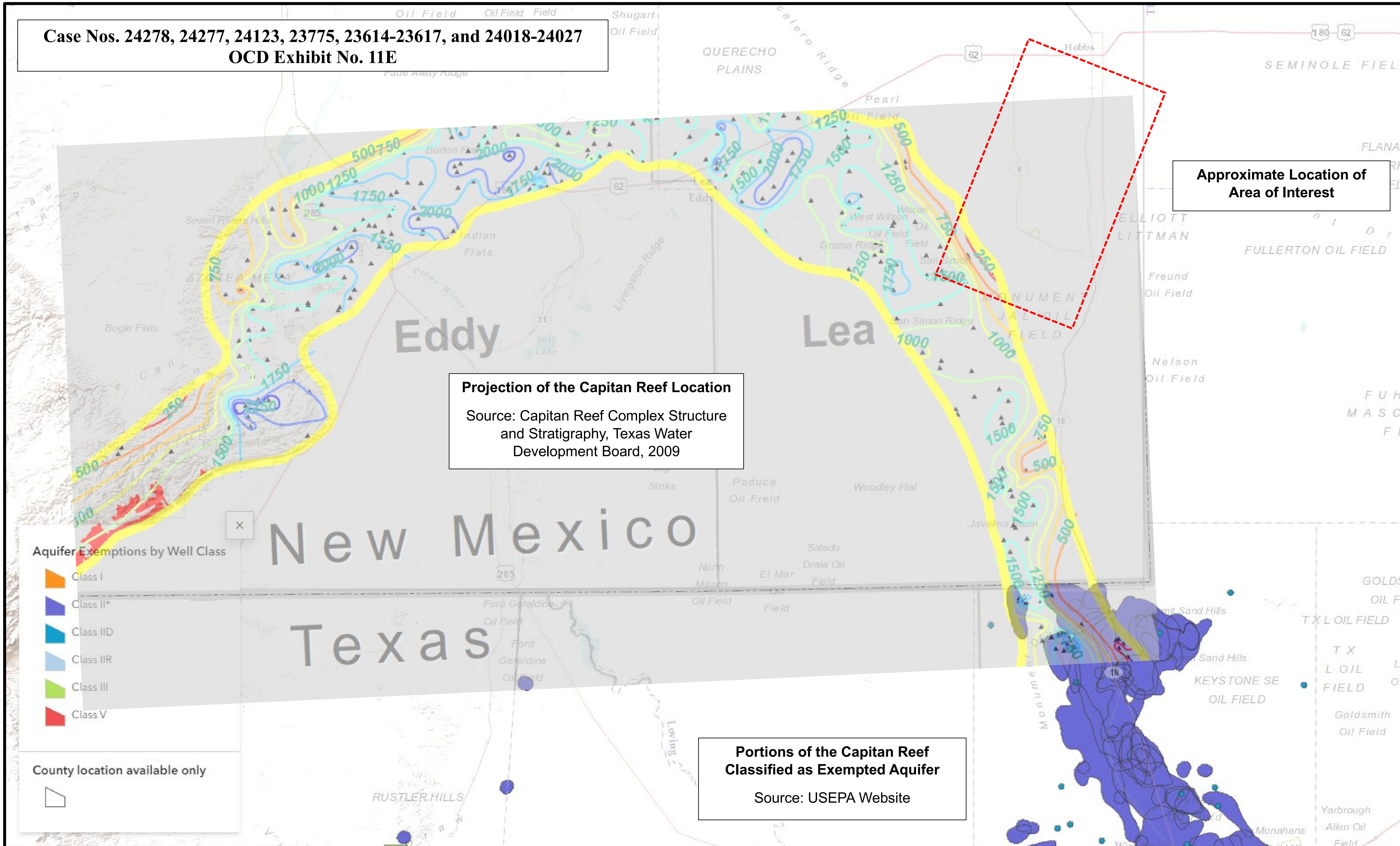
Thank you for your assistance.

Sincerely,

Lawrence O. Van Ryan,
Chief Engineer

LOVR/RGS

State of New Mexico
Energy, Minerals and Natural Resources Department
Oil Conservation Division



Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027
OCD Exhibit No. 12A

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, CA 94105-3901

December 22, 2014

Jonathan Bishop
Chief Deputy Director
California State Water Resources Control Board
P.O. Box 100
Sacramento, CA 95812-0100

Steven Bohlen
Oil and Gas Supervisor
Division of Oil, Gas and Geothermal Resources
California Department of Conservation
801 K Street, MS 18-05
Sacramento, CA 95814-3530

Dear Messrs. Bishop and Bohlen:

I am writing to follow up on EPA's July 17, 2014 letter to CalEPA and the Resources Agency regarding the State's administration of the federal Safe Drinking Water Act Class II Oil and Gas Underground Injection Control program. In that letter, we described serious deficiencies in California's Class II program and inconsistencies with federal UIC regulations and State Program primacy requirements. The letter also set forth comprehensive requirements and deadlines for the State to address the deficiencies and bring the program into compliance. Enclosed is a summary of the status of the State's responses to the July 17 letter.

Our frequent dialogue and your efforts in the last six months have illuminated the breadth and complexity of the challenges and the substantial workload faced by the State agencies in overcoming the program's deficiencies. The State's submittals and conceptual plans presented since July are a step in the right direction. However, a more definitive overall plan of State actions and milestones is critically needed by February 6, 2015, to bring the Class II program into compliance by February 15, 2017.

This letter highlights the main areas of recent discussion and provides direction for the State's submittal of a program revision plan by February 6, 2015. This plan should comprehensively address the results of EPA's 2011 audit and 2012 review, and any other related reviews available to the State; assure completion of the outstanding items listed in the enclosure; provide a detailed list of planned actions based on a two-year schedule of tiered priorities, specific deliverables, interim and final milestones; and identify the resources to be deployed to accomplish this work.

Injection Well Evaluations: Priority must be given to completing and submitting the review of existing Class II wells which may be injecting into non-exempt aquifers, particularly in non-hydrocarbon producing zones, as this is the critical path for evaluating the highest potential impacts to drinking water sources. The drinking water source evaluation for these wells should then proceed expeditiously, followed by appropriate actions to address any threats to drinking water (e.g., emergency orders to cease injection, permit rescission, information orders or exercise of other authorities).

Where injection for enhanced oil recovery or waste disposal is contemplated to continue via existing wells into aquifers without approved exemptions, or into portions of aquifers that are outside the specific areas exempted, the State needs to establish a process, priorities, and a schedule to evaluate and address any potential threats from these operations, and for timely development of aquifer exemption proposals. The schedule should reflect environmental and public health priorities and provide adequate time for public participation and for EPA to finalize any needed decisions on these aquifers over the course of the next two years, and no later February 15, 2017. The State must take actions to prohibit injections after February 15, 2017 in any aquifers for which EPA has not approved an aquifer exemption.

Further, State approval of any new wells in aquifers without approved exemptions or into portions of aquifers that are outside the specific area exempted should be limited to State-approved projects in hydrocarbon producing zones, and should include considerations such as: information from drinking water well surveys and recent water quality data in the vicinity of the injection wells; use of formations with greater than 3000 ppm TDS (as we understand the State is analyzing the conditions, if any, under which continued injection into hydrocarbon producing zones with water quality of less than 3000 ppm TDS should be permitted); use of compliance orders or exercise of comparable State authorities to compel operators' submittal of complete applications for aquifer exemptions, and to prohibit injections after February 15, 2017 in any aquifers for which EPA has not approved an aquifer exemption; availability of alternate disposal options; public review processes undertaken; and concurrence by DOC/DOGGR and State/Regional Boards. It is important to note that the State's granting of an authorization for an injection well prior to obtaining EPA's approval of an aquifer exemption does not guarantee EPA's approval, which will be based on regulatory criteria.

Aquifer Exemption Process: Aquifer exemptions are an essential component of the State's Class II well permitting program. The State must determine which aquifers to exempt, provide for public participation and submit proposed exemptions to EPA for approval. The State must support the proposed exemptions with strong technical data and robust evaluations before presenting them to the public and EPA. Given the multiple state agencies involved, explicit internal processes and procedures are needed to guide the gathering and thorough evaluation of the necessary data, and seek EPA approval regarding the specific aquifer exemptions. EPA's Aquifer Exemption Checklist, provided previously and again as an enclosure with this letter, outlines the requirements for aquifer exemptions. We also provided several examples and met with State staff on November 3, 2014 to discuss required documentation.

Historic Aquifer Exemptions: In addition to wells known to the State to be injecting into zones that do not have aquifer exemptions, some existing wells inject into 11 aquifers which have been historically treated as exempt, though data provided by the State to EPA with its 1981 primacy application indicate that these 11 aquifers were non-hydrocarbon producing and contained water that was less than 3000 ppm TDS. Pursuant to Section II(H) of the Underground Injection Control Program Memorandum of Agreement Between California Division of Oil and Gas and the United States Environmental Protection Agency, EPA believes the collection and consideration of current data on the water quality of these aquifers will afford the State the opportunity to determine whether existing wells in these aquifers should continue to operate. The State's program revision plan should outline performance of specific activities by the State and operators on a schedule that will allow EPA to finalize any needed decisions on these aquifers by December 31, 2016. No new wells should be authorized in an aquifer prior to the conclusion of this process for that aquifer.

EPA is committed to working with the State under 40 CFR 145.33 to enable the State to maintain primacy for the Class II Oil and Gas Underground Injection Control program. Given the need to resolve the program's serious deficiencies in a timely matter, EPA has strengthened oversight and support of the program. As part of this investment, EPA is prepared to re-direct a portion of the State's anticipated FY15 federal UIC grant allocation of approximately $550,000 to specific efforts targeted to advance the State's Class II program toward compliance with the Safe Drinking Water Act. We will consult with you on work to be led by EPA with these funds.

We look forward to continuing our collective efforts towards achieving our shared commitment to protect California's underground sources of drinking water, and anticipate receiving your program revision plan by February 6, 2015.

Sincerely,

Jane Diamond
Director, Water Division

Enclosures
(1) Status of State Response to EPA's July 17, 2014 letter
(2) EPA Aquifer Exemption Checklist

Status of State Response to EPA's July 17, 2014 Letter

1. Drinking Water Source Evaluation

State to provide initial assessment of whether any existing and potential sources of drinking water are at risk of contamination from improper Class II injection (due Sept 15th).

Location of private and public water system wells that may be at risk due to permitted Class II injection ***SEPTEMBER 15 SWRCB SUBMITTAL OF INITIAL REVIEW COMPLETED. DOGGR review of records and list of all remaining injection wells that are discharging into non-exempt, non-hydrocarbon zones of aquifers planned for completion and submittal to the State Water Board by January 5, 2015. Depending on the number of wells that are submitted, State Water Board expects to be able to identify any injection wells that are potentially impacting water supply wells by February 6, 2015.***

A plan to ensure protection of human health from actual or potential exposure to DW affected by any injection wells ***IN PROGRESS. State has issued some shut-in orders and information orders and plans to expand use of these tools as needed as evaluations are completed.***

A plan to communicate information to the public and to address subsequent questions/concerns ***OVERDUE.***

2. Documentation of Aquifer Exemptions

Provide all documents that pertain to the State's requests for aquifer exemptions, EPA's approval or denial of such requests, and any post-primacy appeals by the State regarding aquifer exemptions (due August 18th). ***COMPLETED--State has indicated orally that all documents have been provided. Some documents received via e-mail on August 18, 2014; one CD of 175 documents received on September 5, 2014; one CD of 40 documents received on November 4, 2014.***

3. Tiered Review of Class II Wells

a. Provide the number and location of all Class II wells permitted to inject in non-hydrocarbon producing formations with water quality less than 10,000 ppm TDS (excluding the formations known to be exempt). For each well, submit: operator's name, well type, depth, field and formation names, date injection commenced, water quality of both injection formation and injection fluid, and other pertinent details. (Due August 18th). ***PARTIAL DATA SET RECEIVED; STATE ACKNOWLEDGED IT WAS INCOMPLETE AND CONTAINED INACCURACIES.***

b. Provide the number and location of all Class II wells permitted to inject in non-exempt hydrocarbon-producing formations with water quality below 10,000 ppm TDS. For each well, submit: operator's name, well type, depth, field and formation names, date injection commenced, water quality of both injection formation and injection fluid, and other pertinent details. (Due October 15th). ***PARTIAL DATA SET RECEIVED; STATE ACKNOWLEDGED IT WAS INCOMPLETE AND CONTAINED INACCURACIES.***

c. Submit a plan and timeline for completion of a searchable database of all Class II injection well information statewide (along with a GIS overlay of the injection wells, injection formations, and aquifer exemptions). (Due September 15th). ***OVERDUE. The Division of Oil Gas and Geothermal Resources' web site contains a searchable database available to the public; however, we are awaiting a plan and timeline for making the database more robust and including additional information, such as aquifer exemptions.***

Develop a plan and timeline for submission to EPA of any new or revised aquifer exemption requests, which the State determines are appropriate. (Due September 15th). ***IN PROGRESS.***

4. State Program Consistency

Provide a status report on DOGGR's progress on the November 2012 Action Plan, which addressed Class II program deficiencies identified by EPA in our 2011 program audit. EPA also asked for a schedule for any proposed revisions to the Plan and for completing implementation of the Action Plan. (Due August 18th). ***IN PROGRESS.***

Aquifer Exemption Checklist

Reviewed by: ______________________ ***Date***_________

A- Regulatory Background and Purpose

An aquifer or a portion thereof which meets the criteria for an "underground source of drinking water" in § 146.3 may be determined to be an "exempted aquifer". The aquifer exemption criteria at 146.4 must be met as follows:

- Class I-V wells must meet criteria **146.4(a) and 146.4(b)(1)**; or **146.4(a) and 146.4(b)(2)**; or **146.4(a) and 146.4(b)(3)**; or **146.4(a) and 146.4(b)(4)**; or **146.4(a) and 146.4(c)**.
- Class VI wells must meet the criteria **146.4(d)**[1].

Regardless of the AE request or the type of injection activity, in all cases, first and foremost a demonstration that the aquifer or portion thereof does not currently serve as a source of drinking water is the required first step in the process. **EPA must evaluate each AE request to ensure the criteria are met prior to approval. EPA should also document its rationale for approving or disapproving each AE request in its statement of basis and, in case of exemptions that are substantial program revisions, EPA must provide public notice and an opportunity for the public to comment and request a public hearing.**

The purpose of this checklist is to ensure that appropriate and adequate information is collected to facilitate review of AE requests, and documentation of AE decisions. Some information described here may not apply to all AE requests.

B- General Information

AE request received by EPA on ____________________________

Is the aquifer exemption Substantial___________ **Non-Substantial**________________
Describe basis for substantial/non-substantial determination____
Is the aquifer exemption Complex? (Existence of drinking water wells, populated area ...) _______________________
Did the state or tribe provide public notice and opportunity for public hearing on the aquifer exemption request (144.7 (b)) Y/N
Were there any public comments? Y/N If yes, identify where they may be located________________________________
Date(s) of notice(s) published_____________, Public meeting(s) held__________________, Hearing held
_______________, any notable findings or pending litigation ____
Describe the notice and comment process and the final decision____
Describe the basis for the decision to exempt the aquifer or the basis for the decision to withhold or deny approval of the exemptions request____
Any anticipated issues associated with EPA approval or disapproval of the AE request Y/N___________________________________
Any meetings between EPA/States/Tribes/Operator to discuss issues Y/N list_______________________________

Is the request submitted by a primacy state or tribe? Y/N If yes name the State/Tribe/Agency
________ **Contact:**____
AE identified by the Primacy State or tribe and submitted for EPA review and final determination on _______________

Name of the Owner/operator_____________________________________
Well/Project Name:____ **Well Class** ___________________________
Purpose of injection: __________________________________(mineral mining/oil and gas/other)

Where is the proposed aquifer exemption located? Township, Section, Range, Quarter Section or other method used to identify the area ______________ Latitude and longitude information __________County__________ City____________ State___________ Add information about distance to nearest Town, County ____

Name of aquifer or portion of aquifer to be exempted ____

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[1] Additional Class VI only requirements in 40 CFR 144.7(d)(1) and (2) apply. This checklist does not address those requirements.

Areal extent of the area proposed for exemption____
Depth and thickness of the aquifer ____
Discuss the total dissolved solid (TDS) content of the aquifer, including the TDS at the top and bottom of the exempted zone, and the locations and depths of all fluids samples taken. ____________________________

C- Regulatory Criteria

An aquifer or a portion thereof may be determined to be an exempted aquifer for Class I-V wells if it meets the criteria in paragraphs (a) –(c) below. Other than EPA approved aquifer exemption expansions that meet the criteria set forth in 146.4(d), new aquifer exemptions for Class VI wells shall not be issued.

146.4: ( ) (a) ***Not currently used as a drinking water source*** **and:**

( ) **(b)(1)** It is mineral, hydrocarbon, or geothermal energy producing, or can be demonstrated by a permit applicant as part of a permit application for a Class II or Class II operation to contain minerals or hydrocarbons that considering their quantity and location are expected to be commercially producible; or
( ) **(b)(2)** It is situated at a depth or location which makes recovery of water for drinking water purposes economically or technologically impractical; or
( ) **(b)(3)** It is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption; or
( ) **(b)(4)** It is located over a Class III well mining area subject to subsidence or catastrophic collapse; or
( ) **(c)** TDS is more than 3,000 and less than 10,000 mg/l and it is not reasonably expected to supply a public water system.

( ) **(d)** *The areal extent of an aquifer exemption for a Class II enhanced oil recovery or enhanced gas recovery well may be expanded for the exclusive purpose of Class VI injection for geologic sequestration under § 144.7(d) if it does not currently serve as a source of drinking water; and the TDS is more than 3,000 mg/l and less than 10,000 mg/l; and it is not reasonably expected to supply a public water system.*

1- Demonstration that the aquifer or portion thereof does not currently serve as a source of drinking water per 146.4(a)

Describe the proposed exempted area and how it was determined:____________________________________
____

TDS:________________________ **Top:**________________________ **Bottom:**______________________
Lithology: ____
Permeability: __________ **Porosity:** _________ **Groundwater flow direction:** ________________________
Upper and Lower Confining Zone(s) and description of vertical confinement from USDWs:
____
Oil or mineral production history:____

Are there any public or private drinking water wells within and nearby the proposed exempted area for which the proposed exempted portion of the aquifer might be a source of drinking water Y/N If yes, list all those wells
____

- Include: pertinent map(s) visually showing the areal extent of exemption boundary, depth and thickness of the aquifer proposed for exemption, all known subsurface structures such as faults affecting the aquifer, and each of the inventoried water well locations by well # or owner name.
- Include: Table of all inventoried water wells showing: Well Name/#, Owner, (Private/Public), Contact information, Purpose of well (Domestic, Irrigation, Livestock, etc.), depth of source water, name of aquifer, well completion data, age of well (if known), and the primary source of well data (Applicant/State/Tribe/EPA).
- Include: Map showing the areal extent of exemption boundary, all domestic water wells considered potentially down gradient of the exemption and hydraulically connected to the exemption. If wells are deemed horizontally and/or vertically isolated from the exemption, this should be foot noted on the Table as well. Use arrow(s) to indicate the direction and speed of GW in the aquifer proposed for exemption.

- Describe the evidence presented in the application and/or methodology used to conclude GW direction and speed when relevant.
- *Include*: any source water assessment and/or protection areas and designated sole source aquifers located within the delineated area.

What is the appropriate area to examine for drinking water wells? Although guidance 34 says it should be a minimum of 1/4 mile, the determination of the appropriate area is on a case by case basis. Describe area and give a rationale.

Are there any public or private drinking water wells or springs capturing (or that will be capturing) or producing drinking water from the aquifer or portion thereof within the proposed exemption area? Y/N*

- Evaluate the capture zone of the well (s) in the area near the proposed project (i.e., the volume of the aquifer(s) or portion(s) thereof from within which groundwater is expected to be captured by that well).
- A drinking water well's current source of water is the volume (or portion) of an aquifer which contains water that will be produced by a well in its lifetime. What parameters were considered to determine the lifetime of the well?

  ____

- (*) If the answer to this question is Yes, therefore the aquifer currently serves as a source of drinking water.

2- Demonstration that the aquifer or portion thereof is mineral, hydrocarbon or geothermal energy producing per 146.4(b)(1)

Did the permit applicant for a Class II or III operation demonstrate as part of the permit application that the aquifer or portion thereof contains minerals or hydrocarbons that, considering their quantity and location are expected to be commercially producible? Did the permit applicant furnish the data necessary to make the demonstration as required by 40 C.F.R. 144.7(c)(1) and (2)? Summarize this demonstration and data ______________________________

- Include narrative statement, logs, maps, data and state issued permit.
- If the proposed exemption is to allow a Class II enhanced oil recovery well operation in a field or project containing aquifers from which hydrocarbon were previously produced, commercial producibility shall be presumed by the Director upon a demonstration of historical production having occurred in the project area or field. Many times it may be necessary to slightly expand an existing Class II operation to recover hydrocarbons and an aquifer exemption for the expanded area may be needed. If the expanded exemption for the Class II EOR well is for a well field or project area where hydrocarbons were previously produced, commercial producibility would be presumed.
- For new or existing Class II wells not located in a field or project containing aquifers from which hydrocarbons were previously produced, information such as logs, core data, formation description, formation depth, formation thickness and formation parameters such as permeability or porosity shall be considered by the Director, to the extent available.
- Many Class II injection well permit applicants may consider much information concerning production potential to be proprietary. As a matter of policy, some states/tribes do not allow any information submitted as part of a permit application to be confidential. In those cases where potential production information is not being submitted, EPA would need some record basis for concluding that the permit application demonstrates that the aquifer contains commercially producible minerals or hydrocarbons. For example, the permit application may include the results of any R & D pilot project. In this case, the applicant should state the reasons for believing that there are commercially producible quantities of minerals within the expanded area. Also, exemptions relating to new or existing Class II wells not located in a field or project containing aquifers from which hydrocarbons were previously produced should include the following types of information:
  - a- Production history of the well if it is a former production well which is being converted.
  - b- Description of any drill stem tests run on the horizon in question. This should include information on the amount of oil and water produced during the test
  - c- Production history of other wells in the vicinity which produce from the horizon in question.
  - d- Description of the project, if it is an enhanced recovery operation including the number of wells and there location.

For Class III wells, the Director must require an applicant to furnish data necessary to demonstrate that the aquifer is expected to be mineral or hydrocarbon producing and the Director must consider information contained in the mining plan for the proposed project, such as a map and general description of the mining zone, general information on the mineralogy and geochemistry of the mining zone, analysis of the amenability of the mining zone to the proposed mining method, and a time-table of planned development of the mining zone. Information to be provided may also include: a summary of logging which indicates that commercially producible quantities of minerals or hydrocarbons are present.

3- Demonstration that the aquifer or portion thereof is situated at a depth or location which makes recovery of water for drinking water purposes economically or technologically impractical per 146.4(b)(2)

Is the aquifer or portion thereof situated at a depth or location which makes recovery of water for drinking water purposes economically or technologically impractical? ______________________________

- List evidence in the application showing how this demonstration was made.
- EPA consideration of an aquifer exemption request under this provision would include information related to: The availability of less costly and more readily available alternative supplies, the adequacy of alternatives to meet present and future needs, and costs for treatment (including cost of disposal of treatment residuals) and or development associated with the use of the aquifer.
- The economic evaluation, submitted by the applicant, should consider the above factors, and these that follow:

1. Distance from the proposed exempted aquifer to public water supplies.
2. Current sources of water supply for potential users of the proposed exempted aquifer.
3. Availability, quantity and quality of alternative water supply sources.
4. Analysis of future water supply needs within the general area.
5. Depth of proposed exempted aquifer.
6. Quality of the water in the proposed exempted aquifer.

4- Demonstration that the aquifer or portion thereof is too contaminated per 146.4(b)(3)

Is the aquifer or portion thereof proposed for exemption so contaminated that it would be economically or technologically impractical to render that water fit for human consumption ______________________________

- List evidence in the application showing that the area to be exempted is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption.
- Economic considerations would also weigh heavily in EPA's decision on aquifer exemption requests under this section. Unlike the previous section, the economics involved are controlled by the cost of technology to render water fit for human consumption. Treatment methods can usually be found to render water potable. However, costs of that treatment may often be prohibitive either in absolute terms or compared to the cost to develop alternative water supplies.
- EPA's evaluation of aquifer exemption requests under this section will consider the following information submitted by the applicant:

(a) Concentrations, types, and source of contaminants in the aquifer.
(b) If contamination is a result of a release, whether contamination source has been abated.
(c) Extent of contaminated area.
(d) Probability that the contaminant plume will pass through the proposed exempted area.
(e) Ability of treatment to remove contaminants from ground water.
(f) Current and alternative water supplies in the area.
(g) Costs to develop current and future water supplies, cost to develop water supply from proposed exempted aquifer. This should include well construction costs, transportation costs, water treatment costs, etc.
(h) Projections on future use of the proposed aquifer.

5- Demonstration that the aquifer or portion thereof is located over a Class III well mining area subject to subsidence or catastrophic collapse per 146.4(b)(4)

Is the aquifer or portion thereof proposed for exemption located over a Class III well mining area subject to subsidence or catastrophic collapse?

- List evidence in the application showing that the area to be exempted is located over a Class III well mining area subject to subsidence or catastrophic collapse______________________________

- Discuss the mining method and why that method necessarily causes subsidence or catastrophic collapse. The possibility that non-exempted underground sources of drinking would be contaminated due to the collapse should also be addressed in the application.

6- Demonstration that the aquifer or portion thereof has TDS more than 3,000 and less than 10,000 mg/l and it is not reasonably expected to supply a public water system per 146.4(c)

Is the TDS of the aquifer or portion thereof proposed for exemption more than 3,000 and less than 10,000 mg/l?______

Is the aquifer proposed for exemption or portion thereof not reasonably expected to supply a public water system?____

- Identify and discuss the information on which the determination that the total dissolved solids content of the ground water in the proposed exemption is more than 3,000 and less than 10,000 mg/l and the aquifer is not reasonably expected to supply a public water system.
- Include information about the quality and availability of water from the aquifer proposed for exemption. Also, the exemption request must analyze the potential for public water supply use of the aquifer. This may include: a description of current sources of public water supply in the area, a discussion of the adequacy of current water supply sources to supply future needs, population projections, economy, future technology, and a discussion of other available water supply sources within the area.

7- Demonstration that a Class II aquifer exemption may be expanded to Class VI per 146.4(d) *(Refer to additional requirements in EPA's regulations for Class VI aquifer exemptions for this demonstration)*

May the areal extent of an aquifer exemption for a Class II enhanced oil recovery or enhanced gas recovery well be expanded for the exclusive purpose of Class VI injection for geologic sequestration under § 144.7(d)?______________

- List evidence in the application showing an existing Class II operation associated with AE that is being converted into Class VI____

EDMUND G. BROWN JR., GOVERNOR

DEPARTMENT OF CONSERVATION
DIVISION OF OIL, GAS, & GEOTHERMAL RESOURCES

CALIFORNIA Water Boards
STATE WATER RESOURCES CONTROL BOARD
REGIONAL WATER QUALITY CONTROL BOARDS

February 6, 2015

Ms. Jane Diamond
Director, Water Division
Region IX
United States Environmental Protection Agency
75 Hawthorne Street
San Francisco, CA 94105-3901

Re: Class II Oil and Gas Underground Injection Control

Dear Ms. Diamond:

Thank you for your letter of December 22, 2014, regarding the several meetings and dialogue we have been engaging in for the past several months, and your request for a more detailed plan of action to address issues with California's Class II Oil and Gas Underground Injection Control program.

Our agencies share a common goal with the United States Environmental Protection Agency (US EPA): to ensure public health and safety and the protection of groundwater resources for California residents who live and work near oil producing areas of California. The Division of Oil, Gas, and Geothermal Resources (Division) is responsible for ensuring that operators of oil and gas injection wells adhere to environmental rules and permit requirements that protect groundwater and other resources. The State Water Resources Control Board (State Water Board) assists the Division with the protection of water resources. Consistent with our mutual roles related to ongoing injection activities, the Division and the State Water Board are working closely together for more integrated oversight of the underground injection control program.

Following a discussion of the relevant background, we lay out the intended approach jointly developed by the Division and the State Water Board to address what has been the primary focus of our discussions since last summer: details about the review and, where necessary, redirection of underground injection operations in this State. We then address your request for detail on our intended plan to meet the critique expressed in the 2011 report of the Horsley Witten Group (Horsley Witten). Finally, we conclude with a discussion of plans to communicate these developments to the public.

BACKGROUND

Oil and gas production in California is a $34 billion annual industry, employing more than 25,000 people with an annual payroll of over $1.5 billion. California is the third largest oil-producing state in the nation, producing about 575,000 barrels per day. Property and other tax payments to the State and local governments from the industry amount to about $800 million annually. There are approximately 90,000 active or idle production and injection wells in the State.

Injection wells have been an integral part of California’s oil and gas operations for more than 50 years. Currently, over 50,000 oilfield injection wells are operating in the State. Injection wells are used to increase oil recovery and to safely dispose of fluid produced with oil and natural gas. About 75 percent of California’s oil production is the result of Enhanced Oil Recovery (EOR) methods such as steam flood, cyclic steam, water flood, and natural gas injection. Of these injection wells subject to UIC regulations, approximately 1,500 are fluid disposal wells, which are necessary to re-inject water produced with oil and gas and other fluids that cannot be disposed of through any other method, such as treatment, beneficial use, or recycling for other industrial applications. Most of the oil and gas fields in the State are quite mature. Many are in the waning stages of their productive cycle and require EOR techniques for continued development. The use of injection wells has been increasing in recent years. The increased use of injection potentially creates additional health and safety risks.

The protection of California’s aquifers from contamination is a matter of the highest priority for the Division and the State Water Board, and of special importance given the state of emergency resulting from our unprecedented drought. Therefore, this effort to modernize the regulation of the State’s injection wells must be both urgent and thorough. As explained more fully below, the Division has begun systematically reviewing these wells and applicable regulations as part of its mandate to protect public health and safety.

2011 Audit and Horsley Witten Report

In 2010, the Division worked with US EPA to conduct an audit to review the Division’s practices and regulations, and ensure the Division’s compliance with its obligations to properly administer its Class II injection program as a primacy state under the US Safe Drinking Water Act (SDWA) and applicable California law. The audit, conducted by the Horsley Witten Group, was completed in the summer of 2011. Horsley Witten highlighted several areas of concern, and the US EPA requested a plan to address the gaps identified. The Division responded in November 2012 (Enclosure A) by committing to adopt regulations and provide additional resources to close the gaps identified in the audit and create a stronger, more robust regulatory program.

In 2013, the Department took important steps toward meeting this commitment, including:

- Added 36 staff positions and enhanced staff training on UIC Program mandates and requirements
- Added resources to address orphan well plugging and abandonment
- Worked with the Legislature to help it enact revisions for the financial requirements for bonding
- Established a Division monitoring and compliance unit to conduct internal assessment of the UIC Program

Injection Project Review and Aquifer Exemptions

The Division acknowledges that in the past it has approved UIC projects in zones with aquifers lacking exemptions. The Division has not kept up with the task of applying for the necessary aquifer exemptions in hydrocarbon-bearing zones required by statute, even though many of these zones possess attributes that would qualify them for exemption. The Division has thus been slow to reconcile the reality that industry has expanded the productive limits of oil fields established in the 1982 primacy agreement with SDWA requirements to obtain aquifer exemptions.

Complicating matters, 11 aquifers with historical injection activities before 1982 were described in State documents in the early 1980s as proposed for exemption, and were endorsed as exempt in subsequent federal documents.[1] This led to the issuance of a number of injection permits in those 11 aquifers. However, the geologic basis for such exemptions is now in question. Therefore, in addition to the zones of aquifers that are lacking exemptions, these 11 aquifers that have historically been treated as exempt will also be evaluated to determine their appropriate exemption status.

<u>Injection Project Review Process</u>

The Division acknowledges injection project review continues, and a process has been developed to determine the wells with the highest risks associated with injection, and the steps to be taken to bring injection well permits into compliance with the primacy agreement with US EPA. This review examines the following groups of wells, in this order:

[1] Among these documents are (1) a December 13, 1982, Region IX memo forwarding to US EPA headquarters a version of the Memorandum of Agreement containing no significant exemption denials, described by Region IX as resolving “all known issues” with California’s primacy application, and (2) a May 17, 1985, letter from Frank Covington, US EPA’s then-Director of the Water Management Division for Region IX that appears to confirm that US EPA did not deny any of the exemptions proposed by the Division in its primacy application.

Category 1 Wells: Class II water disposal wells injecting into non-exempt, non-hydrocarbon-bearing aquifers or the 11 aquifers historically treated as exempt

Category 2 Wells: Class II enhanced oil recovery (EOR) wells injecting into non-exempt, hydrocarbon-bearing aquifers

Category 3 Wells: Class II water disposal and EOR wells that are inside the surface boundaries of exempted aquifers, but that may nevertheless be injecting into a zone not exempted in the primacy agreement

This review covers over 30,000 wells, more than 29,000 of which are cyclic steam wells in hydrocarbon zones. Review of wells in Category 1 is nearing completion. Review of wells in Categories 2 and 3 is expected to be complete in early 2016 as annual project reviews are completed in compliance with regulation. When completed, this review will serve to clarify records and improve data quality so that the full review of the UIC program can be completed.

An initial list of wells injecting into non-exempt USDW aquifers was previously provided to US EPA. That list includes Category I and II wells. While updating, reviewing, and validating that list is ongoing, attached (Enclosure B) is a summary of the information. Of the 2,553 wells on the list, approximately 140 of the active wells have been tabbed for immediate review by the State Water Board because the aquifers are reported to be lacking hydrocarbons and contain water with less than 3,000 mg/l total dissolved solids (TDS). The State Water Board is currently reviewing those wells to screen for proximity to water supply wells or any other indication of risk of impact to drinking water and other beneficial uses.

The Division review and updating of all injection well records in this list will be completed by May 15, 2015. The State Water Board expects to be able to review each injection well at a rate of approximately 150 wells per month.

Aquifer Exemptions Process

Together, the Division and the State Water Board have identified a process for aquifer status evaluation and potential aquifer exemptions. Although injection is occurring into aquifers that have not been exempted and the 11 aquifers historically treated as exempt, the potential risks associated with such injection differ from zone to zone. Last summer, as you know, some injection wells that potentially presented health or environmental risks were ordered to cease injection, and the operators ordered to provide specific data so that the regulatory agencies could fully evaluate whether these wells could potentially have had any measurable impact on nearby water supply wells. To date, the analytical data from the water supply wells that the State ordered to be tested have not shown any contamination of the water supply wells by oil and gas injection activities.

As injection activities in non-exempt aquifers and the 11 aquifers historically treated as exempt are delineated and described, the Division will require relevant oil and gas operators to obtain and prepare the necessary supporting documentation to justify aquifer exemptions. If these data support an aquifer exemption proposal, the Division will prepare and submit draft proposals for aquifer exemptions to the State Water Board for their concurrence. Once both agencies are satisfied with the proposed exemption and justification, the Division will submit the aquifer exemption applications to the US EPA for approval. A more detailed statement of the Division's and State Water Board's process for development of aquifer exemption applications is described in Enclosure C.

Going forward, the Division will take the following steps in this general order:

1. Work with US EPA to clearly articulate to the public the requirements for aquifer exemptions. This will be undertaken via two US EPA-sponsored workshops, one in Bakersfield the last week of February 2015 and the second in Los Angeles the last week of March 2015. The purpose of these workshops is to inform interested stakeholders, of the kind of data and data analysis essential to the development of a robust application by the State for an exemption of a portion of an aquifer from the SDWA by the US EPA.

2. Delineate a clear process for operators to supply the required supporting data to support and justify an aquifer exemption application. The Division will prepare its own guidance document to facilitate receiving appropriate information and data from operators to prepare justifiable aquifer exemption applications. A guidance document should be available by April 1, 2015.

Although this timeline suggests that the Division may not be able to move forward with aquifer exemptions until after April 1, 2015, this is not necessarily the case. The Division has already been evaluating the data supplied by operators for the preparation of a number of aquifer exemption requests by the State. Moreover, to enhance efficiency and reduce duplication of efforts, the Division is instructing oil and gas operators to develop a process by which several adjacent operators can combine data so that portions of aquifers relevant to the operations of different operators can be considered as a whole.

The Division will provide the data and an analysis of the data to the State Water Board for consultation prior to submitting them to US EPA. The Division will submit the exemption request to US EPA if the portion of the aquifer meets the criteria for exemption and the State Water Board determines that injection into the aquifer will not adversely affect existing or potential beneficial uses of groundwater.

Wind-Down of Existing Injection and Permitting of New Injection

The Division proposes to use a combination of administrative mechanisms to ensure that existing and new injection into non-exempt aquifers and the 11 aquifers historically treated as exempt is either phased out or covered by an aquifer exemption, and that any threats to drinking water or other beneficial uses of water are urgently addressed.

To summarize, the Division will use rulemaking to codify a wind-down schedule that provides transparency to the regulated community and the public at large. The schedule will provide for the phased elimination of new and existing injection into aquifers that have not been approved as exempt by the US EPA by February 15, 2017. New injection will be allowed only if strict criteria are met, and, like existing injection, will have to cease if no new exemption has been timely obtained. At the same time, the Division, in consultation with the State Water Board, will issue administrative orders to address specific circumstances where injection poses a threat to drinking water or other beneficial uses of water. Major highlights of the approach to address existing injection and new injection into these aquifers are presented below. A more detailed and complete description of the approach is contained in Enclosure D.

Rulemaking

By April 1, 2015, the Division will initiate rulemaking to establish a regulatory-compliance schedule to eliminate Class II injection into undisputedly non-exempt aquifers statewide. The proposed regulations will require the following:

1. The first principle of the regulations will be that all Class II injection into non-exempt aquifers with less than 10,000 TDS must, in all cases, cease by February 15, 2017, unless and until an aquifer exemption has been duly approved by US EPA. Injection may be ordered to cease earlier if a well is determined to potentially impact water supply wells,[2] as discussed further, below. ("Administrative Orders.")

[2] Injection wells potentially impacting water supply wells include injection wells into aquifers with 3,000 TDS or less that meet either of the following criteria: (1) the uppermost depth of the injection zone is less than 1,500 feet below ground surface (regardless of whether any existing supply wells are in the vicinity of the injection well), or (2) the injection depth is within 500 feet vertically and 1 mile horizontally of the screened portion of any existing water supply well.

2. Where a non-exempt aquifer contains 3,000 TDS or less and is non-hydrocarbon producing, injection must cease by October 15, 2015, unless and until an aquifer exemption has been approved by US EPA.

3. Where a non-exempt aquifer is hydrocarbon producing, new wells that are part of a previously approved project may be permitted if groundwater in the vicinity of the hydrocarbon-bearing zone does not currently have any beneficial use.[3] Such approvals will include the express condition that the permit expires on February 15, 2017, unless US EPA approves an aquifer exemption before then.

4. With respect to the 11 aquifers historically treated as exempt, the State Water Board and the Division will work with US EPA to evaluate these 11 aquifers. If any portion of these aquifers meets the criteria for exemption and the State Water Board determines that injection into the aquifer will not adversely affect existing or potential beneficial uses of groundwater, the Division will prepare and submit an exemption evaluation to US EPA. The evaluation and subsequent decision for these 11 aquifers will be completed by February 15, 2017. Either by the planned regulation or by other appropriate means, the Division may allow for limited new injection into these 11 aquifers in the unusual case where the proposed injection well is part of an approved project and an initial screening of the target zone shows that the zone contains hydrocarbons, has very high levels of naturally-occurring constituents (e.g., arsenic or boron), or there are other factors that make any affected groundwater unsuitable for beneficial use. Finally, the regulation would provide that any approval is subject to evaluation of the appropriate exemption status of the aquifer.

Administrative Orders

During the process of codifying the compliance schedule to phase out injection into non-exempt aquifers, the Division will issue administrative orders to halt any injection that potentially impacts water supply wells. The Division and the State Water Board are presently evaluating all injection into non-exempt USDWs and the 11 aquifers historically treated as exempt to identify potential for such impacts. The evaluation includes screening for water wells in the area of the injection well and collection and review of data regarding the water quality and depth of the aquifer where injection is occurring. Where the evaluation indicates that an injection well potentially impacts

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[3] Note that this does NOT include any use of produced water.

water supply wells, the Division will issue an emergency order to the operator to cease injecting immediately.

Issues Identified in the Horsley Witten Report

The Class II UIC Program is complex, consisting of several components that have distinct attributes and therefore require focused sets of regulations, compliance approaches, and review requirements. Given the rapid evolution of technologies and industry practices to extract more oil and gas from the State's mature fields, regulations developed even a decade ago may not fully address all of the issues created by what is now routine industry practice.

Horsley Witten included several recommendations pertaining to the practices, processes and policies of the Division used to implement the State's oil and gas regulations (Enclosure C). Report recommendations address a wide range of the Division's practices, activities and regulations, either directly or indirectly, in these areas:

- The definition and protection of underground sources of drinking water (USDW) area of review (AOR) and zone of endangering influence (ZEI)
- Well construction and cementing requirements
- Plugging and abandoning requirements
- Requirements for fluid disposal
- Requirements for monitoring of zone pressure
- Annual project reviews
- Well monitoring requirements
- Idle-well planning and testing program
- Financial responsibility requirements
- Cyclic steam injection wells
- Production from diatomite

<u>Regulation Development</u>

Many aspects of the recommendations of the Horsley Witten report can be implemented through existing Division regulations. However, others will require new regulation. Moreover, though cyclic steam injection wells and techniques employed for oil production in diatomite formations were not specifically addressed in the Horsley Witten report, they are extensively used in California, and existing regulations in these areas can be improved.

The Division has not had significant changes to its UIC regulations since the original primacy application. Regulatory amendments will be pursued through a rulemaking process to address these needs. The Division's goal is to ensure its regulations:

- Protect public health, the environment, and resources
- Address the UIC program mandates
- Address industry practices now and into the foreseeable future
- Are developed with the public participation contemplated by statute
- Set predictable standards for the regulated community
- Are implemented and enforced properly

These regulations will be quite extensive and will take some time to develop. The Division anticipates scheduling workshops, public meetings and other outreach to discuss regulations to cover a range of topics. The workshops should include at least the following: US EPA, State Water Board, Regional Water Quality Control Boards, Department of Toxic Substances Control, Air Resources Board, oil and gas operators, county and city agencies, non-government organizations, and the general public.

Potential Areas for New and Modified Regulations

We envision that a thorough review of the UIC program, the necessary attendant revision of existing regulations, and the development of needed new regulatory measures will require a period of approximately three years. The areas in which the Division is contemplating new or modified regulations include:

- Well construction and cementing requirements
- Plugging and abandoning requirements
- Evaluation of the zone of endangering influence (ZEI)
- Requirements for fluid disposal
- Requirements for monitoring of zone pressure
- Annual project reviews
- Well monitoring requirements
- Inspections and compliance/enforcement practices and tools
- Idle-well planning and testing program
- Cyclic steam injection wells
- Production from diatomite

Exclusive of proposed program revisions and aquifer exemption, the following milestones need to be met:

- Review of each and all current UIC projects for completeness of records and development of a list of deficiencies.
- Meetings with operators to review records and project deficiencies, and develop a compliance schedule (exclusive of aquifer exemptions).
- Initiate and complete rulemaking as a comprehensive package.

The Division will prepare a more detailed work plan for UIC rulemaking by April 15, 2015.

<u>Searchable Database for Class II Wells</u>

Activities to review UIC projects, check and revise data on all injection wells, and the development of aquifer exemption applications will all drive improvement in the Division's data that in turn will drive the need for vastly improved data management systems.

The Division's data management systems need significant upgrades. In response to the demands created by the requirements of the well stimulation program as a result of Senate Bill 4, the Division has hired additional GIS staff whose combined capabilities will be sufficient to manage all of the Division's needs. However, other aspects of the data management problem will be more difficult to resolve and will be conducted continuously in the background as project reviews, well reviews, and aquifer exemption information are compiled in a GIS environment.

You asked for a forecast of when the Division might be able to have a fully searchable database of injection wells available. Unfortunately, we cannot respond with specificity to this request due to inadequacies in the data management environment itself, and current lack of financial resources needed to create an adequate environment. The Division is, however, strongly committed to this effort and will follow up with US EPA when we can provide a more definitive answer.

The Division has created a team to develop a Feasibility Study Report (FSR) that will consider the Division's current and future requirements for data management and the kind of data environment that is needed for the Division to serve all stakeholders far more efficiently and effectively in the future. The FSR is a fundamental first step in the State's IT-procurement process and will be completed in December 2015. An approved

FSR will lead to a budget change proposal to seek the funds needed for system development.

Communication Plans

The closure of injection wells in Kern County during the summer of 2014, has required focused attention to communication with key stakeholder groups. These include industry, environmental organizations, elected officials – especially the state and federal elected representatives – the press, and via the press, the public.

The Division and the State Water Board have responded to a large number of stakeholder and public inquiries, and, to enhance public awareness, have developed frequently asked questions, statements, and presentations delivered at numerous public fora.

In short, much preparatory work has been accomplished. However we will continue to build on this communications foundation with additional attention to meet growing inquiries. We take seriously our responsibility to address growing public concern and press inquiries in a timely and informative manner.

Communication and outreach can be amplified by providing regularly updated information on the UIC program, background documents and reports, frequently asked questions, and work status on priority items noted above, specifically aquifer exemption applications, all clearly linked on the Division's web page. This page will serve as a clearinghouse for information on program activities, items of interest to stakeholders, and meeting and other notifications.

The Division and the State Water Board will continue to meet regularly with industry, environmental and other non-governmental organizations, elected officials, as well as US EPA.

CONCLUSION

The severe drought emergency, new regulations for well stimulation with ground water monitoring and other requirements, as well as long overdue revisions to the UIC program, have fundamentally changed how the Division and the State Water Board work together to protect public health and ensure the security of the State's groundwater resources. We are committed to making this relationship effective so that the State can achieve full compliance with the SWDA, and we are committed to revising the UIC program efficiently, and with public safety as a first priority. We look forward to continuing our active dialog with you and to advancing our Federal-State partnership.

Sincerely,

Steve Bohlen
State Oil and Gas Supervisor

Sincerely,

Jonathan Bishop
Chief Deputy Director

Attachments

cc: Cliff Rechtschaffen, Governor's Office
John Laird, Natural Resources Agency
Matthew Rodriquez, CalEPA

Enclosure A: Division’s November 16, 2012 Response to Report of Horsley Witten Group

DEPARTMENT OF CONSERVATION

Managing California's Working Lands

DIVISION OF OIL, GAS, & GEOTHERMAL RESOURCES

801 K STREET • MS 20-20 • SACRAMENTO, CALIFORNIA 95814

PHONE 916 / 445-9686 • **FAX** 916 / 323-0424 • **TDD** 916 / 324-2555 • **WEB SITE** conservation.ca.gov

November 16, 2012

David Albright, Manager
Ground Water Office
United States Environmental Protection Agency
75 Hawthorne Street
San Francisco, CA 94105-3901

Dear Mr. Albright:

The Division of Oil, Gas, and Geothermal Resources (Division) has reviewed the California Class II UIC Program Review report, prepared by Horsley Witten Group, Inc. (the Horsley Report), and has developed a plan to address the concerns and recommendations referenced in the report. As we have previously discussed, the Division began to evaluate its Underground Injection Control (UIC) program in 2009 with the hopes of bringing the program into conformance with state laws and regulations. Although we have improved our UIC program, and continue to evaluate it, the Division is aware that more work is required.

In your letter dated July 18, 2011, US EPA requested an action plan that includes clarification, improved procedures, and consistent standardized implementation in several areas, including:

- UIC staff qualifications;
- annual project reviews;
- mechanical integrity surveys and testing;
- inspections and compliance/enforcement practices and tools;
- idle well planning and testing program;
- financial responsibility requirements; and
- plugging and abandonment requirements.

Attached, please find the Division's plan to address the concerns of the US EPA and to identify those areas where the Division can improve its UIC program to more fully advance the objectives of the Safe Drinking Water Act. The Division views this action plan as a living document, which can be updated to incorporate any additional needed changes.

The Division looks forward to continuing our long-standing partnership with US EPA in protecting California's water resources. This plan will provide guidance as we update our UIC Program. We welcome your feedback and discussions regarding the elements in this action plan.

Sincerely,

Tim Kustic
State Oil and Gas Supervisor

cc: Mark Nechodom, Director, Department of Conservation
Rob Habel, Chief Deputy
Dan Wermiel, Technical Program Manager
Jerry Salera, UIC Program Manager

Department of Conservation
Division of Oil, Gas, and Geothermal Resources

Underground Injection Control Action Plan

RESPONSE TO THE US EPA JUNE 2011 REVIEW OF CALIFORNIA'S UIC PROGRAM

Background and Introduction

The EPA approved the Division of Oil, Gas, and Geothermal Resources' (Division, or DOGGR) application for primacy in the regulation of Class II injection wells under section 1425 of the Safe Drinking Water Act in March 1983. This approval gave the Division primary responsibility and authority over all Class II injection wells in the State of California. The EPA remains a Division regulatory partner with Division oversight authority and separate enforcement authority for Class II well operators. Class II wells inject fluids associated with oil and natural gas production.

The Division is fully committed to implementing a strong Underground Injection Control (UIC) program and will continue to pursue additional resources to address program growth and/or UIC well count increases.

This Action Plan is in response to a review of California's UIC program, requested by EPA's Region Nine Ground Water Office, and performed by the Horsley Witten Group. The Horsley Report, March 2011 (Report) was submitted to EPA in June 2011, and forwarded to the Division on July 18, 2011.

The Report included several recommendations pertaining to the practices, processes and policies of the Division used to implement the State's oil and gas regulations. To address a number of Report recommendations and other needed UIC regulatory updates, the Division will begin a rulemaking in 2013 to update the UIC program, well construction, and plugging and abandonment regulations. Additionally, the Division will determine whether statutory changes are needed and work with the California Legislature as necessary.

It is important to note the Division has added 43 staff positions during the past three years; these staff are working in UIC program or other closely related programs. Additionally, the Division implemented an internal review processes such as audits and mandatory Headquarters technical reviews to ensure greater compliance with UIC mandates.

The Division has followed the Report's format in this Action Plan and responded to each recommendation as presented in the Report. Each recommendation is presented in summary form below in bulleted paragraphs using italicized text.

USDW DEFINITION AND PROTECTION

- *The DOGGR Class II UIC Program should address the lack of clarity regarding USDW protection and ensure that all USDWs are fully protected from fluid movement and resulting degradation. USDWs containing more than 3,000 mg/l TDS should be protected as much as fresh water aquifers are protected in the permitting, construction, operation, and abandonment of injection wells.*

The Division's UIC program protects underground sources of drinking water (USDW) and requires that all injection is confined to the approved zone of injection. When the injection fluid is confined to the intended zone, all other zones and waters are protected.

Sections 3220 and 3228 of the California Public Resources Code (PRC) require zonal isolation. These standards have been followed for setting casing in, and plugging and abandonment of, all wells, including injection wells. Since these statutes predate the Safe Drinking Water Act, the USDW term is not found in state law.

During the rulemaking process to begin in 2013, the Division will pursue, as necessary, additional plugging and cementing requirements to increase USDW protection.

AREA OF REVIEW / ZONE OF ENDANGERING INFLUENCE

These recommendations address area of review/zone of endangering influence (AOR/ZEI) determinations, well construction practices and the status of wells located within the AOR, and corrective action requirements.

AOR/ZEI Determinations

- *The ZEI should be calculated, especially for disposal wells, with an accurate representation or reasonable estimate of all the relevant parameters that determine the ZEI, including the static pressures of the injection zone and USDWs in the project area.*
- *Disposal into non-hydrocarbon zones and normally* [sic] *pressure hydrocarbon bearing zones should be carefully monitored for reservoir pressure increases beyond normal hydrostatic pressures that could cause the ZEI to increase beyond the AOR over time.*
- *A fall-off pressure test should be run to determine the static reservoir pressure in wells in which shut-in pressures do not fall to zero after an*

extended shut-in period. If not done, the permit to inject should be rescinded.

- *The ZEI calculations should be reviewed if fall-off test results indicate higher than normal hydrostatic pressure in the injection zone. If the original AOR is smaller than the ZEI, the AOR should be expanded, or the permit to inject should be rescinded.*

Well Construction Practices and Status of Wells Located within the AOR

- *When casing repairs occur or when wells are plugged and abandoned, cement placement should be required at the base of USDWs in injection wells and AOR wells.*
- *Unless USDWs are known to be absent in the area, new injection wells should be required to have long string casing cemented to the surface.*

As outlined in our Primacy Application (ftp://ftp.consrv.ca.gov/pub/oil/publications/safe_water.pdf), the Division utilizes the one-quarter (1/4) mile fixed radius; if appropriate data is available, a radial flow equation may also be used to determine the ZEI. Although the Division has typically utilized the one-quarter mile fixed radius, we are now using other methods, such as Bernard's equation, the modified Theis equation, and equations included in the EPA's publication *Radius of Pressure Influence of Injection* (EPA-066/2-79-170) to determine the ZEI. The Division is pursuing new requirements for waste fluid disposal wells, and will consider including a more in-depth evaluation of the ZEI.

The Division is concerned with any injection well where injection zone pressure exceeds hydrostatic pressure. This may indicate an over-pressurized injection zone and a greater threat of non-confinement. In these cases, the Division looks at the ZEI and evaluates all wellbores within the ZEI to ensure fluid confinement to the intended zone of injection. In addition to the AOR, the Division requires mechanical integrity testing of all injection wells on a periodic basis. If a well lacks mechanical integrity, the Division requires the operator to immediately cease injection and to repair the well.

As for well construction requirements, the Division's long-standing requirements set by regulation dictate isolation of all oil and gas zones and any underground or surface water suitable for irrigation or domestic purposes. This is accomplished by requiring the cementing of casing and the placement of cement plugs. In addition, when wells are plugged and abandoned, the Division requires the use of heavy drilling mud in those portions of the hole that do not have cement. All these requirements will be evaluated for adequacy and updated as necessary in the rulemaking to begin in 2013 to ensure UIC program requirements are adequate for USDW protection.

DIVISION ANNUAL PROJECT REVIEW

- *This recommendation addresses records of well activity, pressures, inactive well and noncompliance data associated with injection well projects. Comprehensive project reviews should be conducted annually for all active injection well projects, including meetings with the operators for the most critical projects.*

The Division is fully committed to comprehensive project reviews. There are now two processes in place to address this concern -- a project audit, and an annual project review.

The Division has acquired additional staff who will audit injection projects to ensure that the projects are:

- permitted in accordance with state mandates;
- continued in compliance with mandates and approvals; and
- monitored and tested to ensure that fluid is injected into the intended zone.

This practice is authorized by the broad protection mandates of PRC section 3106 (a).

Additionally, the Division has increased UIC staff to ensure an annual project review for all injection projects. This amounts to a review of District office project data, and when necessary, a corresponding request that operators submit any missing data. Division staff will also meet with operators to discuss injection project operations to ensure that projects are operating in accordance with their project applications and approvals.

MONITORING PROGRAM

These monitoring program recommendations address mechanical integrity tests (MIT) and maximum allowable surface pressure (MASP).

Mechanical Integrity Tests

- *SAPT pressures equal to the maximum allowable surface injection pressure should be required if it will not cause damage to the casing. The newer wells should be able to withstand the MASP.*
- *If tested at less than the MASP, more frequent SAPTs and monitoring/reporting for anomalous pressure on the annulus should be required.*
- *Static temperature logs should be required more often in slimhole/tubingless completions where USDWs are present and especially for USDWs that are protected by only one casing string and/or lack cement at the base of USDWs.*

- *Cement bond logs should be required in new and newly converted injection wells unless USDWs are known to be absent in the area.*
- *Static temperature logs should be required if an existing well lacks sufficient cement at the base of USDWs, and/or squeeze cementing should be considered at the USDW base to ensure isolation from fluid movement.*

Maximum Allowable Surface Injection Pressures

- *Injection pressure should be maintained below fracture pressure in all new and existing projects, as determined by approved SRTs.*
- *SRTs should be required in new wells to determine the fracture pressure of the injection zone unless the formation fracture gradient is known with acceptable confidence based on SRTs in nearby wells.*
- *A pressure gauge should be required to measure bottom-hole pressures in SRTs directly rather than relying on calculation of friction losses from surface pressure measurements and injection rates.*

The Division now mandates that the Standard Annular Pressure Test (SAPT) be performed either to the approved injection pressure or 200 psi, whichever is higher. The Division does not allow variance from this policy unless there is the potential to damage well casing.

Since continuous monitoring of the annular space has advantages over the once-every-5-years SAPT, the Division now allows a positive-pressure annulus monitoring system with regular reporting with a lower-pressure, 5-year SAPT. These two testing options verify annular integrity while providing flexibility to operators.

The Division agrees that if wells are completed by way of slimhole/tubingless completions, static temperature logs should be required more often than for traditional completions. Division staff is moving forward to develop a policy to address this issue; if additional regulations are necessary, the Division will include this item in the rulemaking to begin in 2013.

The Division's regulations require that injection pressure be maintained below the fracture pressure as determined by a Step Rate Test (SRT). The Division has implemented a new SRT policy, based largely on EPA's procedures, which require downhole pressure monitoring. These improvements, along with additional field inspection staff and upgrades to electronic data management systems, increase the Division's oversight of injection operations, particularly the injection pressure.

INSPECTIONS AND COMPLIANCE / ENFORCEMENT PRACTICES AND TOOLS

- *A high priority should be placed for inspection of wells in or near residential areas and where USDWs are present.*
- *Cement placement operations should be witnessed to ensure the correct volumes and quality of cement are pumped into a well.*
- *Witnessing RATs in enhanced recovery wells should be given a higher priority, especially where USDWs may be present. At least 25 percent of RATs and all SAPTs in wells where USDWs are present should be witnessed.*
- *Whenever possible, districts should avoid giving advance notice of routine inspections to operators.*
- *Copies of an inspection report should be provided to the operator whether or not deficiencies are found during inspections.*
- *The installation of a pressure gauge on the tubing and the casing/tubing annulus should be required as a permanent fixture on all injection wells.*
- *Wells that fail MITs should be repaired or plugged and abandoned within a set time period, preferably within six months or sooner depending on the nature of the leak and potential threat to USDWs.*

The Division has successfully pursued additional UIC field staffing resources to increase UIC oversight in all areas. Although the Division regulations do not distinguish between rural and urban injection wells, the Division does allocate additional resources to oil fields in highly urbanized areas.

The Division's additional UIC resources have increased its oversight of wells in direct relation to their priority. The Division places a higher priority on inspecting water disposal wells which can pose a greater risk of contaminating USDW and fresh water.

The Division requires the witnessing of cement plugging operations. The witnessing of the plugging operations continues to be one of the highest priorities for Division field staff. In the office, detailed reviews of well work histories by Division engineers determine whether plugging operations comply with State mandates. If not, remedial work is ordered. Additional staffing, along with increased training, is ensuring the Division is properly evaluating cementing operations.

The Division has a goal to witness at least 25% of the Mechanical Integrity Tests (MIT), with a higher emphasis on disposal wells. Once new UIC personnel are fully trained the Division intends to increase this percentage.

The Division has been evaluating the performance of cyclic steam wells, which should be tested at least once a year, or immediately if evidence of casing damage or failure is found. This testing requirement is supported by data showing that cyclic steam wells undergo more stress than other types of injection wells. The Division will address additional cyclic steam well testing in the rulemaking to begin in 2013.

When staff witness detailed tests, a report is provided to the operator. In addition to witnessing tests, the Division performs thousands of inspections a year without prior notice to the operators. Because of the volume of inspections, the Division only documents that an inspection was performed and what deficiencies were found. The list of deficiencies is included in a letter to the operator, which details what must be done and the timeframe to bring the operation into compliance.

The permanent installation of pressure gauges on UIC wells is not a current requirement. With technological advancements, capturing pressure data is non-burdensome to operators. In 2013 when the Division moves forward with updating its UIC regulations, pressure monitoring via a gauge or equivalent equipment will be pursued.

If the MIT should indicate a mechanical integrity issue, the well is required to be shut-in immediately. The Division does not allow injection until the well is repaired. If the well should become idle (i.e. no injection for six continuous months over a five-year period) the well previously fell under the Division's idle well program (IWP) only. The IWP, which includes fluid level and casing integrity testing, is designed to eliminate the potential threat caused by idle wells. In addition to IWP, the Division has changed processes to ensure idle injection wells remain within the UIC program to ensure UIC program testing is conducted. Since current regulations lack clarity on when a well is to be repaired or plugged and abandoned, the Division will pursue such clarity in the rulemaking to begin in 2013.

IDLE WELL PLANNING AND TESTING PROGRAM

- *The idle well management and testing guidelines at Section 138 in the MOI should be modified to clarify which provisions apply statewide and which apply only to District 4.*
- *Idle well fees and bond/escrow amounts should be reviewed and increased amounts to levels that would encourage operators to reactivate or plug idle wells.*
- *The testing program should be modified to base the fluid level survey pass/fail results on the rise of fluid to the base of USDWs rather than the BFW.*
- *SAPTs should be required in wells after two years of inactivity and every two years after that where USDWs are present.*

- *Regardless of the fluid level survey results, an SAPT should be required if USDWs are present in wells with tubing and packers installed.*
- *Bridge plugs or cement plugs above the injection and below the base of USDWs should be required where USDWs are present in wells lacking tubing and packers. In addition, wells should be required to successfully pass an SAPT to remain in idle status.*
- *Idle wells that fail the SAPT should be repaired or plugged and abandoned within six months in areas where USDWs are present or within 60 days if USDWs are at risk of potential fluid movement.*

The Division will revisit the Idle IWP through the legislative process with the intent to update the law to address the excessive number of idle wells. The solution will address the potential financial liability to the State, the obligations of owners, and intends to address all of the recommendations listed in the above. Although program implementation in the 1990s did result in a drop in the idle well count, the idle well count in recent years has stabilized or crept upward.

Since all wells within an AOR are evaluated for zonal isolation, idle wells are reviewed as part of the Division's UIC program. The Division's IWP is operated separately from the Division's UIC program. However, both programs share the common goal of resource protection.

FINANCIAL RESPONSIBILITY REQUIREMENTS

- *Bond amounts should be reviewed and updated periodically to cover current plugging and abandonment costs.*
- *The financial responsibility program should be modified to require bonds and other financial responsibility instruments be held until wells are plugged and abandoned.*
- *Operator funding requirements and the number of deserted wells plugged and abandoned should be increased to numbers that will significantly reduce the inventory of orphan/deserted wells each year.*

The current bonding amount requirements are specified in State statute passed by the legislature; these amounts are outdated and therefore insufficient. Additionally California oil and gas wells are not required to have life-of-the-well bonding. The Division is committed to working with the legislature, the oil and gas industry, and interested parties to bring bonding requirements up to reasonable standards.

To partially offset the financial liability to California's citizens from orphan wells, the legislature has provided the Division with funding for orphan well plugging and abandonments.

PLUGGING AND ABANDONMENT REQUIREMENTS

- *Cement plugs should be placed at the base of USDWS to ensure long-term protection from fluid movement into or between USDWs.*
- *The presence of a DIVISION inspector should be required during cement placement in P&A operations to monitor and ensure that adequate cement quality and adequate quantities are pumped into a well.*

The Division's mandates require resource protection. Because the Division's UIC program requires that the injected fluid remain confined to the intended zone and that all oil and gas zones are isolated, USDWs are protected from any harm caused by injection. These basic requirements have not changed since the Division was granted Class II primacy; however the Division will review them to determine if updates are necessary for USDW protection.

Division inspectors are present during well plugging operations. To address the volume of plugging operations, regulations require that Division staff witness either the plug placement or the plug tagging (location and hardness) to verify that the plugging operation was completed in accordance with State mandates.

UIC STAFF QUALIFICATIONS

- *UIC-specific training (e.g., EPA-sponsored UIC Inspector Training Course) should be provided to new and recent hires in the DIVISION UIC Program within one year of employment.*
- *Inspectors should be required to hold a petroleum engineering or geology bachelor's degree or related degree or equivalent college courses and relevant experience.*
- *Consideration should be taken to adjusting compensation and benefits for UIC professional positions to levels more consistent with the oil and gas industry.*

The work required from Division staff is based on geology and petroleum engineering, and the Division is taking steps to ensure that the most qualified individuals are hired and promoted.

In the UIC program, knowledge of geology and petroleum engineering are critical. In addition to the knowledge acquired through formal education, the Division is seeking individuals with experience relevant to the duties they will be performing.

The Division is assessing existing staff to identify weaknesses and is providing training to ensure that staff is knowledgeable in critical areas. In cases where staff lack the appropriate education, their job duties will be limited until they gain the necessary knowledge and skill sets.

The Division operates within the State's civil service compensation mandates. Salaries are negotiated with established bargaining units. The Division has interest in ensuring that compensation mandates meet our needs and will work with the administration to achieve our goals.

GENERAL AND DISTRICT-SPECIFIC RECOMMENDATIONS

Although this section of the Report listed specific cases in various District offices, the Division is responding in more general terms. The Division has had several meetings with staff to discuss and explain duties and expectations. It has been made clear to staff that these expectations will be enforced uniformly throughout the Division.

To address UIC shortcomings the Division aggressively pursued and was granted additional resources. The Division has focused on the evaluation of new and existing project applications, and field surveillance to ensure compliance. The recommendation to acquire software to aid staff with regulating UIC operations is being pursed along with other Division data management needs.

The Division's UIC program includes more than protecting USDWs and fresh water; the Division is also mandated to protect hydrocarbon zones from damage. Under our statutes, the protection of fresh water and USDW s coexists with the protection of hydrocarbon resources.

The Report recommends higher inspection priority for wells located near residential areas or when a USDW is present. Although inspection frequency is not addressed in regulations, additional staffing is augmenting Division resources for all UIC inspection needs. As indicated above, the Division's regulations do not distinguish between rural and urban injection wells. However, the Division does allocate additional resources to oil fields in highly urbanized areas.

Conclusion

The Division has been required to protect oil, gas, and water resources, since its inception in 1915. Some statutes have changed very little since that time. With changes in oilfield practices and advancements in technology, the Division has been slow to change its regulatory framework. Although the Division has a strong regulatory program, the Division is pursuing greater and more consistent enforcement.

In 2009, the Division began an in-depth evaluation of the UIC program and identified some barriers to full compliance. This was the first of many steps to bring the Division's program back into greater compliance with our mandates. The Division has already ensured greater UIC program compliance by:

- Providing staff greater understanding of UIC program mandates and staff expectations;
- Adding 43 additional staff to UIC and associate programs;
- Creating an internal audit program; and
- Requiring an additional technical review for UIC projects.

The Division acknowledges that some operators have operated UIC projects without meeting all the requirements outlined in statutes and regulations, and have resisted coming into full compliance. The Division is committed to bringing all operators into compliance.

The Division has not had significant changes to its UIC regulations since the original primacy application. Regulatory amendments will be pursued through a rulemaking process to address these needs. The Division's goal is to ensure our regulations are:

- adequate for protection of public health, the environment, and resources;
- adequate to address the UIC program mandates;
- flexible to address industry practices now and into the foreseeable future;
- created in a transparent process;
- predictable for the regulated community; and
- properly implemented and enforced.

Tim Kustic
State Oil and Gas Supervisor
November 2012

Enclosure B: Breakdown of Wells Potential Injecting into Non-exempt USDW Zones.

Enclosure B: Breakdown of Wells Potentially Injecting into Non-exempt USDW Zones and the Eleven Aquifers that have Historically Been Treated As Exempt

Breakdown review completed as of February 5, 2015

A. List of Water Disposal Wells – 532 Wells

Wells with	Number of Wells	Number of wells issued orders	Number of wells (idle) in the 11 aquifers historically treated as exempt	Total Number of idle wells
Total Dissolved Solids (TDS) less than 3,000 mg/l	176	10	87 (20)	48
TDS between 3,000 and 10,000 mg/l	282	0	7 (4)	47
TDS under review or Data Requested	32	0	0	14
Subtotal	**490**	**10**	**94 (24)**	**109**
TDS greater than 10,000 mg/l (Wells being removed from list)	**42**			
Total	**532**			

B. List of Enhanced Oil Recovery Wells – 2021 Wells

Wells with	Number of Wells	Number of wells issued orders	Number of wells (idle) in the 11 aquifers historically treated as exempt	Total Number of idle wells
Total Dissolved Solids (TDS) less than 3,000 mg/l	503	0	0	57
TDS between 3,000 and 10,000 mg/l	1327	0	0	225
TDS under review or Data Requested	157	0	0	62
Subtotal	**1987**	**0**	**0**	**344**
TDS greater than 10,000 mg/l (Wells being removed from list)	**34**			
Total	**2021**			

Enclosure C: Division and Water Board Aquifer Exemption Submittal and Review Process

Enclosure C: Division and Water Board Aquifer Exemption Submittal and Review Process

Division of Oil, Gas, and Geothermal Resources - Aquifer Exemption Submittal and Review Process

The Division of Oil, Gas, and Geothermal Resources (Division) is the state agency responsible for approving the injection of Class II fluid through an agreement with the United States Environmental Protection Agency (US EPA). Through this agreement, which is referred to as "Primacy", the Division is responsible for ensuring proposed zones of injection are exempt under the Safe Drinking Water Act and the criteria of 40 CFR 146.4. If an operator, or operators, wish to inject Class II fluid into a zone where the water quality is less than 10,000 mg/l TDS, and the zone has not been previously exempted, DOGGR will request data from the operator(s) to provide supporting documentation necessary to meet the aquifer exemption criteria as specified in 40 CFR 146.4 (see Exhibit A).

DOGGR's evaluation of the supporting documentation provided by the operator(s) must verify:

A) The aquifer does not currently serve as a source of drinking water.

This evaluation will/must include a survey of all water wells in the area of the proposed injection that are likely to have hydrologic conductivity with the zone of injection. Although the area of proposed injection may be smaller than the area of hydrologic conductivity, the supporting documentation must include data and hydrologic modeling that indicates the impacts of injection into the formation would not impact wells in the surrounding areas. Although this criteria states that the aquifer does not serve as a sources of drinking water, the State will evaluate this criterion to a higher standard, that of evaluating whether the aquifer is currently being used for beneficial uses.

B) The aquifer cannot now, and will not in the future, serve as a source of beneficial water because:

(1) The aquifer is mineral, hydrocarbon or geothermal energy producing, or can be demonstrated to contain minerals or hydrocarbons that considering their quantity and location are expected to be commercially producible.

Supporting documentation must include such data as: production data and/or maps generated using geophysical logs to indicate the oil/water contact of historic and/or current hydrocarbon production. To extent the area will include future hydrocarbon production, the supporting documentation must include definitive data of potential future hydrocarbon production.

(2) The aquifer is situated at a depth or location that makes recovery of water for drinking water purposes economically or technologically impractical.

Data must be provided that clearly indicates the depth of all impacted water that has the potential to be used for beneficial purposes. Based on current data, water wells are being drilled deeper and deeper because of the drought. Many wells are being drill below 4,000 feet. Because wells are being drilled increasingly deeper, supporting data must be current and accurate.

(3) The aquifer is so contaminated that it would be economically or technologically impractical to render that water fit for beneficial use.

The drought has forced people of the State to use water of lesser quality to meet their needs. Data provided to support the claim that the water is so contaminated that it would be economically or technologically impractical to render that water fit for beneficial use must be current and accurate. Although the initial application will be evaluated by DOGGR, the State Water Resources Control Board and the Regional Water Quality Control Board(s) will be providing their expertise in the final analysis.

(4) The total dissolved solids content of the ground water is more than 3,000 and less than 10,000 mg/l and other water quality constituents render the water to be of a certain quality that it is not reasonably expected to be used for beneficial uses.

During the process of evaluating the supporting documentation, the Division will confer with the State Water Board, and the operators as necessary to ensure the supporting data is accurate, up-to-date, and complete. Once the Division is satisfied with the supporting documentation, all supporting documentation, an application, and a draft letter to the US EPA requesting an aquifer exemption will be forwarded to the State Water Board for comment. If necessary, the Division and the State Water Board will meet and discuss the supporting documentation. Where appropriate, the operators affected by the proposed aquifer exemption may be included in meetings to clarify or to provide additional supporting documentation. If both the Division and the State Water Boards are in agreement, and if appropriate, the State Water Board will provide a written concurrence to the application.

Although timelines to prepare an aquifer exemption would be helpful, the variety in the complexity and size of each individual application makes it impossible to clarify a definitive timeline to prepare a specific application. However, it is the Division's goal to collect the necessary documentation, evaluate the supporting data, and provide a draft application to the State Water Board as soon as possible after receiving and verifying the required supporting documentation.

Once DOGGR and the State Water Board have reached an agreement to forward an aquifer exemption application to the US EPA, DOGGR will proceed with providing the appropriate public notification and solicit comments on the proposed aquifer exemption. Upon conclusion of the public comment period, and once comments have been appropriately addressed, the Division will forward the application to US EPA – Region 9.

State Water Resources Control Board - Aquifer Exemption Application and Review Process

Aquifer Exemption Application

1. Aquifer exemption applications, along with the Division of Oil, Gas, and Geothermal Resources' (DOGGR) recommendations are submitted to the State and Regional Water Quality Board (State Water Boards).
2. State Water Boards review the aquifer exemption application and DOGGR's recommendations (submittal review criteria detailed below). If necessary, this review may include meetings with DOGGR and operator(s) affect by the application. Review time will depend on the scale of the application and complexity of the proposed aquifer exemption (estimated 30 to 60 days).
3. State Water Boards and DOGGR will work towards reaching a consensus that the aquifer exemption application contains sufficient documented evidence to meet the criteria for an aquifer exemption. If additional information is required to justify an aquifer exemption, DOGGR and/or the State Water Board, depending on the information required, will request additional data from the affected operator(s). This is anticipated to take 15 to 30 days, depending on the data requested.

Every effort will be taken to work both with DOGGR and the affected operator(s) to resolve a lack of supporting data to justify an aquifer exemption.

Note: Review of an aquifer exemption application by the Water Boards is estimated to take 50 to 95 days. If additional information is required, the review process will be greater.

Review Process Criteria

The State Water Boards will review and evaluate the aquifer exemption application(s) in accordance with the following criteria:

1. Identification of underground sources of drinking water and exempted aquifers (Code of Federal Regulations, Title 40, Section 144.7)
2. U.S. Environmental Protection Agency (EPA) Guidance for Review and Approval of State Underground Injection Control (UIC) Programs and Revisions to Approved State Programs (Attachment 3: Guidelines for Reviewing Aquifer Exemption Requests)
3. EPA Aquifer Exemption Checklist
4. Technical demonstration by operator that the waste will remain in the exempted portion of the aquifer(s)

5. A review of current and future beneficial sources of water (e.g. domestic, municipal, irrigation, industrial)
6. Pertinent elements of Regional Water Board Basin Plan(s)

Upon conclusion of the State Water Boards review, the State Water Boards will provide one of the following findings:

a. If the State Water Boards concur with DOGGR that the aquifer exemption application meets the review criteria, the State Water Board will send a letter of concurrence to DOGGR, and copies to the affected operator(s). This is anticipated to take 5 days after concurring with DOGGR's recommendations.
b. If the State Water Boards concur that only portions of the aquifer exemption application meet the review criteria, the State Water Boards will send a letter to DOGGR and copies to the affected operator(s) requesting additional information. This is anticipated to take 5 days after making a determination.
c. If the State Water Boards conclude that the aquifer will not meet the criteria of an aquifer exemption, the State Water Boards will send a letter of its findings to DOGGR, with copies of these findings being sent to the affected operator(s). This is anticipated to take 5 days after making a determination.

Exhibit A - 40 CFR 146.4: Criteria for Exempted Aquifers

An aquifer or a portion thereof which meets the criteria for an "underground source of drinking water" in § 146.3 may be determined under § 144.7 of this chapter to be an "exempted aquifer" for Class 1-V wells if it meets the criteria in paragraphs (a) through (c) of this section. Class VI wells must meet the criteria under paragraph (d) of this section:

(a) It does not currently serve as a source of drinking water; and

(b) It cannot now and will not in the future serve as a source of drinking water because:

(1) It is mineral, hydrocarbon or geothermal energy producing, or can be demonstrated by a permit applicant as part of a permit application for a Class II or III operation to contain minerals or hydrocarbons that considering their quantity and location are expected to be commercially producible.

(2) It is situated at a depth or location which makes recovery of water for drinking water purposes economically or technologically impractical;

(3) It is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption; or

(4) It is located over a Class III well mining area subject to subsidence or catastrophic collapse; or

(c) The total dissolved solids content of the ground water is more than 3,000 and less than 10,000 mg/1 and it is not reasonably expected to supply a public water system

(d) The areal extent of an aquifer exemption for a Class II enhanced oil recovery or enhanced gas recovery well may be expanded for the exclusive purpose of Class VI injection for geologic sequestration under§ 144.7(d) of this chapter if it meets the following criteria:

(1) It does not currently serve as a source of drinking water; and

(2) The total dissolved solids content of the ground water is more than 3,000 mg/1 and less than 10,000 mg/1; and

(3) It is not reasonably expected to supply a public water system.

Priorities, timelines and process

Taken in series, the sequence and timelines leading to a decision on aquifer exemptions will create a high level of concern that: 1. The body of work needing to be accomplished in a two-year period either cannot be managed, or, 2. The process will result in a large proportion of applications sent to US EPA in the final months of the period, without hope for resolution by February 15, 2017. Hence there is an essential need for the Water Board and DOGGR to work together in parallel as data are accrued by operators in support of exemptions to maximize parallel efforts and minimize serial efforts. To a large degree, such parallel work can only be possible if the data submitted are accurate, up to date and compiled in a readily accessible, standardized way. Further, the case for exemption must be rendered in a succinct, fact-driven form, supported by supporting data in appendices.

To facilitate an efficient workflow, DOGGR will establish a team of staff whose sole purpose will be to manage aquifer exemptions applications, and whose job it will be to know the status of any application at a given time and to work with operators to facilitate the development of a complete data set needed for the development of an aquifer exemption application to US EPA.

There are potentially as many as 100 aquifers for which portions are of interest to multiple operators and are likely candidates for consideration for exemption. Though a clear set of priorities is being developed in consultation with industry associations, who will assist in this effort, criteria that will drive priority consideration will include: date all data and justifications are certified as complete by DOGGR, impact on production levels within the state, impact on operator ability to produce, quality of the data submitted, timeliness of operator response to questions and data requests, and clarity of the case for exemption.

Enclosure D:
More Detailed Look At
Administrative Concepts

ENCLOSURE D: MORE DETAILED LOOK AT ADMINISTRATIVE CONCEPTS

The following actions will be initiated through an appropriate combination of proposed rulemaking and enforceable orders.

1. Disposal into non-hydrocarbon producing zones[1] of aquifers that are clearly not exempt:

    a. No new disposal wells will be permitted unless and until EPA approves an aquifer exemption.
    b. Existing disposal wells:
        i. If potentially impacting water supply wells,[2] the Division will issue emergency order to operator to cease injection immediately. Water Board will issue an information order.[3]
        ii. If not potentially impacting water supply wells, and the aquifer is 3,000 mg/L total dissolved solids (TDS) or less, injection must cease no later than October 15, 2015 unless EPA approves an aquifer exemption. Water Board will issue an information order.
        iii. If not potentially impacting water supply wells, and the aquifer is more than 3,000 mg/L TDS and less than 10,000 mg/L TDS, injection must cease no later than February 15, 2017 unless EPA approves an aquifer exemption. Water Board will issue an information order. If there are supply wells in any portion of the aquifer, or if any portion of the aquifer is at a depth that may be reasonably expected to supply a public water system, the Division and the Water Board may issue orders on a higher priority basis.

2. Injection into hydrocarbon producing zones of aquifers that are clearly not exempt:

    a. If groundwater in the vicinity of the hydrocarbon producing zone does not currently have any beneficial use[4]

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[1] Hydrocarbon producing zone is the portion of an aquifer that "cannot now and will not serve as a source of drinking water" because: "It is mineral, hydrocarbon or geothermal energy producing, or can be demonstrated by a permit applicant as part of a permit application for a Class II or III operation to contain minerals or hydrocarbons that considering their quantity and location are expected to be commercially producible." (40 CFR § 146.4 (b)(1).)

[2] Injection wells potentially impacting water supply wells include injection wells into aquifers with 3,000 mg/L total dissolved solids (TDS) or less that meet either of the following criteria: (1) the uppermost depth of the injection zone is less than 1500 feet below ground surface (regardless of whether any existing supply wells are in the vicinity of the injection well), or (2) the injection depth is within 500 feet vertically and 1 mile horizontally of the screened portion of any existing water supply well.

[3] Water Board information order will require that the operator submit information related to the injection and the quality of groundwater.

[4] Note that this does not include any use of produced water.

        i. New wells that are part of an approved project may be permitted with the express condition that permit expires on February 15, 2017, unless EPA approves an aquifer exemption.
        ii. For existing wells, injection must cease by February 15, 2017, unless EPA approves an aquifer exemption.
    b. If groundwater in the vicinity of the hydrocarbon producing zone has any current beneficial use
        i. No new permits will be issued.
        ii. For existing wells, injection must cease by February 15, 2017 (or sooner, depending on the use of the groundwater), unless EPA approves an aquifer exemption.

3. <u>Injection into eleven aquifers with disputed exemption status:</u>

    a. No new disposal wells will be permitted unless and until EPA approves an aquifer exemption evaluation. An exception may be made in the unusual case where the proposed injection well is part of an approved project, and an initial screening of the target zone shows that the zone contains hydrocarbons, has very high levels of naturally-occurring constituents (e.g., arsenic or boron), or there are other factors that make it unsuitable for beneficial use.
    b. Existing disposal wells:
        i. If potentially impacting water supply wells, the Division will issue emergency order to operator to cease injection immediately. Water Board will issue an information order.
        ii. If not potentially impacting water supply wells, injection must cease no later than February 15, 2017, unless EPA approves an aquifer evaluation. Water Board will issue an information order. If there are supply wells in any portion of the aquifer, or if any portion of the aquifer is at a depth that may be reasonably expected to supply a public water system, the Division and the Water Boards may issue orders on a higher priority basis.

4. <u>The Division will submit any exemption requests or evaluations for the above three categories of aquifers over time, and with sufficient opportunity for EPA to review the requests and approve or disapprove all of them by February 15, 2017.</u>

Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027
OCD Exhibit No. 12C

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, CA 94105-3901

March 9, 2015

Jonathan Bishop
Chief Deputy Director
California State Water Resources Control Board
P.O. Box 100
Sacramento, CA 95812-100

Steven Bohlen
State Oil and Gas Supervisor
Division of Oil, Gas Geothermal Resources
California Department of Conservation
801 K Street, MS 18-05
Sacramento, CA 95814-3530

Dear Messrs. Bishop and Bohlen:

Thank you for your February 6, 2015 letter setting forth a comprehensive plan to ensure that California's Class II Underground Injection Control ("UIC") program will come into compliance with the Safe Drinking Water Act (SDWA). We are pleased that you have initiated action to implement the plan, for example by issuing orders on March 3, 2015 to operators to immediately cease injection where your ongoing evaluation revealed that an injection well was potentially impacting water supply wells. To ensure that the State continues to make progress towards full compliance with the SDWA, we have indicated to you the need to establish additional milestones prior to February 15, 2017, which is the final compliance deadline for Class II wells currently injecting into a non-exempt aquifer. Enclosed is a schedule of required activities and deliverables, with target milestones and compliance deadlines, which are described below.

Drinking Water Protection Well Evaluations: Getting a complete picture of the scope of the problem is key to achieving full compliance, and the State's plan includes an ongoing process to review wells that may be injecting into non-exempt aquifers. The process described on pages 3-4 of the February 6th letter divides the wells into three categories based on the potential risk to groundwater and includes review by both DOGGR and the State Water Board. The February 6th letter states that you anticipate completing this review in early 2016. EPA has established deadlines for the State's completion of the combined injection well and water supply well screening for each of the three categories identified in the February 6th letter. The deadlines are as follows:

- May 15, 2015 for Class II water disposal wells injecting into non-exempt, non-hydrocarbon-bearing aquifers and the 11 aquifers historically treated as exempt (Category 1);
- July 31, 2015 for Class II enhanced oil recovery (EOR) wells injecting into non-exempt, hydrocarbon-bearing aquifers (Category 2); and

- February 15, 2016 for Class II disposal and EOR wells that are inside the surface boundaries of exempted aquifers, but that may be injecting into a zone not exempted by EPA (Category 3).

DOGGR has continued to review well records and in the process has proposed that EPA consider an additional category of wells which inject steam into hydrocarbon producing formations to enhance product recovery (cyclic steam). We understand you are in the process of collecting information on these wells, which were not included in Enclosure B of your February 6th letter. By May 15, 2015, DOGGR shall update Enclosure B to include cyclic steam wells and provide a schedule for completing the State's review of these wells and bringing them into compliance by February 15, 2017.

Keeping these well evaluations on schedule will facilitate prompt issuance of emergency orders, as needed, to protect water supply wells, as described on pages 7-8 of the February 6th letter.

Aquifer Exemption Process: The State's plan describes an aquifer exemption process that requires both DOGGR and the State Water Board to agree that an aquifer exemption is appropriate before the State forwards an exemption application to EPA for consideration. Informing the public and the regulated community about this process and the requirements, in addition to obtaining public input on specific exemptions, is essential. DOGGR's planned release of guidance on the aquifer exemption process around April 1, 2015 will facilitate this outreach. We appreciated the opportunity to participate in the public workshop you held in Bakersfield on February 24; we plan to participate in a second workshop in Long Beach on March 24 and will make ourselves available as needed for future outreach.

A critical aspect of the aquifer exemption process will be providing EPA with adequate time to review any proposed exemption to determine whether it satisfies the SDWA's regulatory requirements. Given the compliance deadlines to eliminate all injection into non-exempt aquifers by October 15, 2015 (for wells injecting into non-hydrocarbon bearing zones under 3,000 mg/L TDS) and February 15, 2017 (for all remaining Class II wells), EPA is establishing interim milestones to make sure that EPA does not receive a substantial number of aquifer exemption applications to review at the last minute, and to prioritize any exemptions sought for disposal wells injecting into non-hydrocarbon-bearing aquifers. Accordingly, EPA expects that the State will submit aquifer exemption applications as follows:

- 100% of proposed aquifer exemptions for Category 1 disposal wells injecting into non-exempt, non-hydrocarbon-bearing aquifers containing 3,000 mg/L TDS or less: July 15, 2015;
- 90% of proposed aquifer exemptions for Category 1 disposal wells with injection into non-exempt, non-hydrocarbon bearing aquifers containing 3,000 -10,000 mg/L TDS, and all proposed exemptions for any of the 11 aquifers historically treated as exempt: November 15, 2015;
- 90% of proposed aquifer exemptions for Category 2 wells: February 15, 2016;
- 90% of proposed aquifer exemptions for Category 3 wells: August 15, 2016; and
- 100% of remaining proposed aquifer exemptions for existing wells by October 15, 2016.

Failure to submit applications in accordance with this schedule will seriously jeopardize EPA's ability to take final action on aquifer exemption requests in advance of the compliance deadlines.

With respect to the 11 aquifers that have historically been treated as exempt, we look forward to working with your agencies to evaluate whether those aquifers meet State and EPA criteria for Class II injection. As an initial step, we request that the State evaluate the current quality of each of these aquifers and provide a preliminary assessment by July 15, 2015 of whether available data would support an aquifer exemption proposal. Given existing data that indicates these aquifers contain less than 3,000 mg/L TDS and are not hydrocarbon-bearing, the State shall not permit new injection wells in these aquifers, even in the limited circumstances proposed on page 7 (and Enclosure D) of the February 6th letter, prior to State submittal of supporting information to EPA and an EPA decision. Further, the State shall require that existing wells cease injection into these aquifers by December 31, 2016, absent an EPA decision that the aquifer(s) meet criteria for Class II injection based on State submittal of supporting information between now and then.

To facilitate consideration of aquifer exemption requests, the State should require operators to provide the State with all necessary data and analyses in a manner that allows for review, public notice, and timely application to EPA for exemption, if appropriate. Anticipating that there will be situations where an operator, or the State, decides not to seek an exemption from EPA for an existing well in a non-exempt aquifer, the State should establish a plan and timeframes to discontinue use of wells after such decisions are made. Please submit this plan to EPA by July 15, 2015.

Rulemakings for Corrective Action and Class II UIC Program Improvements: The February 6th letter describes the State's plan to implement the compliance deadlines for winding down of injection activity in non-exempt aquifers through an administrative rulemaking. The target dates for this corrective action rulemaking process are:

- Submit Proposed Emergency Rulemaking to the Office of Administrative Law (OAL) by April 9, 2015;
- Finalize Emergency Rule by April 30, 2015;
- Initiate Permanent Rulemaking by June 1, 2015; and
- Finalize Permanent Rulemaking by April 30, 2016

Further, DOGGR is continuing to evaluate its entire Class II program and proposing to make programmatic improvements through a series of rulemaking actions and revisions to DOGGR's internal processes and program implementation. In lieu of submitting a work plan for a programmatic UIC rulemaking on April 1, 2015 as described in the February 6th letter, DOGGR will submit to EPA a detailed plan for comprehensive Class II program improvements that covers both proposed rulemaking and non-rulemaking program improvements by July 15, 2015. In addition, the target dates for regulatory revisions are:

- Submit initial proposed regulatory revisions to OAL by September 30, 2016; and
- Complete regulatory revisions by September 2018

EPA encourages earlier implementation of program improvements and the completion of interim steps and corrective action as soon as possible.

As one of these program improvements, DOGGR shall create a searchable injection well database. An effectively designed searchable database is necessary for DOGGR to properly manage permitting and enforcement of injection activity across the State, for EPA to conduct its oversight of the Class II program, and for the public to monitor injection activity. We understand that to accomplish this task, DOGGR must prepare and submit a Feasibility Study Report (FSR) to the California Technology Agency. The February 6th letter states that DOGGR has created a team to develop the FSR, which is targeted for completion by December 2015, to be followed by proposed inclusion in the State budget and a February

2017 target date to initiate operation of the database. EPA looks forward to close communication with the State regarding the progress and proposed framework for this essential database resource.

Communication and Outreach: In addition to the aquifer exemption workshops already mentioned, the State and EPA should continue to coordinate outreach and conduct additional informational workshops in the future, as needed. Also, we plan to meet monthly with representatives from your agencies to discuss the progress of the State's plan and the steps identified above. Please provide us with a detailed progress report prior to each meeting, and notify us as soon as you become aware of circumstances that may affect the plan's implementation.

We look forward to continuing our joint effort to protect California's underground sources of drinking water and ensure compliance with the SDWA.

Sincerely,

Jane Diamond
Director
Water Division

Enclosure

California Class II UIC Program Corrective Action Plan Schedule

A. Drinking Water Protection Well Evaluations

- Complete evaluations for "Category 1" injection wells **(May 15, 2015)**
- Complete evaluations for "Category 2" injection wells **(July 31, 2015)**
- Revise Enclosure B of the State's February 6th letter to incorporate cyclic steam wells and provide a schedule for completing a review of these wells and submitting proposed aquifer exemptions, as applicable, to meet the February 15, 2017 compliance deadline **(May 15, 2015)**
- Complete evaluations for "Category 3" injection wells **(February 15, 2016)**

B. Well Shut-Ins

- Shut-in deadline for wells injecting into non-exempt, non-hydrocarbon-bearing aquifers with TDS levels below 3,000 mg/l TDS **(October 15, 2015)**
- Shut-in deadline for wells injecting into the 11 aquifers historically treated as exempt, unless aquifer(s) is exempted by EPA pursuant to this corrective action plan **(December 31, 2016)**
- Shut-in deadline for all existing wells injecting into non-exempt aquifers with TDS levels below 10,000 mg/L TDS **(February 15, 2017)**

C. Aquifer Exemption Process

- Issue Aquifer Exemption Guidance **(April 1, 2015)**
- Deadline for submission to EPA of all proposed aquifer exemptions for Category 1 wells injecting into aquifers containing 3,000 mg/L TDS or less (excluding wells injecting into the 11 aquifers historically treated as exempt) **(July 15, 2015)**
- Deadline for submission to EPA of an evaluation of each of the 11 aquifers historically treated as exempt with a preliminary assessment of whether current data would support an aquifer exemption proposal by the State **(July 15, 2015)**
- Deadline for submission to EPA of a plan and timeframes to address closure of injection wells for which the State is not seeking an aquifer exemption **(July 15, 2015)**
- Category 1 wells: Target for submission of 90% of proposed aquifer exemptions, and 100% of proposed exemptions for any of the 11 aquifers historically treated as exempt **(November 15, 2015)**
- Category 2 wells: Target for submission of 90% of proposed aquifer exemptions **(February 15, 2016)**
- Category 3 wells: Target for submission of 90% of proposed aquifer exemptions **(August 15, 2016)**
- Deadline for submission to EPA of all proposed aquifer exemptions for decision by February 15, 2017 **(October 15, 2016)**

D. Rulemakings for Well Shut-Ins, Corrective Action and Class II UIC Program Improvements

Well Shut-Ins

- Initiate Emergency Rulemaking - submit proposed rule to OAL **(April 9, 2015)**
- Final Emergency Rule – estimated completion date **(April 30, 2015)**
- Initiate Permanent Rulemaking **(June 1, 2015)**
- Final Permanent Rulemaking – estimated completion date **(April 30, 2016)**

Regulatory Revisions and Non-Regulatory Improvements

- Submit detailed plan for comprehensive Class II program improvements to EPA (proposed rulemaking actions and non-rulemaking steps) **(July 15, 2015)**
- Submit initial proposed regulatory revisions to OAL **(September 30, 2016)**
- Complete regulatory revisions **(September 2018)**

Searchable Well Database

- Complete Feasibility Study Report **(December 31, 2015)**
- Award Database contract **(July 2016)**
- Implement database **(February 2017)**

E. Communication and Outreach

- Aquifer Exemption workshop **(March 24, 2015)**
- Agencies meet monthly to review progress. Prior to each meeting DOGGR/SWRCB will provide a progress report to EPA **(March 2015 - March 2017)**

State of California • Natural Resources Agency
Department of Conservation
Division of Oil, Gas, and Geothermal Resources
801 K Street • MS 18-05
Sacramento, CA 95814
(916) 445-9686 • FAX (916) 319-9533

Edmund G. Brown Jr., *Governor*
Kenneth A. Harris Jr., *State Oil and Gas Supervisor*

March 7, 2017

Mr. Michael Montgomery
United States Environmental Protection Agency – Region IX
75 Hawthorne Street
San Francisco, CA 94105-3901

Dear Mr. Montgomery:

By letter of March 9, 2015, the United States Environmental Protection Agency (US EPA) directed the Division of Oil, Gas, and Geothermal Resources (Division) to evaluate eleven aquifers that were historically treated as exempt to determine whether available data would support an aquifer exemption proposal for any of these aquifers or portions thereof. The Division, with concurrence from the State Water Resources Control Board (State Water Board), has completed its evaluation and has determined that the eleven aquifers should not be considered exempt, except with respect to the portions of the Walker Formation and Santa Margarita Formation that were exempted under the recently approved Round Mountain and Fruitvale aquifer exemptions, and except with respect to any portion(s) that the State identifies for exemption and US EPA approves in the future as the result of an exemption proposal. The Division hereby requests that US EPA enter into the addendum (attached hereto as Enclosure A) to the 1982 Underground Injection Control Program Memorandum of Agreement between the Division and US EPA for the purpose of clarifying the current, non-exempt status of the eleven aquifers.

By its terms, the addendum would not preclude future consideration of new exemption proposals or changes in exemption status for these aquifers. If the Division in the future receives new information establishing that any of these aquifers (or portions thereof) meet the exemption criteria and are appropriate for injection, the Division may elect to submit an aquifer exemption proposal to US EPA following the required legal procedure. This is important to note in part because the Division has formally requested in separate correspondence that US EPA approve an aquifer exemption for portions of one of the eleven aquifers (the Walker Formation underlying the Round Mountain Field). While the addendum to the Memorandum of Agreement is not intended to preclude or affect in any way US EPA's consideration of that exemption proposal, the Division nevertheless requests that the aquifer's current status be clarified along with the others as non-exempt unless and until, and only so far as, US EPA approves an exemption for the aquifer.

The Division's determinations and request for formal clarification regarding these eleven aquifers is the result of an evaluation of available water quality data for these formations (attached hereto as Enclosure B). The Division made this data its preliminary assessments available on November 15, 2016 for a 30-day public comment period, which included a public comment hearing on December 14, 2016. A copy of the November 15, 2016 public notice is attached hereto as Enclosure C. The public comments received did not change the Division's determination to request this clarifying addendum from US EPA. The Division's comment summaries and responses are attached hereto as Enclosure D.

If you have questions or wish to discuss this matter, please contact me at (916) 323-1777 or by email at Ken.Harris@conservation.ca.gov.

Sincerely,

Kenneth A. Harris Jr.,
State Oil and Gas Supervisor

Enclosures:

Enclosure A:	Addendum to Underground Injection Control Program Memorandum of Agreement Between California Division of Oil, Gas, and Geothermal Resources and the United States Environmental Protection Agency Region 9.
Enclosure B:	Preliminary assessment of the eleven aquifers historically treated as exempt.
Enclosure C:	November 15, 2016 notice of public comment and hearing.
Enclosure D:	Division's public comment summaries and responses.

ADDENDUM to

Underground Injection Control Program
Memorandum of Agreement
Between
California Division of Oil, Gas, and Geothermal Resources
and
the United States Environmental Protection Agency Region 9

Whereas the California Division of Oil, Gas, and Geothermal Resources ("Division") and the United States Environmental Protection Agency ("EPA") (collectively, the "Parties") desire to clarify, as specified below, that eleven aquifers are not exempted aquifers for purposes of the Safe Drinking Water Act, the Parties hereby agree to the following Addendum to the Underground Injection Control Program Memorandum of Agreement signed by the Parties on September 28, 1982 and September 29, 1982 ("1982 Agreement"):

1. Notwithstanding any prior statement or attachment to the 1982 Agreement or historical practice to the contrary, the following aquifers are not exempted aquifers except with respect to any portion(s) that the State identifies for exemption and EPA approves as exempt as a result of a future exemption proposal:

    - The Pico Formation underlying the boundaries of the South Tapo Canyon Field;
    - The Tumey Formation underlying the boundaries of the Blackwell's Corner Field;
    - The Kern River Formation underlying the boundaries of the Kern Bluff Field;
    - The Santa Margarita Formation underlying the boundaries of the Kern Front Field, except for portions exempted by the Fruitvale aquifer exemption;
    - The Chanac Formation underlying the boundaries of the Kern River Field;
    - The Santa Margarita Formation underlying the boundaries of the Kern River Field;
    - The Walker Formation underlying the boundaries of the Mount Poso Field;
    - The Olcese Formation underlying the boundaries of the Round Mountain Field;
    - The Walker Formation underlying the boundaries of the Round Mountain Field, except for portions exempted by the Round Mountain aquifer exemption;
    - All aquifers underlying the boundaries of the Bunker Gas Field that are not in a hydrocarbon-producing zone; and
    - All aquifers underlying the boundaries of the Wild Goose Field that are not in a hydrocarbon-producing zone

2. This Addendum does not preclude future consideration of exemption proposals, or changes to exemption status following the applicable legal procedure, for the above aquifers or portions thereof.

3. All other terms and conditions of the Agreement remain unchanged and in effect.

4. The effective date of this Addendum shall be the date of execution.

________________________________	________________________________
Alexis Strauss Acting Regional Administrator Environmental Protection Agency Region 9	Kenneth A. Harris Jr. State Oil and Gas Supervisor California Division of Oil, Gas, and Geothermal Resources
________________________________	________________________________
Date	Date

Division of Oil, Gas, and Geothermal Resources

Preliminary Assessment of Eleven Aquifers Historically Treated as Exempt

July 15, 2015

Executive Summary

The Division of Oil, Gas and Geothermal Resources has made a preliminary evaluation of whether current data support a determination that the eleven aquifers historically treated as exempt currently meet the criteria for an aquifer exemption.

The eleven aquifers historically treated as exempt, and significant relevant data for each, are as follows:

- The **South Tapo Canyon** field - the **Pico** formation (no longer being used);

  Injection Wells: 0 TDS: 1,900 ppm NaCl Depth: 0-1,000'

- The **Blackwell's Corner** field - The **Tumey** formation (no longer being used);

  Injection Wells: 0 TDS: 2,100 -2,600 mg/l Depth: 945' – 1,473'

- The **Kern Bluff** field – the **Kern River** formation (no longer being used);

  Injection Wells: 0 TDS: 400 – 900 mg/l Depth: 0-200'

- The **Kern Front** field – the **Santa Margarita** formation;

  Injection Wells: 13 TDS: 460 – 2,318 mg/l Depth: 2,197' – 2,840'

- The **Kern River** field -the **Chanac** formation;

  Injection Wells: 12 TDS: 926 – 3,325 mg/l Depth: 425' – 1,335'

- The **Kern River** field – the **Santa Margarita** formation;

  Injection Wells: 32 TDS: 490 – 1,584 mg/l Depth: 760' – 2,285'

- The **Mount Poso** field – the **Walker** formation;

  Injection Wells: 5 TDS: 1,069 mg/l Depth: 1,740' – 1,796'

- The **Round Mountain** field – the **Olcese** formation;

  Injection Wells: 6 TDS: 2,693 mg/l Depth: 710' – 850'

- The **Round Mountain** field - the **Walker** formation;

  Injection Wells: 30 TDS: 2,335 mg/l Depth: 1,890' – 2,590'

- The **Bunker Gas** field - **all aquifers** within the field that are not in a hydrocarbon producing zone (no longer being used);

  Injection Wells: 0 TDS: 1,215 mg/l Depth: 3,000'

- The **Wild Goose** field - **All aquifers** within the field that are not in a hydrocarbon producing zone (no longer being used);

  Injection Wells: 0 TDS: 2,800 -5,000* mg/l Depth: 2,700' - 3,400'

  *More recent analysis indicate TDS around 24,000 mg/l

Key portions of the above data, in spreadsheet form:

Historically Treated as Exempt Aquifers Snapshot

Field	Formation	Number of Active Injection Wells	Total Dissolved Solids of Formation	Total Disolved Solids of Injected Fluid	Depth	Historic Volumes Injected Since 1983 in Barrels
South Tapo Canyon	Pico	0	1,900 ppm NaCl	600 ppm NaCl	1,000'	0
Blackwell's Corner	Tumey	0	2,100 - 2,600 mg/l	29,000 ppm NaCl	945' - 1,475'	2,425
Kern Bluff	Kern River	0	400 - 900 mg/l	600 mg/l	200	5,816,190
Kern Front	Santa Margarita	13	460 - 2,318 mg/l	360 - 6,400 mg/l	2,197' - 2,840'	151,820,215
Kern River	Chanac	12	926 -3,325 mg/l	491 - 2,000 mg/l	425' - 1,335'	568,987,463
Kern River	Santa Margarita	32	490 - 1,584 mg/l	491 -74,924 mg/l	760' - 2,285'	799,041,272
Mount Poso	Walker	5	1,069 mg/l	650 mg/l	1,740' - 1,796'	63,777,556
Round Moutain	Olcese	6	2,693 mg/l	1,900 mg/l	710' - 850'	160,798,008
Round Mountain	Walker	30	2,335 mg/l	1,600 - 2,900 mg/l	1,890' - 2,590'	1,529,910,014
Bunker	Undifferentiated	0	1,215 mg/l	10,675 - 11,025 ppm Chloride	3,000'	51,454
Wild Goose	Undifferentiated	0	24,349 mg/l	24,349 mg/l	2,700' - 3,400'	0

Division of Oil, Gas, and Geothermal Resources

Preliminary Assessment of Eleven Aquifers Historically Treated as Exempt

July 15, 2015

The US EPA, State Water Board, and the Division have agreed that the State will submit an evaluation of each of the 11 Historically Treated as Exempt (HTAE) aquifers with a preliminary assessment as to whether current data would support a determination that the criteria for an aquifer exemption are met.

11 HTAE aquifers historically treated as exempt are as follows:

- The **Pico** formation within the boundaries of the **South Tapo Canyon** field (no longer being used);
- The **Tumey** formation within the boundaries of the **Blackwell's Corner** field (no longer being used);
- The **Kern River** formation within the boundaries of the **Kern Bluff** field;
- The **Santa Margarita** formation within the boundaries of the **Kern Front** field;
- The **Chanac** formation within the boundaries of the **Kern River** field;
- The **Santa Margarita** formation within the boundaries of the **Kern River** field;
- The **Walker** formation within the boundaries of the **Mount Poso** field;
- The **Olcese** formation within the boundaries of the **Round Mountain** field;
- The **Walker** formation within the boundaries of the **Round Mountain** field;
- **All aquifers** within the **Bunker Gas** field that are not in a hydrocarbon producing zone and that have groundwater that has less than 10,000 TDS (no longer being used); and
- **All aquifers** within the **Wild Goose** field that are not in a hydrocarbon producing zone and that have groundwater that has less than 10,000 TDS (no longer being used).

More detail on each aquifer is set out below.

South Tapo Canyon Field, Pico Zone, Ventura District

1) Number of disposal wells permitted in the zone:
   0

2) Number of active producers:
   0

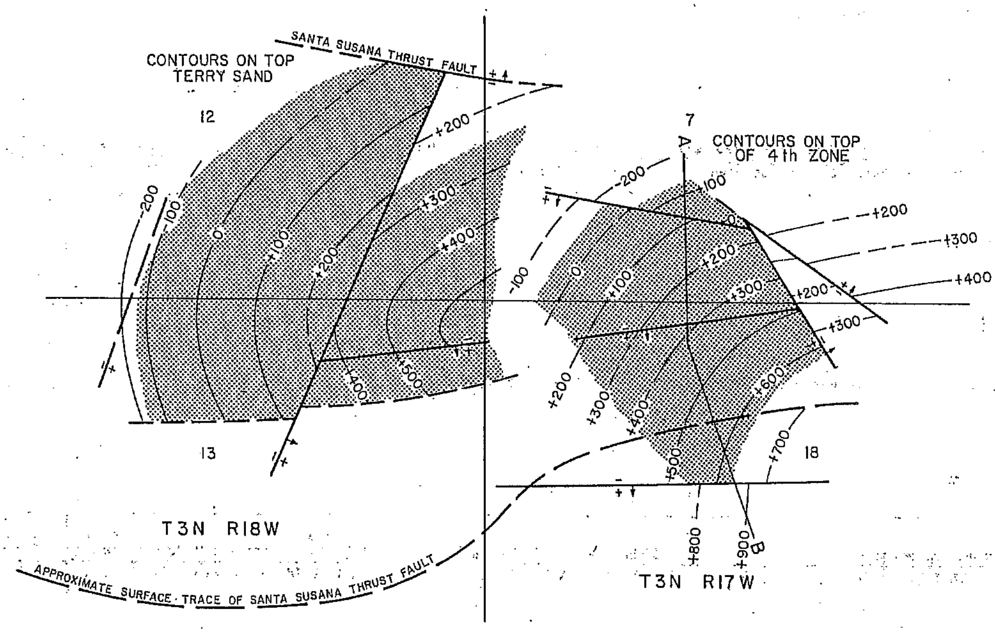
3) Depth of the zone across the field:
   At the surface on the south side of the field to 1,000' below surface depth on the north side. There are opposing thrust faults therefore, there is a wide range in zone depth across the field. Zone dips to the north across the field. This is based on the data sheet.

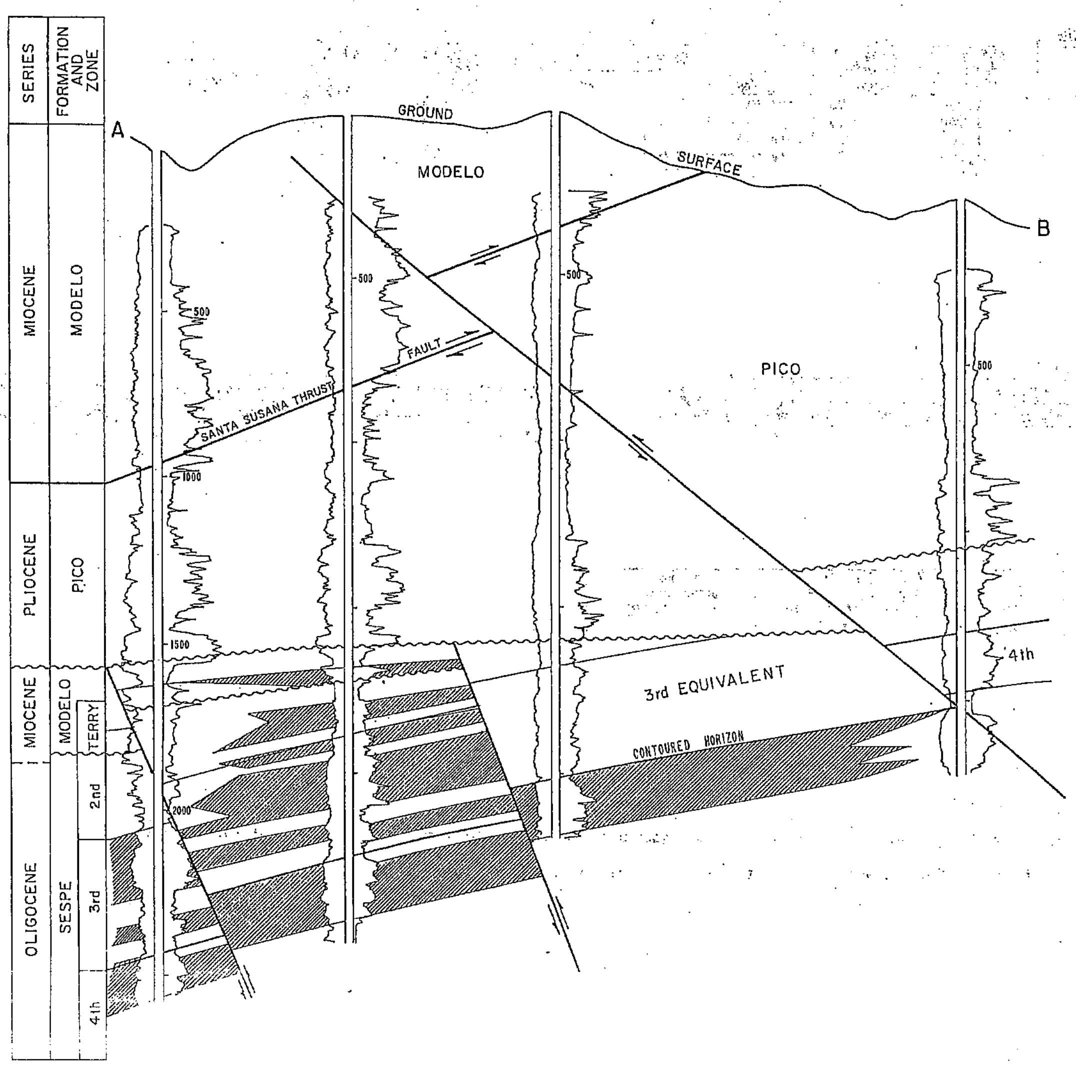
4) Volumes Injected Historically since 1983:
   None. District confirmed that there is no documentation that injection ever historically occurred in the Pico zone. The 5/17/1985 EPA letter contradicts this and indicates that injection did occur starting in 1948 and 1,903,000 Bbls was historically injected in this zone.

5) TDS of zone:
   1,900 ppm NaCl according to 5/17/1985 EPA letter

6) TDS of injection water:
   600 ppm NaCl according to the 5/17/1985 EPA letter

SOUTH TAPO CANYON OIL FIELD





LOCATION: 32 miles northeasterly of Ventura

TYPE OF TRAP: Faulted anticline

ELEVATION: 2,440

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Terry	Crown Central Petroleum Corp. "Tapo" 2	Terry and Jensen "Tapo" 2	13 3N 18W	SB	720	100	Feb 1953
2nd Sespe	Union Oil Co. of Calif. "South Tapo-Gillibrand" 11-7	Union Oil Co. of Calif. "Simi" 11-7	7 3N 18W	SB	99	411	Jul 1954
3rd Sespe	Same as above	Same as above	7 3N 18W	SB	*	*	Jul 1954
4th Sespe	Same as above	Same as above	7 3N 18W	SB	*	*	Jul 1954

Remarks: * Initial production from the 2nd, 3rd and 4th Sespe zones was commingled.

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Havenstrite Oil Co. "Tapo" 1	Same	Jan 1949	13 3N 18W	SB	8,394	Llajas	Eocene

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Terry	2,200	60	Miocene	Modelo	32	*90	II
2nd Sespe	1,800	70	Oligocene	Sespe	18	1,030	II
3rd Sespe	1,880	220	Oligocene	Sespe	18	1,030	II
4th Sespe	2,200	180	Oligocene	Sespe	18	1,030	II

PRODUCTION DATA (Jan. 1, 1974)

1973 Production Oil (bbl)	1973 Production Net gas (Mcf)	1973 Production Water (bbl)	1973 Proved acreage	1973 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
40,260	509	140,374	210	14	4,332,509	1,905,031	905,009	1953	50	35	240

STIMULATION DATA (Jan. 1, 1974)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
--			

SPACING ACT: Applies

BASE OF FRESH WATER: None

CURRENT CASING PROGRAM: 11 3/4" cem. 100; 7" combination string landed through zone and cemented through ports above zone.

METHOD OF WASTE DISPOSAL: All waste water is injected into a water-disposal well.

REMARKS: * Terry zone water is high in bicarbonates and total dissolved solids. A cyclic-steam project was started in 1964 and was discontinued in 1965 after the injection of 11,063 bbls. of water (in the form of steam).

REFERENCES: Hardoin, J.L., South Tapo Canyon Oil Field, Calif. Div. of Oil and Gas, Summary of Operations--Calif. Oil Fields, Vol. 44, No. 1 (1958).

Blackwell’s Corner Field, Tumey Zone, Bakersfield District office

1) Number of disposal wells permitted in the zone:
   0

2) Number of active producers:
   0

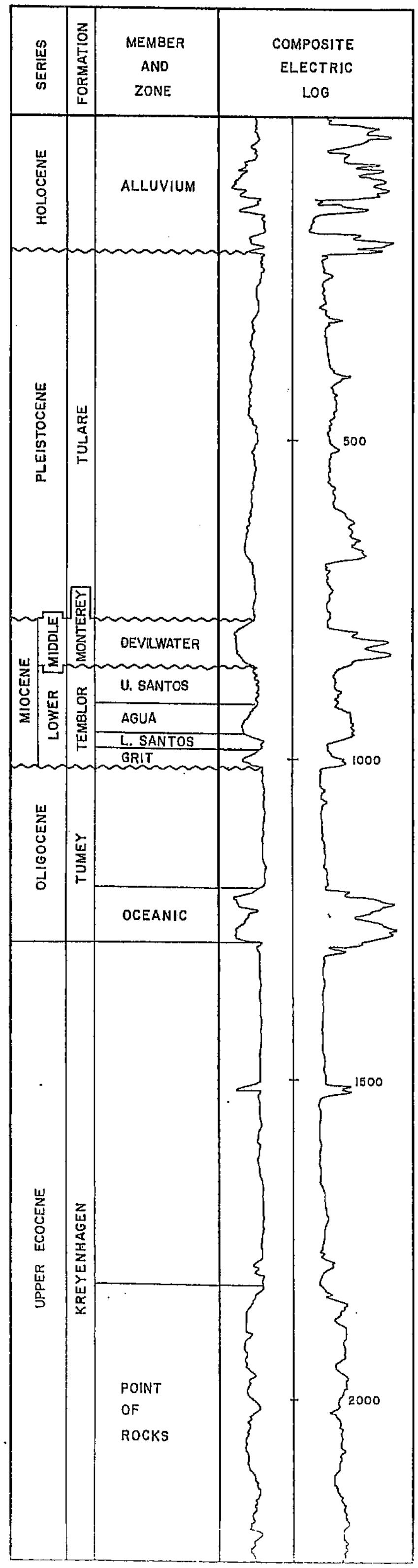
3) Depth of the zone across the field:
   945’ to 1,473’ below surface depth. Zone dips significantly to the Southeast across the field. Zone truncated by angular unconformity about ½ mile northwest of field.

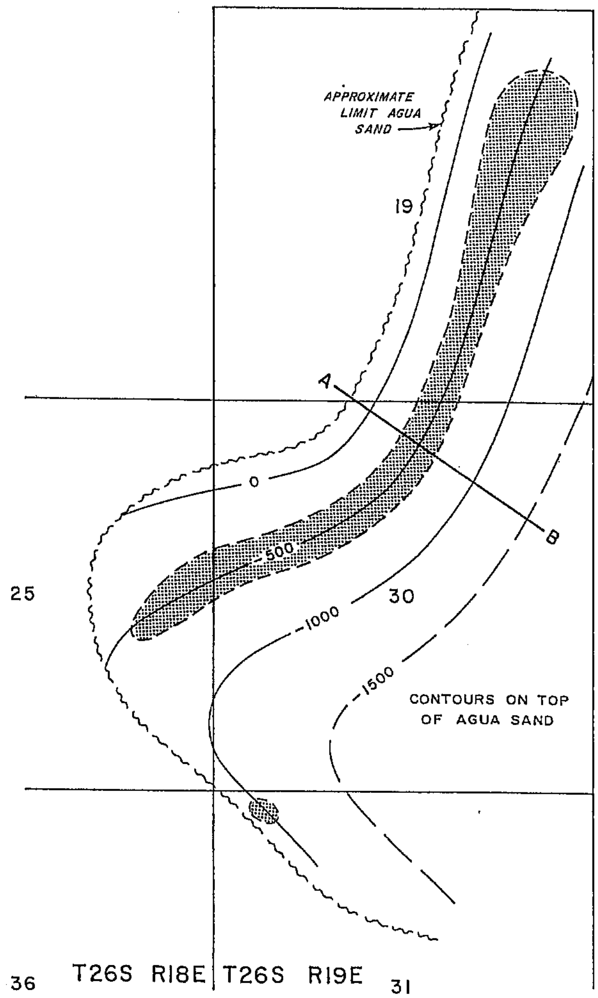
4) Volumes injected historically since 1983:
   2,425 Bbls, last injected on 5/1/1986

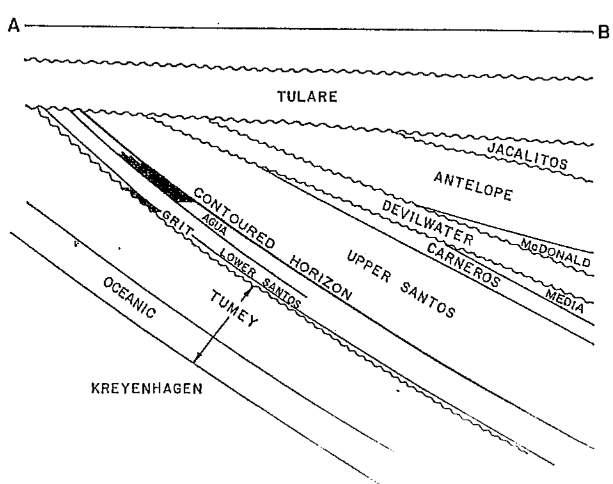
5) TDS of zone:
   Prior to injection 2,100 – 2,600 mg/l TDS (calculated) according to the 5/17/1985 EPA letter

6) TDS of injection water:
   29,000 ppm NaCl according to the 5/17/1985 EPA letter

BLACKWELLS CORNER OIL FIELD







LOCATION: 45 miles northwest of Taft

TYPE OF TRAP: Permeability barrier on an anticlinal nose

ELEVATION: 700

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Devilwater	General Crude Oil Co. Oper. "Occidental" 10	Etienne Lang "Occidental" 10-N.W. 30	30 26S 19E	MD	20	N.A.	Jun 1944
Agua	General Crude Oil Co. Oper. "Occidental" 3	Etienne Lang "Occidental" 3-N.W. 30	30 26S 19E	MD	50	N.A.	Dec 1943
Grit	General Crude Oil Co. Oper. "Occidental" 5	Etienne Lang "Occidental" 5-N.W. 30	30 26S 19E	MD	30	N.A.	Aug 1944

Remarks:

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
The Superior Oil Co. "O.L.C." 7	Same	Jul 1954	30 26S 19E	MD	3,224	Tumey	Oligocene

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Devilwater	700	25	middle Miocene	Temblor	13	N.A.	None
Agua	1,300	85	early Miocene	Temblor	14	790	None
Grit	1,400	5	early Miocene	Temblor	14	790	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
15,659	0	111,178	240	18	813,907	90,521	81,106	1946	63	38	250

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
--			

SPACING ACT: Applies

BASE OF FRESH WATER: None

CURRENT CASING PROGRAM: 7" cem. above zone; 5 1/2" liner landed through zone.

METHOD OF WASTE DISPOSAL: Evaporation and percolation sumps.

REMARKS: Formerly known as Shale Hills Area.

REFERENCES: Karmelich, F.J., Blackwells Corner Oil Field: Calif. Div. of Oil and Gas, Summary of Operations--Calif. Oil Fields, Vol. 37, No. 2 (1951).

Kern Bluff Field, Kern River Zone, Bakersfield District, East Side

1) Number of disposal wells permitted in the zone:
   0

2) Number of active producers:
   0

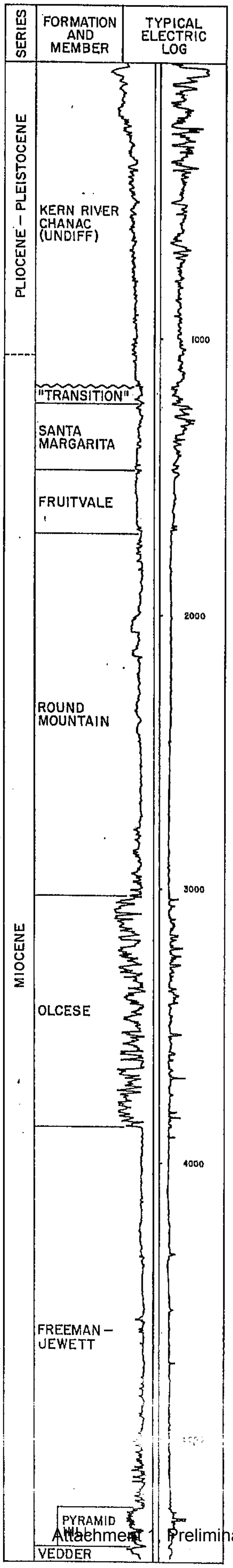
3) Depth of the zone across the field:
   Surface depth. Former WD well (API #02908849) uppermost perf is at 200' depth.

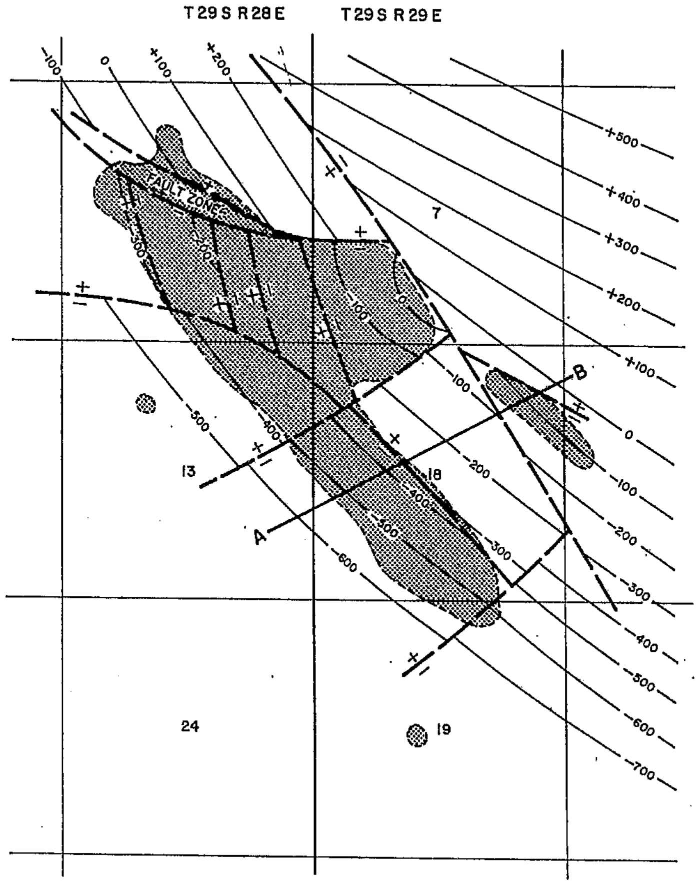
4) Volumes injected historically since 1983:
   5,816,190 Bbls, last injected on 6/1/1993

5) TDS of zone:
   400 – 900 mg/l according to the 5/17/1985 EPA letter

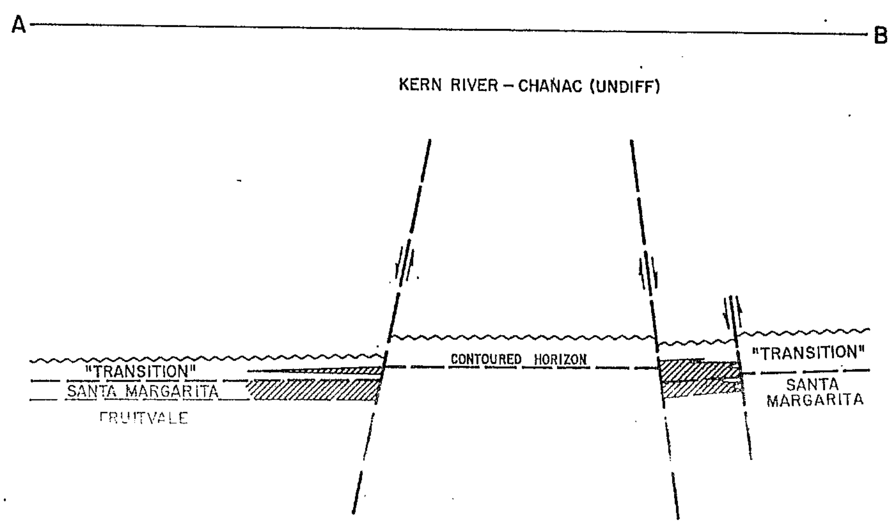
6) TDS of injection water:
   600 mg/l according to 5/17/1985 EPA letter

KERN BLUFF OIL FIELD





CONTOURS ON TOP OF SANTA MARGARITA



LOCATION: 6 miles northeast of Bakersfield

TYPE OF TRAP: Faulted homocline

ELEVATION: 800

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Transition	Shell Oil Co. "Afana" 1	Same as present	18 29S 29E	MD	18	N.A.	Feb 1944
Santa Margarita	Gulf Oil Corp. "Needham-Bloemer" 15	Oceanic Oil Co. "Needham-Bloemer" 1	7 29S 29E	MD	90	N.A.	Sep 1947

Remarks:

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Kernview Oil Co. "Muir" 13	Gene Reid Exploration Co. "Muir" 13	Feb 1949	18 29S 29E	MD	5,425	Vedder	early Mio

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Transition	740 - 1,350	30 - 80	late Miocene	Transition	14	5	None
Santa Margarita	950	55	late Miocene	Santa Margarita	14	5	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
216,477	0	3,365,718	670	131	9,410,522	0	845,373	1949	214	166	690

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
Cyclic-steam	1965	3,701,855	124

SPACING ACT: Applies

BASE OF FRESH WATER: 950

CURRENT CASING PROGRAM: 8 5/8" cem. above zone and across base of fresh-water sands; 6 5/8" liner landed through zone.

METHOD OF WASTE DISPOSAL: Waste water is injected in disposal wells (808,148 bbls. in 1972), steam injection wells, and in unlined sumps where water quality meets Div. of Oil and Gas standards.

REMARKS:

REFERENCES: Corwin, C.H., Kern Bluff Oil Field: Calif. Div. of Oil and Gas, Summary of Operations--Calif. Oil Fields, Vol. 36, No. 1 (1950).

Kern Front Field, Santa Margarita Zone, East Side Bakersfield District

1) Number of disposal wells permitted in the zone:
   13

2) Number of active producers:
   0

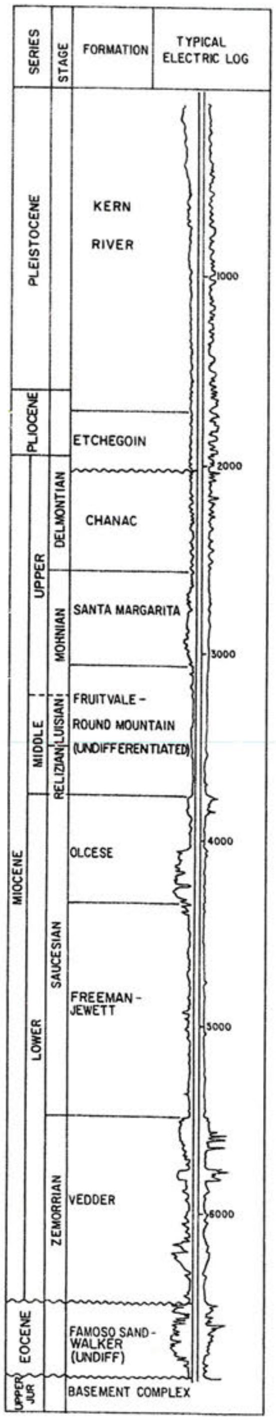
3) Depth of the zone where the injection wells are located:
   2,197' to 2,840' below surface

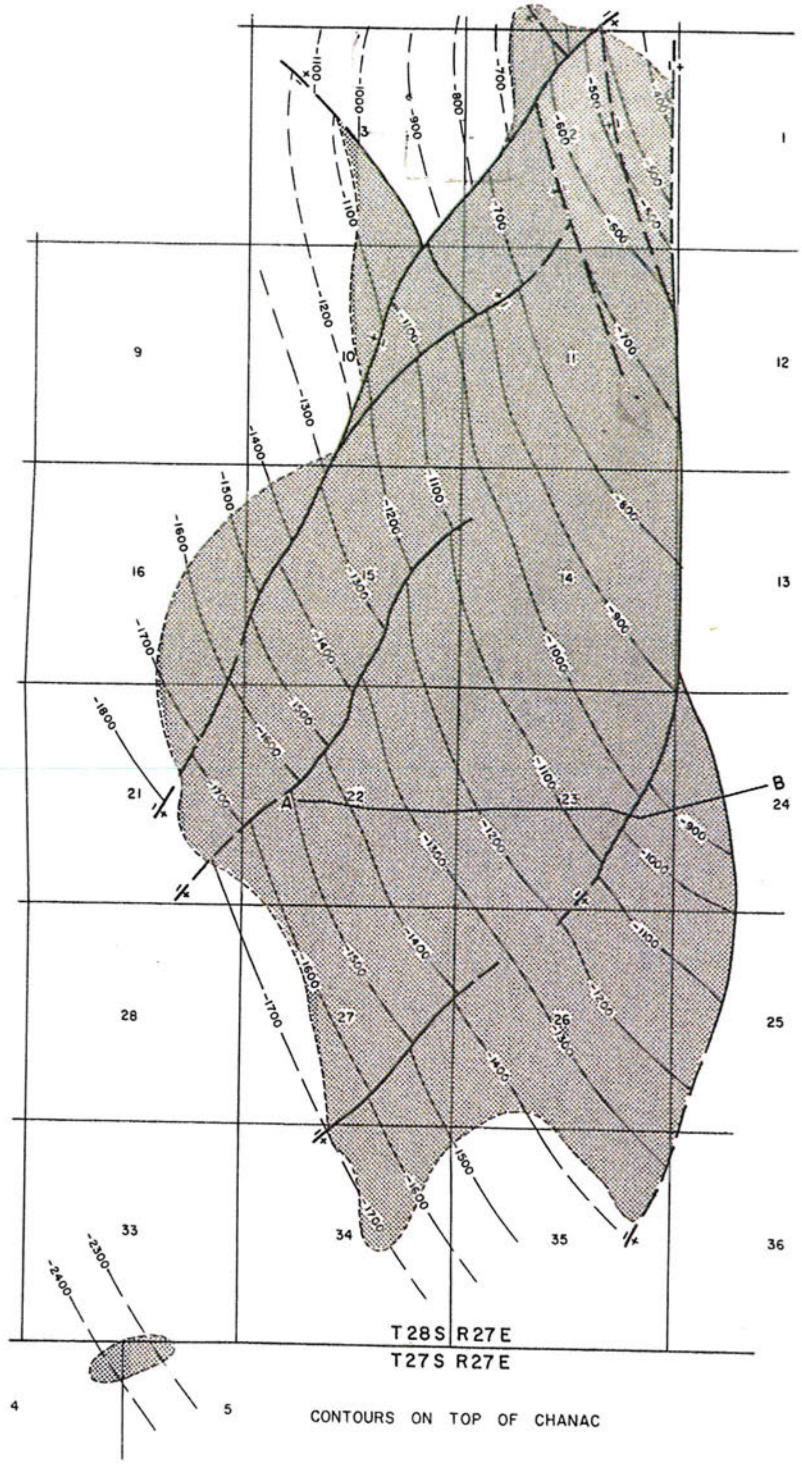
4) Volumes injected historically since 1983:
   151,820,215 Bbls injected, last injected on 3/1/2015

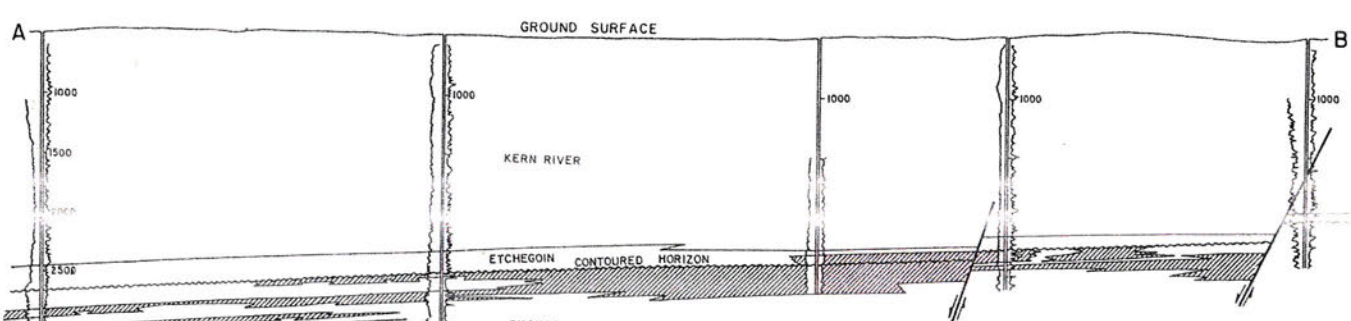
5) TDS of zone:
   460 mg/l - 2,318 mg/l TDS
   The 460 mg/l TDS sample is from the lower Santa Margarita zone in 4-4W well (029-62979) collected at a depth between 3,425'-3,255' on 12/9/1988 and the 2,318 mg/l TDS sample is from WD#1 (029-54754) well at a depth of 2,300' on 9/17/1975.

6) TDS of injection water:
   360 mg/l – 880 mg/l and 6,400 mg/l TDS.
   The 360mg/l TDS sample is from "injection wells "Movius" 3, 2 and D11 on 8/27/2010, the 880 mg/l TDS sample is from well Sec. 27 waste water to "Valley Waste KFF" on 11/2/1997 and the 6,400 mg/l TDS sample is the only high concentration sample collected from "waste water at injection well" on 4/11/2011. The 6,400 mg/l TDS sample is from project #33800012 and is most likely from the cogeneration and scrubber brine waste water. The permitted injection fluids in the Kern Front field, Santa Margarita zone consists of produced water from the Chanac, Etchegoin and Santa Margarita zones and cogeneration and scrubber brines from a plant.

KERN FRONT OIL FIELD







CALIFORNIA DIVISION OF OIL AND GAS

KERN FRONT OIL FIELD

Kern County

LOCATION: 5 miles northwest of Bakersfield

TYPE OF TRAP: Permeability variations on a faulted homocline

ELEVATION: 750

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Etchegoin	Standard Oil Co. of Calif. No. 1	Same as present	15 28S 27E	MD	10	N.A.	1912
Chanac	Standard Oil Co. of Calif. No. 1	Same as present	27 28S 27E	MD	190	N.A.	Aug 1914

Remarks:

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Atlantic Richfield Co. "Kramer" 1	Richfield Oil Corp. "Kramer" 1	Sep 1941	34 28S 27E	MD	7,738	Basement (slate)	Late Jur

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Etchegoin	2,265	70	Pliocene	Etchegoin	14	N.A.	None
Chanac	2,320	250	late Miocene	Chanac	15	5	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
3,148,559	293,008	25,578,898	5,000	852	128,591,808	14,667,840	4,535,059	1929	1,322	1,206	5,055

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
Cyclic-steam	1964	14,142,183	478

SPACING ACT: Does not apply

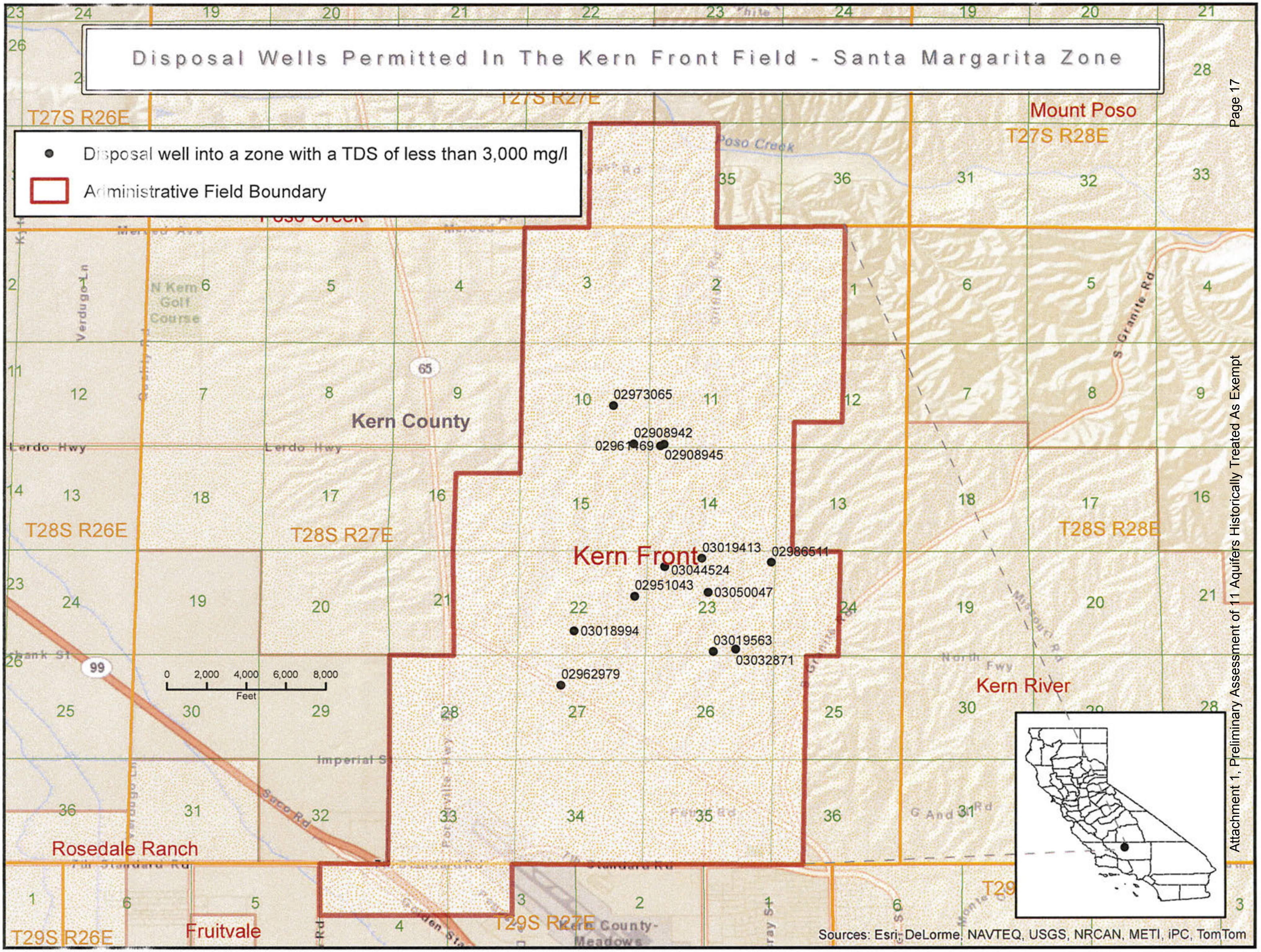
BASE OF FRESH WATER: 1,300

CURRENT CASING PROGRAM: 8 5/8" cem. above zone and across base of fresh-water sands; 6 5/8" liner landed through zone.

METHOD OF WASTE DISPOSAL: Unlined sumps.

REMARKS: A steam displacement project was started in the Kern River - Chanac zone in 1966 and terminated after 99,587 bbls. was injected.

REFERENCES: Brooks, T.J., Kern Front Oil Field, A.A.P.G., S.E.P.M., S.E.G., Guidebook Joint Annual Meeting, Los Angeles, Calif., 1952, p. 159-161.
Park, W.H., Kern Front Oil Field: Calif. Div. of Oil and Gas, Summary of Operations--Calif. Oil Fields, Vol. 51, No. 1 (1965).



Disposal Wells Permitted In The Kern Front Field - Santa Margarita Zone
Disposal well into a zone with a TDS of less than 3,000 mg/l
Administrative Field Boundary
Kern Front
Kern County
Mount Poso
Kern River
Rosedale Ranch
Fruitvale
Poso Creek
T27S R26E
T27S R27E
T27S R28E
T28S R26E
T28S R27E
T28S R28E
T29S R26E
T29S R27E
02973065
02908942
02961469
02908945
03019413
02986511
03044524
02951043
03050047
03018994
03019563
03032871
02962979
0
2,000
4,000
6,000
8,000
Feet
Sources: Esri, DeLorme, NAVTEQ, USGS, NRCAN, METI, iPC, TomTom

Kern River Field, Chanac Zone, East Side Bakersfield District

1) Number of disposal wells permitted in the zone:
   12 (10 of these are permitted in both the Santa Margarita and Chanac Zones in the Kern River field)

2) Number of active producers:
   0

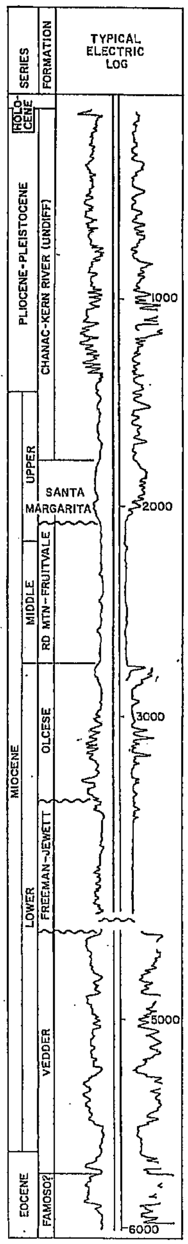
3) Depth of the zone where the injection wells are located:
   425' to 1,335' below surface. Zone dips to the Southwest across the field.

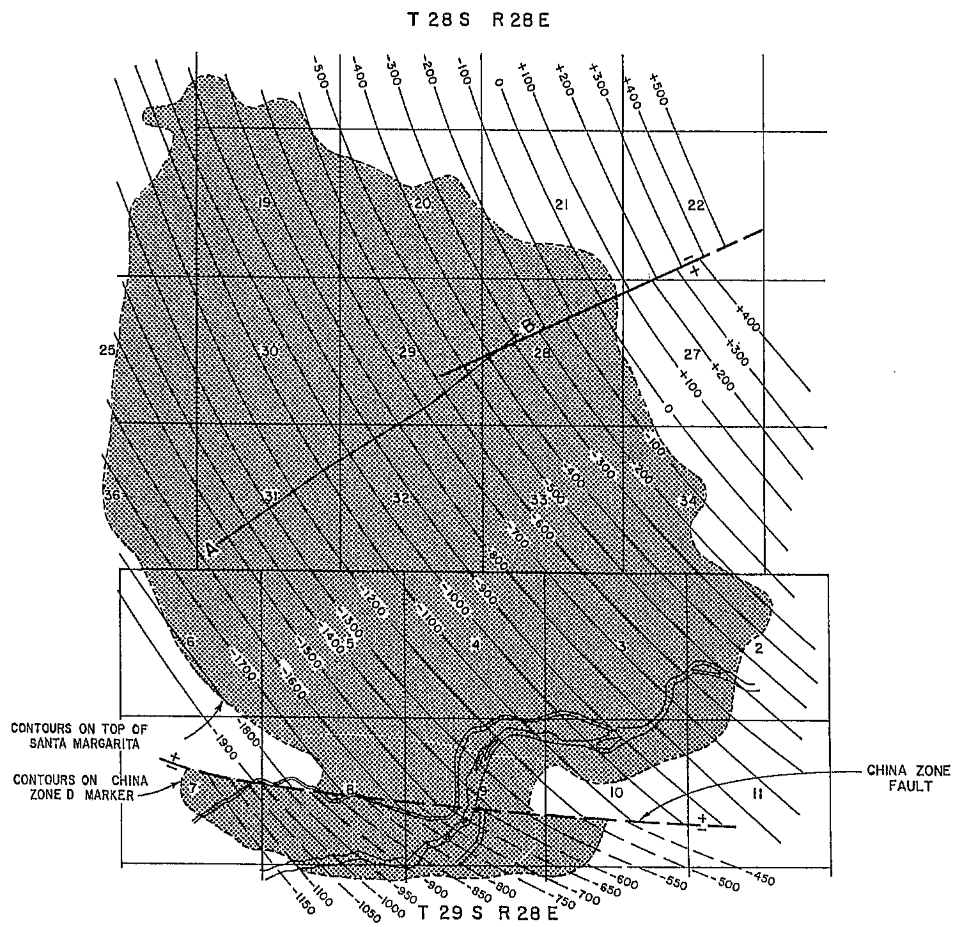
4) Volumes injected historically since 1983:
   568,987,463 Bbls, last injected on 3/1/2015

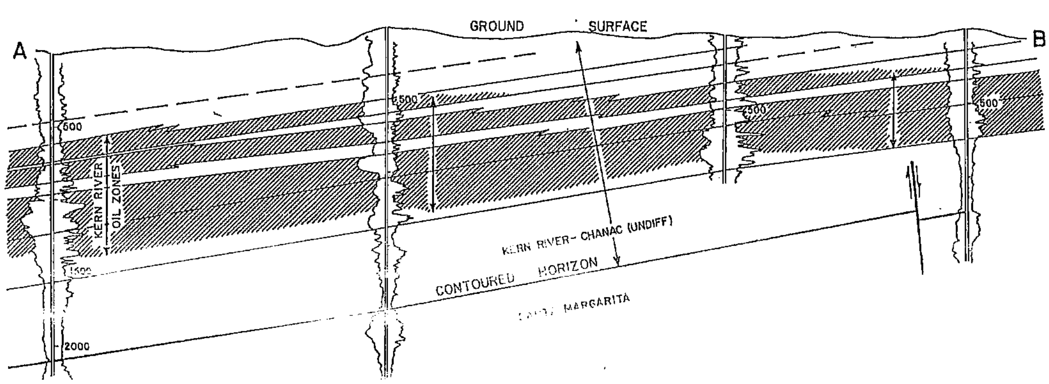
5) TDS of zone:
   926 mg/l – 3,325 mg/l TDS
   The 926 mg/l TDS sample is from well 21-4 top zone perf 1,220-1,223" (upper Chanac) on 05/22/1978 and sample 3,325 mg/l TDS sample is from "Chanac Zone KCL-10 2x" on 2/11/1987.

6) TDS of injection water:
   491 mg/l – 2,000 mg/l TDS
   The 491 mg/l TDS sample is from "Jost Plant Sec. 10, T29S/28E Waste disposal plant tank" on 11/23/1999 and sample 2,000 mg/l TDS sample is from "Cogen Disposal Water" on 11/26/1997. Permitted fluid in the Chanac zone, Kern River field consists of produced Kern River produced water from Kern River field and co-gen waste.

KERN RIVER OIL FIELD







LOCATION: 5 miles north of Bakersfield

TYPE OF TRAP: Permeability variations on a homocline

ELEVATION: 400 - 1,000

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Kern River	Elwood Brothers (no name well)	Same as present	3 29S 28E	MD	N.A.	N.A.	1899
China Zone	Westates Petroleum Co. "KCL" 1	Horace Steele and L.C. Gould "KCL" 1	8 29S 28E	MD	50	0	Sep 1947

Remarks: The discovery well was dug by hand in the spring of 1899 on what is now Chanslor-Western Oil Development Co. property. "Gassy vapors" caused the well to be abandoned without a test of its commercial possibilities. In June 1899 McWhorter Bros. drilled the first commercial well 400 feet north of the discovery well.

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Standard Oil Co. of Calif. "KCL-26" 1-11	Same	Oct 1948	9 29S 28E	MD	6,986	Granite	Jurassic

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Kern River	900	700	late Pliocene	Kern River	13	5	None
China Zone	1,300	100 - 500	late Pliocene	Kern River	13	40	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
27,154,427	4,165	188,121,732	9,535	4,526	576,511,857	2,599,678	27,154,427	1972	7,942	6,978	9,850

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
Cyclic-steam	1961	300,849,501	5,215
Steam flood	1962	189,380,134	780

SPACING ACT: Does not apply

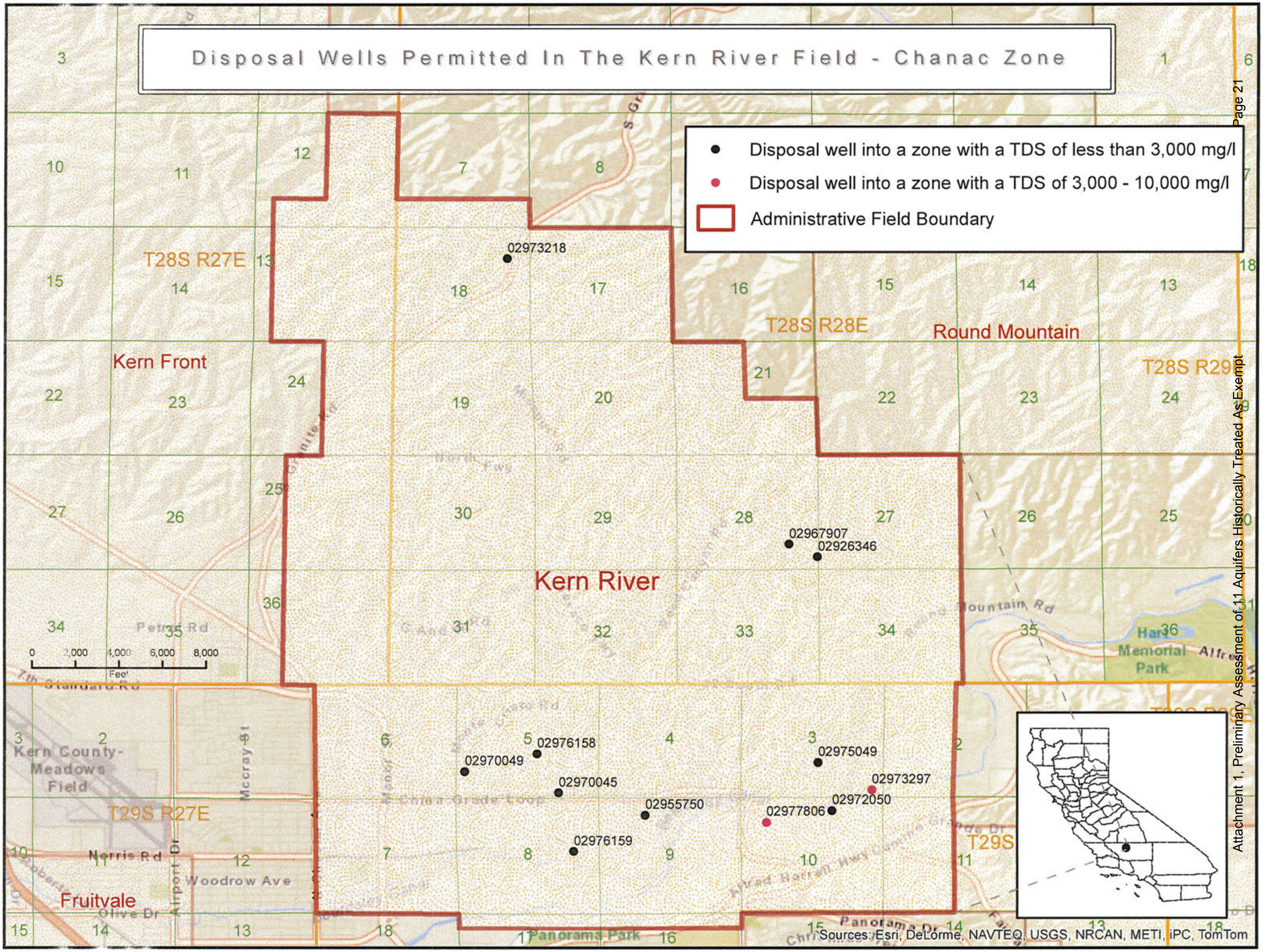
BASE OF FRESH WATER: 2,500

CURRENT CASING PROGRAM: 6 5/8" cem. through zone.

METHOD OF WASTE DISPOSAL: Waste water is injected into the Santa Margarita and Vedder, 12,143,578 bbls. in 1972. Waste water is also used in steam generation. The balance of the water is of a suitable enough quality that it is allowed to enter percolation ponds, irrigation canals, & the Kern River

REMARKS:

REFERENCES: Crowder, R.E., Kern River Oil Field: Calif. Div. of Oil and Gas, Summary of Operations--Calif. Oil Fields, Vol. 38, No. 2 (1952).



Disposal Wells Permitted In The Kern River Field - Chanac Zone
Disposal well into a zone with a TDS of less than 3,000 mg/l
Disposal well into a zone with a TDS of 3,000 - 10,000 mg/l
Administrative Field Boundary
Kern River
Kern Front
Round Mountain
Fruitvale
T28S R27E
T28S R28E
T29S R27E
02973218
02967907
02926346
02976158
02970049
02970045
02955750
02976159
02975049
02973297
02972050
02977806
Kern County-Meadows Field
Panorama Park
Hart Memorial Park
0 2,000 4,000 6,000 8,000
Feet
Sources: Esri, DeLorme, NAVTEQ, USGS, NRCAN, METI, iPC, TomTom

Kern River Field, Santa Margarita Zone, East Side Bakersfield District

1) Number of disposal wells permitted in the zone:
   32 (10 of these are permitted in both the Santa_Margarita and Chanac Zones in the Kern River field)

2) Number of active producers:
   0

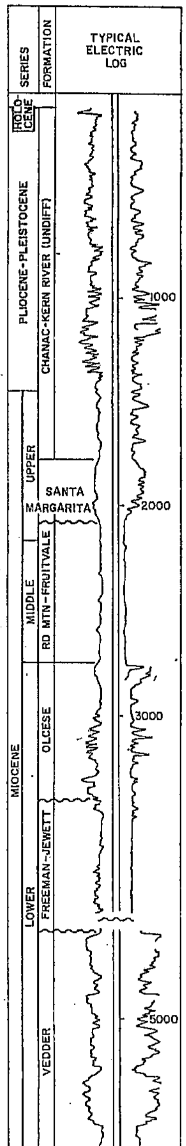
3) Depth of the zone where the injection wells are located:
   760’ to 2,285’ below surface. Zone dips to the Southwest across the field.

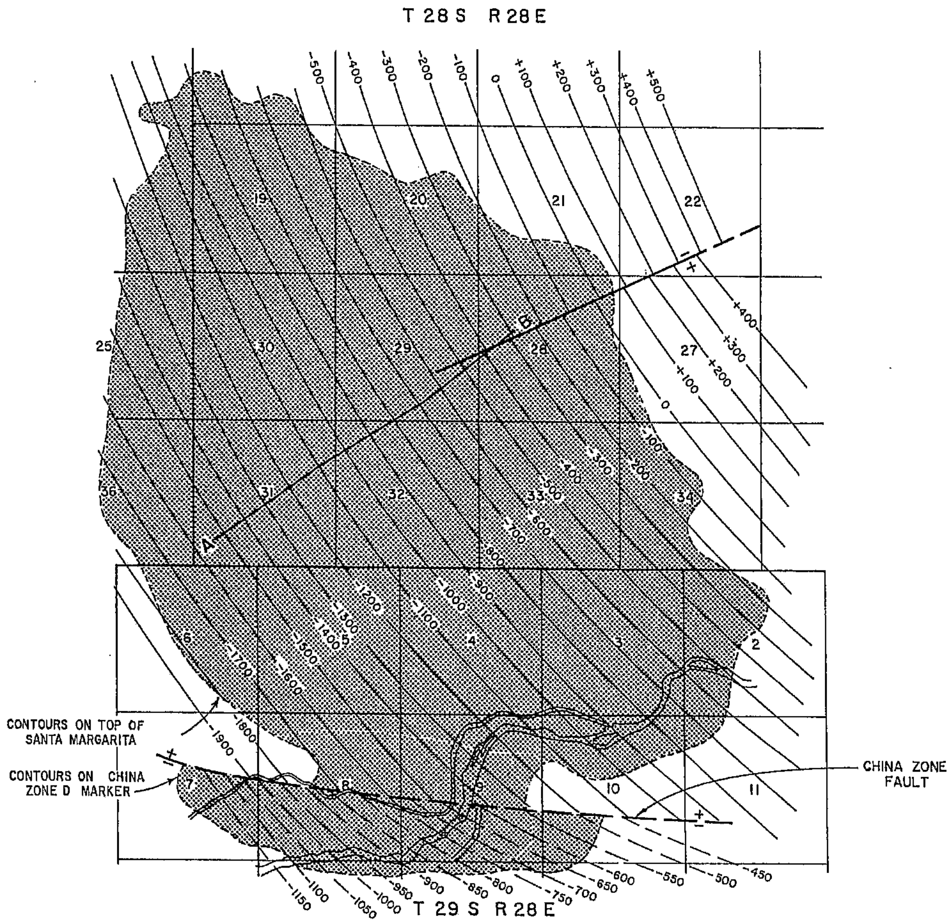
4) Volumes injected historically since 1983:
   799,041,272 Bbls, last injected on 3/1/2015

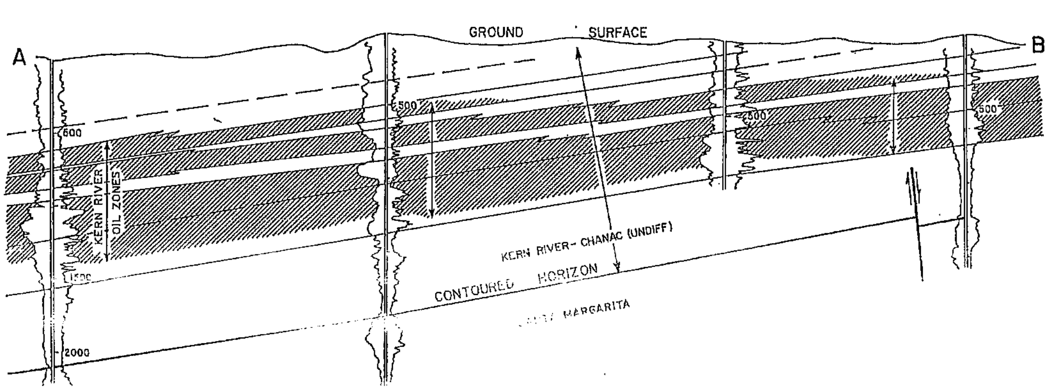
5) TDS of zone:
   490 mg/l – 1,584 mg/l TDS
   The 490 mg/l TDS sample is from “KCL – 10 Well #2X” (perf 1,068 – 1,196’) on 12/30/1985 and the 1,584 mg/l TDS sample is from ““Rambler” 71 W” (perf 1,667-1,875’) on 12/22/1965.

6) TDS of injection water:
   491 mg/l – 855 mg/l and 74,924 mg/l TDS
   The 491 mg/l TDS sample is from the “Jost plant Sec. 10 T29S/28E Waste Disposal Tank” on 11/23/1999, the 855 mg/l TDS sample is from the “Overland plant Sec. 28 T28S/R28E, produced water injection tank” on 11/23/1999, and the 74,924 mg/l is from the “Overland plant Sec. 28 T28S/R28E Brine Disposal Tank” (project 34000035). Permitted fluids for injection into the Santa Margarita zone, Kern River field consist of Kern River produced water, cogeneration and regeneration brine.

KERN RIVER OIL FIELD







LOCATION: 5 miles north of Bakersfield

TYPE OF TRAP: Permeability variations on a homocline

ELEVATION: 400 - 1,000

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Kern River	Elwood Brothers (no name well)	Same as present	3 29S 28E	MD	N.A.	N.A.	1899
China Zone	Westates Petroleum Co. "KCL" 1	Horace Steele and L.C. Gould "KCL" 1	8 29S 28E	MD	50	0	Sep 1947

Remarks: The discovery well was dug by hand in the spring of 1899 on what is now Chanslor-Western Oil Development Co. property. "Gassy vapors" caused the well to be abandoned without a test of its commercial possibilities. In June 1899 McWhorter Bros. drilled the first commercial well 400 feet north of the discovery well.

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Standard Oil Co. of Calif. "KCL·26" 1-11	Same	Oct 1948	9 29S 28E	MD	6,986	Granite	Jurassic

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Kern River	900	700	late Pliocene	Kern River	13	5	None
China Zone	1,300	100 - 500	late Pliocene	Kern River	13	40	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
27,154,427	4,165	188,121,732	9,535	4,526	576,511,857	2,599,678	27,154,427	1972	7,942	6,978	9,850

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
Cyclic-steam	1961	300,849,501	5,215
Steam flood	1962	189,380,134	780

SPACING ACT: Does not apply

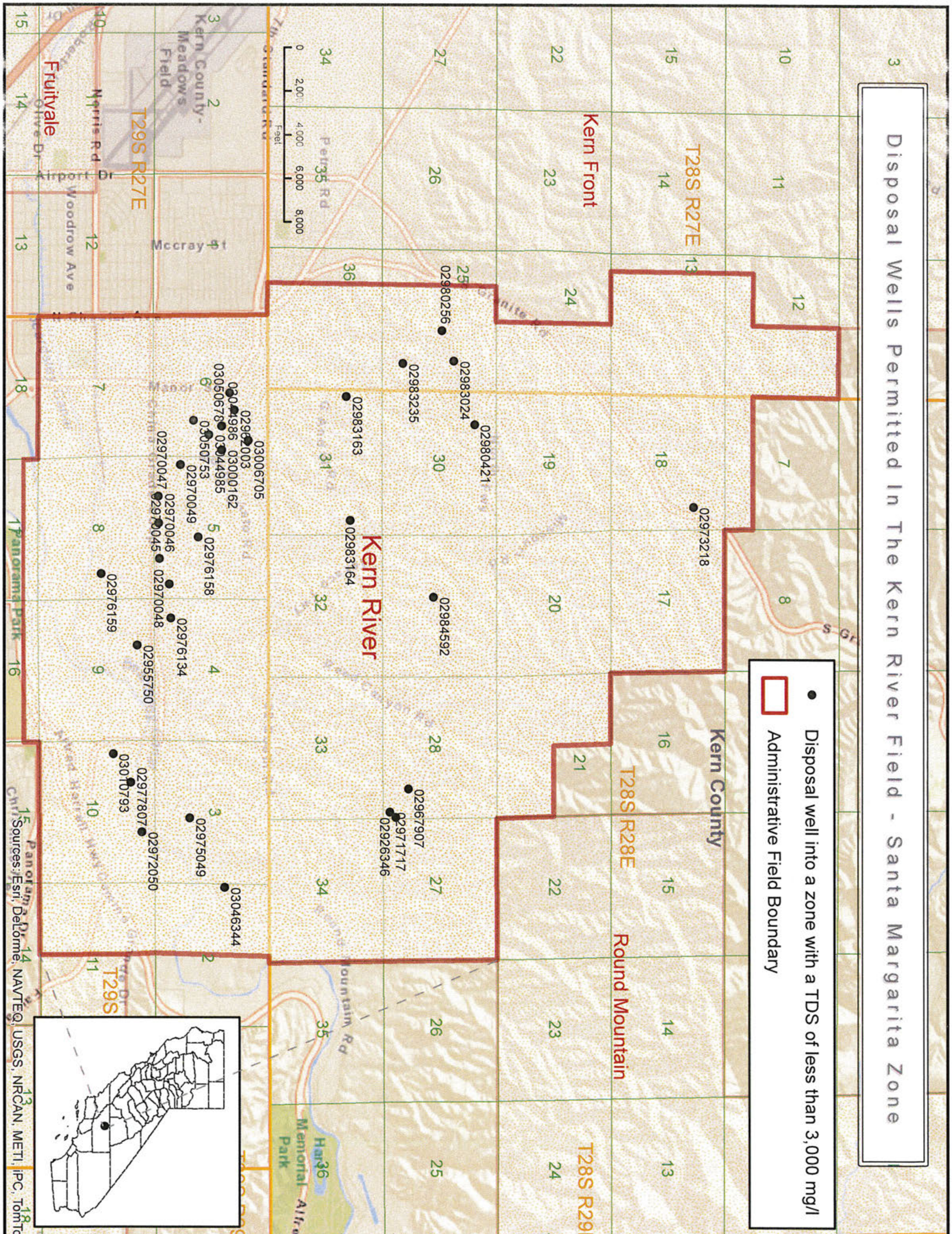
BASE OF FRESH WATER: 2,500

CURRENT CASING PROGRAM: 6 5/8" cem. through zone.

METHOD OF WASTE DISPOSAL: Waste water is injected into the Santa Margarita and Vedder, 12,143,578 bbls. in 1972. Waste water is also used in steam generation. The balance of the water is of a suitable enough quality that it is allowed to enter percolation ponds, irrigation canals, & the Kern River

REMARKS:

REFERENCES: Crowder, R.E., Kern River Oil Field: Calif. Div. of Oil and Gas, Summary of Operations--Calif. Oil Fields, Vol. 38, No. 2 (1952).



Disposal Wells Permitted In The Kern River Field - Santa Margarita Zone
Disposal well into a zone with a TDS of less than 3,000 mg/l
Administrative Field Boundary
Kern River
Kern Front
Round Mountain
Kern County
T28S R27E
T28S R28E
T29S R27E
Fruitvale
Kern County Meadows Field
Airport Dr
Norris Rd
Woodrow Ave
Mccray St
Panorama Park
Hart Memorial Park
Feet
0
2,000
4,000
6,000
8,000
02980256
02983024
02983235
02980421
02983163
02973218
02983164
02984592
03006705
02962003
03044986
03000162
03050678
03044985
03050753
02970049
02970047
02970046
02970045
02976158
02970048
02976134
02976159
02955750
02967907
02971717
02926346
03010793
02977807
02972050
02975049
03046344
Sources: Esri, DeLorme, NAVTEQ, USGS, NRCAN, METI, iPC, TomTom

Mount Poso Field, Walker Zone, East Side Bakersfield District

1) Number of disposal wells permitted in the zone:
   5

2) Number of active producers in the zone:
   0

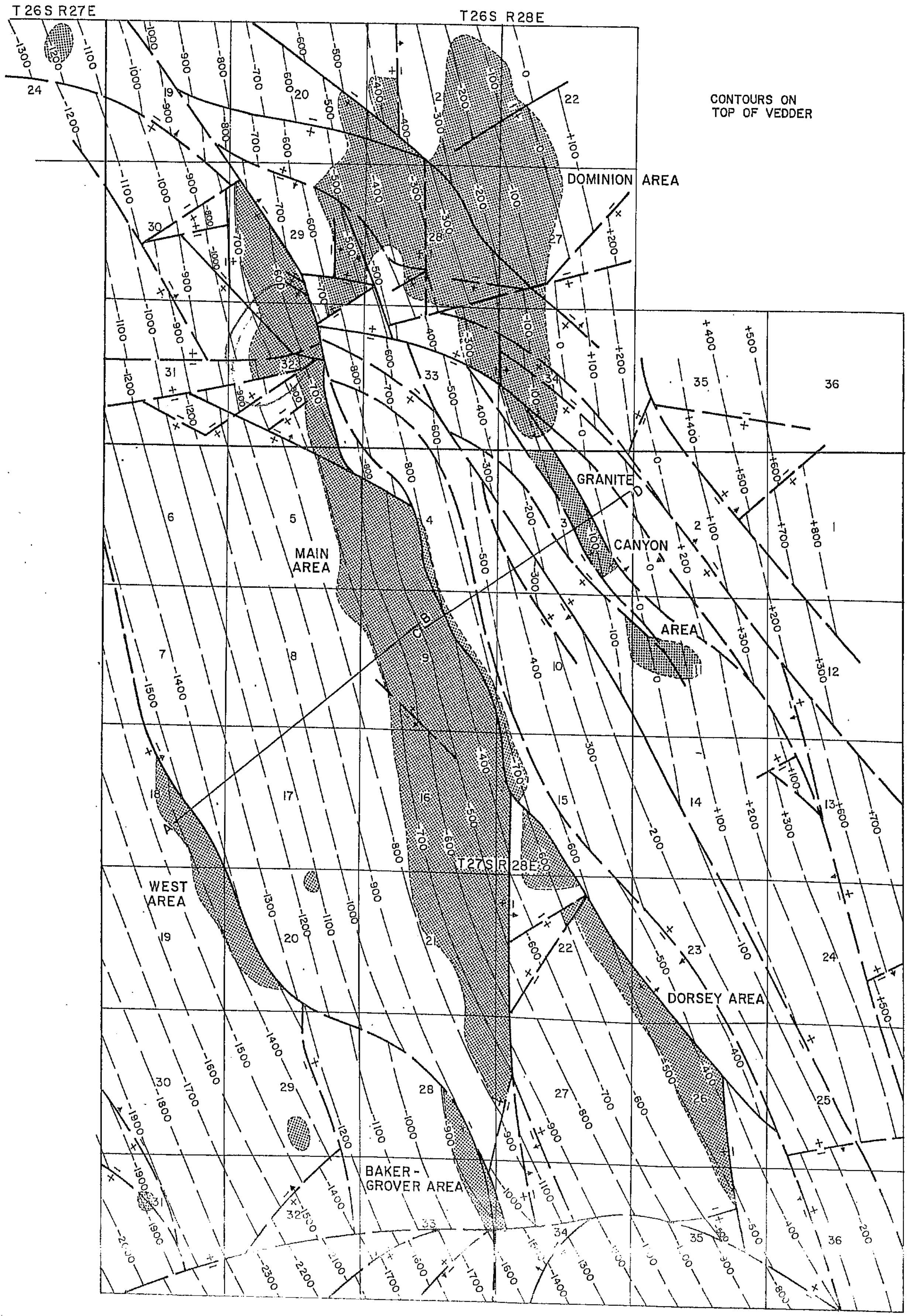
3) Depth of the zone where the injection wells are located:
   1,740' to 1,796' below surface (top of the Vedder/Walker zone). Injected only in combination with the laterally interfingered Vedder, which extends throughout the field.

4) Volumes injected historically since 1983:
   63,777,556 Bbls, last injected on 3/1/2015

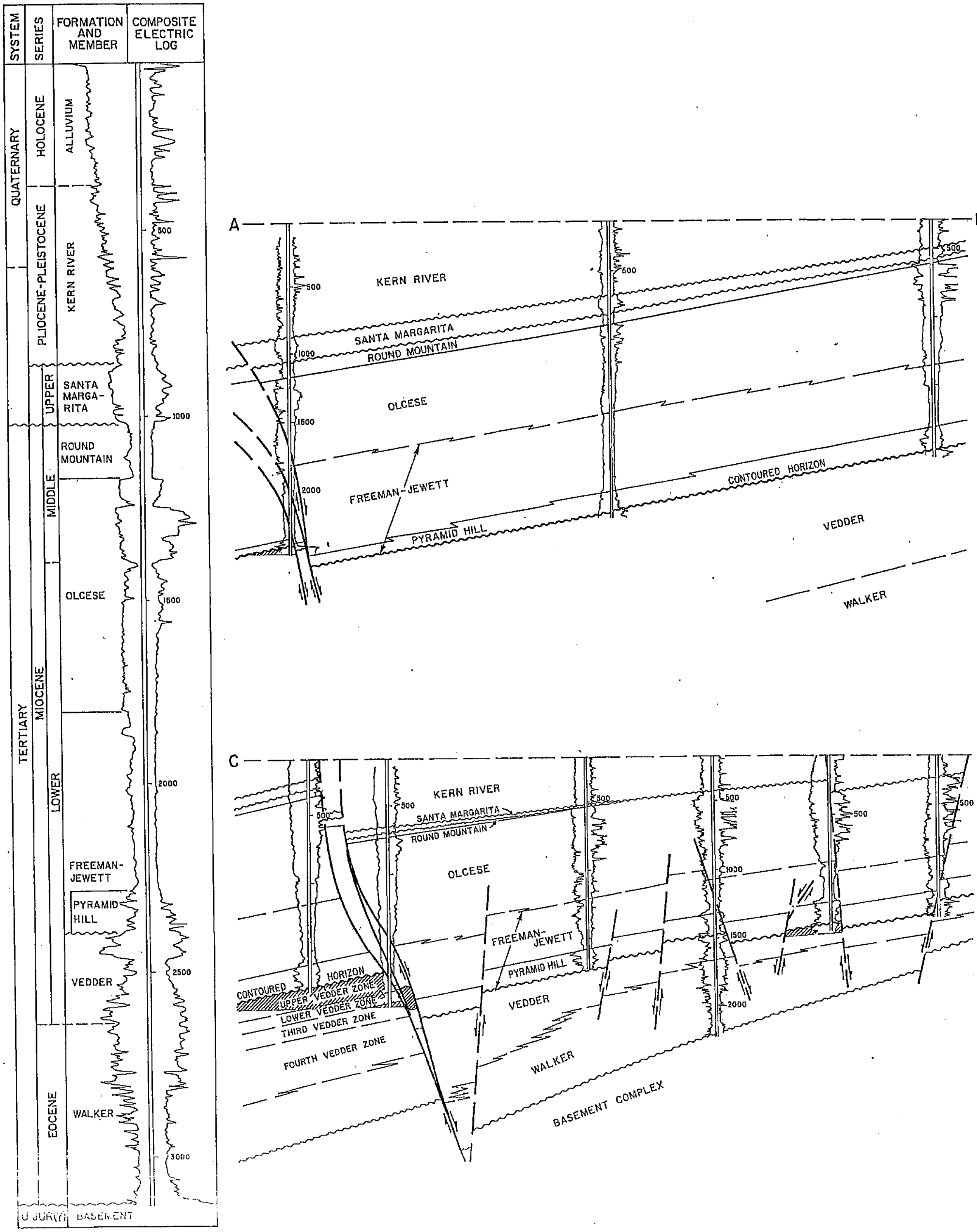
5) TDS of zone:
   1,069 mg/l TDS
   The 1,069 mg/l TDS zone sample is from "Black Foot Sump" on 05/31/1973.

6) TDS of injection water:
   650 mg/l TDS
   The 650 mg/l TDS sample is from "Shapiro 234 Water Sample from Water Disposal" on 12/4/2008.

MOUNT POSO OIL FIELD



MOUNT POSO OIL FIELD



LOCATION: 13 miles northeast of Bakersfield

TYPE OF TRAP: See areas

ELEVATION: 650 - 1,450

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Pyramid Hill and Upper Vedder	Shell Oil Co. "Vedder" 1	Shell Co. of California "Vedder" 1	9 27S 28E	MD	300	N.A.	Jul 1926

Remarks:

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Pacific Oil and Gas Dev. Corp. "City of San Francisco" 56-32	Same	Aug 1957	32 27S 28E	MD	3,759	Walker	Eocene

PRODUCING ZONES (See areas)

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
1,830,017	728	84,316,129	3,630	532	164,558,017	1,977,245	8,427,304	1943	1,184	828	3,805

STIMULATION DATA (Jan. 1, 1973) (See areas)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection

SPACING ACT: See areas.

BASE OF FRESH WATER: See areas.

CURRENT CASING PROGRAM: See areas.

METHOD OF WASTE DISPOSAL: See areas.

REMARKS:

REFERENCES: Albright, M.B., A.G. Hluza, and J.C. Sullivan, Mount Poso Oil Field, Calif. Div. of Oil and Gas, Summary of Operations--Calif. Oil Fields, Vol. 43, No. 2 (1957).

LOCATION. See map sheet of Mount Poso Oil Field

TYPE OF TRAP: Faulted regional homocline

ELEVATION: 650 - 1,050

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Upper Vedder	Emjayco "Baker" 1	Baker-Grover Co. "Baker" 1	33 27S 28E	MD	250	N.A.	Jul 1935

Remarks:

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
The White Hills Oil Co. No. 1	Ralph R. Whitehill No. 1	Apr 1961	34 27S 28E	MD	2,483	Vedder	early Mio

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Upper Vedder	1,750	25	early Miocene	Vedder	15	190	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
9,991	0	883,158	80	4	3,700,652	0	276,899	1937	49	23	90

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
--			

SPACING ACT: Applies

BASE OF FRESH WATER: 1,100

CURRENT CASING PROGRAM: 7" cem. above zone; 5 1/2" liner landed through zone.

METHOD OF WASTE DISPOSAL: Evaporation and percolation sumps (to be phased out).

REMARKS:

REFERENCES:

LOCATION: See map sheet of Mount Poso Oil Field

TYPE OF TRAP: Faulted homocline; lithofacies variations

ELEVATION: 1,100 - 1,350

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Vedder	Robert B. Doe, "Dominion" 2	A. Bruce Frame "Dominion" 2	28 26S 28E	MD	435	N.A.	Dec 1928

Remarks:

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Glen H. Mitchell "SP" 1	Same	May 1945	33 26S 28E	MD	2,512	Schist	Late Jur

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Vedder	1,560	35	early Miocene	Vedder	15	10	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
107,317	0	4,482,093	675	74	5,735,208	0	197,189	1933	195	128	690

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
Cyclic-steam	1964	177,242	12

SPACING ACT: Does not apply

BASE OF FRESH WATER: No saline waters present

CURRENT CASING PROGRAM: 7" cem. above zone; 5 1/2" liner landed through zone.

METHOD OF WASTE DISPOSAL: Injection into the Vedder; evaporation and percolation sumps.

REMARKS:

REFERENCES:

LOCATION: See map sheet of Mount Poso Oil Field

TYPE OF TRAP: Faulted homocline

ELEVATION. 900 - 1,250

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Upper Vedder	Thomas Oil Co. "Dorsey" 2	R.S. Lytle "Dorsey" 2	26 27S 28E	MD	570	N.A.	Sep 1928

Remarks:

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Emjayco "Glide" 15-1	Harry H. Magee, Opr. "Glide" 15-1	Oct 1956	15 27S 28E	MD	2,000	Vedder	early Mio

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Upper Vedder	1,500	30	early Miocene	Vedder	16	5	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
86,429	0	1,913,270	375	47	4,676,008	0	204,880	1958	142	76	410

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
--			

SPACING ACT: Does not apply

BASE OF FRESH WATER: Basement

CURRENT CASING PROGRAM: 8 5/8" cem. above zone; 6 5/8" liner landed through zone.

METHOD OF WASTE DISPOSAL: Percolation and evaporation sumps on outcrop of Round Mountain Silt; injection wells.

REMARKS: Vedder zone water contains 1.75 ppm boron.

REFERENCES:

CALIFORNIA DIVISION OF OIL AND GAS

MOUNT POSO OIL FIELD

GRANITE CANYON AREA

Kern County

LOCATION: See map sheet of Mount Poso Oil Field

TYPE OF TRAP: Faulted homocline; lithofacies variations

ELEVATION: 1,300

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Upper Vedder	Road Oil Sales, Inc. "SP" 2	J.J. Chevalier "Southern Pacific" 2	3 27S 28E	MD	50	N.A.	Nov 1936

Remarks:

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Lyle A. Garner & Assoc. "S.P." 3-1	Same	May 1952	3 27S 28E	MD	2,226	Granite	Late Jur

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Upper Vedder	1,390	30	early Miocene	Vedder	15	10	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
3,808	0	20,675	80	10	823,450	0	65,780	1949	65	30	130

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
--			

SPACING ACT: Applies

BASE OF FRESH WATER: Basement

CURRENT CASING PROGRAM: 8 5/8" cem. above zone; 6 5/8" liner landed through zone.

METHOD OF WASTE DISPOSAL: Evaporation sumps on outcrop of Round Mountain Silt.

REMARKS: A cyclic-steam project was started in 1967 and discontinued after 19,069 bbls. of water in the form of steam were injected. A pilot fire flood project, initiated in 1963, was terminated in 1965.

REFERENCES:

LOCATION: See map sheet of Mount Poso Oil Field

TYPE OF TRAP: Faulted homocline

ELEVATION: 700 - 1,450

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Pyramid Hill and Upper Vedder	Shell Oil Co. "Vedder" 1	Shell Oil Co. of Calif. "Vedder" 1	9 27S 28E	MD	300	N.A.	Jul 1926
Lower Vedder [A]	Shell Oil Co. "Vedder" 6	Same as present	9 27S 28E	MD	835	N.A.	Jan 1933
Third Vedder	Unknown	Unknown	4 27S 28E or 9	MD	N.A.	N.A.	Prior to 1957
Fourth Vedder [B]	Shell Oil Co. "Glide" 6	Same as present	15 27S 28E	MD	134	N.A.	Aug 1957

Remarks: The first separate well that produced from the Pyramid Hill zone was Shell Oil Co. "Security" 3, Sec. 9, T. 27S., R. 28E. Initial production was 4 barrels per day.
[A] Commingled production from Upper Vedder and Lower Vedder.
[B] Commingled production from Third Vedder and Fourth Vedder.

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Trico Industries, Inc. "USL" 6-2	Trico Oil and Gas Co. "USL" 6-2	Jul 1960	6 27S 28E	MD	2,665	Vedder	early Mio

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Pyramid Hill	1,600	160	early Miocene	Pyramid Hill	17	N.A.	None
Upper Vedder	1,750	140	early Miocene	Vedder	16	80	None
Lower Vedder	1,900	80	early Miocene	Vedder	16	N.A.	None
Third Vedder	1,985	120	early Miocene	Vedder	16	75	None
Fourth Vedder	2,105	50	early Miocene	Vedder	16	65	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
1,590,436	728	75,595,054	2,225	374	146,734,300	1,977,245	7,982,576	1943	641	524	2,265

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
Steam flood	1963	9,351,042	11

SPACING ACT: Does not apply

BASE OF FRESH WATER: 1,000 - 1,500

CURRENT CASING PROGRAM: 8 5/8" cem. above zone and across base of fresh-water sands; 6 5/8" liner landed through zone.

METHOD OF WASTE DISPOSAL: Evaporation and percolation sumps; injection into Vedder sand.

REMARKS: A cyclic-steam project was started in 1963 and discontinued after 116,623 bbls. of water in the form of steam was injected. A water flood project was started in 1952 and discontinued after 608,470 bbls. of water was injected.

REFERENCES:

CALIFORNIA DIVISION OF OIL AND GAS

WEST AREA

MOUNT POSO OIL FIELD

Kern County

LOCATION: See map sheet of Mount Poso Oil Field

TYPE OF TRAP: Faulted homocline with permeability variations

ELEVATION: 700 - 1,075

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Upper Vedder	Thomas Oil Co. "Ring 18" 1	Dwight G. Vedder No. 1	18 27S 28E	MD	0	5,300	Dec 1943

Remarks: Gas cap was of limited volume. After being shut in for one year the discovery well was recompleted producing oil.

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Pacific Oil & Gas Dev. Corp. "City of San Francisco" 56-32	Same	Aug 1957	32 27S 28E	MD	3,759	Walker	Eocene

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Upper Vedder	2,575	15 - 50	early Miocene	Vedder	16	60	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
32,036	0	1,421,879	195	23	2,888,399	0	190,765	1957	92	47	220

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
--			

SPACING ACT: Applies

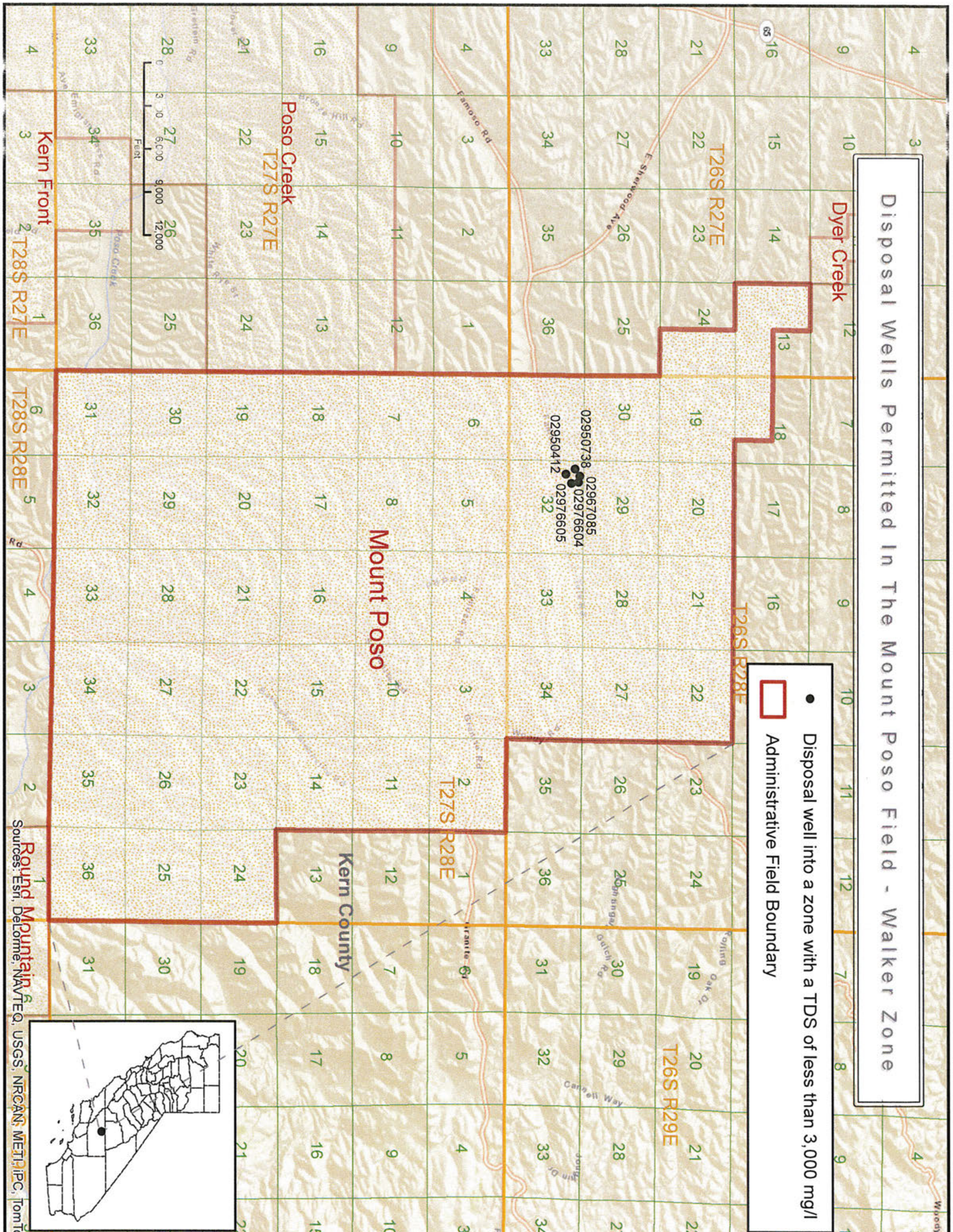
BASE OF FRESH WATER: 1,800

CURRENT CASING PROGRAM: 7" cem. above zone and across base of fresh-water sands; 5 1/2" liner landed through zone.

METHOD OF WASTE DISPOSAL: Evaporation and percolation sumps (to be phased out).

REMARKS: Vedder zone water contains 3 to 4 ppm boron.

REFERENCES:


Disposal Wells Permitted In The Mount Poso Field - Walker Zone
Disposal well into a zone with a TDS of less than 3,000 mg/l
Administrative Field Boundary
Mount Poso
Poso Creek
Kern Front
Dyer Creek
Round Mountain
Kern County
T26S R27E
T26S R28E
T26S R29E
T27S R27E
T27S R28E
T28S R27E
T28S R28E
02950738
02967085
02976604
02950412
02976605
Feet
0
3,000
6,000
9,000
12,000
Famoso Rd
E Sherwood Ave
Sources: Esri, DeLorme, NAVTEQ, USGS, NRCAN, METI, iPC, TomTom

Round Mountain Field, Olcese Zone, East Side Bakersfield District

1) Number of disposal wells permitted in the zone:
   6 (4 wells are permitted in both the Olcese and Walker Zones in Round Mountain Field)

2) Number of active producers:
   0

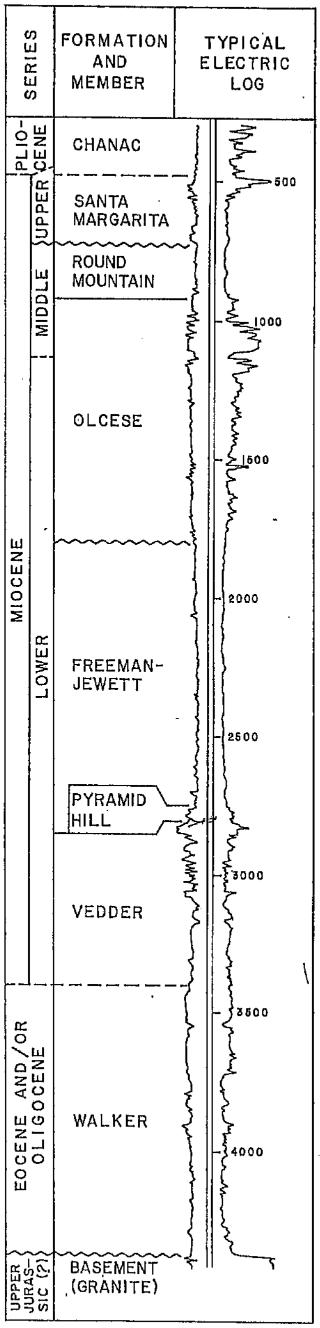
3) Depth of the zone where the injection wells are located:
   710' to 850' below surface. These zone depths are from wells API #029-18114 and API #029-18119, which are currently injecting in the Olcese zone. The remaining wells in the field (029-47441, 029-47543, 030-51960 and 030-51959) are permitted to inject in the Olcese, Freeman-Jewett, Vedder and Walker but are currently perforated in the Vedder and/or Walker zones only. For these 4 wells there are no logs available that pick the top of the Olcese zone since there is no injection there. Zone is fault bounded 1 ½ miles east of field limits, and pinches out 5 miles west of field limits.

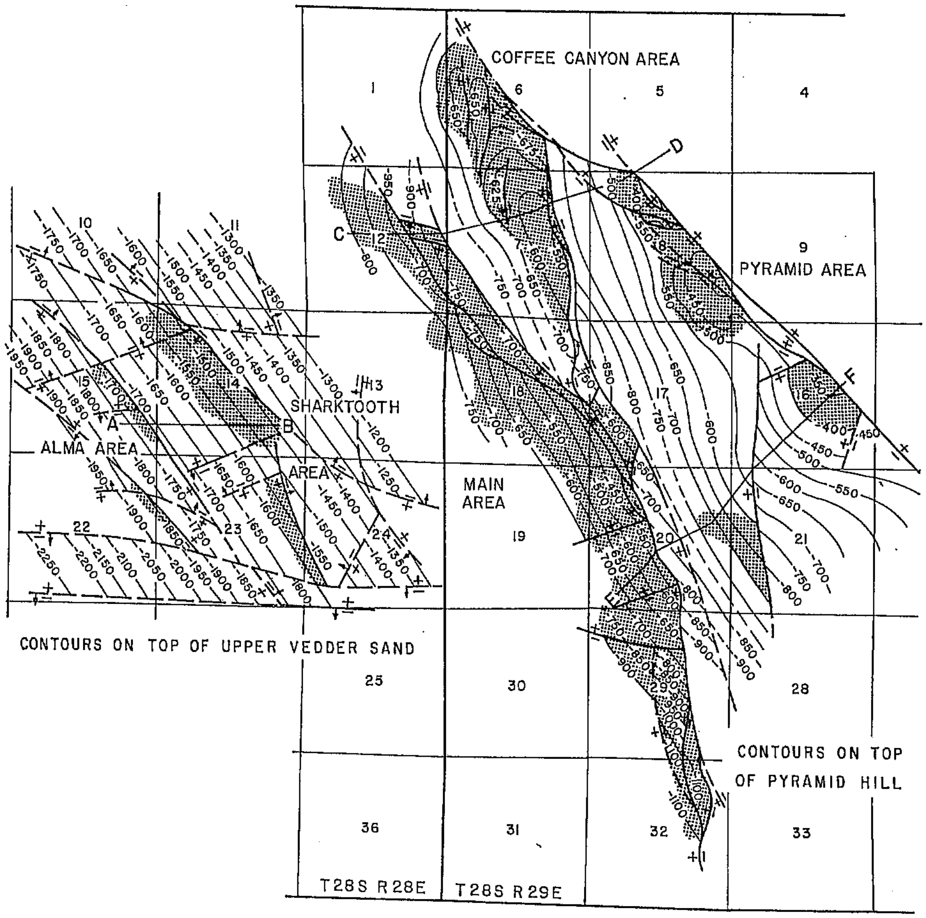
4) Volumes injected historically since 1983:
   160,798,008 Bbls, last injected on 1/1/2015

5) TDS of zone:
   2,693 mg/l TDS
   Sample collected from "water from Bishop #6 Bailer Sample at 600'" on 4/27/1974.

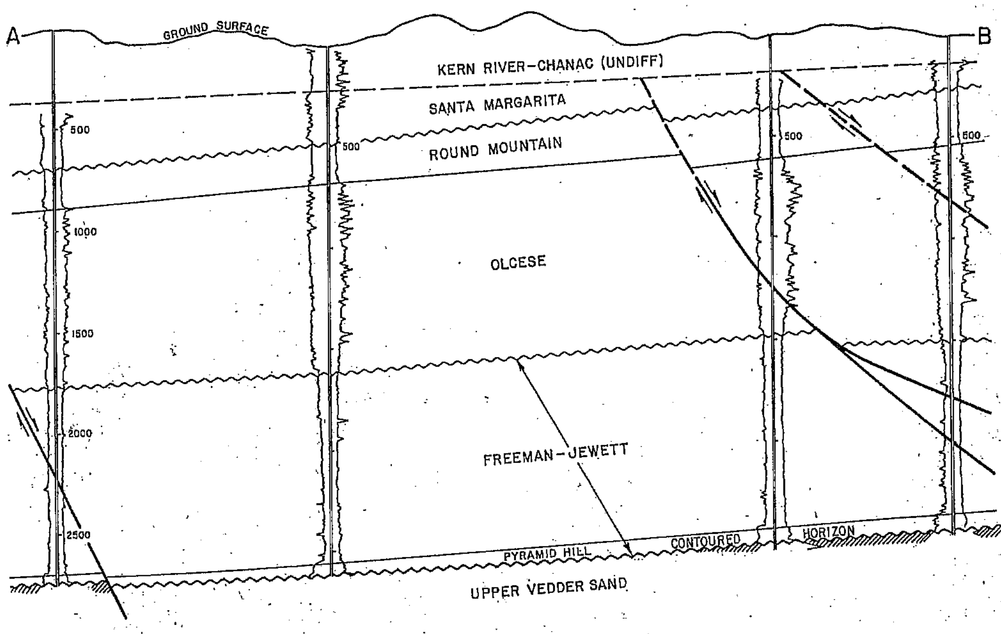
6) TDS of injection water:
   1,900 mg/l TDS
   Sample collected from "Sec. 20 produced water" (Olcese WD#342 & 343) on 2/23/2009. Permitted fluids for injection into the Olcese Zone in Round Mountain field consist of Pyramid Hill, Jewett, Freeman-Jewett and Vedder zones.

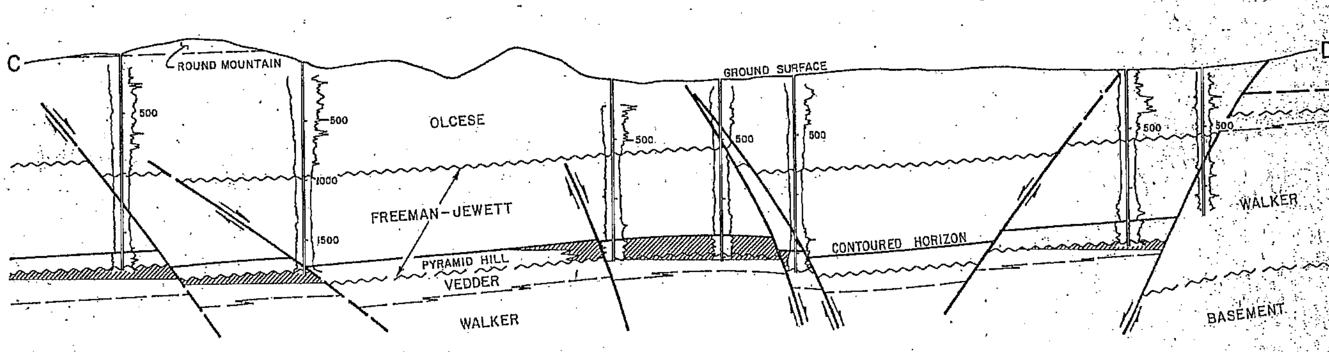
ROUND MOUNTAIN OIL FIELD

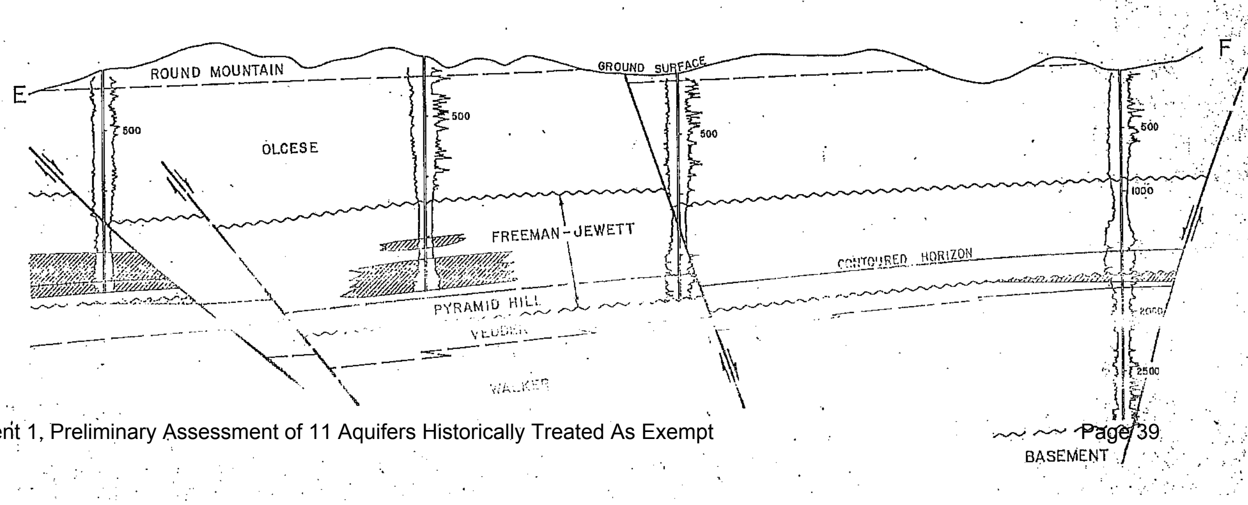




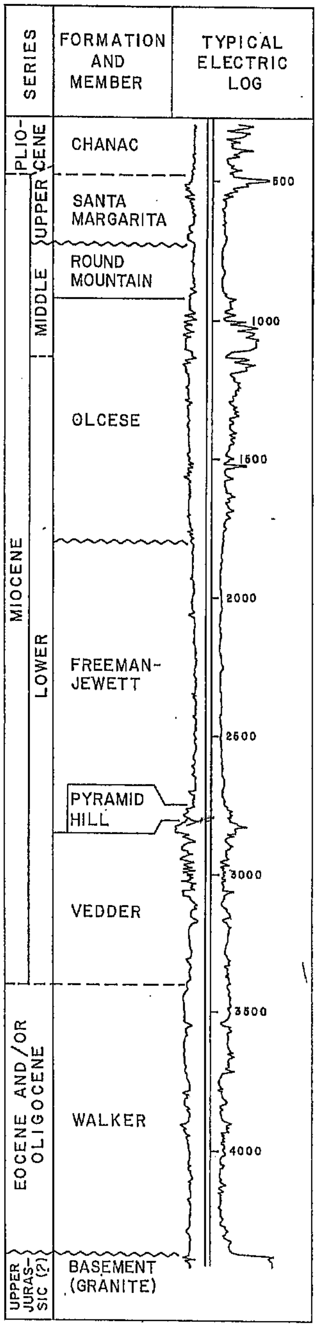
ROUND MOUNTAIN OIL FIELD

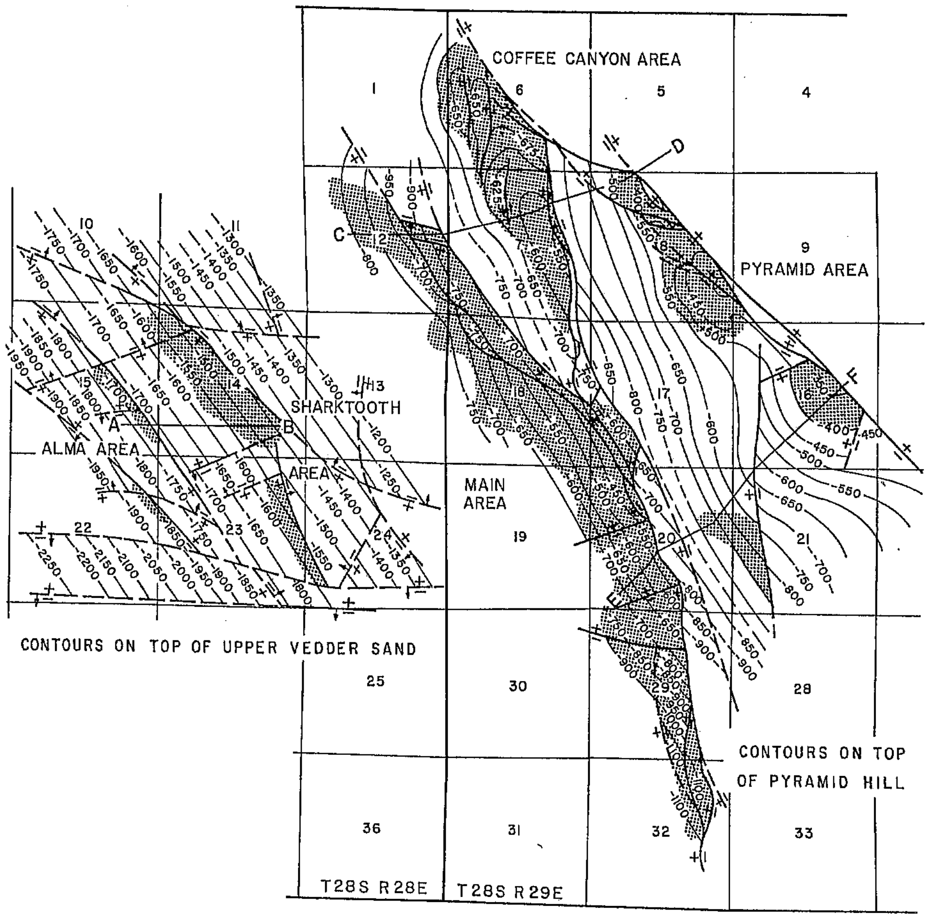






ROUND MOUNTAIN OIL FIELD





LOCATION: 14 miles northeast of Bakersfield

TYPE OF TRAP: See areas

ELEVATION: 600 - 1,500

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Jewett	Getty Oil Co. No. 2	Elbe Oil Land Dev. Co. No. 2	20 28S 29E	MD	*204	N.A.	May 1927
Pyramid Hill	Same as above	Same as above	20 28S 29E	MD	N.A.	N.A.	May 1927
Vedder	Same as above	Same as above	20 28S 29E	MD	N.A.	N.A.	May 1927

Remarks: * Production listed for Jewett is the combined production rate from the Jewett, Pyramid Hill, and Vedder zones.

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
C.C. Killingsworth "Alma" 6	Barnsdall Oil Co. "Alma" 6	Mar 1948	15 28S 28E	MD	4,418	Basement (Granite)	Late Jur (?)

PRODUCING ZONES (See areas)

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
711,406	46,635	48,630,496	2,435	292	89,199,121	1,424,213	5,453,194	1938	665	468	2,590

STIMULATION DATA (Jan. 1, 1973) (See areas)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection

SPACING ACT: See areas.

BASE OF FRESH WATER: See areas.

CURRENT CASING PROGRAM: See areas.

METHOD OF WASTE DISPOSAL: See areas.

REMARKS:

REFERENCES: See areas.

CALIFORNIA DIVISION OF OIL AND GAS

ROUND MOUNTAIN OIL FIELD

ALMA AREA

Kern County

LOCATION: See map sheet of Round Mountain Oil Field

TYPE OF TRAP: Faulted homocline

ELEVATION: 700 - 1,270

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Vedder	Harold C. Morton & H.S. Kohlbush "Alma" 1	Same as present	15 28S 28E	MD	152	N.A.	Feb 1947

Remarks:

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
C.C. Killingsworth "Alma" 6	Barnsdall Oil Co. "Alma" 6	Mar 1948	15 28S 28E	MD	4,418	Basement (Granite)	Late Jur.

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Vedder	2,600	15	early Miocene	Vedder	13	N.A.	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
6,240	0	107,447	50	3	598,904	0	113,392	1948	47	21	80

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
--			

SPACING ACT: Applies

BASE OF FRESH WATER: None

CURRENT CASING PROGRAM: 8 5/8" cem. above zone; 6 5/8" liner landed through zone.

METHOD OF WASTE DISPOSAL: Evaporation and percolation sumps on outcrops of the Round Mountain Silt.

REMARKS:

REFERENCES: Albright, M.B. Jr., Sharktooth and Alma Areas of Round Mountain Oil Field: Calif. Div. of Oil and Gas, Summary of Operations--Calif. Oil Fields, Vol. 42, No. 1 (1956).

LOCATION: See map sheet of Round Mountain Oil Field

TYPE OF TRAP: Faulted homocline

ELEVATION: 690 - 1,300

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Gas (Mcf)	Date of completion
Pyramid Hill	Acacia Oil Co. "Coffee" 1	Reynolds Oil and Gas Co. No. 1	6 28S 29E	MD	*600	N.A.	Sep 1928
Vedder	Acacia Oil Co. "Lindsay" 1	Lindsay Oil Co. No. 1	6 28S 29E	MD	800	N.A.	Aug 1928

Remarks: * Production is commingled from Pyramid Hill and Vedder.

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	Age
Richard S. Rheem, Opr. "Smoot-Vedder" 2	Same	May 1957	1 28S 28E	MD	2,313	Vedder	early Mio

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Pyramid Hill	1,500	150	early Miocene	Jewett	18	50	None
Vedder	1,650	30	early Miocene	Vedder	16	75	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	Net gas (Mcf)	Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Gas (Mcf)	Peak oil production Barrels	Year	Total number of wells Drilled	Completed	Maximum proved acreage
103,176	0	7,292,707	435	50	18,507,039	67,567	1,857,108	1937	133	104	475

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
Water flood	1960	3,815,746	1

SPACING ACT: Does not apply

BASE OF FRESH WATER: 0 - 200

CURRENT CASING PROGRAM: 7" cem. above zone; 5 1/2" liner landed through zone.

METHOD OF WASTE DISPOSAL: Evaporation and percolation sumps on outcrops of the Round Mountain Silt.

REMARKS: A cyclic-steam injection project in the Pyramid Hill and Vedder zones was started in 1965 and terminated in 1968. Cumulative injection totals 12,200 bbls. The Pyramid Hill zone was originally known as the Elbe zone.

REFERENCES: Park, W.H., J.R. Weddle, J.A. Barnes, Main, Coffee Canyon, and Pyramid Areas of Round Mountain Oil Field: Calif. Div. of Oil and Gas, Summary of Operations--Calif. Oil Fields, Vol. 49, No. 2 (1963).

MAIN AREA

Kern County

LOCATION: See map sheet of Round Mountain Oil Field

TYPE OF TRAP: Faulted homocline

ELEVATION: 600 - 1,500

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Jewett	Getty Oil Co. No. 2	Elbe Oil Land Dev. Co. No. 2	20 28S 29E	MD	*204	N.A.	May 1927
Pyramid Hill	Same as above	Same as above	20 28S 29E	MD	N.A.	N.A.	May 1927
Vedder	Same as above	Same as above	20 28S 29E	MD	N.A.	N.A.	May 1927

Remarks: * Production listed for Jewett is the combined production rate from the Jewett, Pyramid Hill, and Vedder zones.

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Shell Oil Co. "Jewett" 3	Same	Jun 1928	29 28S 29E	MD	2,678	Walker	Eo &/or Olig.

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Jewett	1,600	130	early Miocene	Freeman-Jewett	22	N.A.	None
Pyramid Hill	1,900	150	early Miocene	Jewett	18	N.A.	None
Vedder	2,000	80	early Miocene	Vedder	16	95	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
510,916	46,561	35,953,284	1,415	171	59,572,216	1,293,959	3,794,620	1938	302	225	1,465

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
--			

SPACING ACT: Does not apply

BASE OF FRESH WATER: None

CURRENT CASING PROGRAM: 7" cem. above zone; 5 1/2" liner landed through zone.

METHOD OF WASTE DISPOSAL: 4,845,286 bbl. of waste water was injected during 1972 into two disposal wells; percolation and evaporation sumps on outcrops of the Round Mountain Silt.

REMARKS: A water flood project in the Vedder zone was started in 1961 and terminated in 1963. Cumulative injection totals 872,587 bbls.

REFERENCES: Park, W.H., J.R. Weddle, J.A. Barnes, Main, Coffee Canyon, and Pyramid Areas of Round Mountain Oil Field: Calif. Div. of Oil and Gas, Summary of Operations--Calif. Oil Fields, Vol. 49, No. 2 (1963).

LOCATION: See map sheet of Round Mountain Oil Field

TYPE OF TRAP: Faulted homocline

ELEVATION: 730 - 1,470

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Pyramid Hill	Thomas Oil Co. "Olcese" 2	Harp & Brown "Olcese" 2	17 28S 29E	MD	5	0	May 1944
Vedder	Crestmont Oil Co. "Olcese" 1	Eastmont Oil Co. "Olcese" 1	16 28S 29E	MD	250	N.A.	May 1937
Walker	Crestmont Oil Co. "Staley" 11	Same as present	8 28S 29E	MD	40	N.A.	Jul 1943

Remarks:

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Piute Holding Co. "Smith" 1	Same	Oct 1929	17 28S 29E	MD	3,110	Walker	Eo &/or Olig

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Pyramid Hill	1,250	130	early Miocene	Jewett	18	50	None
Vedder	1,390	40	early Miocene	Vedder	16	80 - 110	None
Walker	1,535	50	Eo &/or Olig	Walker	20	N.A.	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
55,714	74	1,527,767	290	37	5,692,349	6,876	378,882	1946	98	60	300

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
--			

SPACING ACT: Applies

BASE OF FRESH WATER: None

CURRENT CASING PROGRAM: 8 5/8" or 7" cem. above zone; 6 5/8" or 5" liner landed through zone.

METHOD OF WASTE DISPOSAL: Evaporation and percolation sumps on outcrops of the Round Mountain Silt.

REMARKS:

REFERENCES: Park, W.H., J.R. Weddle, J.A. Barnes, Main, Coffee Canyon, and Pyramid Areas of Round Mountain Oil Field: Calif. Div. of Oil and Gas, Summary of Operations--Calif. Oil Fields, Vol. 49, No. 2 (1963).

LOCATION: See map sheet of Round Mountain Oil Field

TYPE OF TRAP: Faulted homocline

ELEVATION: 700 - 1,300

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Vedder	G M V Oil Co. "Signal-Mills" 1	Bandini Petroleum Co. "Signal Mills" 1	24 28S 28E	MD	214	N.A.	Sep 1943

Remarks:

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Mobil Oil Corp. "Bradford" 1	General Petroleum Corp. "Bradford" 1	Jun 1943	15 28S 28E	MD	2,995	Vedder	early Mio

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Vedder	2,400	25	early Miocene	Vedder	13	N.A.	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
35,360	0	3,749,291	245	31	4,828,613	55,811	503,449	1947	85	58	270

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
--			

SPACING ACT: Applies

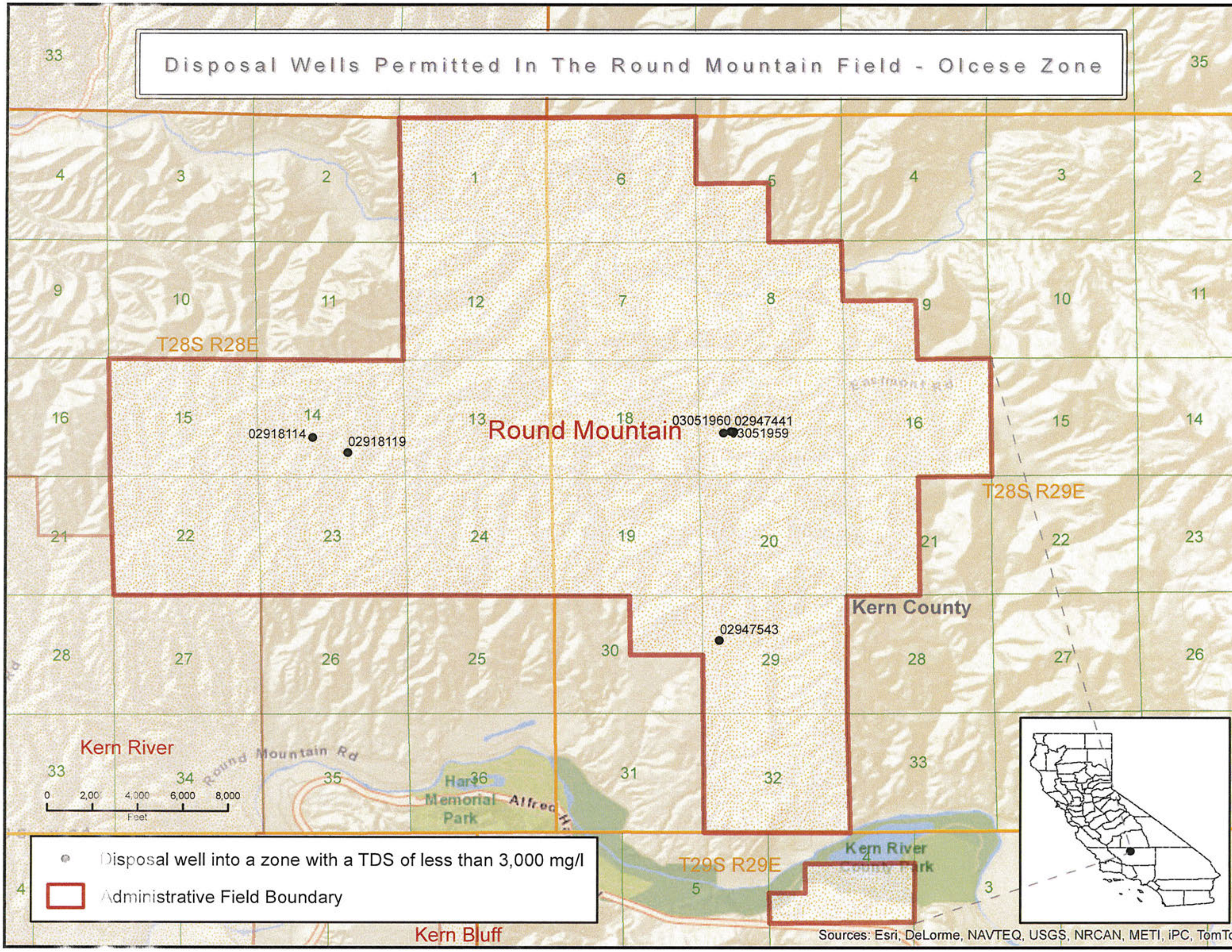
BASE OF FRESH WATER: None

CURRENT CASING PROGRAM: 8 5/8" cem. above zone; 6 5/8" liner landed through zone.

METHOD OF WASTE DISPOSAL: Evaporation and percolation sumps on outcrops of the Round Mountain Silt.

REMARKS:

REFERENCES: Albright, M.B. Jr., Sharktooth and Alma Areas of Round Mountain Oil Field: Calif. Div. of Oil and Gas. Summary of Operations--Calif. Oil Fields, Vol. 42, No. 1 (1956).


Disposal Wells Permitted In The Round Mountain Field - Olcese Zone
Round Mountain
T28S R28E
T28S R29E
T29S R29E
Kern County
Kern River
Kern Bluff
Round Mountain Rd
Hart Memorial Park
Kern River County Park
02918114
02918119
03051960
02947441
03051959
02947543
0
2,000
4,000
6,000
8,000
Feet
Disposal well into a zone with a TDS of less than 3,000 mg/l
Administrative Field Boundary
Sources: Esri, DeLorme, NAVTEQ, USGS, NRCAN, METI, iPC, TomTom

Round Mountain Field, Walker Zone, East Side Bakersfield District

1) Number of disposal wells permitted in the zone:
   30 (4 of these are permitted in both the Olcese and Walker Zones in Round Mountain Field). There are 2 gas disposal wells.

2) Number of active producers:
   4 wells (Note that although this aquifer was historically treated as exempt as a non-hydrocarbon producing formation, the Walker zone within the field has current production.)

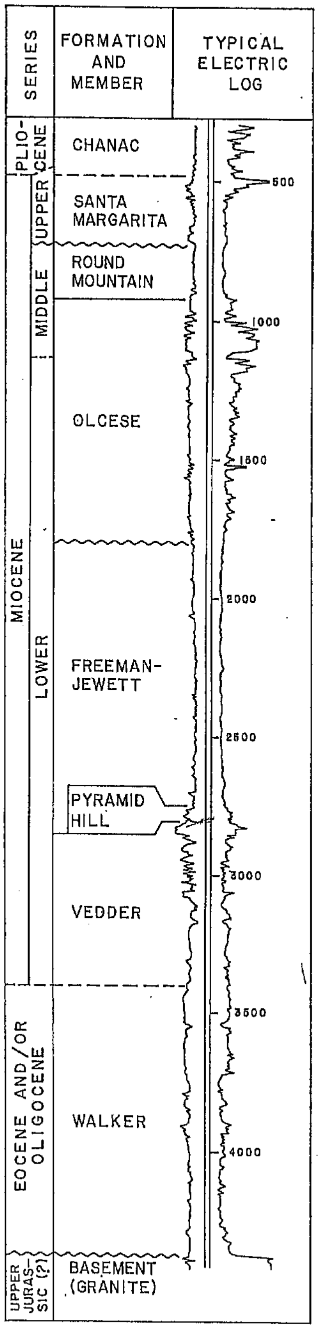
3) Depth of the zone where the disposal wells are located:
   1,890' to 2,590' below surface

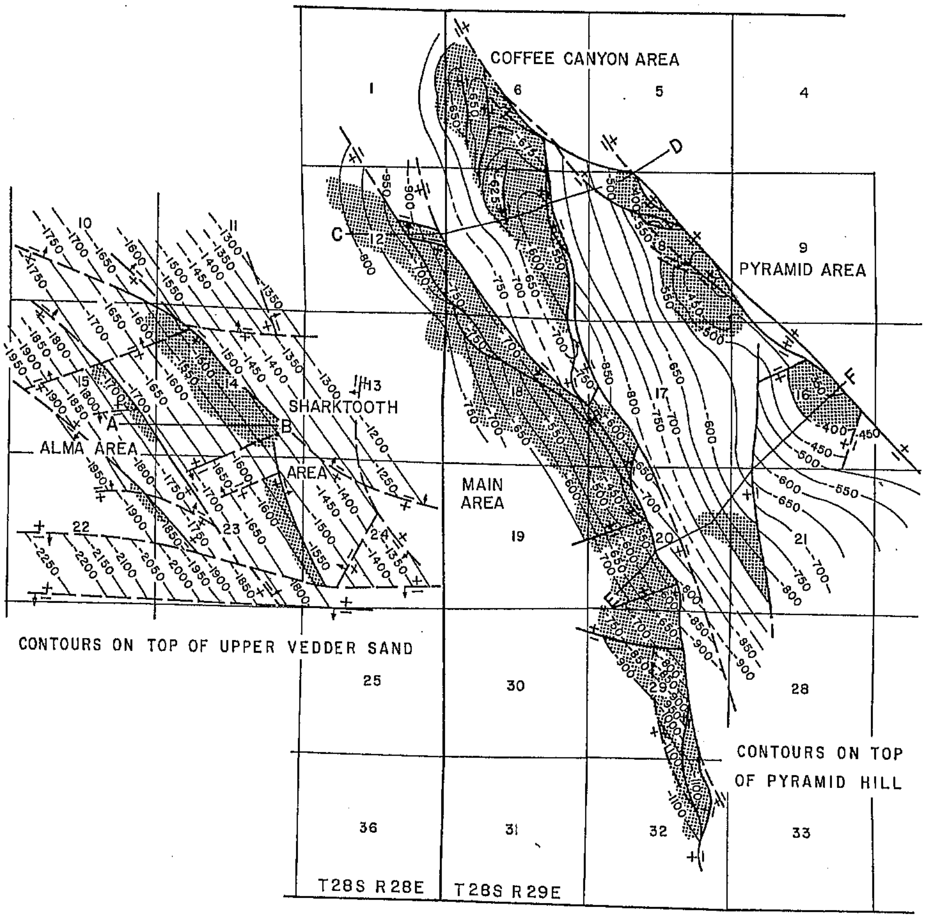
4) Volumes injected historically since 1983:
   1,529,910,014 Bbls, last injected on 3/1/2015

5) TDS of zone:
   2,335 mg/l TDS
   Sample 2,335 mg/l TDS is from "Walker zone formation water" (Round Mountain WD 1-20) on 10/17/1983.

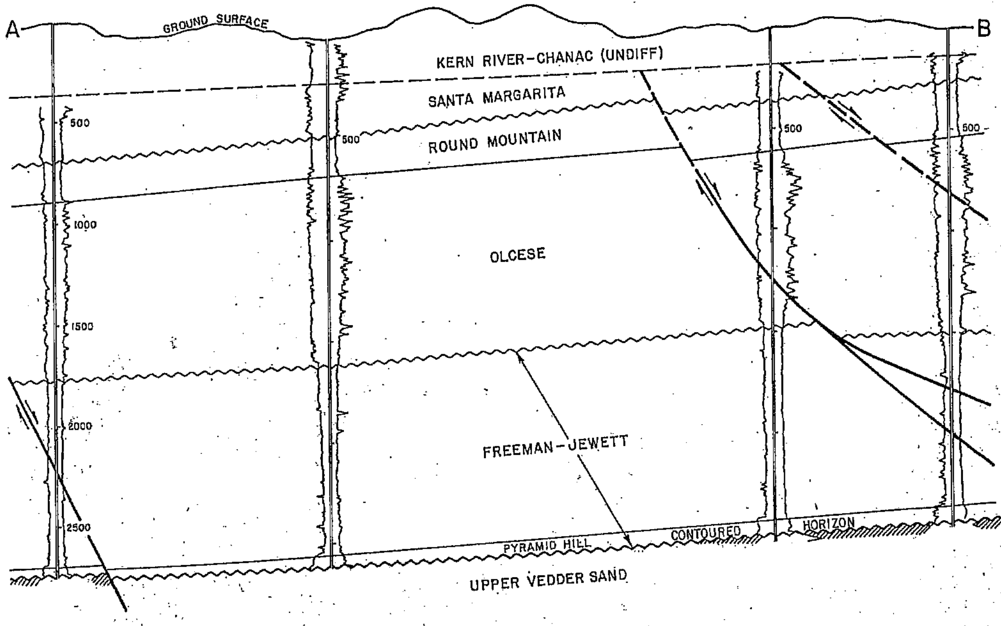
6) TDS of injection water:
   1,600 – 2,900 mg/l TDS
   The 1,600 mg/l TDS sample is from "NAM Produced water (West signal #8) on 1/1/2009 and the 2,900 mg/l TDS sample is from "18-WD7" on 9/20/2012. Permitted fluids for injection into the Walker Zone in Round Mountain field consist of Pyramid Hill, Jewett, Freeman-Jewett and Vedder zones production fluid.

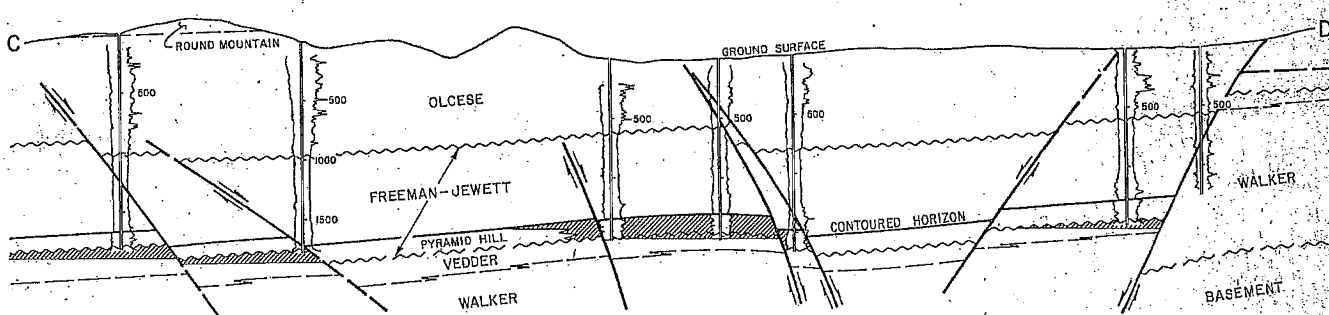
ROUND MOUNTAIN OIL FIELD

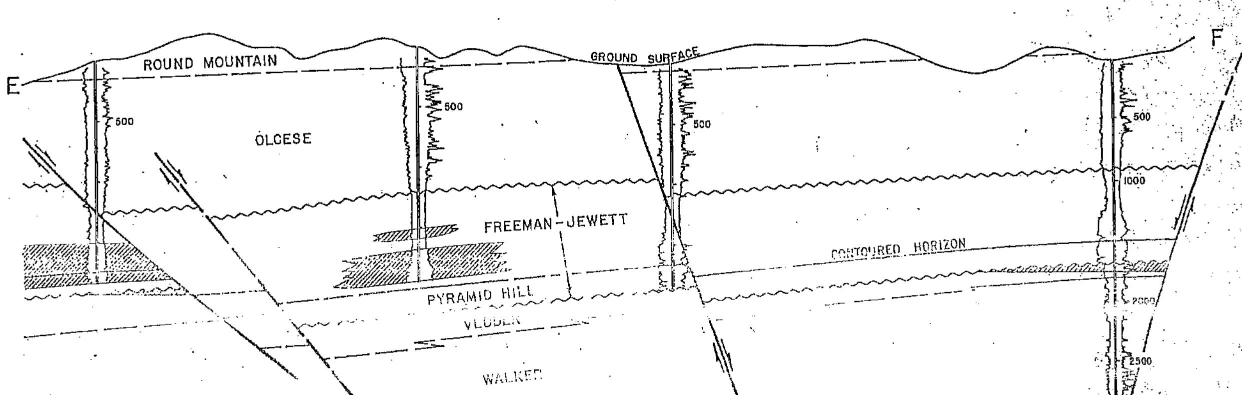




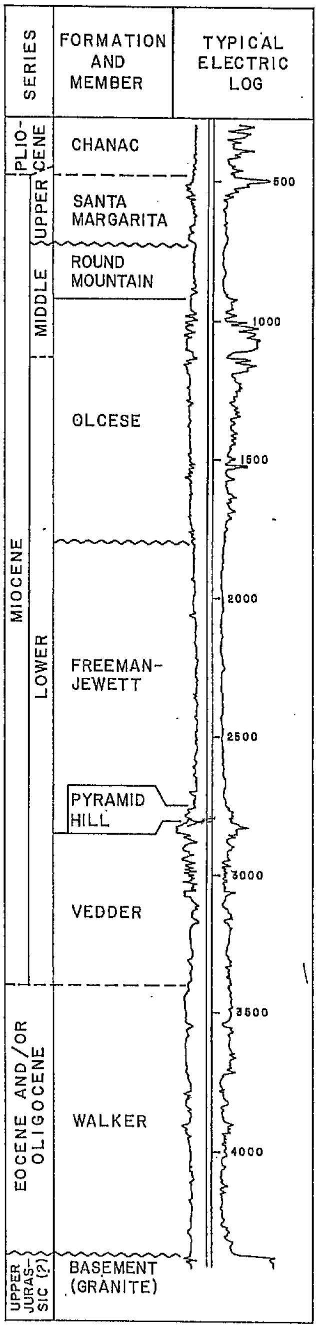
ROUND MOUNTAIN OIL FIELD

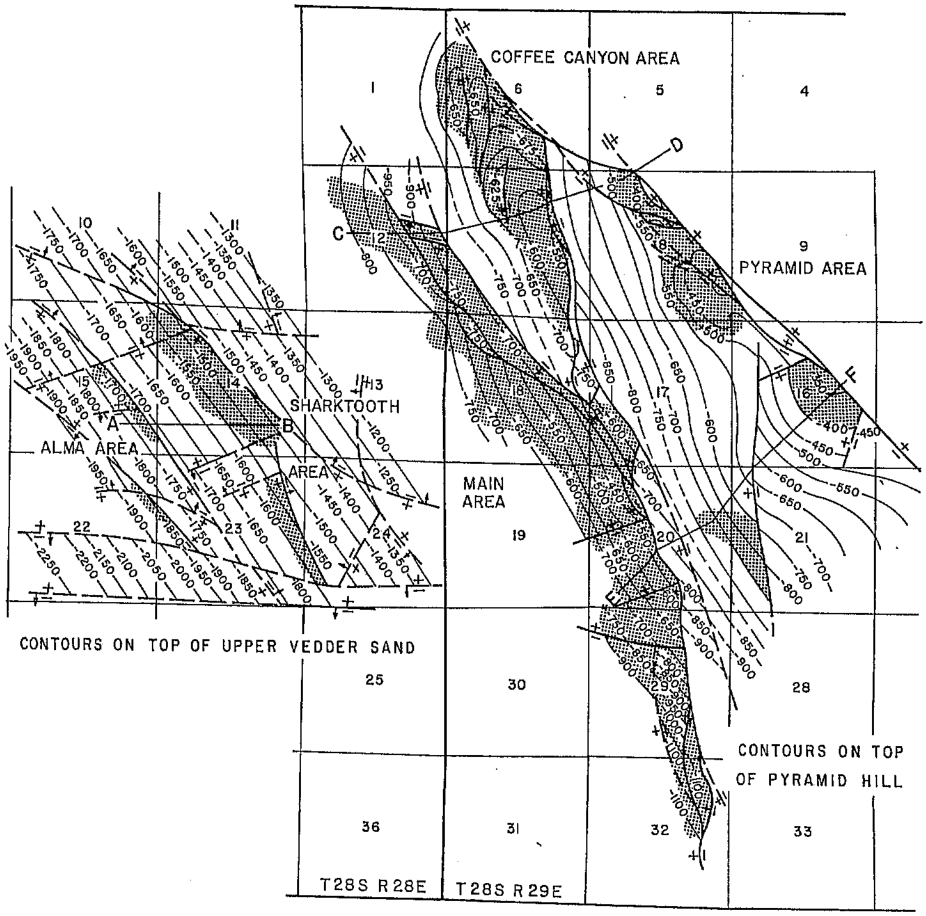






ROUND MOUNTAIN OIL FIELD





LOCATION: 14 miles northeast of Bakersfield

TYPE OF TRAP: See areas

ELEVATION: 600 - 1,500

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Jewett	Getty Oil Co. No. 2	Elbe Oil Land Dev. Co. No. 2	20 28S 29E	MD	*204	N.A.	May 1927
Pyramid Hill	Same as above	Same as above	20 28S 29E	MD	N.A.	N.A.	May 1927
Vedder	Same as above	Same as above	20 28S 29E	MD	N.A.	N.A.	May 1927

Remarks: * Production listed for Jewett is the combined production rate from the Jewett, Pyramid Hill, and Vedder zones.

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
C.C. Killingsworth "Alma" 6	Barnsdall Oil Co. "Alma" 6	Mar 1948	15 28S 28E	MD	4,418	Basement (Granite)	Late Jur (?)

PRODUCING ZONES (See areas)

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
711,406	46,635	48,630,496	2,435	292	89,199,121	1,424,213	5,453,194	1938	665	468	2,590

STIMULATION DATA (Jan. 1, 1973) (See areas)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection

SPACING ACT: See areas.

BASE OF FRESH WATER: See areas.

CURRENT CASING PROGRAM: See areas.

METHOD OF WASTE DISPOSAL: See areas.

REMARKS:

REFERENCES: See areas.

CALIFORNIA DIVISION OF OIL AND GAS

ROUND MOUNTAIN OIL FIELD

ALMA AREA

Kern County

LOCATION: See map sheet of Round Mountain Oil Field

TYPE OF TRAP: Faulted homocline

ELEVATION: 700 - 1,270

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Vedder	Harold C. Morton & H.S. Kohlbush "Alma" 1	Same as present	15 28S 28E	MD	152	N.A.	Feb 1947

Remarks:

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
C.C. Killingsworth "Alma" 6	Barnsdall Oil Co. "Alma" 6	Mar 1948	15 28S 28E	MD	4,418	Basement (Granite)	Late Jur.

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Vedder	2,600	15	early Miocene	Vedder	13	N.A.	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
6,240	0	107,447	50	3	598,904	0	113,392	1948	47	21	80

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
--			

SPACING ACT: Applies

BASE OF FRESH WATER: None

CURRENT CASING PROGRAM: 8 5/8" cem. above zone; 6 5/8" liner landed through zone.

METHOD OF WASTE DISPOSAL: Evaporation and percolation sumps on outcrops of the Round Mountain Silt.

REMARKS:

REFERENCES: Albright, M.B. Jr., Sharktooth and Alma Areas of Round Mountain Oil Field: Calif. Div. of Oil and Gas, Summary of Operations--Calif. Oil Fields, Vol. 42, No. 1 (1956).

CALIFORNIA DIVISION OF OIL AND GAS

COFFEE CANYON AREA

LOCATION: See map sheet of Round Mountain Oil Field

TYPE OF TRAP: Faulted homocline

ELEVATION: 690 - 1,300

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Pyramid Hill	Acacia Oil Co. "Coffee" 1	Reynolds Oil and Gas Co. No. 1	6 28S 29E	MD	*600	N.A.	Sep 1928
Vedder	Acacia Oil Co. "Lindsay" 1	Lindsay Oil Co. No. 1	6 28S 29E	MD	800	N.A.	Aug 1928

Remarks: * Production is commingled from Pyramid Hill and Vedder.

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Richard S. Rheem, Opr. "Smoot-Vedder" 2	Same	May 1957	1 28S 28E	MD	2,313	Vedder	early Mio

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Pyramid Hill	1,500	150	early Miocene	Jewett	18	50	None
Vedder	1,650	30	early Miocene	Vedder	16	75	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
103,176	0	7,292,707	435	50	18,507,039	67,567	1,857,108	1937	133	104	475

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
Water flood	1960	3,815,746	1

SPACING ACT: Does not apply

BASE OF FRESH WATER: 0 - 200

CURRENT CASING PROGRAM: 7" cem. above zone; 5 1/2" liner landed through zone.

METHOD OF WASTE DISPOSAL: Evaporation and percolation sumps on outcrops of the Round Mountain Silt.

REMARKS: A cyclic-steam injection project in the Pyramid Hill and Vedder zones was started in 1965 and terminated in 1968. Cumulative injection totals 12,200 bbls. The Pyramid Hill zone was originally known as the Elbe zone.

REFERENCES: Park, W.H., J.R. Weddle, J.A. Barnes, Main, Coffee Canyon, and Pyramid Areas of Round Mountain Oil Field: Calif. Div. of Oil and Gas, Summary of Operations--Calif. Oil Fields, Vol. 49, No. 2 (1963).

LOCATION: See map sheet of Round Mountain Oil Field

TYPE OF TRAP: Faulted homocline

ELEVATION: 600 - 1,500

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Jewett	Getty Oil Co. No. 2	Elbe Oil Land Dev. Co. No. 2	20 28S 29E	MD	*204	N.A.	May 1927
Pyramid Hill	Same as above	Same as above	20 28S 29E	MD	N.A.	N.A.	May 1927
Vedder	Same as above	Same as above	20 28S 29E	MD	N.A.	N.A.	May 1927

Remarks: * Production listed for Jewett is the combined production rate from the Jewett, Pyramid Hill, and Vedder zones.

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Shell Oil Co. "Jewett" 3	Same	Jun 1928	29 28S 29E	MD	2,678	Walker	Eo &/or Olig.

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Jewett	1,600	130	early Miocene	Freeman-Jewett	22	N.A.	None
Pyramid Hill	1,900	150	early Miocene	Jewett	18	N.A.	None
Vedder	2,000	80	early Miocene	Vedder	16	95	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
510,916	46,561	35,953,284	1,415	171	59,572,216	1,293,959	3,794,620	1938	302	225	1,465

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
--			

SPACING ACT: Does not apply

BASE OF FRESH WATER: None

CURRENT CASING PROGRAM: 7" cem. above zone; 5 1/2" liner landed through zone.

METHOD OF WASTE DISPOSAL: 4,845,286 bbl. of waste water was injected during 1972 into two disposal wells; percolation and evaporation sumps on outcrops of the Round Mountain Silt.

REMARKS: A water flood project in the Vedder zone was started in 1961 and terminated in 1963. Cumulative injection totals 872,587 bbls.

REFERENCES: Park, W.H., J.R. Weddle, J.A. Barnes, Main, Coffee Canyon, and Pyramid Areas of Round Mountain Oil Field: Calif. Div. of Oil and Gas, Summary of Operations--Calif. Oil Fields, Vol. 49, No. 2 (1963).

LOCATION: See map sheet of Round Mountain Oil Field

TYPE OF TRAP: Faulted homocline

ELEVATION: 730 - 1,470

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Pyramid Hill	Thomas Oil Co. "Olcese" 2	Harp & Brown "Olcese" 2	17 28S 29E	MD	5	0	May 1944
Vedder	Crestmont Oil Co. "Olcese" 1	Eastmont Oil Co. "Olcese" I	16 28S 29E	MD	250	N.A.	May 1937
Walker	Crestmont Oil Co. "Staley" 11	Same as present	8 28S 29E	MD	40	N.A.	Jul 1943

Remarks:

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Piute Holding Co. "Smith" 1	Same	Oct 1929	17 28S 29E	MD	3,110	Walker	Eo &/or Olig

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Pyramid Hill	1,250	130	early Miocene	Jewett	18	50	None
Vedder	1,390	40	early Miocene	Vedder	16	80 - 110	None
Walker	1,535	50	Eo &/or Olig	Walker	20	N.A.	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
55,714	74	1,527,767	290	37	5,692,349	6,876	378,882	1946	98	60	300

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
---			

SPACING ACT: Applies

BASE OF FRESH WATER: None

CURRENT CASING PROGRAM: 8 5/8" or 7" cem. above zone; 6 5/8" or 5" liner landed through zone.

METHOD OF WASTE DISPOSAL: Evaporation and percolation sumps on outcrops of the Round Mountain Silt.

REMARKS:

REFERENCES: Park, W.H., J.R. Weddle, J.A. Barnes, Main, Coffee Canyon, and Pyramid Areas of Round Mountain Oil Field: Calif. Div. of Oil and Gas, Summary of Operations--Calif. Oil Fields, Vol. 49, No. 2 (1963).

CALIFORNIA DIVISION OF OIL AND GAS

ROUND MOUNTAIN OIL FIELD

Kern County

SHARKTOOTH AREA

LOCATION: See map sheet of Round Mountain Oil Field

TYPE OF TRAP: Faulted homocline

ELEVATION: 700 - 1,300

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Vedder	G M V Oil Co. "Signal-Mills" 1	Bandini Petroleum Co. "Signal Mills" 1	24 28S 28E	MD	214	N.A.	Sep 1943

Remarks:

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
Mobil Oil Corp. "Bradford" 1	General Petroleum Corp. "Bradford" 1	Jun 1943	15 28S 28E	MD	2,995	Vedder	early Mio

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Vedder	2,400	25	early Miocene	Vedder	13	N.A.	None

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
35,360	0	3,749,291	245	31	4,828,613	55,811	503,449	1947	85	58	270

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
--			

SPACING ACT: Applies

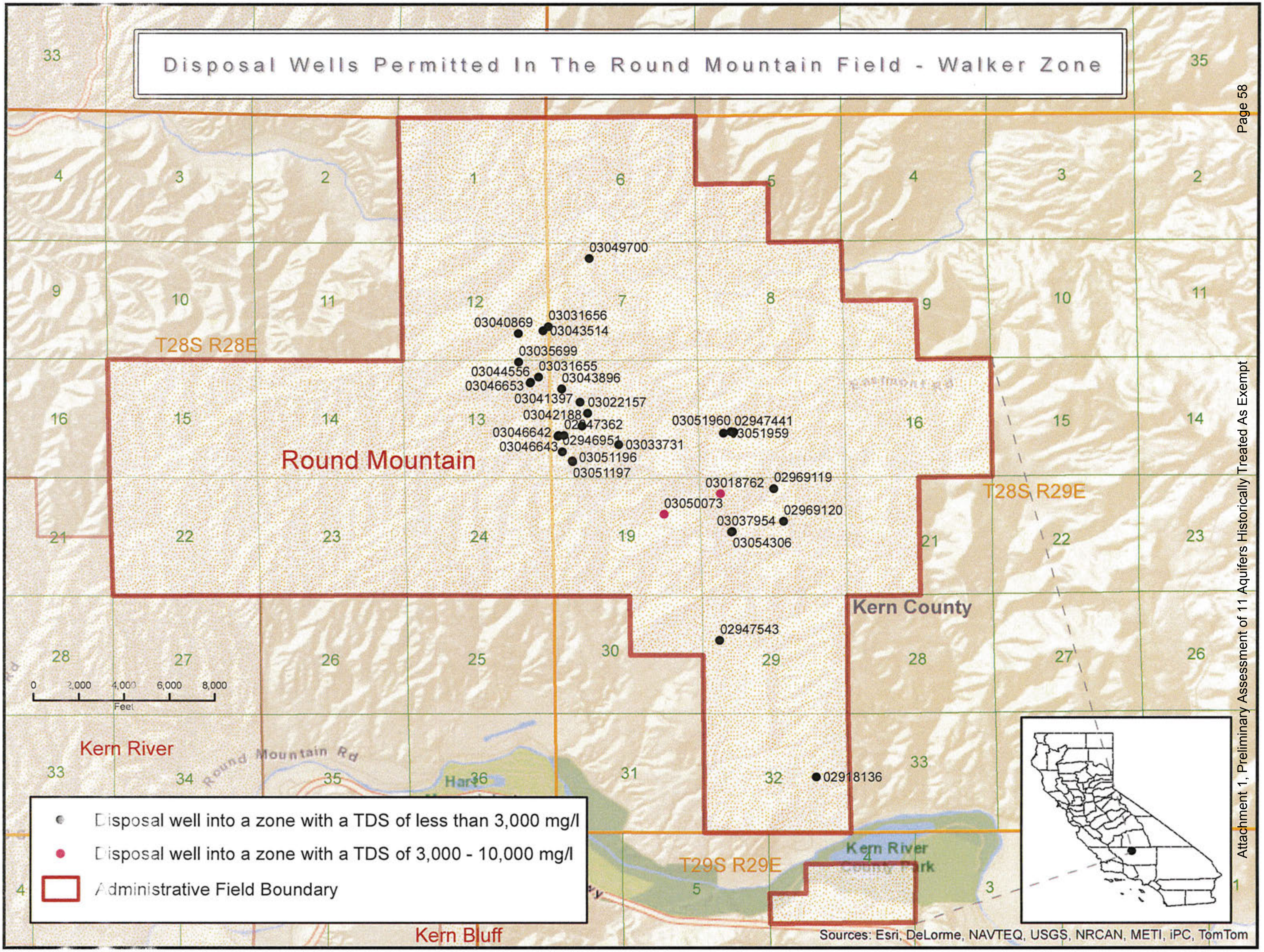
BASE OF FRESH WATER: None

CURRENT CASING PROGRAM: 8 5/8" cem. above zone; 6 5/8" liner landed through zone.

METHOD OF WASTE DISPOSAL: Evaporation and percolation sumps on outcrops of the Round Mountain Silt.

REMARKS:

REFERENCES: Albright, M.B. Jr., Sharktooth and Alma Areas of Round Mountain Oil Field: Calif. Div. of Oil and Gas. Summary of Operations--Calif. Oil Fields, Vol. 42, No. 1 (1956).



Disposal Wells Permitted In The Round Mountain Field - Walker Zone
Round Mountain
T28S R28E
T28S R29E
T29S R29E
Kern County
Kern River
Kern Bluff
Round Mountain Rd
Kern River County Park
03049700
03031656
03040869
03043514
03035699
03031655
03044556
03043896
03046653
03041397
03022157
03042188
02947362
03046642
02946951
03033731
03046643
03051196
03051197
03051960
02947441
03051959
03018762
02969119
03050073
02969120
03037954
03054306
02947543
02918136
0 2,000 4,000 6,000 8,000
Feet
Disposal well into a zone with a TDS of less than 3,000 mg/l
Disposal well into a zone with a TDS of 3,000 - 10,000 mg/l
Administrative Field Boundary
Sources: Esri, DeLorme, NAVTEQ, USGS, NRCAN, METI, iPC, TomTom

Bunker Gas Field, Undiff. (Post Eocene) Zone, Sacramento District Office

1) Number of disposal wells permitted in the zone:
   0

2) Number of active producers:
   0

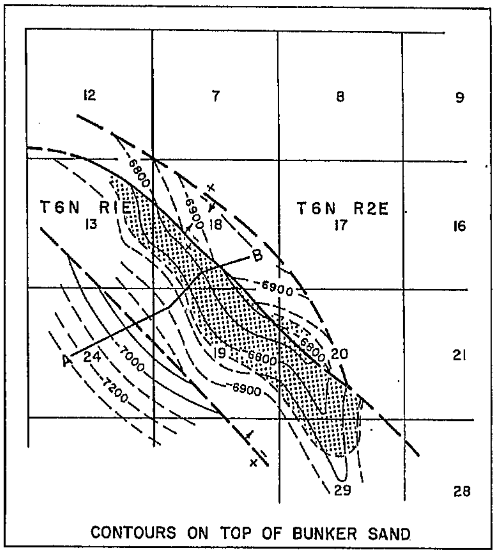
3) Depth of the zone across the field:
   3,000’ below surface

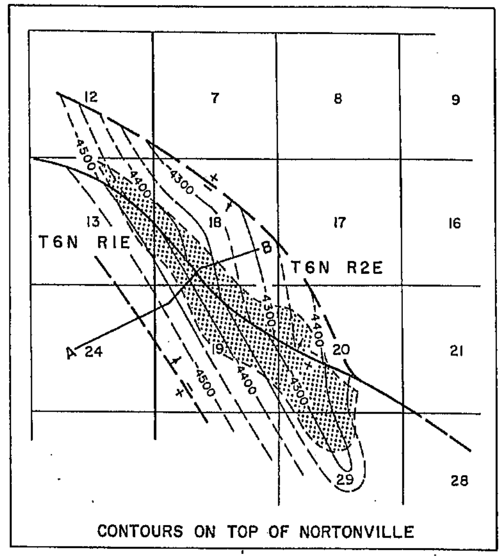
4) Volumes injected historically since 1983:
   51,454 Bbls, last injected on 11/1/1985. WD well API #095-00016 was P&A on 12/9/1986.

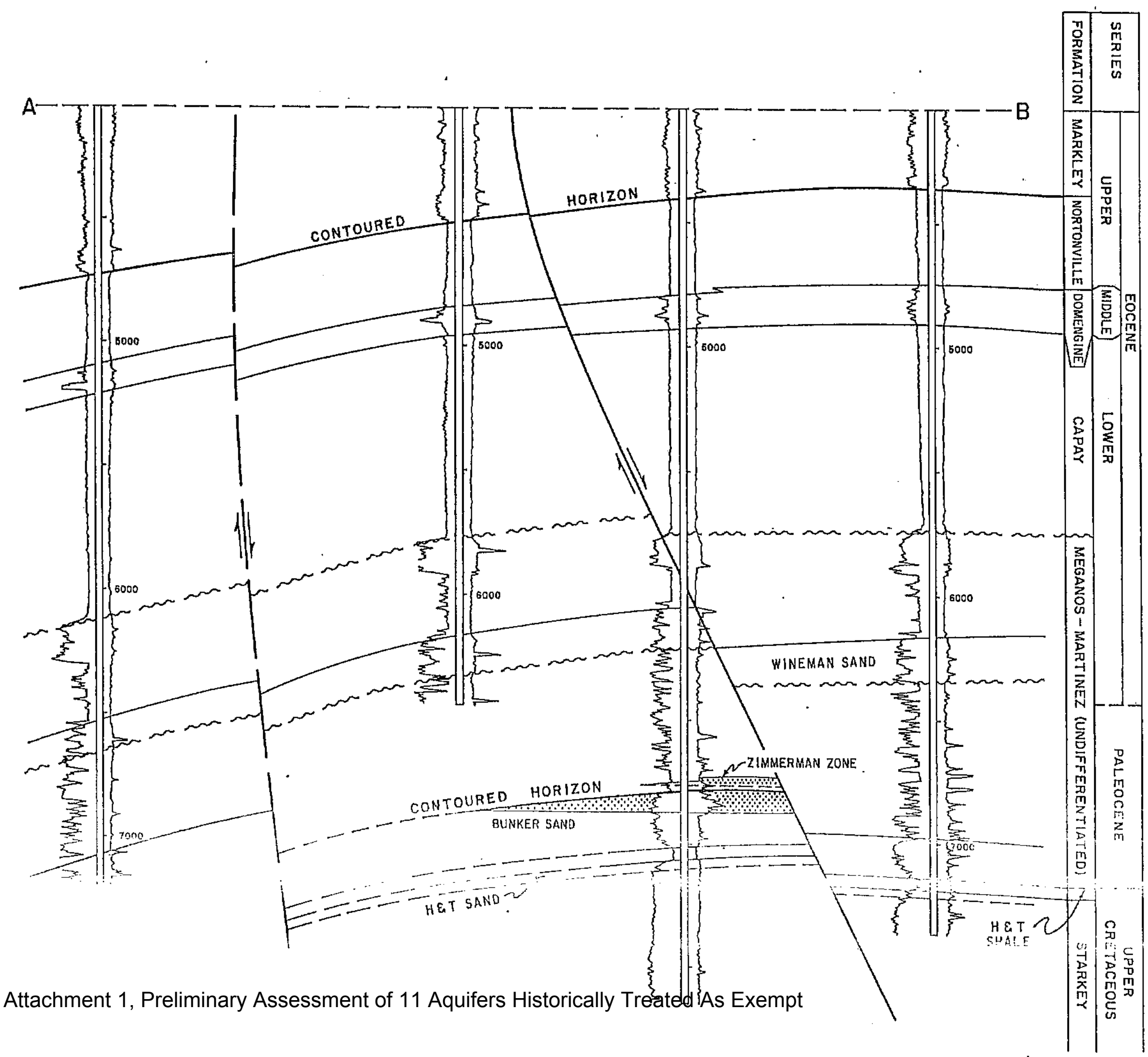
5) TDS of zone:
   1,215 mg/l TDS
   Sample collected from “BGZU” 601 well on January 16, 1974.

6) TDS of injection water:
   10,675 – 11,025 ppm Chloride
   Sample collected from “Bunker B-2 Zone” on April 26, 1973.

BUNKER GAS FIELD







LOCATION: 22 miles southwest of Sacramento

TYPE OF TRAP: Faulted anticline

ELEVATION: 25

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial production Daily (Mcf)	Flow pressure (psi)	Bean size (in.)	Date of completion
Zimmerman	Amerada Hess Corp., Unit Oper. "BGZU" 901	Amerada Petroleum Corp., Oper. "Zimmerman" 1	29 6N 2E	MD	3,890	2,250	9/32	Aug 1961
Bunker	Amerada Hess Corp., Unit Oper. "BGZU" 701	G.E. Kadane & Sons "Main Prairie Gas Unit A" 1	20 6N 2E	MD	3,425	2,250	1/4	Jun 1960

Remarks:

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	Age
Amerada Hess Corp., Unit Oper. "BGZU" 702	G.E. Kadane & Sons "Maine Prairie Gas Unit A" 2	Jan 1962	19 6N 2E	MD	10,098	Winters	Lt Cret

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Formation	Gas (btu)	Salinity of zone water gr/gal	Original zone pressure (psi)	Class BOPE required
Zimmerman	6,780	15	Paleocene	Martinez	1,075	4	2,930	IV
Bunker	6,845	25	Paleocene	Martinez	1,075	2	2,975	IV

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Net gas (Mcf)	Water (bbl)	1972 Proved acreage	1972 Maximum number producing wells	Cumulative gas production (Mcf)	Peak gas production (Mcf)	Year	Total number of wells Drilled	Completed	Maximum proved acreage
3,073,729	6,704	810	8	53,141,694	10,457,830	1963	22	10	850

SPACING ACT: Applies

BASE OF FRESH WATER: 2,500 - 3,100

CURRENT CASING PROGRAM: 9 5/8" or 7" cem. 600; 4 1/2" cem. through zones and across base of fresh-water sands.

METHOD OF WASTE DISPOSAL: Disposal into sumps at well sites.

REMARKS: Commercial gas deliveries began in October 1961. 1972 condensate production 11,256 bbl.; cumulative condensate production 233,716 bbl.

REFERENCES: Hunter, W.J., Bunker Gas Field: Calif. Div. of Oil and Gas, Summary of Operations--Calif. Oil Fields, Vol. 47, No. 1 (1961).

Wild Goose Field, Undiff. Zone, Sacramento District Office

1) Number of disposal wells permitted in the zone:
   0 (only contains gas storage wells in this zone)

2) Number of active producers:
   0

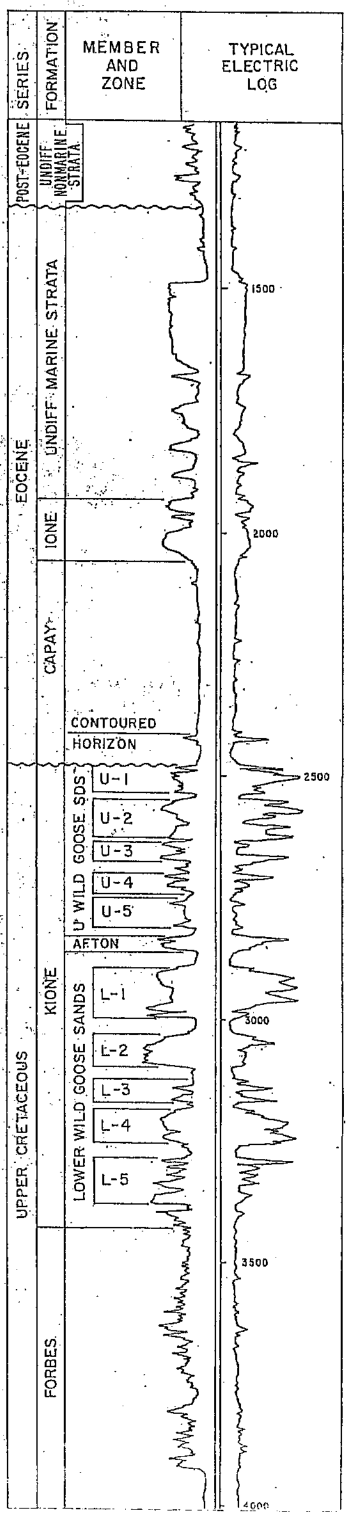
3) Depth of the zone across the field:
   2,700' – 3,400' below surface.

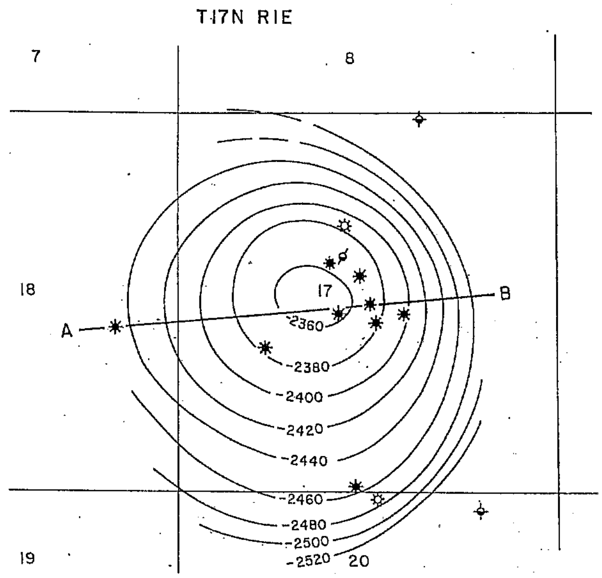
4) Volumes injected historically since 1983:
   None, only contains gas storage wells

5) TDS of zone:
   24,349 mg/l TDS
   Geochemical Analysis of Kione L4 sample provided in UIC Project File.

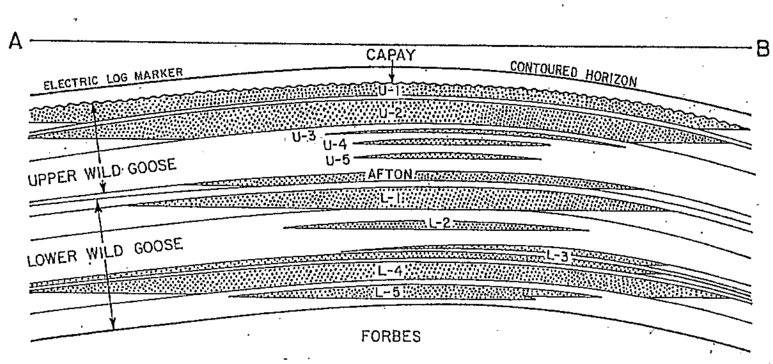
6) TDS of injection water:
   24,349 mg/l TDS
   Geochemical Analysis of Kione L4 sample provided in UIC Project File.

WILD GOOSE GAS FIELD





CONTOURS ON ELECTRIC LOG MARKER IN CAPAY



LOCATION: 10 miles northwest of Colusa

TYPE OF TRAP: Dome

ELEVATION: 65

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial production: Daily (Mcf)	Flow pressure (psi)	Bean size (in.)	Date of completion
Hangtown (Sub Capay)	Exxon Corp. "Wild Goose Gas Unit 1" 6	Humble Oil & Rfg. Co. "Wild Goose" 6	17 17N 1E	MD	4,000	940	24/64	Sep 1963
Upper Wild Goose	Exxon Corp. "Wild Goose Gas Unit 1" 4	Honolulu Oil Corp. "Honolulu-Humble Wild Goose" 4	17 17N 1E	MD	7,340	880	36/64	Jul 1953
Afton	Exxon Corp. "Wild Goose Gas Unit 1" 6	Humble Oil & Rfg. Co. "Wild Goose" 6	17 17N 1E	MD	*4,840	1,040	24/64	Sep 1963
Lower Wild Goose	Exxon Corp. "Wild Goose Gas Unit 1" 1	Honolulu Oil Corp. "Honolulu-Humble Wild Goose" 1	17 17N 1E	MD	4,020	1,370	24/64	Aug 1951

Remarks: * Commingled production from Afton and Upper Wild Goose. Honolulu Oil Corp. tested this zone in open hole at a maximum rate of 2,980 Mcf per day in "Honolulu-Humble Tule Goose" 1 (now Exxon Corp. "Wild Goose Gas Unit 1" 7) during July 1952.

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth: Strata	Age
Exxon Corp. "Wild Goose Gas Unit 1" 11	Humble Oil & Rfg. Co. "Wild Goose Country Club" 7	Aug 1967	18 17N 1E	MD	7,004	Dobbins	Late Cret

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic: Age	Formation	Gas (btu)	Salinity of zone water gr/gal	Original zone pressure (psi)	Class BOPE required
Hangtown (Sub Capay)	2,400	10	Lt Cretaceous	Kione	N.A.	N.A.	1,105	IV
Upper Wild Goose	2,500	200	Lt Cretaceous	Kione	800	1,780 - 3,250	1,200 - 1,310	IV
Afton	2,850	30	Lt Cretaceous	Kione	N.A.	N.A.	1,335	IV
Lower Wild Goose	2,900	250	Lt Cretaceous	Kione	805	1,800 - 2,650	1,345 - 1,500	IV

PRODUCTION DATA (Jan. 1, 1973)

1972 Production: Net gas (Mcf)	Water (bbl)	1972 Proved acreage	1972 Maximum number producing wells	Cumulative gas production (Mcf)	Peak gas production: (Mcf)	Year	Total number of wells: Drilled	Completed	Maximum proved acreage
1,382,761	0	340	9	99,229,200	8,248,811	1961	16	11	360

SPACING ACT: Applies

BASE OF FRESH WATER: 1,050

CURRENT CASING PROGRAM: 9 5/8" cem. 500; 5 1/2" cem. through zones and across base of fresh-water sands.

METHOD OF WASTE DISPOSAL: Water is injected into Exxon Corp. disposal well.

REMARKS: Commercial gas deliveries began in November 1951.

REFERENCES: Hunter, G.W., Wild Goose Gas Field: Calif. Div. of Oil and Gas, Summary of Operations--Calif. Oil Fields, Vol. 41, No. 1 (1955).

Attachment 2:

Plan for Class II Program Improvements

Introduction

Since at least the time of the US EPA's 1983 delegation of primacy to the Division of Oil, Gas and Geothermal Resources (Division), the Division's largest regulatory endeavor has been its Class II underground injection control (UIC) program. Significant improvements to this plan will, by necessity, require significant changes in all aspects of the Division – leadership, staffing, training, data management, establishment of metrics, internal review and monitoring against standards. Organizational change of this magnitude is profound, affecting every employee action every day. The Brown Administration, the Department of Conservation and the Division have committed to this organizational restructuring, of which this Plan for Class II UIC Program Improvements is an important – but not sole -- piece.

Given the years of work and level of resources required, it is critical to know what the target is. This plan should be understood in the context of this vision for the Division:

> The Division will become a modern, efficient, collaborative, science-driven agency that intelligently and consistently regulates State oil and gas activities using modern field tools integrated with advanced data management systems that allow for oversight of a greater number of activities. Safety and training will become integrated cultural norms. The Division will be much better connected with oil and gas-related research activities in industry, academia, and national laboratories so that it can see regulatory challenges coming in advance and apply regulations from an elevated platform of understanding. The Division will perform its duties with integrated collaboration of other State agencies to reduce the environmental impact of oil and gas development. Internal monitoring and compliance will be routine and fully integrated with all that we do so that Division performance can be measured objectively. The Division will be paperless and have instant access to data and information, and hence be able to support all stakeholder groups. Likewise, stakeholder groups will be able to routinely observe Division activities and retrieve information of interest. The Division will have more effective communications capabilities and be more comfortable engaging stakeholder groups.

BACKGROUND AND OVERVIEW

Injection wells have been an integral part of California's oil and gas operations for over 50 years. Currently, over 50,000 oilfield injection wells are operating in the state. Injection wells are used to increase oil recovery and to safely dispose of waste fluid produced with oil and natural gas. About 70-75 percent of California's oil production is the result of enhanced oil recovery (EOR) methods such as steam flood, cyclic steam, water flood, and natural gas injection, all of which involve some sort of injection activity.

Most of the oil and gas fields in the state are mature and require EOR to be productive. Each year more responsibility rests with the Division's Underground Injection Control (UIC) Program to deal with the enhanced recovery of the resource. This includes new methods and techniques developed by the industry to produce the oil and gas. The increased use of injection, such as cyclic steaming, also presents new public health and safety risks, especially in fields with older wells. These risks include groundwater contamination, reservoir fluids leaking to the surface, and fires and blowouts caused by the migration of oil and gas. Urban encroachment on or around older oil and gas wells raises additional issues and concerns.

The Horsley Witten audit, conducted at the request of the Division for the US EPA, was completed and sent to the Division in September 2011. The following issues were outlined in the audit:

- Additional plugging and cementing requirements to protect underground sources of drinking water (USDW)
- More in-depth evaluation of the zone of endangering influence (ZEI)
- Requirements for waste fluid disposal
- Changes to requirements for pressure gauges and/or monitoring of zone pressure
- Well construction and cementing
- Annual project reviews
- Standard Annual Pressure Test (SAPT) requirements
- Well monitoring requirements instead of the SAPT
- Mechanical integrity surveys and testing
- Inspections and compliance/enforcement practices and tools
- Idle well planning and testing program
- Financial responsibility requirements
- UIC staff qualifications
- Cyclic steam injection well testing requirements

In addition to the US EPA audit, the legislature has been involved with several UIC issues and has noted other areas that need to be addressed in regulation. These include:

- H2S/Waste Gas Disposal
- Freshwater usage relating to EOR projects
- CO2 EOR Projects

Additional areas of concern relating to the Division's UIC program include:

- Production from shallow diatomite formations
- Surface expressions
- Aquifer exemption process

- Well construction standards
- Injection relating to formation fracturing pressure

ACTIONS TAKEN TO DATE

The Division first identified issues with its UIC Program in 2009. Division management began a review of then-current practices in regards to approving injection projects, annual project reviews, and the evaluation of wells within the Area of Review (AOR). At the conclusion of the Division's self-assessment, it developed a general plan to work with the administration and Legislature to increase the number of staff so that several deficiencies in the program could be addressed proactively. 17 positions (PYs) established in the FY 2010-2011 budget were spread throughout the Division to add staff to the UIC program to ensure project applications were reviewed according to both the program specifications outline in the Primacy application to the US EPA and in accordance with State statutes and regulations. In addition, Division management also put in place a Letter of Expectations to remove any confusion regarding how injection project applications were to be evaluated. These expectations were issued in May 2010 and revised in November 2010. The Letter of Expectations was mentioned and supported in the Horsley Witten Report.

As the Division continued to monitor its performance and the pace of program improvements, the Division recognized that additional resources were needed to reach improvement goals and therefore requested and received additional staff in FY 2011-2012. Most of these positions were added to the UIC program to provide additional staff to conduct an adequate UIC project application review. Several PYs were used to form an internal monitoring and compliance group to dig deeper into the UIC project files to provide a more refined evaluation of the Division's internal adherence to UIC requirements. Once established, the Monitoring and Compliance Group began an assessment of the Division's activities in District 1 (Los Angeles Basin) regarding past and current work regarding UIC project approvals, area of review and zone of endangerment assessments, project monitoring and annual reviews.

To meet the objectives listed in the Letter of Expectations, Division management executed an internal strategy to explain and train staff regarding the requirements for an UIC project approval, and how existing projects were to be reviewed, remediated and monitored to move UIC projects to full compliance.

As these activities were underway, Division management recognized the need to address the emergence of cyclic steam enhanced oil recovery as not only a rapidly evolving technology but one that was being employed to produce a major fraction of the state's oil. Further, the Division set in motion steps to deal with the mismatch between existing regulations and the realities in the state's oilfields. Of greatest concern was cyclic steam production from shallow diatomite formations as this type of production was rapidly emerging, and the state's regulations were inadequate to properly regulate these activities and ensure protection of USDWs.

Moving Forward and UIC Assessment

Even though there has been consistent recognition by several top leaders within the Division that the UIC program has had significant deficiencies, Division plans and actions for UIC improvement have been less effective than needs demand. In part, the mismatch between plan objectives and results have been caused by numerous management changes. Furthermore, it was not fully understood that fundamental problems with the lack of consistent business processes, poor record-keeping and the lack of modern data management tools were only some of the root causes of the Division's lack of performance in the UIC program. Hence, until recently, a coherent plan addressing broad, fundamental foundational problems was not developed. This spring, with the strong support of the Brown administration, the Division requested and received 23 additional positions to address deficiencies in a number of areas – capacity in program leadership, monitoring and compliance, data management and geographic information systems, emerging technologies, and environmental review. Furthermore, as part of the overall plan, the Division requested and received funding for a modern data management system designed for the oil and gas regulatory environment. Further changes will be forthcoming in the weeks ahead to better align the Division for significant performance improvements.

The Division has already started its UIC program evaluation and will continue the following efforts:

- Identifying gaps in UIC Program compliance and develop a corrective action plan
- Hiring qualified personnel to fill retirement and new position vacancies
- Providing technical and regulatory training for UIC staff
- Increasing management oversight of UIC staff
- Increasing accountability for technical work
- Conducting outreach to the public regarding state and federal mandates
- Conducting outreach to the oil and gas industry to raise awareness of changes in Division regulatory approaches and monitoring
- Pursuing and implementing electronic data systems development

California is moving forward to meet the changing regulatory imperatives with respect to technology, demographics, and more aggressive oversight of oil and gas production. To reiterate, the target is to evolve the Division to a modern, efficient, collaborative, science-driven agency that intelligently and consistently regulates State oil and gas activities using modern field tools integrated with advanced data management systems that allow for oversight of a greater number of activities. Safety and continuous training and improvement will become integrated cultural norms. The Division will be much better connected with oil and gas-related research activities in industry, academia, and national laboratories so that it can see regulatory challenges coming in advance and apply regulations from an elevated platform of understanding. The Division will perform its duties with integrated collaboration of other State agencies to reduce the environmental impact of oil and gas development. Internal monitoring and compliance will be routine and fully integrated with all that is done so that Division performance can be measured objectively. The Division will be able to support all stakeholder groups because it will be paperless and have instant access to data and information. Hence stakeholder groups will be able to routinely observe Division activities and retrieve information of interest. The Division will have more effective communications capabilities and be more comfortable engaging the constellation of stakeholder groups.

Such profound organizational renewal will consume several years and require constant, focused attention. This work plan is an important initial piece of that renewal. The UIC plan is designed to strengthen the current UIC Program through new regulations, consistent, ongoing training, enhanced compliance oversight, and an evaluation of existing projects and UIC operations.

Assessment by Monitoring and Compliance Unit

The Division has conducted a partial assessment of the Division UIC Program by sampling and reviewing program activities and compliance oversight in one of its District offices. In the development of the assessment, the Division considered the following concerns to help develop a priority list:

- Risk to the public
- Risk to health and safety
- Risk to property
- Risk to natural resources
- Risk of litigation

Based upon known conditions at the time of the assessment, the injection projects located in the Cypress District (Division – District 1) appeared to have the highest priority. The District has around 800 injection projects, which includes over 2,000 injection wells.

The assessment was designed to give greater insight into the range of shortcomings in the Division's UIC program. The UIC program standards that should be used are listed in both California's Primacy application and the federal regulations associated with the Safe Drinking Water Act and Class II injection wells. The assessment has:

- Evaluated a representative sampling of old projects that are in fields that were discovered in the 1930's and 1940's to determine if appropriate Area of Reviews (AOR) were completed and to determine if possible conduits for the injection fluid are present
- Evaluated a representative sampling of recent projects to determine if appropriate AORs were completed and to determine if possible conduits for injection fluid are present
- Evaluated a representative sampling of the records for annual project reviews to determine if they were performed and documented adequately to determine if the project is in compliance with the project approval

- Evaluated a representative sampling of the Division's UIC monitoring program to determine if adequate Mechanical Integrity Testing (MIT) surveys were conducted, evaluated, and documented to ensure mechanical integrity of the injection wells
- Evaluated a representative sampling of the Division's UIC monitoring program to determine if the Maximum Allowable Surface Pressures (MASP) are determined correctly and monitored to ensure compliance with the project approval
- Evaluated if the Division's UIC staff are appropriately educated and trained and have the necessary tools to enforce the Safe Drinking Water Act in regards to Class II wells
- Evaluated if the Division has enough staff and resources to adequately enforce the Safe Drinking Water Act in regards to Class II wells

A draft report that lists the results of the assessment in our Cypress district office has been prepared and is under final administration review.

Bonding

The State has already addressed some of the financial responsibility requirements. Effective January 1, 2014, the State has increased its bonding amounts to address the rising costs to remediate problem wells that become the responsibility of the State. These changes also affect the number of wells that may be covered by a blanket bond. What is not clear, pending further review, is the magnitude of the state's financial liabilities and whether the incremental changes heretofore are sufficient to address long-term needs.

DIVISION'S NEXT STEPS

Individual Project Evaluation

The Division will undertake improvements to its administration of the UIC Program through a series of actions including increasing program leadership talent, enhancing field monitoring of compliance with regulations, a series of rulemakings on priority topics, and a project-by-project review of each UIC project to assess the status of the project with respect to compliance with UIC regulations, testing requirements and adherence to limitations placed on the project in project approval letters. This plan will be informed based upon the findings of the partial assessment of the UIC program already conducted. The Division will take the following steps to ensure all injection projects are in compliance with State law and the Primacy agreement with the US EPA:

1. District staff will review all of the active injection projects in the State and determine what, if any, data are missing to fully evaluate the injection project and ensure the protection of Underground Sources of Drinking Water (USDW). Any data that need to be updated because of changes or modifications to the original approval, will be identified and collected, and the project files organized and

prepared to meet two goals: improved, consistent regulatory oversight and efficient uploading of project data into the coming new data management system.

2. As this project-by-project review is underway, Division staff will meet with operators to discuss the list of deficiencies and develop a compliance schedule for all issues. Operators will be given no more than 6-12 months to supply the Division with the missing or updated data. Depending on the data requests, this timeline may be greatly reduced. Based on the project-by-project review, projects could be terminated or modified.

3. Division staff will evaluate the data submitted and require operators to make changes to ensure the project is still viable. Projects will be modified or cancelled based on this analysis.

4. All projects will be evaluated by the District office and sent to Sacramento for review and concurrence by the program director prior to being approved.

5. Projects may require a new Project Approval Letter (PAL) with additional conditions and/or reporting requirements to ensure compliance.

6. All projects will be reviewed to assess containment of injection fluids. The Division will work closely with the State Water Quality Control Board on the evaluation of fluid containment and the adequacy of the required zone of endangering influence and area of review.

7. All injection data will be entered or verified in the State's databases. Because existing databases may not have the capacity to manage all the data required, the Division will implement a temporary database until the Division's data management system is developed and implemented.

8. All required mechanical integrity tests will be confirmed and verified.

9. Once every year thereafter, the projects will be evaluated to ensure the projects are operated in compliance with the PAL and all testing and monitoring requirements have been met in compliance with UIC regulations.

Project-by-Project Review Schedule

The project-by-project review process will be time consuming and demand significant investment if staff time. In the Cypress and Bakersfield districts, this effort will be very significant. Even though with the implementation of the Letter of Expectations, project applications and project files have improved, many of the injection projects were evaluated and approved under a less stringent process. Many of the Districts have had District policies in place that fell short of directives in the primacy application, statutes, and regulations. The time to complete this review will vary based upon the following:

- Number of projects in each District
- Number of injection wells in the project
- Number of wells within the AOR (project area)
- Amount and type of data missing from the project file
- Current status of the project

Division leadership expects that a review of this depth could require as much as a week (5 working days) to evaluate what is missing from a project file. Such a review can be complicated and complex since the data provided needs to be relevant and accurate, and requires comparison with the project application.

All projects are not equal in size or complexity, and based upon the project status and number of injection projects by District, the following is an estimate of time needed for initial review to evaluate existing data, identify gaps and the develop a list of compliance deficiencies:

District 1 (Cypress)
Number of projects: 817 (X 40 hours) = 32,680 hours

District 2 (Ventura)
Number of projects: 322 (X 40 hours) = 12,880 hours

District 3 (Orcutt)
Number of projects: 255 (X 40 hours) = 10,200 hours

District 4 (Bakersfield)
Number of projects: 1342 (X 40 hours) = 53,680 hours

District 5 (Coalinga)
Number of projects: 195 (X 40 hours) = 7,800 hours

District 6 (Sacramento)
Number of projects: 43 (X 40 hours) = 1,720 hours

The Division is mindful that review of all projects will not consume a full 40 hours. Some projects are no longer active, so the District staff will prioritize the projects based upon their status. Based upon these numbers it is estimated to take anywhere from six to 18 months to complete this first phase. Phase II -- developing a compliance schedule required of operators and certifying the completion of requirements-- will consume, in total, approximately an additional 12-18 months. Therefore, the overall time to fully complete the project review, certify remedial work, and move the program into full regulatory compliance is estimated to be three years.

The Division anticipates that the review and compliance process can be completed in different districts on different schedules. Beginning October 1, 2015, the Division has developed the following schedule:

Districts 3 and 6, review complete within 7 months, compliance certification within 18 months (18 months start to finish);

Districts 2 and 5, review complete in 9 months, compliance certification in 24 months (24 months total).

District 1, review complete in 10 months, compliance certification in 28 months (28 months total).

District 4, review complete in 16 months, compliance certification in 36 months (36 months total)

A very significant unknown in this review will be the amount of time needed for joint Division and Water Board assessment and validation of containment of injected fluids. Furthermore, demands on staff time for aquifer exemption data review and preparation for the implementation of the new data management system will be significant and will have to be orchestrated to meet these timelines. Once an initial assessment of file status in each of the Districts is complete, the Division can develop a more refined assessment of schedule.

Aquifer Exemptions

The Division continues to evaluate wells that have been permitted to inject into non-exempt aquifers, according to the compliance schedule agreed upon by the Division, State Water Board, and US EPA. The Division, working with the State Water Board, is continuing to evaluate potential impacts to water supply wells and, where precautionary measures are needed, ordering wells to cease injection if there is a potential impact to any water supply well. In addition to the well evaluation, the Division and State Water Board are working with operators to obtain additional data on aquifers to determine if the State will pursue aquifer exemption applications to the US EPA. The State continues to meet its obligations to the compliance schedule and acknowledges that a failure to receive approval from the US EPA on proposed aquifer exemptions will result in additional injection well closures.

Staffing

As noted above, the Division has recently received 23 additional positions to augment the Division's program. Ten positions will be deployed to the district offices to enhance field presence and the review of UIC projects. Five positions will be added to the GIS/Data Management Unit to ensure data quality and support to the district staff evaluating UIC project applications and reviews. Three positions will be added to the California Environmental Quality Act (CEQA) Unit to ensure compliance with project approvals and environmental reviews associated with the approvals. Four positions will be added to the Monitoring and Compliance Unit, which will increase capacity to the current Monitoring and Compliance Unit to ensure there is consistency throughout the Division and that all districts are fully implementing the UIC program. We have also added one position to the legal staff to assist with rulemakings, litigation, and other legal issues associated to UIC issues.

The Division is also assessing its organizational structure, workload, and supervisory oversight requirements of the organization and is preparing to make adjustments to be more effective and to better assimilate the additional staff. These adjustments, based upon identified priorities, will be announced soon.

Compliance Monitoring

This work plan includes utilizing the Division's Monitor and Compliance Unit to verify District staff are following statutes, regulations, and policies in the regulating of the UIC projects. This unit is separate from the UIC Program and therefore can provide objective analysis of the adequacies of the UIC Program improvements. This unit is comprised of one Senior Oil and Gas Engineer to oversee the unit, seven Engineers, and one Associate Government Program Analyst. This team will provide the necessary resources to assist with the improvement plan implementation and execution, and then continued monitoring to ensure Division statutes, regulations, and policies are followed. This unit is providing feedback to the Technical Services Manager, UIC Program Manager, and the Chief Deputy to ensure accountability.

Training

The Division is seeking a Technical Training Coordinator to evaluate training needs of the Division's technical staff. As we move to fill this position, the Division is also moving to put in place training contracts and training requirements for staff to complete, prior to going into the field and evaluating UIC project applications. The Division is also in the process of developing a training plan that clearly outlines the necessary training requirements for each level of engineer as well as a list of skills, knowledge, and abilities for each level of engineer. This plan is also expected to be ready by autumn, 2015.

In addition to specific training courses, the Division will continue its meetings of engineers in the Districts. The Division has had two such meetings in the last year.

These meetings are designed to develop team work and share important information regarding different aspects of the work district engineers perform. They provide a forum to share findings regarding investigations of injection activities the Division has undertaken and provide guidance as to how to monitor and identify issues before problems occur.

Business Process

The Division lacks clear and consistent business process. To deal with this challenge, the Division has contracted for assistance with:

1. Identification of the various permitting processes throughout the Division
2. Identification of common relevant steps in each the process
3. Recommendations of statewide processes for our permitting

Along the way, the contract will ensure that legislative mandates are being captured in our existing processes. Much of the work done for this will also contribute to essential preparations for the implementation of our data management project.

Phase 1 of the contract will require 90 days. The contractor is now traveling to District offices to interview employees who have a part of the UIC program.

Data Management System

The Division has already begun working with the California Department of Technology to evaluate our current systems and to develop a plan to meet the Division's future data management needs. This plan will include looking at a data management system that captures all the required data and a method for either the Division to push data to an US EPA-wide data management system or a method for EPA to download data. The State employs a "Stage/Gate" model process to assess business needs and processes and develop deliverables and project completion schedules. The entire process of assessment to delivery of a complete system could take 3-4 years including the uploading of legacy data.

Rulemaking

The Division has identified an ambitious list of regulatory goals to be accomplished by rulemaking action. This list of regulatory goals is based on the Division's own evaluation of its UIC Program, concerns raised in the review prepared by the Horsley Witten Group, input from stakeholders, and input from other regulatory agencies. In addition, these regulatory goals dovetail with issues related to the UIC Program that were identified by the California Council on Science and Technology in the independent scientific assessment of well stimulation treatments in California that it conducted pursuant to Senate Bill 4 (Pavley 2013).

These regulatory goals each relate to the Division's UIC Program, but some issues – such as well construction standards and idle well management – are actually broader in scope than just injection regulation. Because these rulemaking goals are likely to be more than could be effectively addressed at one time, the Division will undertake its rulemaking efforts around these goals in two phases. The regulatory goals to be addressed in these two phases of rulemaking are as follows:

<u>Phase 1</u>

- *Clarify standards for ensuring zonal isolation of injection projects*
- *Expressly define the quality of water to be protected when constructing wells*
- *Codify best practices for well construction*
- *Establish permitting and regulatory requirements specific to cyclic steam operations*
- *Establish requirements specific to cyclic steam in diatomite, including a regulatory framework for responding to surface expressions and clarification regarding injection above fracture gradient*
- *Clarifying process and standards for establishing maximum allowable surface pressure for injection operations*

<u>Phase 2</u>

- *Codify requirements for ongoing project review*
- *Establish requirements for securing idle wells and standards for well abandonment*
- *Elaborate on existing idle well testing requirements*

Generally, these rulemaking goals will be accomplished through a process of (1) identifying interested parties and engaging with stakeholders to solicit concerns and suggestions; (2) drafting proposed regulations and informally soliciting input on the draft regulations; and then (3) commencing formal rulemaking to adopt proposed regulations.

The Division has already started this process for Phase 1 of its rulemaking effort. The Division has circulated a notice identifying the Phase1 regulatory goals and encouraging people to identify themselves as interested parties for the rulemaking effort. In the near future, the Division will be sending notice to interested parties of workshops to be conducted this fall throughout the state, in order to provide an opportunity to provide input on how to best accomplish the regulatory goals identified. The Division's goal is to informally circulate draft regulations in November 2015, commence formal rulemaking in January 2016, and complete the rulemaking process for the Phase 1 rulemaking effort by winter of 2016.

Although the Division has already begun giving consideration to Phase 2 regulatory goals, the Division will not begin working in earnest to pursue the Phase 2 rulemaking effort until formal rulemaking for the Phase 1 rulemaking effort is near completion. Accordingly, the Division estimates that the Phase 2 rulemaking effort will not begin until fall of 2016, and will not be completed until winter of 2017.

Conclusion

The job of meeting the many goals laid out here is indeed a substantial one. But with the continued support and effort of those involved, doing the job well will result in a modern and responsive regulatory unit that is able to meet the challenge of helping to shepherd our oil and gas resources in a way that will, to the greatest extent possible, both protect public health and the environment and maintain California's significant oil production economy.

Attachment 3: Public Participation Process For Aquifer Exemption Proposals

The purpose of this document is to explain the public participation process that the Department of Conservation, Division of Oil, Gas, and Geothermal Resources (Division) will follow before submitting an aquifer exemption proposal to the US Environmental Protection Agency (U.S. EPA). The Division will not submit an aquifer exemption proposal to U.S. EPA without concurrence from the State Water Board and the appropriate Regional Water Quality Control Board (collectively Water Boards) that the proposal is appropriate, and the Division will not submit a proposal for public comment unless the Division and the Water Boards agree that the proposal merits consideration.

- **Public Notice and Comment**
  - Timing. Public notice and opportunity to comment will be provided after the Division and the Water Boards make an initial determination to request U.S. EPA approval of a new aquifer exemption, but before any final proposal is submitted to U.S. EPA.
  - Newspaper Publication. The Division will publish notice of proposed aquifer exemptions in at least one newspaper. The most appropriate newspaper will be determined on a case-by-case basis, but generally will be the most widely-circulated, daily-issue newspaper in the county where the aquifer is located. Notice may be published in a second newspaper, if deemed necessary to target a wider audience or more local community. All notices will be published for three consecutive days, beginning (but not necessarily ending) on a weekday.
  - Length of Notice and Comment Period. The Division will accept public comment for a period of at least 30 days beginning on the first day notice is published in the newspaper. If substantial changes are made to the proposed exemption after the close of the initial notice and comment period, the Division will reopen a supplemental, 15-day notice and comment period beginning on the first day the supplemental notice is published in the newspaper.
  - Website. The Division will establish a webpage within its current website to hold all notices, information submitted in support of exemptions, public comments, and other materials on which the Division relies. The notices will direct readers to the webpage for more information, which will more fully inform the public and enable a meaningful opportunity to comment.
  - List Serve. The webpage for aquifer exemptions will allow individuals to join a list serve for receiving email notification of all future aquifer

exemption proposals. Email notification will be sent on the same day notice is published in the newspaper, or as soon as possible thereafter.

- Outreach. On the same day notice is published in the newspaper, or as soon as possible thereafter, the Division will email or mail notice to the following:

  - Director of the Water Management Division, U.S. EPA Region IX;
  - Chairperson of the State Water Resources Control Board;
  - Chairperson of the Regional Water Quality Control Board(s) with jurisdiction over the area in which the aquifer is located;
  - The Board of Supervisors of the county(s) in which the aquifer is located, and any other local officials identified as likely to be interested;
  - State Senators in the following committees: Agriculture; Energy, Utilities and Communications; Environmental Quality; Natural Resources and Water;
  - State Assembly Members in the following committees: Agriculture; Natural Resources; Water, Parks & Wildlife; and
  - Industry associations and non-governmental organizations identified as likely to be interested;

- **Public Comment Hearings**

  - Schedule and Notice. A joint public comment hearing will be held with a designee from the State Water Board for the purpose of providing an opportunity for people to provide oral comments. The initial notices for a proposed aquifer exemption will specify the date of the hearing date, which will always be at least 30 days from the date of the notice.

  - Location. Hearings will be held at a location convenient for the parties involved or in Sacramento.

  - Consolidation. The Division and State Water Board will set aside one day every month (or every other month, depending on the rate of proposals under review) for holding a public hearing on proposed aquifer exemptions. Several aquifer exemption proposals will normally be considered at each hearing, with each proposal allocated a separate time slot. The number of exemption proposals at issue in a hearing will depend on readiness of the proposals and their relative complexity.

  - Requests for U.S. EPA Participation. The Division and State Water Board may elect to request U.S. EPA's participation at the hearing. Requests for

U.S. EPA participation will be made at least 10 days prior to the date of the hearing.

- Conduct. Public hearings will be conducted as follows:

  - Division staff will provide a brief introduction regarding each aquifer exemption;

  - The purpose of the public comment hearings is to receive public input – the Division and State Water Board will receive public comments but will not necessarily answer questions or debate issues;

  - All attendees will be provided an opportunity to provide oral or written statements, though the Division and State Water Board may impose reasonable limitations on oral presentations;

  - Hearings will be recorded by an audio/video recording device, or by a stenographer; and

  - If an attendance list or similar document is posted or circulated at the hearing, the document will state that signing-in is voluntary and that all persons may attend regardless of whether they sign-in.

- **Outcome**

  - Notice of Substantial Changes. As noted above, the Division will reopen a 15-day supplemental notice and comment period for substantial changes made to the proposed exemption following close of the initial comment period.

  - Decision and Response to Comments. If the Division and the Water Boards elect to submit an aquifer exemption proposal to U.S. EPA, it will prepare a document that (1) announces the decision, (2) provides a concise statement of the basis for the decision, and (3) summarizes the substantive comments received (including oral comments received at a hearing) and the disposition of those comments. This document will be included in the submittal to U.S. EPA.

  - Submission to U.S. EPA. In the unlikely event it takes the Division longer than one year from the date of initial notice to submit an aquifer exemption to U.S. EPA, the Division will consider whether there are any changed circumstances that may reasonably require a new round of notice and comment.

PUBLIC NOTICE OF DETERMINATION AND REQUEST FOR U.S. EPA ACTION REGARDING ELEVEN AQUIFERS HISTORICALLY TREATED AS EXEMPT:

The Pico Formation underlying the boundaries of the South Tapo Canyon Field

The Tumey Formation underlying the boundaries of the Blackwell's Corner Field

The Kern River Formation underlying the boundaries of the Kern Bluff Field

All aquifers underlying the boundaries of the Bunker Gas Field that are not in a hydrocarbon-producing zone

The Santa Margarita Formation underlying the boundaries of the Kern River Field

The Chanac Formation underlying the boundaries of the Kern River Field

The Walker Formation underlying the boundaries of the Mount Poso Field

The Olcese Formation underlying the boundaries of the Round Mountain Field

All aquifers underlying the boundaries of the Wild Goose Field that are not in a hydrocarbon-producing zone

The Walker Formation underlying the boundaries of the Round Mountain Field

The Santa Margarita Formation underlying the boundaries of the Kern Front Field

30-DAY PUBLIC COMMENT PERIOD

Notice Published November 15, 2016

NOTICE IS HEREBY GIVEN that the California Department of Conservation, Division of Oil, Gas, and Geothermal Resources ("Division"), in consultation with the State Water Resources Control Board ("Water Board") (collectively, "State Agencies"), intends to advise the United States Environmental Protection Agency ("US EPA") that ten of the eleven aquifers historically treated as exempt do not meet the federal regulatory criteria for exemption from the federal Safe Drinking Water Act ("SDWA"). Accordingly, the State Agencies intend to request an amendment to the Memoranda of Agreement between the Division and US EPA for the purpose of clarifying that these aquifers are not exempt aquifers.

In addition, the State Agencies intend to advise US EPA that the one other aquifer historically treated as exempt – the Walker Formation underlying the Round Mountain Field – is currently the subject of aquifer exemption proposals. The proposal for the Walker Formation has been finalized and published for public comment (but not yet submitted to US EPA). Portions of this aquifer are included in the exemption proposal, while other portions are not included. The State Agencies therefore intend to also request that the amendment to the Memoranda of Agreement between the Division and US EPA clarify that this aquifer is *not* exempt, except with respect to any portion(s) that US EPA approves for exemption as a result of a future exemption proposal.

WRITTEN COMMENT PERIOD AND PUBLIC COMMENT HEARING

Any person, or his or her authorized representative, may submit to the Department of Conservation ("Department") written statements, arguments, or comments relevant to this determination. Comments may be submitted by email to comments@conservation.ca.gov, by facsimile (fax) to (916) 324-0948, or by mail to:

Department of Conservation
801 K Street, MS 24-02
Sacramento, CA 95814
ATTN: Eleven Aquifers

The written comment period closes at 5 p.m. on December 16, 2016. The Department will not consider any comments received at the Department's offices after that time.

Additionally, any interested person, or their authorized representative, may present, either orally or in writing, comments regarding the proposed action at the public hearing, to be held at the following time and place:

December 14, 2016 at 4pm
Four Points Sheraton
5101 California Avenue
Bakersfield, CA 93309

Services, such as translation between English and other languages, may be provided upon request. To ensure availability of these services, please make your request no later than ten working days prior to the hearing by calling the staff person identified in this notice.

Servicios, como traducción de inglés a otros idiomas, pueden hacerse disponibles si usted los pide en avance. Para asegurar la disponibilidad de éstos servicios, por favor haga su petición al mínimo de diez días laborables antes de la reunión, llamando a la persona del personal mencionada en este aviso.

BACKGROUND

The Division regulates the underground injection of fluids associated with oil and gas production ("Class II injection") through an underground injection control ("UIC") program approved by US EPA pursuant to the federal SDWA. The SDWA requires the protection of underground sources of drinking water ("USDWs"), which are defined broadly in federal regulation as including any aquifer that supplies or contains a sufficient quantity of groundwater to supply a public water system and that has a total dissolved solids ("TDS") composition of less than 10,000 mg/l. (See 40 C.F.R. § 144.3.)

Under federal law, an aquifer, or a portion of an aquifer, that would otherwise qualify as a USDW may be "exempted" from protection as a USDW if it meets specific exemption criteria enumerated in federal regulation and undergoes an exemption process that involves both the State and US EPA. (See 40 C.F.R., §§ 146.4, 144.7.) Specifically, a USDW may be exempted for purposes of Class II injection if it meets the following criteria:

(a) It does not currently serve as a source of drinking water; and

(b) It cannot now and will not in the future serve as a source of drinking water because:

(1) It is mineral, hydrocarbon or geothermal energy producing, or can be demonstrated by a permit applicant as part of a permit application for a Class II or III operation to contain minerals or hydrocarbons that considering their quantity and location are expected to be commercially producible.

(2) It is situated at a depth or location which makes recovery of water for drinking water purposes economically or technologically impractical;

(3) It is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption; or

(c) The TDS content of the ground water is more than 3,000 and less than 10,000 mg/l and it is not reasonably expected to supply a public water system.

(40 C.F.R. § 146.4.). Exempted aquifers may be designated by the State and submitted to US EPA for review and possible approval. No aquifer exemption is valid unless and until it is approved by US EPA. (*See* 40 C.F.R. § 144.7.)

When US EPA approved the State's UIC program in 1983, the Division and US EPA entered a Memorandum of Agreement ("Primacy MOA") that identified the aquifers for which US EPA granted aquifer exemptions. Program records have produced two competing versions of the Primacy MOA, each with the same signature page and dates, which differ with respect to the non-hydrocarbon-producing aquifers US EPA agreed to exempt. One version purports to deny exemptions for eleven non-hydrocarbon-producing aquifers, while the second version purports to approve exemptions for those same aquifers. The Division and US EPA have historically treated these eleven aquifers as exempt. Following a US EPA audit of the State's UIC program in 2012, US EPA determined that these eleven aquifers may not actually be exempt, and ordered the State to reevaluate the aquifers to ascertain whether the aquifers meet the federal exemption criteria and whether the aquifers are appropriate for ongoing injection of fluid associated with oil and gas production. Additionally, US EPA prescribed detailed corrective actions to bring the State's UIC program into compliance with the SDWA. One of the corrective actions requires the State to prohibit injection into the eleven aquifers "historically treated as exempt" by December 31, 2016 absent a US EPA determination that the aquifer(s) meet the regulatory criteria for exemption. The Division has implemented this and other compliance dates in its Aquifer Exemption Compliance Schedule Regulations. (Cal. Code Regs., tit. 14, § 1779.1.)

DETAILS OF THE STATE AGENCIES' DETERMINATION

Ten Aquifers Have Not Been Shown to Meet Exemption Criteria

Based on the available information, the State Agencies' current assessment is that ten of the eleven aquifers do not meet the federal regulatory criteria for exemption from the SDWA. These aquifers may in the future serve as a source of drinking water. The ten aquifers are:

- The Pico Formation underlying the boundaries of the South Tapo Canyon Field.
- The Tumey Formation underlying the boundaries of the Blackwell's Corner Field.
- The Kern River Formation underlying the boundaries of the Kern Bluff Field.

- All aquifers underlying the boundaries of the Bunker Gas Field that are not in a hydrocarbon-producing zone.
- The Santa Margarita Formation underlying the boundaries of the Kern River Field.
- The Chanac Formation underlying the boundaries of the Kern River Field.
- The Walker Formation underlying the boundaries of the Mount Poso Field.
- The Olcese Formation underlying the boundaries of the Round Mountain Field.
- All aquifers underlying the boundaries of the Wild Goose Field that are not in a hydrocarbon-producing zone. [*]
- The Santa Margarita Formation underlying the boundaries of the Kern Front Field.

The State Agencies' current assessment of these ten aquifers, and the proposed request to US EPA, would not preclude future consideration of exemption proposals. If the State Agencies in the future receive new information establishing that any of these aquifers, or portions thereof, meet the exemption criteria and are appropriate for injection, the State Agencies may elect to submit an aquifer exemption proposal to US EPA following the required legal procedure, including public notice and a public hearing.

Portions of One Aquifer May Qualify for Exemption

Portions of one of the eleven aquifers historically treated as exempt are being considered for exemption. That aquifer is:

- The Walker Formation underlying the boundaries of the Round Mountain Field.

An exemption proposal for the Walker Formation underlying the Round Mountain Field has been finalized and the Division is currently considering public comments on the proposal.[†] Only those portions of the Walker formation that are included in the State Agencies' exemption proposal and approved for exemption by US EPA should be confirmed as exempt. The omission of any portion(s) of the formations from a final exemption proposal would be due to there being a lack of evidence for the State Agencies to find that such portion(s) are eligible for exemption. Accordingly, the State Agencies intend to request an amendment to the Memoranda of Agreement between the Division and US EPA for the purpose of clarifying that the Walker Formation underlying the Round Mountain Field is not exempt, except with respect to any portions of the formation that US EPA approves for exemption as a result of a future exemption proposal submitted to US EPA.

DOCUMENTS AVAILABLE FOR REVIEW

Documents reviewed by the State Agencies in the course of making this determination are available on the Division's public internet website at:

http://www.conservation.ca.gov/dog/Pages/Aquifer_Exemptions.aspx.

[†] The proposal and supporting materials for the Round Mountain Field exemption are available at http://www.conservation.ca.gov/dog/Pages/Aquifer_Exemptions.aspx.

RESPONSE TO COMMENTS

The State Agencies will review and respond to all timely and relevant comments received (including oral comments received at the hearing) following the written comment period and public hearing. Thereafter, the Division may proceed with the request to US EPA to amend the Memoranda of Agreement between the Division and US EPA for the purpose of clarifying the exempt status of the eleven aquifers.

CONTACT PERSON

Inquiries concerning the proposed action may be directed to:

Tim Shular
Department of Conservation
801 K Street, MS 24-02
Sacramento, CA 95814
Phone: (916) 322-3080
Email: Comments@conservation.ca.gov

Department of Conservation, Division of Oil, Gas, and Geothermal Resources
Public Comment Solicitation for Assessment of
Eleven Aquifers Historically Treated as Exempt

PUBLIC COMMENT SUMMARIES AND RESPONSES

On November 15, 2016, the Department of Conservation, Division of Oil, Gas, and Geothermal Resources ("Division"), in consultation with the State Water Resources Control Board ("Water Board"), sent public notice regarding the intent to advise the United States Environmental Protection Agency ("US EPA") that, with the exception of portions of two aquifers that are addressed in recent aquifer exemption proposals, the eleven aquifers historically treated as exempt do not meet the federal regulatory criteria for exemption from the federal Safe Drinking Water Act ("SDWA"). Accordingly, the Division and the Water Board intend to request an amendment to the Memoranda of Agreement between the Division and US EPA for the purpose of clarifying that these aquifers are not exempt aquifers. The eleven aquifers are:

- The Pico Formation underlying the boundaries of the South Tapo Canyon Field.
- The Tumey Formation underlying the boundaries of the Blackwell's Corner Field.
- The Kern River Formation underlying the boundaries of the Kern Bluff Field.
- All aquifers underlying the boundaries of the Bunker Gas Field that are not in a hydrocarbon-producing zone.
- The Santa Margarita Formation underlying the boundaries of the Kern River Field.
- The Chanac Formation underlying the boundaries of the Kern River Field.
- The Walker Formation underlying the boundaries of the Mount Poso Field.
- The Olcese Formation underlying the boundaries of the Round Mountain Field.
- All aquifers underlying the boundaries of the Wild Goose Field that are not in a hydrocarbon-producing zone. [1]
- The Santa Margarita Formation underlying the boundaries of the Kern Front Field.

Following publication of a notice in a local newspaper, and mailing or emailing notice to interested parties, public comments on the proposal were accepted from November 15, 2016 through December 16, 2016. On December 14, 2016, the Division and the State Water Board jointly conducted a public comment hearing in Bakersfield. Included below is a summary of all of the comments received from the public together with the Division's and State Water Board's responses.

Over the course of the public comment period, the Division received a number of public comments via email, regular mail, and public comment hearing. Each commenter and subsequent comment was given a unique numerical signifier. The chart below provides the numerical signifier for each commenter. Below, you will find either grouped or individual comment numerical signifiers, followed by a summary or specific comment, followed by a response (italicized).

COMMENTERS:

Number	Name and/or Entity
0001	California Resources Corporation
0002	CA State Building and Construction Trades Council
0003	Brian Pellens
0004	Natural Resources Defense Council, Clean Water Action
0005	Nancy

COMMENT SUMMARIES:

COMMENTS IN SUPPORT

0004-1
The commenter concur with the Division of Oil, Gas, and Geothermal Resources' (Division) and the State Water Resources Control Board's (Board) (collectively "State Agencies") intent to advise the U.S. EPA that ten of the eleven aquifers historically treated as exempt do not meet the federal regulatory criteria for exemption from the federal Safe Drinking Water Act (SDWA). The State Agencies' assessment makes clear that the version of the Primacy Memorandum of Agreement (MOA) between the Division and U.S. EPA that purports to approve exemptions for these eleven non-hydrocarbon-producing aquifers was issued in error, and that the version denying these exemptions is correct.

0005-1
We have laws for a reason, and in this case it appears that public safety is being pitted against economic vitality and pecuniary interests. I urge you to reject all of the proposed exemptions to the Act.

<u>Response to comments 0004-1, 0005-1:</u>
Thank you for your comments.

COMMENTS IN OPPOSITION

<u>General Opposition</u>
0001-1, 0002-1
The public comment period should be extended passed the arbitrary December 31, 2016 deadline. CRC has invested millions of dollars in water treatment, conveyance systems, and use of reclaimed water; and has identified alternative zones for water disposal. The state has not forwarded a separate aquifer exemption package or reviewed additional UIC permits related to the alternate injection zone. Many jobs will be put in jeopardy if the deadline is not extended.

0001-2
The MOA between the Division and USEPA that has been used for decades, and which was used to issue multiple permits must be formally amended. Until this happens, there is no basis to interfere with or

penalize any injection into these exempted aquifers. The Division does not provide any specific finding of environmental harm or impact. The injectate at CRC's operations in Kern Front is higher quality than the zones into which it is being injected. It is unclear why there would need to be an amendment to the MOA.

Response to comments 0001-1, 0002-1, 0001-2:
California Code of Regulations, title 14, section 1779.1, subdivision (b) provides that injection in these aquifers must cease by December 31, 2016, unless and until US EPA, subsequent to April 20, 2015, determines that the aquifer or the portion of the aquifer where injection is occurring meets the criteria for aquifer exemption. Extended the period for the public to comment on this evaluation would not affect that regulation.

Deficient Analysis

0003-1

While a proper analysis should rely on potentially thousands of pages of data, maps, cross sections, modern logs, and thousands of hours of analysis by highly skilled professional geologists, petrophysicists and others; the Division's analysis consists mainly of photocopied pages from a document first published in 1960 (with data relying on decades-old information) to delineate general locations of oil. A complete technical and economic feasibility study is needed for each of the eleven aquifers before any determination of whether the exemption criteria are met or not. As the non-applicability of the exemption criteria have not been demonstrated, any determination with respect to these aquifers should be delayed until such time as a proper analysis has been prepared and vetted.

0003-2

Any of the four clauses of 40 CFR 146.4(b) may be used to determine an aquifer exempt. Conversely, due to the fact that the "or" conjunction is used between the criteria, if one is to determine that the criteria of 40 CFR 146.4(b) are not met, one must demonstrate that **none** are met. As such, the Division's analysis must show that none of the following are true: see 40 CFR 146.4 (b) (1-4).

0003-3

The Division's analysis is clearly not complete. For example, in the evaluation of (b)(3), I would offer that it is possible that a large desalinization plant could be built to produce drinking water from sea water (as has been done in many places around the world) and piped to these field locations far cheaper on a per gallon basis, than siting a much smaller plant on top of any of these naturally-impaired aquifers for local supply. It should be noted also for the required analysis that the federal standard for exemption in (b)(3) is to "render that water fit for human consumption" -- not for agricultural or other use, such that drinking water standards are the applicable treatment goal. It should further be noted that while some widely varying and scarce data is given for Total Dissolved Solids (TDS), there are many other naturally occurring contaminants in that water which would likely complicate any process to render it fit for human consumption. Another consideration is that a coastal desalination plant may use existing water transportation infrastructure if such infrastructure has available capacity, further decreasing the costs. There may be other alternatives to the scenario above as well which must be explored. If any of these alternatives are less expensive on a per gallon basis to supply drinking water fit for human consumption, it is economically infeasible to use the water subject to the Division's determination to supply drinking water.

Response to comments 0003-1, 0003-2, 0003-3:
California Code of Regulations, title 14, section 1779.1, subdivision (b) provides that injection in these aquifers must cease by December 31, 2016, unless and until US EPA, subsequent to April 20, 2015, determines that the aquifer or the portion of the aquifer where injection is occurring meets the criteria for aquifer exemption. The data and evaluation made available for public comment indicate that the aquifers in question meet the definition in federal regulation of an underground source of drinking water. In the two instances where data and analysis has been provided to the State that indicate that portions of these aquifers do meet the criteria in federal regulation for an aquifer exemption, the State Agencies have made aquifer exemption proposals that have been approved by US EPA. If other data and analysis are provided, then the State Agencies' will work the applicant to develop other such aquifer exemption proposals.

Other

0004-2
The Division and the Water Board should institute a full investigation to determine the extent of any contamination in these 11 aquifers. As detailed in the State Agency's assessment, the HTAE aquifers contain high-quality drinking water and in some cases injection of low quality brines has been occurring for decades. The State Agencies have a duty to determine the environmental and public health impacts from this improper injection and remediate any ongoing threats.

Response to comment 0004-2:
Thank you for your comments.

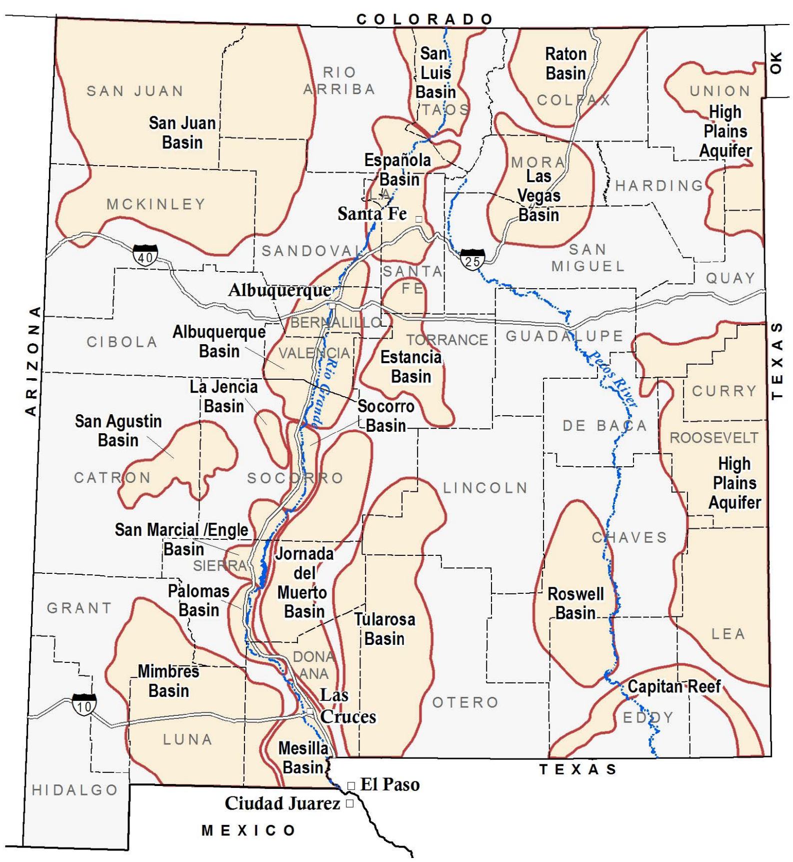
Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027
OCD Exhibit No. 13

OVERVIEW OF FRESH AND BRACKISH WATER QUALITY IN NEW MEXICO

Lewis Land

As New Mexico considers the use of desalinated brackish water (less than 10,000 mg/L total dissolved solid) to diversify the public water supply, many questions must first be answered. Where are the brackish water resources? What data are available? What exactly is the water chemistry? How feasible is it to use brackish water for public supply?

With funding from the New Mexico Environment Department, Drinking Water Bureau (related to Source Water Protection), the New Mexico Bureau of Geology, Aquifer Mapping Program, has compiled a number of water quality resources and data. These data were derived from the Aquifer Mapping Program, digitized historical water reports, the U.S. Geological Survey, and the New Mexico Environment Department. All publicly available data are now on an interactive map found here, under Water Resources: geoinfo.nmt.edu/maps. For an analysis and review of the compiled water quality data, we have attempted to assess the brackish water resources in the state of New Mexico in a regional approach. It is apparent that very large regions of New Mexico lack sufficient data to assess the brackish water resources. Most of the data compiled in this review are from existing water supply wells, and therefore are not representative of the brackish water resources. These data also represent, in general, the shallowest parts of the aquifers where water wells are commonly completed. Each of the regions of assessment shown on the map are provided in individual chapters for quick review. These chapters are part of a larger technical report that is available from the New Mexico Bureau of Geology and Mineral Resources at: geoinfo.nmt.edu/publications/openfile/details.cfml?Volume=583

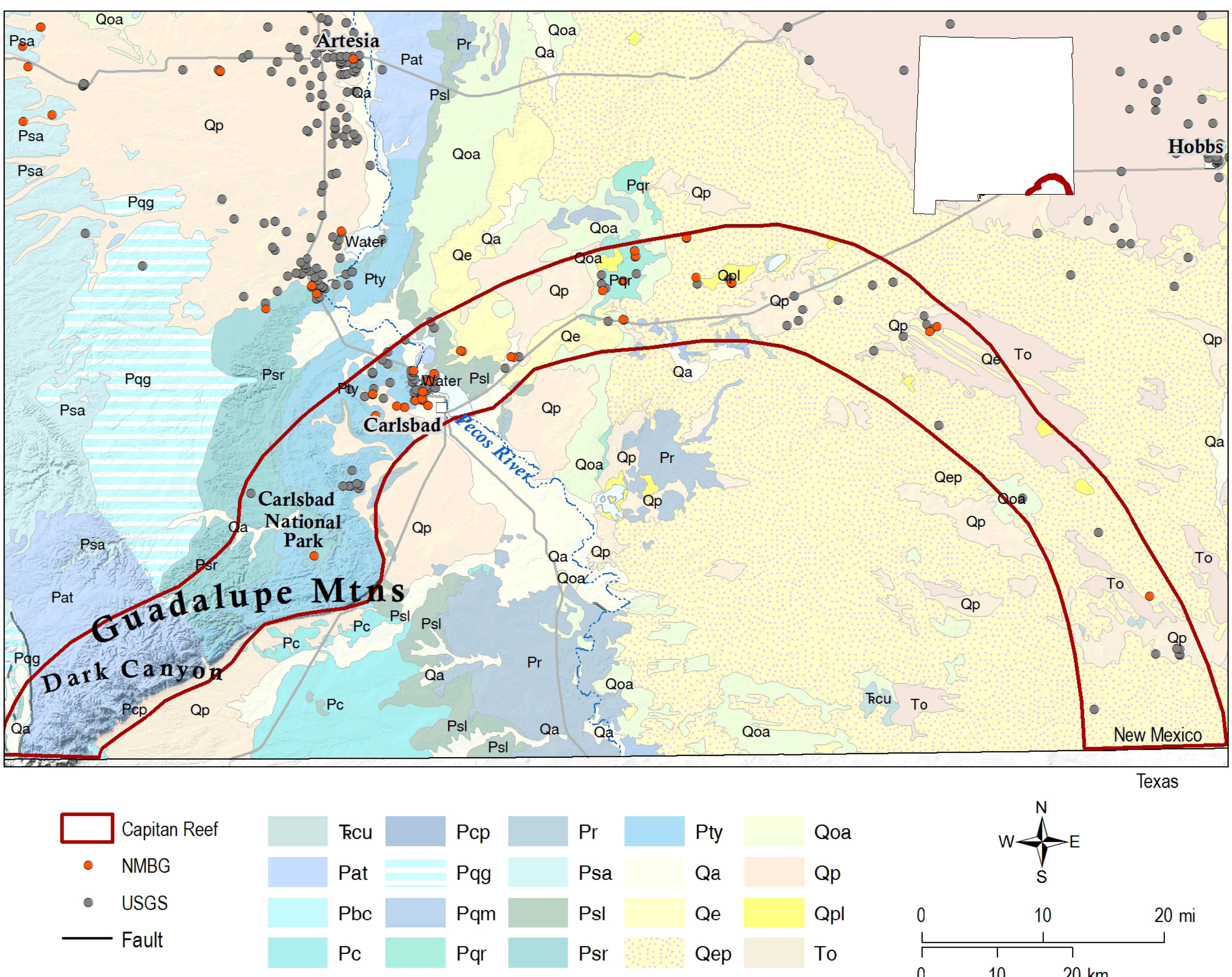


New Mexico counties, groundwater basins and aquifers discussed in this report.

Capitan Reef

The Capitan Reef is a fossil limestone reef of middle Permian age that is dramatically exposed along the southeast flank of the Guadalupe Mountains in Eddy County, New Mexico, reaching its maximum elevation in west Texas, in Guadalupe Mountains National Park. In New Mexico, the reef serves as the host rock for the Big Room in Carlsbad Cavern. A few miles northeast of Carlsbad Caverns National Park, the reef dips into the subsurface and passes beneath the city of Carlsbad, where it forms a karstic aquifer that is the principal source of fresh water for that community (Land and Burger, 2008). The Capitan Reef continues in the subsurface east and south into Lea County, then south for ~150 miles to its southeasternmost outcrop in the Glass Mountains of west Texas.

Recharge to the Reef Aquifer occurs by direct infiltration into outcropping cavernous zones formed in the Capitan limestone and equivalent backreef units of the Artesia Group. A significant component of this recharge occurs during flood events in Dark Canyon in the Guadalupe Mountains, where the reef crops out in the bed of Dark Canyon arroyo. Groundwater flows northeastward through the reef and discharges from springs along the Pecos River within the city of Carlsbad (Bjorklund and Motts, 1959). Evidence of cavernous porosity and conduit flow is well documented within the Reef aquifer, indicated by blowing wells and bit drops during drilling operations; and by the presence of water in channels and cavities at different horizons within the reef (Hendrickson and Jones, 1952; Motts, 1968). Carlsbad Cavern may thus be thought of as an upper end-member example of cavernous porosity development within the Capitan Formation (Land and Burger, 2008).



Capitan Reef aquifer, surface geology and data distribution.

Fresh water is present in the aquifer only in the immediate vicinity of its recharge area in the Guadalupe Mountains. Mineral content rapidly increases east of the Pecos River, and throughout most of its extent the Capitan Reef is a brine reservoir, with TDS concentrations >100,000 mg/l in some of the deep monitoring wells in Lea County (Hiss, 1975a; 1975b).

The data set for the Capitan Reef aquifer is very limited, consisting of only 13 wells, most of which were last sampled almost half a century ago. The small data set is primarily due to the extremely limited amount of fresh water available in the reef aquifer. The city of Carlsbad, because of its proximity to recharge areas in the Guadalupe Mountains, is the only community in the region that is favorably positioned to exploit the fresh-water segment of the reef. Because of the highly saline nature of groundwater in the Capitan Reef east of the Pecos River, very few water supply wells are completed in that portion of the aquifer. Until recently, the only water quality information available for the reef east of the Pecos River was from a network of monitoring wells installed by the U.S. Geological Survey in the mid-20th century (Hiss, 1975a; 1975b). These records confirm the highly mineralized character of groundwater in the eastern segment of the Capitan Reef, resulting in a mean TDS concentration for the entire aquifer of >54,000 mg/l. We have chosen not to plot TDS and specific conductance vs. depth for the Capitan Reef because the lateral distribution of dissolved solids most accurately characterizes the distribution of salinity within this aquifer.

Brackish water resources are clearly available in the Capitan Reef aquifer, although for the most part that water is more accurately described as a brine, and would thus not be suitable for conventional desalination technologies. However, this highly saline water is a valuable resource for industrial applications in southeastern New Mexico and west Texas. Both the petroleum and potash mining industries have recently expressed interest in exploiting brackish water in the reef aquifer for water flooding of mature oil fields in the Permian Basin region and for processing of potash ore.

Capitan Reef aquifer, summary of water chemistry, based in part on preliminary analysis of samples collected by Sandia National Labs.

	Specific Cond. (µS/cm)	TDS (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	Cl (mg/l)	F (mg/l)	As (mg/l)	U (mg/l)	Well depth
Maximum	196,078	184,227	5,902	2,046	46,700	784	4,970	107,949	1.9	0.001	0.001	5,713
Minimum	602	364	48.9	32.6	5.1	56	14.3	10	0.1	0.001	0.001	327
Mean	64,412.8	54,046.5	1,555.6	737.5	15,021.1	338.7	2,204	29,959.8	0.69	0.001	0.001	3,285
Median	39,000	26,900	1,240	463.4	2,357.5	271	1,862.9	13,800	0.5	0.001	0.001	3,250

Please cite this information as: Land, Lewis, 2016, Overview of fresh and brackish water quality in New Mexico, Open-file Report 583, 49 p.

New Mexico Bureau of Geology and Mineral Resources
A division of New Mexico Institute of Mining and Technology

Socorro, NM 87801
(575) 835 5490
Fax (575) 835 6333
geoinfo.nmt.edu

State of New Mexico
Energy, Minerals and Natural Resources Department
Oil Conservation Division

Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027

OCD Exhibit No. 14

Proposed Investigation and Monitoring Plan Regarding the Capitan Reef Aquifer and Disposal in the San Andres Formation in the Area of Interest

Only limited data has been obtained in the area of interest since Hiss completed the initial study of the Capitan Reef and the associated Hobbs Channel. The record of water level data has been sporadic and inconsistent while the proper sampling of ground water is extremely rare. The OCD proposes that a monitoring and sampling program be developed to satisfy three major goals:

1. Determine the hydrologic relationship between the Capitan Reef and Hobbs Channel;
2. Determine any impacts to water quality if commingling does exist between disposal fluids injected in the San Andres and the Capitan Reef; and
3. Characterize the Capitan Reef in this area to determine the current status as protectable with the intent of either establishing a monitoring plan for continued management as an USDW or considering the possibility for Aquifer Exemption for the portion of the Captain Reef from the Hobbs Channel to the New Mexico-Texas state line.

Suggested general approach: immediate actions and long-term projects:

1. Immediate: Establish a sampling program using existing monitoring well. The USGS established a network of production wells that were recompleted with
2. Immediate: Explore opportunities for sampling events of Capitan Reef and San Andres formation water for wells to be drilled in the area.
3. Immediate: Develop a comprehensive workplan and submit request for proposal for consultant. As part of an immediate action of the workplan, include consideration of plugged wells in the vicinity for the possibility of re-entry for conversion to monitoring wells for either the San Andres or the Capitan Reef.
4. Long-term: new monitoring wells (along with funding for sampling) specifically dedicated to the Capitan Reef in the area of interest. Definition of models to be used to demonstrate any communication or lack of communication between the two features. Consider the feasibility for the use of remote sensing and geophysical tools for obtaining additional subsurface information with the drilling of new wells.
5. Long-term: based on the findings and if required, prepare a monitoring plan using the new and existing network to ensure no migration of injected fluids of degradation the Capitan Reef; or
6. Long-term: based on initial findings, prepare an Aquifer Exemption for the portion of the Capitan Reef that qualifies with the acquired data.
7. Long-term: integrate findings (any continued monitoring) of the investigation with Aquifer Mapping Project managed by the New Mexico Bureau of Mines and Mineral Resources.

Ultimately the product of the effort is to provide more accurate information to be used in permitting both UIC Class II disposal wells and enhanced recovery wells while meeting the OCD's obligation to resolve the issues regarding the management for this portion of the Capitan Reef complex as protectable waters.

Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027
OCD Exhibit No. 15

CURRICULUM VITAE

BRANDON POWELL

SUMMARY

Mr. Powell is the Oil Conservation Division's (OCD) Deputy Director overseeing the Engineering and Environmental bureaus. He has served with OCD for more than seventeen years. He began his career in 2006 as an environmental specialist overseeing environmental releases and remediation. In 2011, he was promoted to inspection and enforcement supervisor for OCD's district office in Aztec. In that position, he supervised down-hole engineering and compliance with OCD rules. In 2019, he was promoted to District Supervisor, which involved oversight of day-to-day operations for the San Juan Basin. In 2020 he was promoted to the Engineering Bureau Chief and then in 2023 was promoted to Deputy Director. Mr. Powell has extensive experience applying OCD rules to all aspects of oil and gas development and has testified as an expert in OCC rulemakings, including the pit rule (19.15.17 NMAC), the produced water rule (19.15.34 NMAC), the release rule (19.15.29 NMAC) and the natural gas waste rules (19.15.27 and 19.15.28 NMAC).

EMPLOYMENT

May 2023- Current
New Mexico Oil Conservation Division
Deputy Director

- As Deputy Director, I provide oversight and management for the OCD's Engineering Bureau and Environmental Bureau. In my position I have 2 direct reports which are the Environmental Bureau Chief and Engineering Bureau Chief. I also have ~48 additional indirect reports in those groups.
  - The Engineering bureau currently has 34 employees and is in the process of filling additional positions. The Engineering bureau is made up of 4 major groups Inspection Compliance Program, Underground Injection Control (UIC) Program, Administrative Permitting Program, Engineering Projects and Hearings group.
  - The Environmental bureau is currently has 16 employees and is currently in the process of filling additional positions. The environmental program contains 3 major groups, Permitting, Environmental Special Projects and Incident/Inspections.

November 2020 – May 2023
New Mexico Oil Conservation Division
Chief, Engineering Bureau

- Oversight and Management of the OCD's Engineering Bureau which includes
  - Administrative Compliance Program
  - Underground Injection Control (UIC) Program
  - Administrative Permitting Program.
- Ensures that OCD goals and objectives are met by assigning and directly supervising the work of the Administrative Compliance, UIC, and Administrative Permitting Programs.
- Conducts training and performance evaluations of personnel and acts upon leave requests. This position designs and develops programs to address new technical issues as they arise and as technical advances in the oil and gas industry are implemented.

May 2019- November 2020
New Mexico Oil Conservation Division
District Supervisor

- Managed operations for OCD’s Northern District, ensuring the proper management of more than 24,000 oil and gas wells and associated facilities to protect public health and the environment.
- Managed relations with four tribes and allottees, federal agencies including Bureau of Land Management, Bureau of Reclamation, and Forest Service, and private landowners.
- Supervised seven staff members, including geologist, compliance officers, and environmental specialists.
- Managed office assignments, fleet repair and maintenance, and the District’s Reclamation Fund (RFA) plugging program.
- Coordinated with the Engineering and Environmental Bureaus to ensure consistency in permitting and enforcement across the state.
- Supervised the District’s UIC activities and coordinated with the UIC Program Manager to ensure consistency in testing and compliance.
- Conducted training for OCD and District staff.
- Assisted in the tasks described below when necessary for District operations, particularly in the absence of staff.
- Served as the District’s representative on the New Mexico Oil and Gas Northwest Public Lands Committee.
- Assisted in development of standard operating procedures for wide range of OCD’s business practices.
- Participated in strategic planning for OCD, including crisis management, electronic transition, enforcement, and rulemaking.

April 2011-May 2019
New Mexico Oil Conservation Division
Staff Manager & Inspection and Enforcement Supervisor

- Supervised four district compliance officers and their activities regarding oil, gas, injection, brine and non-hazardous waste wells to protect public health, fresh water and other natural resources, including the review and approval of applications the conduct of investigations, and the recommendation of engineering solutions.
- Supervised environmental specialists, geologists, and data managers when the District Supervisor was not available and after he retired.
- Substituted for the geologist and environmental specialists during their absence and position vacancy for two years, including reviewing pools, logs and formation tops.
- Reviewed drilling, production, and closure of wells and other oil and gas facilities to ensure compliance with OCD rules, including:
  - Scheduled and conducted field inspections;
  - Initiated enforcement actions;
  - Reviewed applications for well work-overs, completion and plugging; and
  - Observed field activities.
- Provided technical assistance to OCD staff and operators.
- Coordinated office activities, including the review and approval of personnel documents and the conduct of other supervisory duties on behalf of the District Supervisor.
- Assisted in the development of rules.
- Served as the District’s representative for the New Mexico Oil and Gas Northwest Public Lands Committee.

April 2006 thru April 2011 New Mexico Oil Conservation Division
Environmental Specialist, Deputy Oil and Gas Inspector, and Loss Control Officer

- I Supervised industries operations to ensured proper remediation of releases.
- I would respond to urgent releases which endangered the environment or the public.
- Reviewed permits for work requested to be performed, and subsequent reports for work already performed.
- I would draft environmental compliance and enforcement documents
- Testify in environmental compliance and enforcement cases.
- Work with other governmental agencies to find solutions to problems that arise
- Prepare and give environmental training to industry and other agencies.
- Work with Companies to ensure their continual compliance.
- Track District internal injuries and incidents and prepare yearly OSHA forms.

- Respond to citizen complaints.

June 2004-April 2006 Envirotech, Inc.
Sr. Environmental Technician, Soil Remediation Facility Manager, and Mold Inspector.

- Prepared reports for various agencies for the on-site documentation for various types of releases.
- Managed the soil remediation facility and subsequent personnel which averaged 1-3 people. I categorized waste to determine if wastes were acceptable pursuant to the facility permits.
- Performed hazardous waste characterization and disposal of oil field and non-oilfield waste.
- Project manager and field supervisor which included supervising multiple people.
- Prepared job quotes and project summaries.

TESTIMONY IN RULEMAKING PROCEEDINGS

19.15.17 NMAC – *Pits, Close-Loop Systems, Below-Grade Tanks and Sumps, 2008 and 2013*
19.15.34 NMAC – *Produced Water, Drilling Fluids, and Liquid Oil Field Waste, 2015*
19.15.29 NMAC – *Releases, 2018*
19.15.27 NMAC – *Venting and Flaring of Natural Gas, 2021*
19.15.28 NMAC – *Natural Gas Gathering Systems, 2021*

CERTIFICATIONS AND TRAINING

Hazardous Waste Management Certification, Lion Technologies, September 2004
Hazmat Site Supervisor Training, High Desert Safety, 2005
Confined Space Certification, High Desert Safety, 2005
Hot Work Certification, High Desert Safety, 2005
OSHA Forty Hour Certification, 2005
Surveillance Detection Course for Commercial Operators, Department of Homeland Security, 2008

PHILLIP R. GOETZE

UIC Group, Oil Conservation Division, EMNRD
Albuquerque, NM

Over 40 years of experience developing and implementing a variety of projects with environmental, hydrologic, or regulatory applications.

PROFESSIONAL EXPERIENCES:

February 2013 to Present: UIC Manager / Petroleum Geologist / Geohydrologist
Engineering Bureau, Oil Conservation Division, Energy, Minerals and Natural Resources Department
1220 South St. Francis Drive, Santa Fe, NM 87505

Administrative permitting for development and management of oil and gas resources under the state Oil and Gas Act. These projects include technical review of administrative applications and preparation of orders for non-standard locations, pool delineations, and non-standard proration units. Lead technical reviewer of applications for all Class II wells (including saltwater disposal wells and enhanced oil recovery (EOR) projects) under the New Mexico primacy agreement with the United States Environmental Protection Agency (USEPA) for its Underground Injection Control (UIC) Program under the Safe Drinking Water Act. Hearing examiner for Division hearings for cases regarding both protested and unprotested applications for approval of non-standard oil and gas circumstances that cannot be administratively permitted. Additional assignments related to the position:

- Provide technical assistance to District personnel and General Counsel staff regarding compliance issues for disposal and EOR wells.
- Development of protocols and recommended guidance for UIC related subjects such as induced seismicity, exempted aquifers and Class II disposal impacts on producing intervals.
- Prepare quarterly reports for review by the UIC coordinator for submission to the USEPA.
- Recommend changes in policy reflecting application of new technology or processes (e.g. injection rules per 19.15.26 NMAC).
- Provided expert testimony before the Oil Conservation Commission for applications and in support of rulemaking (e.g. acid gas injection well applications, casing requirements in the Roswell Artesian Basin, and reporting requirements for fracturing fluids).
- Provided expert testimony before the New Mexico Water Quality Control Commission (NMWQCC) in support of rulemaking (e.g. expanded authority for UIC Class I hazardous disposal wells).

Appointed as hearing examiner by the Division Director under 19.15.4.18 NMAC.

March 2007 to February 2013: Hydrogeologist / Environmental Scientist / Project Manager
Gloreita Geoscience, Incorporated
1723 Second Street, Santa Fe, NM 87505

Multiple projects for environmental, hydrologic, and natural resource assessments including:

- Los Alamos National Laboratory (LANL): contract team leader for ground-water sampling (including springs, shallow wells, monitoring wells with Baski and Westbay systems) in support of the Ground Water Stewardship Program; four years of sediment mapping and soil sampling for contaminants as part of the LANL assessment of geomorphic influences following the Cerro Grande and Las Conchas fires; waste characterization sampling following LANL and New Mexico Environment Department (NMED) protocols.
- Oversight of drilling, logging, and construction of deep exploration wells as part of Rio Rancho's City Water Program and the NM Office of the State Engineer (Ft. Sumner project).
- Hydrologic modeling and ground-water abatement plan development for multiple dairy facilities in southern and eastern New Mexico.

- Numerous Phase I Environmental Site Assessments (ESAs) for commercial, industrial, and undeveloped properties in northern New Mexico, Nevada, and Texas.
- Establish protocols, sampling requirements, and compile data for annual reporting for clients with Closure and Post Closure plans for landfills.
- Oversight of petroleum storage tank removals, closures, and Minimum Site Investigations following closure.
- Preparation and annual reporting of NPDES permits for commercial clients in New Mexico.
- Preparation and implementation of Stage I Abatement Plans for dairies in violation of the NMWQCC ground-water standards.
- Quality assurance for ground-water modeling and various sampling programs including mandatory monitoring and special client-specific events.

April 2006 to January 2007: Hydrogeologist / Project Manager
Tetra Tech EM Incorporated
6121 Indian School Road NE, Suite 205, Albuquerque, NM 87110

This position included responsibility for redevelopment of previous client relationships while maintaining obligations to state, Federal and private projects. Most significant projects include the following:

- Supervising geologist for drilling, construction, and development of deep monitoring wells at Kirtland Air Force Base for Long-Term Monitoring Program.
- Preparation of sampling and analysis plans for Texas Department of Criminal Justice landfills.

September 1999 to March 2006: Hydrogeologist / Project Manager
ASCG Incorporated of New Mexico (now the WH Pacific Corporation)
6501 Americas Parkway NE, Suite 400, Albuquerque, NM 87110

Responsible for a variety of environmental services for site assessment and remediation of contaminated sites associated with Federal, state, and private clients in New Mexico, Arizona, and the Navajo Nation. Significant projects entail the following:

- Field Technical Leader (as subcontractor) for drilling, construction, and development of deep and shallow monitoring wells at LANL for 2005.
- Developed and supervised assessment drilling programs for Risk-Based Corrective Action assessments of petroleum-contaminated NMED and Bureau of Indian Affairs (BIA) sites in New Mexico and Arizona.
- Responsible for project development and management of soil and ground-water remediation of hydrocarbon and solvent-contaminated sites including quarterly water sampling events and air monitoring for compliance.
- Supervised and participated in resolution of correction actions identified under USEPA CA/CO 1998-02 at approximately 35 Bureau of Indian Affairs federal facilities including review of asbestos programs, PCB investigations and remediations, Phase I ESAs for property transfer, AST/UST removals, hazardous waste disposal activities, environmental audits, and validation sampling of previous remedial activities.
- Completed development and oversight of voluntary corrective actions of hazardous wastes cited in notice of violations at the Southwestern Polytechnic Indian Institute.
- Provided sampling program for the AMAFCA Storm Water Study for assistance in compliance of the MS4 for the City of Albuquerque.
- Completed assessment for hydrocarbon contamination and prepared plans for remedial actions for five locations at BIA facilities during the last quarter of 2004.

July 1996 to August 1999: Geologist / Environmental Scientist; General Contractor
Phillip R. Goetze, Consulting Geologist, Edgewood, New Mexico

Subcontractor for environmental firms providing on-site technical support and report preparation. Primary contractors included the following:

Billings and Associates, Inc., Albuquerque, New Mexico

Responsible for acquisition of both soil and water data for assessment and for installation of remediation systems for hydrocarbon-contaminated sites.

Roy F. Weston Inc., Albuquerque, New Mexico

Temporary position with responsibilities for on-site supervisor for data acquisition (three drilling rigs), for health and safety monitoring, and for quality assurance of installation of multiple ground-water wells at a Department of Energy tailings remediation (UMTRA) site near Tuba City, Arizona.

January 1993 to July 1996: Project Geologist / Project Manager
Billings and Associates, Inc.
6808 Academy Pkwy, E-NE, Suite A-4, Albuquerque, NM 87109

Responsible for acquisition of air, soil, and water data for site assessments related to leaking underground storage tanks throughout New Mexico. Participated and supervised installation, operation, and maintenance of biosparging/SVE remediation systems at five New Mexico locations. Site assessment activities included preparation of health and safety plans, drilling supervision, water and soil sampling preparation, chain-of-custody maintenance, analytical data review and compilation, and report preparation.

June 1985 to December 1992: Independent Geologist and Environmental Scientist
Phillip R. Goetze, Consulting Geologist, Albuquerque, New Mexico

Subcontracting services for data acquisition in geophysics and mineral exploration. Primary contractors included:

Charles B. Reynolds and Associates, Albuquerque, New Mexico

Performed functions of seismologist and crew chief for consulting group specializing in shallow seismic geophysics for environmental and engineering applications. Projects included USGS hydrologic assessment of Mesilla Bolson; plume and paleosurface mapping at Johnson Space Center facility north of Las Cruces; plume and paleosurface mapping in Mortandad Canyon and TA-22 site, LANL; plume and paleosurface mapping at Western Pipeline facility at Thoreau, NM; plume and paleosurface mapping at UNC Partners mill and tailings site north of Milan; engineering assessment of collapsible soils at Tanoan residential development and along the east edge of Albuquerque.

Glorieta Geoscience, Inc., Santa Fe, New Mexico

Initiated and conducted sampling program for assessing economic potential of low-grade gold occurrence in southwest New Mexico.

November 1983 to September 1984: Fluid Minerals Geologist
Bureau of Land Management, Department of Interior, Cheyenne, Wyoming

Temporary detail to Casper office to alleviate backlog of assessments of federal oil and gas leases in Wyoming and Nebraska. Assessments required geologic evaluation of oil and gas potential for lands in Powder River, Wind River, Big Horn and Denver-Julesburg Basins. Determination of “known geologic structures (KGSs)” per Secretarial Order for categorizing federal oil and gas minerals into competitive and non-competitive status. Deposed as expert witness and provide expert summaries and affidavits for cases before the Interior Board of Land Appeals (example: Case No. IBLA 84-798 for protest of KGS delineation).

June 1982 to September 1983: Field Geologist
United States Bureau of Mines, Department of Interior, Lakewood, Colorado

Assisted primary authors with field inventory and evaluation of mineral occurrences in 15 wilderness areas in Colorado (Central Mineralized Region), southern Wyoming, and eastern Utah. Field work included field mapping and sampling of abandoned mines and mineral occurrences within these areas and adjacent areas with potential impacts on wilderness designation.

July 1979 to January 1982: Geologist
United States Geological Survey, Department of Interior, Casper, Wyoming and Lakewood, Colorado

First two years exclusively mapping, drilling, and classifying coal resources in south central Wyoming. Detailed for two years to special team for preparation of impact statement: one of four principal authors for the Cache Creek-Bear Thrust Environmental Impact Statement which documented effects of two proposed oil and gas wells in designated wilderness area near Jackson, Wyoming. Deposed as expert witness in federal court. Final year primarily responsible for assessments of federal oil and gas leases for lands in Wyoming and Nebraska.

July 1977 to July 1979: District Geologist
Bureau of Land Management, Department of Interior, Socorro District Office, Socorro, New Mexico
Responsible for District minerals program for federal lands in west central portion of state. Assisted in environmental reports for land exchanges, classification of saleable mineral sites, mining claim validity determinations, inspection of surface reclamation for mineral extractions, inspection of oil exploration and geothermal gradient wells, and assessments for location of water wells in support of grazing projects.

EDUCATION:
New Mexico Institute of Mining and Technology, Socorro, New Mexico
Bachelor of Science in Geology, 1977

Additional Courses: EPA course requirements for Asbestos Inspector (10 years as active inspector); completion of state program for Licensed Contractor (NM; GS-29); EPA course requirements for Lead-Based Paint Risk Assessor (EPA Regions VI and IX; two years as active inspector); GSI Course *Application of Ground Penetrating Radar*; NGWA Course *Monitoring Natural Attenuation of Contaminants*.

PROFESSIONAL MEMBERSHIPS, LICENSES, OR CERTIFICATIONS:
American Institute of Professional Geologist, Certified Professional Geologist No. 6,657
Alliance of Hazardous Materials Professionals, CHMM No. 11,401
ASTM International, Member No. 1,314,118 (Voting Member); Committees D18 (Soil and Rock) and E50 (Environmental Assessment, Risk Management and Corrective Action)
OSHA 40HR and 8HR Refresher Hazardous Waste Operations and Emergency Response (Current)
OSHA Hazardous Waste Operations and Emergency Response Manager/Supervisor (Current)
State of Alaska, Licensed Professional Geologist; No. 514
State of Arizona, Registered Professional Geologist; No. 40,812
State of Texas, Licensed Professional Geologist; No. 2,278

Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027
OCD Exhibit No. 17

Aquifer Classification for the UIC Program: Prototype Studies in New Mexico

by Lee Wilson[a] and Michael T. Holland[b]

ABSTRACT

Three case studies from New Mexico illustrate methods by which aquifers can be classified for purposes of the Federal Underground Injection Control program. The principal technique involves preparation of hydrogeologic maps or cross sections which display information on the permeability of rock units and the dissolved solids content of formation fluids. Because deep water wells are lacking in most areas, the analysis normally requires considerable interpretation of geological and geophysical logs collected by energy and mineral companies, plus use of a general model or concept about regional hydrogeology. Injection of waste fluids into aquifers containing water with less than 10,000 mg/l dissolved solids is not allowed unless an exemption is justified by economic, engineering and other factors. Based on the case studies, regulatory exemptions will be possible for aquifers which are hydrocarbon or mineral-producing, or which are important for brine disposal purposes.

INTRODUCTION

Subsurface injection of water and other fluids is regulated by the Federal Underground Injection Control program (UIC), which was established by the Safe Drinking Water Act of 1974 (Public Law 93-523). The primary goal of UIC is to protect from contamination those aquifers which are or may become a source of drinking water. Much of the injection in the U.S. occurs in Texas, Oklahoma, Louisiana, and New Mexico, within the jurisdiction of Region VI of the U.S. Environmental Protection Agency (EPA). Consequently, Region VI was the first to explore methods by which aquifers could be identified, mapped and classified as to the need for UIC protection. The work was performed in part through grants to agencies of the State of New Mexico in 1979-82. These agencies, the N.M. Oil Conservation Division and N.M. Environmental Improvement Division, funded a series of consultant studies which: established a system for classification of aquifers according to UIC criteria; demonstrated methodologies by which the classification can be performed; and provided specific aquifer classifications in all parts of the State where injection is active.

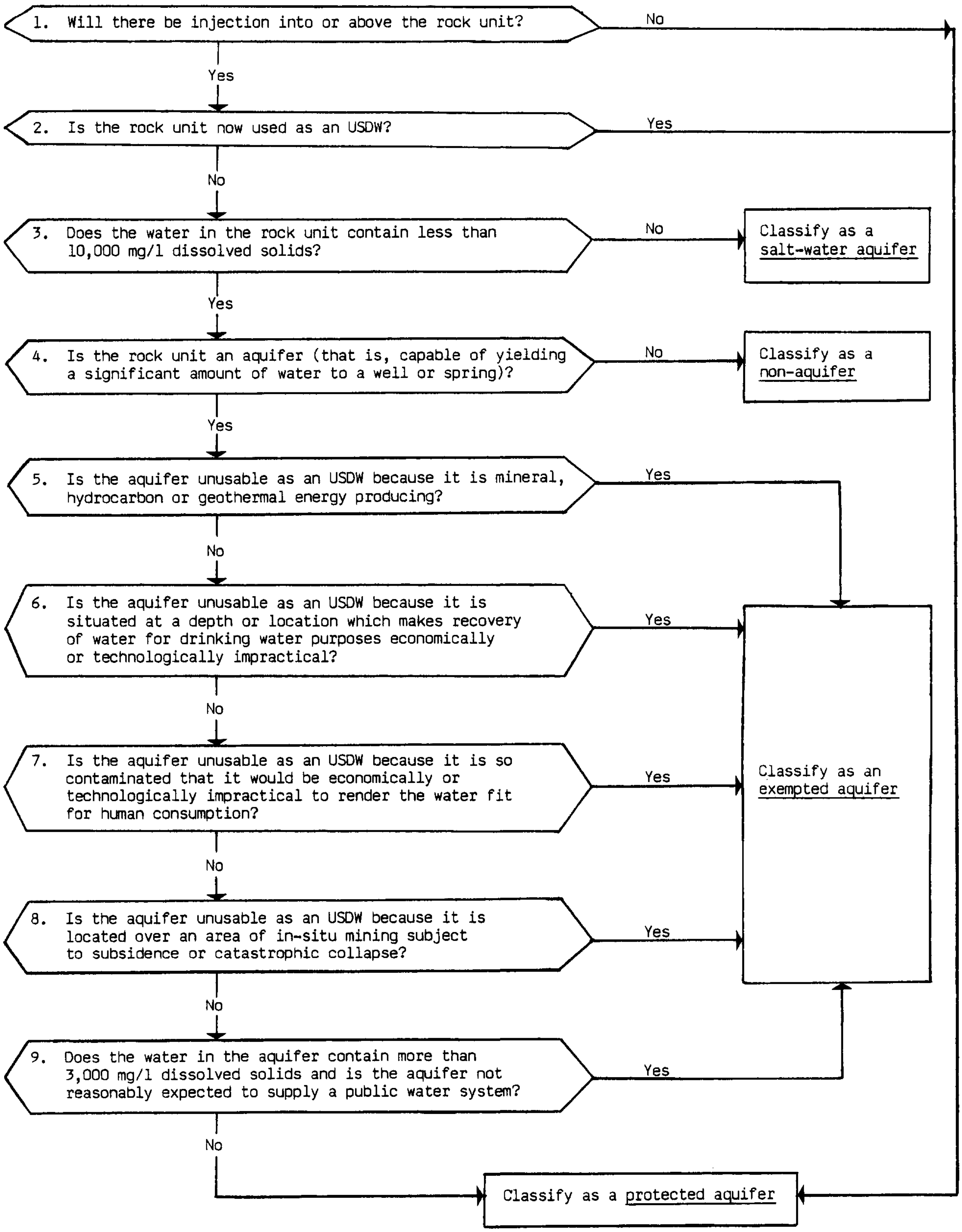
This article summarizes the New Mexico UIC studies which involved aquifer classification: Holland *et al.,* 1979; Holland *et al.,* 1980; and Wilson *et al.,* 1981. Not discussed here are those parts of the UIC studies concerned with salt-water extraction wells (Wilson, 1982) and geothermal injection (Wilson, 1983).

AQUIFER CLASSIFICATION

EPA's UIC regulations contain complex instructions as to the kinds of rock units into which injection may be allowed. An early step in the New Mexico work was to summarize the regulations in a flow chart which sets forth what may be termed "the UIC Aquifer Classification Process" (see Figure 1). The figure clarifies the concepts in the regulations and provides a unified terminology for classification purposes.

The classification process involves questions about rock units which can be answered by yes or

[a]President, Lee Wilson and Associates, Inc., P.O. Box 931, Santa Fe, New Mexico 87504.
[b]Project Geologist, Terra Tek Research, 420 Wakara Way, Salt Lake City, Utah 84108.
Received November 1983, revised June 1984, accepted July 1984.
Discussion open until May 1, 1985.



USDW = underground source of drinking water, defined as an aquifer or portion thereof which supplies any public water supply system or which supplies drinking water of less than 10,000 mg/l TDS for human consumption.

Source: Lee Wilson, based on reading of UIC regulations, principally 40 CFR 146.3 and 146.4.

Fig. 1. UIC Aquifer Classification Process.

no; depending on the answer, the rock unit will be classified or the evaluation process will move on to the next step. The UIC regulations contain no term for the geological units which must be studied during the classification process. The term rock unit was used for this purpose. A rock unit is a geological formation, or part thereof, which can be mapped and evaluated as to its general water-bearing and water-quality characteristics.

Under the UIC program, injection of waste waters such as oil field brines is not allowed above the base of the deepest *protected aquifer*. The regulations specify well construction and operation requirements to prevent casing leaks or other problems above the injection zone. As indicated by step 2 of Figure 1, a designation of protected aquifer applies to any rock unit which is a present source of drinking water. Rock units which are not now a source of drinking water are also protected aquifers unless they are explicitly classified into one of three categories for which UIC protection is not required: salt-water aquifer, nonaquifer, or exempted aquifer.

Salt-water aquifers are rock units which contain water having a total dissolved solids (TDS) content in excess of 10,000 mg/l; see step 3 of Figure 1. *Nonaquifers* are rock units which are not able to yield usable amounts of water to a well or spring (step 4). *Exempted aquifers* are rock units which are excluded as a potential source of drinking water for reasons of economics, technology, gross contamination, or relationship to subsidence or collapse zones (steps 5-9).

EPA's initial guidance regarding the aquifer evaluation process indicated that it should be relatively thorough and detailed (Ground-Water Program Guidance No. 4.2, 1978). The agency specifically suggested the use of techniques such as: maps and cross sections showing TDS isocons; maps showing depth to base of fresh water; maps of aquifer thickness, elevation, and saturated thickness; maps of water levels in different aquifers at different dates; and many others.

PROTOTYPE STUDY OF THE ARTESIA AREA

In order to provide a real-world test of the guidance, EPA and the New Mexico Oil Conservation Division funded an initial prototype project to gather and interpret data necessary for an aquifer classification in a lithologically complex area near Artesia, in southeastern New Mexico (Figure 2). Within this area, drinking water and hydrocarbons are produced from the same stratigraphic unit, the San Andres Formation of Permian age. Chloride-rich brines coproduced with the oil are disposed of by injection back into the oil reservoir, often for the purpose of enhanced recovery (waterflood). Under UIC regulations, such injection should not occur into or above a protected aquifer. If the entire San Andres were designated for protection, much of the waterflood activity in New Mexico would cease and brine disposal would become an expensive, perhaps impossible operation. Clearly, the San Andres poses a complex and economically important problem in UIC aquifer classification.

Methods

Geologic, hydrologic and energy-resource data for the Artesia area were gathered from published reports and from the files of Federal, State and local agencies concerned with water or energy resources. Tables were prepared to summarize aquifer properties, water well records, and records of oil, gas and injection wells. Although considerable information is available on that part of the San Andres now used for drinking water, there is a marked absence of conventional hydrologic data for oil-yielding zones. In these zones, information on salinity and porosity was determined primarily from geophysical logs. The dual laterolog and

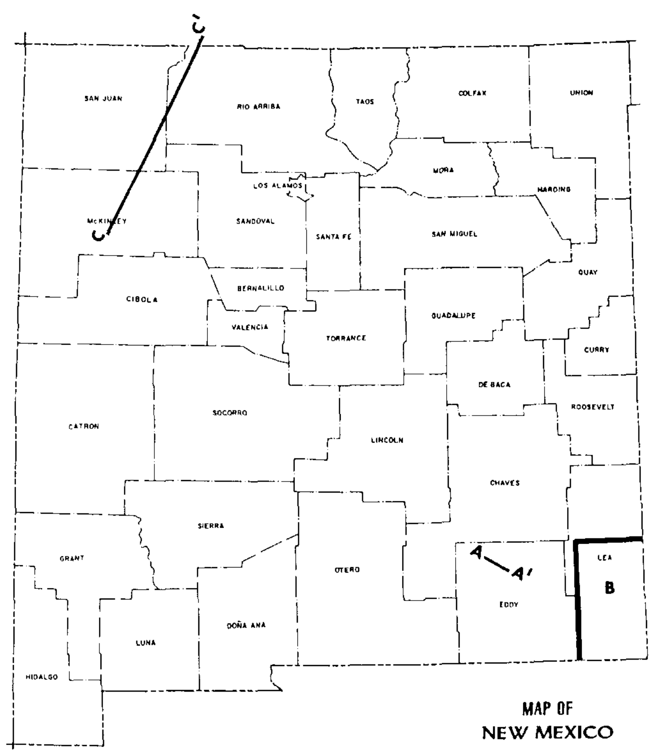


Fig. 2. Location of prototype study areas. Cross section A-A′ is in the Artesia area; see Figures 3 through 6. Area B is in southern Lea County; see Figure 7. Cross section C-C′ is in the San Juan Basin; see Figure 8.

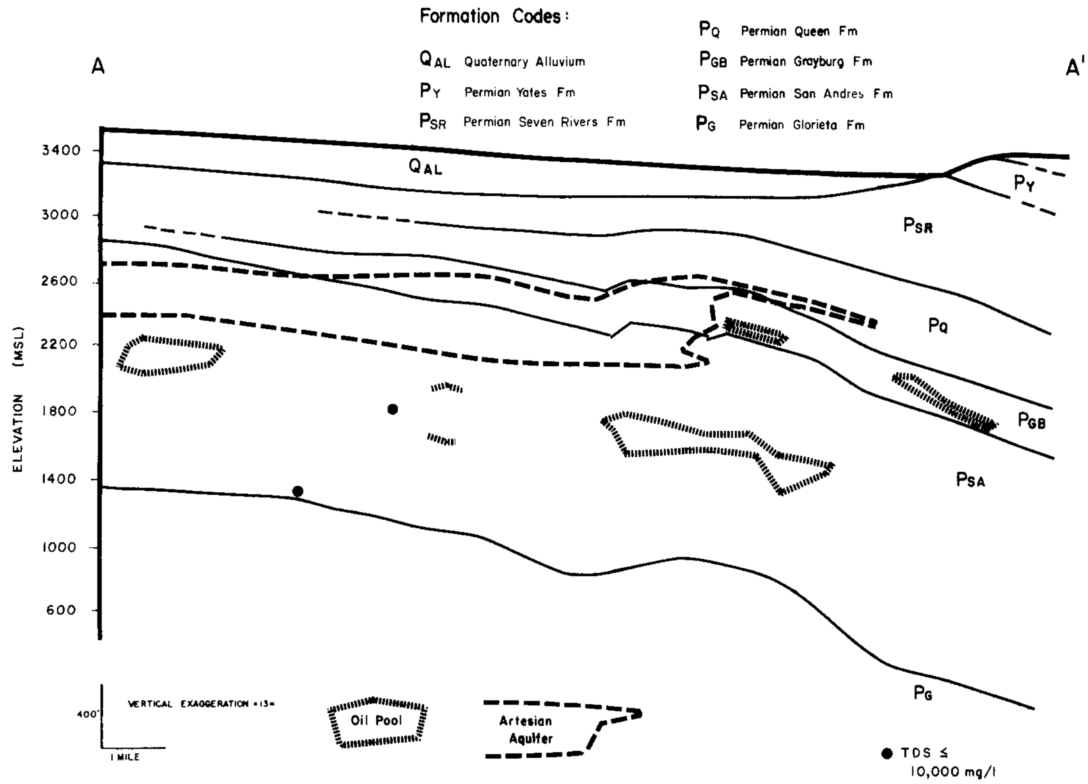


Fig. 3. Hydrogeologic cross section of the Artesia area, New Mexico. Primary oil-bearing zone is located 200-400 feet below the base of the artesian aquifer. The potentiometric surface of the artesian aquifer lies just beneath the land surface.

compensated neutron log have been run on most recent, deep gas wells and can be used to determine resistivity of formation fluids (hence salinity) and formation porosity; see Keys and MacCary (1973).

The tabulated data were interpreted to develop maps displaying structure contours, potentiometric surfaces, the location of shallow oil and gas pools, and the location of data wells. No one map contained all of the information important to the aquifer evaluation process, but the maps could be combined and interpreted to develop a single hydrogeologic cross section of the Artesia area showing all of the information which is important to an aquifer classification for UIC purposes. Figure 3 displays this cross section.

Hydrogeology

The Artesia area is in the shelf zone of the Permian Basin province. The Permian rocks are dominantly dolomitic, with limestone increasing in frequency southeastward toward the main Capitan Reef, and redbeds and evaporites increasing north and west. In general, the Permian units dip toward the southeast and thicken in the same direction.

Most of the region's drinking water comes from an artesian aquifer which occurs near the top of the San Andres Formation and which locally extends into the overlying Grayburg Formation (Figure 3). Water in the artesian aquifer generally contains less than 3,000 mg/l dissolved solids, but higher concentrations do occur, especially toward the east, where San Andres water is naturally saline.

The lower boundary of the artesian aquifer shown in Figure 3 represents the maximum depth of present fresh-water wells. In most locations, water containing 10,000 mg/l or less TDS is not found in wells which penetrate below this boundary. However, the resistivity data obtained from geophysical logs indicate that fresh water may extend to the base of the San Andres in some locations (see solid dots, Figure 3). In all such cases, the logs indicate that the fresh water occurs in rocks with low porosity (averaging less than 7 percent), suggesting that the pores contain irreducible connate water with little potential for cost-effective production. No fresh-water yield is obtained from any well which penetrates below the base of the artesian aquifer.

Hydrocarbon yields in the San Andres occur primarily from a dolomite zone with locally developed porosity; total dissolved solids in coproduced brine always exceed 10,000 mg/l. Subtle changes of strike and dip couple with variations in effective

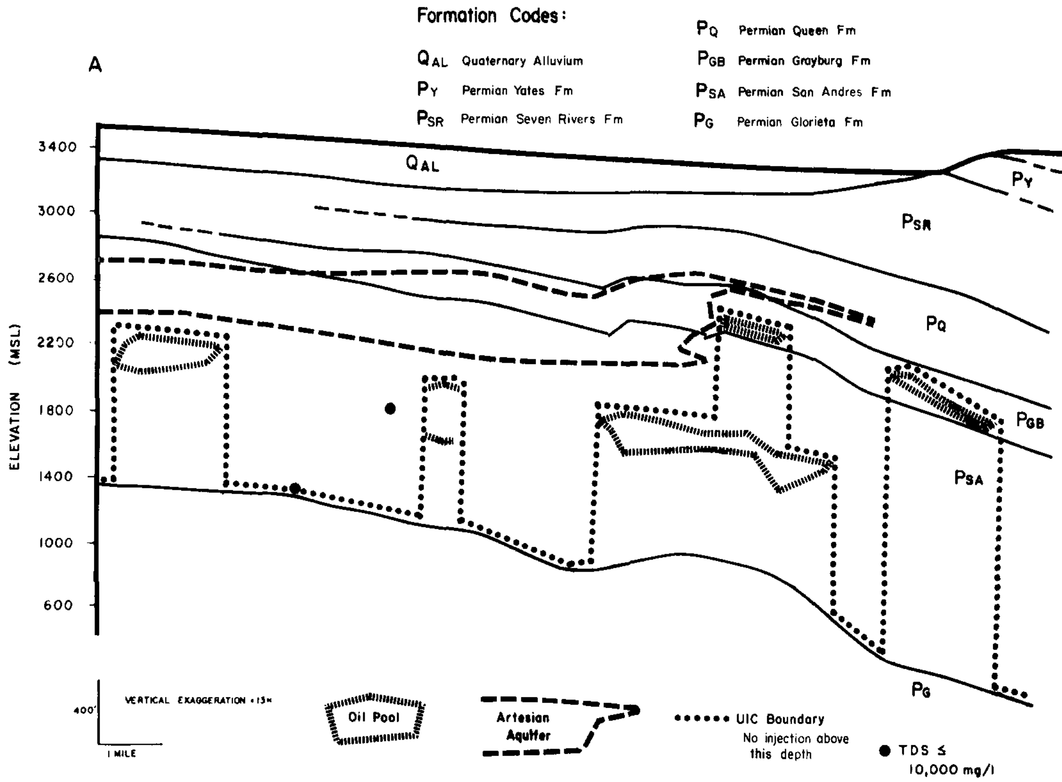


Fig. 4. Alternative UIC classification in which protection extends to base of San Andres Formation except for oil pools, which would be exempted per step 5 of Figure 1.

porosity to control regional pinchouts of hydrocarbon production. Rocks with low porosity and low vertical permeability act as barriers which separate the drinking water of the artesian aquifer from the oil and gas pools in the reservoir zone. If there were no vertical barriers, the oil pools could not exist; if horizontal barriers were absent, the oil pools would be merged.

Oil production in local porosity zones of the Grayburg results in hydrocarbon occurrence adjacent to, as well as beneath, the artesian aquifer (Figure 3). Again, a barrier must exist between the hydrocarbons and the fresh water, otherwise the low-density oil would readily migrate into the artesian aquifer. For additional details on area hydrogeology, refer to: Hantush (1955); Hood (1963); NMGS (1969); Gross *et al.* (1976); LeFebre (1977).

Aquifer Classification

The evaluation process shown in Figure 1 requires boundaries to be drawn around aquifers which are to be protected against injection. The base of the confining layer immediately below the deepest protected aquifer represents the shallowest interval at which injection of a nonpotable water would be allowed. In the prototype study, three alternative aquifer classifications were evaluated; these are illustrated in Figures 4 through 6.

Alternative 1. Designate the entire San Andres Formation as a protected aquifer, but use step 5 of the classification process to exempt all oil pools from protection (Figure 4). This would allow waterflooding to continue; as formation pressures from waterflood do not exceed the natural pressures which occurred when hydrocarbon production began, waterflood injection would not be expected to breach the barriers which now separate the oil pools from the drinking-water aquifer. Brine disposal into nonproducing zones would be prohibited, even where such zones contain saline water.

Alternative 2. Limit protection to the freshwater part of the San Andres; that is, draw the aquifer boundary along the 10,000 mg/l TDS isocon (Figure 5). All existing waterflood and brine disposal wells inject below this line.

Alternative 3. Designate for protection only the artesian aquifer which now is used for drinking-water supplies (Figure 6). (In practice it would be appropriate to provide a margin of safety and draw the boundary at least 100 feet below the base of the artesian aquifer.) This approach is based on a hydrogeologic concept which recognizes that in

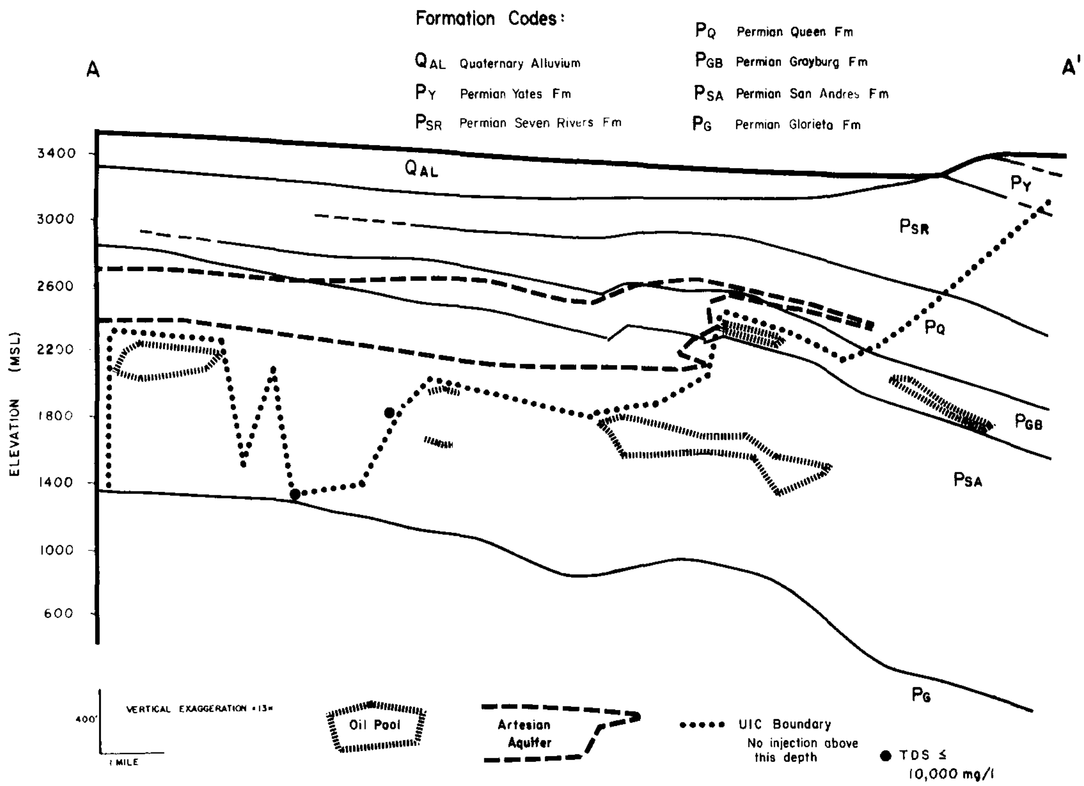


Fig. 5. Alternative UIC classification in which protection extends to base of water known to contain 10,000 mg/l total dissolved solids or less. Rock units below UIC boundary would be classified as nonaquifers.

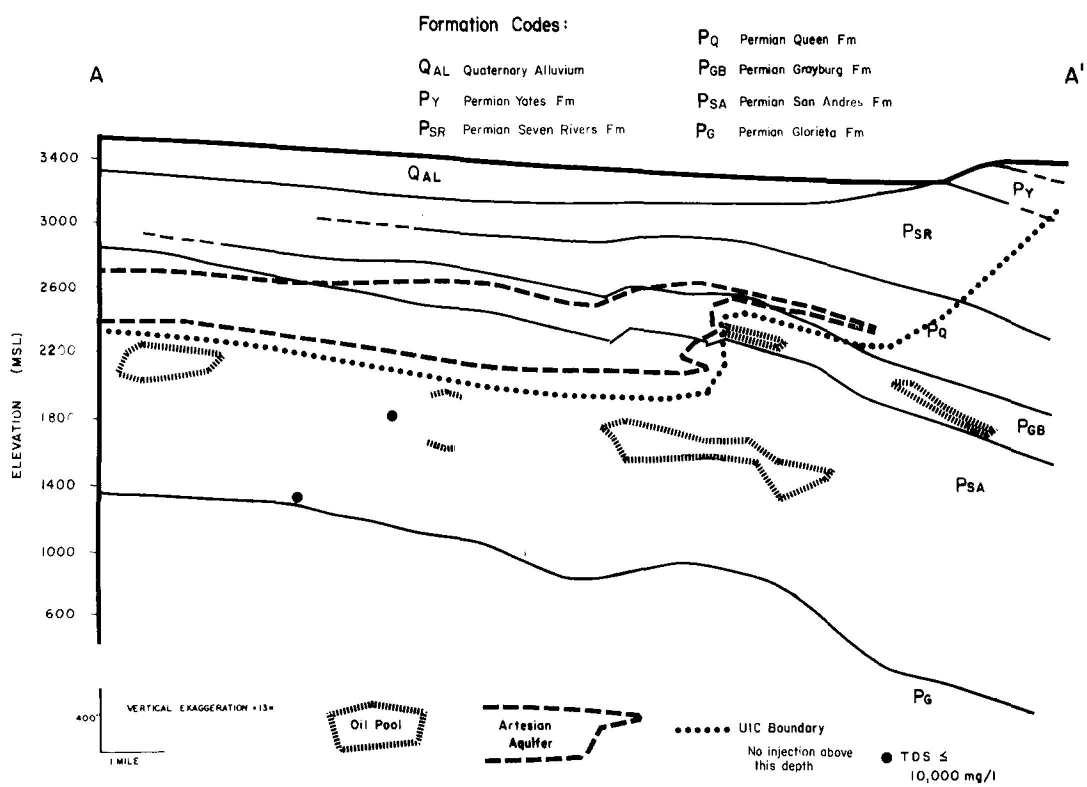


Fig. 6. Alternative UIC classification in which protection extends to base of formations known to be sufficiently permeable to yield significant amounts of water to wells and to contain water with 10,000 mg/l total dissolved solids or less. Rock units below UIC boundary would be classified as nonaquifers or salt-water aquifers.

the rocks beneath the artesian zone, permeability is so low that the unit can be considered as a nonaquifer, per step 4 of Figure 1.

Both alternatives 1 and 2 have significant drawbacks. Alternative 1 would disallow San Andres injection which is not into an oil pool; at least some existing brine disposal wells would be shut down. This would have important economic consequences, as will be shown by the Lea County case study discussed subsequently. Alternative 1 also poses an administrative problem: aquifer boundaries would need to be redrawn each time an oil pool is discovered or extended. Under EPA's UIC regulations, a lengthy public review and hearing process would be required for each new exemption. Alternative 2 is technically and economically feasible, but because water-quality data are scarce in the deeper parts of the San Andres, extension of the isocon boundary outside the prototype area would entail time-consuming, expensive interpretation of geophysical logs.

Alternative 3 is simple to implement because the base of the artesian aquifer has been mapped over a large region using data from extensive water well records. It provides full protection to all of the producible fresh water in the area. Alternative 3 (Figure 6) is the preferred classification because it: corresponds to UIC regulations; provides full protection of existing or potential sources of drinking water; and poses no unusual administrative problems. The concepts shown in the figure can be used by the regulatory agency to propose aquifer classifications for hearing and possible adoption.

LEA COUNTY

The Artesia study was followed by a second prototype project, involving aquifer evaluation in the portion of the Permian Basin which occurs in Lea County (Figure 1).

Level of Detail Needed in UIC Aquifer Evaluation

Preparation of detailed cross sections, based in large part on well log analysis, is a time-consuming process. To determine if less costly methods would be adequate for UIC purposes, the initial Lea County aquifer evaluation was based on a simple review of the technical literature on drinking-water resources of the area. The results were then checked using the more detailed techniques established in the Artesia area.

The literature search indicated that the San Andres and other Permian formations of Lea County are salt-water aquifers and that the base for UIC protection can be drawn at the base of overlying Triassic sediments; exceptions occur in a few locations where slightly saline water is known to occur in the reef limestones of the Permian Capitan Formation. The more detailed analysis reached a *different conclusion*, namely that actual measurements of water quality on file with the U.S. Geological Survey demonstrate that slightly-saline water containing less than 10,000 mg/l TDS does occur in the San Andres and many other Permian units over a sizeable part of the oil-producing area of Lea County. Moreover, in contrast to the Artesia region, this slightly-saline water commonly occurs in zones of good permeability and is capable of being produced by water wells.

The conclusions reached are: UIC evaluations require detailed analyses of logs and other types of data in order to ensure that areas of fresh water are adequately defined; in Lea County, such a detailed analysis indicates that UIC protection may be needed for a number of Permian rock units where injection is active.

Regional Hydrogeologic Model

The area potentially needing UIC protection was mapped based on the location of the 10,000 mg/l isocon as inferred from the regional hydrogeologic model of Hiss (1980). This model indicates that the relatively fresh water in the Permian formations of Lea County originated as recharge from the Glass Mountains in Texas, a source intercepted by Pleistocene incision of the Pecos River. The flow path was controlled by a number of lithologic features and is shown by the heavy black arrow in Figure 7. The remnant fresh water is found in the Capitan Reef and in a limestone sand facies deposited in a paleobathymetric area known as the Hobbs Channel. The facies interfingers with relatively impermeable sediments and cannot be separately mapped from available data. It is necessary to conclude that the entire Hobbs Channel and most of the Capitan Reef are potential sources of drinking water.

Consideration of an Aquifer Exemption

The San Andres and other Permian formations of Lea County are prolific oil producers and support many waterflood projects and salt-water disposal wells. Perhaps one-fifth to one-quarter of all brine injection in southeastern New Mexico occurs into zones which potentially require UIC protection. If injection to these aquifers were disallowed, then hundreds of injection wells would

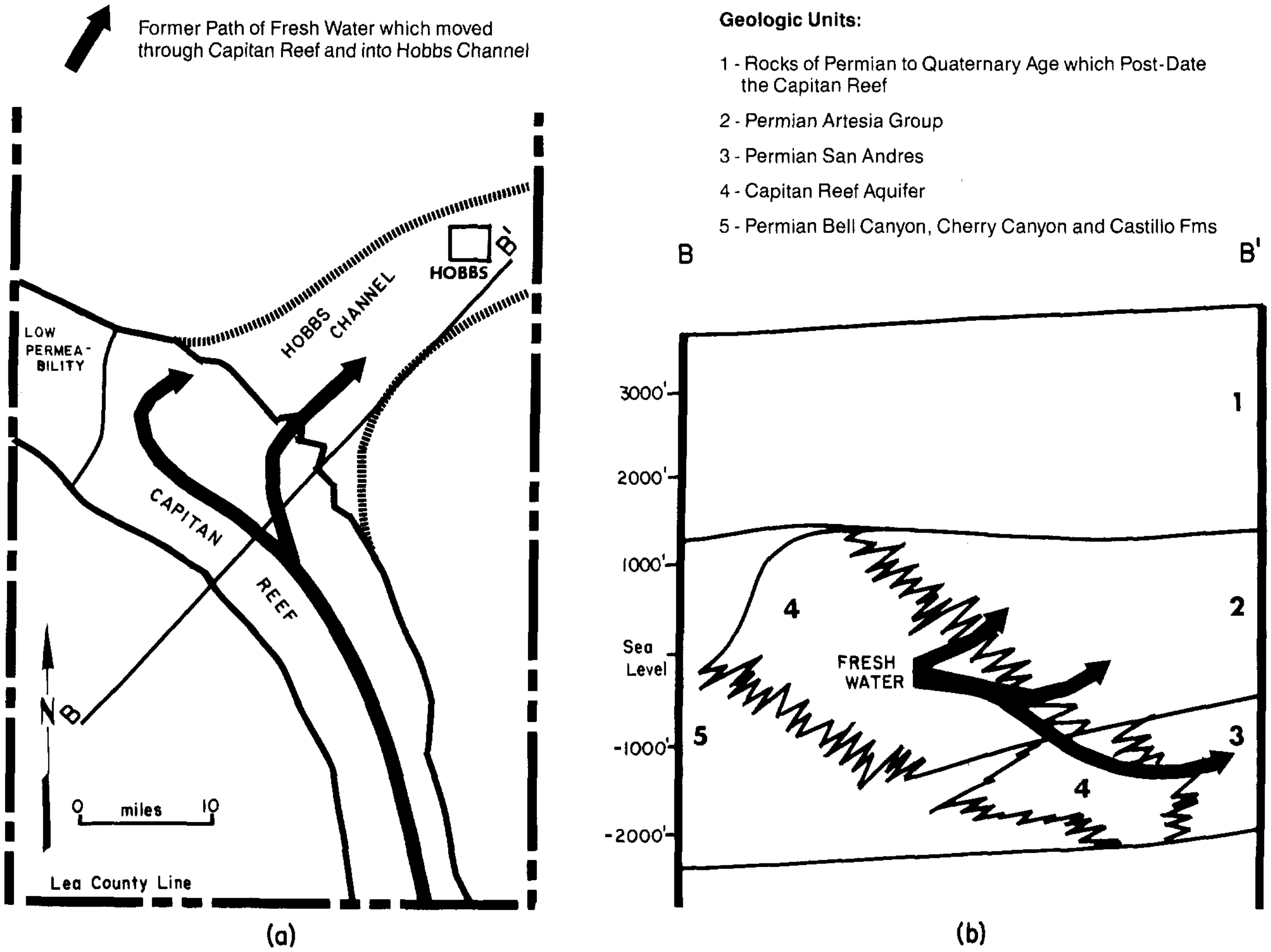


Fig. 7. Hydrologic features important to UIC classification in southern Lea County, New Mexico. The 10,000 mg/l TDS isocon inferred from the water-supply literature occurs in the upper part of unit 1, at about 3,000 feet elevation (msl).

have to be shut down. Waterflood operations would cease, and brine disposal would have to occur in the next deeper permeable zone containing saline water—which is Devonian strata at depths of up to 10,000 feet (versus 4,000-5,000 feet at present). Such a change in injection practices would have obvious economic consequences.

At the time the study was performed, EPA's UIC regulations did not include step 9. Application of steps 5 through 8 in the aquifer evaluation process (Figure 1) indicated that only step 6 fully resolved the apparent conflict between then-existing UIC rules and industry practices. Step 6 indicates that injection may be allowed in a fresh-water aquifer which is "unusable as a source of drinking water because it is situated at a depth or location which makes recovery of water for drinking-water purposes economically or technologically impractical." The criteria of "economic impracticality" suggests that exemption might be allowed if it made no economic sense to ever use a given aquifer as a drinking-water resource. Application of step 6 to the Permian aquifers of Lea County involved the following steps and findings.

1. The San Andres Formation contains the largest and freshest of the potential drinking-water resources in the Permian units of the Hobbs Channel; the City of Hobbs is the principal area where drinking water is needed. Therefore, the analysis assumed that the fresh water in the San Andres Formation was a potential source of drinking water for Hobbs.

2. The need for water in Hobbs was estimated for a 100-year period; the total requirement is 1.5 million acre-feet. Hobbs can obtain this supply from a nearby shallow source of ground water (the Tertiary Ogallala Formation) at a cost of $75 per acre-foot.

3. In contrast, the cost of San Andres water would exceed $900 per acre-foot. The high price primarily reflects the need to desalt the slightly

saline water in order to make it potable; pumping costs also are much greater than for the shallow ground water.

4. The cost to industry of developing new disposal wells into the Devonian would be about $1,000 per acre-foot of San Andres water which would be protected.

When all factors are considered, protection and use of the San Andres Formation for Hobbs drinking water would cost nearly $2,000 per acre-foot, or about 25 times more than the alternative of using Ogallala ground water. This cost differential demonstrates that production of San Andres water for drinking-water purposes is economically impractical and that a step 6 exemption is justified. The same conclusion would apply to the smaller amounts of fresh water in other Permian aquifers. This conclusion is specific to the area studied; economics might *not* support an exemption in an area where alternative supplies of drinking water are scarce. (Note: After the study was completed, New Mexico revised its regulations to allow a step 6 exemption only where TDS exceeds 5,000 mg/l; this does not affect the Lea County aquifers.)

SAN JUAN BASIN

A third study applied the lessons from hydrocarbon-producing areas of southeastern New Mexico to the uranium-producing San Juan Basin in the northwestern part of the State (Figure 1). Two new insights were gained in the San Juan study.

Classification Strategy

A different strategy toward UIC classification was used in the San Juan Basin because, at the time of the study, only one small, experimental injection project was active in this region. Based on step 1 of Figure 1, it is appropriate to provide UIC protection for all rock units in the Basin. Reclassifications or exemptions can be provided on a case-by-case basis as industry makes specific injection proposals.

The most likely exemptions would involve in-situ uranium mining, where a lixivant would be injected into water-bearing ore bodies (Wilson *et al.*, 1981). Such injection may be allowed per step 5 of Figure 1. The anisotropic nature of the ore-bearing formations makes it difficult to predict the fate of the injected lixivant. Also, the uranium ore is often in the least permeable part of the rock, which makes it difficult to prevent leachate excursions. Because of these problems it may be necessary to exempt aquifers over a much larger area than indicated by the idealized in-situ flow system and to limit the exemption to the time frame of the mining. Monitoring networks will need to be extensive, and aquifer restoration will be required to ensure that any remnant leachates do not migrate to areas outside the exempted zone. New Mexico's UIC regulations do in fact specify time limits to step 5 exemptions, and require aquifer restoration.

Regional Hydrogeologic Model

Modern geophysical logs are absent over much of the San Juan Basin. To develop a regional hydrogeologic model it was necessary to extrapolate limited information on water quality and lithology. The model was based primarily on three facts.

1. The San Juan Basin contains a thick sequence (up to 15,000 feet) of Cambrian to Holocene sedimentary rocks within a large, mildly deformed, asymmetric structural basin that is typical of the Colorado Plateau tectonic province. Based primarily on the literature (Berry, 1959; Shomaker, 1971; West, 1972; Lyford, 1979; BIA, 1980) and on water well data, it can be demonstrated that, in one location or another, every stratigraphic unit contains (or has the potential to contain) some permeable beds with water of less than 10,000 mg/l TDS. This supports the concept of classifying every rock unit as a protected aquifer, unless there is some basis for a determination to the contrary.

2. Textural facies changes in Permian rocks result in coarser sediments toward the north of the basin while Cretaceous rocks coarsen to the south. This pattern is modified by cement dissolution, which is greatest near recharge areas along the southern margin of the basin. The result is that, in general, transmissivity decreases towards the center of the basin.

3. Total dissolved solids vary laterally within individual aquifers. The freshest water is found close to recharge areas at the south basin margin. Salinity increases as the ground water migrates toward the basin center.

Figure 8 illustrates the net effect of the relationships described. The heavy dotted line is the approximate location of the 10,000 mg/l TDS isocon. Near the major recharge zone at the southwest basin margin, no base of fresh water has been identified. Near the basin center the base of fresh water occurs near the land surface. In between there are alternating zones of "fresh" (by

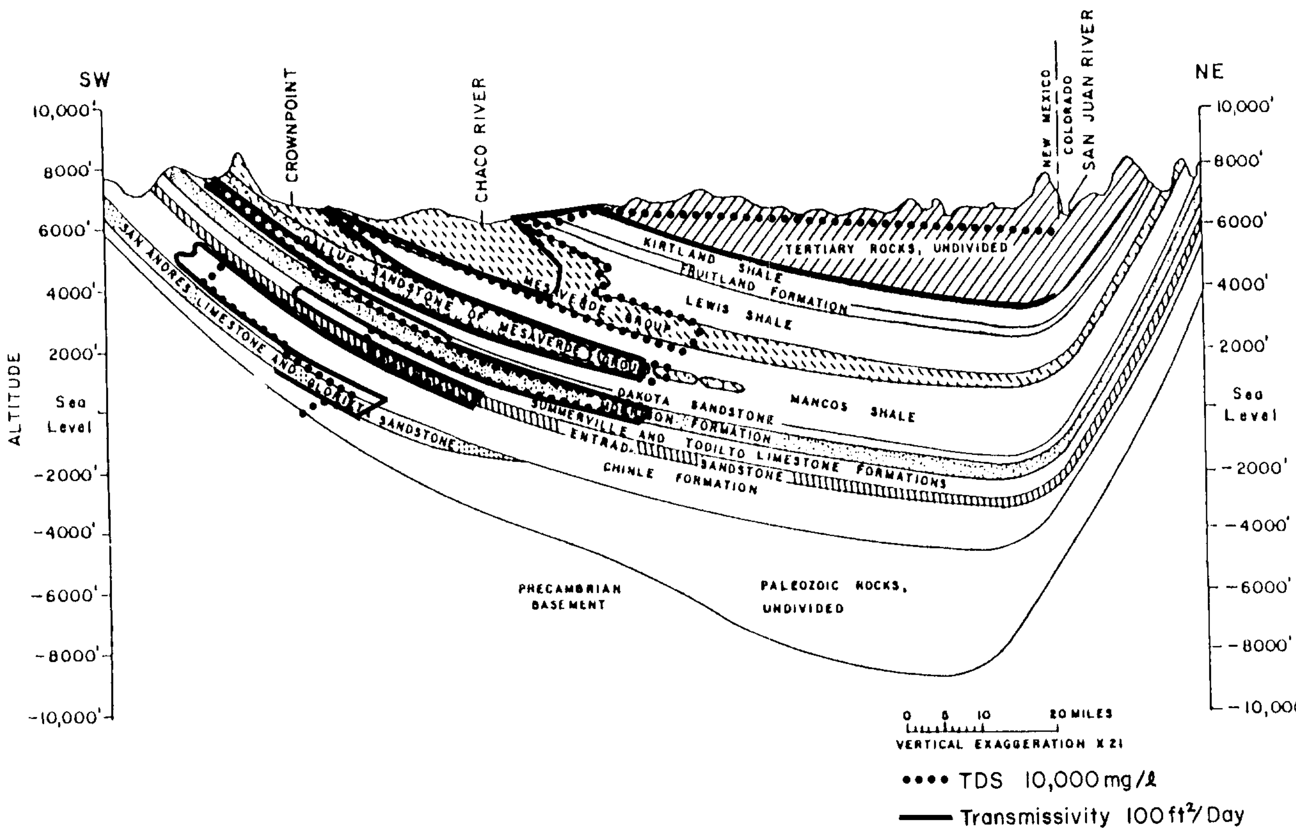


Fig. 8. Hydrogeologic cross section of the San Juan Basin, New Mexico. Water containing 10,000 mg/l or less total dissolved solids occurs above and to the west of heavy dotted line. Formations with a transmissivity of 100 ft^2/day or greater occur above and to the west of solid line. Section taken from Lyford (1979).

UIC standards) and saline water. The fresh water appears in cross section as fingers pointing toward the center of the basin; each finger is located along a relatively permeable unit such as the main Mesaverde Group, Gallup sandstone, Morrison Formation, Entrada sandstone, and San Andres limestone/Glorieta sandstone. Conversely, fingers of saline water point toward the southwest basin margin; each saline finger is associated with a relatively impermeable formation, most often a shale. The heavy line in Figure 8 shows that, in general, the fresh water occurs in rocks with a transmissivity greater than 100 feet squared per day.

If Figure 8 is supported by future studies, then injection will be feasible into the salt-water aquifers which occur at relatively shallow depths in the northern half of the basin, and into saline portions of the Chinle or older units to the south. At the southern margin of the basin, which is where much of the uranium activity is concentrated, injection will require a temporary aquifer exemption.

CONCLUSIONS

The three studies demonstrate that it is practical but not simple to implement the aquifer classification component of the UIC regulations. Aquifer classification involves the steps shown in Figure 1 and relies upon hydrogeologic cross sections which reflect understanding of regional hydrology and geology, and which utilize data obtained from well records and geophysical logs. Nongeologic considerations, such as economics, become important in areas where UIC classifications could conflict with existing or proposed industry practices.

Based on these prototype studies, the cost of a UIC aquifer classification should be in the range of $0.50 to $1.00 per square mile. The expense would be much higher, except that precise classifications are needed only in areas of active injection. Elsewhere, aquifers can be protected to the deepest plausible level unless and until a particular applicant provides site-specific data in support of an aquifer reclassification or exemption.

ACKNOWLEDGMENTS

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Lee Wilson earned his B.A. in Geology at Yale University, and received his Ph.D. in Geology from Columbia University in 1971. For the past 11 years he has been President of Lee Wilson and Associates, a water resource consulting firm located in Santa Fe, New Mexico, where he has managed more than 100 hydrogeologic and environmental impact studies.

Mike Holland obtained his B.A. in Geology from North Carolina State University in 1978. Formerly a Project Geologist with the Oil Conservation Division of the State of New Mexico, he is now Project Geologist with Terra Tek Research in Salt Lake City.

National Cave and Karst Research Institute

Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027
OCD Exhibit No. 18

Using brackish water from karstic aquifers to augment freshwater resources in the semi-arid southwest

Lewis Land
New Mexico Bureau of Geology and Mineral Resources
and National Cave and Karst Research Institute

New Mexico Bureau of Geology and Mineral Resources
New Mexico Tech
Earth Science for the 21st Century

- Access to adequate supplies of fresh water is becoming an increasingly critical issue in many parts of the world.

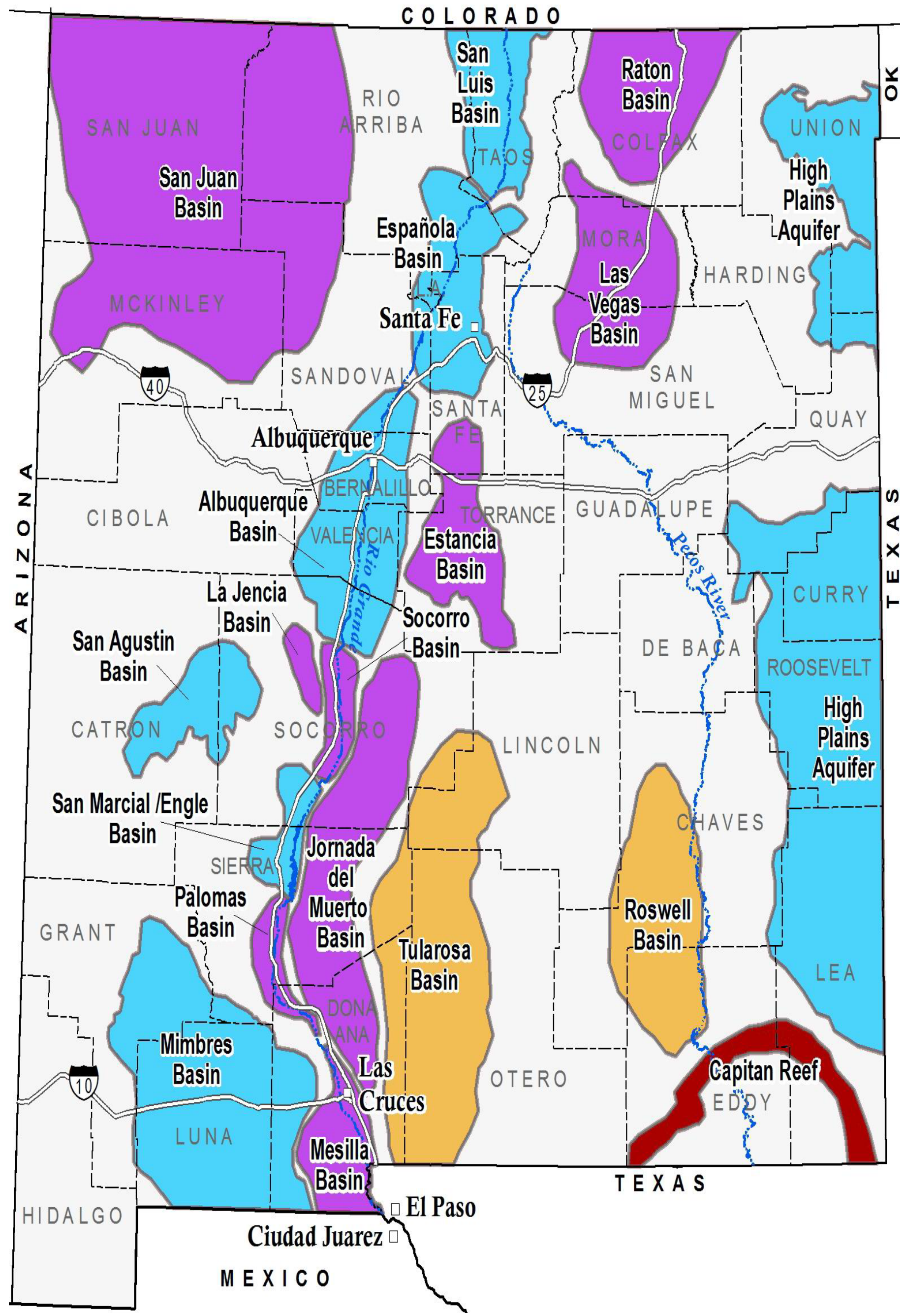
- In arid regions of the southwestern United States, diminishing water supplies and extended periods of drought have generated an interest in non-traditional water resources.

- New Mexico has limited supplies of fresh water, but very large reserves of brackish groundwater. However, our knowledge of the quality and volume of these brackish water resources varies significantly across the state.

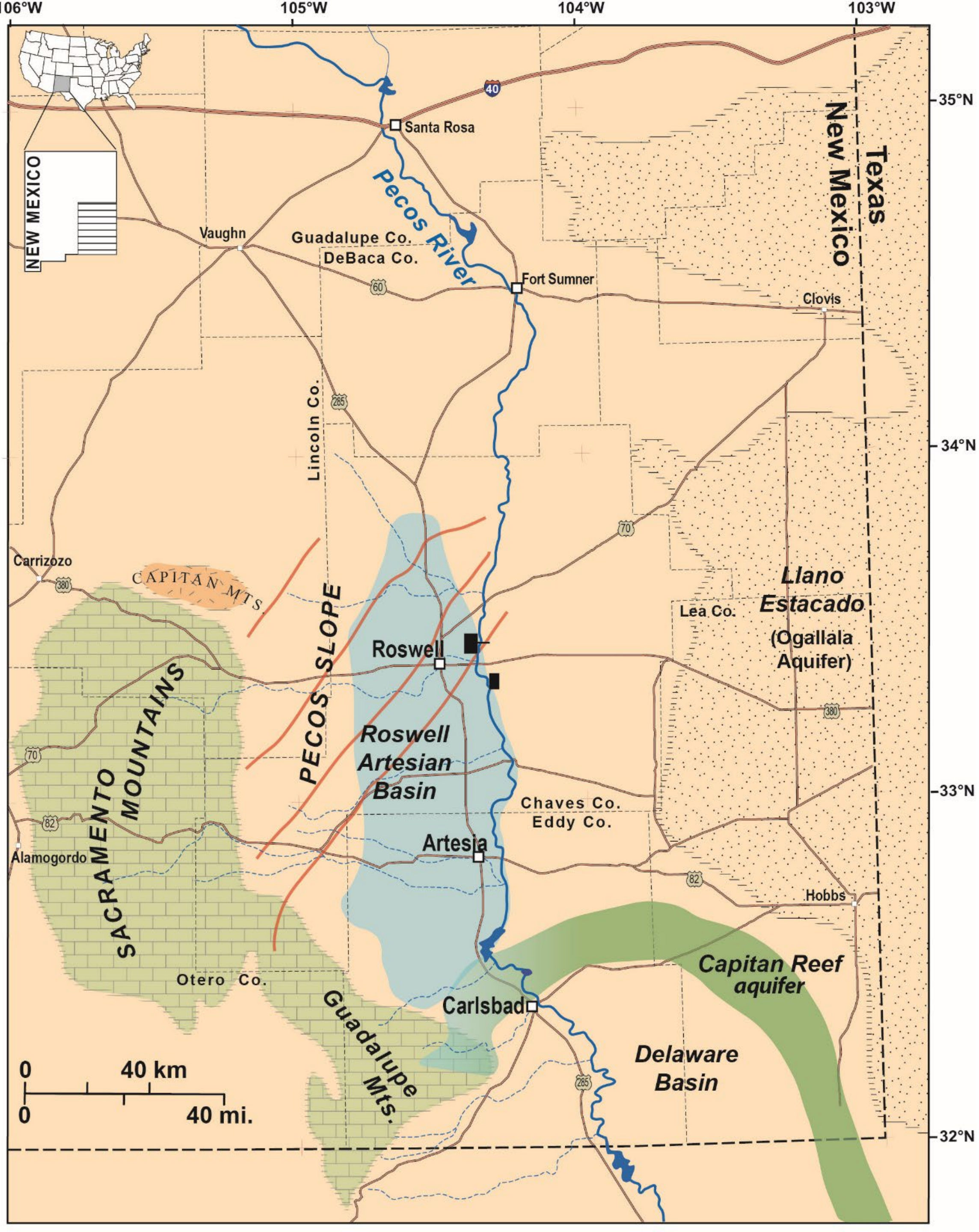
Distribution of brackish water in New Mexico.

Blue	**<1000 mg/l**
Purple	**1000 – 3000 mg/l**
Orange	**3000 – 10,000 mg/l**
Red	**>10,000 mg/l**

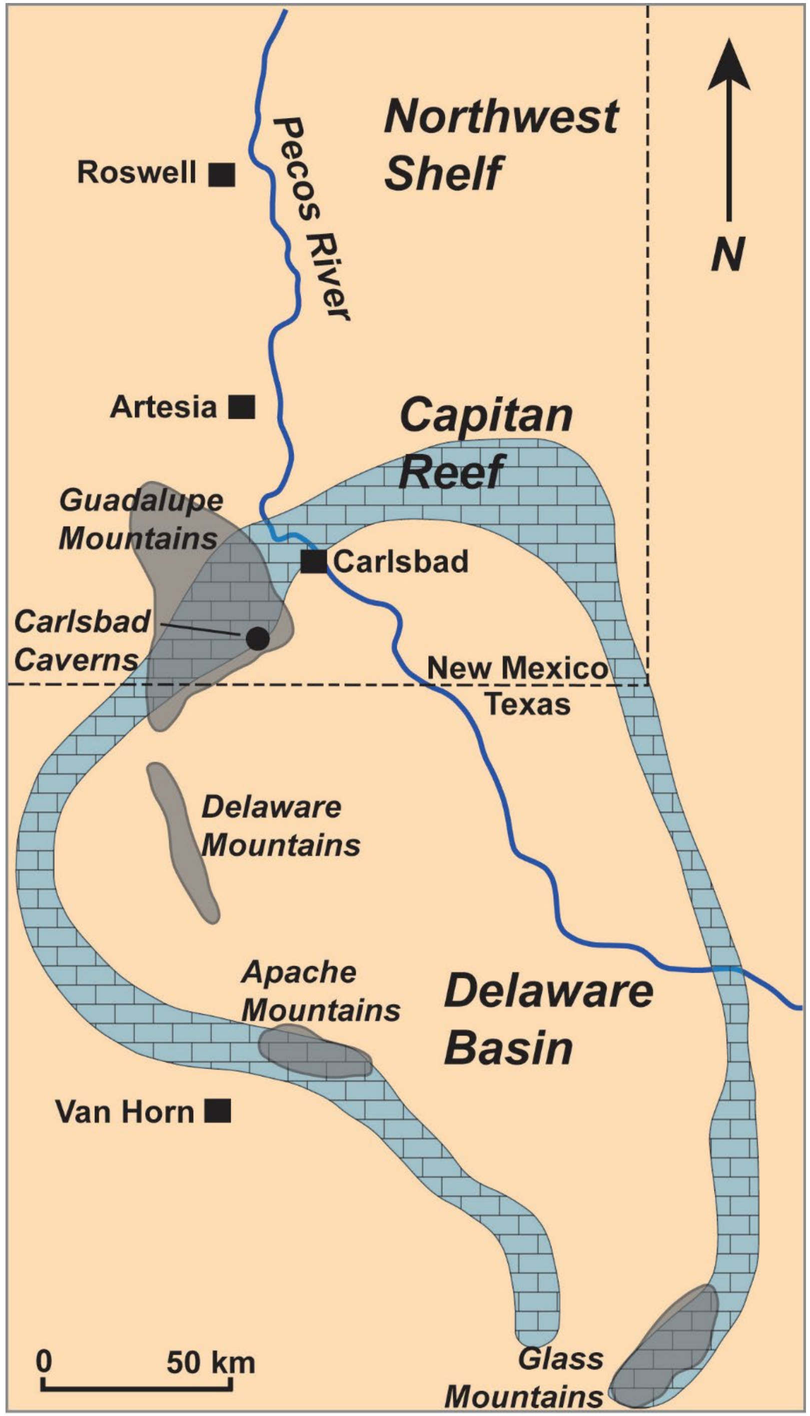
The two saltiest aquifers in the state, the San Andres aquifer in the Roswell Artesian Basin, and the Capitan Reef, are both formed in middle-Permian karstic limestone.



Basin/Region	Number of available records	Mean TDS (mg/L)
San Luis Basin	300	330
San Agustin Basin	185	341
Española Basin	612	390
Mimbres Basin	265	617
San Marcial and Engle Basins	32	704
Albuquerque Basin	987	881
High Plains Aquifer	560	996
Socorro and La Jencia Basins	379	1,002
Mesilla Basin	408	1,217
Estancia Basin	561	1,288
Palomas Basin	203	1,297
Jornada del Muerto Basin	173	1,354
Raton and Las Vegas Basins	80	2,336
San Juan Basin	1,011	2,373
Tularosa Basin	959	3,184
Roswell Artesian Basin	632	3,548
Capitan Reef Aquifer	13	54,046



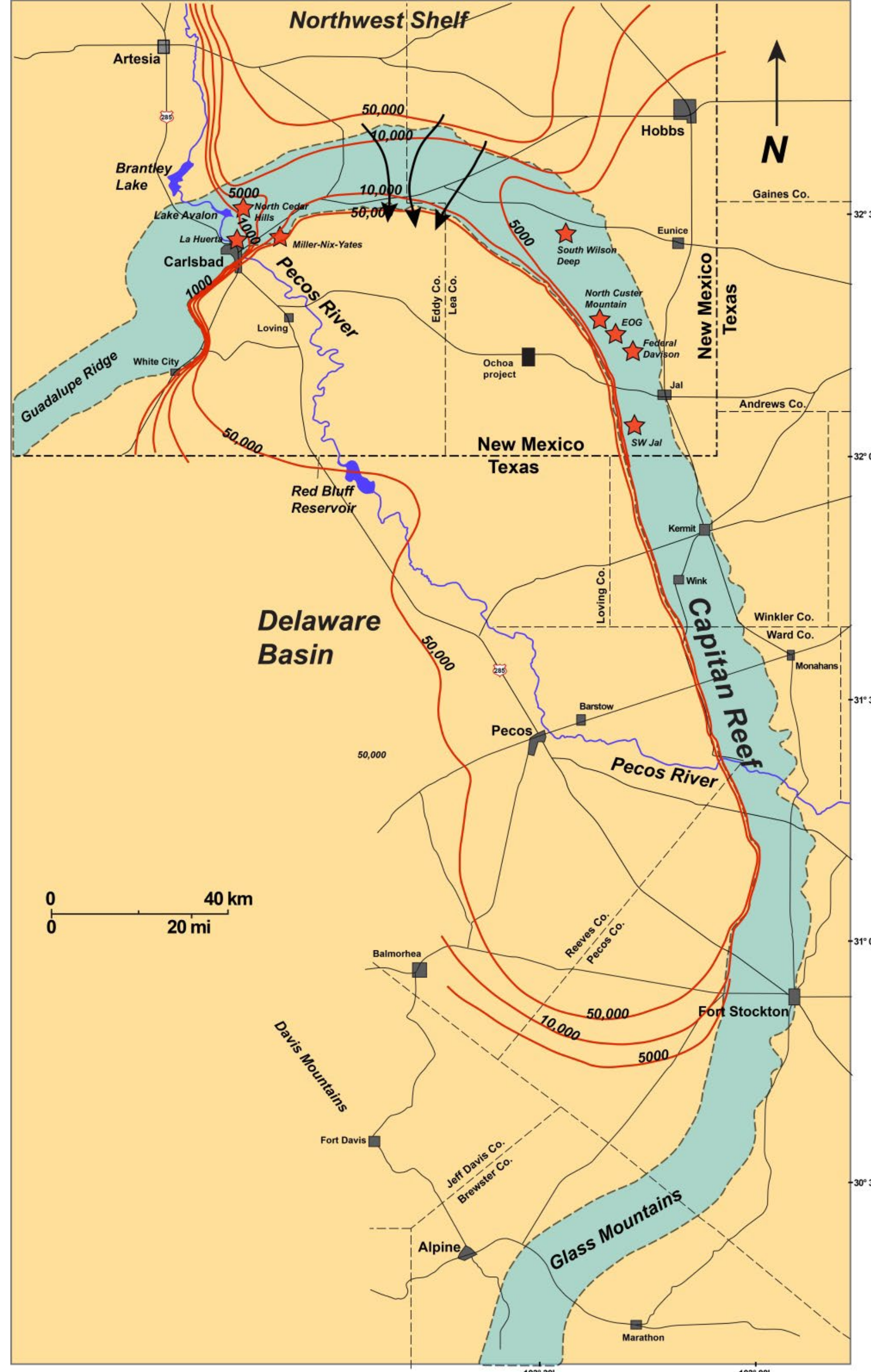
The big three major aquifers of the lower Pecos region include karstic limestone aquifers of the San Andres formation in the Roswell Artesian Basin, and the Capitan Reef.

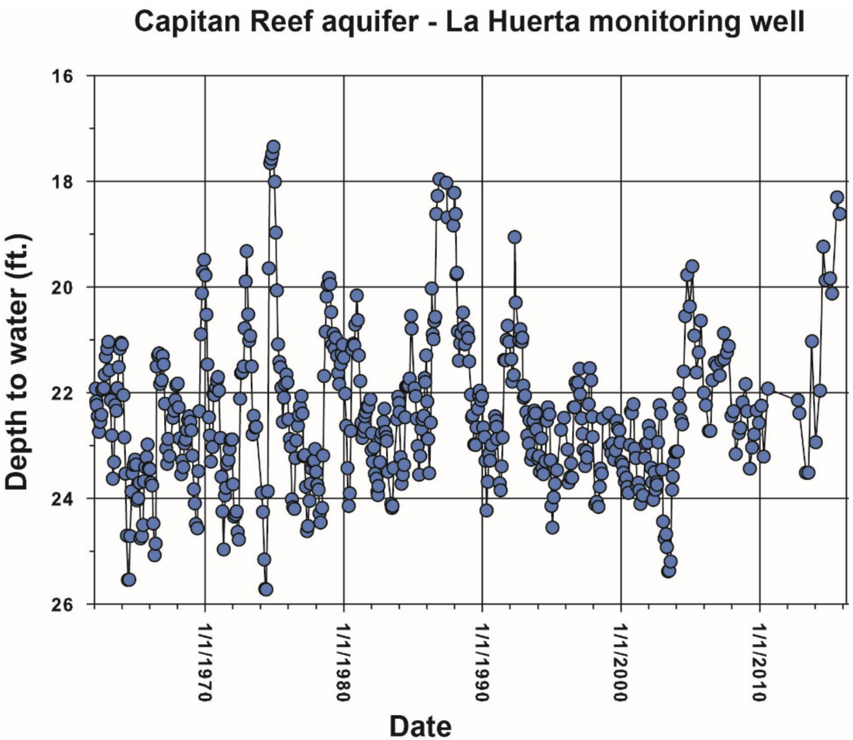

Northwest
Shelf
N
Roswell
Pecos River
Artesia
Capitan
Reef
Guadalupe
Mountains
Carlsbad
Carlsbad
Caverns
New Mexico
Texas
Delaware
Mountains
Apache
Mountains
Delaware
Basin
Van Horn
0
50 km
Glass
Mountains

In 1975 Bill Hiss completed his doctoral dissertation at the University of Colorado on stratigraphy and hydrology of the Capitan Reef, based on water level and water quality records measured in a network of USGS monitoring wells completed in the reef aquifer (red stars).

Throughout most of its extent, the Capitan Reef is a brine aquifer, with chloride concentrations ranging from 1000 to >5000 mg/l, and TDS >140,000 mg/l.

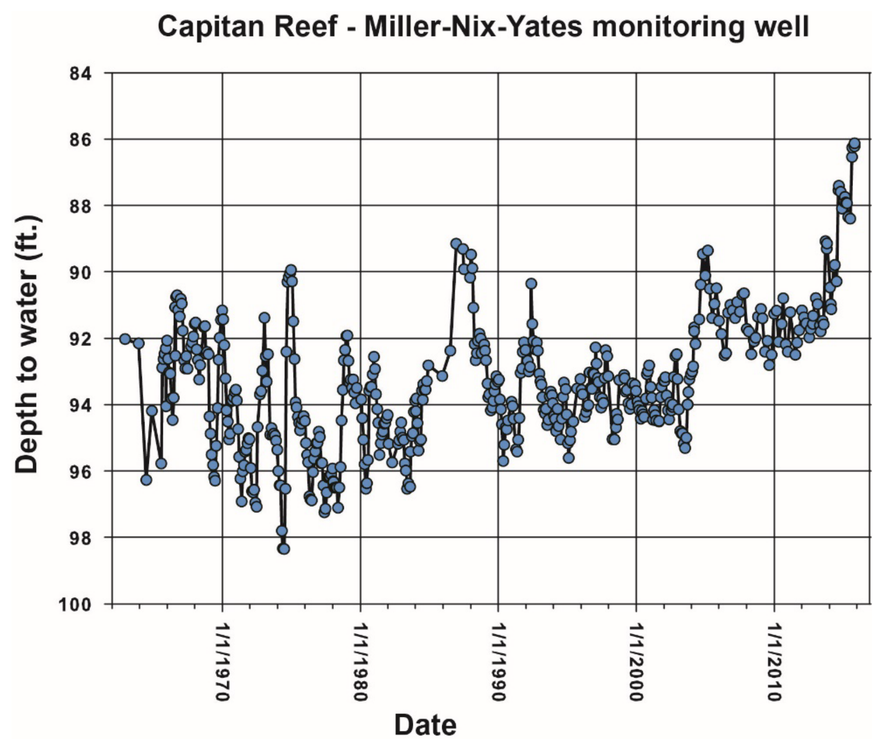
Carlsbad is the only community in the region positioned to exploit the fresh water segment of the reef aquifer.

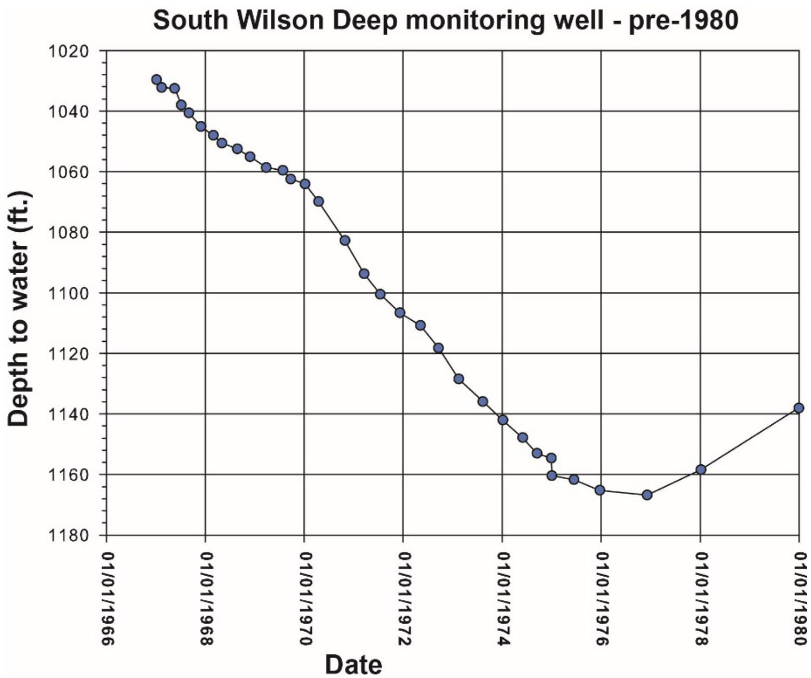




Water levels in the western segment of the reef, in Eddy Co., respond quickly to meteorological events because of proximity to recharge areas in the Guadalupe Mountains.

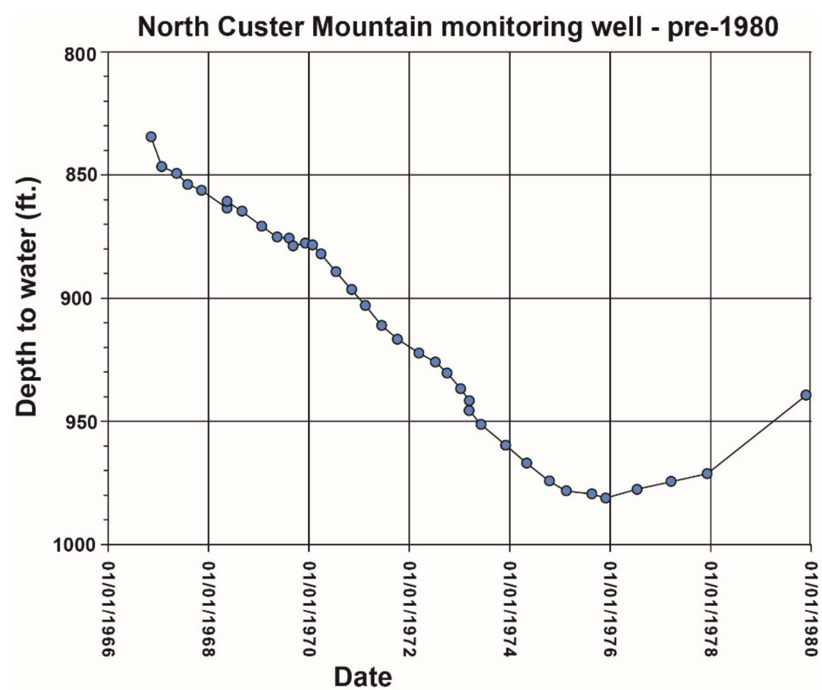
Apologies in advance for non-metric units…

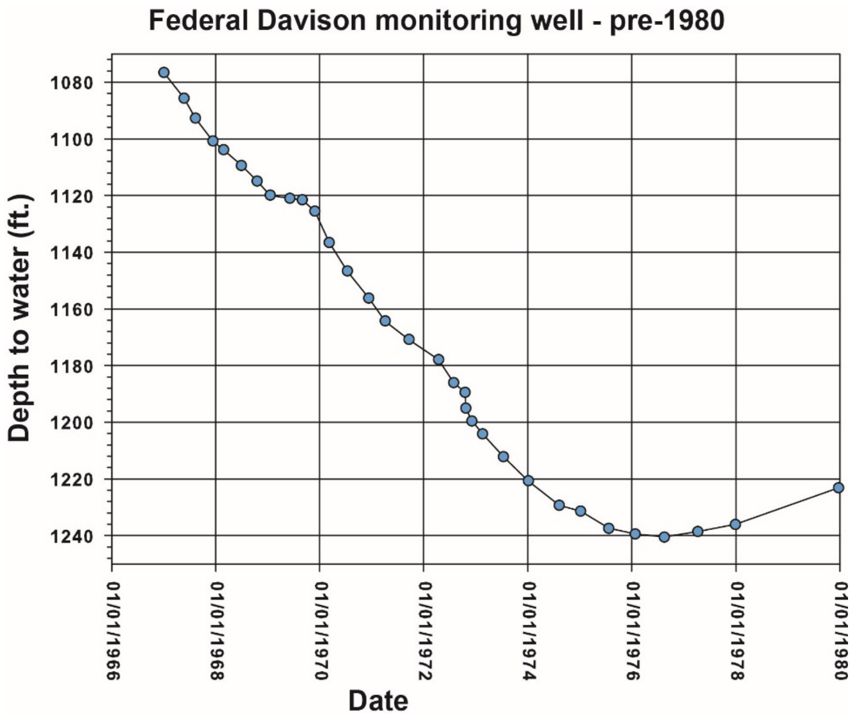




Water levels in the eastern segment of the reef, in Lea county, are not influenced by meteorological phenomena. Instead they show only long declines through the 1960s and 1970s because of withdrawals by oil companies for waterflooding of oil fields in the Permian Basin region.

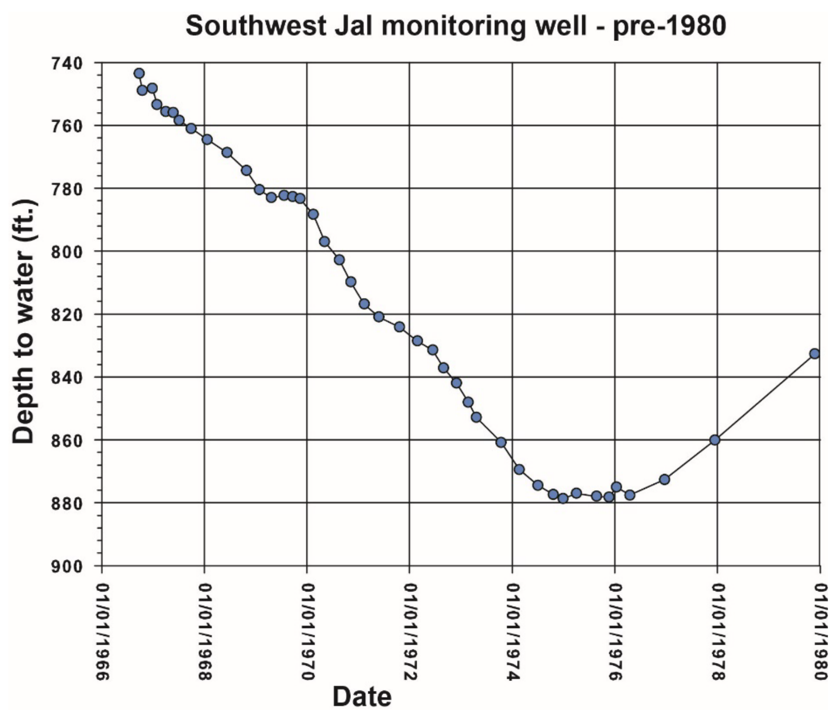
In the late 1970s the decline in water levels in the Lea co. wells began to reverse when industry withdrawals ended. At this time water level measurements also ended when Hiss concluded his research on the reef aquifer.



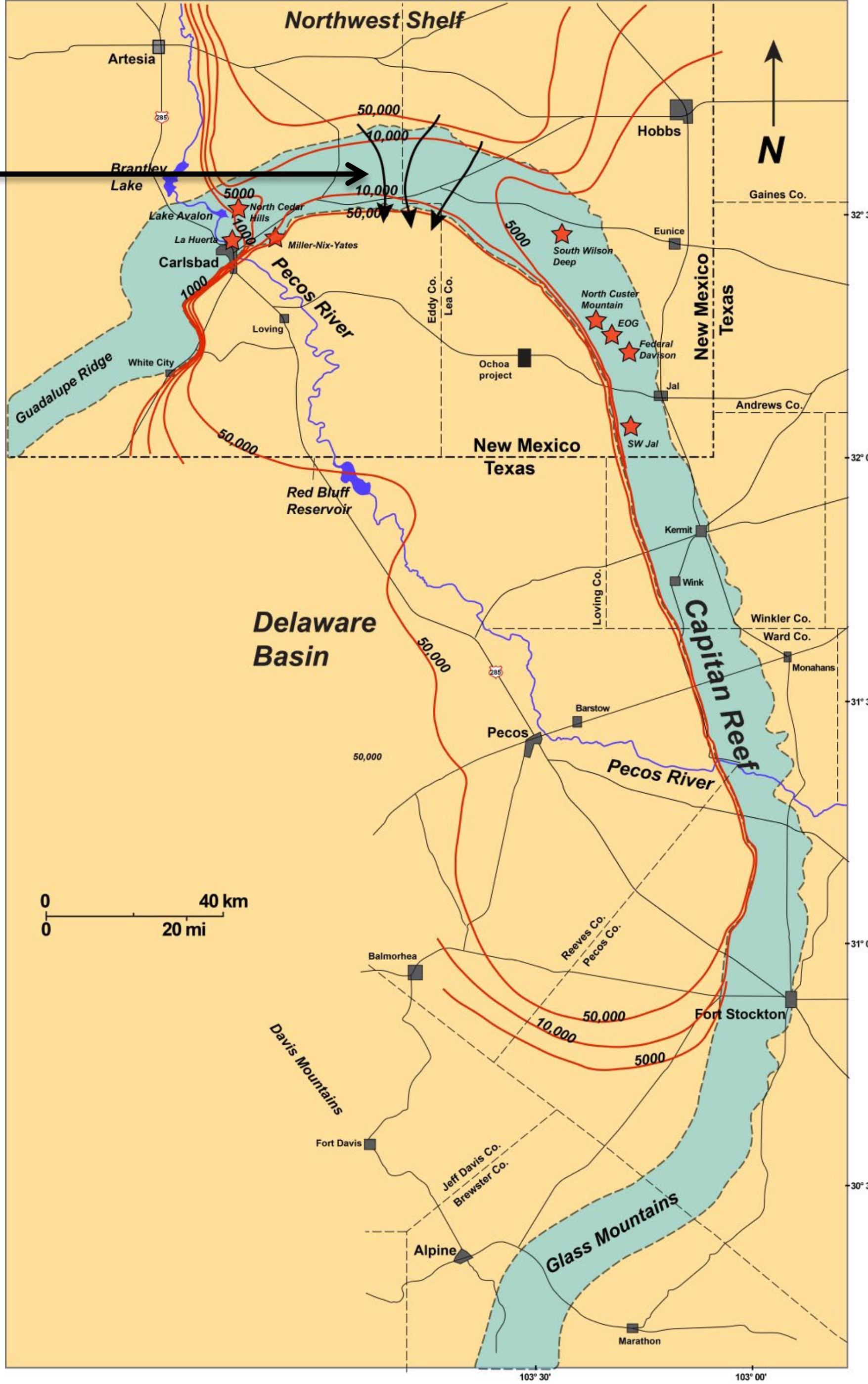


Hiss attributed the difference in hydrograph response to the presence of a partial hydraulic barrier near the Eddy-Lea county line that inhibits communication between the eastern and western segments of the reef.

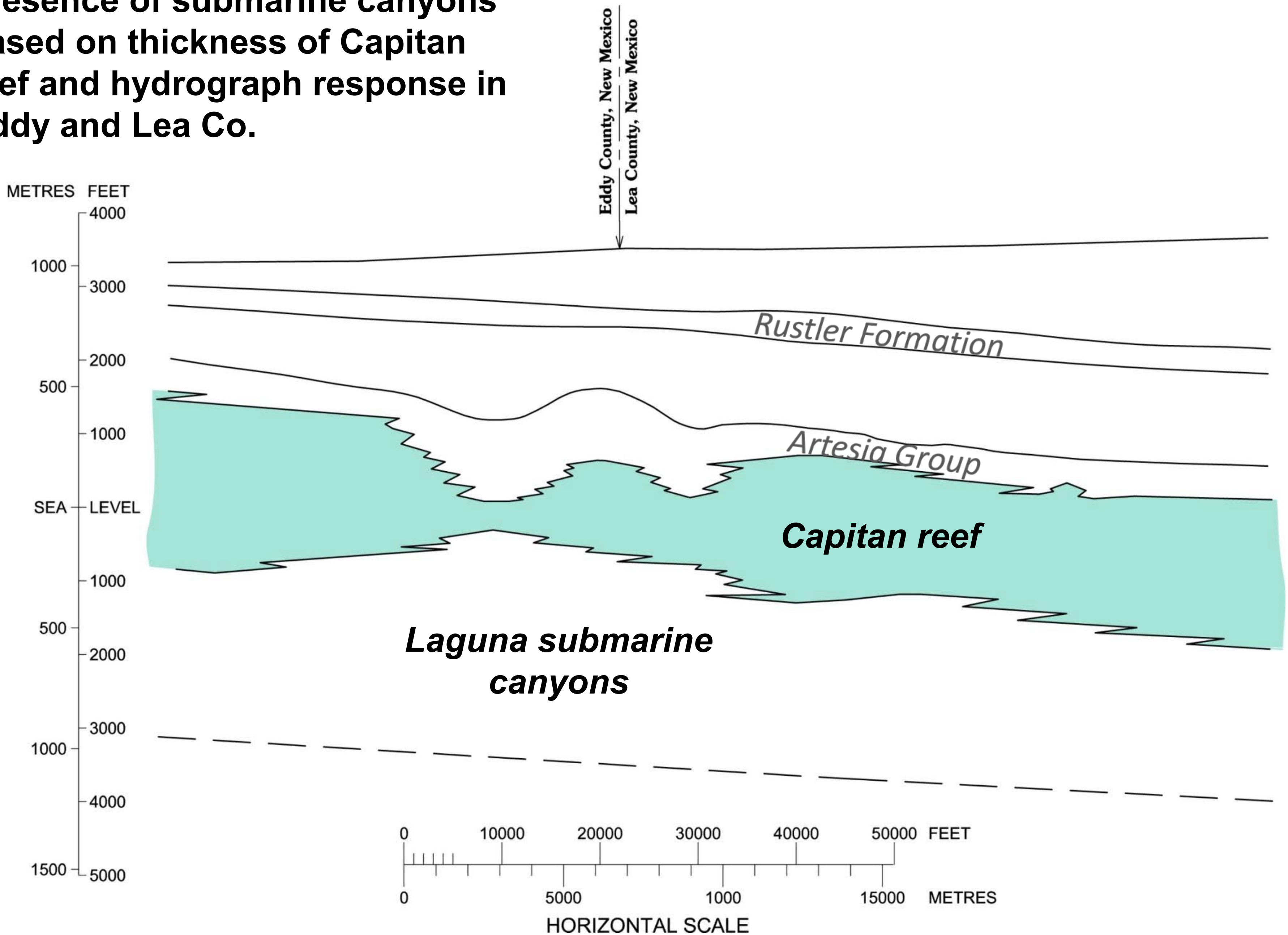
Hiss assumed the hydraulic barrier was the result of low-permeability sediment deposited in submarine canyons that cut across the reef in mid-Permian time.



Laguna submarine canyons



Presence of submarine canyons based on thickness of Capitan reef and hydrograph response in Eddy and Lea Co.

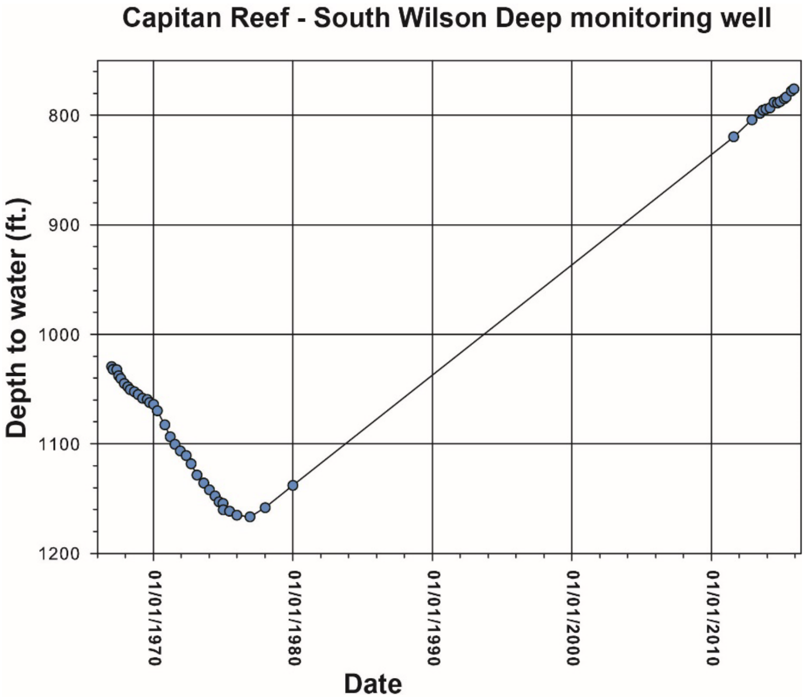


- Brackish water resources in the Capitan Reef aquifer are now being targeted by both the petroleum industry, primarily for fracking, and the potash industry, for processing potash ore (polyhalite: K_2SO_4-$MgSO_4$-$2CaSO_4$-$2H_2O$) at the Ochoa Project in SW Lea Co.

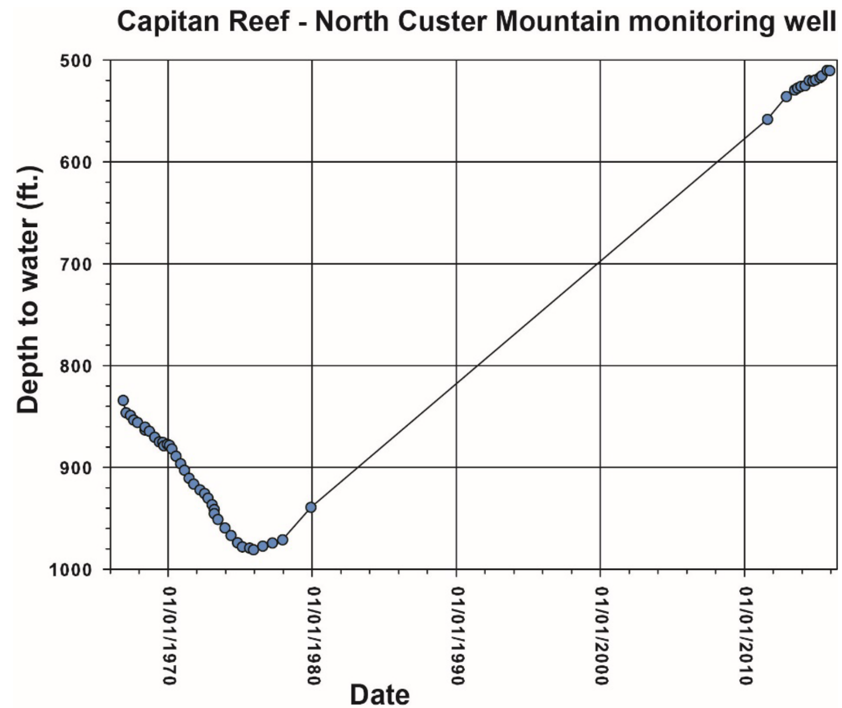
- The impact of brackish water withdrawals on fresh water resources near Carlsbad, and on baseflow into the Pecos River, is thought to be minimal because of the presence of the hydraulic barrier (submarine canyons) that separates the eastern and western segments of the reef.

- Water in the western segment of the reef is presumably very young because of proximity to recharge in the Guadalupe Mountains.

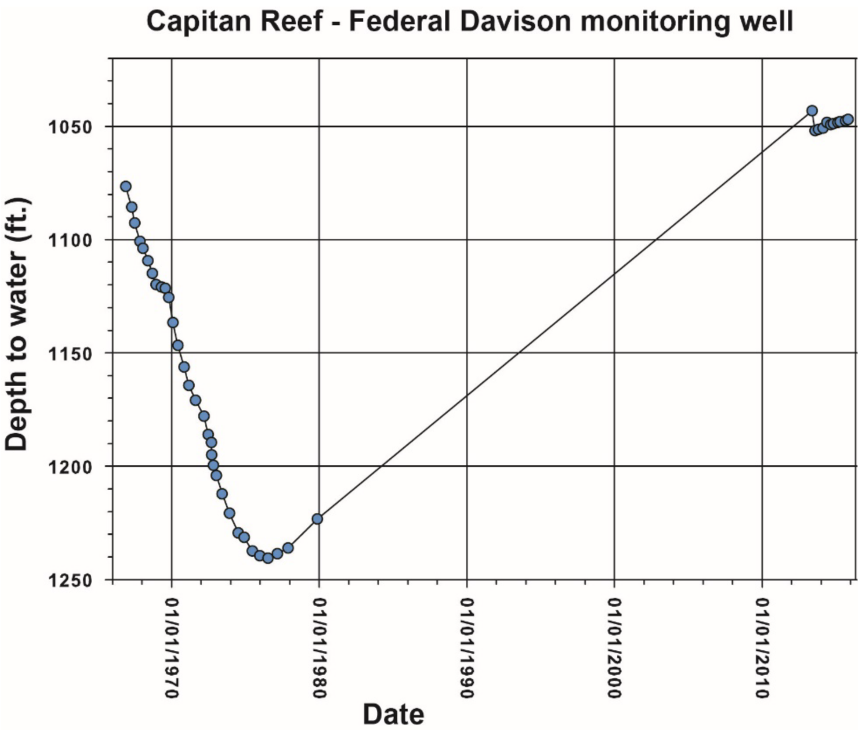
- Water in the eastern segment of the reef is thought to be recharged from the Glass Mountains in west Texas, and from adjacent shelf and basin aquifers, although flow patterns are not as well-constrained.



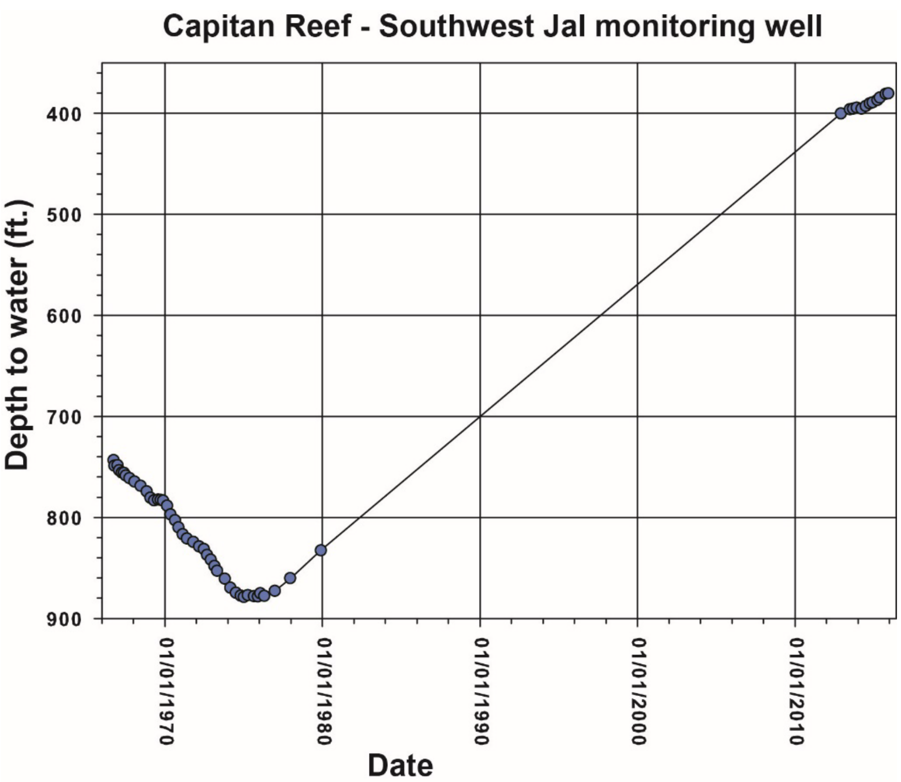
In 2012 BLM personnel relocated seven of Hiss's monitoring wells and began quarterly measurements of water levels.



Water levels in the Lea co. wells have risen several hundred feet since the last measurements were made in 1979.



This remarkable rise in water levels in the Lea co. monitoring wells raises interesting questions about sources of recharge and the age of groundwater in the eastern segment of the reef aquifer.



- If brine in the eastern segment of the Capitan Reef is hydrologically isolated from the western segment it may be very old, possibly representing recharge that occurred during the Pleistocene.

- A knowledge of the age distribution of groundwater within the reef aquifer would provide valuable insight into groundwater flow paths and flow rates, and the impact of brackish water withdrawals on fresh water resources within the reef.

- Water levels in the eastern segment of the reef aquifer are several hundred feet deep; perforations in the Lea Co. monitoring wells are all >4000 ft. bgl, making a conventional sampling program logistically challenging and prohibitively expensive. We propose to use grab sampling methods for sampling these deeper wells at ~1% of the cost of a conventional sampling program.

- Samples are being analyzed for major ions, trace metals, stable isotopes, contaminants, tritium, and carbon-14.

Snap sampler deployment

Sending snap samplers to >4000 ft. bgl can also be logistically challenging (and so far, not possible).

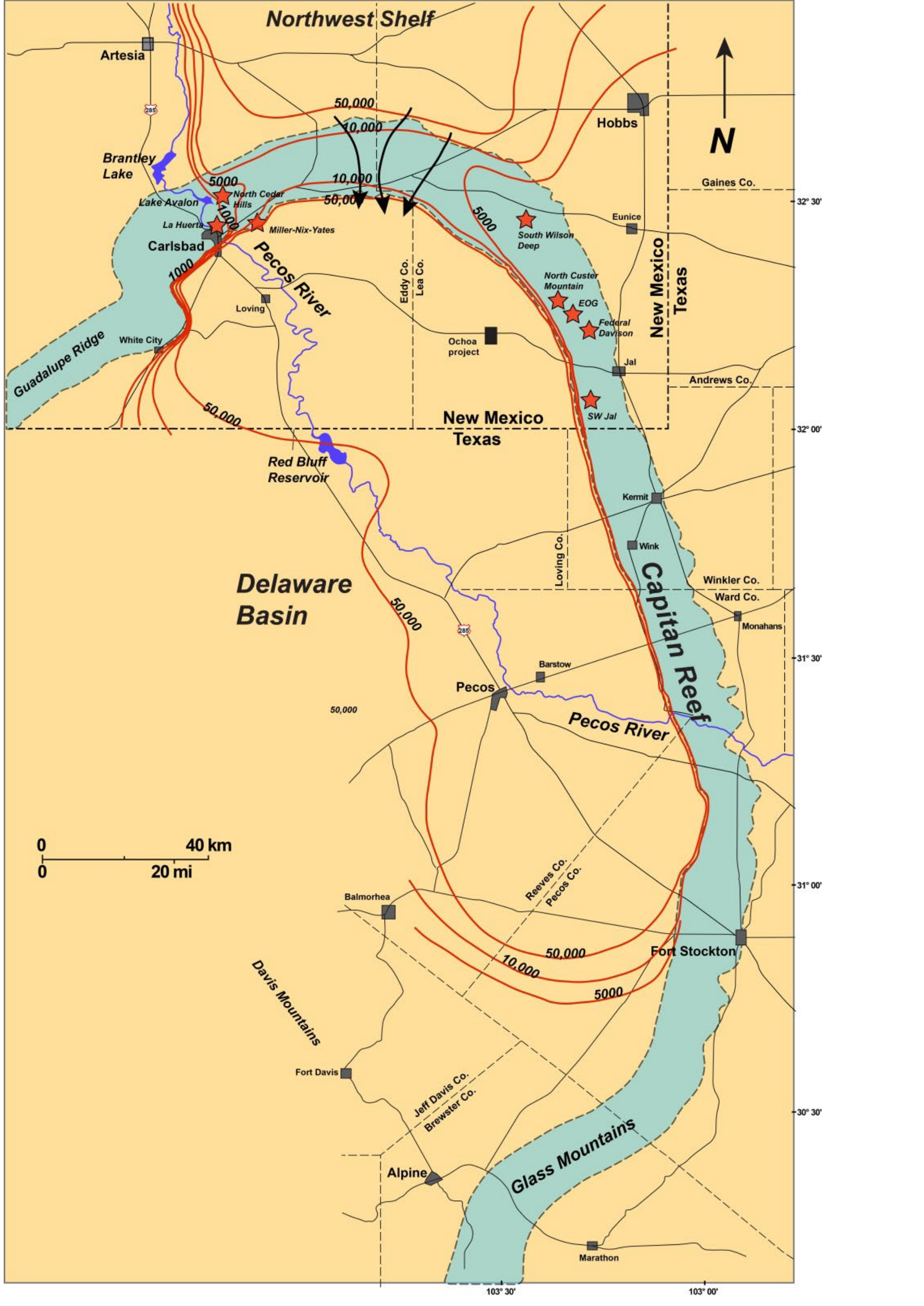
Preliminary sampling results (14C data uncorrected)

- La Huerta, Eddy Co.
  - Cl 389 mg/l
  - TDS 1951 mg/l
  - 14C 51.7 pMC
  - 3H 1.89 TU

- Federal Davison, Lea Co.
  - Cl 82,936 mg/l
  - TDS 140,028 mg/l

- EOG*, Lea Co.
  - 14C 0.8 pMC
  - 3H -0.04 TU

*This sample was generously provided by EOG Resources, from one of their frackwater supply wells completed in the Capitan Reef.



Preliminary results

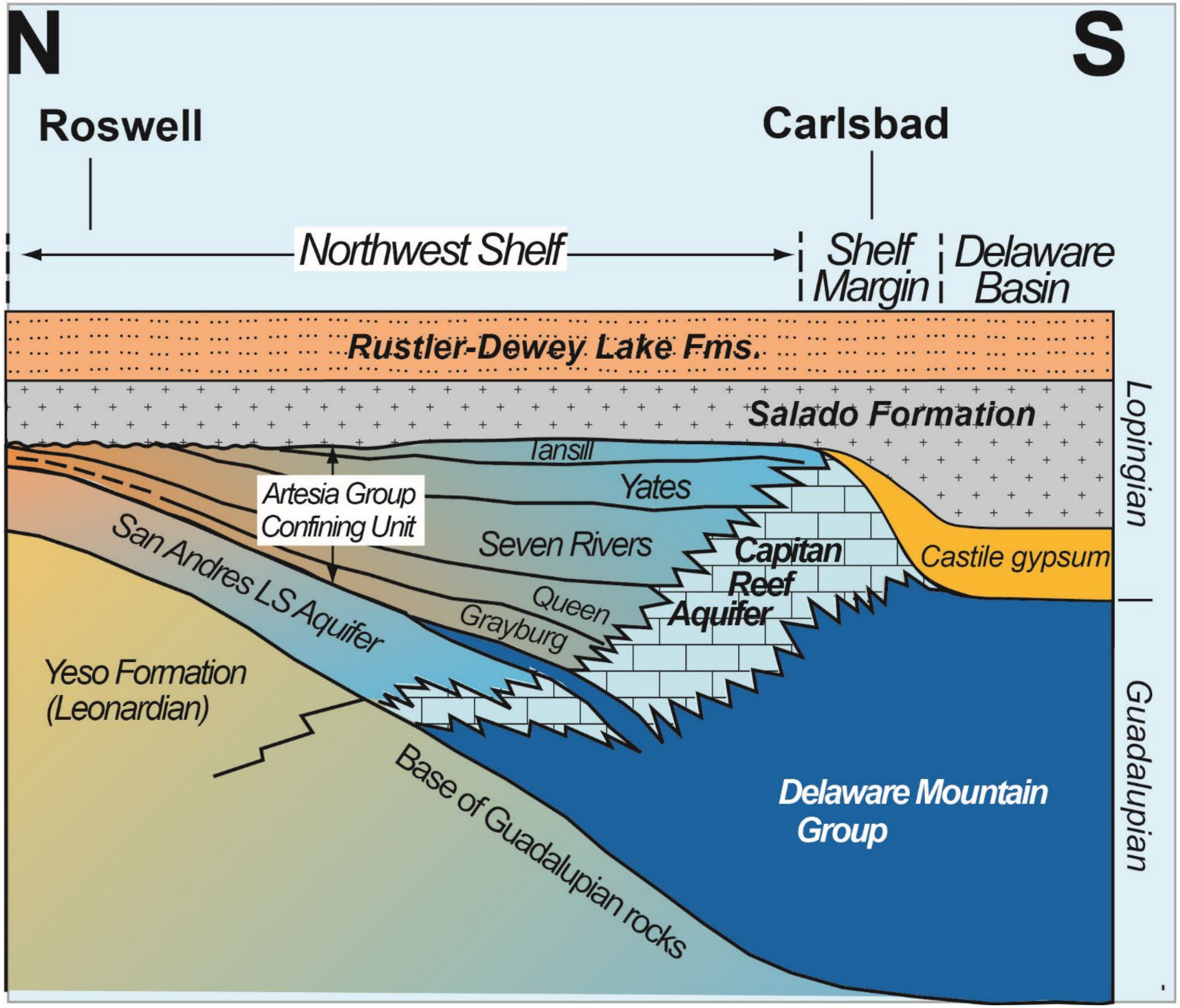
- *Uncorrected* 14C data indicate that water in the eastern segment of the reef is either (a) very old and/or (b) has taken a much longer, and more geochemically reactive path through the reef aquifer than water samples collected in the western segment.

- Tritium concentrations provide non-quantitative estimates of groundwater age. *Nevertheless*, tritium data from the Lea county well, with no measurable tritium, demonstrate that water in the eastern segment of the reef is pre-modern.

- Preliminary data support conceptual models of hydrologic isolation of the eastern segment of the Capitan Reef, but do not address the question of why water levels have been steadily rising for the last three decades in the Lea county wells.

Take-home message: Assuming that brackish water withdrawals from the Capitan Reef aquifer will not adversely impact freshwater resources near Carlsbad, then use of treated brine from the Capitan Reef for industrial purposes will reduce the impact of withdrawals on the limited freshwater resources in the region.

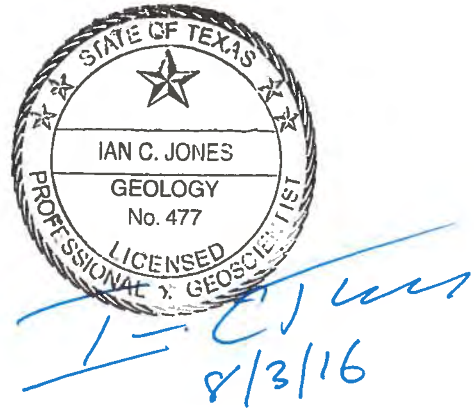

El Capitan, Guadalupe Mountains,
on the road to El Paso…


N
S
Roswell
Carlsbad
Northwest Shelf
Shelf Margin
Delaware Basin
Rustler-Dewey Lake Fms.
Salado Formation
Lopingian
Tansill
Yates
Artesia Group Confining Unit
Seven Rivers
Capitan Reef Aquifer
Castile gypsum
Queen
Grayburg
San Andres LS Aquifer
Yeso Formation (Leonardian)
Base of Guadalupian rocks
Delaware Mountain Group
Guadalupian

Case Nos. 24278, 24277, 24123, 23775, 23614-23617, and 24018-24027
OCD Exhibit No. 19

Conceptual Model: Capitan Reef Complex Aquifer of Texas

Ian C. Jones, Ph.D., P.G.
Texas Water Development Board
August 3, 2016



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EXECUTIVE SUMMARY

The Capitan Reef Complex Aquifer is a minor aquifer located in the Trans-Pecos area of western Texas and southeastern New Mexico. The aquifer occurs in a horseshoe-shaped band of carbonate rocks exposed at the land surface where uplifted by tectonic processes but otherwise buried beneath younger sediments. The area of primary interest in this project is the eastern arm of the Capitan Reef Complex, extending from Brewster County through Pecos, Ward and Winkler counties in Texas to Lea County and part of Eddy County in New Mexico. This report documents the development of a conceptual model focusing primarily on the eastern arm of the Capitan Reef Complex Aquifer. We selected the eastern arm of the Capitan Reef Complex Aquifer because part of the western arm of the Capitan Reef Complex Aquifer is already included in the groundwater flow model for the Bone Spring-Victorio Peak Aquifer (Hutchison, 2008).

The Capitan Reef Complex Aquifer consists of the stratigraphic units of the Capitan Reef Complex that were deposited along the margins of the Delaware Basin. These stratigraphic units include the Carlsbad and Capitan limestones, and the Goat Seep Dolomite. The aquifer crops out in Brewster, Culberson, Hudspeth, and Pecos counties in Texas and in Eddy County in New Mexico. These outcrops coincide with areas of uplift that resulted in the formation of the Guadalupe, Apache, and Glass mountains. The Capitan Reef Complex Aquifer also occurs in subcrop only in parts of Jeff Davis, Pecos, Reeves, Ward, and Winkler counties in Texas and Lea County in New Mexico. The Capitan Reef Complex Aquifer generally dips towards the north and east. This is partially due to uplift that resulted in the formation of the previously mentioned mountain ranges that are located on the western and southern portions of the reef.

Available water level data show that groundwater flow in the Capitan Reef Complex Aquifer occurs parallel to the reef trends. Groundwater generally flows away from aquifer outcrop recharge zones towards deeper parts of the aquifer. Groundwater in the Capitan Reef Complex Aquifer likely naturally discharges by cross-formational flow through adjacent stratigraphic units. Discharge by any other mechanism is highly unlikely considering: (1) the lack of contact between the Capitan Reef Complex Aquifer and any surface-water bodies, such as, springs and rivers, and (2) the occurrence of artesian wells and water levels higher than those in overlying aquifers suggesting upward hydraulic gradients, especially in the eastern part of the aquifer.

Groundwater in the Capitan Reef Complex Aquifer is used primarily for oil and gas production in the northern and eastern parts of the aquifer, but is also used locally for livestock and irrigation. Sparse multi-year water-level data indicates static, declining, and fluctuating water levels in different parts of the Capitan Reef Complex Aquifer.

There is a general lack of hydraulic property data for the Capitan Reef Complex Aquifer. However, the data available show significant variability in the aquifer properties resulting from structural complexity within the basin, variability in lithology, and the effects of post-

depositional processes including karstification. Hydraulic conductivity values for the Capitan Reef Complex range from less than 0.01 feet per day to more than 500 feet per day and display no apparent spatial trends. The median hydraulic conductivity of the Capitan Reef Complex Aquifer is orders of magnitude higher than that of the adjacent basin and shelf stratigraphic units.

Water quality in the Capitan Reef Complex Aquifer is generally brackish to saline. Freshwater occurs in or adjacent to aquifer outcrops. In the subcrop, groundwater ranges from brackish to saline, with the highest salinity in the deepest parts of the aquifer—in Ward County, Texas and Lea County, New Mexico. Capitan Reef Complex Aquifer groundwater compositions range from calcium-magnesium-bicarbonate compositions to calcium-magnesium-sulfate compositions to sodium-chloride compositions, reflecting interaction with minerals—calcite, dolomite, gypsum, and halite—that occur within the Capitan Reef Complex and adjacent stratigraphic units.

Compositions of various isotopes in Capitan Reef Complex Aquifer groundwater indicate that: (1) most recharge to the aquifer occurs in the Guadalupe and Glass mountains aquifer outcrops, (2) relatively little recharge occurs in the Apache Mountains outcrop, and (3) rapid recharge to subcrop parts of the aquifer occurs south of the Delaware Mountains. Additionally, isotopes indicate that recharge to the Capitan Reef Complex Aquifer occurs under a wider range of altitude and climatic conditions in the western arm of the Capitan Reef Complex Aquifer than in the eastern arm. The data suggest that the groundwater flow system in the eastern arm of the aquifer is simple with a single recharge zone—the Glass Mountains aquifer outcrop.

The conceptual model of the eastern arm of the Capitan Reef Complex Aquifer is a simplified representation of the hydrogeological features—hydrostratigraphy, hydraulic properties, hydrologic boundaries, recharge, and discharge—that influence groundwater flow through the aquifer. The conceptual model for the eastern arm of the Capitan Reef Complex Aquifer—the basis used to construct a groundwater flow model—is composed of up to five model layers simulating groundwater flow through the Capitan Reef Complex Aquifer and overlying aquifers and confining units that occur within the Monument Draw Trough. This conceptual model is characterized by recharge to the aquifer outcrop in the Glass Mountains and limited inflow from the north margin the modeled area, groundwater flow into subcrop parts of the Capitan Reef Complex Aquifer, and discharge by upward flow through overlying aquifers.

1.0 INTRODUCTION

The Capitan Reef Complex Aquifer is a minor aquifer—one of nine major and 21 minor aquifers in Texas (Figures 1.0.1 and 1.0.2). The Texas Water Development Board defines a major aquifer as an aquifer that produces large amounts of water over a large area, and minor aquifers as aquifers that produce minor amounts of water over large areas or large amounts of water over small areas (George and others, 2011). The Capitan Reef Complex Aquifer meets the definition of a minor aquifer because (1) most of its extent is overlain by major aquifers—such as the Pecos Valley and Edwards-Trinity (Plateau) aquifers— that are more attractive to well drilling due to shallower depth, (2) it underlies a relatively small area that has a small population and little irrigation, and (3) poor water quality in most parts of the aquifer make it unattractive for most water uses. Historically, the Capitan Reef Complex Aquifer has been used for secondary recovery by the petroleum industry (White, 1987). Total pumping from the Texas portion of the Capitan Reef Complex Aquifer has ranged from a high of more than 15,000 acre-feet per year to less than 200 acre-feet per year during the period 1980 through 2008. This aquifer is important because drawdown in overlying major aquifers—especially the Pecos Valley Aquifer—can induce upward groundwater flow from the underlying aquifers such as the Capitan Reef Complex Aquifer (Jones, 2004). The Capitan Reef Complex Aquifer is also becoming more important as use of desalinated groundwater increases its potential as a groundwater source.

This report describes the aquifer data used to develop a conceptual model for the eastern arm of the Capitan Reef Complex Aquifer. This conceptual model will be the basis for the construction of a groundwater availability model for that portion of the Capitan Reef Complex Aquifer. Once this model is calibrated, it can be used as a quantitative tool to evaluate the effects of pumping, drought, and different water management scenarios on the groundwater flow system. This report includes descriptions of (1) the study area, (2) previous investigations of the Capitan Reef Complex Aquifer, (3) the hydrologic setting including hydrostratigraphy, geologic framework, groundwater hydrology, recharge, discharge, surface water, hydraulic properties, and water quality, and (4) the resultant conceptual model.

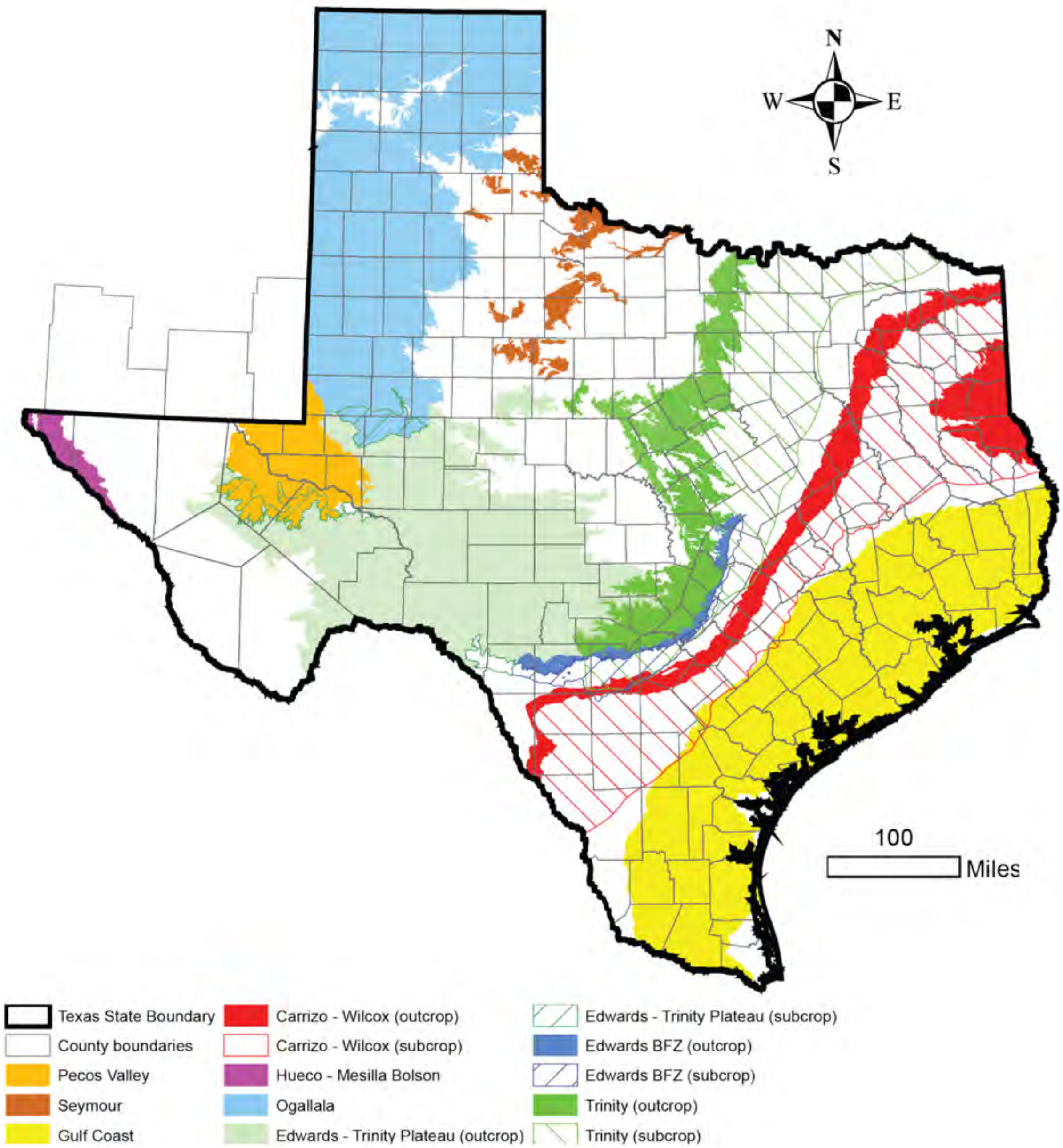


Figure 1.0.1. **Locations of the major aquifers in Texas.**

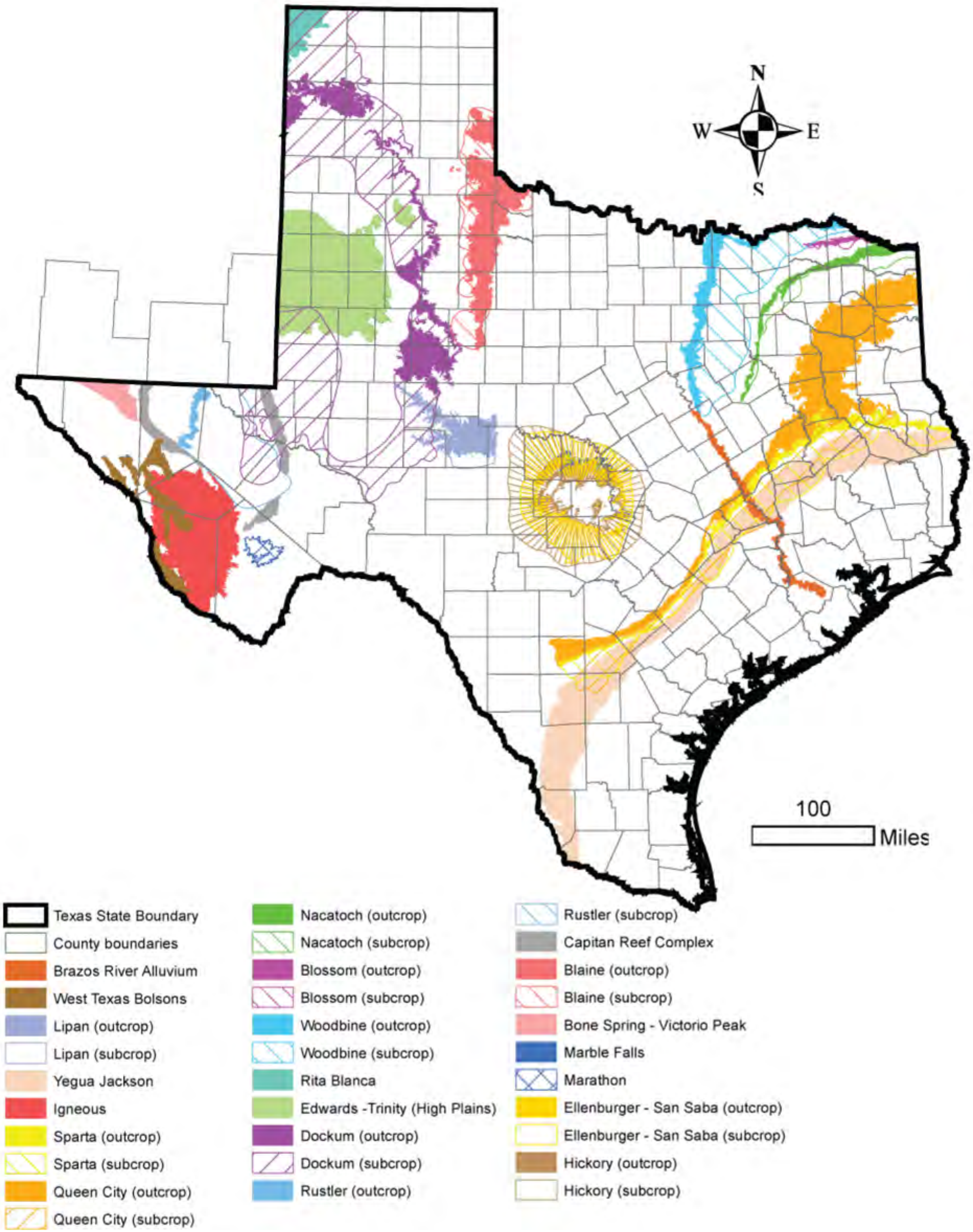


Figure 1.0.2. Locations of the minor aquifers in Texas.

2.0 STUDY AREA

The Capitan Reef Complex Aquifer occurs in outcrop and subcrop in a relatively narrow horseshoe-shaped band in the Trans-Pecos area of western Texas and southeastern New Mexico (Figure 2.0.1). The outcrops are located in the Guadalupe, Apache, and Glass mountains (Figure 2.0.2). The Capitan Reef Complex Aquifer boundaries used in this study were defined by work by Standen and others (2009). These alternative boundaries differ from the aquifer boundaries defined by the Texas Water Development Board (Figure 2.0.2). The alternative boundaries are used in this study because they are based on the most up-to-date data with regards to the spatial distribution of the Capitan Reef Complex.

Figure 2.0.3 shows the counties, major roadways, and cities in the study area. The Capitan Reef Complex Aquifer underlies eight counties in Texas and three counties in New Mexico. Cities overlying the Capitan Reef Complex Aquifer include Carlsbad in New Mexico, and Fort Stockton, Kermit, Monahans, Pyote, Wickett, and Wink in Texas. The locations of rivers, streams, lakes, and reservoirs in the study area are shown on Figure 2.0.4. The Pecos River and a few of its tributaries are the only perennial streams in the study area. The Pecos River—where it flows over Capitan Reef Complex Aquifer near Carlsbad, New Mexico—is the only perennial stream that interacts with the Capitan Reef Complex Aquifer. It should be noted that the Capitan Reef Complex does not crop out along the Pecos River channel.

Figures 2.0.5 and 2.0.6 show the major and minor aquifers that occur within the study area. Major aquifers occurring in the study area include parts of the Pecos Valley and Edwards-Trinity (Plateau) aquifers. In addition to the Capitan Reef Complex Aquifer, minor aquifers occurring in the study area include parts of the Dockum, Igneous, Rustler, and West Texas Bolsons aquifers.

The Capitan Reef Complex Aquifer underlies part of the Far West Texas Regional Water Planning Area and the Region F Regional Water Planning Area (Figure 2.0.7). The aquifer also underlies parts of the Middle Pecos Groundwater Conservation District, Brewster County Groundwater Conservation District, Jeff Davis County Underground Water Conservation District, Reeves County Groundwater Conservation District, and Culberson County Groundwater Conservation District (Figure 2.0.8). The Capitan Reef Complex Aquifer underlies portions of Groundwater Management Areas 3, 4, and 7 (Figure 2.0.9). The Capitan Reef Complex Aquifer does not occur within the boundaries of any river authority.

The Capitan Reef Complex Aquifer is contained wholly within the Rio Grande river basin (Figure 2.0.10). For all but the Pecos River and a few of its larger tributaries, rivers and streams in the study area are normally dry. When flow does occur in the smaller rivers and streams, it rarely reaches the Pecos River but rather seeps into the channel beds or spreads out over broad valleys (Ashworth, 1990).

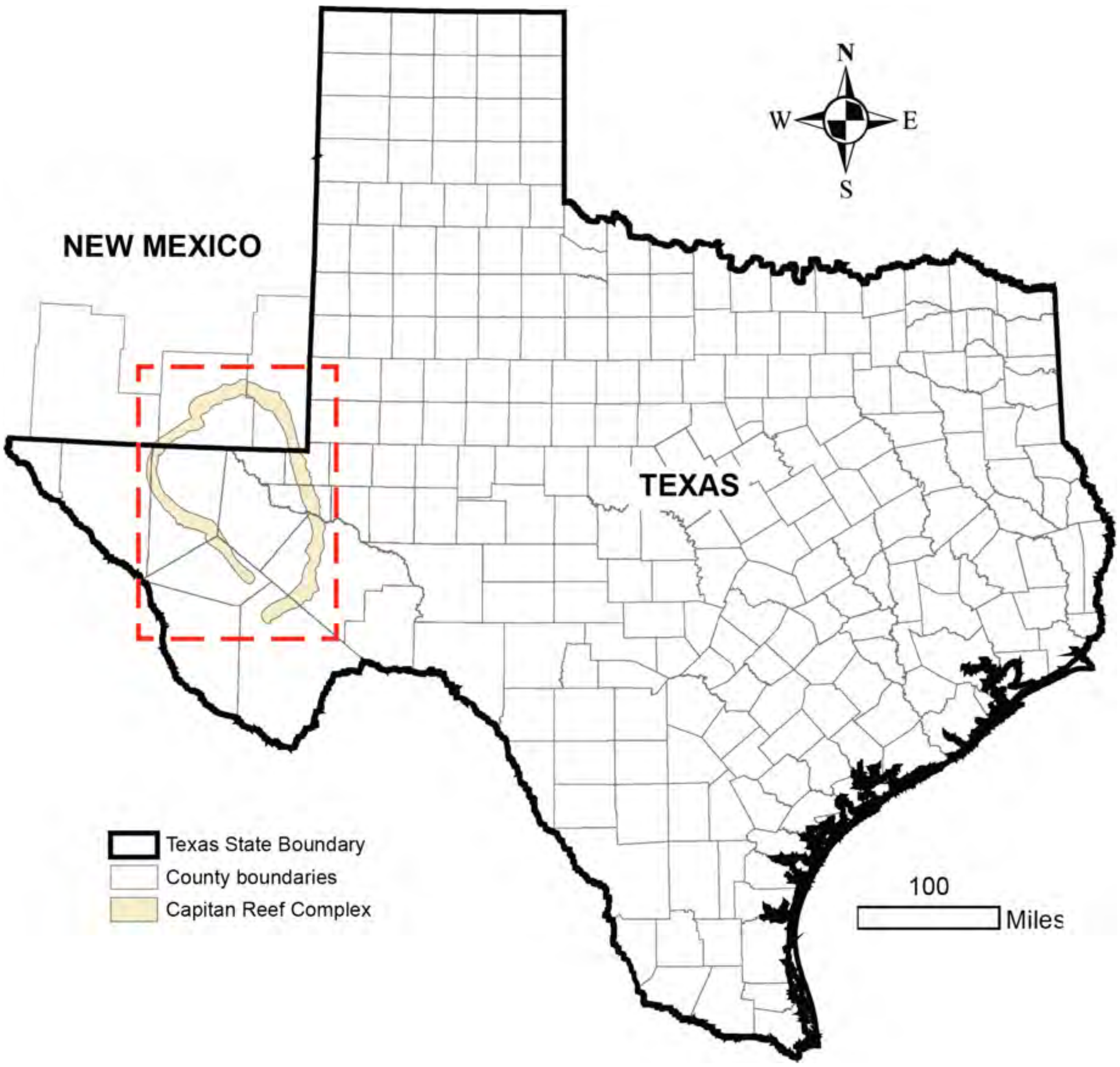


Figure 2.0.1. Study area for the Capitan Reef Complex Aquifer. Aquifer boundaries are based on work by Standen and others (2009).

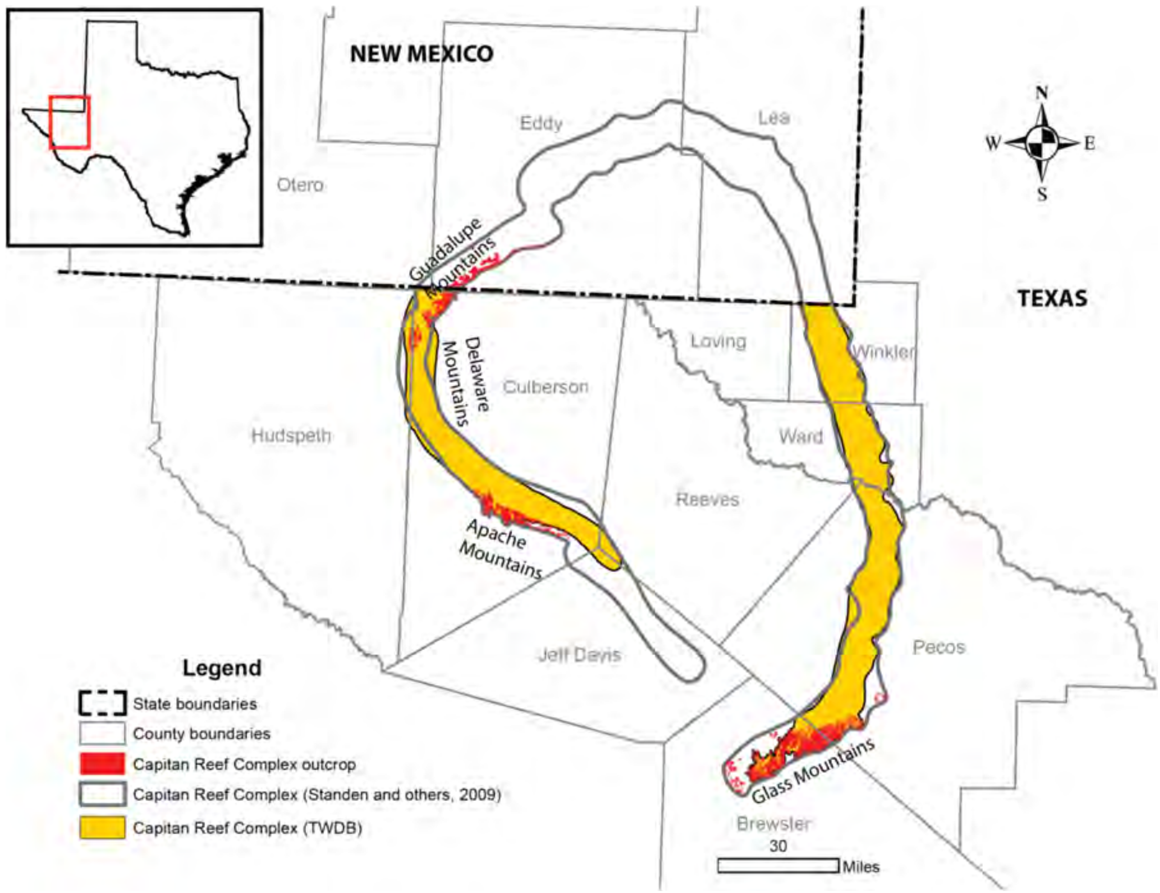


Figure 2.0.2. **The official (Texas Water Development Board) and alternative boundaries of the Capitan Reef Complex Aquifer based on work done by Standen and others (2009) including the location of key mountain ranges in the study area.**

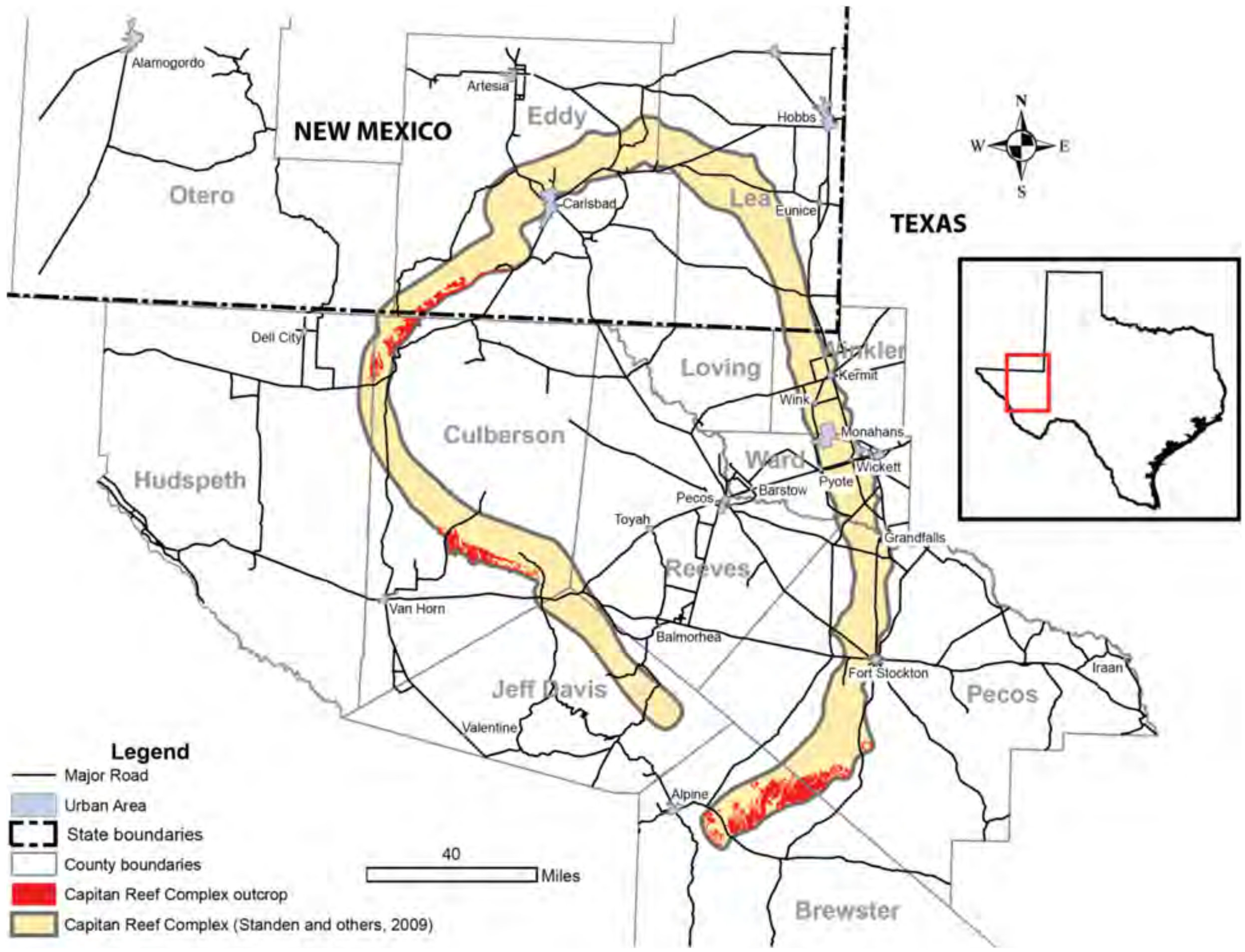


Figure 2.0.3. Cities and major roadways in the study area.

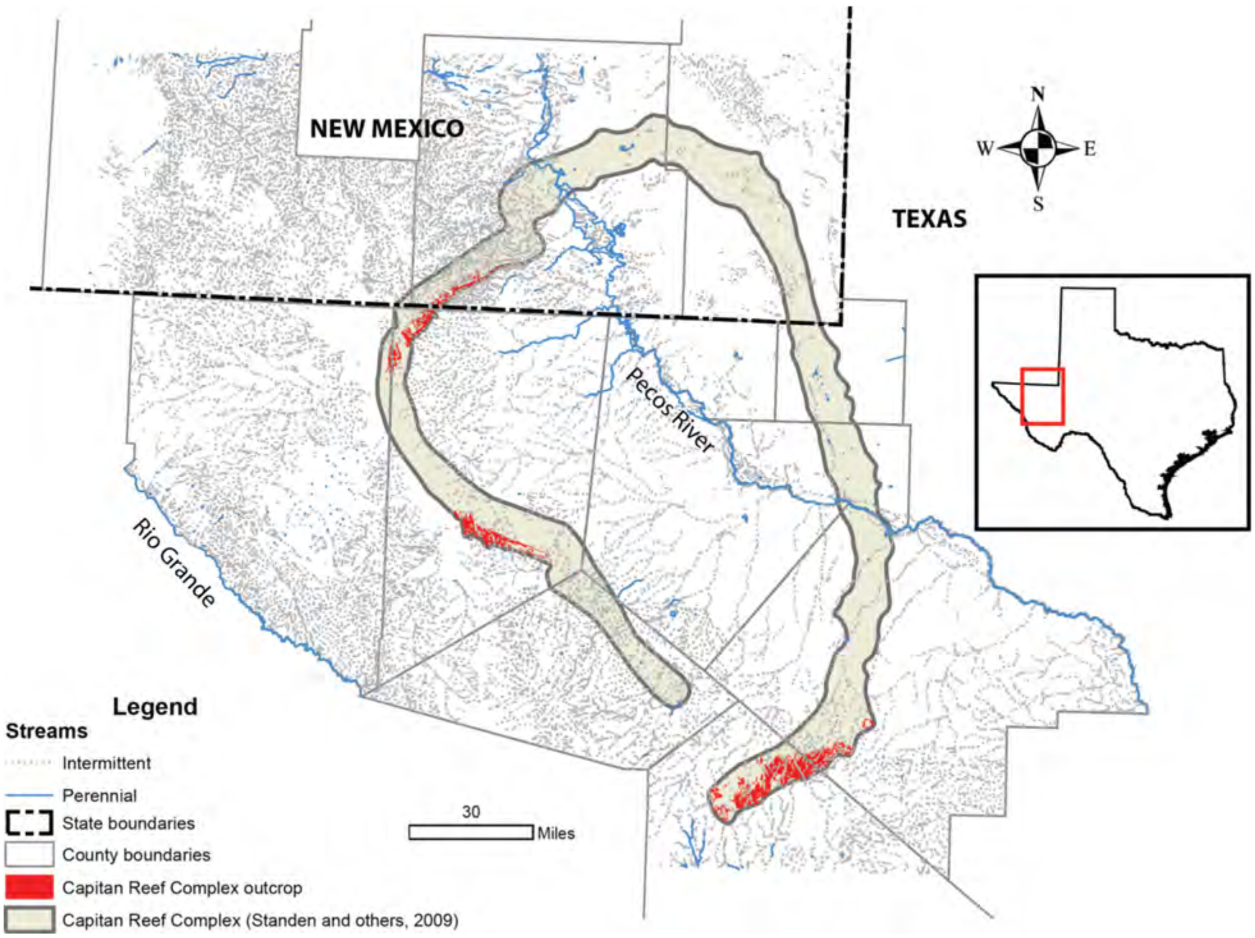


Figure 2.0.4. Rivers, streams, lakes, and reservoirs in the study area.

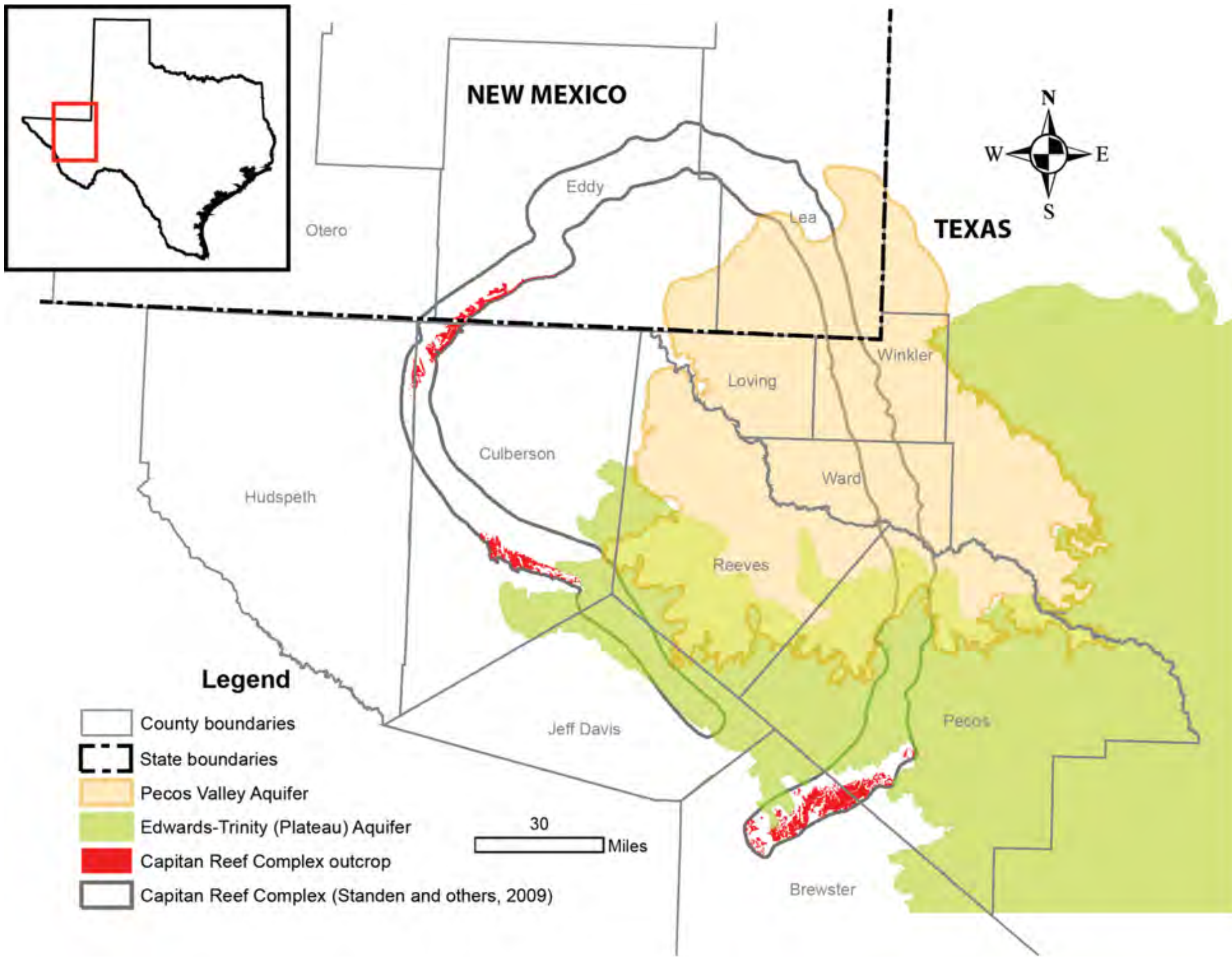


Figure 2.0.5. **Major aquifers in the study area.**

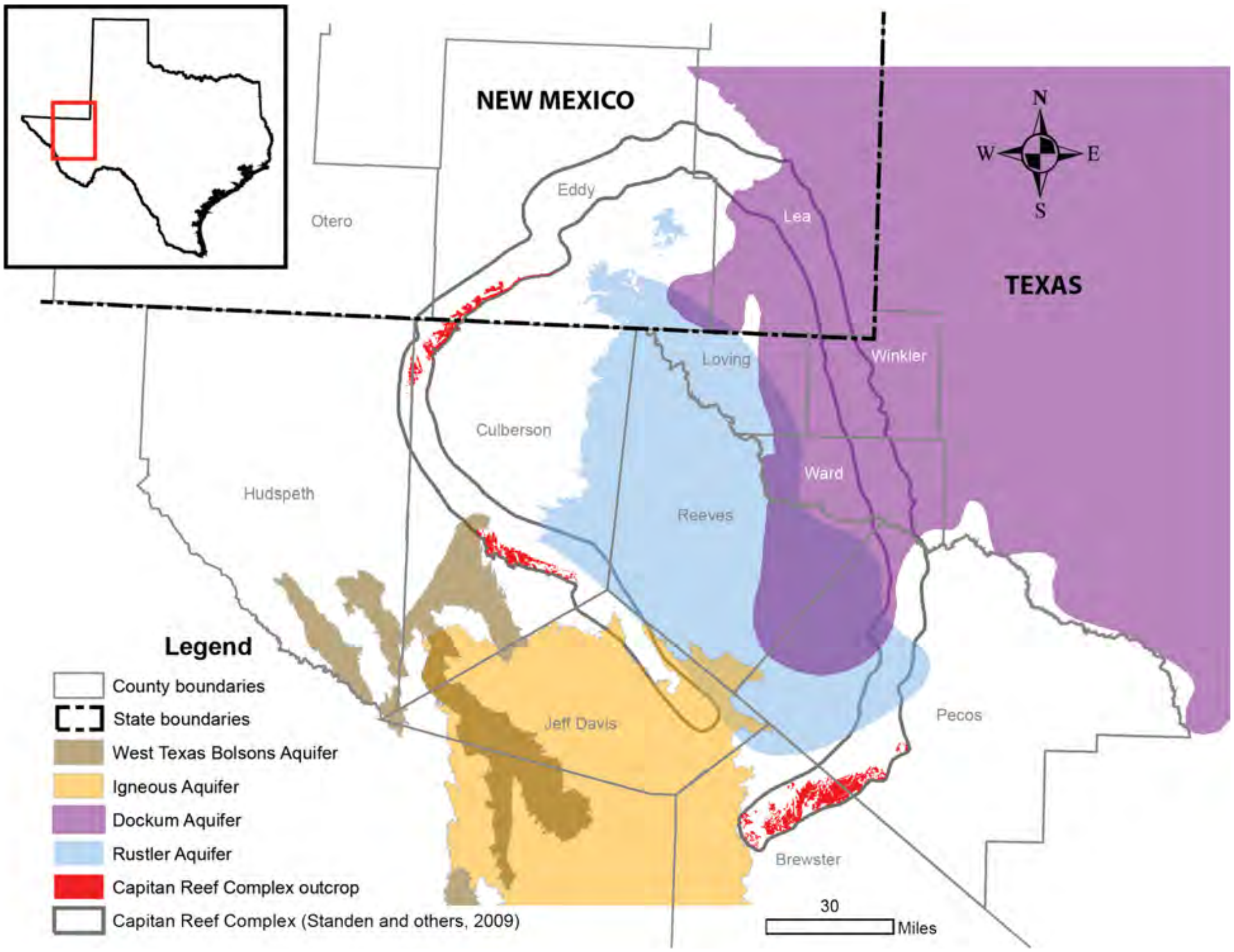


Figure 2.0.6. **Minor aquifers in the study area.**

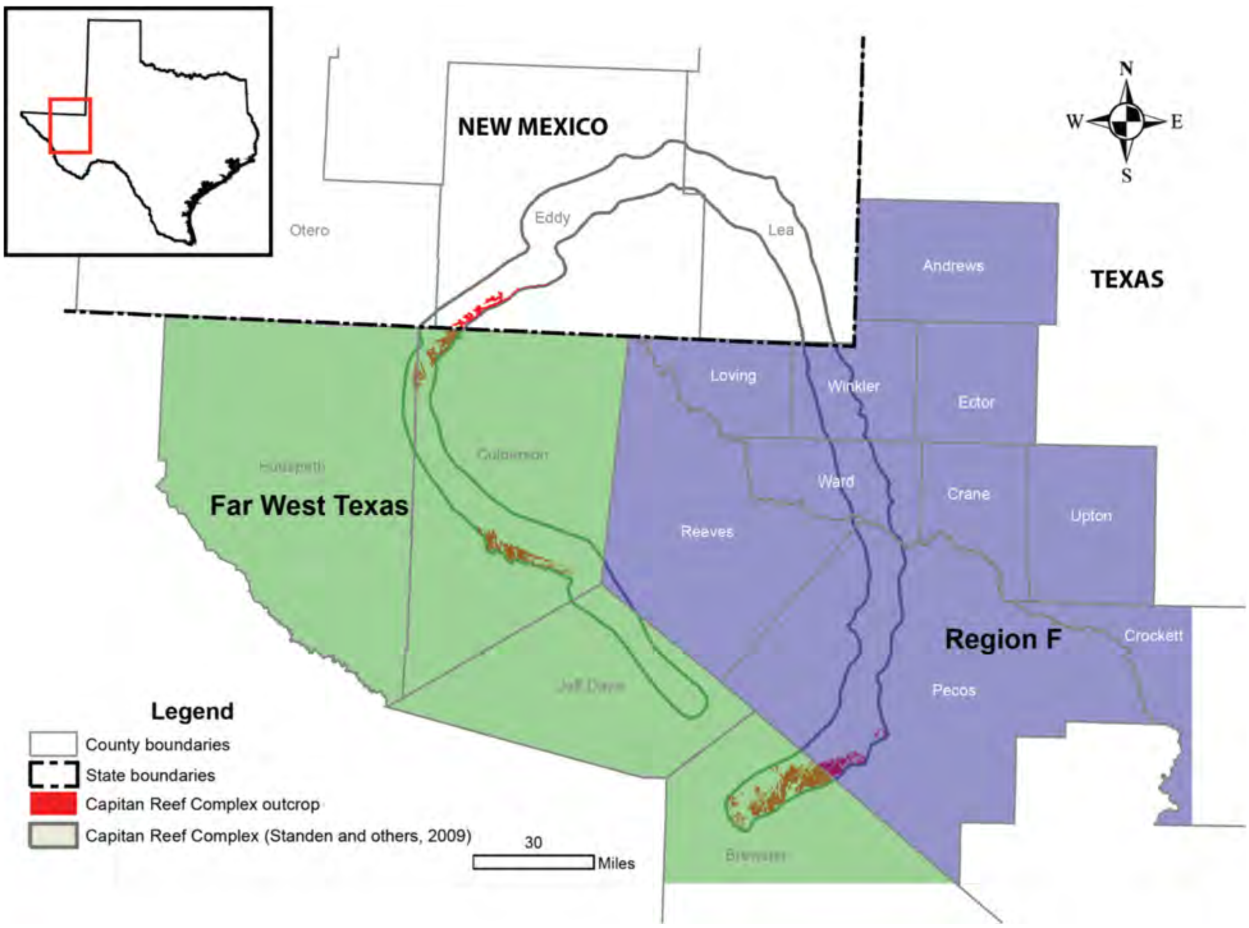


Figure 2.0.7. Texas regional water planning areas in the study area.

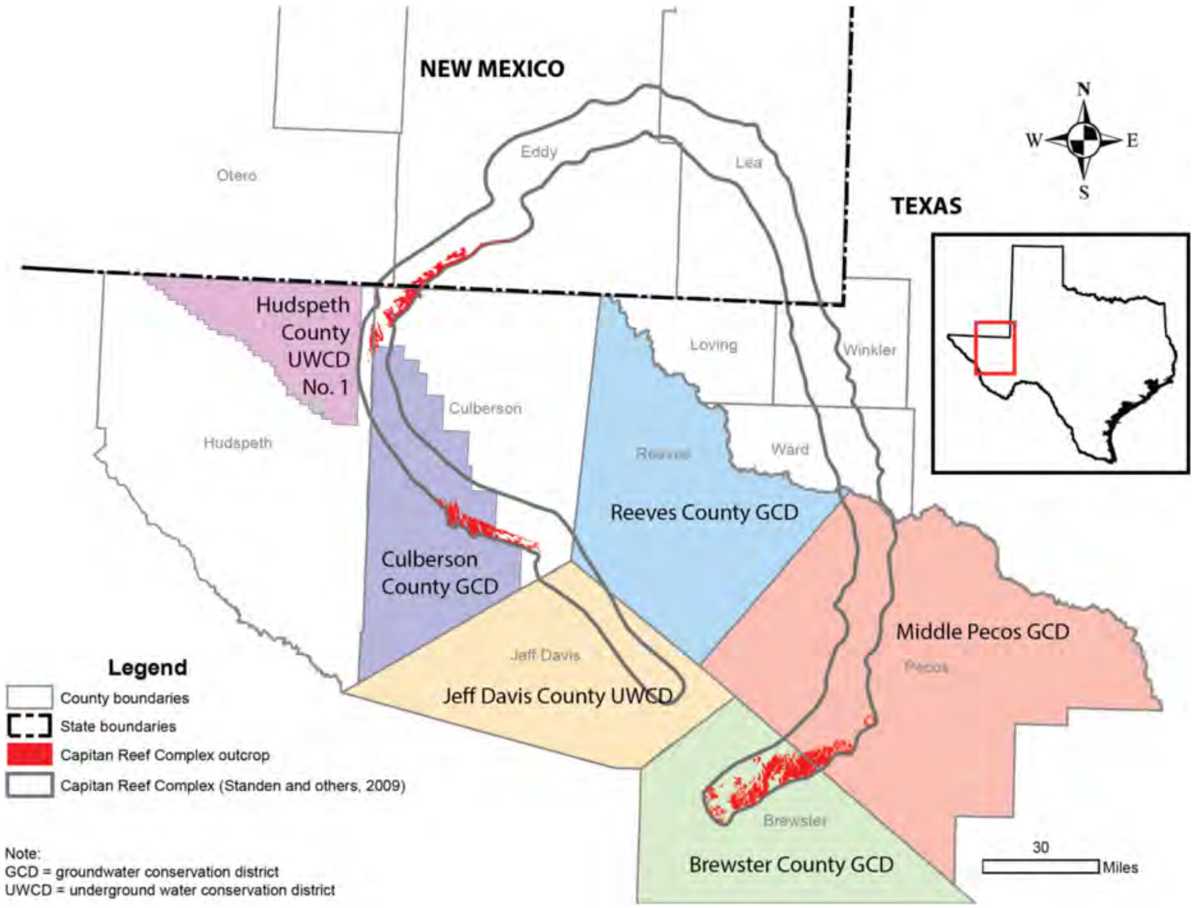


Figure 2.0.8. **Texas groundwater conservation districts in the study area as of February 2014.**

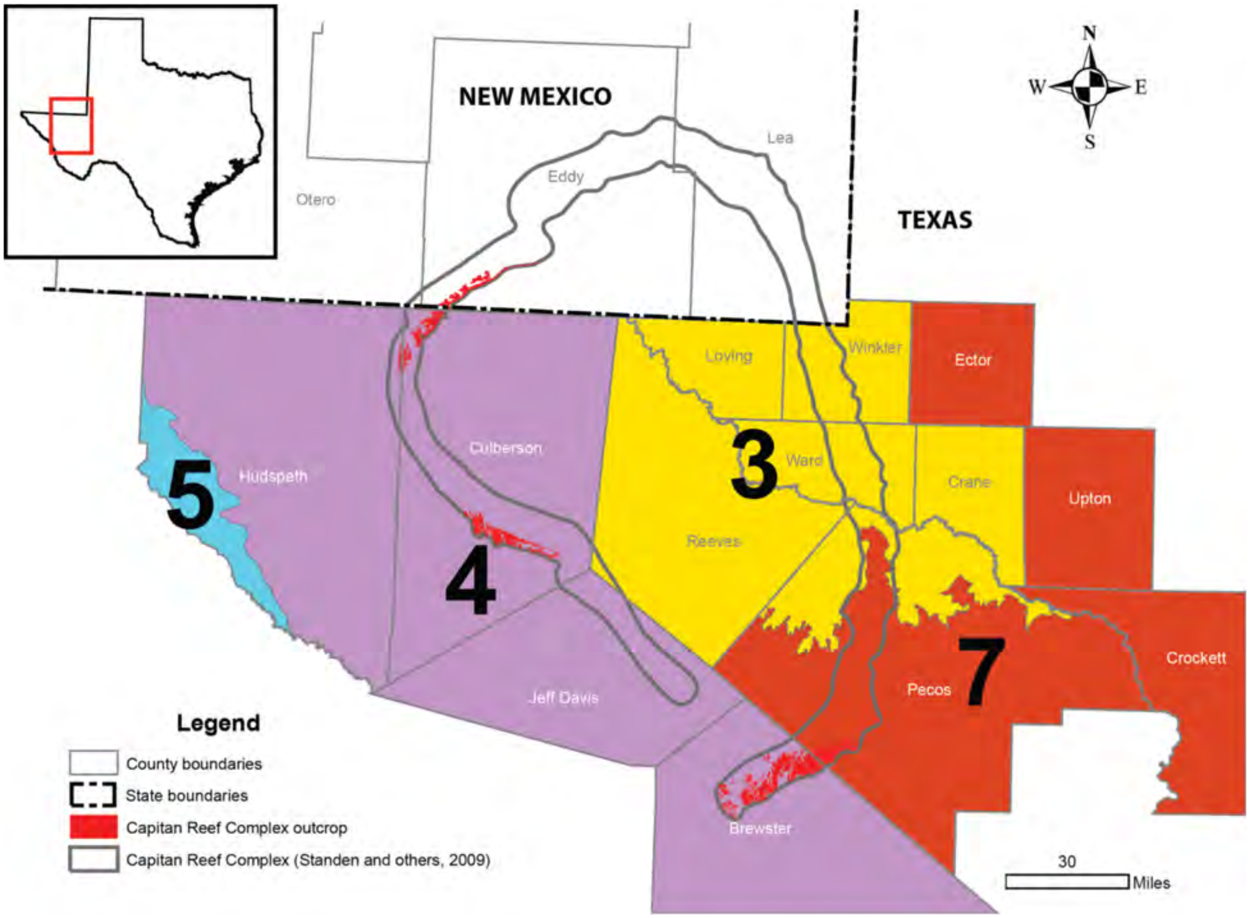


Figure 2.0.9. **Texas groundwater management areas in the study area.**

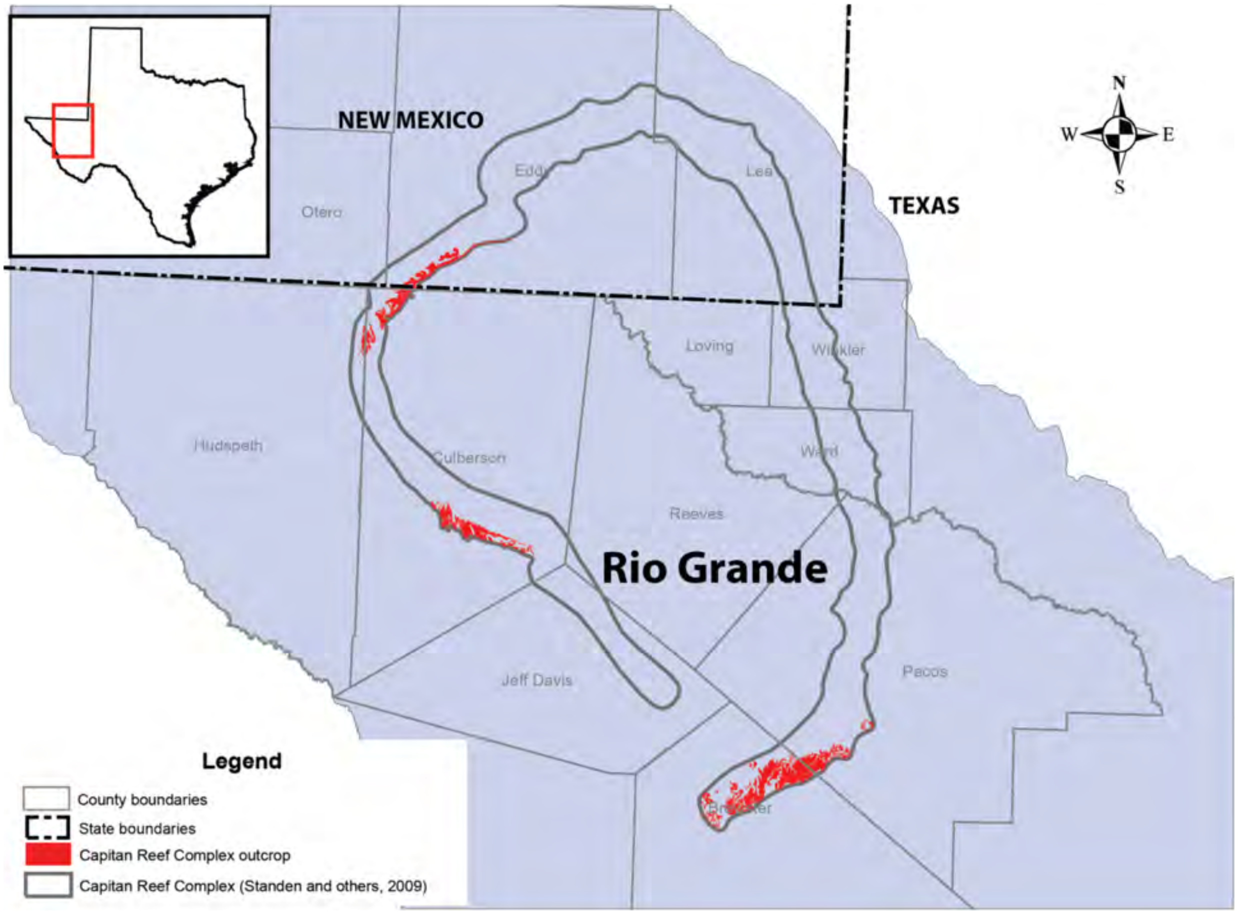


Figure 2.0.10. Major river basins in the study area.

2.1 Physiography and Climate

The study area includes parts of the Great Plains and Basin and Range physiographic provinces (Figure 2.1.1). In the study area, the Great Plains physiographic province consists of the Pecos Valley, Edwards Plateau, and High Plains sections, while the Basin and Range province consists of the Mexican Highland and Sacramento sections (United States Geological Survey, 2002). The Pecos Valley section is a long trough lying between the High Plains to the east and the Basin and Range to the west. Its topography varies from flat plains to rocky canyon lands. This section consists chiefly of the valley of the Pecos River. The Edwards Plateau also includes the Stockton Plateau located west of the Pecos River. The two parts of the Edwards Plateau are separated by the canyon of the Pecos River. The Stockton Plateau terminates against the mountains of the Mexican Highland section to the west. The High Plains are remnants of a former fluvial plain that stretched from the Rocky Mountain physiographic province located to the west—north of the study area. It is composed mostly of silt and sand with smaller quantities of gravel deposited by streams flowing eastward from the Rocky Mountains producing an extremely flat plain. The thickness of the unconsolidated material varies up to more than 500 feet (Leighty & Associates, Inc., 2001). Wermund (1996) describes the Basin and Range province in the study area as mountains peaks that rise abruptly from barren rock plains flanked by plateaus with nearly horizontal rocks less deformed than the adjacent mountains. The Mexican Highland is a section of the Basin and Range province that mostly occurs in Mexico but also extends along the Rio Grande. The Sacramento Section, located north of the Mexican Highland, is characterized by tilted plateaus (Leighty & Associates, Inc., 2001).

The Capitan Reef Complex Aquifer is located predominantly in the Chihuahuan Deserts Level III ecological region (Figure 2.1.2). However, parts of the aquifer also underlie the Arizona/New Mexico Mountains and High Plains ecological regions. The Chihuahuan Deserts region consists of desert grassland and desert scrub in the lowlands and low mountains and wooded vegetation in the higher mountains (United States Environmental Protection Agency, 2011a). A wide variety of plant and animal life can be found in this region. Texas Parks and Wildlife Department (2012) states that *"more rare and endemic species can be found in this region than in any other part of Texas."* The Capitan Reef Complex Aquifer crops out in the Guadalupe Mountains which is part of the Arizona/New Mexico Mountains region. The Arizona/New Mexico Mountains region has a variety of climates, depending on latitude and elevation, ranging from severe alpine climates to mid-latitude steppe and desert climates. In general, the region is marked by warm to hot summers and mild winters. Many intermittent streams and some perennial streams—both characterized by moderate to high gradients—occur in this ecological region (United States Environmental Protection Agency, 2011a). The High Plains region has a dry mid-latitude steppe climate. Historically, the High Plains region had mostly short and midgrass prairie vegetation. In the study area, the High Plains region has few to no streams. Surface water occurs in numerous playas that act as recharge areas for underlying aquifers (United States Environmental Protection Agency, 2011a).

Figure 2.1.3 provides a topographic map of the study area (Gesch and others, 2002). Land-surface elevation is greatest along an axis formed by a northwest-southeast oriented line of mountains—the Guadalupe, Delaware, Apache, Davis, Barilla, and Glass mountains—and generally decreases to the east and west to the Pecos River Valley and Salt Basin, respectively. Land-surface elevation in the footprint of the Capitan Reef Complex Aquifer varies from over 8,000 feet above mean sea level in the Guadalupe Mountains in Culberson and Eddy counties to about 2,000 feet above mean sea level at the Pecos River along the border of Ward and Pecos counties.

The climate in the study area, shown in Figure 2.1.4, is classified as subtropical arid over most of the Capitan Reef Complex Aquifer, continental steppe to the northeast, and mountain in the Guadalupe Mountains of Culberson County and the Davis Mountains in Jeff Davis County (Larkin and Bomar, 1983). The subtropical arid climate is the result of decreasing moisture content of air flowing inland from the Gulf of Mexico (Larkin and Bomar, 1983). This climate region is characterized by anomalous summertime rainfall associated with mountains. The continental steppe climate is the typical climate of the High Plains. It is a semi-arid climate characterized by large variations in daily temperatures, low relative humidity, and irregularly spaced moderate rainfall (Larkin and Bomar, 1983). The mountain climate is characterized by cooler temperatures, lower relative humidity, and mountainous precipitation anomalies typical of areas with orographic precipitation controls. This climate is associated with the highest mountain ranges in the region—the Davis and Guadalupe mountains—which include the highest mountain peaks in Texas (Larkin and Bomar, 1983). The average annual maximum air temperature in the study area ranges from a high of about 58 degrees Fahrenheit in the Pecos River Valley to a low of about 46 degrees Fahrenheit in the Guadalupe Mountains (Figure 2.1.5).

Figure 2.1.6 shows average annual precipitation for the period 1971 through 2000 (Oregon State University, 2006a). The highest annual precipitation of about 28 inches per year occurs in the Guadalupe Mountains in Culberson County and the lowest annual precipitation of less than 10 inches per year occurs in an adjacent part of the Salt Basin along the Culberson-Hudspeth county boundary.

Precipitation data are available at 23 Texas and 18 New Mexico stations within the study area (Figure 2.1.7). In general, measurements are not continuous on a month-by-month or year-by-year basis for the gages. Annual precipitation recorded at eight stations in the study area is shown in Figure 2.1.8. Figure 2.1.8 indicates wide interannual variation of precipitation, ranging from lows of about 5 inches to more than 25 inches per year. Figure 2.1.9 shows long-term average monthly variation in precipitation at eight gages in the study area. In the study area, monthly precipitation is generally highest during summer and early fall months—May through October.

The average annual net pan evaporation rate in the study area ranges from a high of 72 inches per year to a low of 55 inches per year and averages about 64 inches per year (Figure 2.1.10; Texas Water Development Board, 2012a). Average annual net pan evaporation is generally lowest in the southern part of the study area, increasing to the north and east. Pan evaporation rates significantly exceed the annual average precipitation. Monthly variations in lake surface evaporation are shown for seven locations in the study area (Figure 2.1.11; Texas Water Development Board, 2012a). These values represent the average of the monthly lake surface evaporation data from January 1954 through December 2011. Figure 2.1.11 shows that average lake evaporation peaks in June or July.

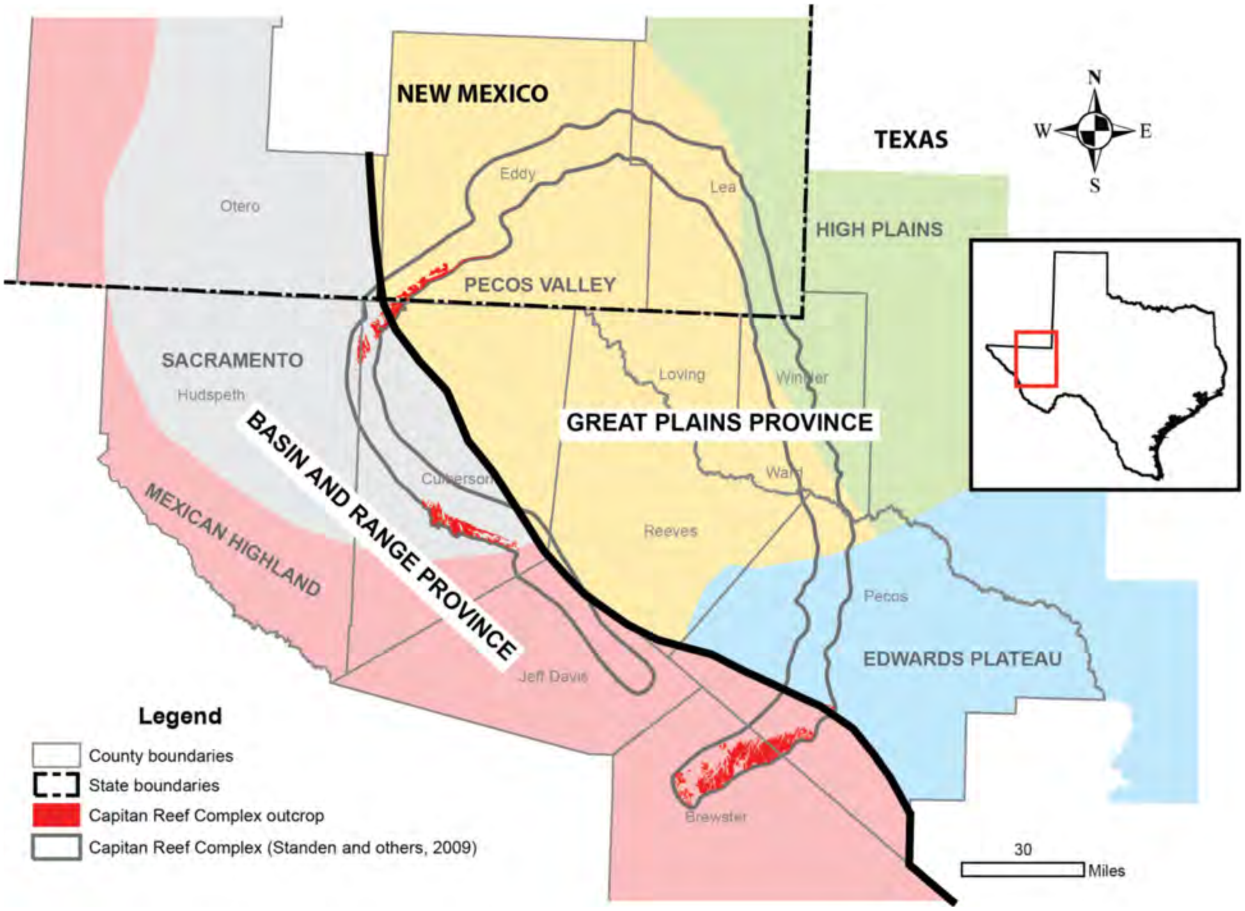


Figure 2.1.1. Physiographic provinces in the study area (United States Geological Survey, 2002).

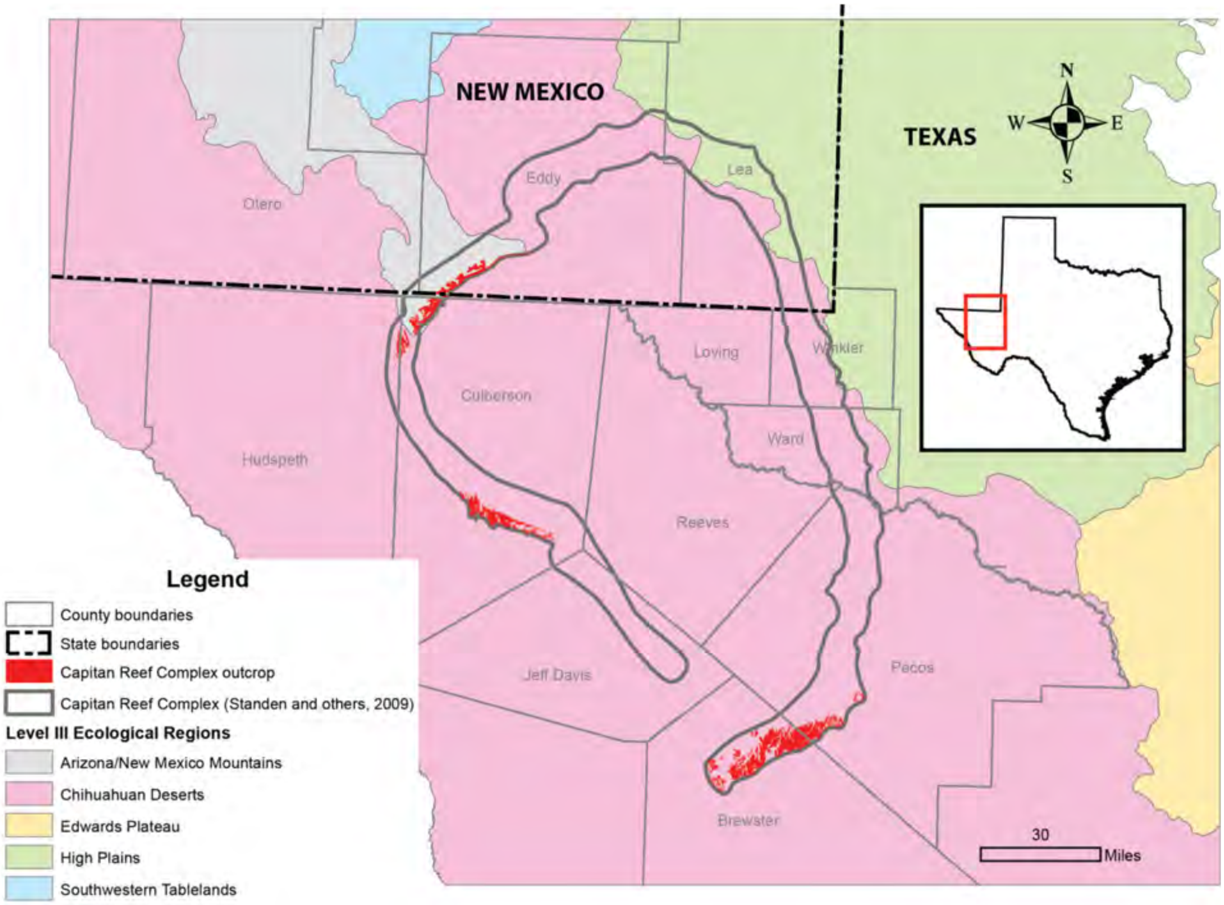


Figure 2.1.2. **Level III ecological regions in the study area (United States Environmental Protection Agency, 2011b).**

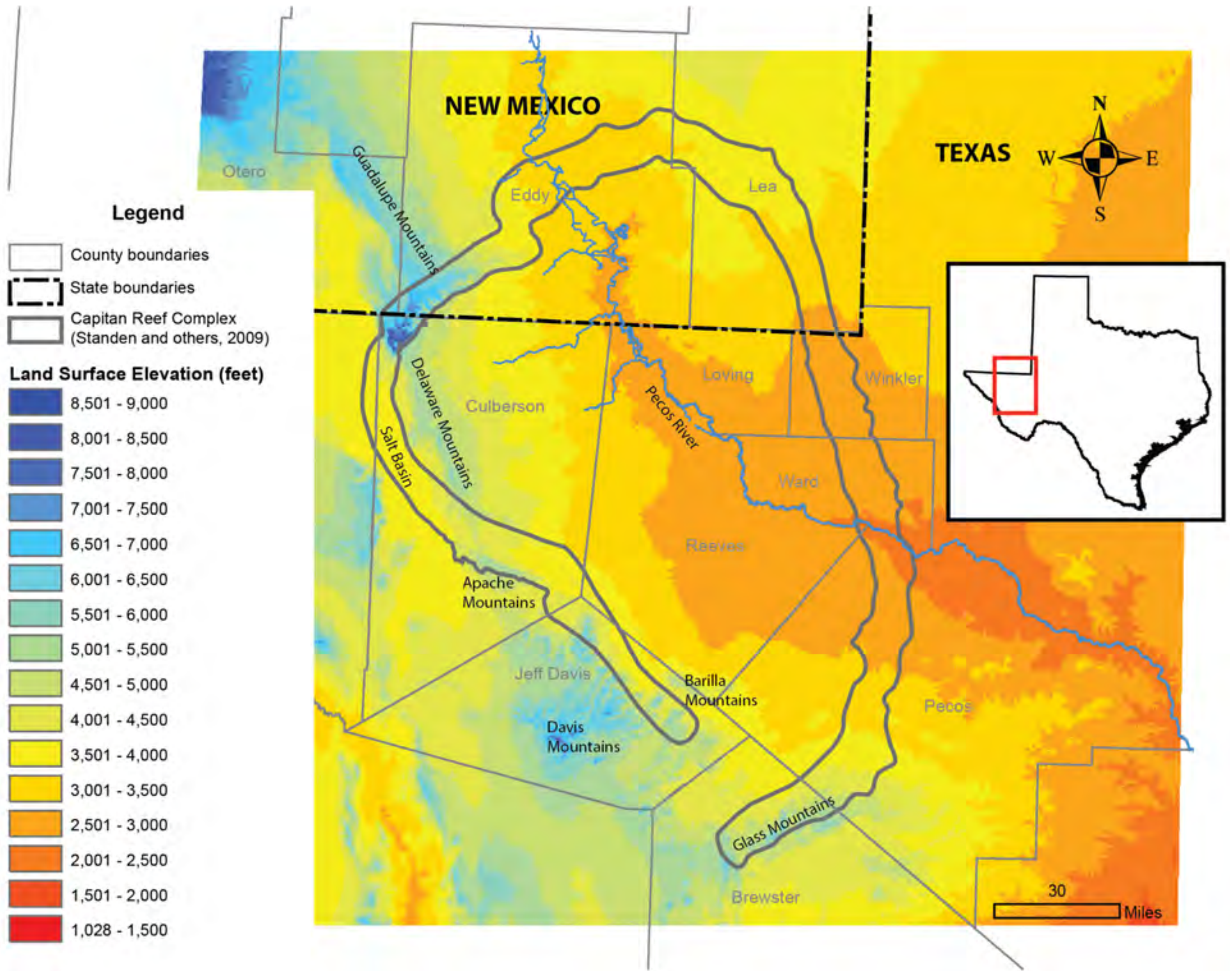


Figure 2.1.3. **Topographic map of the study area showing land surface elevation in feet above mean sea level. Based on data from Gesch and others (2002).**

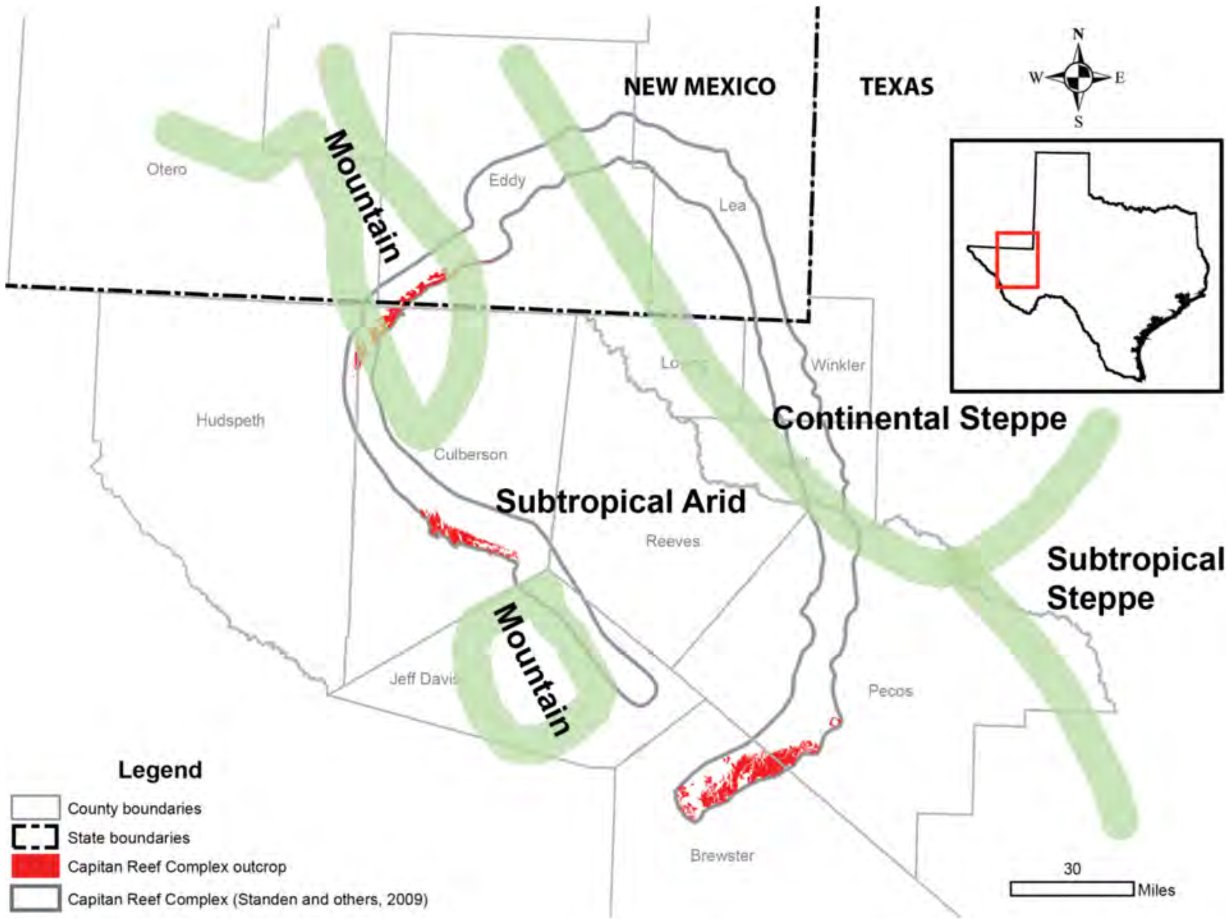


Figure 2.1.4. Climate classifications in the study area (modified from Larkin and Bomar, 1983).

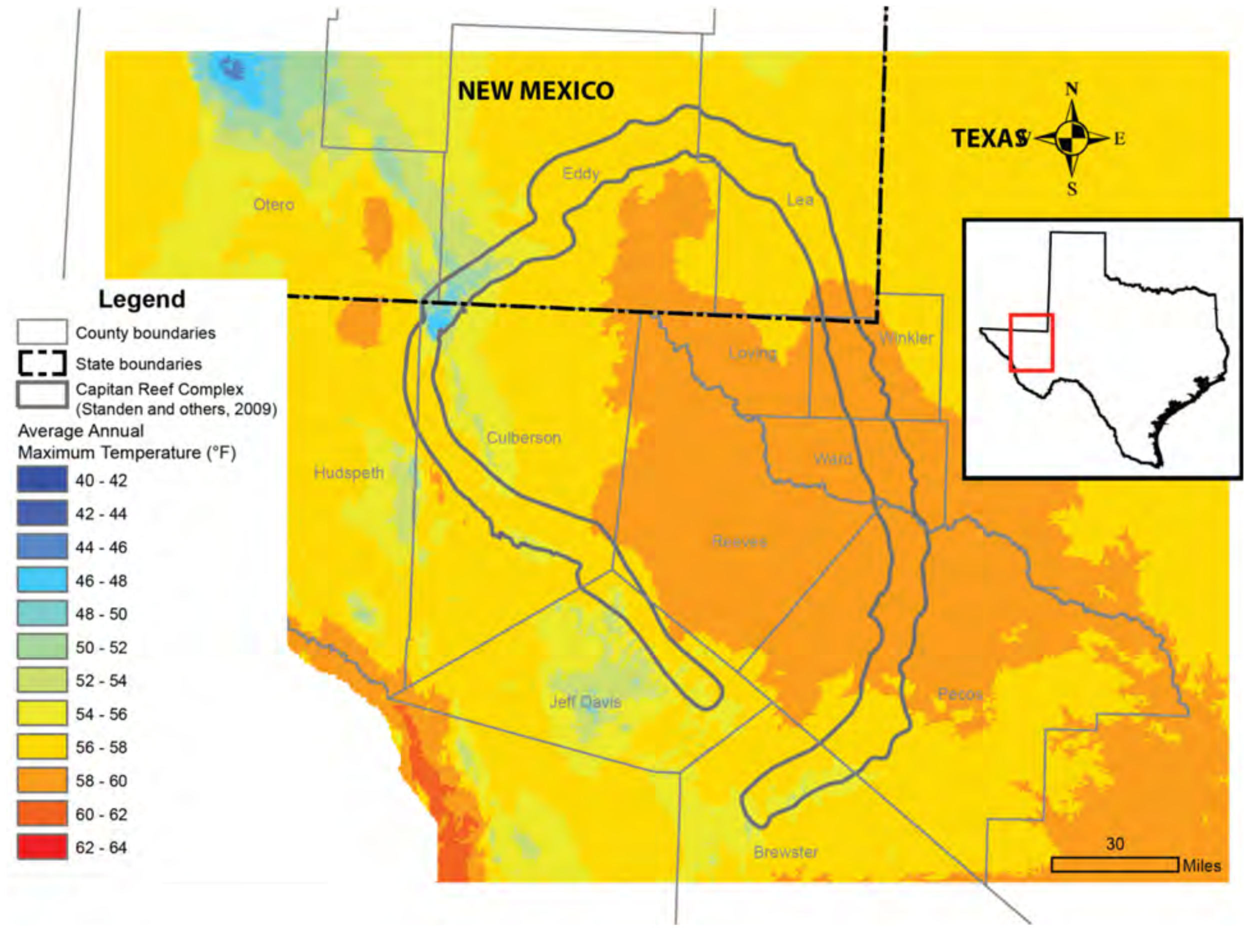


Figure 2.1.5. **Average annual air temperature in degrees Fahrenheit in the study area. Based on 1971 to 2000 PRISM data (Oregon State University, 2006b).**

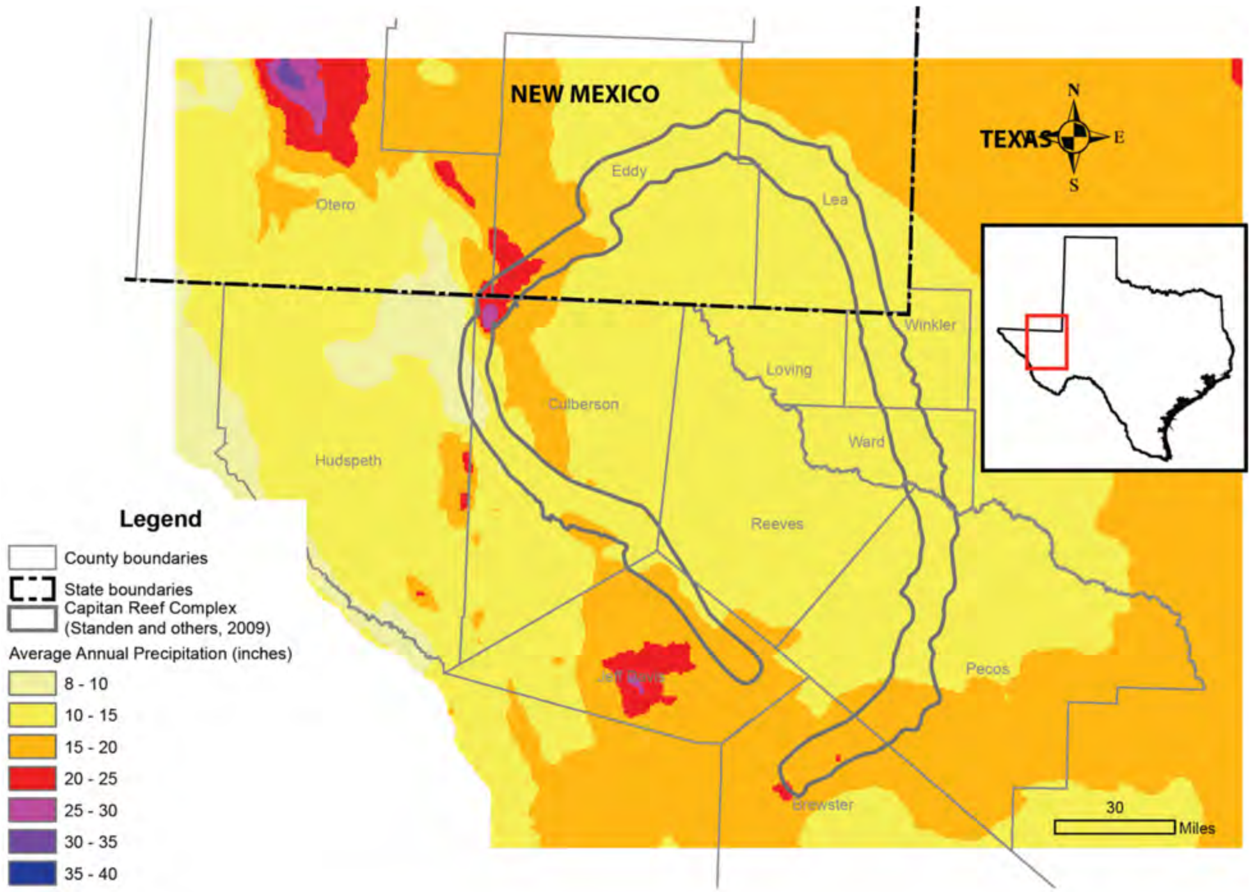


Figure 2.1.6. Average annual precipitation in inches per year in the study area for the time period 1971 through 2000 (Oregon State University, 2006a).

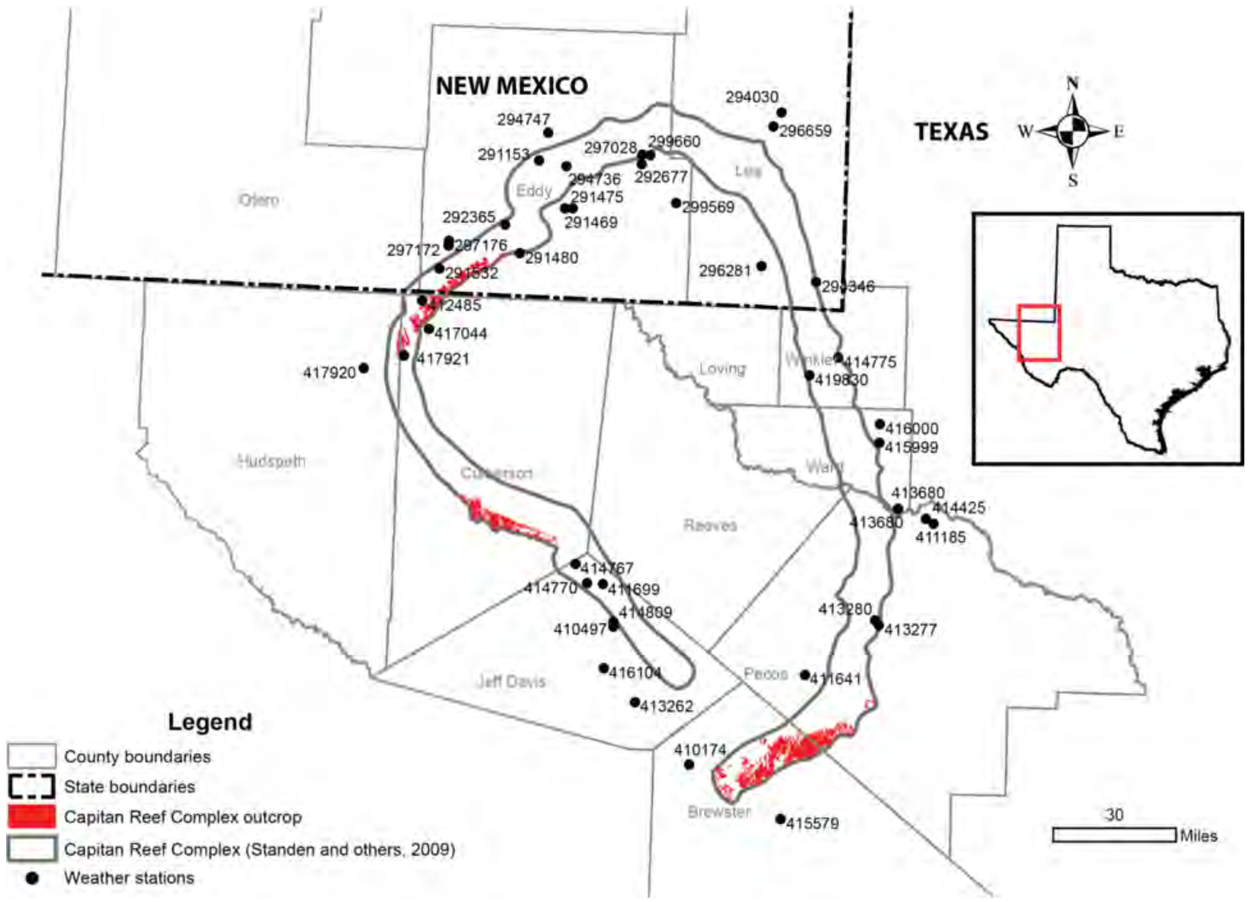


Figure 2.1.7. Location of precipitation gages in the study area (National Climatic Data Center, 2011).

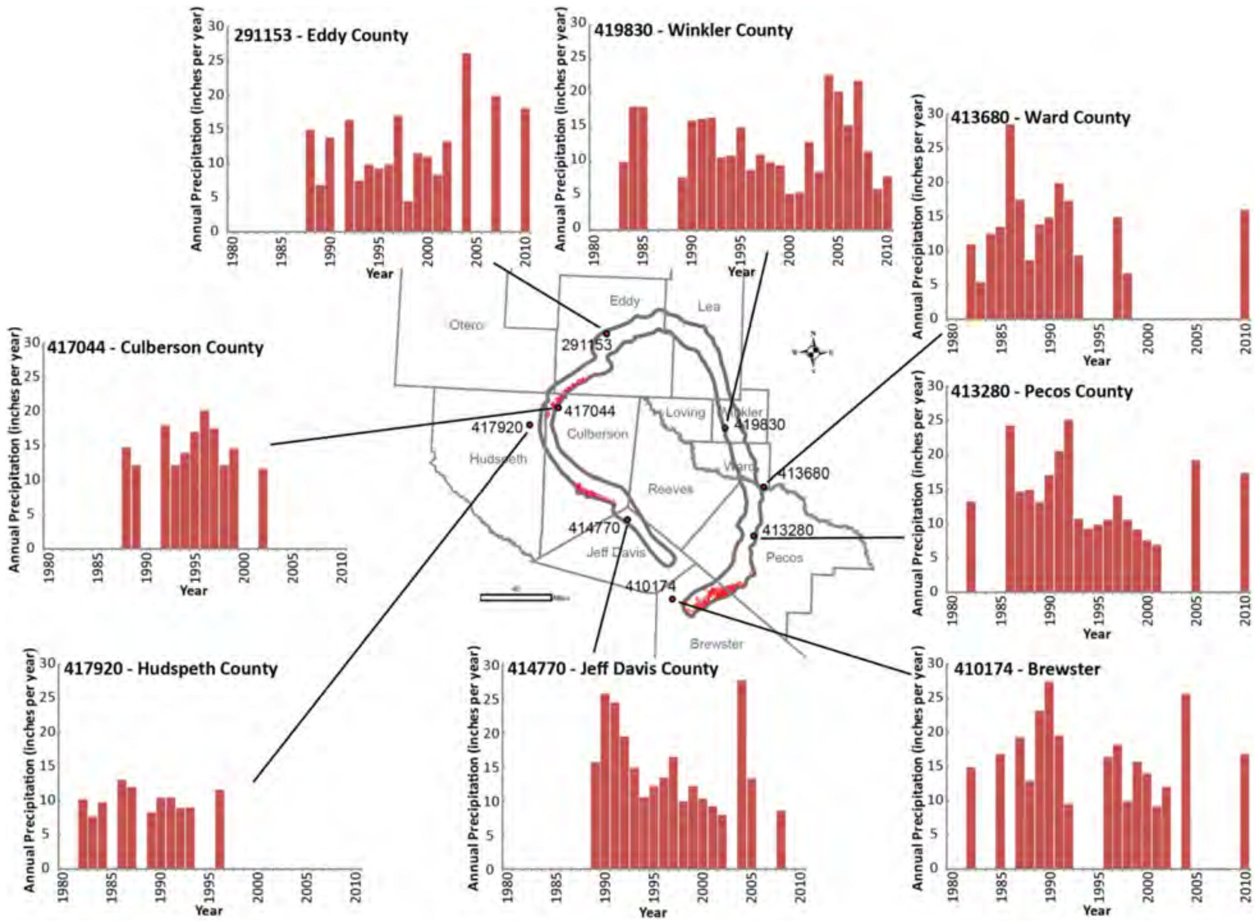


Figure 2.1.8. **Selected time series of annual precipitation in inches per year in the study area (National Climatic Data Center, 2011). Zero values indicate missing data.**

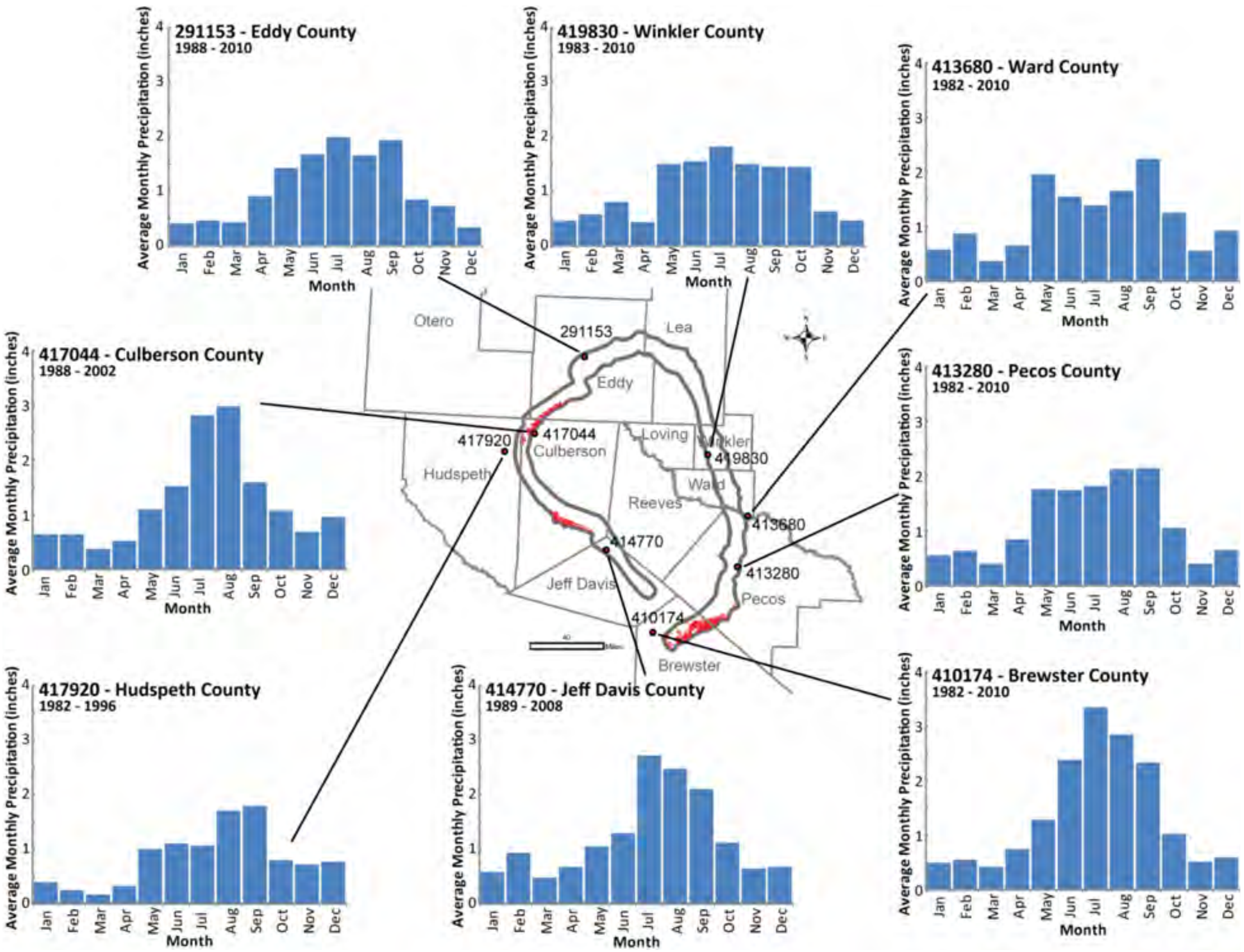


Figure 2.1.9. **Selected time series of average monthly precipitation in inches per month in the study area (National Climatic Data Center, 2011).**

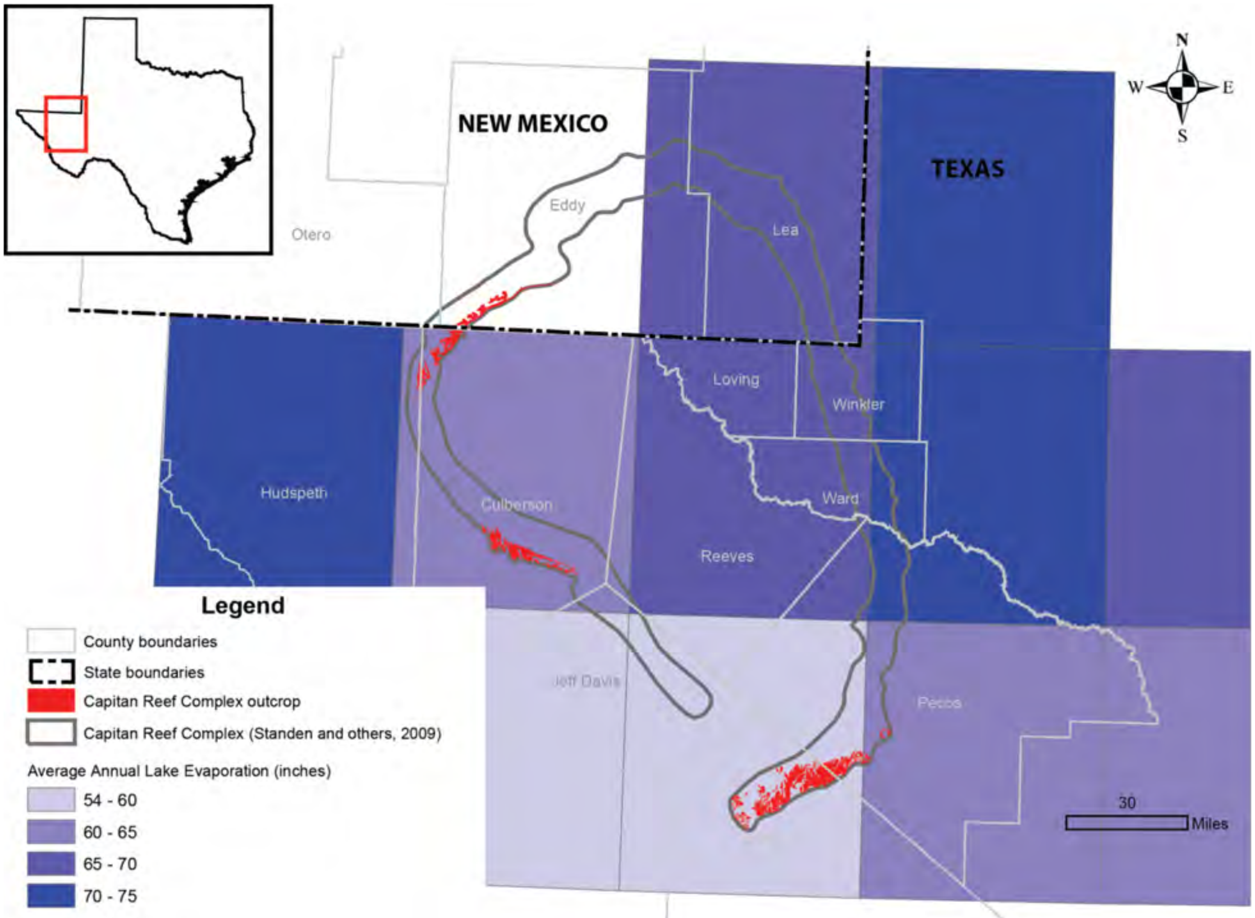


Figure 2.1.10. Average annual net pan evaporation rate in inches per year over the Texas portion of the study area (Texas Water Development Board, 2012a).

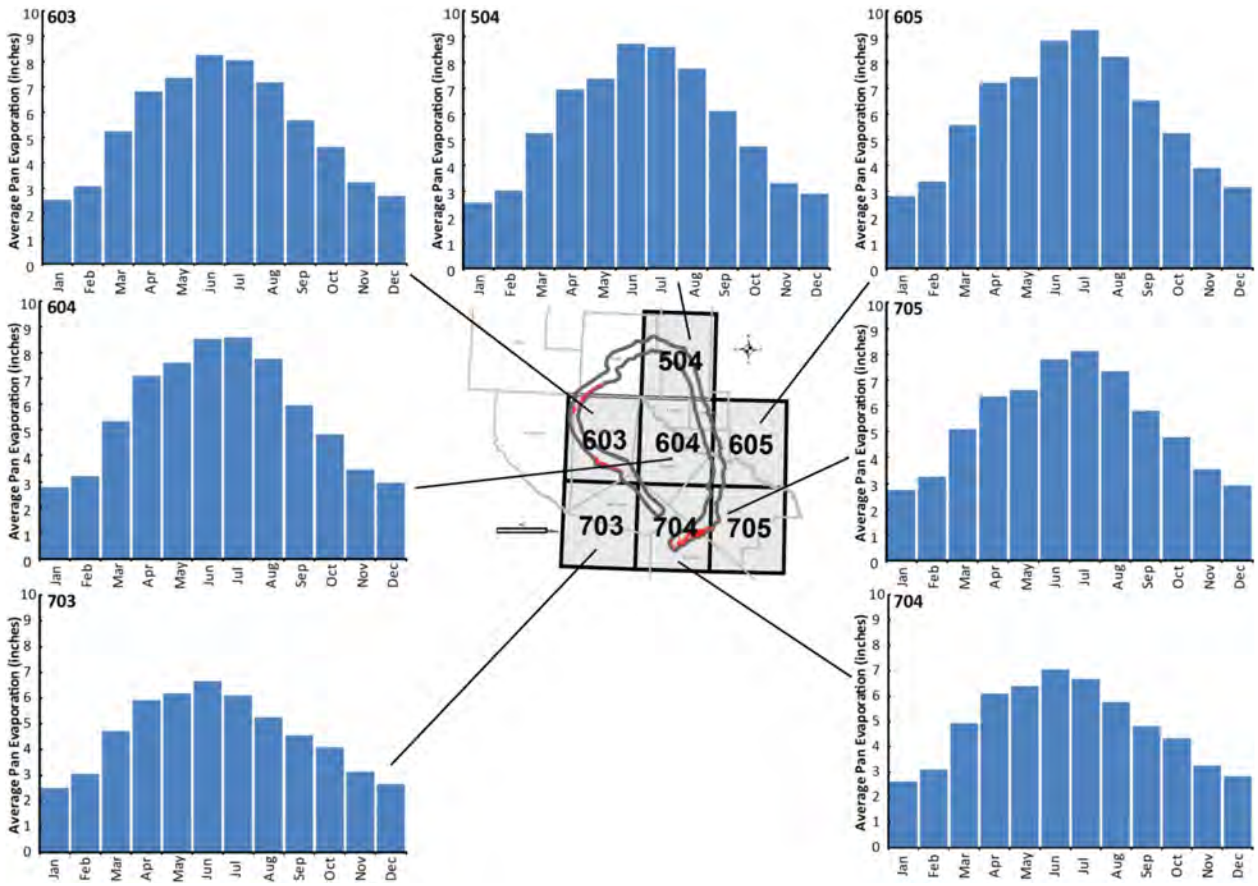


Figure 2.1.11. Average monthly lake surface evaporation in inches in selected map quadrangles in the study area (Texas Water Development Board, 2012a).

2.2 Geology

This section provides a brief discussion of the geology of the study area. The discussion is divided into the structural setting, surface geology, and stratigraphy of the Capitan Reef Complex, including a description of geologic structural cross-sections through the study area.

2.2.1 Structural Setting

The structural setting for the study area is shown in Figure 2.2.1 (after Armstrong and McMillion, 1961). The primary structural features within the study area include the Delaware Basin, Central Basin Platform, Diablo Platform, Northwestern Shelf, Hovey Channel, and Sheffield Channel. The Capitan Reef Complex occurs along the margins of the Delaware Basin. This basin is surrounded by structural highs—the Northwest Shelf to the north, the Central Basin Platform to the east, the Diablo Platform to the west, and the Southern Shelf and Marathon Folded Belt to the south. The Delaware Basin is also connected to adjacent basins by the Hovey and Sheffield channels that connect the Delaware Basin to the Marfa and Midland basins, respectively.

The Delaware Basin—around which the Capitan Reef Complex formed—was a foreland basin formed when the Ouachita Mountains—located south and east of the study area—were uplifted as the southern supercontinent Gondwana collided with the supercontinent Laurasia during the Pennsylvanian period. This basin formed by subsidence that took place through the early and middle Permian—Leonardian and Guadalupian epochs. Rapid subsidence of the basin started in the middle Guadalupian Epoch of the upper Permian. Patch reefs responded by rapid—mostly vertical—growth, resulting in the deposition of the Goat Seep Dolomite reefs (Harris and others, 1997). The Capitan Reef Complex was built primarily from calcareous sponges and encrusting algae such as stromatolites and directly from seawater as a limey mud (Harris and others, 1997).

Sea level dropped as sedimentation continued to infill the Delaware Basin into the Ochoan epoch of the upper Permian, periodically cutting the basin off from its source of seawater. Part of the resulting brine became the deep-water evaporites of the overlying Castile and Salado formations (Harris and others, 1997). The Rustler Formation evaporites and dolomites represent the uppermost occurrence of evaporites in the Delaware Basin as the basin was finally in-filled and buried beneath non-marine sediments (Holt and Powers, 1990a, 1990b, 2011).

The Delaware Basin was filled at least to the top of Capitan Reef Complex and was mostly covered by dry land before the end of the Ochoan epoch. Rivers migrated over its surface and deposited the red silt and sand that now constitute the siltstone and sandstone of the Dewey Lake Formation and Dockum Group (McGowen and others, 1979; Harris and others, 1997). A karst topography developed as groundwater circulated in the buried Capitan Reef Complex limestone formations, dissolving away the rock to form voids and underground caverns, which were later destroyed by infill and erosion (Harris and others, 1997). Uplift associated with the Laramide Orogeny in the late Mesozoic and early Cenozoic resulted in the formation of the Guadalupe Mountains associated with a major fault zone—the Border Fault Zone (Figure 2.2.2). The mountain range forms the tilted upthrown side of the fault zone and the Salt Flat Bolson formed in the downthrown block (Figure 2.2.2). The Capitan Reef Complex was exposed above the surface, with the 8,000-foot-high El Capitan its most prominent feature. Other large outcrops that also formed were located in the Apache Mountains and Glass Mountains to the south (Harris and others, 1997). The Guadalupe Mountains high coincides with the upthrown—eastern—side of the Border Fault Zone. The Apache Mountains—another structural high in the Capitan Reef Complex—coincides with the upthrown side of the Stocks Fault. The relatively low area between the Border Fault Zone and the Stock Fault is a graben that forms part of the Salt Basin.

During the Late Cretaceous and Early Tertiary periods, the study area was uplifted and tilted slightly to the east. Subsequently, Late Tertiary Basin and Range block faulting formed the Guadalupe, Delaware, Apache, and Glass mountains and Patterson Hills. Major displacements of the Capitan Reef Complex by faulting are limited to the mountainous areas along the western and southern margins of the Delaware Basin (Figure 2.2.2). In addition to faults, the Capitan Reef Complex Aquifer has fissures parallel and perpendicular to the reef face.

Faults, fractures, and fissures play a very important role in local and regional groundwater flow patterns within the Capitan Reef Complex Aquifer. Tectonic events that occurred during the past three hundred million years—Ouachita orogeny, Laramide orogeny, and Basin and Range extension—have resulted in fracture patterns that control groundwater flow paths in the Capitan Reef Complex Aquifer (Uliana, 2000). Subsequent karstification of these fractures within the Capitan Reef Complex and overlying Cretaceous carbonates has produced highly permeable pathways for groundwater flow. Most of this karstification is associated with the Guadalupe Mountains, however, karstification also occurs in the Apache and Glass mountains and in the eastern and northern parts of the Capitan Reef Complex (Hill, 1999a). This karstification is influenced by the arrangement of stratigraphic units, degree of dolomitization, fracture patterns, and the occurrence of anticlines. Areas with large fault offsets may result in the stratigraphic alignment of more permeable Capitan Reef Complex carbonates with adjacent less permeable subsurface formations, such as the Delaware Mountain Group or Artesia Group. This juxtaposition of subsurface formations may significantly impact local and regional groundwater flow systems. Even in the absence of faulting, the Capitan Reef Complex Aquifer is surrounded both vertically and laterally by less permeable fore-reef and back-reef stratigraphic units that have the potential to restrict groundwater flow into and out of the Capitan Reef Complex Aquifer (White, 1987; Standen and others, 2009).

2.2.2 Surface Geology

Figure 2.2.3 is a geologic map of the study area. Over the majority of the study area, the predominant surficial deposits are Quaternary-age alluvial and eolian sediments. Permian and Cretaceous outcrops occur in the northwestern and southeastern parts of the study area, mostly associated with mountains, such as the Guadalupe, Delaware, Apache, and Glass mountains. The major outcrops of the Capitan Reef Complex occur in the Guadalupe, Apache, and Glass mountains.

2.2.3 Delaware Basin Stratigraphy

The Capitan Reef Complex forms a horseshoe-shaped feature along the margins of the Permian Delaware Basin and consists of massive fossiliferous white limestone (Figure 2.2.1). The Capitan Reef Complex combines the Goat Seep Dolomite, Capitan Limestone, and Carlsbad Limestone (Hiss, 1975) and grades into adjacent fore-reef and back-reef facies (Figure 2.2.4). The Capitan Reef Complex geologic model of fore-reef, reef, and back-reef facies was described in detail by King (1948) and by Melim and Scholle (1999).

The back-reef or shelf facies occur behind the reef complex. These facies are characterized by quartz sandstone and siltstone with carbonate and evaporite facies, and consist of the Artesia Group—the Grayburg, Queen, Seven Rivers, Yates, and Tansill formations (Figure 2.2.5). The Grayburg, Queen, and Yates formations contain more sandstone beds than the Seven Rivers and Tansill formations (Motts, 1968). Carbonate facies occurs adjacent to the Capitan Reef Complex while the evaporite facies occurs farther away. The boundary between the evaporite and carbonate facies shifts closer to the shelf margin in the younger formations of the Artesia Group from 15 to 20 miles from the shelf margin in the Queen Formation to about 5 to 10 miles in the Tansill Formation.

The fore-reef or basin facies consist of the Castile Formation and the Delaware Mountain Group. The Delaware Mountain Group is 2,700 to 3,500 feet thick and consists of the Brushy Canyon, Cherry Canyon, and Bell Canyon formations (Motts, 1968). The formations of the Delaware Mountain Group are predominantly sandstone with carbonate beds occurring in the Cherry Canyon and Bell Canyon formations. The Castile Formation consists of evaporites and thin beds of limestone, shale, and sandstone.

2.2.4 Capitan Reef Complex

The Capitan Reef Complex is exposed in outcrops in the Guadalupe Mountains (Eddy County, New Mexico and Culberson County, Texas), Patterson Hills (Culberson and Hudspeth counties, Texas), Apache Mountains (Culberson County, Texas), and Glass Mountains (Brewster and Pecos counties, Texas) (Figure 2.2.3). Geologic descriptions stem primarily from detailed mapping in the Guadalupe and Glass Mountains (King, 1930, 1948). Figures 2.2.6 through 2.2.9 show four representative cross-sections through the eastern arm of the Capitan Reef Complex. Figures 2.2.6 and 2.2.7 show east-west oriented cross-sections across the Capitan Reef Complex in Lea County, New Mexico and Pecos County, Texas, respectively, where the Capitan Reef Complex occurs in the subsurface. Figure 2.2.8 is a northwest-southeast oriented cross-section across the Capitan Reef Complex outcrop in the Glass Mountains of Brewster County, Texas. In this area, the Capitan Reef Complex dips towards the northwest, is overlain by Cretaceous sediments, and is cross-cut by faults and Tertiary igneous intrusions. Figure 2.2.9 is a cross-section approximately parallel to the trend of the eastern arm of the Capitan Reef Complex. This cross-section extends from Eddy County, New Mexico to the Glass Mountain Capitan Reef Complex outcrop near the boundary between Pecos and Brewster counties in Texas.

The arc-shaped reef structure of the Capitan Reef Complex is about 10 to 14 miles wide and is dissected by the Hovey Channel in Brewster County (Hill, 1996; Hiss, 1975). There is also some evidence suggesting another channel located in the western part of the Capitan Reef Complex (Hill, 1999b; 2006).

The Capitan Reef Complex is composed of massive white to gray fossiliferous limestone beds. The limestone beds grade from fore-reef to back-reef deposits. The gradation into fore-reef deposits is typically abrupt, with a defined geologic contact, whereas the gradation into back-reef deposits is more transitional, with difficult-to-identify geologic contacts (Hill, 1996; Hiss, 1975).

The rocks that make up the reef complex have been locally dissected by faults and consequently do not form one continuous aquifer but rather a series of disconnected highly permeable aquifers (Hill, 1996; Hiss, 1975) (Figure 2.2.2). For example, the uplifted Guadalupe Mountains divide the Capitan Reef Complex Aquifer into two separate disconnected aquifers, one that trends to the northeast and discharges to the Pecos River in New Mexico and one that originates along the western flank of the Guadalupe Mountains and flows south toward the Apache Mountains (Hiss, 1975; King, 1948).

Streams eroded away the softer sediment, lowering the ground level to its current position. Submarine canyons are incised in the Capitan Reef Complex along the northern and eastern margins of the Delaware Basin. Hiss (1975) identified 25 submarine canyons where the top of the Capitan Reef Complex is structurally low. These submarine canyons were eventually filled with low permeability material. Hiss (1975) believes that these submarine canyons restrict groundwater flow through the reef carbonates. Acidic groundwater excavated caves in the limestone of the higher areas, and eroded sediment helped fill any remaining Permian-aged caves. Unlike most other caves that are formed in limestone, the source of acidity that formed these caves was likely hydrogen sulfide and sulfide-rich brines freed by tectonic activity during the mid-Tertiary age. These acidic brines mixed with oxygenated groundwater, forming sulfuric acid. The Carlsbad Caverns and nearby modern caves started to form during this time below the water table. Additional uplift of the Guadalupe Mountains during the Pliocene and early Pleistocene epochs have enlarged Carlsbad Caverns and other nearby caves (Harris and others, 1997).

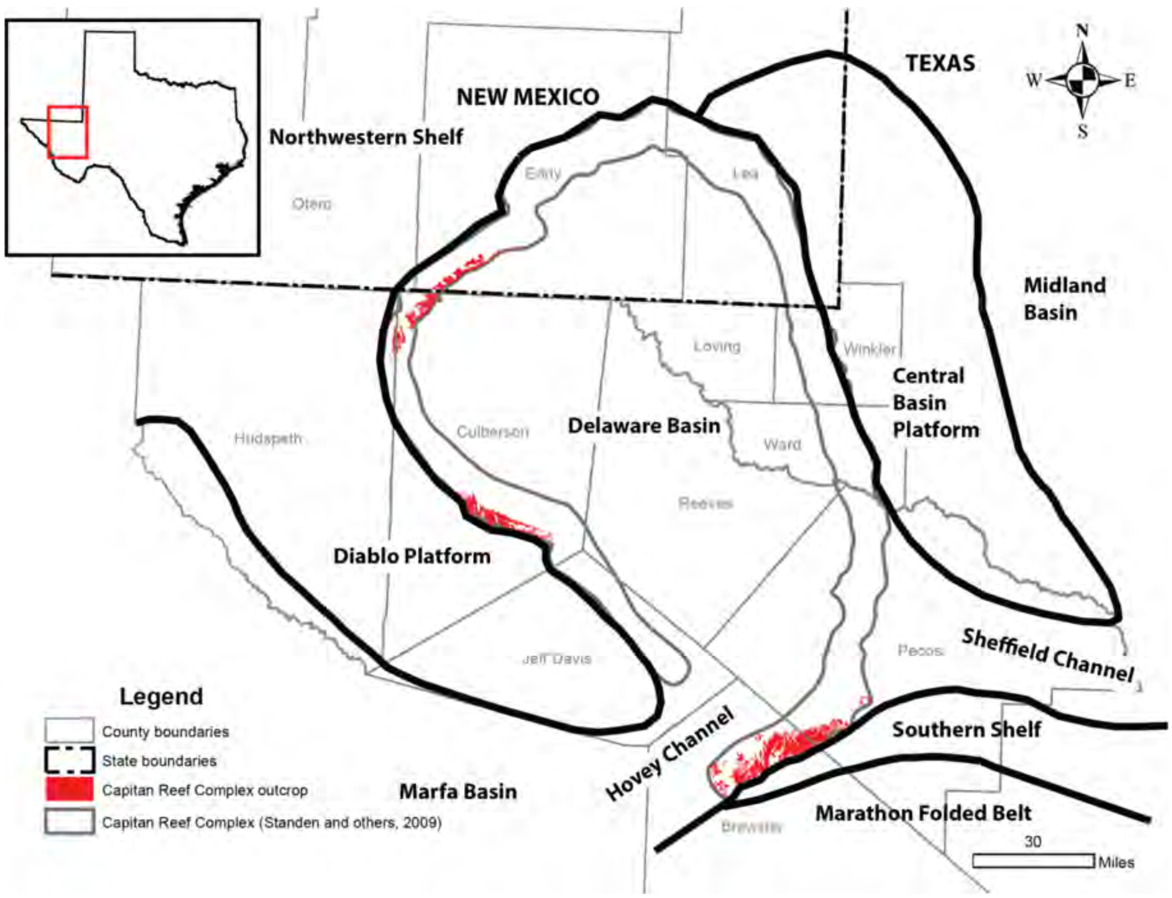


Figure 2.2.1. Major structural features in the study area (from Armstrong and McMillion, 1961).

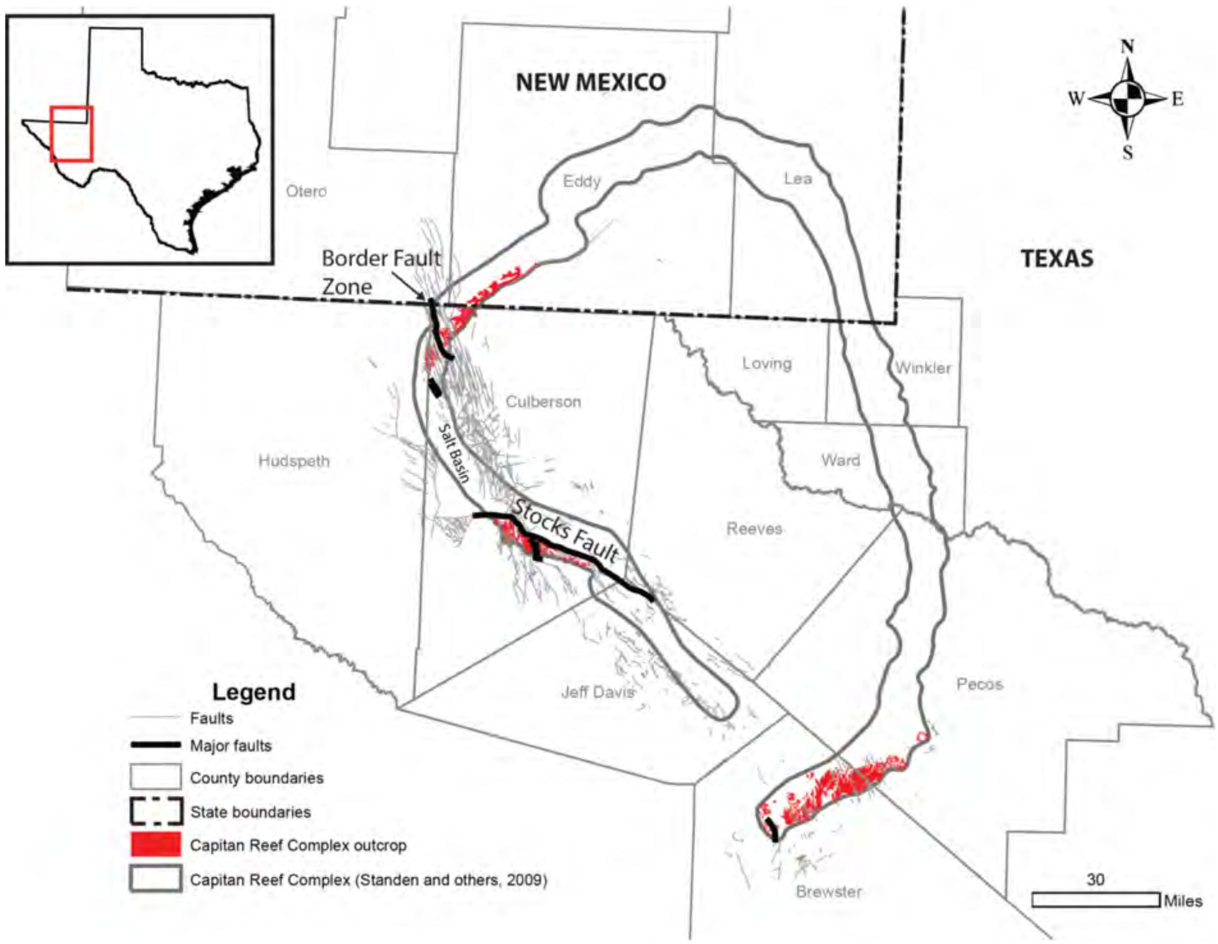


Figure 2.2.2. Faults that cut through or lie adjacent to the Capitan Reef Complex Aquifer.

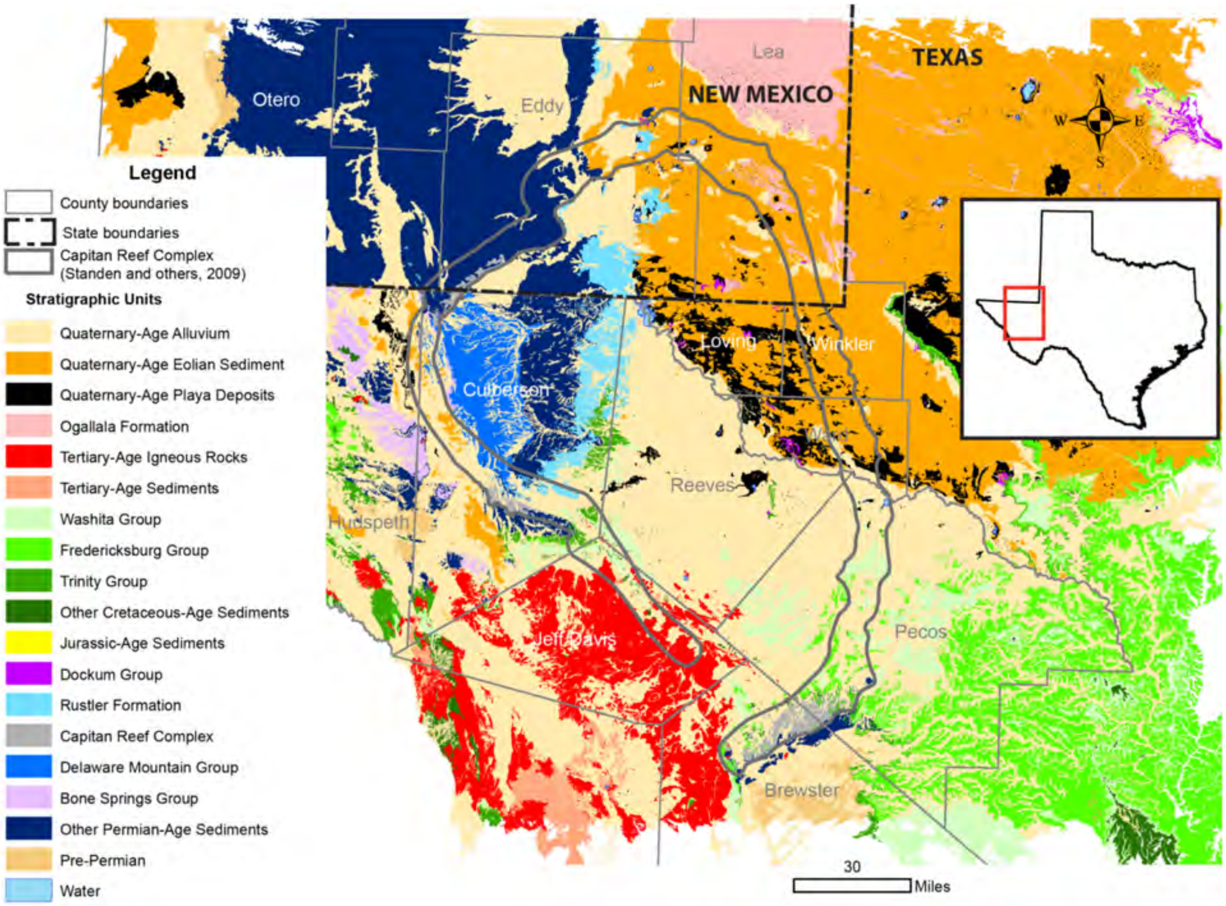


Figure 2.2.3. Generalized surface geology in the study area.

Summary of geologic formations and groups forming the Capitan Reef Complex and Delaware Basin

Period/Epoch or Series	Apache Mountains (Wood, 1968; Uliana, 2001) Back Reef	Apache Mountains Reef	Guadalupe Mountains (King, 1948; Hiss, 1975; Kerans and others, 1994; Kerans and Tinker, 1999) Back Reef	Guadalupe Mountains Reef	Glass Mountains (Hill, 1999) Back Reef	Glass Mountains Reef	Delaware Basin
Quaternary to Tertiary	Quaternary Tertiary Deposits		Quaternary Tertiary Deposits		Quaternary Tertiary Deposits		Pecos Valley Alluvium
Cretaceous					Cretaceous		Edwards/Trinity Groups
Triassic							Dockum Group
Permian/Ochoan				Rustler[a] / Salado[a] / Castile[a]	Tessey		Rustler / Salado / Castile
Permian/ Guadalupian	Artesia Group: Tansill, Yates, Seven Rivers	*Capitan Reef Complex*; Capitan Limestone	Artesia Group: Tansill, Yates, Seven Rivers	*Capitan Reef Complex*; Carlsbad and Capitan Limestones	Gilliam	*Capitan Reef Complex*; Capitan Limestone	Delaware Mountain Group: Bell Canyon
	Munn		Queen/Grayburg	Goat Seep Dolomite	Vidrio		Cherry Canyon
	Cherry Canyon		Upper San Andres; Lower San Andres (Brushy Canyon Equivalent)	Cherry Canyon	Word Formation (Cherry and Brushy Canyon Equivalent)		Brushy Canyon
	Cutoff Shale (Member of Bone Spring Limestone)						Pipeline Shale Member
Permian/ Leonardian	Yeso	Victorio Peak (Member of the Bone Spring Limestone)			Leonard and Hess Member of Leonard Formation		Bone Spring Limestone

Sources: From Standen and others (2009). Modified after King, 1948; Wood, 1968; Hiss, 1975; Uliana, 2001; Hill, 1999; Kerans and others, 1994; Kerans and Tinker, 1999.

[a] Formations overlie Capitan Reef Complex between the Guadalupe and Glass Mountains

Figure 2.2.4. Generalized stratigraphic column for the Capitan Reef Complex and overlying and underlying formations.

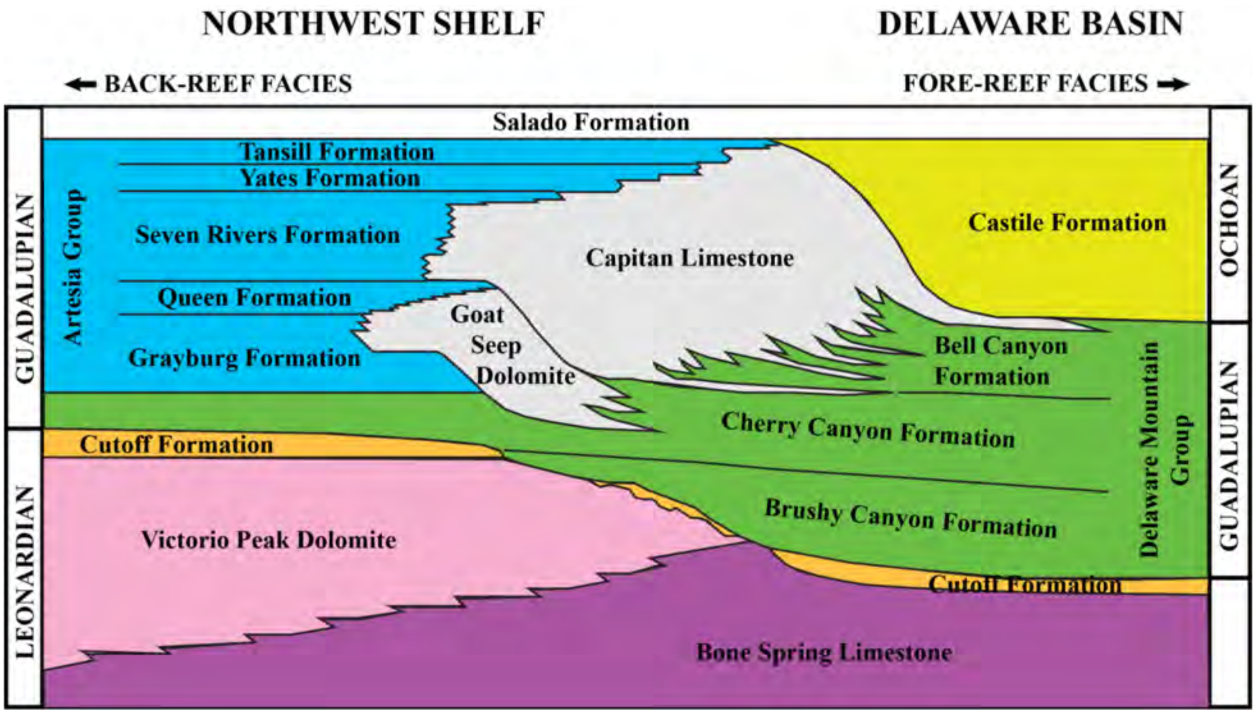
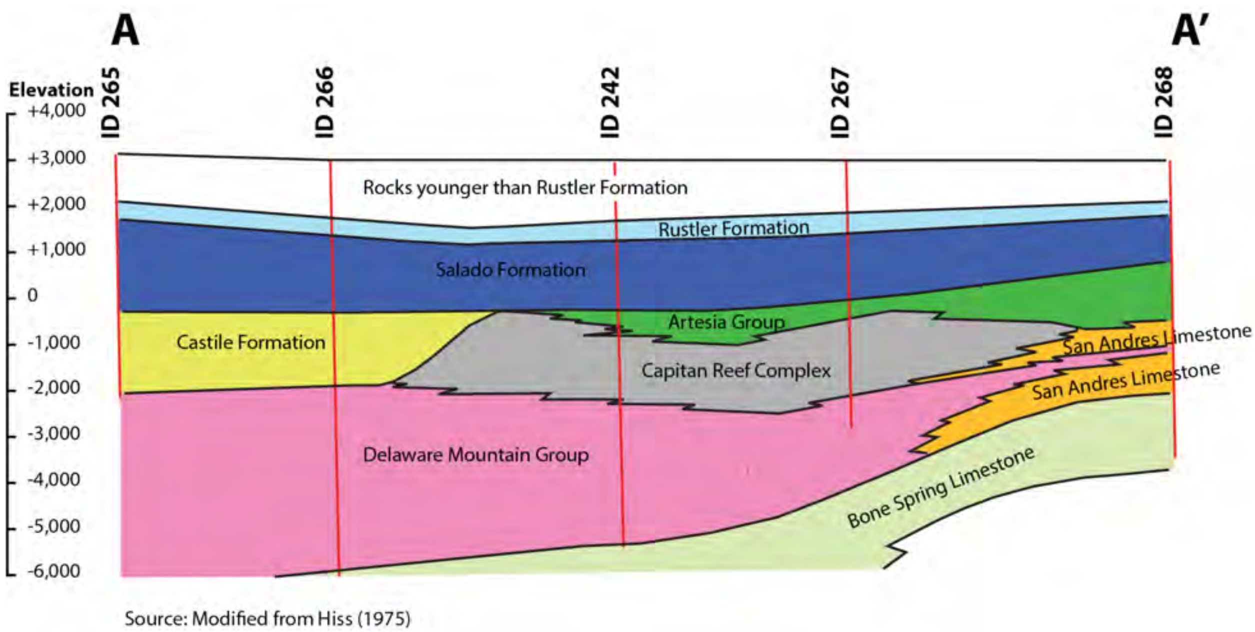


Figure 2.2.5. **Generalized cross-section through the Capitan Reef Complex and associated fore-reef and back-reef facies formations. Modified from Standen and others, 2009; Melim and Scholle, 1999).**



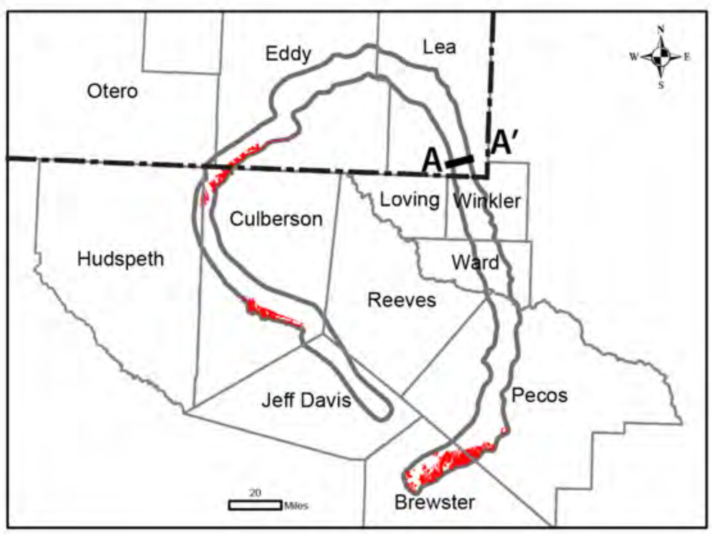
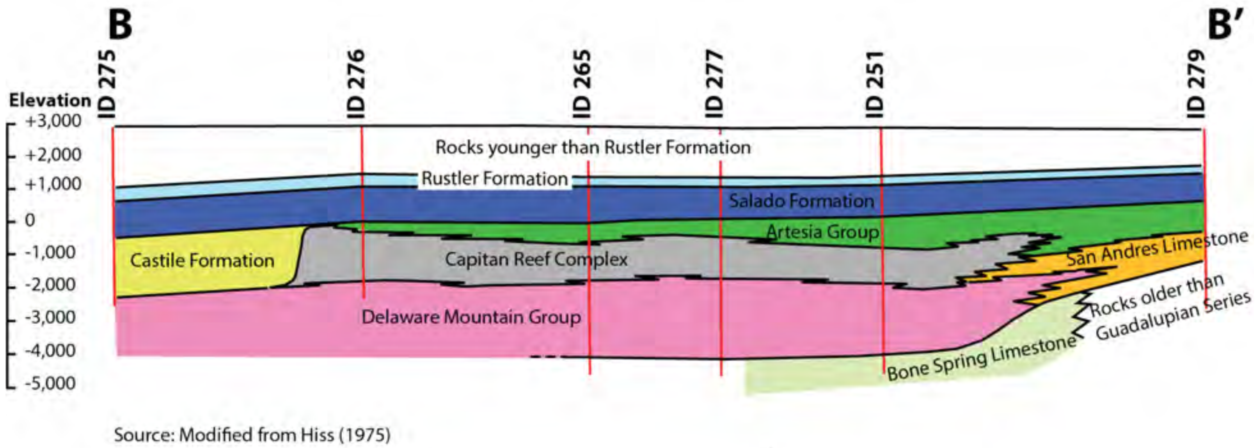


Figure 2.2.6. **A-A' cross-section through the Capitan Reef Complex in Lea County, New Mexico (modified from Standen and others, 2009; Hiss, 1975).**



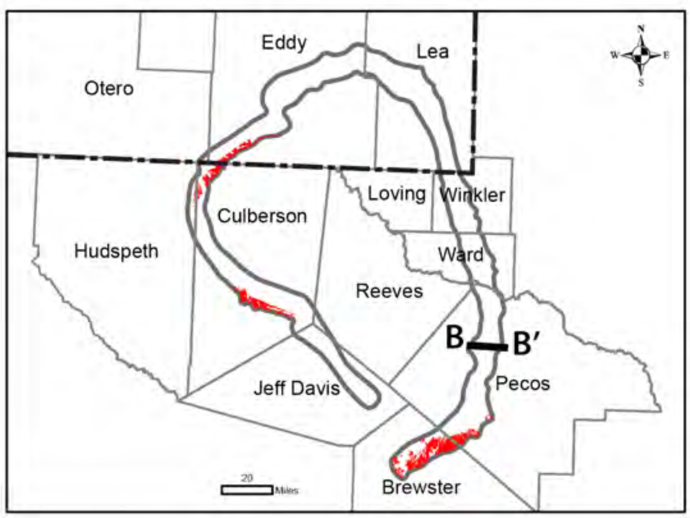


Figure 2.2.7. **B-B' cross-section through the Capitan Reef Complex in Pecos County, Texas (modified from Standen and others, 2009; Hiss, 1975).**

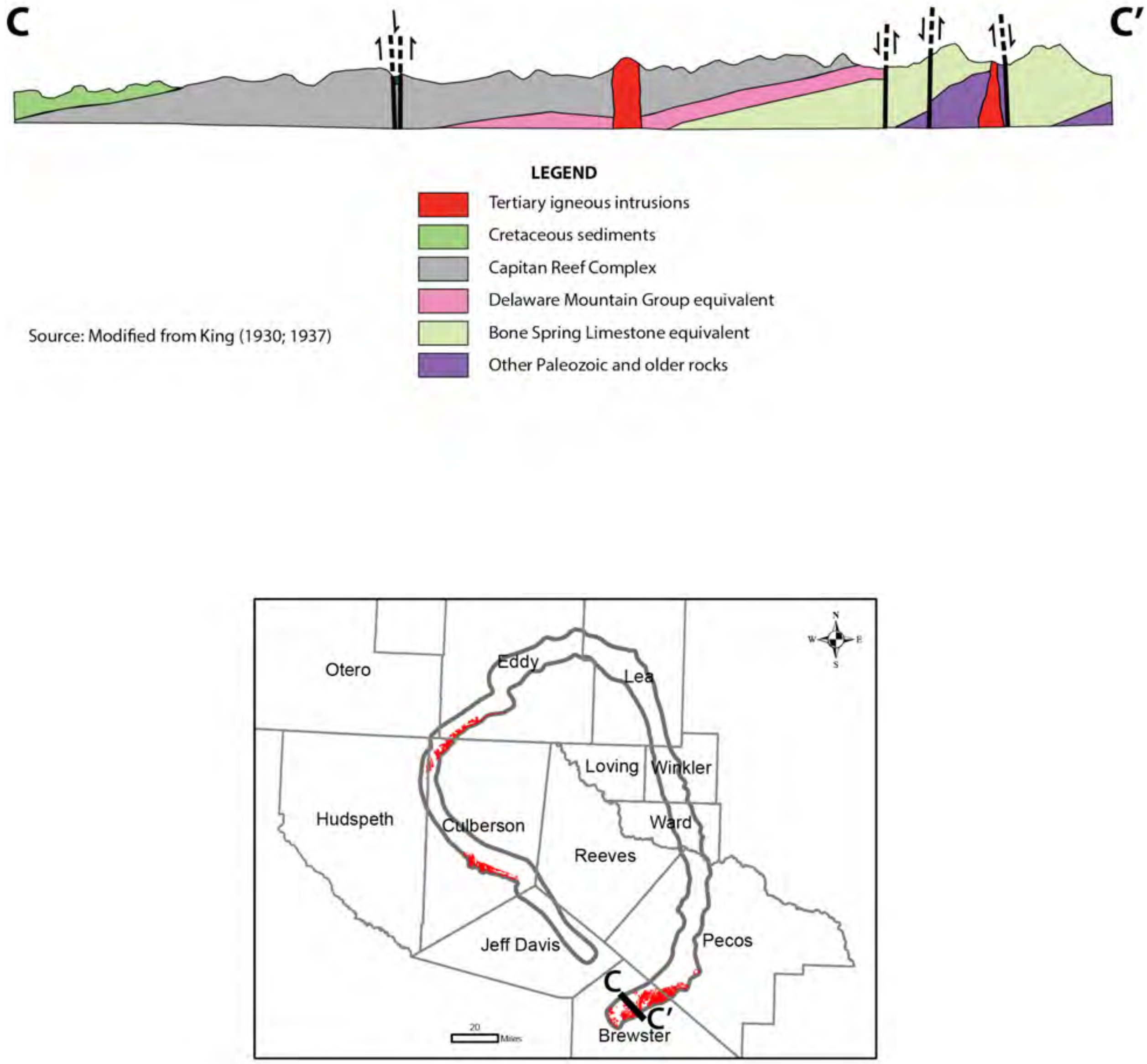


Figure 2.2.8. **C-C' cross-section through the Capitan Reef Complex outcrop in the Glass Mountains, Brewster County, Texas (modified from Standen and others, 2009; King, 1930; 1937).**

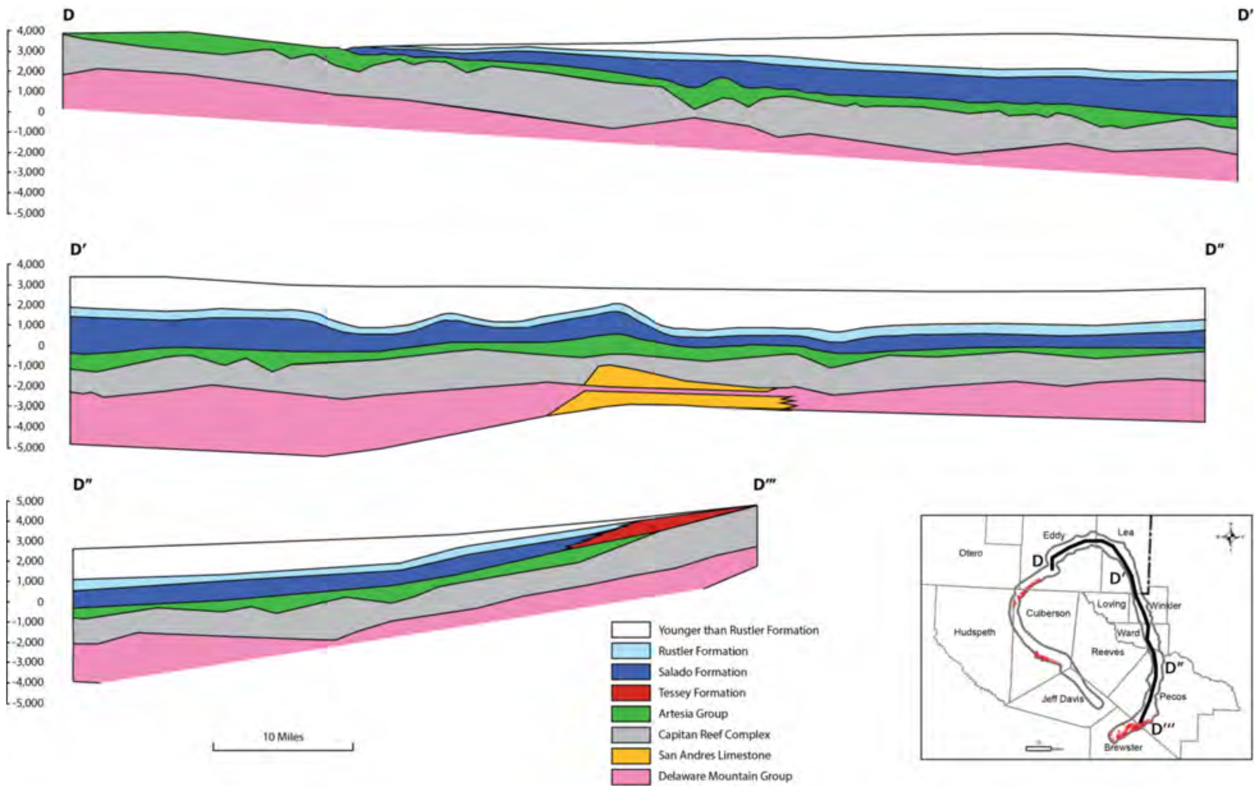


Figure 2.2.9. **D-D''' cross-section through the Capitan Reef Complex outcrop in the Glass Mountains, Brewster County, Texas (modified from Hiss, 1975).**

3.0 PREVIOUS WORK

There have been several studies of the stratigraphy, geologic framework, and hydrogeology of the Capitan Reef Complex—mostly by the United States Geological Survey and the University of Texas at Austin. Studies by King (1948), Hayes (1964), Wood (1965), and Bebout and Kerans (1993) described the geology of the Capitan Reef Complex outcrops in the Guadalupe and Apache mountains. Standen and others (2009) compiled work on the stratigraphy and geologic framework of the Capitan Reef Complex. Standen and others (2009) also used geophysical logs to define the elevations of the top and base of the Capitan Reef Complex and revise its spatial extents.

Several studies investigating the hydrogeology of the Capitan Reef Complex Aquifer include Armstrong and McMillion (1961), White (1987), Hiss (1975; 1980), Richey and others (1985), Sharp (1989), Ashworth (1990), Brown (1997), Uliana (2001), Uliana and Sharp (2001), and INTERA (2013). The Brown (1997) study investigated water quality in the Capitan Reef Complex Aquifer. The groundwater flow system of the Capitan Reef Complex Aquifer has been documented in work by Hiss (1975; 1980), Uliana (2001), and Uliana and Sharp (2001).

Three groundwater flow models simulating groundwater flow in parts of the eastern arm of the Capitan Reef Complex Aquifer have been constructed (Figure 3.0.1). The first groundwater flow model simulates groundwater flow through the Capitan Reef Complex Aquifer and Pecos River alluvium near Carlsbad, New Mexico (Barroll and others, 2004). A simplified groundwater flow model was constructed by INTERA and Cook-Joyce (2012) simulating groundwater flow in part of the eastern arm of the Capitan Reef Complex Aquifer. The purpose of that model was to simulate the potential effects of a well field located in central Ward County. Despite its regional extent, this model was only calibrated based on water-level and pumping data from well fields located within Ward and Winkler counties. The third model simulated the effects of a pair of wells located in Lea County, New Mexico (Castiglia and others, 2013; INTERA, 2013). The groundwater flow models by Barroll and others (2004), INTERA and Cook-Joyce (2012) and Castiglia and others (2013) were constructed to address localized issues, groundwater flow along the Pecos River and potential effects of well fields, respectively. This contrasts with the proposed Texas Water Development Board groundwater availability model of the eastern arm of the Capitan Reef Complex Aquifer that will be designed to simulate groundwater flow between the Glass Mountains outcrop in Brewster County and where the Pecos River interacts with the aquifer near Carlsbad, New Mexico—a study area that includes the areas of interest of all three models.

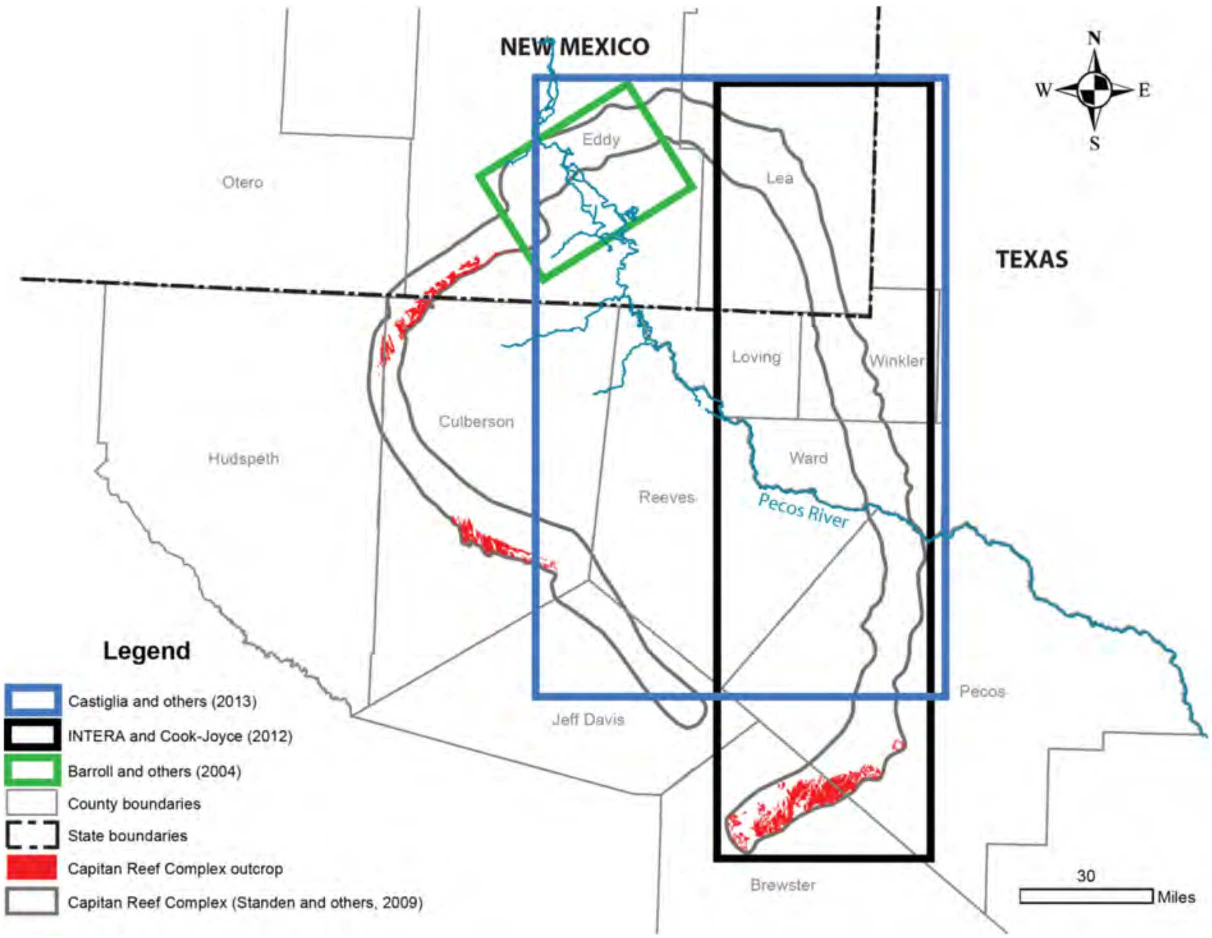


Figure 3.0.1. **Approximate extents of previous model grids for models used for simulating groundwater flow through the Capitan Reef Complex Aquifer.**

4.0 HYDROLOGIC SETTING

The hydrologic setting is a description of the factors that contribute to the groundwater hydrology of the Capitan Reef Complex Aquifer. These factors include the hydrostratigraphy, hydrogeologic framework, water levels and regional groundwater flow, recharge, surface-water bodies, hydraulic properties, discharge, and water quality.

4.1 Hydrostratigraphy and Hydrostratigraphic Framework

The Capitan Reef Complex Aquifer (Figure 2.0.2) is defined as Permian-age carbonate reef-forming rocks that were deposited on the margins of the Delaware Basin (Hiss, 1975). These limestone formations include the Capitan Limestone in the western, southern, and northern parts of the reef complex, and the Carlsbad Limestone and Goat Seep Dolomite in the north (Figure 4.1.1). In the south, the Tessey Limestone—a stratigraphic equivalent to the Salado and Castile formations—is a pathway for recharge to the underlying Capitan Reef Complex Aquifer. In the subsurface, the Capitan Reef Complex Aquifer is bounded laterally and vertically by aquitards made up of the fore-reef Delaware Mountain Group and back-reef Artesia Group. These stratigraphic units are in turn overlain by the evaporites of the Castile and Salado formations that also act as aquitards. Four aquifers—the Rustler, Dockum, Edwards-Trinity (Plateau), and Pecos Valley aquifers—overlie the aquitards.

The top of the Capitan Reef Complex Aquifer has elevations ranging from 1,500 feet below mean sea level to more than 8,000 feet above mean sea level. The top surface of the Capitan Reef Complex Aquifer shown in Figure 4.1.2 is a combination of subsurface top designations using geophysical logs and driller's reports, and 30-meter digital elevation model surface elevations of the Capitan Reef Complex Aquifer outcrops (Standen and others, 2009). Outcrop structural tops within the Capitan Reef Complex Aquifer were identified using the available digital Geological Atlas of Texas (Pearson, 2007). The subsurface top of the Capitan Reef Complex Aquifer is a combination of structural tops and erosional surfaces. Figure 4.1.3 shows the base of the Capitan Reef Complex Aquifer. The Capitan Reef Complex Aquifer base was created by subtracting the Capitan Reef Complex Aquifer thickness (Figure 4.1.4) from the top surface (Figure 4.1.2) using ArcGIS Spatial Analyst (Standen and others, 2009).

Figures 4.1.2 and 4.1.3 indicate that the Capitan Reef Complex Aquifer dips to the northeast with highest elevations associated with outcrops in the Guadalupe and Glass mountains and lowest elevations occurring in the subsurface in Lea, Winkler, Ward and northern Pecos counties. The thickest parts of the Capitan Reef Complex Aquifer occur in the Guadalupe Mountains and in the northern and eastern parts of the reef complex (Figure 4.1.4). The thickest parts of the aquifer occur on the fore-reef side of the Capitan Reef Complex. The thinnest parts of the Capitan Reef Complex Aquifer occur in the southern and back-reef parts of the reef complex.

The Capitan Reef Complex locally underwent erosion during the middle to late Guadalupian period. Hiss (1975) identified Capitan Reef Complex carbonate reef highs—thick carbonate intervals—alternating with erosional valleys—thin carbonate intervals—on the eastern arm of the Capitan Reef Complex (Figure 4.1.4). These erosional valleys extended from the Central Basin Platform, through the Capitan Reef Complex and toward the Delaware Basin (Figure 4.1.4). These erosional valleys were in-filled with silts, clays, and fine sands forming clastic channels overlying and adjacent to the Capitan Reef Complex limestone. In-filling with Cenozoic sediment is also associated with karstification along the fore-reef side of the Capitan Reef Complex (Hill, 1999a). Karstification in the Capitan Reef Complex is also attributed to the development of the overlying Monument Draw Trough through dissolution of overlying evaporites by groundwater discharging from the Capitan Reef Complex Aquifer accompanied by collapse of overlying sediment (Anderson and others, 1978; Anderson, 1981; Hill, 1999a). This process is likely responsible for the formation of the overlying Monument Draw Trough (Jones, 2001; 2004).

The elevations of the top and base of the Rustler Aquifer are shown in Figures 4.1.5 and 4.1.6. These figures indicate low areas coinciding with the Monument Draw and Pecos troughs that are most commonly associated with the overlying Pecos Valley Aquifer (Jones, 2001; 2004). These basins formed due to dissolution of the underlying Salado Formation. The Monument Draw Trough also coincides with the Capitan Reef Complex. The base of the Rustler Aquifer coincides with the top of the Salado Formation which is the top of the underlying aquitards that separate the Capitan Reef Complex Aquifer and the overlying Rustler Aquifer. Figure 4.1.7 shows that the Rustler Aquifer is thickest on the basin side of the Capitan Reef Complex—300 to 600 feet thick—while on the shelf side of the Capitan Reef Complex it thins to less than 100 feet.

Like the underlying Rustler Aquifer, the Dockum Aquifer top and base display low areas coinciding with the Monument Draw and Pecos troughs (Figures 4.1.8 and 4.1.9). The combined thickness of the Dockum Group and Dewey Lake Formation indicate an area of increased thickness coinciding with the Monument Draw Trough and underlying Capitan Reef Complex (Figure 4.1.10).

The Monument Draw and Pecos troughs are not apparent at land surface that forms the tops of the Edwards-Trinity (Plateau) and Pecos Valley aquifers (Figure 4.1.11). However, these basins are apparent as low areas at the base of the respective aquifers and as areas of increased thickness (Figures 4.1.12 and 4.1.13).

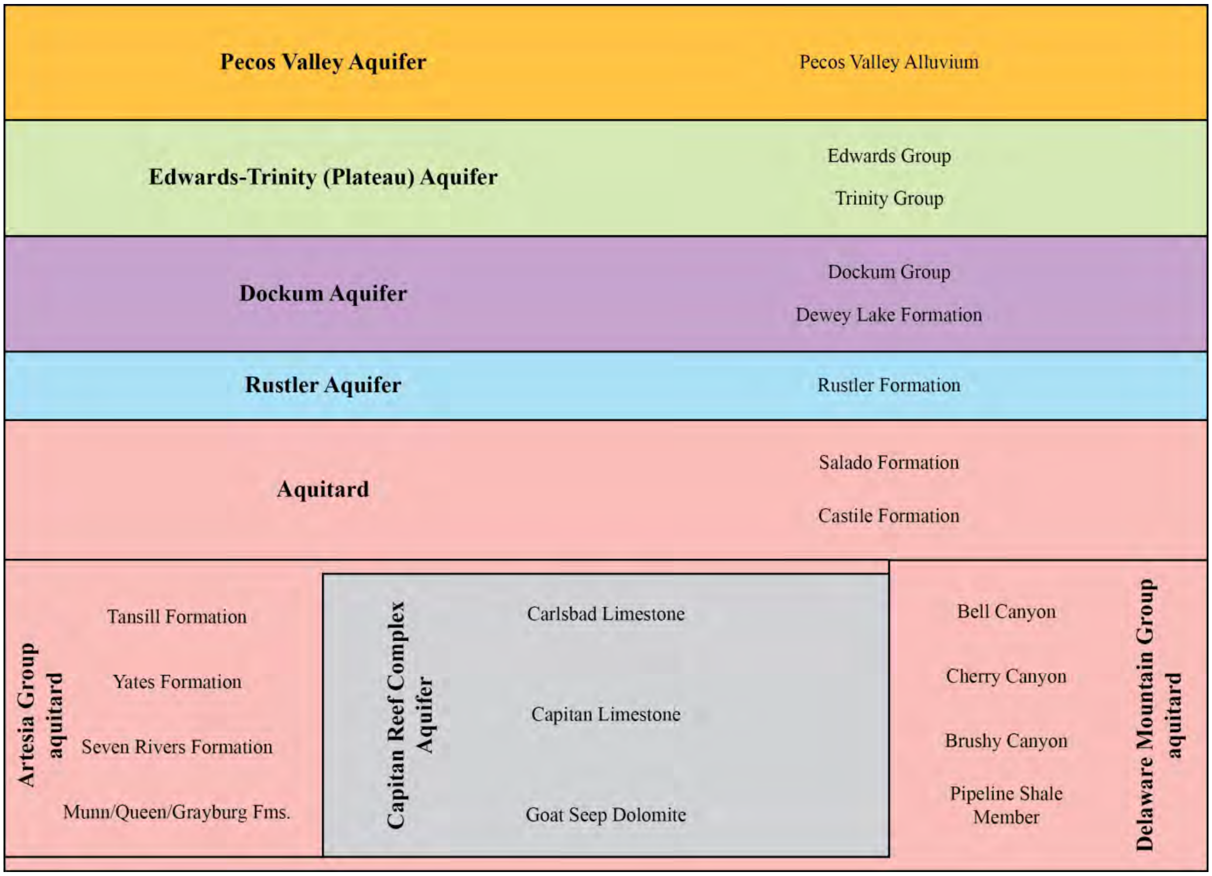


Figure 4.1.1. Hydrostratigraphic chart for down-dip portion of the Capitan Reef Complex and overlying and underlying formations.

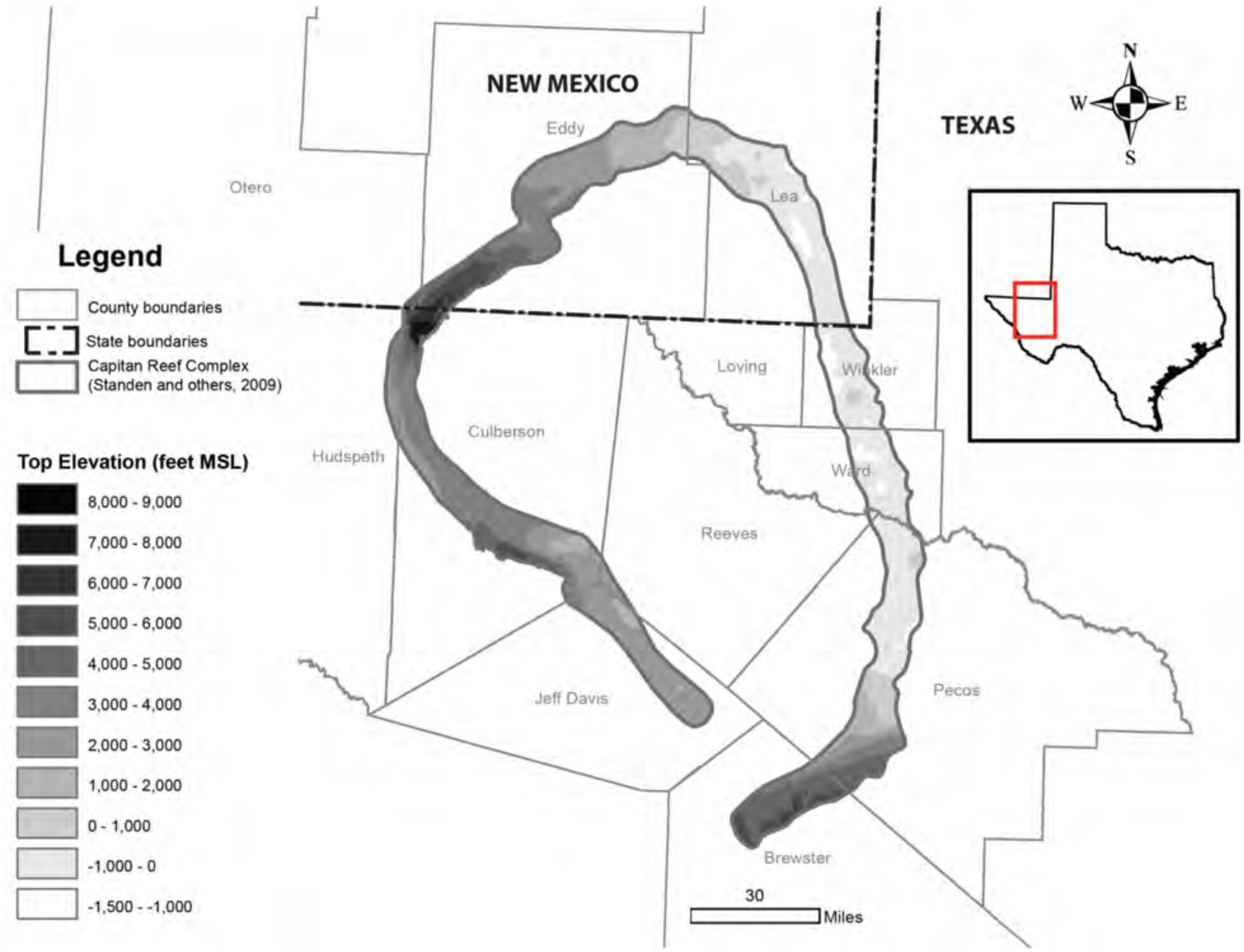


Figure 4.1.2. The elevation (in feet above mean sea level (MSL)) of the top of the Capitan Reef Complex Aquifer (modified from Standen and others, 2009).

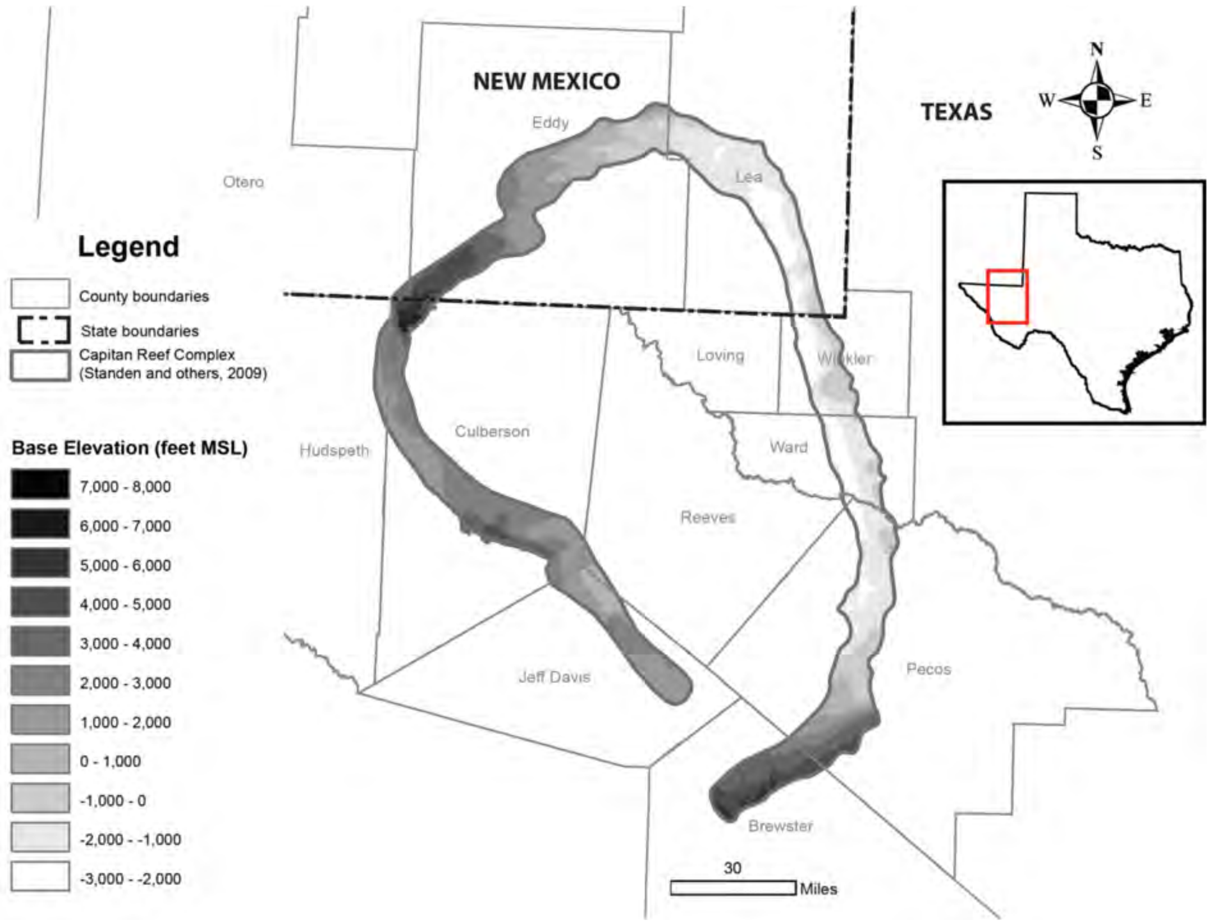


Figure 4.1.3. The elevation (in feet above mean sea level (MSL)) of the base of the Capitan Reef Complex Aquifer (modified from Standen and others, 2009).

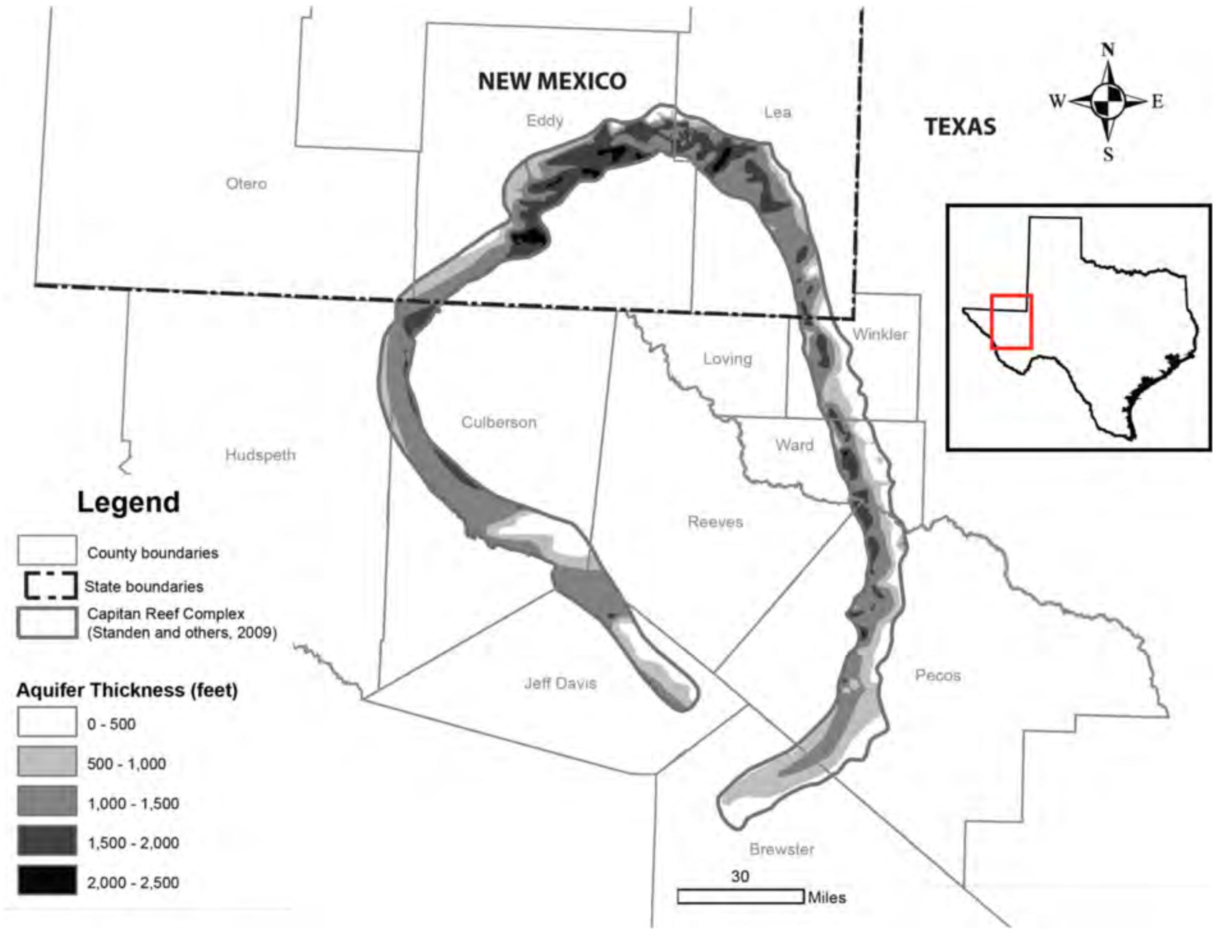


Figure 4.1.4. **Thickness (in feet) of the Capitan Reef Complex Aquifer (modified from Standen and others, 2009).**

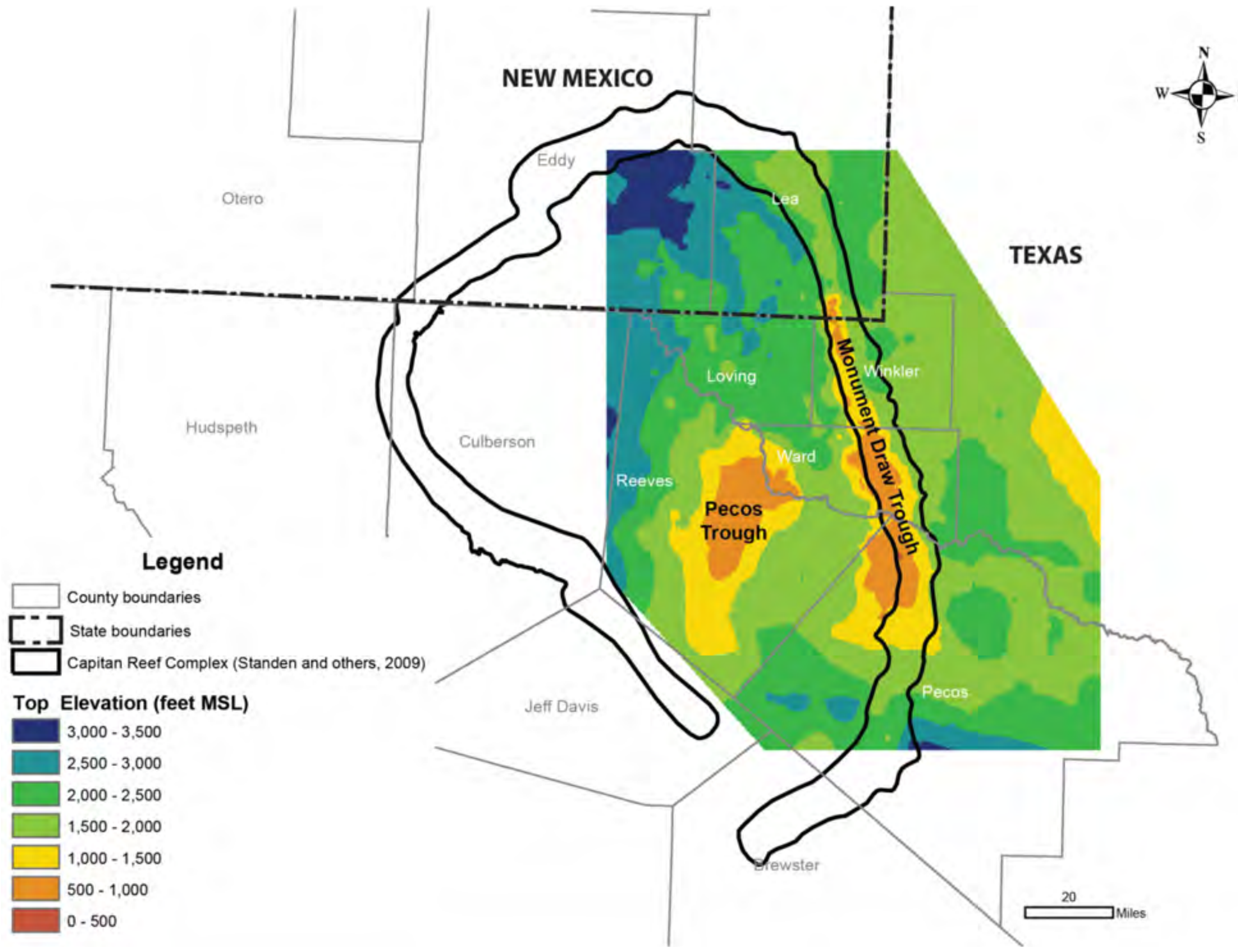


Figure 4.1.5. **The elevation (in feet above mean sea level (MSL)) of the top of the Rustler Aquifer (based on data from Ewing and others, 2012).**

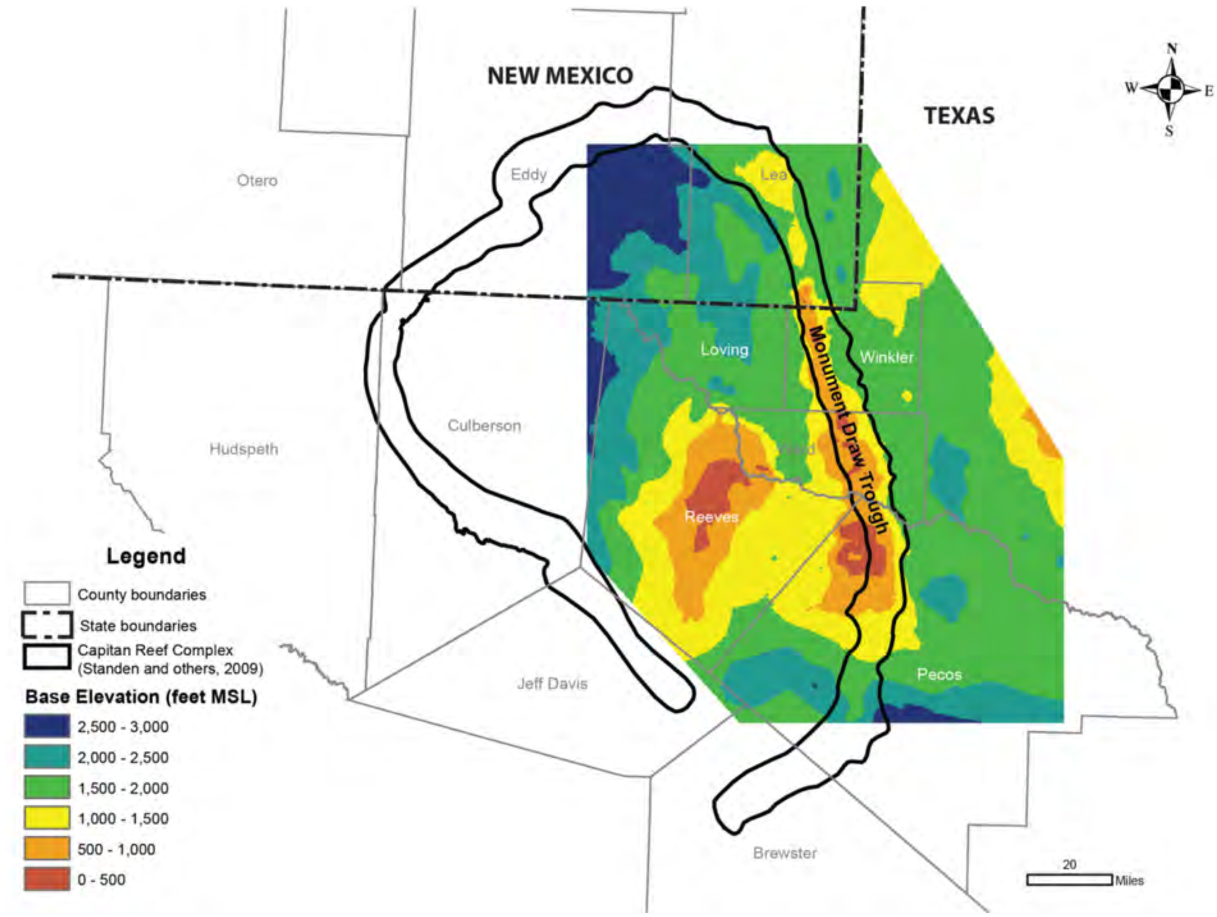


Figure 4.1.6. **The elevation (in feet above mean sea level (MSL)) of the base of the Rustler Aquifer (based on data from Ewing and others, 2012).**

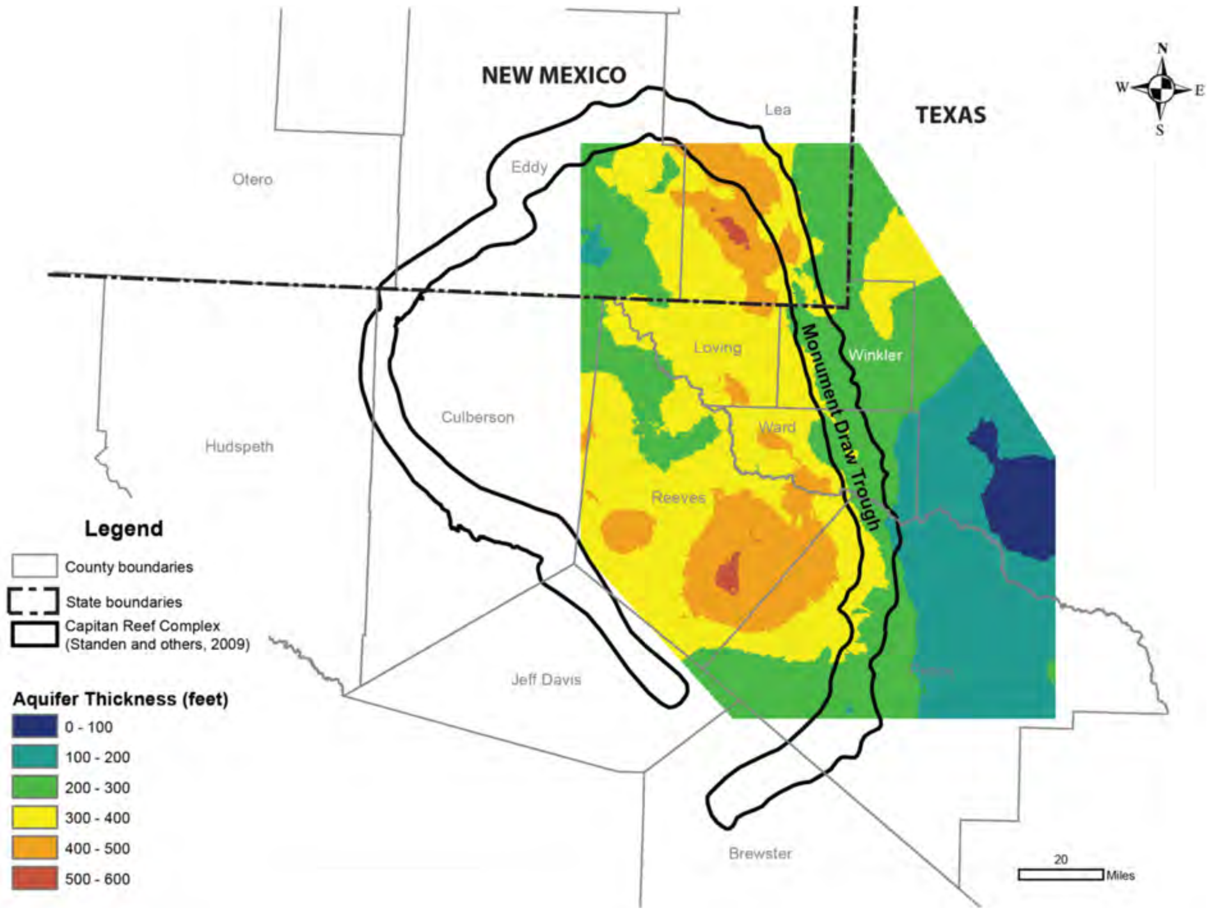


Figure 4.1.7. Thickness (in feet) of the Rustler Aquifer (based on data from Ewing and others, 2012).

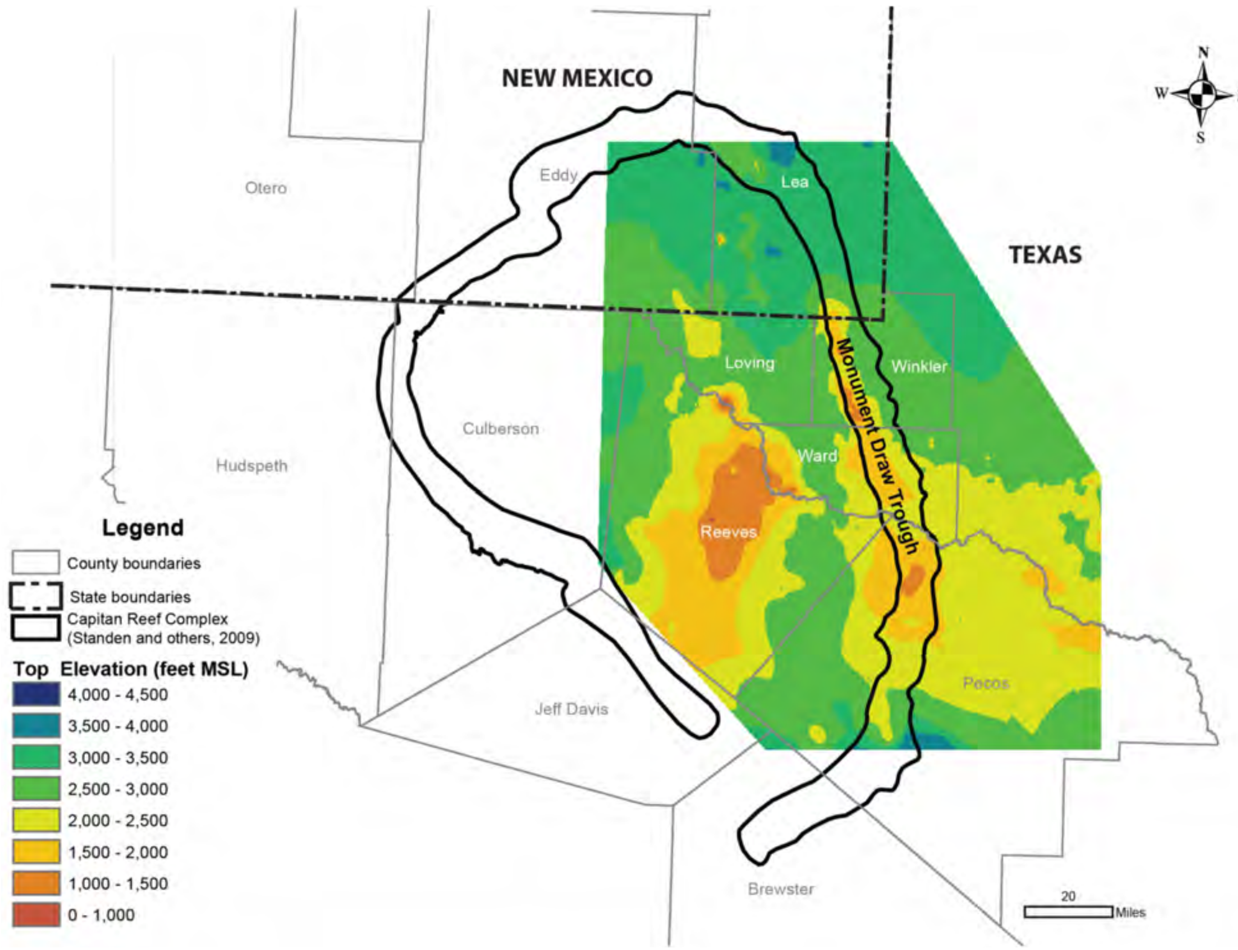


Figure 4.1.8. The elevation (in feet above mean sea level (MSL)) of the top of the Dockum Aquifer (based on data from Ewing and others, 2008).

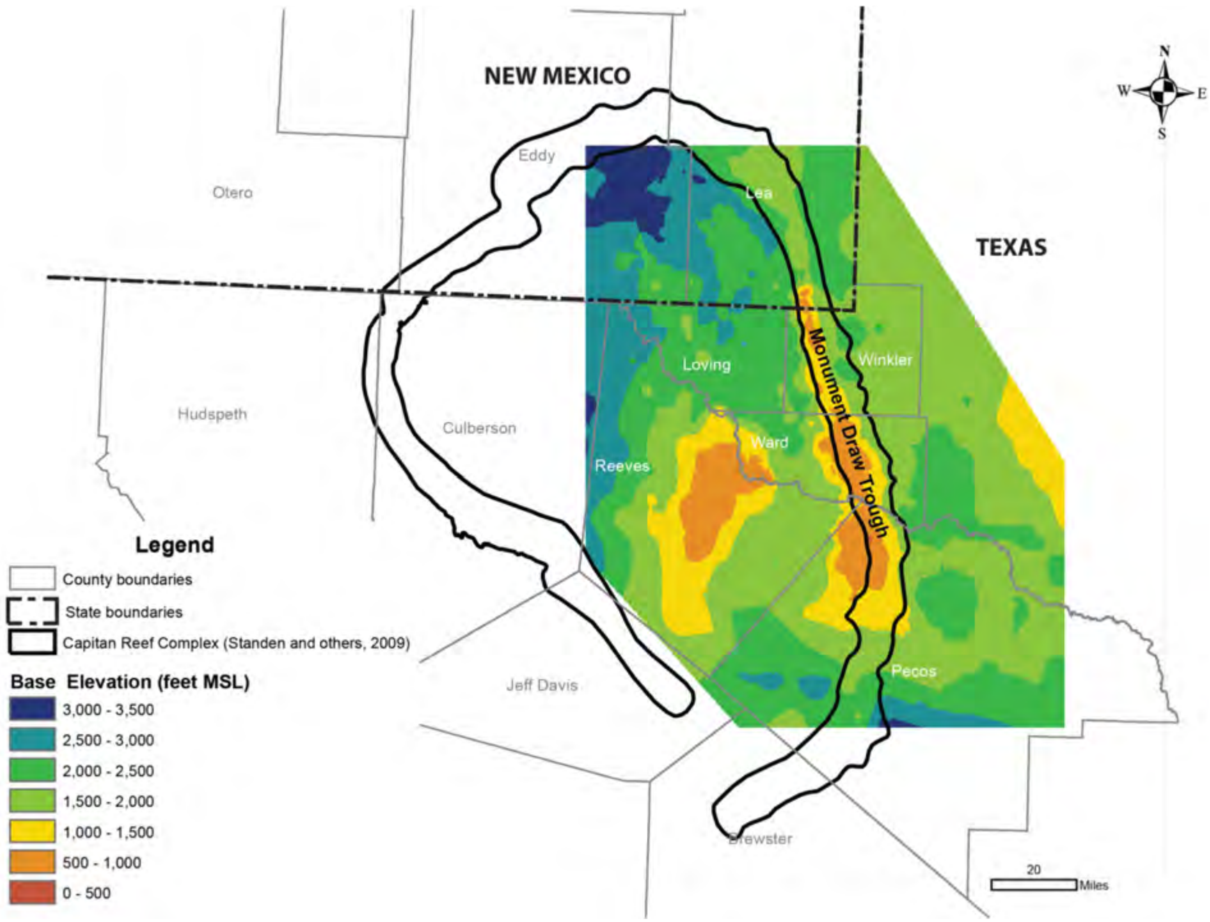


Figure 4.1.9. The elevation (in feet above mean sea level (MSL)) of the base of the combined Dewey Lake Formation and Dockum Aquifer (based on data from Ewing and others, 2008).

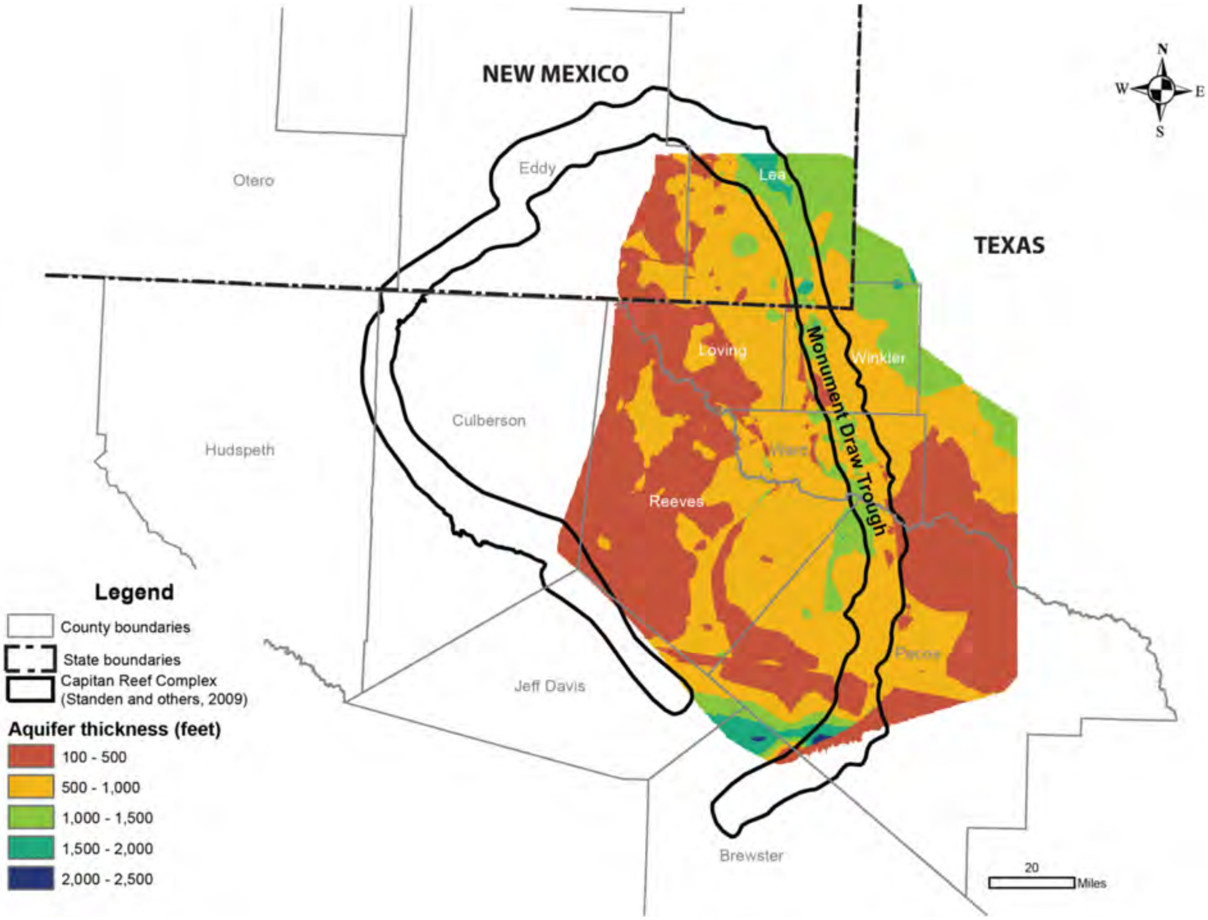


Figure 4.1.10. Total thickness (in feet) of the Dewey Lake Formation and the Dockum Aquifer (modified from Ewing and others, 2008).

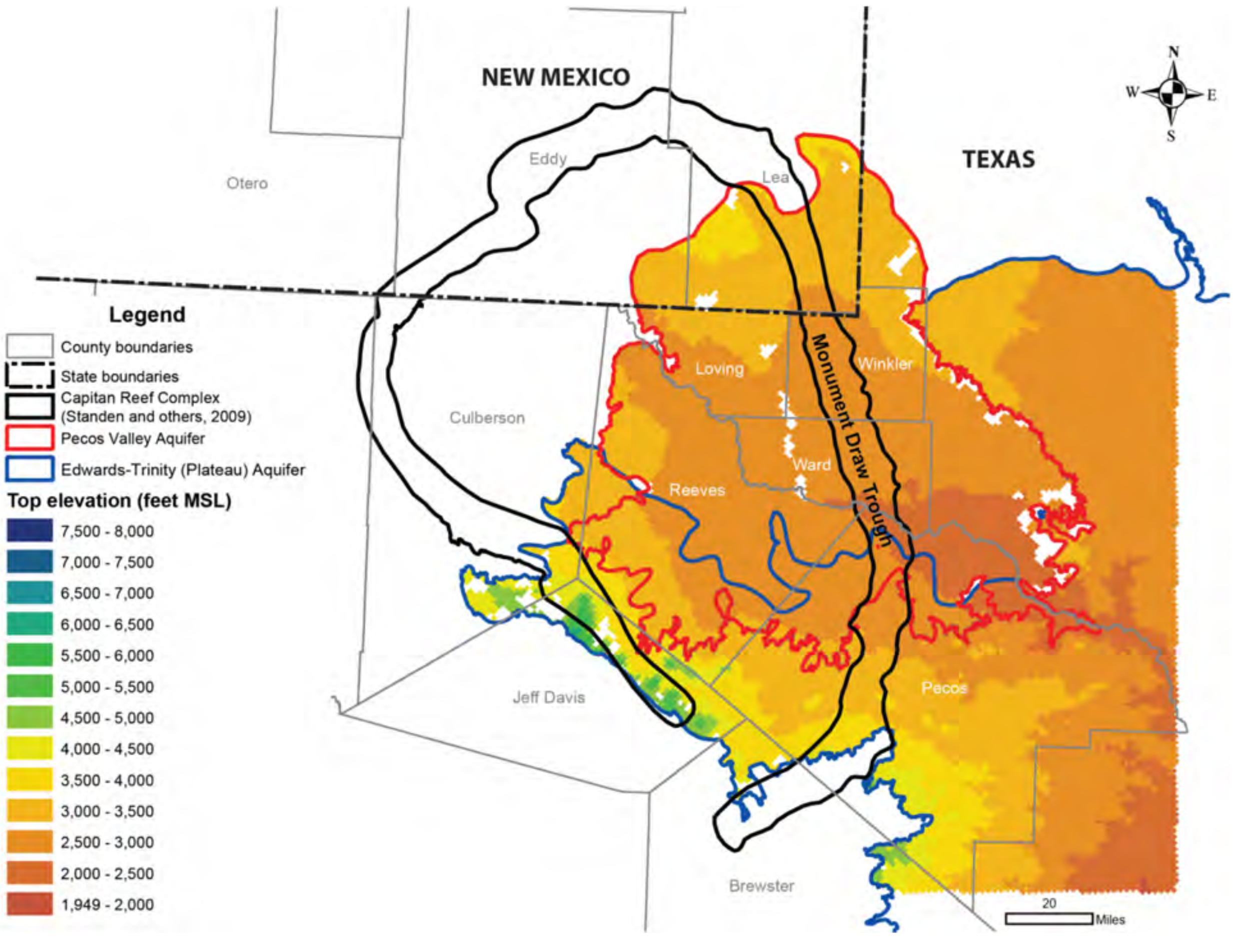


Figure 4.1.11. **The elevation (in feet above mean sea level (MSL)) of the top of the Edwards-Trinity (Plateau) and Pecos Valley aquifers (modified from Hutchison and others, 2011).**

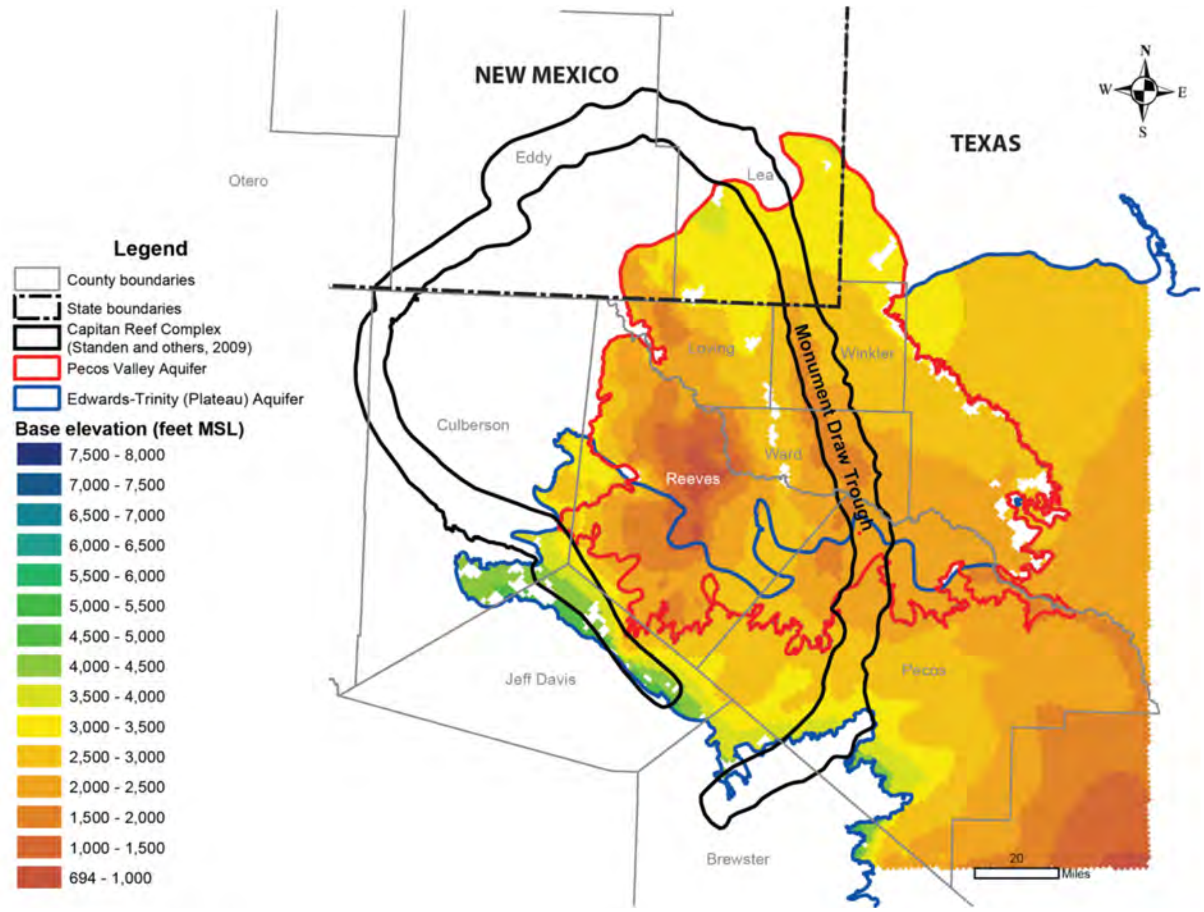


Figure 4.1.12. The elevation (in feet above mean sea level (MSL)) of the base of the Edwards-Trinity (Plateau) and Pecos Valley aquifers (modified from Hutchison and others, 2011).

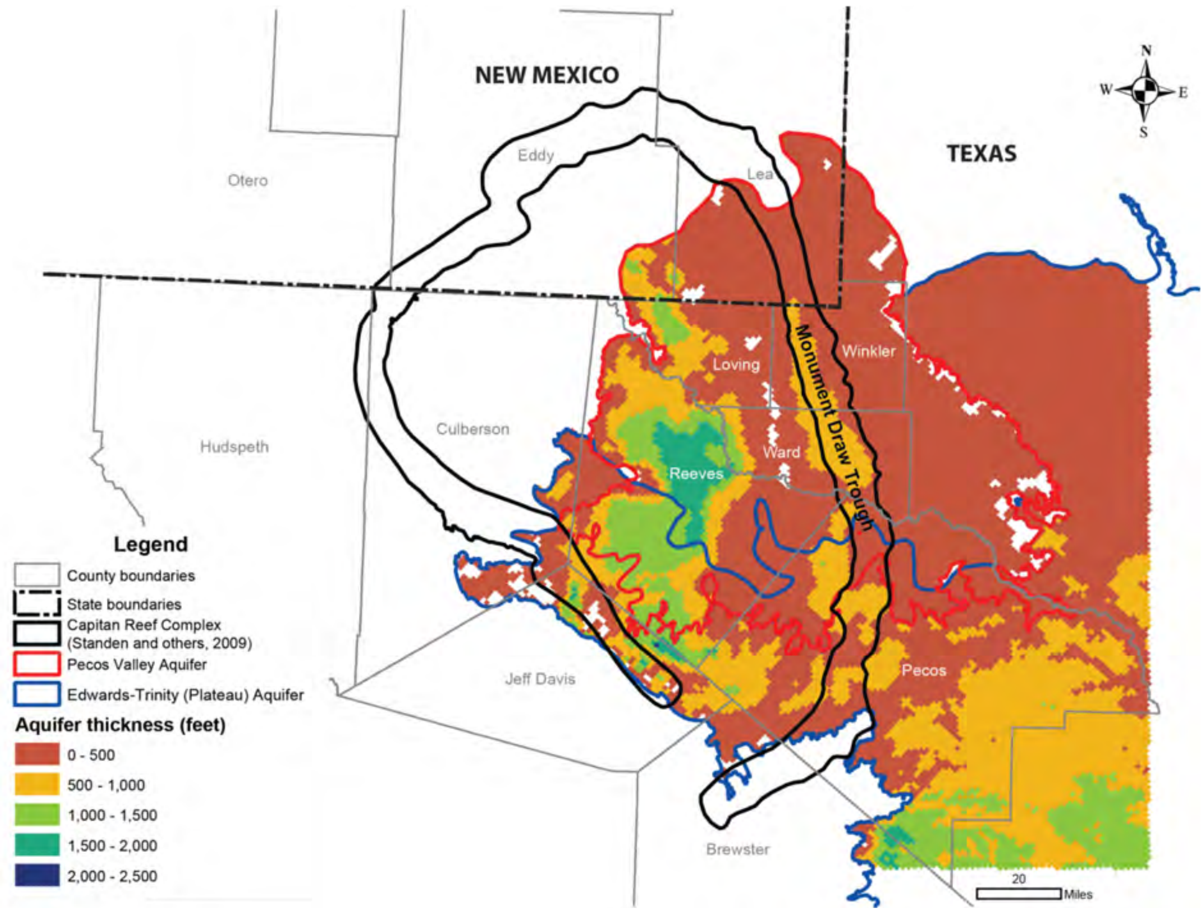


Figure 4.1.13. Thickness (in feet) of the Edwards-Trinity (Plateau) and Pecos Valley aquifers (modified from Hutchison and others, 2011).

4.2 Water Levels and Regional Groundwater Flow

Figure 4.2.1 illustrates regional groundwater flow paths for the Capitan Reef Complex Aquifer (Hiss, 1976; 1980; Uliana, 2001; Sharp, 2001). Hiss (1980) and Richey and others (1985) hypothesized that the uplift of the western side of the Delaware Basin—associated with the Border Fault Zone and the resultant formation of the Guadalupe Mountains—resulted in a topographic gradient for the regional groundwater flow system.

The Border Fault Zone forms a hydrologic divide between two regional groundwater flow systems: one that flows to the northeast from the recharge zone in the Guadalupe Mountains and one that flows to the south (Figure 4.2.1). Regional groundwater also flows northward away from the Glass Mountains—another heavily faulted, topographically high Capitan Reef Complex outcrop (Figure 4.2.1). The Stocks Fault (Figure 4.2.1) is a large fault system with more than 1,000 feet of throw that bounds the northern flank of the Apache Mountains. The fault is probably the result of dissolution of Delaware Basin evaporites north of the fault forming a graben—the Salt basin—between the Stocks Fault and Border Fault Zone (Wood, 1965; LaFave, 1987). The direction of greatest permeability is sub-parallel to the Stocks Fault (Sharp 2001; Uliana, 2000). Regional groundwater flow is probably fracture controlled and is believed to occur from Wild Horse Flat—located immediately west of the Apache Mountains—eastward through the basin sediments underneath the Apache Mountain Capitan Reef Complex outcrop or through the down-faulted Capitan Reef Complex along the northeastern side of the Stocks Fault and toward the Toyah Basin (LaFave, 1987; LaFave and Sharp, 1990; Uliana, 2000; Finch and Armour, 2001). Some of this groundwater may eventually discharge from the San Solomon Spring System located east of the Capitan Reef Complex Aquifer in Reeves and Jeff Davis counties (Chowdhury and others, 2004).

Regional groundwater flow in the Salt Basin portion of the Capitan Reef Complex is believed to occur from the downthrown side of the Border Fault Zone in the Guadalupe Mountains to the Apache Mountains and may not be influenced by the groundwater divides apparent in the overlying alluvial aquifer (Angle, 2001; Finch and Bennett, 2002).

The groundwater flow in the eastern portion of the Capitan Reef Complex Aquifer—east of the Border Fault Zone—has probably changed in response to the incision by the Pecos River above the Capitan Reef Complex Aquifer (Hiss, 1980; Uliana, 2001). This incision took place during the Pliocene—2 to 5 million years ago—when a period of regional uplift caused rivers to erode downward and upstream (Gutentag and others, 1984). The incision of the Pecos River induced groundwater discharge to the river and reduced eastward groundwater flow into the eastern arm of the Capitan Reef Complex Aquifer (Figure 4.2.2). The reduced groundwater flow is due to direct and indirect effects of the river. The direct effects occur along the Pecos River near Carlsbad, New Mexico where the Capitan Reef Complex Aquifer occurs at shallow depths. The indirect effects occur due to induced upward inter-aquifer flow related to discharge to the Pecos River from overlying aquifers, such as the Pecos Valley, Dockum, and Rustler aquifers.

Figure 4.2.3 shows water-level data from the eastern arm of the Capitan Reef Complex Aquifer and surrounding basin and shelf stratigraphic units—fore-reef and back-reef facies, respectively. The water-level contours suggest: (1) eastward groundwater flow across the Delaware Basin and in the Northwestern Shelf and the Central Basin Platform; (2) clockwise groundwater flow in the Capitan Reef Complex Aquifer in New Mexico; (3) counter-clockwise groundwater flow in the Capitan Reef Complex Aquifer in Brewster, Pecos, Ward and Winkler counties; and (4) groundwater convergence in Winkler County. Continuity of water-level contours in the Capitan Reef Complex Aquifer and the basin and shelf stratigraphic units west of the Pecos River in New Mexico suggest hydrologic connections between the stratigraphic units—groundwater flow is all part of the same flow system. Elsewhere, water-level contours indicate unrelated flow systems in the Delaware Basin and Capitan Reef Complex Aquifer—indicating that there is no hydrologic connection as suggested by Bjorklund and Motts (1959) and Motts (1968). Water-level contours suggest hydraulic connections between the Capitan Reef Complex Aquifer and the shelf stratigraphic units observed west of the Pecos River continue east of the Pecos River. The apparent convergence of groundwater flow in Winkler County suggests: (1) discharge by cross-formational flow into the adjacent Central Basin Platform; or (2) discharge by cross-formational flow through the overlying collapse feature that formed due to dissolution of the Salado

Formation, cuts through overlying aquifers—the Rustler and Dockum aquifers—and resulted in the formation of the Monument Draw Trough in the Pecos Valley Aquifer (Jones, 2001; 2004; 2008).

Water-level data from the Capitan Reef Complex Aquifer study area are sparse. A total of 206 wells in the Capitan Reef Complex Aquifer have at least one water-level measurement, with a median of two measurements (Figure 4.2.4). There are only 68 wells in New Mexico—mostly in Eddy County, adjacent to the Pecos River—and no water-level measurements in Winkler County, Texas. Figure 4.2.5 shows the temporal distribution of the Capitan Reef Complex Aquifer water-level data—mostly since 1960. About half of the wells in the deepest part of the Capitan Reef Complex Aquifer—northern Pecos County and Ward County— are artesian or flowing wells (Figure 4.2.6). Water-level data shown in Figure 4.2.7 generally agree with the groundwater flowpaths proposed by Hiss (1980). Highest water levels in the Capitan Reef Complex Aquifer occur in the Guadalupe Mountains, decreasing to the east and west. Water levels are also high in the Glass Mountains decreasing to the north and reaching minimum elevations in Ward County. Figures 4.2.8 through 4.2.10 show water-level data for the aquifers that overlie the Capitan Reef Complex Aquifer—the Rustler, Dockum, Edwards-Trinity (Plateau), and Pecos Valley aquifers. In the Rustler Aquifer, water-level data displayed in Ewing and others (2012) suggest groundwater flow trends from the west and south, converging on the Monument Draw Trough and Pecos River (Figure 4.2.8). Dockum Aquifer water-level data suggest groundwater flow gradients from northwest to southeast (Figure 4.2.9). Water-level data in the Edwards-Trinity (Plateau) and Pecos Valley aquifers in the Capitan Reef Complex Aquifer study area indicate groundwater flow converging on the Pecos River (Figure 4.2.10). The Pecos River is the main groundwater discharge zone for the largely surficial Edwards-Trinity (Plateau) and Pecos Valley aquifers in the study area. Additionally, water-level data for the Pecos Aquifer indicate a cone of depression in central Reeves County attributable to irrigation pumping (Jones, 2001; 2004).

Water-level comparisons were conducted where: (1) the Capitan Reef Complex Aquifer is overlain by other aquifers—the Pecos Valley, Edwards-Trinity (Plateau), Dockum, and Rustler aquifers, and (2) there were available water data from wells located within 5 miles of a Capitan Reef Complex Aquifer well (Figure 4.2.11). Figure 4.2.12 shows the results of this comparison conducted at the five Capitan Reef Complex Aquifer locations shown in Figure 4.2.11. Inter-aquifer water-level comparisons suggest that water levels in the Capitan Reef Complex Aquifer are generally higher than the water levels in the overlying aquifers. This suggests upward hydraulic gradients and groundwater flow from the Capitan Reef Complex Aquifer to the overlying aquifers.

Figure 4.2.13 shows the locations with the most water-level data in each county. The total number of measurements range from 3 in Pecos County, Texas to 516 in Eddy County, New Mexico. Figures 4.2.14 and 4.2.15 show hydrographs of the transient water-level data. The hydrographs indicate: (1) gradual water-level decline over time in the western part of the Capitan

Reef Complex Aquifer—Hudspeth and Culberson counties, (2) a net water-level rise in the eastern part of the aquifer—Pecos and Ward counties, and (3) relatively constant water levels in northern part of the aquifer—Eddy County.

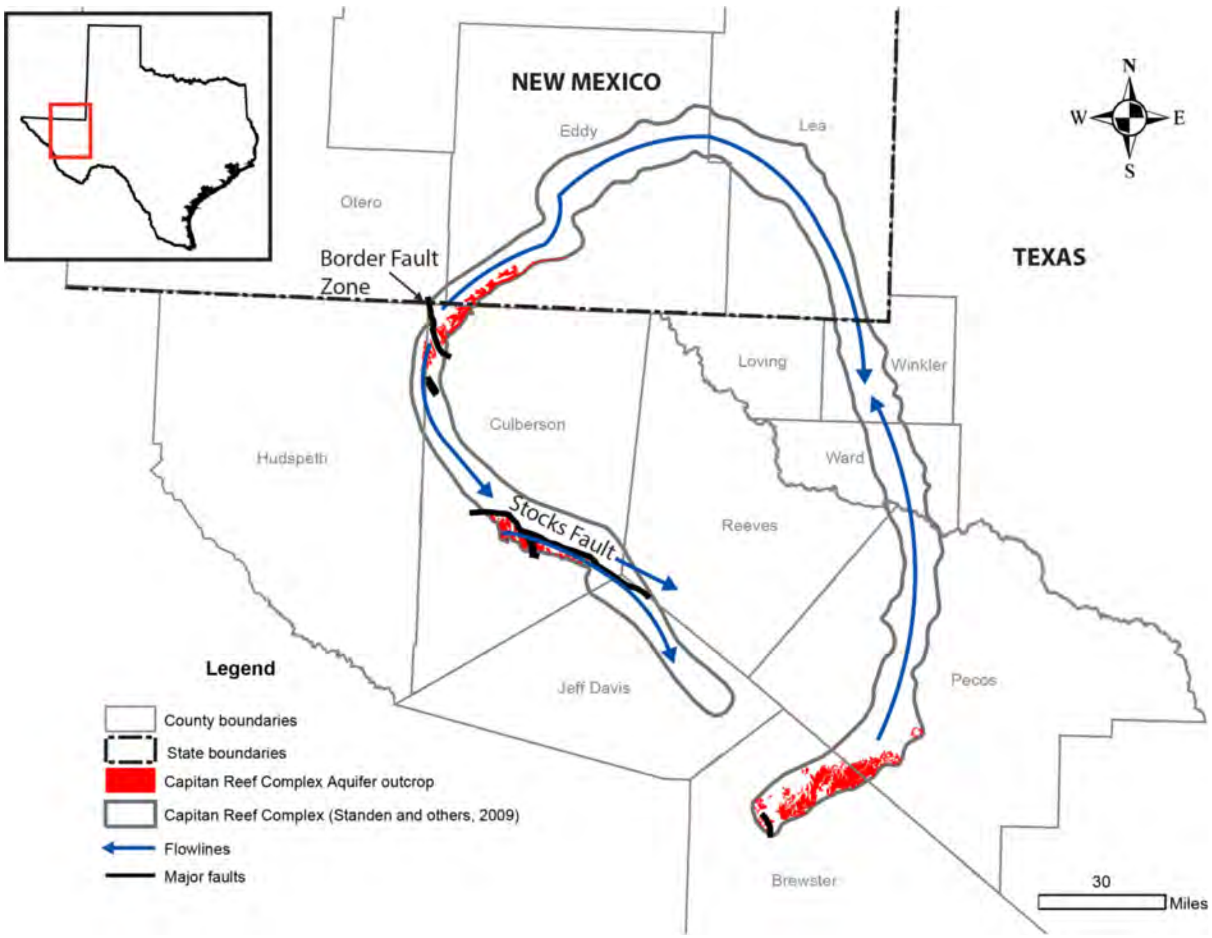


Figure 4.2.1. Conceptual diagram of the proposed flow systems in the Capitan Reef Complex Aquifer based on work by Hiss (1980), Sharp (2001), and Uliana (2001).

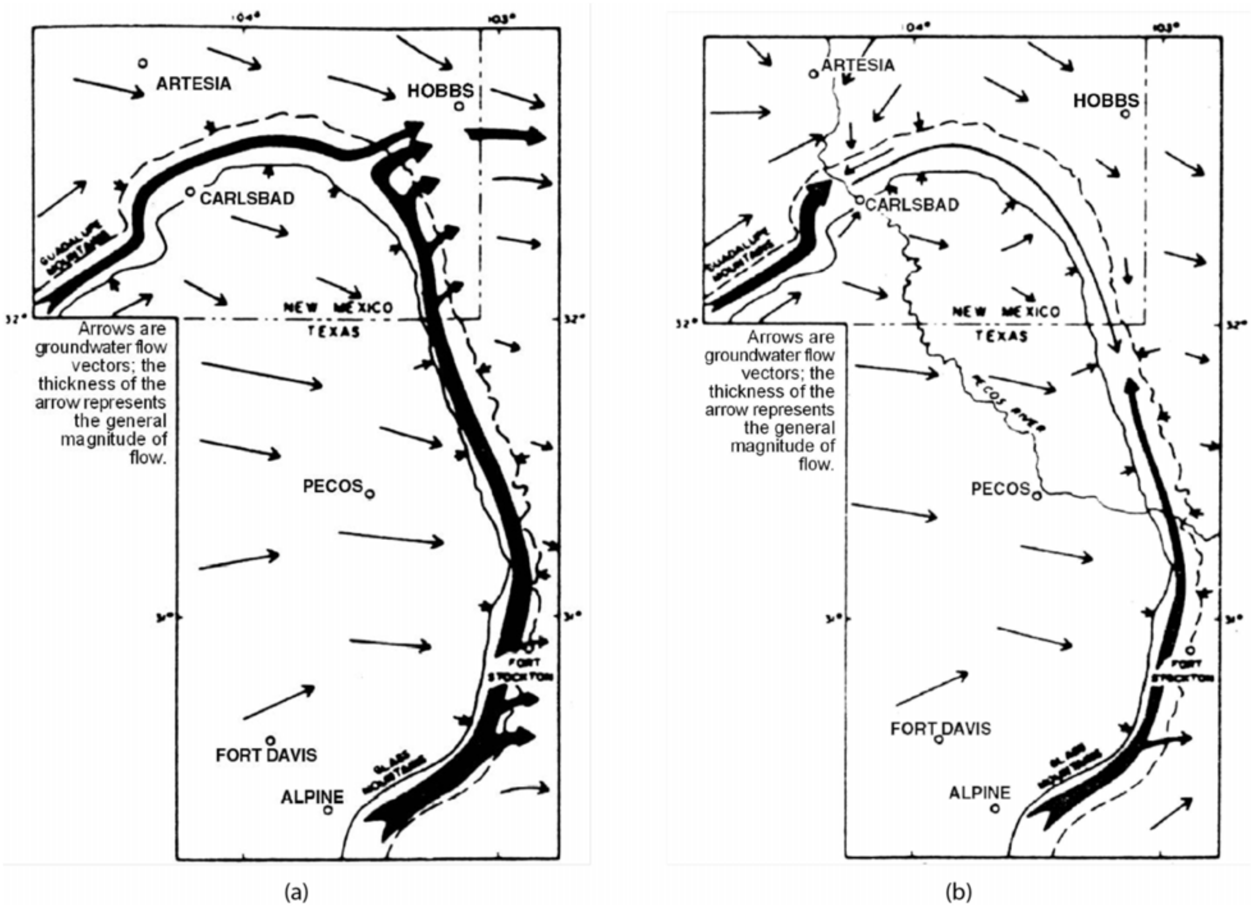


Figure 4.2.2. Groundwater flowpaths through the eastern arm of the Capitan Reef Complex Aquifer have changed over time in response to the development of the Pecos River. These maps show groundwater flowpaths (a) prior to the incision of the Pecos River, and (b) after the incision of the Pecos River (Modified from Hiss (1980)).

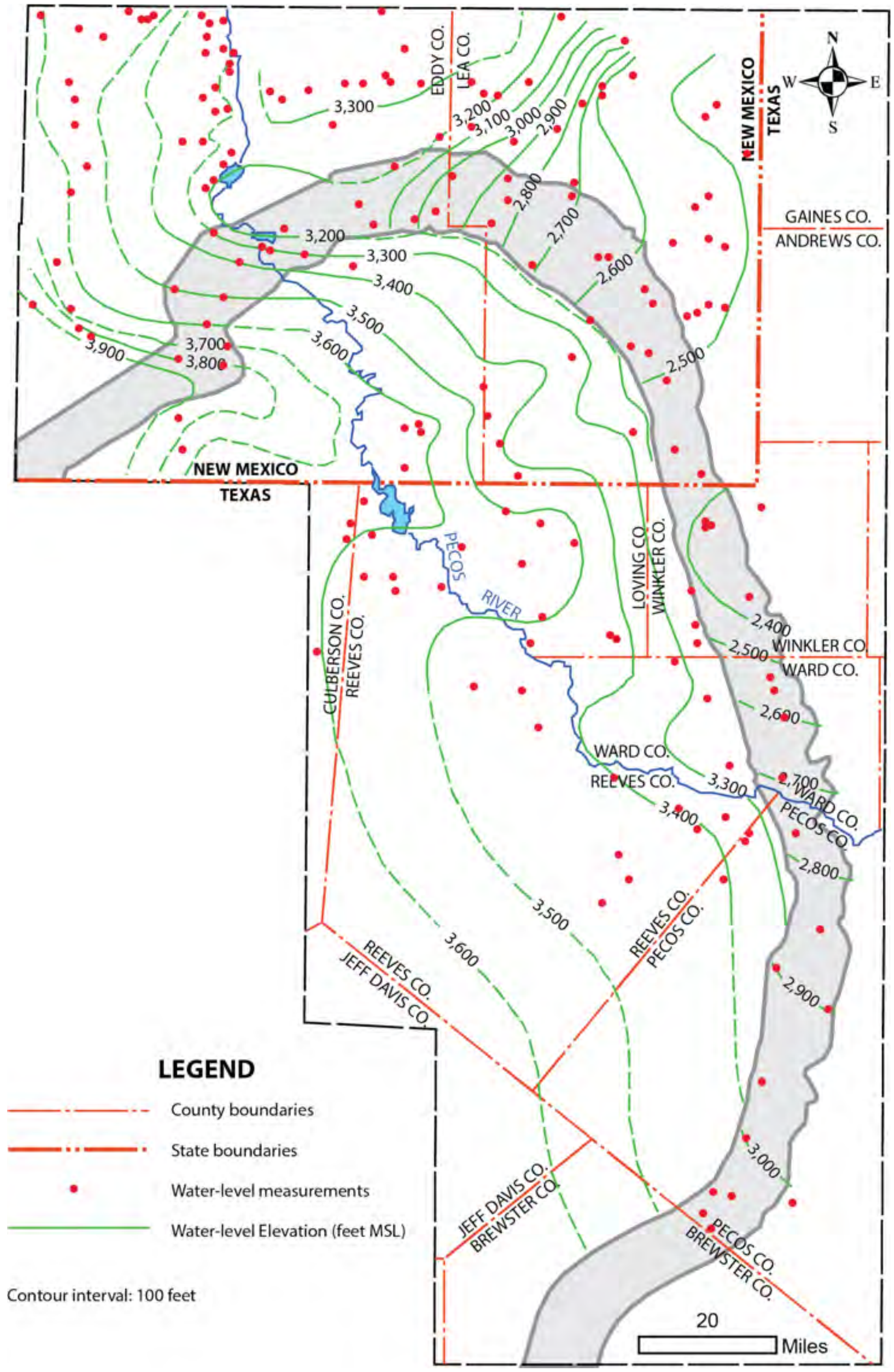


Figure 4.2.3. **Post-development water levels in the Capitan Reef Complex Aquifer and surrounding basin and shelf stratigraphic units (modified from Hiss, 1980). The continuity of water-level contours in the Capitan Reef Complex Aquifer and basin and shelf stratigraphic units in Eddy County indicate hydrologic connections that do not occur elsewhere.**

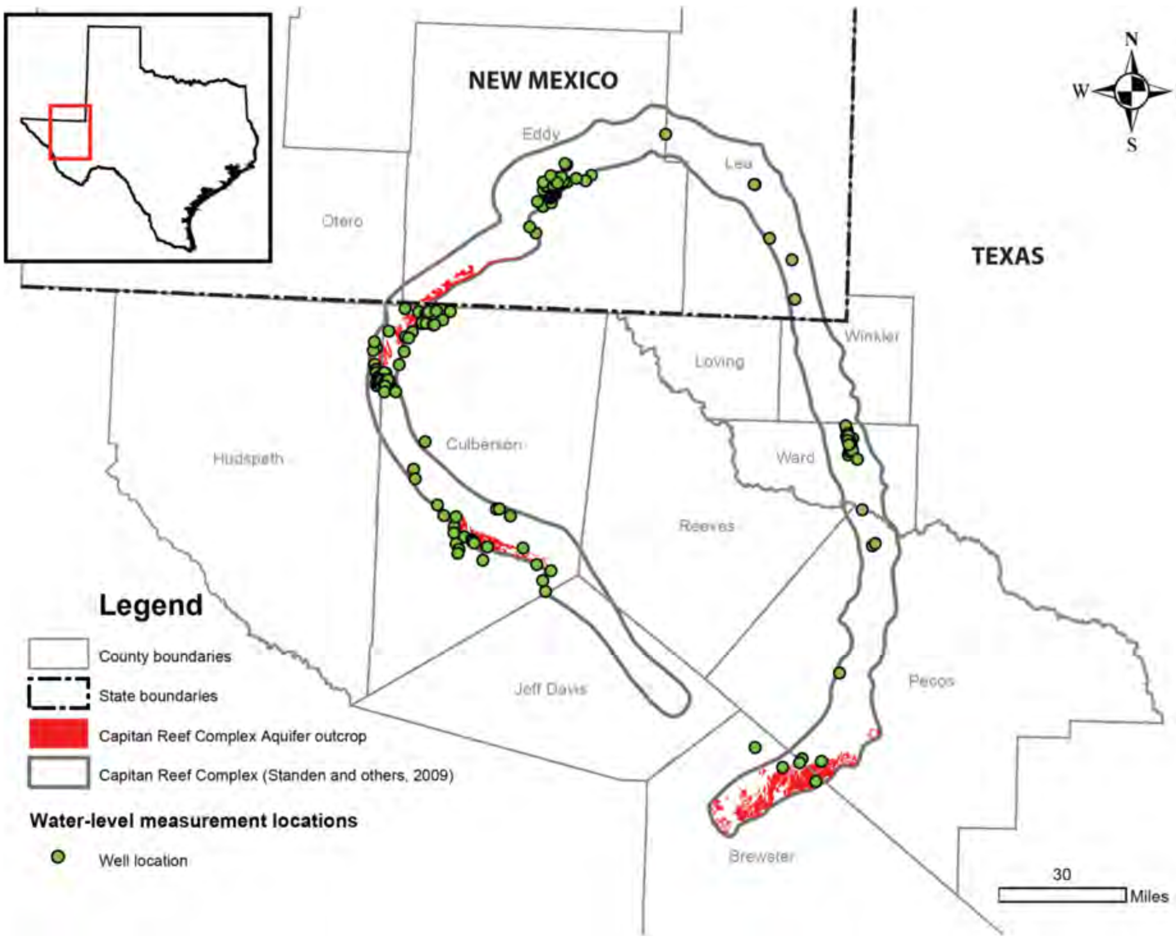


Figure 4.2.4. Water-level measurement locations for the Capitan Reef Complex Aquifer and adjacent areas (Texas Water Development Board, 2012b).

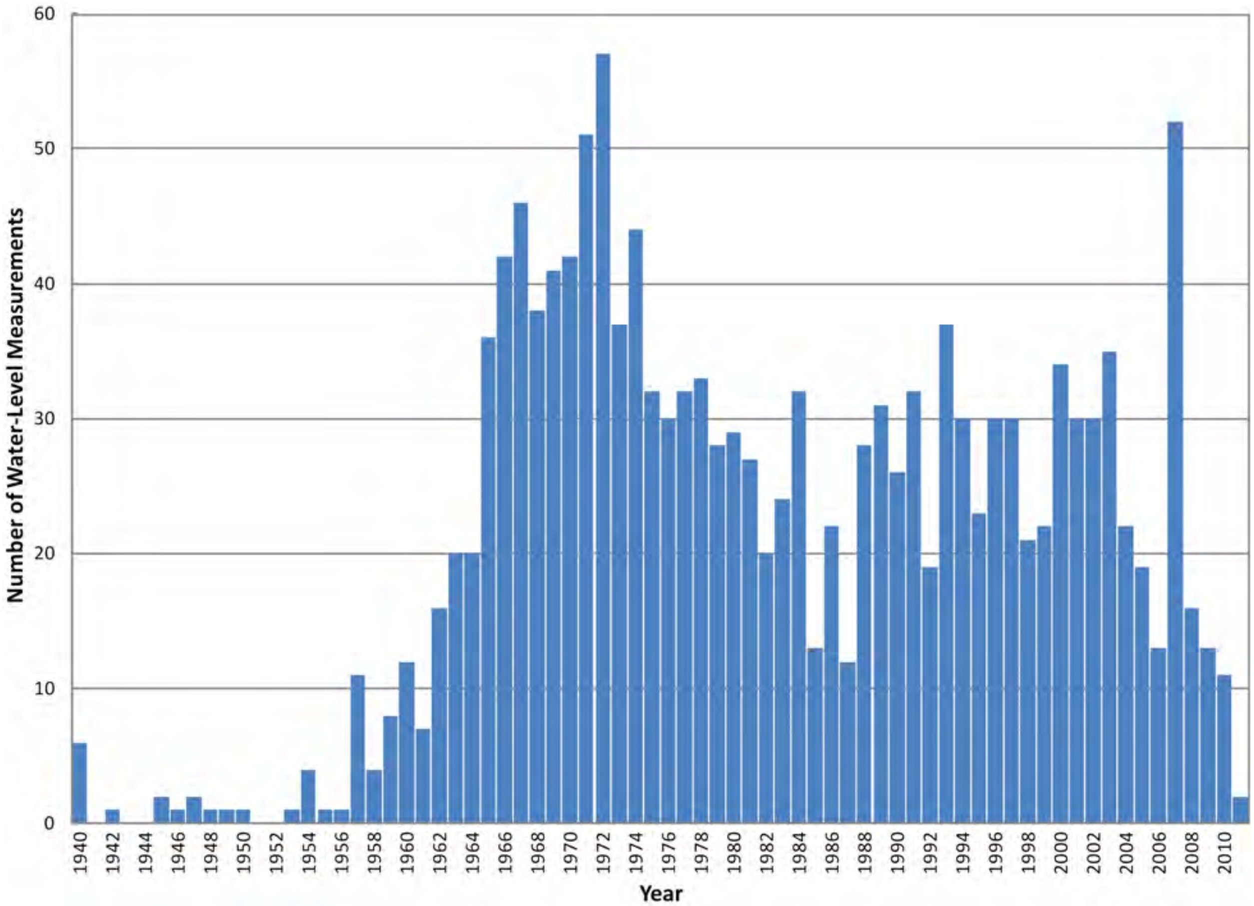


Figure 4.2.5. **Temporal distribution of water-level measurements in the Capitan Reef Complex Aquifer (Texas Water Development Board, 2012b).**

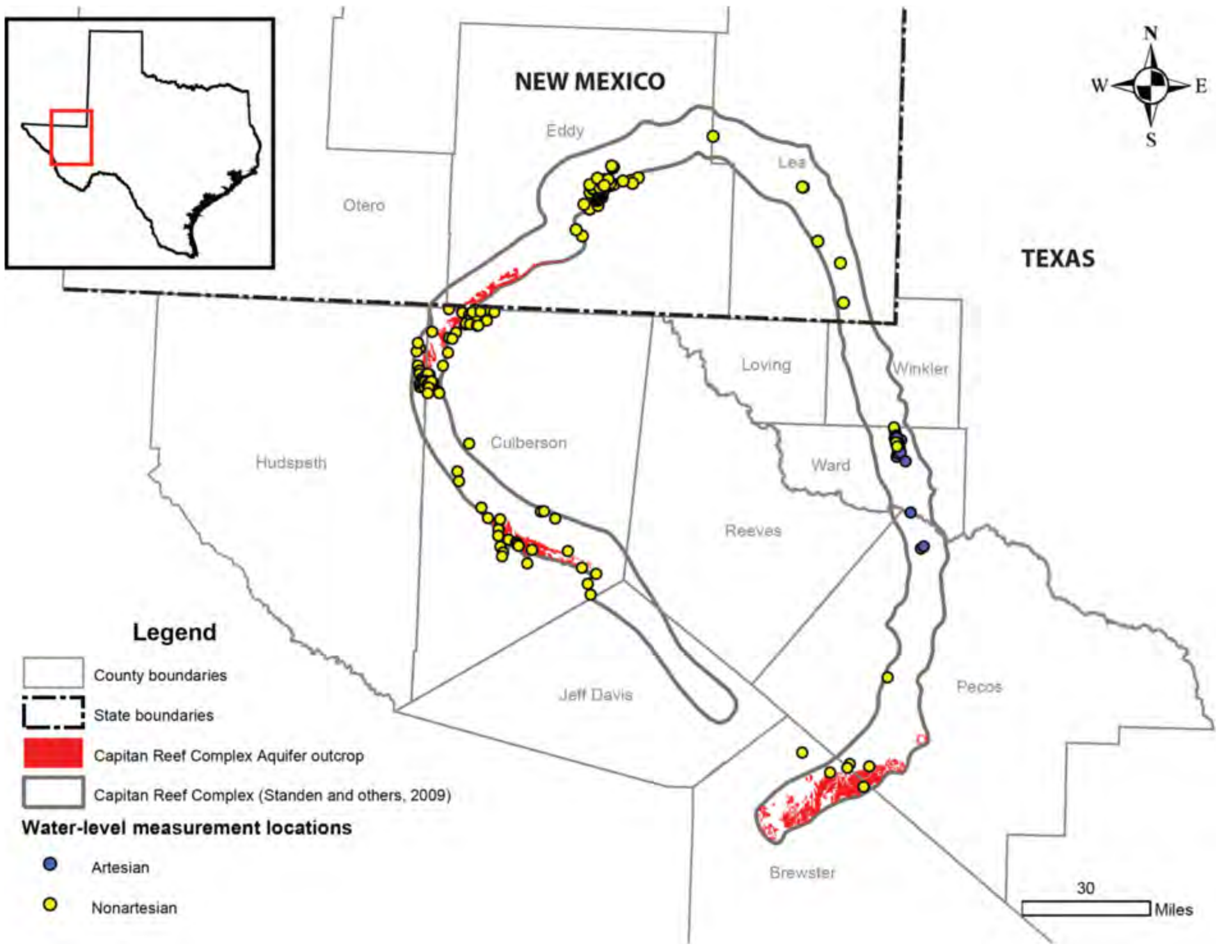


Figure 4.2.6. Locations of Capitan Reef Complex Aquifer historically artesian and non-artesian wells (Texas Water Development Board, 2012b).

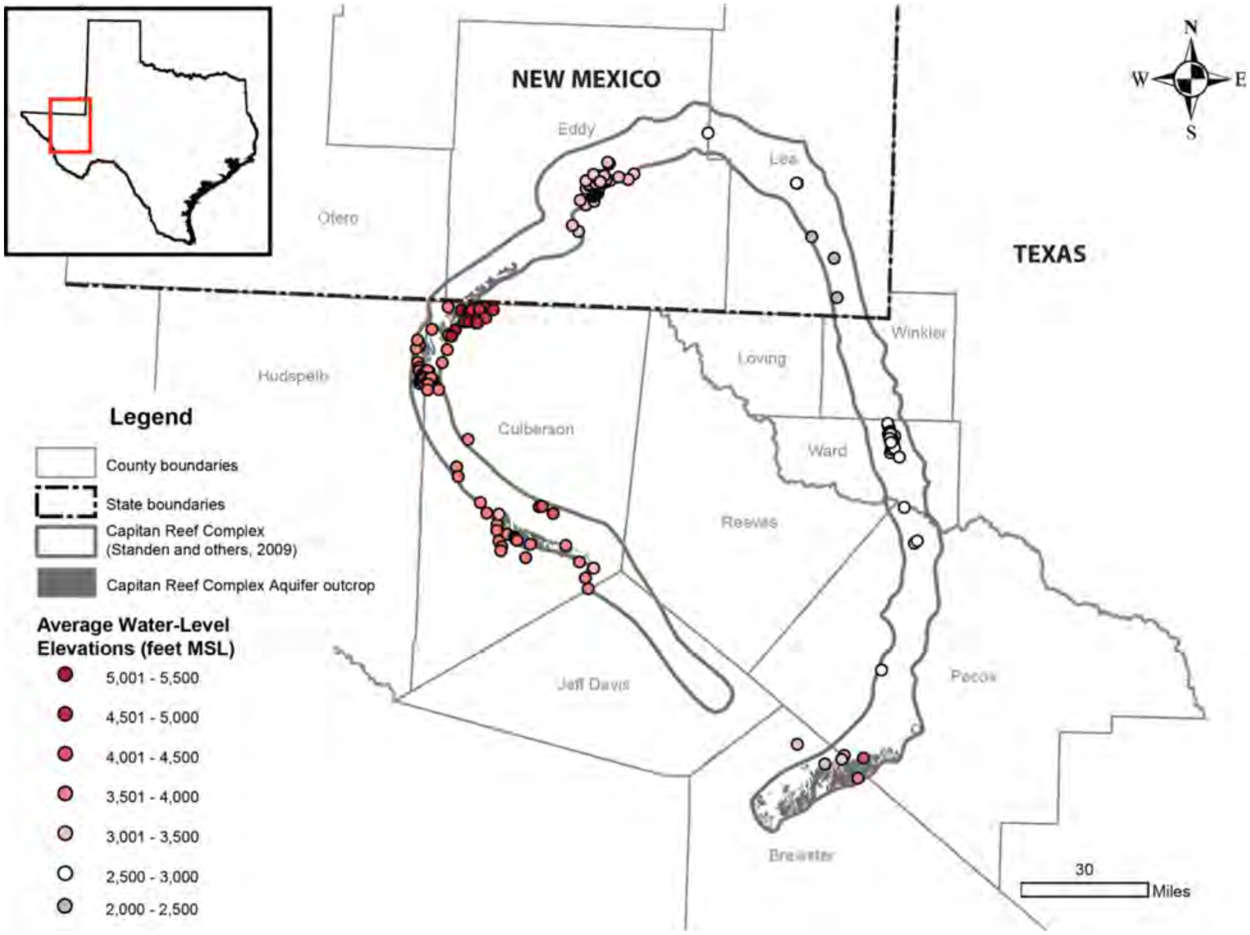


Figure 4.2.7. **Average water-level elevation (in feet above mean sea level (MSL)) for wells completed in the Capitan Reef Complex Aquifer (Texas Water Development Board, 2012b).**

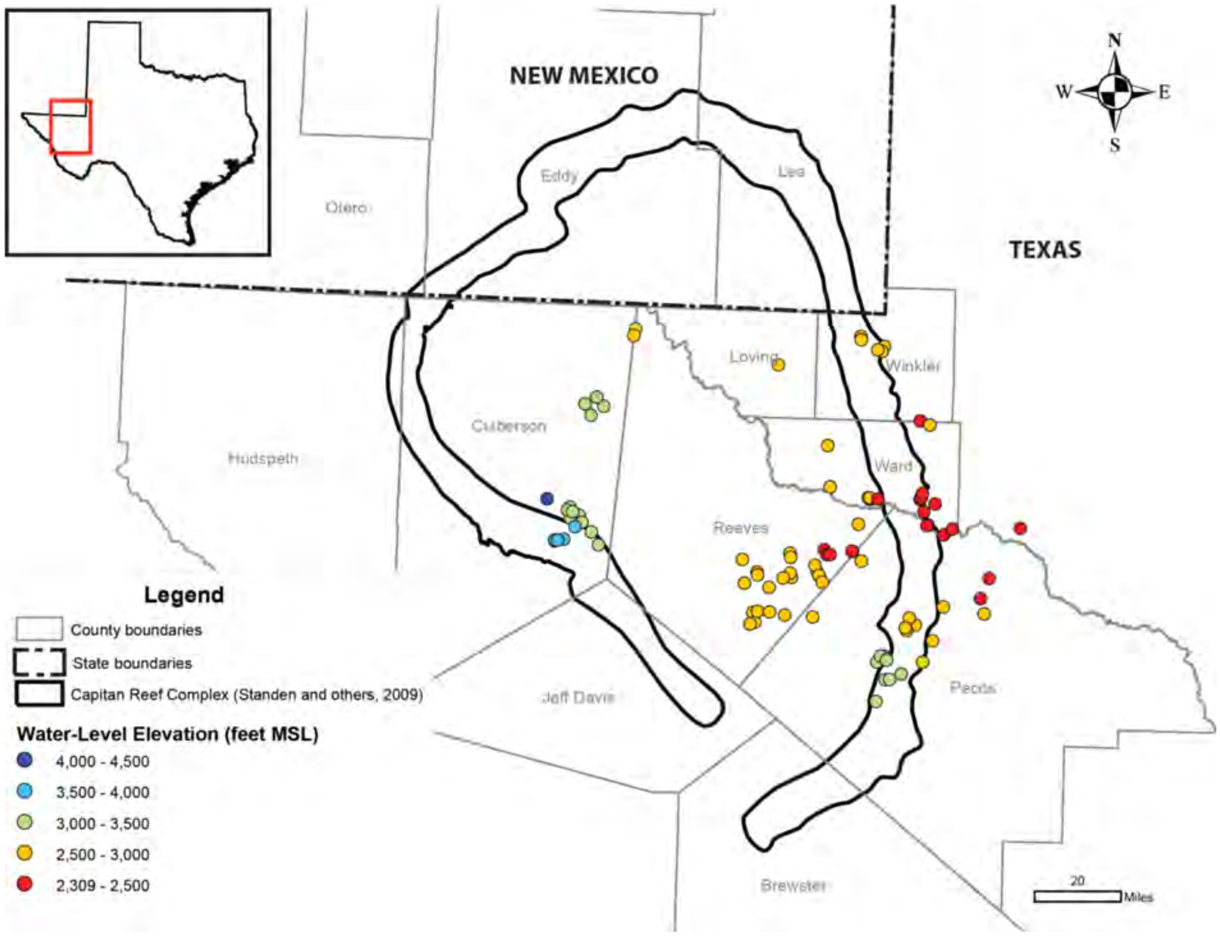


Figure 4.2.8. Average water-level elevation (in feet above mean sea level (MSL)) for wells completed in the Rustler Aquifer (Texas Water Development Board, 2012b).

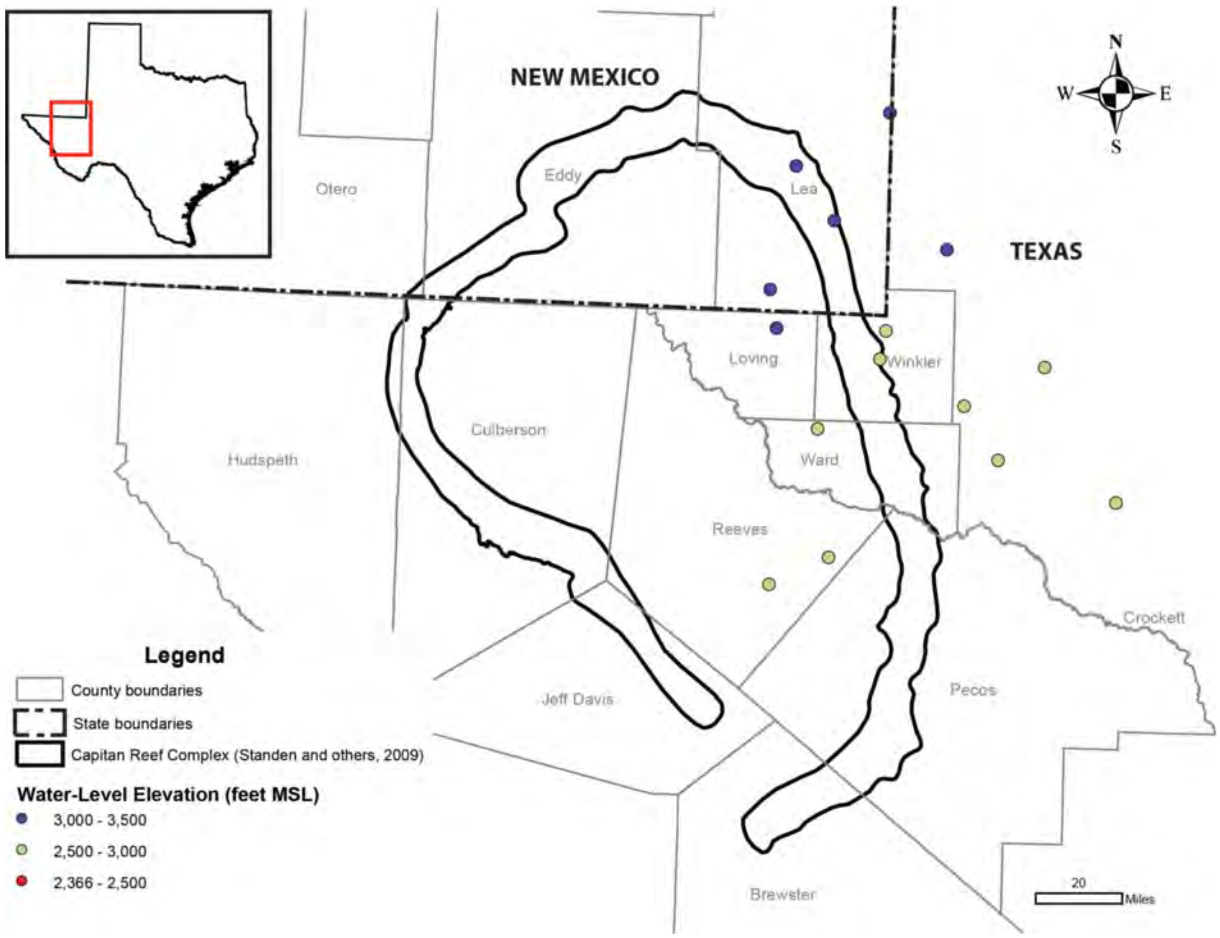


Figure 4.2.9. **Average water-level elevation (in feet above mean sea level (MSL)) for wells completed in the Dockum Aquifer (Texas Water Development Board, 2012b).**

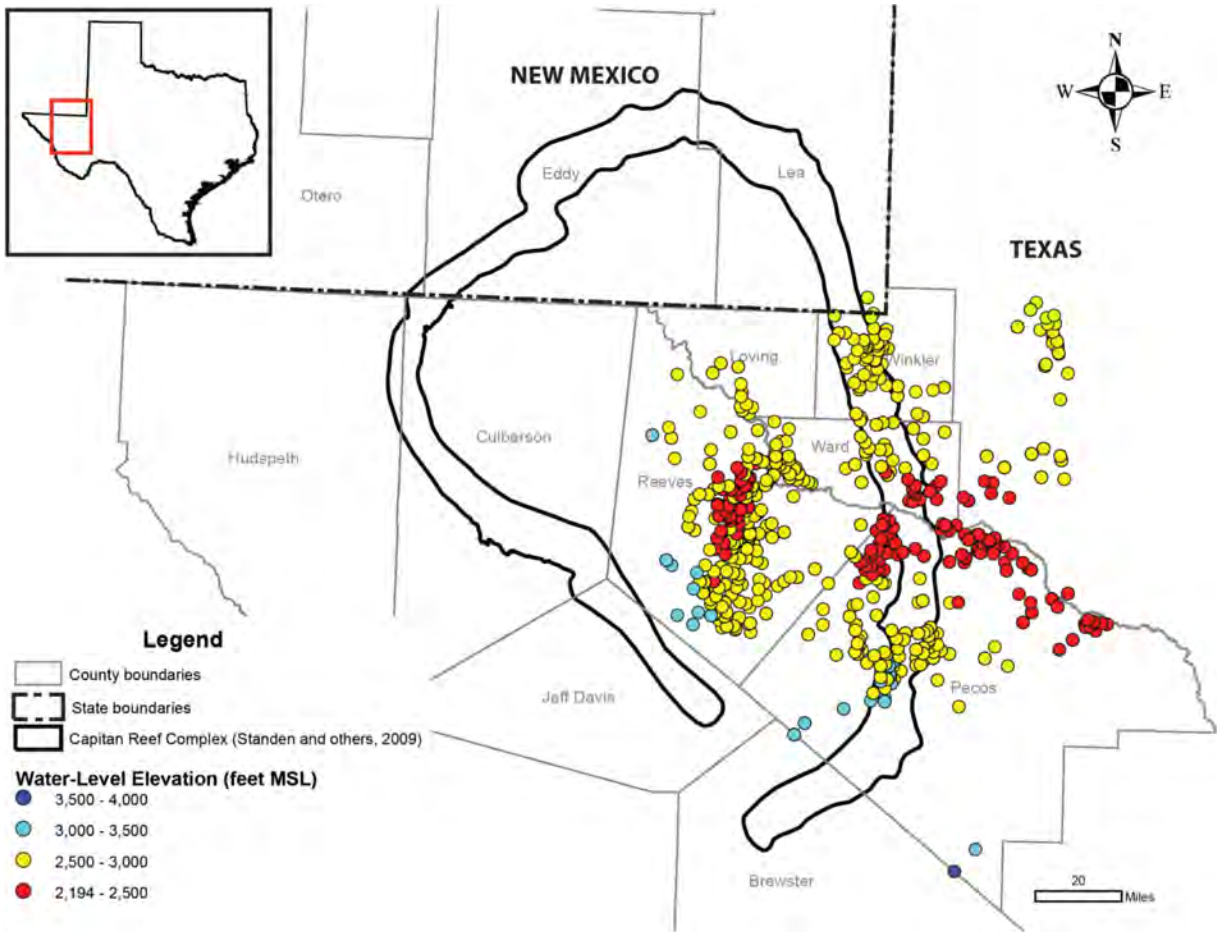


Figure 4.2.10. Average water-level elevation (in feet above mean sea level (MSL)) for wells completed in the Edwards-Trinity (Plateau) and Pecos Valley aquifers (Ewing and others, 2012; Texas Water Development Board, 2012b).

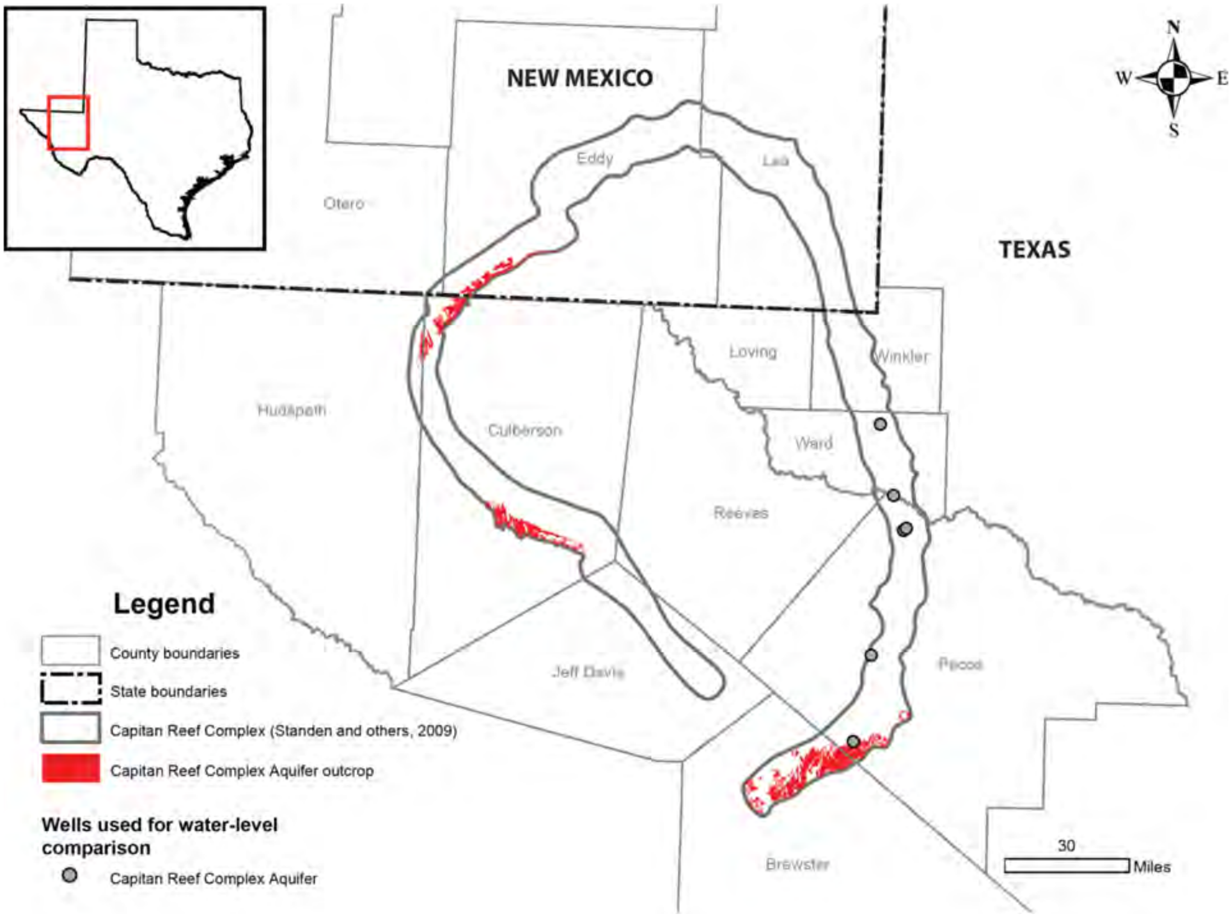
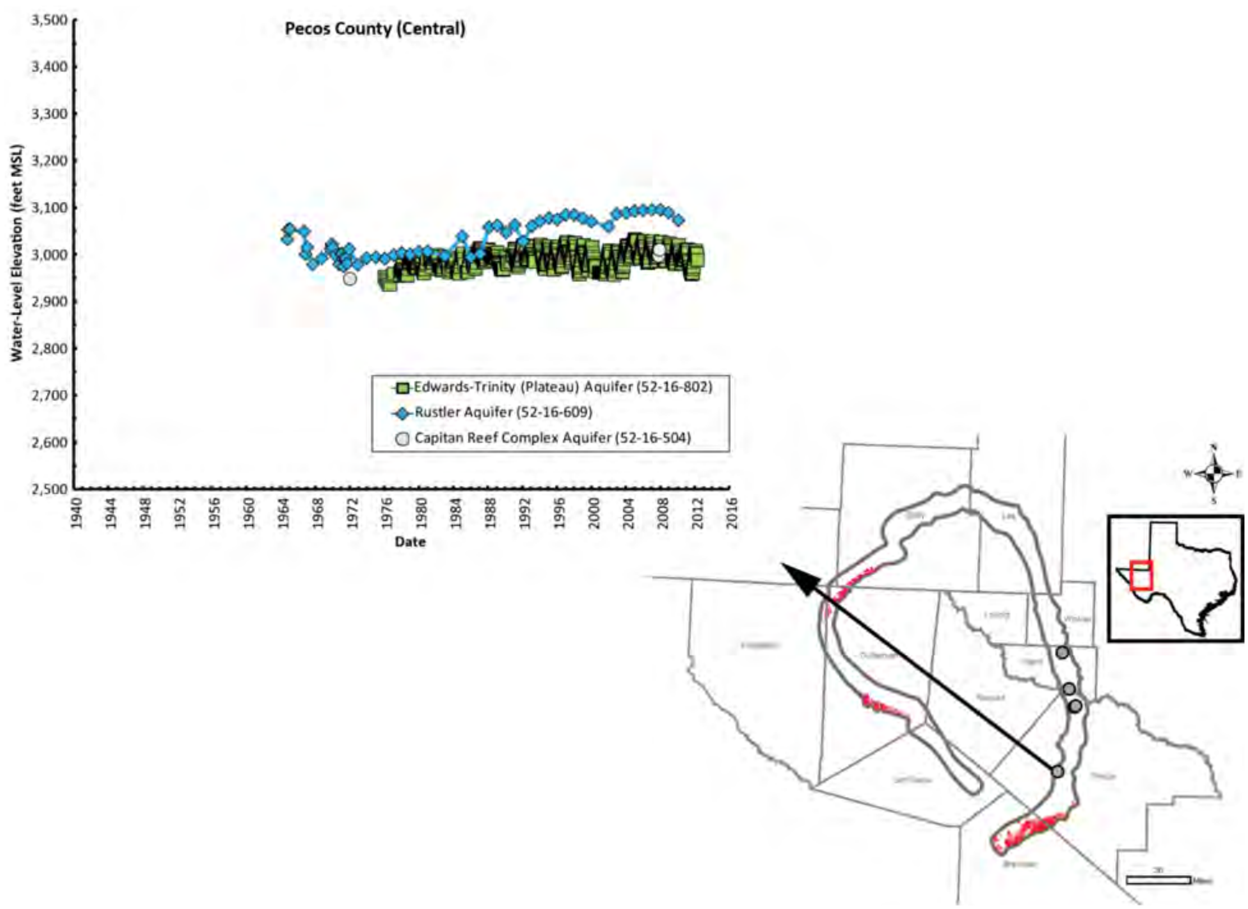
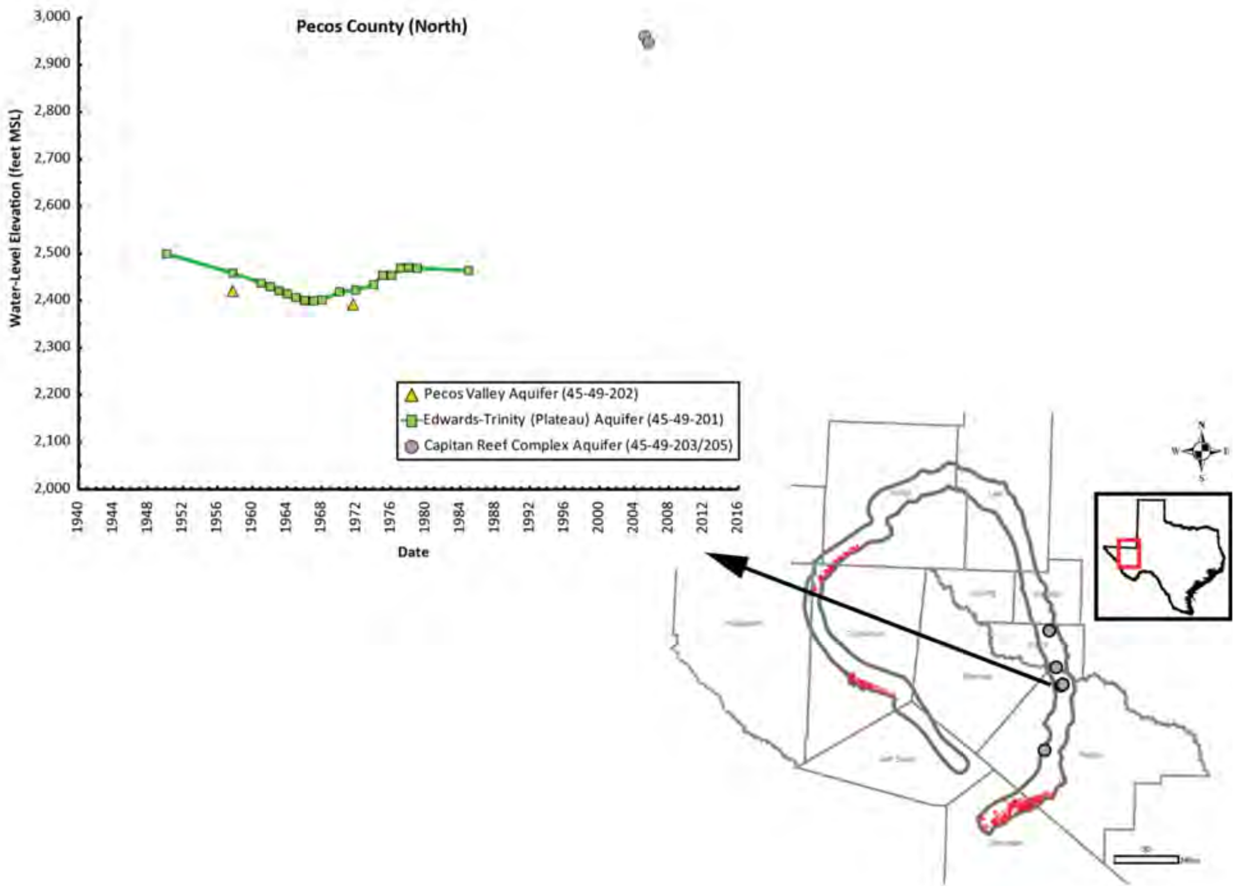


Figure 4.2.11. Locations of wells used for comparing water-level elevations between aquifers (Texas Water Development Board, 2012b).



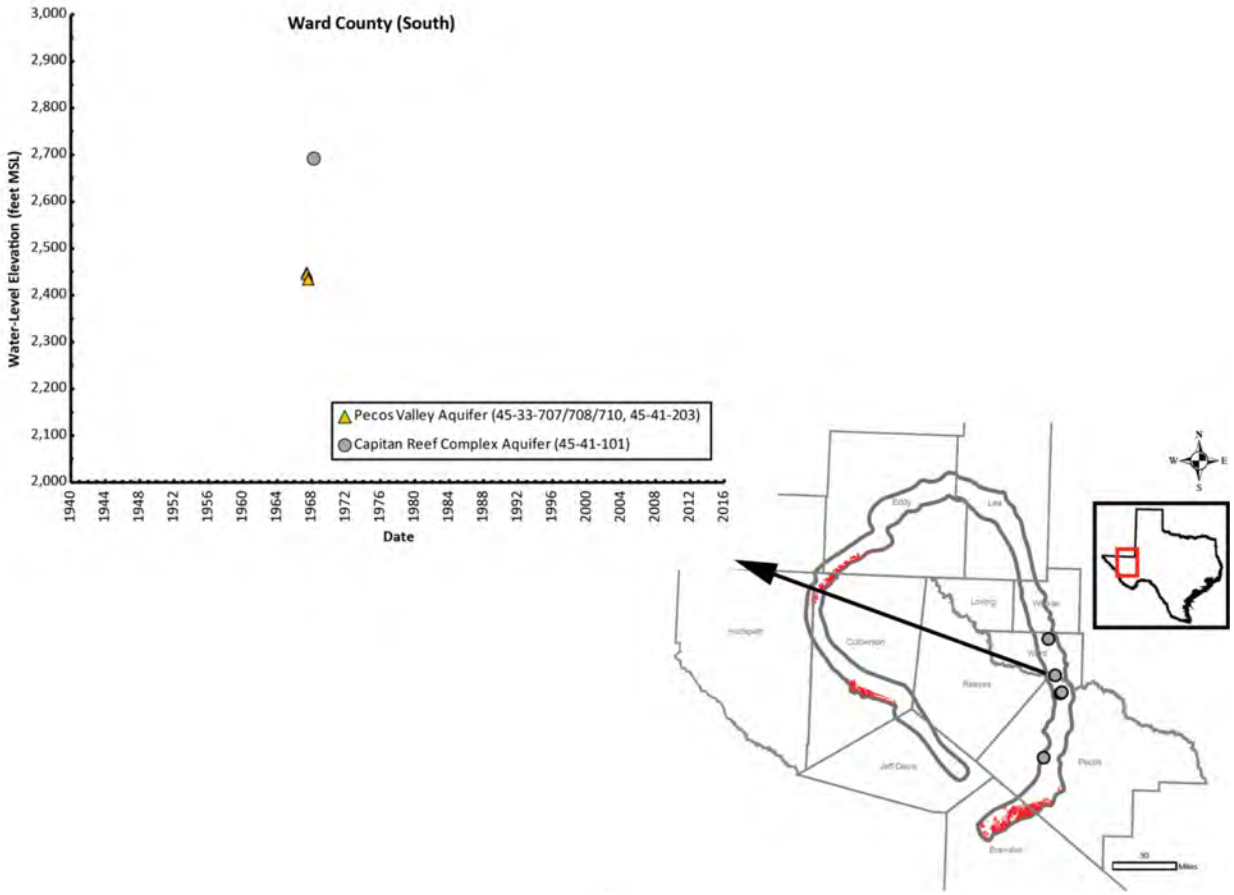
(A)

Figure 4.2.12. **Comparison of water-level elevations (in feet above mean sea level (MSL)) in the Capitan Reef Complex and overlying Rustler, Dockum, Edwards-Trinity (Plateau), and Pecos Valley aquifers (Texas Water Development Board, 2012b).**



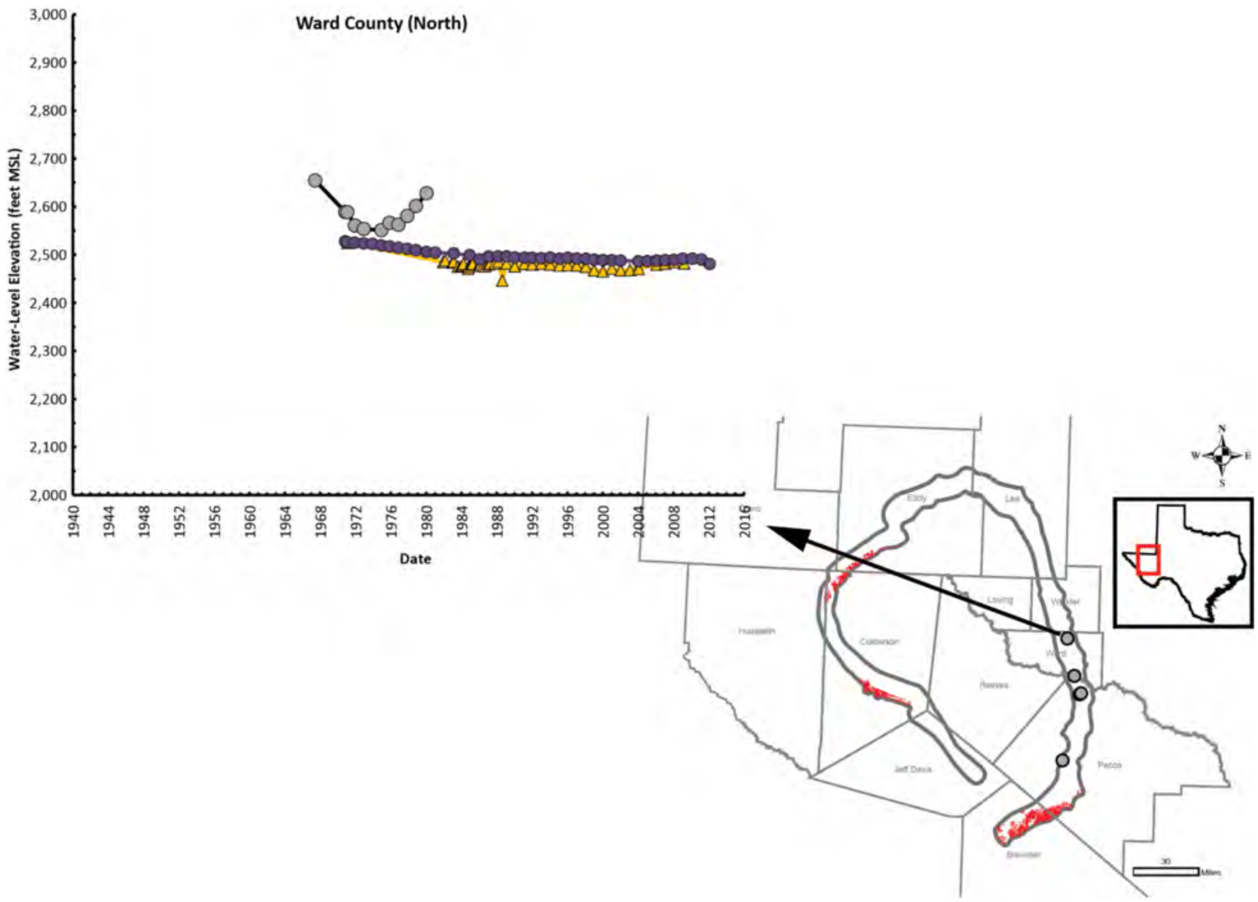
(B)

Figure 4.2.12. (continued)



(C)

Figure 4.2.12. (continued)



(D)

Figure 4.2.12. (continued)

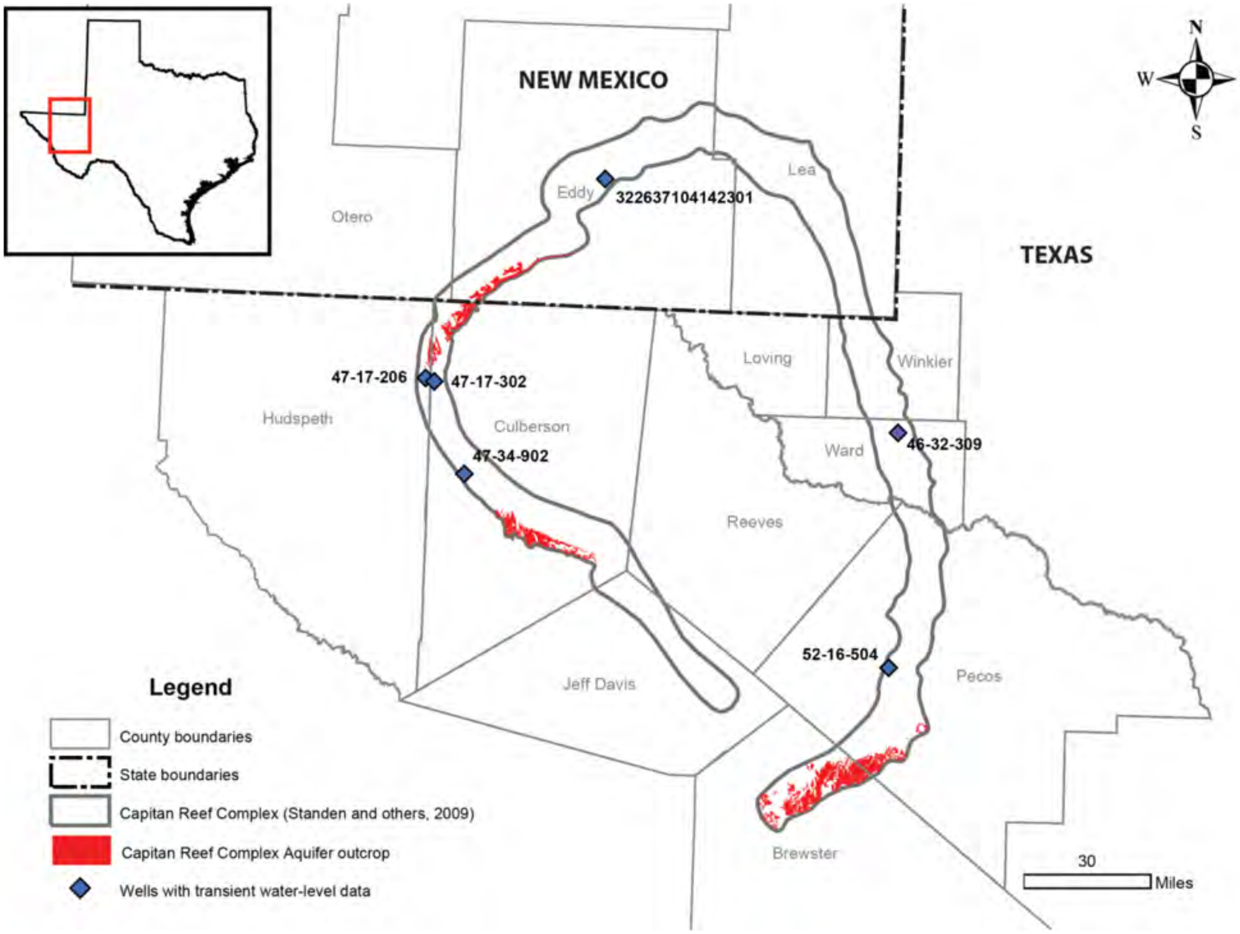


Figure 4.2.13. Locations of selected Capitan Reef Complex Aquifer wells with transient water-level data (Texas Water Development Board, 2012b; United States Geological Survey, 2012a).

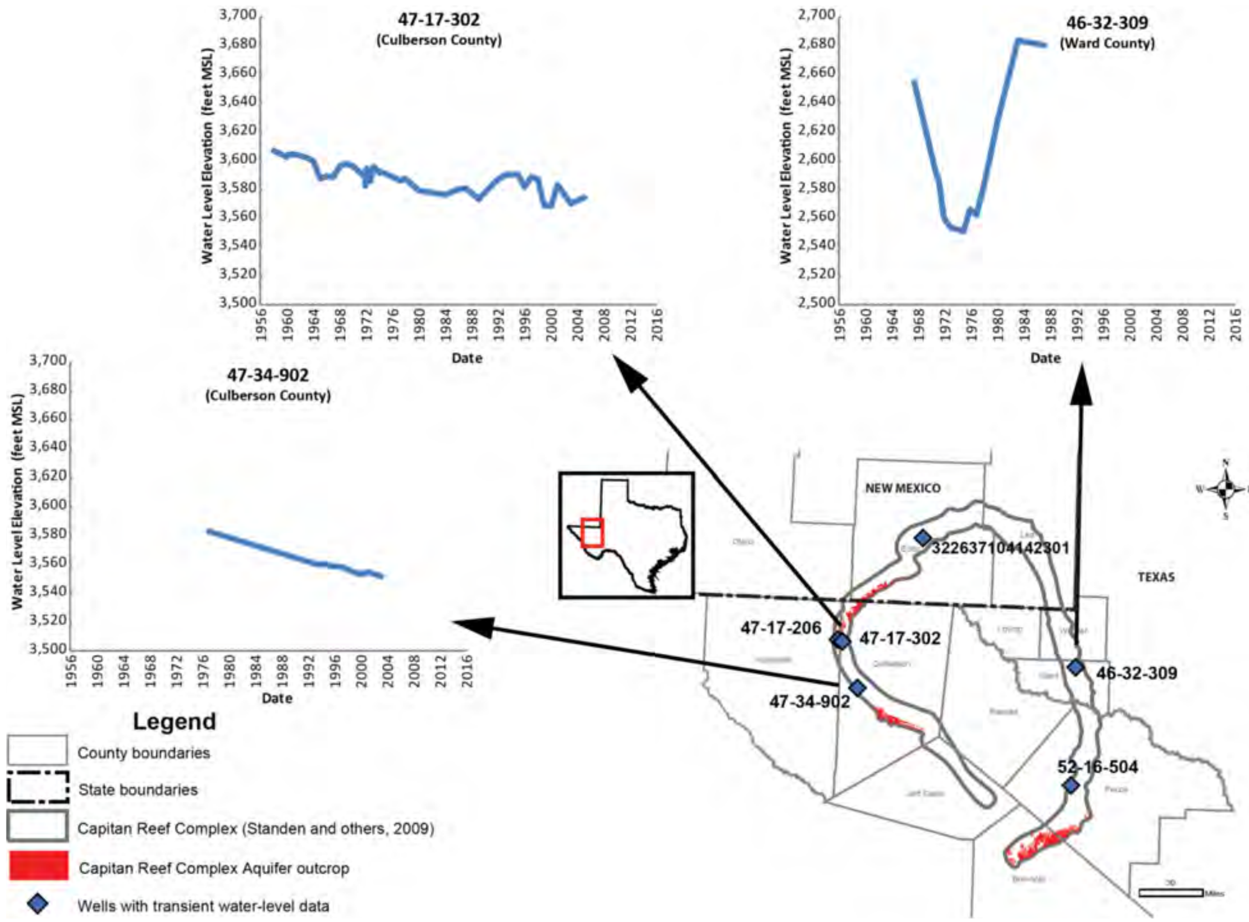


Figure 4.2.14. Hydrographs of transient water-level data (in feet above mean sea level (MSL)) for Capitan Reef Complex Aquifer wells in Culberson and Ward counties (Texas Water Development Board, 2012b).

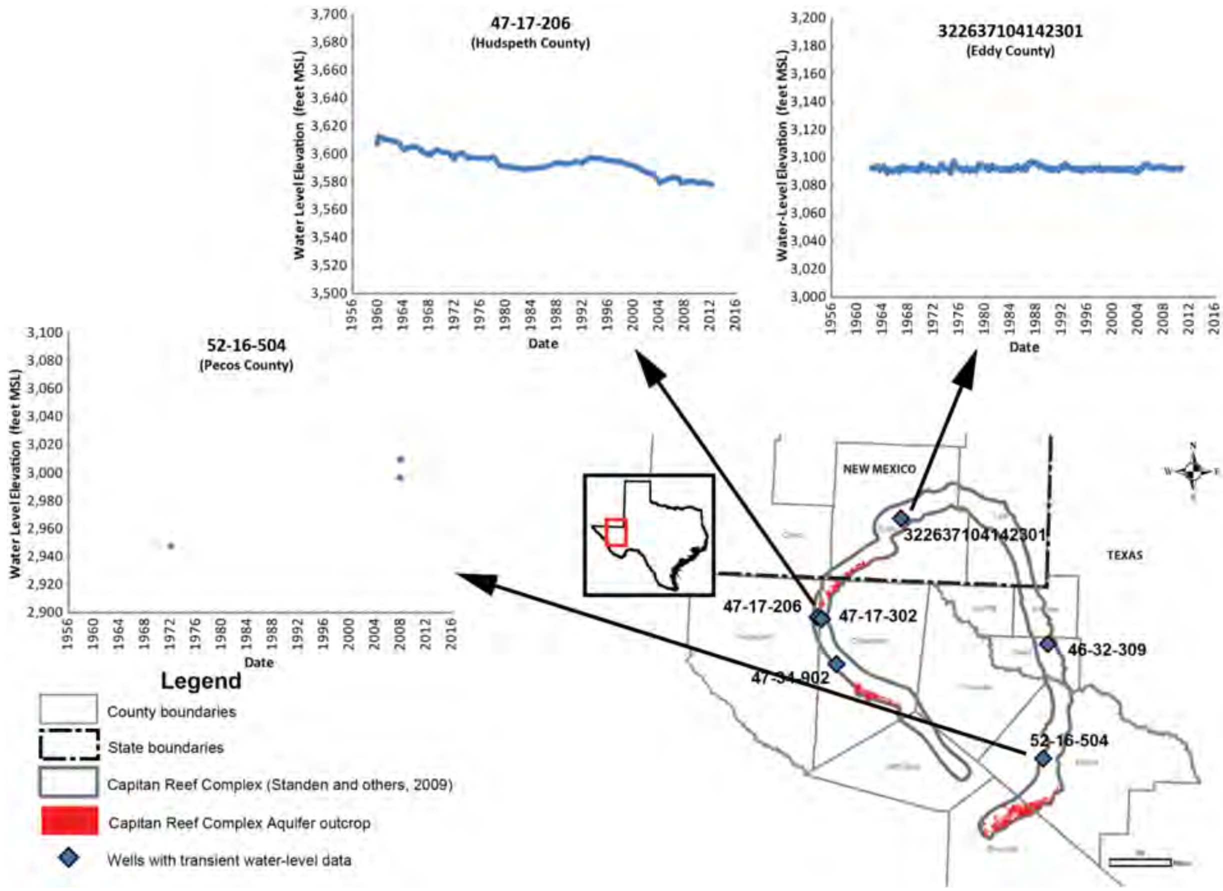


Figure 4.2.15. Hydrographs of transient water-level data (in feet above mean sea level (MSL)) for Capitan Reef Complex Aquifer wells in Hudspeth and Pecos counties in Texas and Eddy County in New Mexico (Texas Water Development Board, 2012b; United States Geological Survey, 2012a).

4.3 Recharge

Recharge is defined as the processes involved in the addition of water to the water table (Jackson, 1997). Potential sources for recharge include infiltration of precipitation and stream water, and irrigation return-flow.

During a rainfall event, some of the precipitation: (1) runs off through streams, (2) is taken up through evapotranspiration, and (3) the remainder—if any—infiltrates into the soil and rock and recharges the underlying aquifer. The potential for the occurrence of recharge to the Capitan Reef Complex Aquifer is greater where it is exposed at land surface (see Figure 4.3.1) compared to areas where infiltrating water must pass through overlying units. Faults and karst dissolution features potentially facilitate recharge by acting as pathways for rapid infiltration of water both where the Capitan Reef Complex Aquifer crops out and where it is confined by overlying aquifers or aquitards—rocks that do not transmit useable amounts of water and thus do not meet the criteria to be aquifers. Recharge to the Capitan Reef Complex Aquifer is potentially topographically controlled, with higher recharge in the areas of higher elevation where the amount of precipitation is highest and the evaporative potential is least (Figures 2.1.3 and 2.1.6).

Isotopes in groundwater, such as carbon-13, carbon-14, tritium, and stable hydrogen and oxygen can be used to determine the spatial and seasonal distribution of recharge to an aquifer (See Section 4.7). The carbon-13 and carbon-14 isotopic compositions of Capitan Reef Complex Aquifer groundwater indicate recharge zones in the Guadalupe and Glass mountains but little recharge in the Apache Mountains—all areas where the aquifer crops out. The carbon-13 and carbon-14 isotopic compositions also indicate recharge associated with faults near the southern margin of the Delaware Mountains. Groundwater tritium compositions indicate that the most recent recharge to the Capitan Reef Complex Aquifer occurred near the southern margin of the Delaware Mountains. The stable oxygen and hydrogen isotopes indicate a relatively simple flow system in the eastern arm of the Capitan Reef Complex Aquifer with a single recharge zone. In the west, there is a more complex system where recharge takes place under a range of conditions.

Ewing and others (2012) estimated potential recharge to the Capitan Reef Complex Aquifer in the Glass Mountains in the range of 1,090 to 14,210 acre-feet per year during their study of the Rustler Aquifer. These estimates are based on assumed recharge factors—percentages of average annual precipitation—ranging from 0.77 percent to 10 percent. These highest recharge factors were justified by the occurrence of karst features in the Glass Mountains that have the potential to facilitate rapid infiltration of large amounts of recharge water. INTERA (2013) estimated recharge to the outcrop of the Capitan Reef Complex Aquifer in the Glass Mountains of 0 to 2.69 inches per year and averaging 0.63 inches per year. Finch (2014) estimated recharge to the Capitan Reef Complex Aquifer outcrop in the Glass Mountains based on daily precipitation. The resultant recharge estimate was 2.56 inches per year or 18 percent of the average annual precipitation. There are some other studies of recharge in arid environments that have some relevance to the Capitan Reef Complex Aquifer (Hibbs and Darling, 1995; Hibbs and others, 1998; Stone and others, 2001; Beach and others, 2004; Wilson and Guan, 2004; Berger and others, 2008). However, these studies are not directly applicable to the Capitan Reef Complex Aquifer.

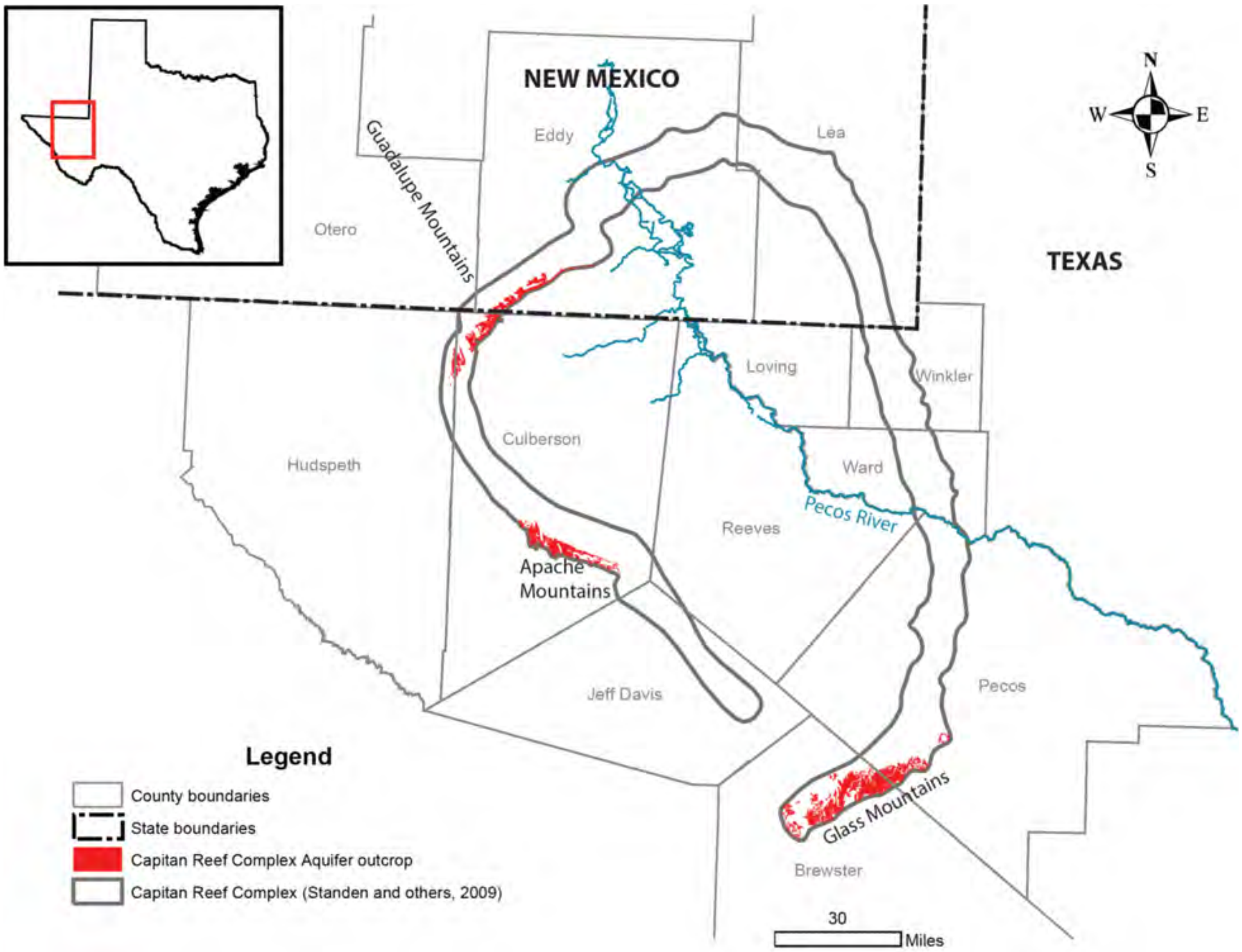


Figure 4.3.1. Capitan Reef Complex Aquifer outcrop regions where the potential for recharge is assumed to be the greatest.

4.4 Rivers, Streams, Springs, and Lakes

Interaction between groundwater and surface water occurs primarily where surface water bodies—rivers and streams, springs, and lakes—intersect with aquifer outcrops. These interactions result in flow between the aquifer and surface-water bodies. The direction of flow depends on the relative groundwater and surface-water levels with water flowing from relatively high to relatively low water levels.

4.4.1 Rivers and Streams

Interaction between groundwater and rivers and streams depends on the relative elevations of the water table and the stream stage. In losing streams, the water table is below the elevation of the stream stage, and the gradient causes water to flow from the stream into the aquifer. In gaining streams, the water table is above the elevation of the stream stage and consequently water flows from the aquifer into the stream.

No existing studies were found to describe river gain/loss in the Capitan Reef Complex Aquifer outcrop. This is not surprising because there are very few perennial water bodies in the study area (Figure 2.0.4). The unproductive search for existing studies included a review of gain/loss studies in Texas completed by Slade and others (2002). Determination of streamflow gain or loss in the Pecos River where it crosses the Capitan Reef Complex Aquifer is difficult because of the presence of a reservoir—Lake Avalon—that disrupts natural flow through the river. Comparison of streamflow at upstream and downstream locations on the Capitan Reef Complex Aquifer footprint—Stations 08401500 and 08405200, respectively—suggest mostly declining streamflow across the outcrop (Figure 4.4.1). This contradicts findings by Hiss (1980) who reported aquifer discharge along the river. The declining streamflow may be explained by increasing storage in Lake Avalon and the fact that due to the presence of the reservoir located between the two gaging stations, the Pecos River does not flow naturally (also see Section 4.4.3).

4.4.2 Springs

Springs are locations where the water table intersects the ground surface. Spring data for the Capitan Reef Complex Aquifer were found in the Texas Water Development Board groundwater database (Texas Water Development Board, 2012b), a database of Texas springs compiled by the United States Geological Survey (Heitmuller and Reece, 2003), and a report on the springs of Texas by Brune (2002). Only one spring identified as discharging from the Capitan Reef Complex Aquifer was located from the three data sources—Frijoles Spring—located in the Guadalupe Mountains (Figure 4.4.2). A second spring—Carlsbad Springs—is located in New Mexico. Discharge from Carlsbad Springs to the Pecos River is reported to include groundwater discharge from the Capitan Reef Complex Aquifer in addition to groundwater from the overlying Artesia Group (Bjorklund, 1958; Thomas, 1963; Texas Department of Water Resources, 1978).

There is very little spring discharge data available for springs discharging from the Capitan Reef Complex Aquifer. Spring discharge from Frijoles Spring was reported as less than 2 gallons per minute (Texas Water Development Board, 2012b). It should be noted that Carlsbad Springs receives water from multiple sources in addition to the Capitan Reef Complex Aquifer (Bjorklund, 1958; Cox, 1967; Texas Department of Water Resources, 1978). These sources include Lake Avalon, return-flow from nearby irrigated farmland, and discharge from overlying stratigraphic units. Reported discharge rates from Carlsbad Springs range from 30 cubic feet per second to 100 cubic feet per second (Bjorklund, 1958).

4.4.3 Lakes and Reservoirs

Typically, interaction between an aquifer and a lake or reservoir is restricted to the outcrop area of an aquifer where the lake or reservoir lies directly on the aquifer. There are no natural lakes or reservoirs in the outcrop of the Capitan Reef Complex Aquifer. However, there is thought to be interaction between the Capitan Reef Complex Aquifer and Lake Avalon, which is located on the

Pecos River overlying the Capitan Reef Complex Aquifer (Figure 4.4.3). Bjorklund (1958) and Cox (1967) discuss the interaction of Lake Avalon, the Capitan Reef Complex Aquifer, and Carlsbad Springs. They found that water seeps from Lake Avalon, recharging the underlying Capitan Reef Complex Aquifer and rapidly discharges back into the Pecos River downstream through the Carlsbad Springs. Bjorklund (1958) suggested that the net effect of seepage from Lake Avalon on discharge at Carlsbad Springs lags by one to three months. These effects are superimposed upon effects associated with fluctuations of the water levels in the Capitan Reef Complex Aquifer.

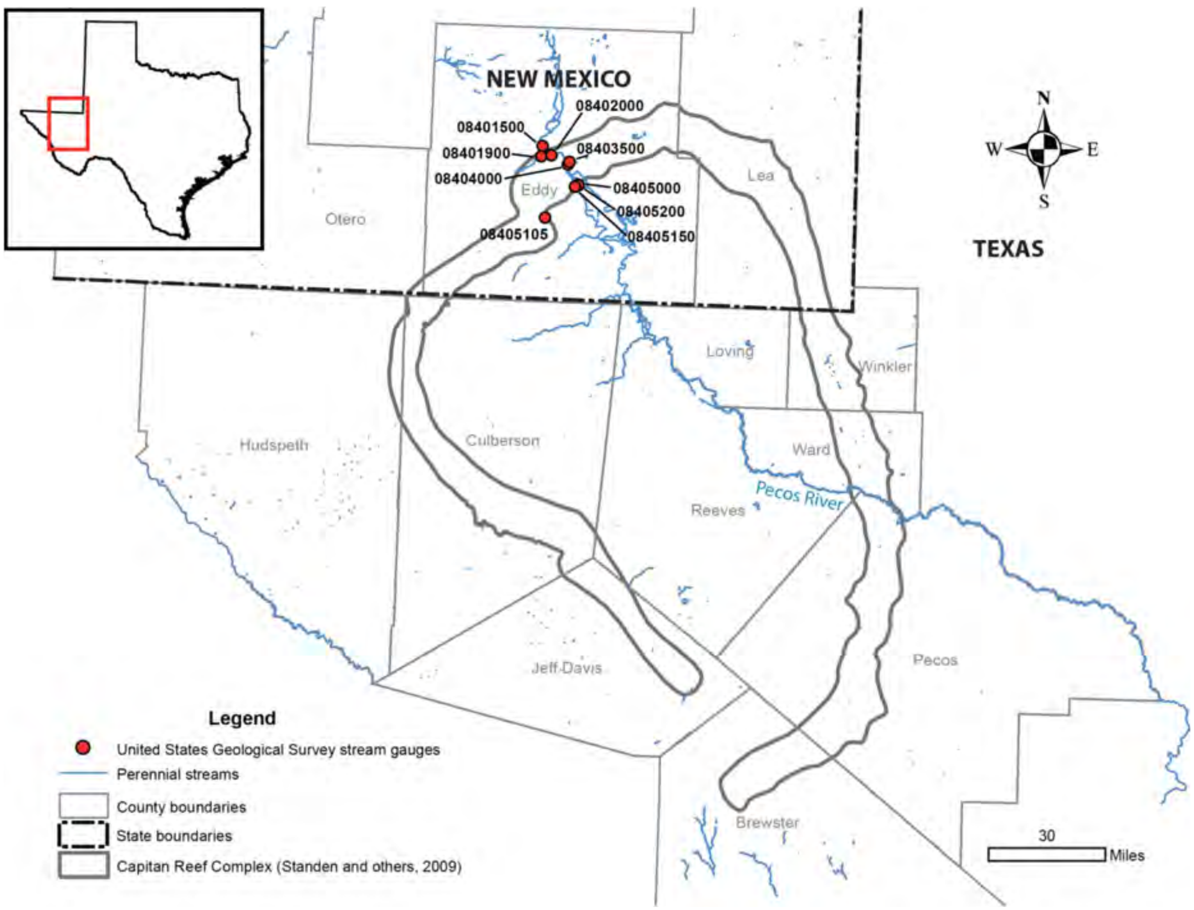


Figure 4.4.1. Locations of and hydrographs from stream gauges along the Pecos River (United States Geological Survey, 2012b).

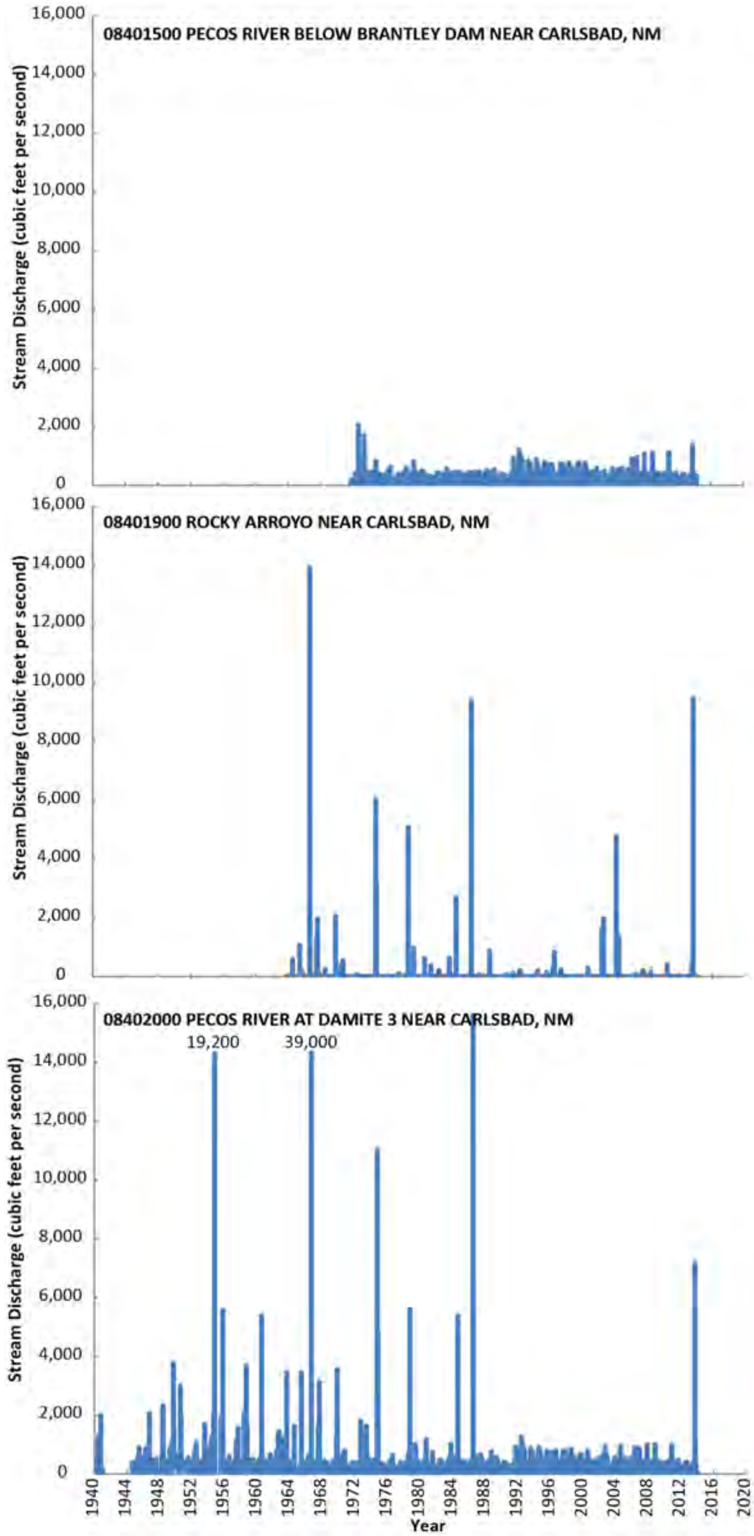


Figure 4.4.1. (continued).

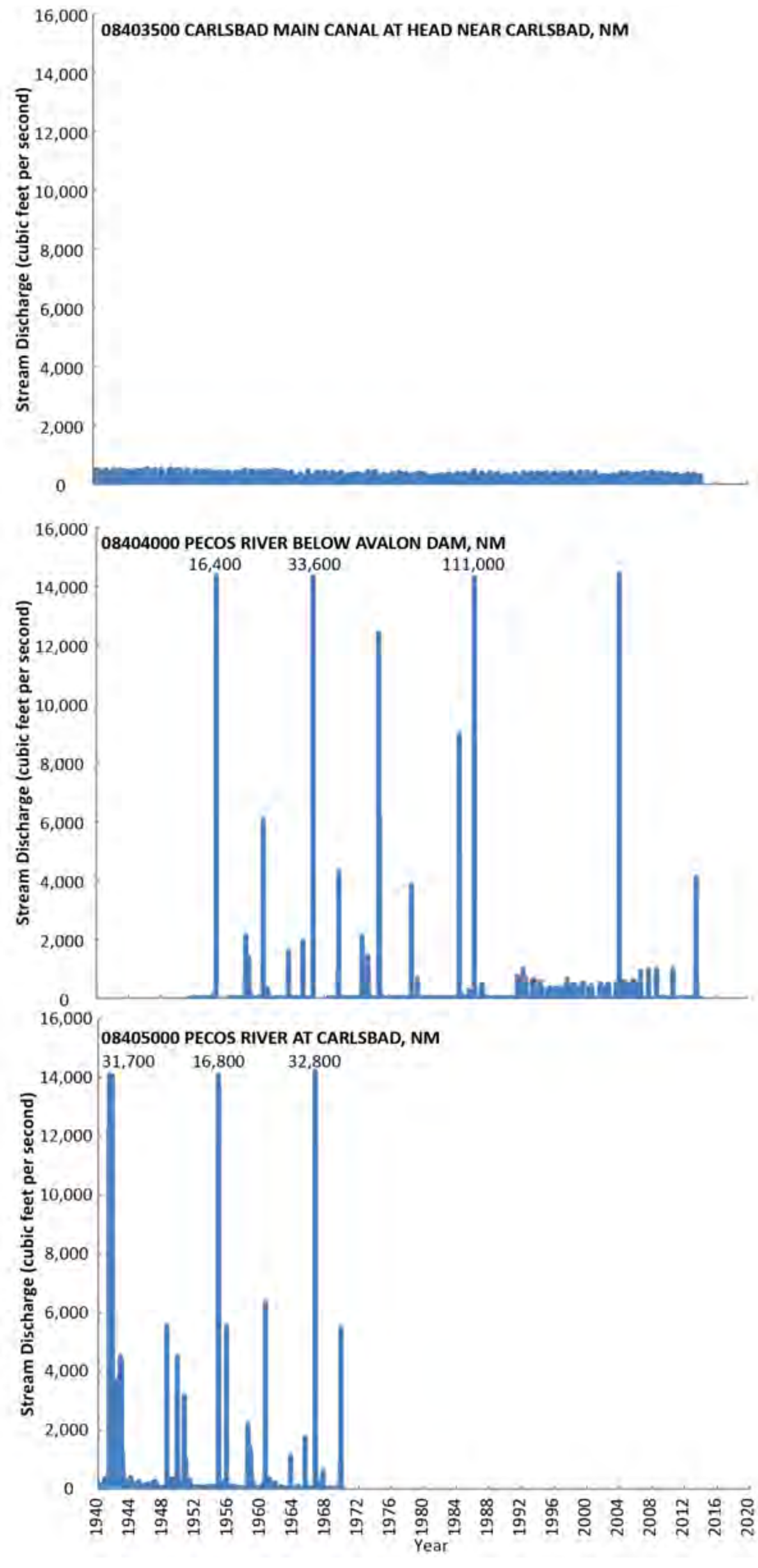


Figure 4.4.1. (continued).

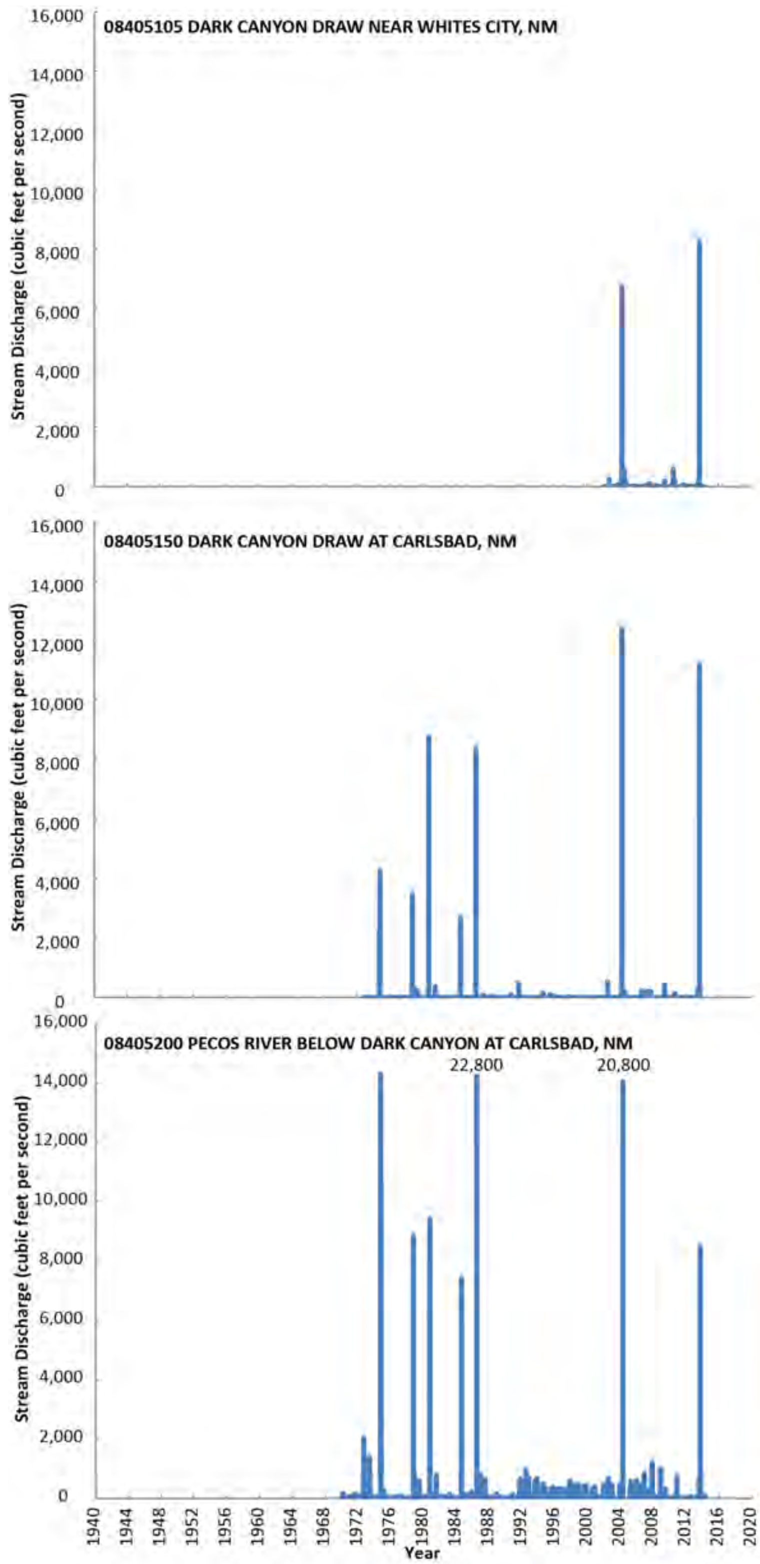


Figure 4.4.1. (continued).

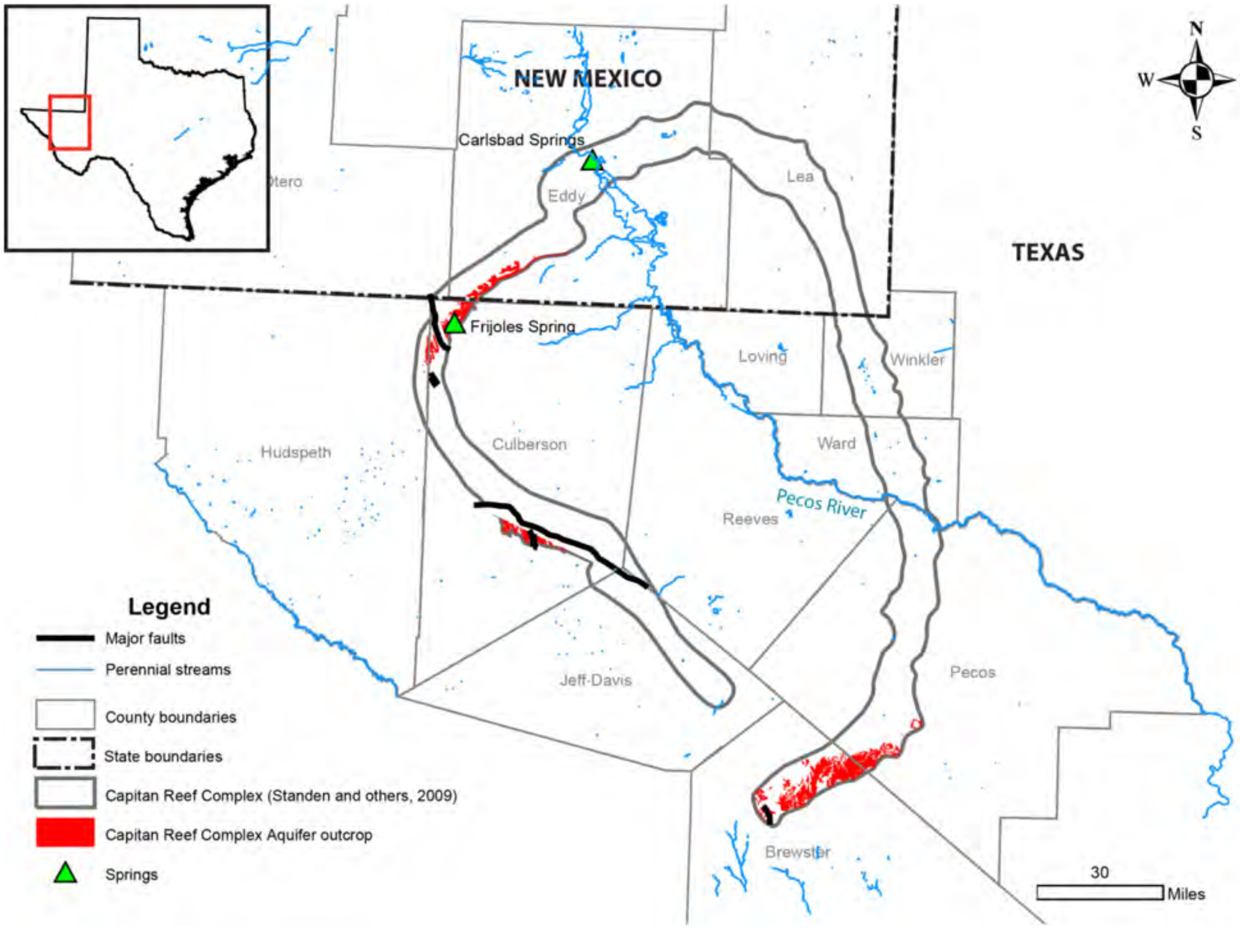


Figure 4.4.2. **Locations of springs flowing from the Capitan Reef Complex Aquifer (Texas Department of Water Resources, 1978; Heitmuller and Reece, 2003).**

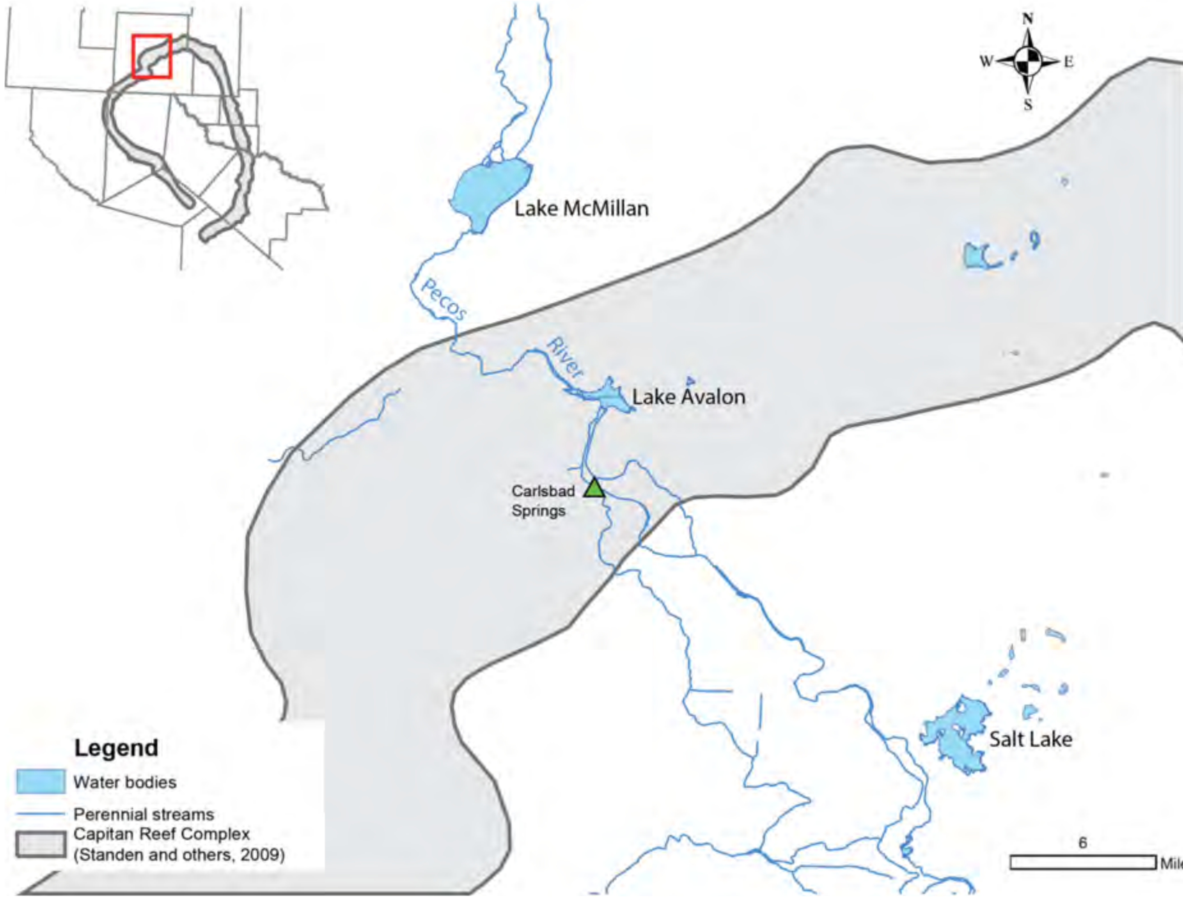


Figure 4.4.3. Reservoirs located along the Pecos River including where it intersects with the Capitan Reef Complex Aquifer near Carlsbad, New Mexico.

4.5 Hydraulic Properties

There is a paucity of hydraulic property data for the Capitan Reef Complex Aquifer. The ability of the aquifer to transmit groundwater to a well varies greatly. Factors impacting the ability of the aquifer to transmit groundwater include: aquifer lithology, karstification, structural deformation, and fracturing. This section reviews the sources of available data describing Capitan Reef Complex Aquifer hydraulic properties. Several hydraulic properties are used to describe groundwater flow in aquifers. The properties discussed here are hydraulic conductivity, transmissivity, coefficient of storage or storativity, and specific capacity. Each of these terms is briefly described below.

Hydraulic conductivity is a measure of the ease with which groundwater can flow through an aquifer. Higher hydraulic conductivity indicates that an aquifer will allow more groundwater flow under the same hydraulic gradient. In this study, units for hydraulic conductivity are expressed in feet per day.

Transmissivity is a term closely related to hydraulic conductivity but is a function of the saturated thickness of an aquifer. Transmissivity describes the ability of groundwater to flow through the entire saturated thickness of an aquifer. As the saturated thickness increases, the transmissivity increases for a given hydraulic conductivity. In this study, units for transmissivity are expressed in square feet per day.

Storativity—also referred to as the coefficient of storage—is the volume of water that a confined aquifer releases per square foot of surface area per foot decline of water level. Storativity is a dimensionless parameter.

Specific capacity is a measure of well productivity represented by the ratio between the well pumping rate and the corresponding drawdown decline in water level. In this study, specific capacity is expressed in gallons per minute per foot of drawdown in a well.

4.5.1 Data Sources

Development of hydraulic properties for the Capitan Reef Complex Aquifer in the study area used multiple sources: Brackbill and Gaines (1964); Richey and others (1985); Myers (1969); Hiss (1973; 1975); Christian and Wuerch (2012); Huff (1997); Garber, and others (1989); INTERA (2012); and specific capacity data from drillers' logs on the Texas Water Development Board website (Texas Water Development Board, 2012b).

Little is known regarding the hydraulic properties of the Capitan Reef Complex Formation in Texas and most of it is semi-quantitative information such as reports of well productivity. Brackbill and Gaines (1964) reported a permeability value of 6 darcies—equivalent to a hydraulic conductivity of 17 feet per day—in Winkler County. Reported well yields in the Capitan Reef Complex Aquifer vary from about 3 gallons per minute up to 6,200 gallons per minute, with a median yield of about 390 gallons per minute (Texas Water Development Board, 2012b). This suggests a wide range of hydraulic conductivity in the aquifer.

The hydraulic property data for the Capitan Reef Complex in New Mexico and Texas are shown in Figure 4.5.1 and Table 4.5.1. Using all sources available, 38 estimates of specific capacity, 7 estimates of transmissivity, 15 estimates of hydraulic conductivity, and 2 estimates of storativity were found for the Capitan Reef Complex Aquifer. INTERA (2012) reports storativity estimates for two wells based on different methodologies.

4.5.2 Calculation of Hydraulic Conductivity from Specific Capacity

Specific capacity values are calculated from the pumping rate and corresponding drawdown, which are commonly reported in well records. However, hydraulic conductivity or transmissivity are more useful parameters than specific capacity for regional groundwater flow modeling. The following methodology was used to estimate transmissivity from specific capacity data.

Point estimates of aquifer transmissivity can be made based on measurements of specific capacity. In the absence of pump test data, transmissivity can still be estimated using the Cooper-Jacob solution for drawdown in a pumping well (Cooper and Jacob, 1946):

$$s = \frac{Q}{4\pi T} ln\left(\frac{2.25Tt}{r^2S}\right) \qquad (4.5.1)$$

where:

s = drawdown in the well [L],

Q = pumping rate [L3/T],

T = transmissivity [L2/T],

t = time [T],

r = radius of the well [L], and

S = storativity [--].

Equation (4.5.1) can be rearranged to solve for specific capacity as:

$$\frac{Q}{s} = \frac{4\pi T}{ln\left(\frac{2.25Tt}{r^2S}\right)} \qquad (4.5.2)$$

For a given specific capacity, transmissivity can be solved iteratively. Table 4.5.2 provides specific capacity and calculated transmissivity and hydraulic conductivity data for Capitan Reef Complex Aquifer wells. Transmissivity was calculated using the iterative method outlined by Equation 4.5.2 and assuming a storativity value of 0.0005. Hydraulic conductivity was calculated by dividing the transmissivity by the well screen length or in the absence of screen information by the thickness of the Capitan Reef Complex Aquifer indicated in Figure 4.1.4.

The estimated hydraulic conductivity values for the Capitan Reef Complex Aquifer range from 0.009 to 517 feet per day, with a median of 3 feet per day (Figures 4.5.2 and 4.5.3). A model by INTERA (2012) divided the eastern arm of the Capitan Reef Complex Aquifer into eight zones with horizontal hydraulic conductivities ranging from 0.005 feet per day to 20 feet per day. Highest hydraulic conductivity in the Capitan Reef Complex Aquifer is associated with karstification of the limestone (Motts, 1968).

Hiss (1975) found that the hydraulic conductivity of the stratigraphic units in the fore-reef Delaware Basin—the Castile Formation and Delaware Mountain Group—are much less than the Capitan Reef Complex Aquifer. The Castile Formation and most units within the Delaware Mountain Group transmit only limited amounts of water (Motts, 1968). Consequently, it is expected that inter-aquifer flow between the Capitan Reef Complex Aquifer and the fore-reef Delaware Basin is limited. The differences in water quality in the Delaware Basin and the Capitan Reef Complex Aquifer adds more evidence that hydrologic interaction is limited (Hiss, 1980). Hydraulic property data for the Delaware Mountain Group indicate hydraulic conductivity in the range of 0.01 to 0.04 feet per day with a average of 0.02 feet per day—much less than the Capitan Reef Complex Aquifer (Hiss, 1975; Huff, 1997).

West of where the Pecos River intersects with the Capitan Reef Complex Aquifer in New Mexico, the back-reef or shelf stratigraphic units of the Artesia Group locally have hydraulic conductivities similar to the Capitan Reef Complex Aquifer (Hiss, 1975; 1980). However, east of the Pecos River, the Artesia Group is readily distinguishable from the Capitan Reef Complex Aquifer in terms of hydraulic properties and water quality (Hiss, 1975). The hydraulic conductivity of the Artesia Group correlates to the mineralogy and texture. The carbonate facies generally have low hydraulic conductivity, except near the boundary with the Capitan Reef Complex. The evaporite facies generally have moderate hydraulic conductivity. The overall hydraulic conductivity of the Artesia Group is several orders of magnitude lower east of the Pecos River than west and is generally one to two orders of magnitude lower than the Capitan Reef Complex Aquifer (Motts, 1968; Hiss, 1980). Consequently, one can deduce significant interaction between the Artesia Group and the Capitan Reef Complex Aquifer west of the Pecos River and limited interaction to the east. Hydraulic property data for the Artesia Group indicate hydraulic conductivity in the range of up to 0.9 feet per day with a median of 0.006 feet per day—much less than the Capitan Reef Complex (Figure 4.5.4; Hiss, 1975; Huff, 1997).

Hydraulic conductivity data from the aquifers overlying the Capitan Reef Complex Aquifer—the Rustler, Dockum, Edwards-Trinity (Plateau), and Pecos Valley aquifers—were obtained from their respective groundwater availability model or alternative model reports (Ewing and others, 2012; Ewing and others, 2008; Hutchison and others, 2011). In the Rustler Aquifer, hydraulic conductivity lies in the range of 0.001 to 1,000 feet per day with an average of about 1 foot per day (Figure 4.5.5). Some of the highest hydraulic conductivities in the Rustler Aquifer occur where the underlying Salado Formation has been partially removed by dissolution—which occurs where the Rustler Aquifer overlies the Capitan Reef Complex Aquifer. Dockum Aquifer hydraulic conductivity adjacent to the Capitan Reef Complex Aquifer lies in the range 0.3 to 300 feet per day which is typical for the rest of the Dockum Aquifer (Figures 4.5.6 and 4.5.7). At the regional scale, hydraulic conductivity ranges in the Edwards-Trinity (Plateau) and Pecos Valley aquifers are 30 to 80 feet per day and 5 to 29 feet per day, respectively (Figure 4.5.8).

4.5.3 Storativity

The specific storage of a confined aquifer is defined as the volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head (Freeze and Cherry, 1979). The storativity is equal to the product of specific storage and aquifer thickness and is dimensionless. For unconfined conditions, the storage is referred to as the specific yield and is defined as the volume of water an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline in water table (Freeze and Cherry, 1979). Aquifer storage properties are directly related to aquifer porosity in the unconfined portions of an aquifer and aquifer porosity and matrix compressibility in the confined portions of the aquifer.

INTERA (2012) storativity estimates in two wells range from 1.58×10^{-4} to 2.43×10^{-5} and 4.78×10^{-5} to 5.52×10^{-7}, respectively, using several different methods. A wide range of storage values—storativity and specific yield—would be expected in the Capitan Reef Complex Aquifer because it is composed of a complex mixture of different carbonate rock types and additionally displays varying degrees of karstification (Garber and others, 1989). A study of a core extending from the Salado Formation to the top of the Cherry Canyon Formation in the Delaware Group—including entire thickness of the Capitan Formation—in Eddy County, New Mexico, indicates porosity in the Capitan Reef Complex Aquifer of up to 15 percent (Garber and others, 1989).

Table 4.5.1. Hydraulic property data from wells shown in Figure 4.5.1, located within the Capitan Reef Complex Aquifer. T= transmissivity, K = hydraulic conductivity, Q = well discharge, SC = specific capacity.

Map	Well No.	Location	Latitude	Longitude	Source	County	Date	T (ft^2/d)	K (ft/d)	Q (gpm)	SC (gpm/ft)
1	4717317		31.7436	-104.9164	Myers, 1969	Culberson	10/28/1965	16,000	148	2,000	58
2	21.27.05.414	T21S R27E Sec05 414	32.5057	-104.2044	Hiss, 1973	Eddy	8/12/1969		2.4	85	
3	21.28.30.14123	T21S R28E Sec30 14123	32.4558	-104.1247	Hiss, 1973	Eddy	8/9/1961		16	100	
4	4632309		31.6056	-103.0367	White, 1971	Ward	6/28/1957			780	10
5	4632307		31.5989	-103.0336	White, 1971	Ward	6/28/1957			640	7.3
6	4632305		31.6042	-103.0208	White, 1971	Ward	6/28/1957			704	7.3
7	4632306		31.5894	-103.0389	White, 1971	Ward	2/20/1957			288	2.5
8	4632308		31.5917	-103.0306	White, 1971	Ward	2/20/1957			655	8.9
9	4632610		31.5592	-103.0333	White, 1971	Ward	2/20/1957			375	3.4
10	4632611		31.5778	-103.0261	White, 1971	Ward	6/28/1957			435	3.8
11	4632901		31.5333	-103.0006	White, 1971	Ward	7/11/1962			1,310	13
12	21.34.24	T21S R34E Sec 24	32.4652	-104.4238	Hiss, 1975	Lea	1/14/1965		3.0	240	
13	21.35.14	T21S R35E Sec 14	32.4797	-103.3382	Hiss, 1975	Lea	7/8/1962		1.7	270	
13	21.35.14	T21S R35E Sec 14	32.4797	-103.3382	Hiss, 1975	Lea	10/15/1966		3.5		
13	21.35.14	T21S R35E Sec 14	32.4797	-103.3382	Hiss, 1975	Lea	12/14/1966		1.9	328	
13	21.35.14	T21S R35E Sec 14	32.4797	-103.3382	Hiss, 1975	Lea	12/15/1966		1.4		
14	24.36.4	T24S R36E Sec 04	32.2467	-103.2697	Hiss, 1975	Lea	2/28/1968		24	550	
14	24.36.4	T24S R36E Sec 04	32.2467	-103.2697	Hiss, 1975	Lea	2/28/1968		25	550	
15	24.36.16	T24S R36E Sec 16	32.2175	-103.2697	Hiss, 1975	Lea	10/4/1967		4.4	504	
16	4717321		31.7264	-104.8839	Christian/Wuerch, 2012	Culberson	11/21/1971	179,591		1,600	195
17	5238301		30.4753	-103.2633	TWDB, 2012b	Brewster					0.04
18	4702801		31.9147	-104.8017	TWDB, 2012b	Culberson					0.01
19	4703206		31.9597	-104.6819	TWDB, 2012b	Culberson					0.19
20	4709903		31.7650	-104.9164	TWDB, 2012b	Culberson					16.8
21	4710401		31.8006	-104.8478	TWDB, 2012b	Culberson					0.85
22	4718402		31.7081	-104.8581	TWDB, 2012b	Culberson					3
23	4734603		31.4461	-104.7725	TWDB, 2012b	Culberson					22
24	4734902		31.4139	-104.7650	TWDB, 2012b	Culberson					52
25	4743503		31.3278	-104.6714	TWDB, 2012b	Culberson					7
26	4752301		31.2150	-104.5292	TWDB, 2012b	Culberson					5
27	4752601		31.2083	-104.5256	TWDB, 2012b	Culberson					44
28	4752602		31.2033	-104.5189	TWDB, 2012b	Culberson					12
29	4709201		31.8550	-104.9425	TWDB, 2012b	Hudspeth					10
30	4709207		31.8453	-104.9550	TWDB, 2012b	Hudspeth					428
31	4709208		31.8744	-104.9519	TWDB, 2012b	Hudspeth					1.3
32	4717204		31.7336	-104.9344	TWDB, 2012b	Hudspeth					6.5
33	4717208		31.7361	-104.9367	TWDB, 2012b	Hudspeth					12
34	142		32.4260	-104.2773	NMOSE, 2012	Eddy	8/19/1954				147
35	143		32.4027	-104.2497	NMOSE, 2012	Eddy	8/20/1954				381
36	151		32.4252	-104.2504	NMOSE, 2012	Eddy	10/29/1939				275
37	153		32.2924	-104.3460	NMOSE, 2012	Eddy	7/29/1955				0.87
38	154		32.3899	-104.2732	NMOSE, 2012	Eddy	4/6/1955				419
39	155		32.3624	-104.2971	NMOSE, 2012	Eddy	6/2/1955				14.10
40	171		32.3972	-104.2626	NMOSE, 2012	Eddy	2/27/1942				6.40
41	172		32.3972	-104.2626	NMOSE, 2012	Eddy	8/18/1954				32.40
42	229		32.4082	-104.2669	NMOSE, 2012	Eddy	8/20/1954				138
43	230		32.3928	-104.2884	NMOSE, 2012	Eddy	6/2/1955				90
44	250		32.1803	-104.3782	NMOSE, 2012	Eddy	12/8/1954				18.30
45	314		32.4540	-104.1293	NMOSE, 2012	Eddy	1/1/1961	6,700			
46		El Capitan SWS			Brackbill & Gaines, 1964	Winkler			17		
47	ICP	Ochoa SOP Mine			Castiglia & others, 2013	Lea		6,993	6.9	491	
48	4549203		31.2397	-102.9311	TWDB, 2012b	Pecos	8/17/2010	17,200			
49	ICP-WS-01		32.2405	-103.3393	INTERA, 2012	Lea	2/8/2012	7,999	8.0		
50	ICP-WS-02		32.2446	-103.3392	INTERA, 2012	Lea	6/9/2012	723	0.7		

Table 4.5.2. Specific capacity data and calculated hydraulic conductivity based on Equation 4.5.2 for wells in the Capitan Reef Complex Aquifer. The map number refers to location numbers in Figure 4.5.1.

Map	Well Number	County	Specific Capacity (gpm/ft)	Drawdown (ft)	Pump Rate (gpm)	Time (h)	Well Diameter (in)	Screen Length (ft)	Transmissivity (ft^2/d)	Hydraulic Conductivity (ft/d)
17	5238301	Brewster	0.04	82	5	5	8	839	9.5	0.011
18	4702801	Culberson	0.01	364	4	161	6	220	2.0	0.009
19	4703206	Culberson	0.19	25	5	2.5	4	60	35.1	0.58
20	4709903	Culberson	16.8	39	656	8	16	375	3,961	10.56
21	4710401	Culberson	0.85	20	17	24	8	799	193.0	0.24
1	4717317	Culberson	58	34	2,000	24	16	70	16,162	231
16	4717321	Culberson	219	7.3	1,600	12	16	564	62,485	110.8
22	4718402	Culberson	3	104	279	12	12	1,513	593	0.39
23	4734603	Culberson	22	103	2,250	24	14	192	5,739	29.9
24	4734902	Culberson	52	49	2,550	23	14	61	14,387	236
25	4743503	Culberson	7	83	550	36	14	321	1,654	5.15
26	4752301	Culberson	5	82	379	2.5	18	550	878	1.60
27	4752601	Culberson	44	9	396	51	18	155	12,256	79.1
28	4752602	Culberson	12	88	1,100	27	18	309	3,087	9.99
29	4709201	Hudspeth	10	3	30	4	6	204	2,480	12.16
30	4709207	Hudspeth	428	3.5	1,500	4	14	234	121,035	517
31	4709208	Hudspeth	1.3	19	25	24	7	135	314	2.33
32	4717204	Hudspeth	6.5	88	570	24	18	830	1,515	1.83
33	4717208	Hudspeth	12	168	2,000	24	18	1,540	2,907	1.89
6	4632305	Ward	7.3	97	778	5	13	178	1,781	10.01
7	4632306	Ward	2.5	113	288	24	13	713	584	0.82
5	4632307	Ward	7.3	88	640	5	10	3,100	1,668	0.54
8	4632308	Ward	8.9	74	655	24	13	564	2,214	3.93
4	4632309	Ward	10	78	780	5	13	455	2,258	4.96
9	4632610	Ward	3.5	110	385	5	13	799	728	0.91
10	4632611	Ward	3.8	115	435	5	13	596	792	1.33
11	4632901	Ward	13	101	1,310	4	9	1,096	3,097	2.83
34	142	Eddy	147	10	1,470	8	12		40,347	23.06
35	143	Eddy	381	7	2,670	8	16		107,029	61.16
36	151	Eddy	275	3	833	8	12		78,271	44.73
37	153	Eddy	0.87	23	20	1	12		125	0.07
38	154	Eddy	419	1	419	8	6		131,482	75.13
39	155	Eddy	14.10	17	240	1	8		2,947	1.68
40	171	Eddy	6.40	25	160	5	12		1,368	0.78
41	172	Eddy	32.40	18	550	5	13		7,291	4.17
42	229	Eddy	138	7	1,238	8	14		48,188	27.54
43	230	Eddy	90	23	350	1	12		3,085	1.76
44	250	Eddy	18.30	6	110	54	12		4,981	2.85

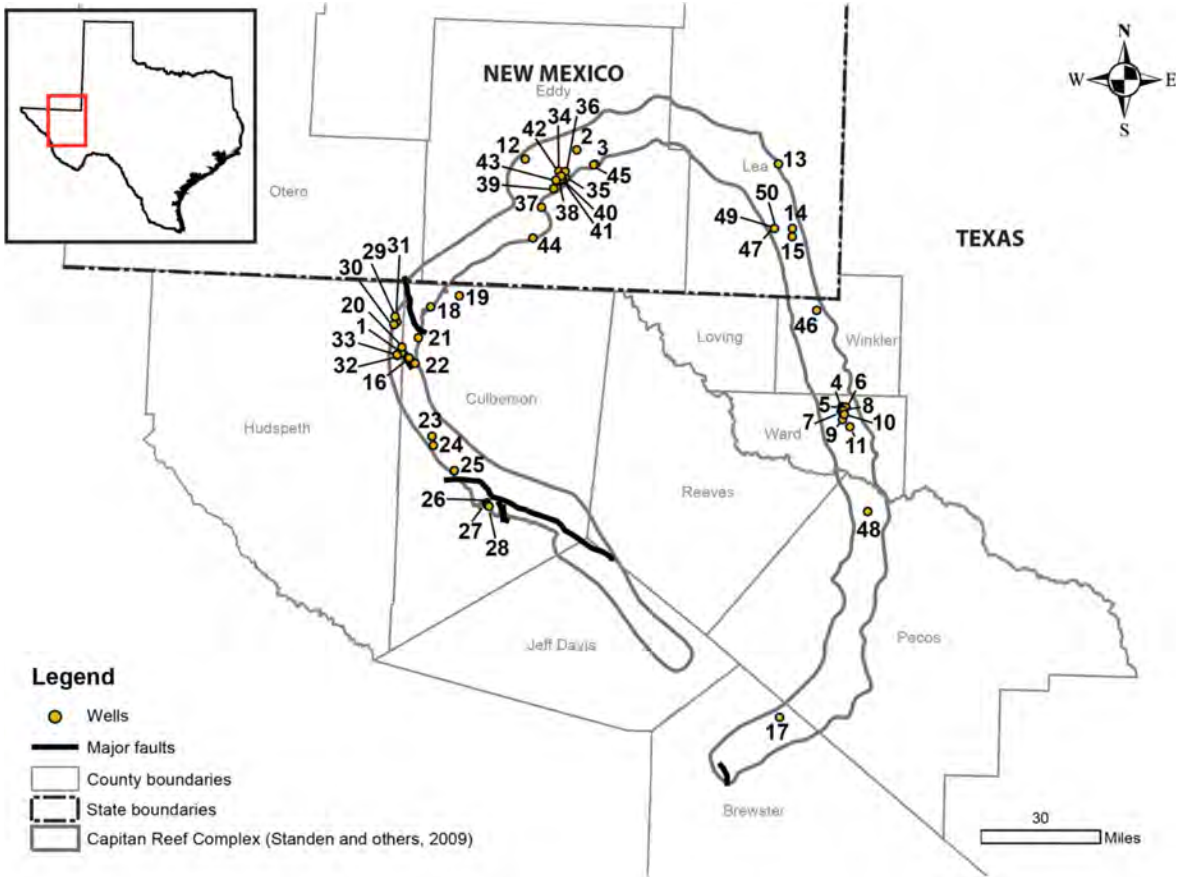


Figure 4.5.1. Hydraulic property data locations for the Capitan Reef Complex Formation in Texas and New Mexico. The numbers refer to wells in Table 4.5.1 and includes references for the source of data.

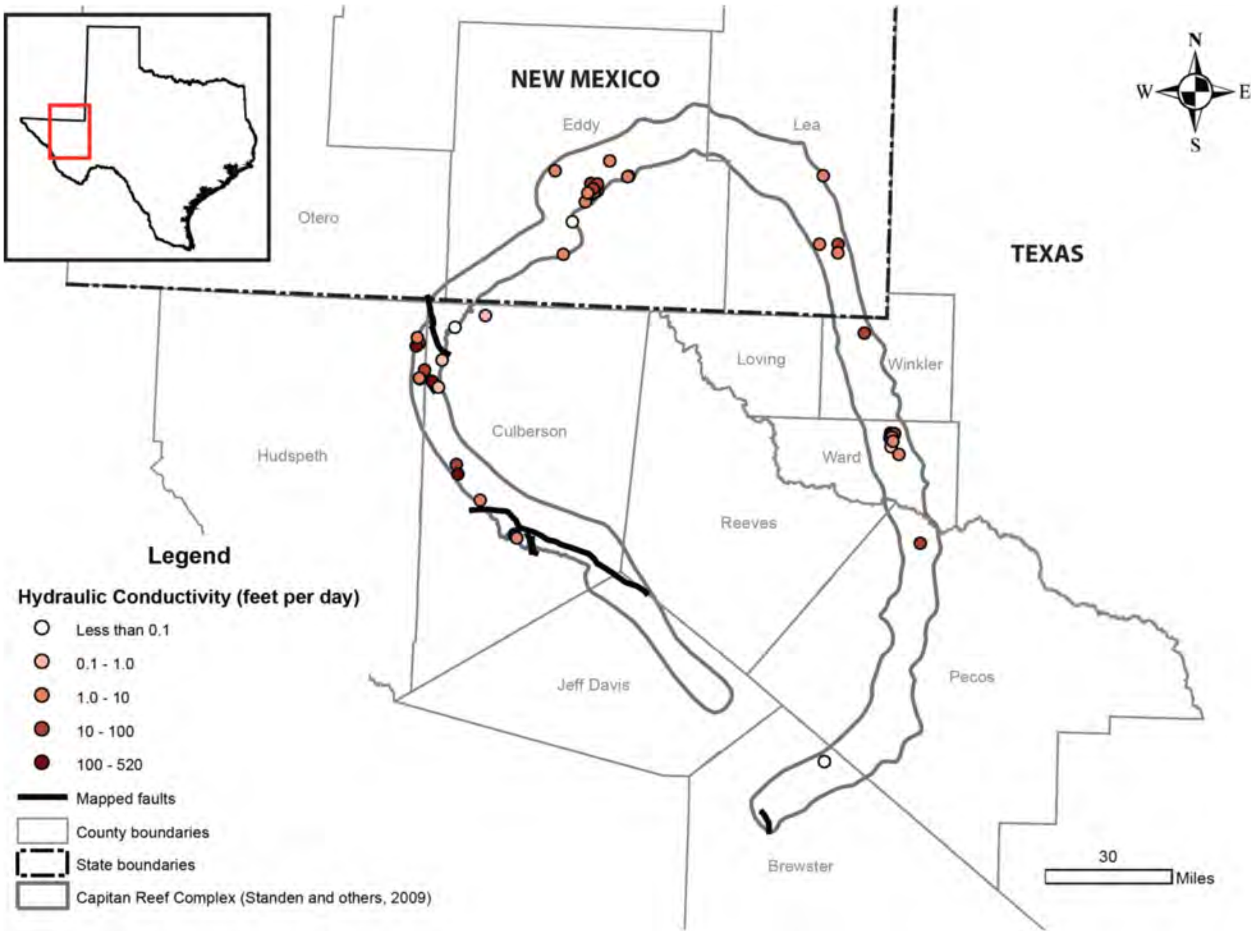


Figure 4.5.2. **Hydraulic conductivity data for the Capitan Reef Complex Aquifer in Texas and New Mexico (see Table 4.5.1 for references of the source of data).**

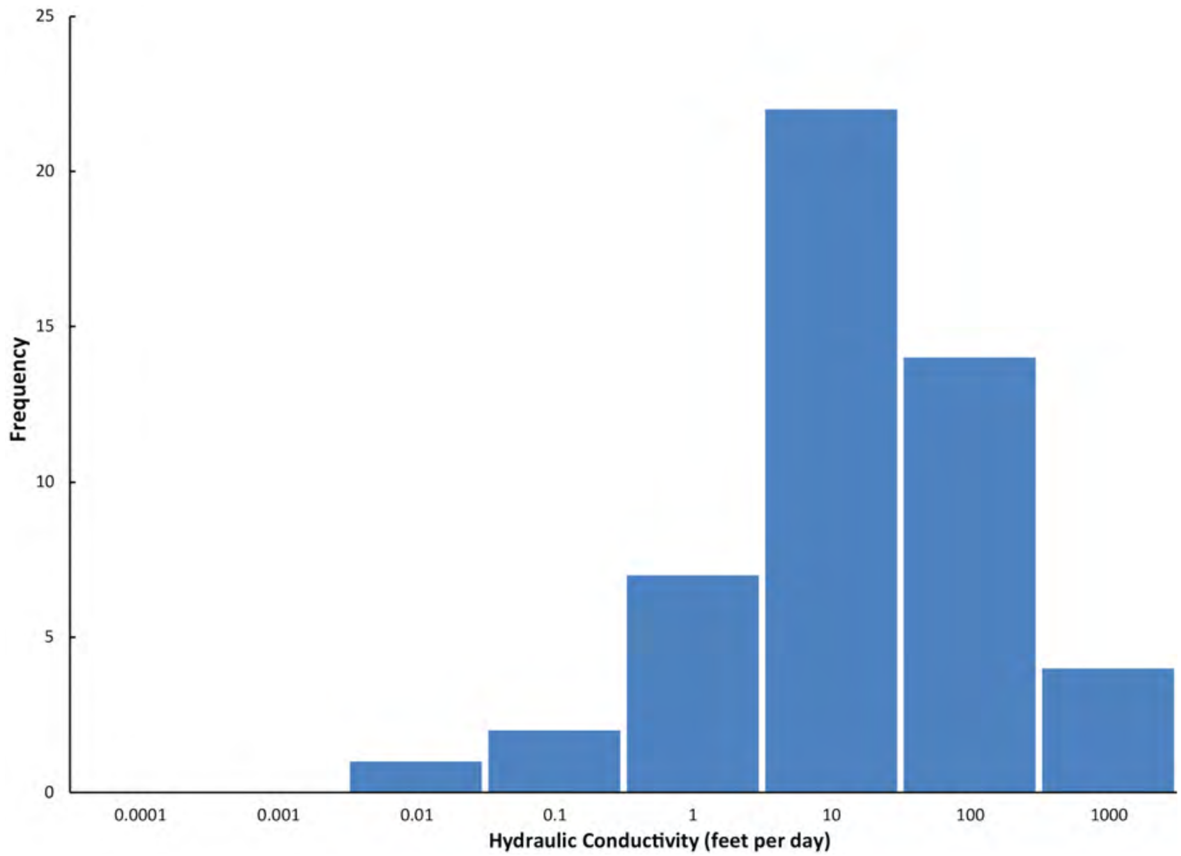


Figure 4.5.3. Histogram of hydraulic conductivity data in feet per day for the Capitan Reef Complex Aquifer based on data from the sources indicated in Table 4.5.1.

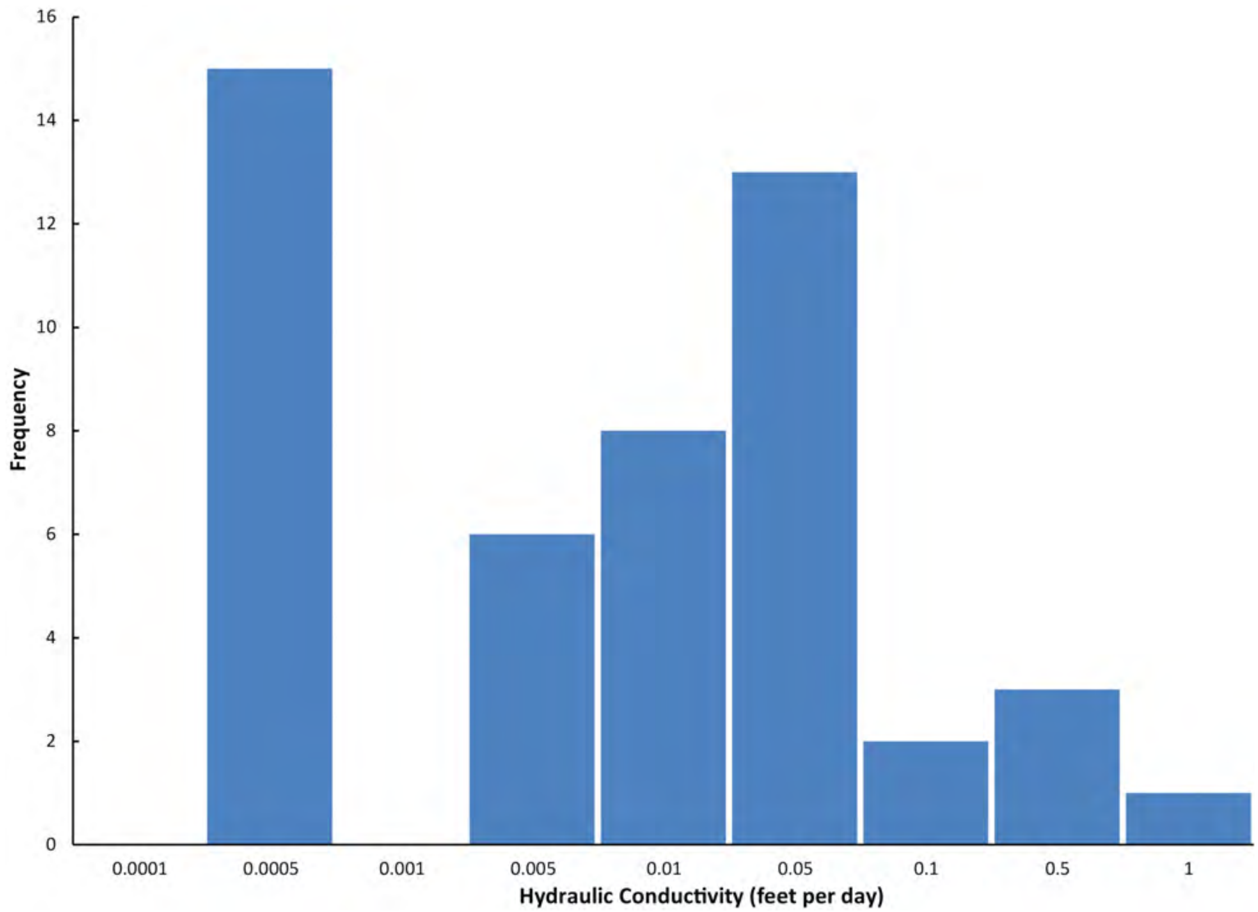


Figure 4.5.4. **Histogram of hydraulic conductivity data in feet per day for the Artesia Group based on data from Huff (1997).**

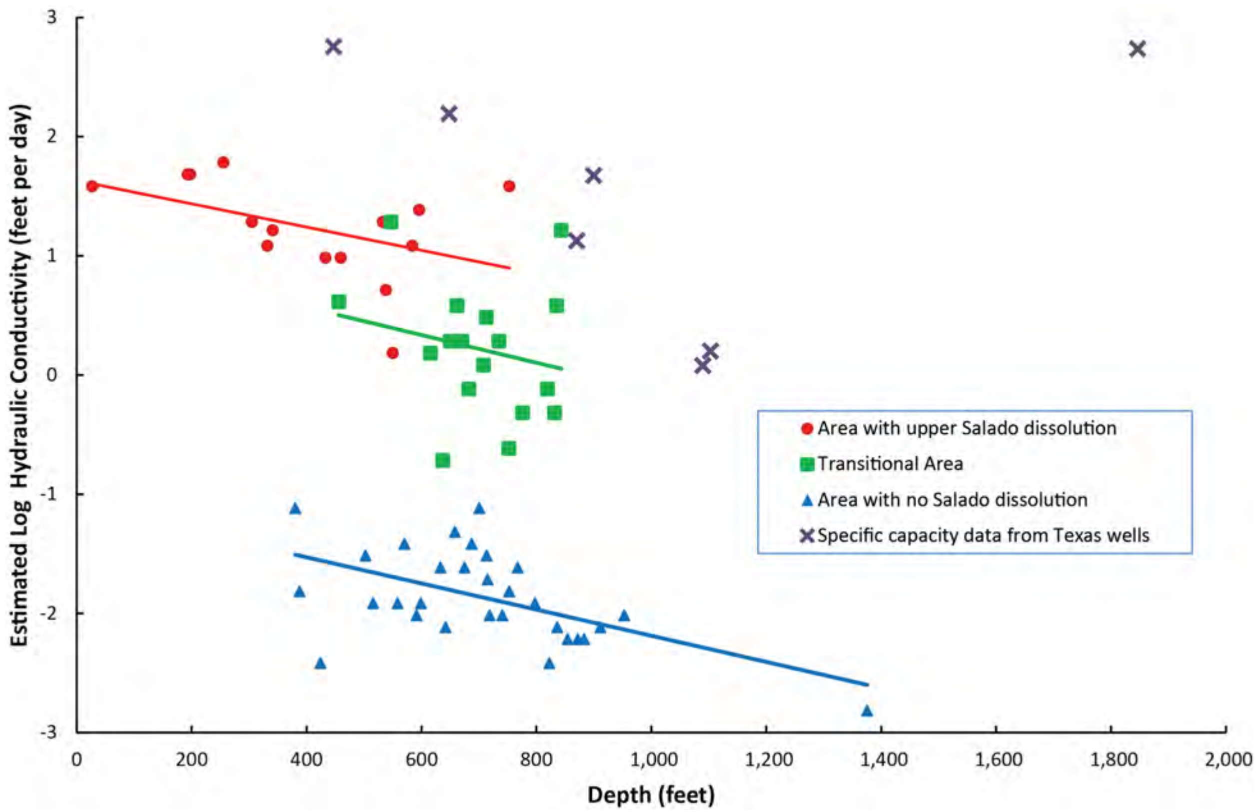


Figure 4.5.5. **Hydraulic conductivity data for the Rustler Aquifer in Texas and New Mexico (from Ewing and others, 2012).**

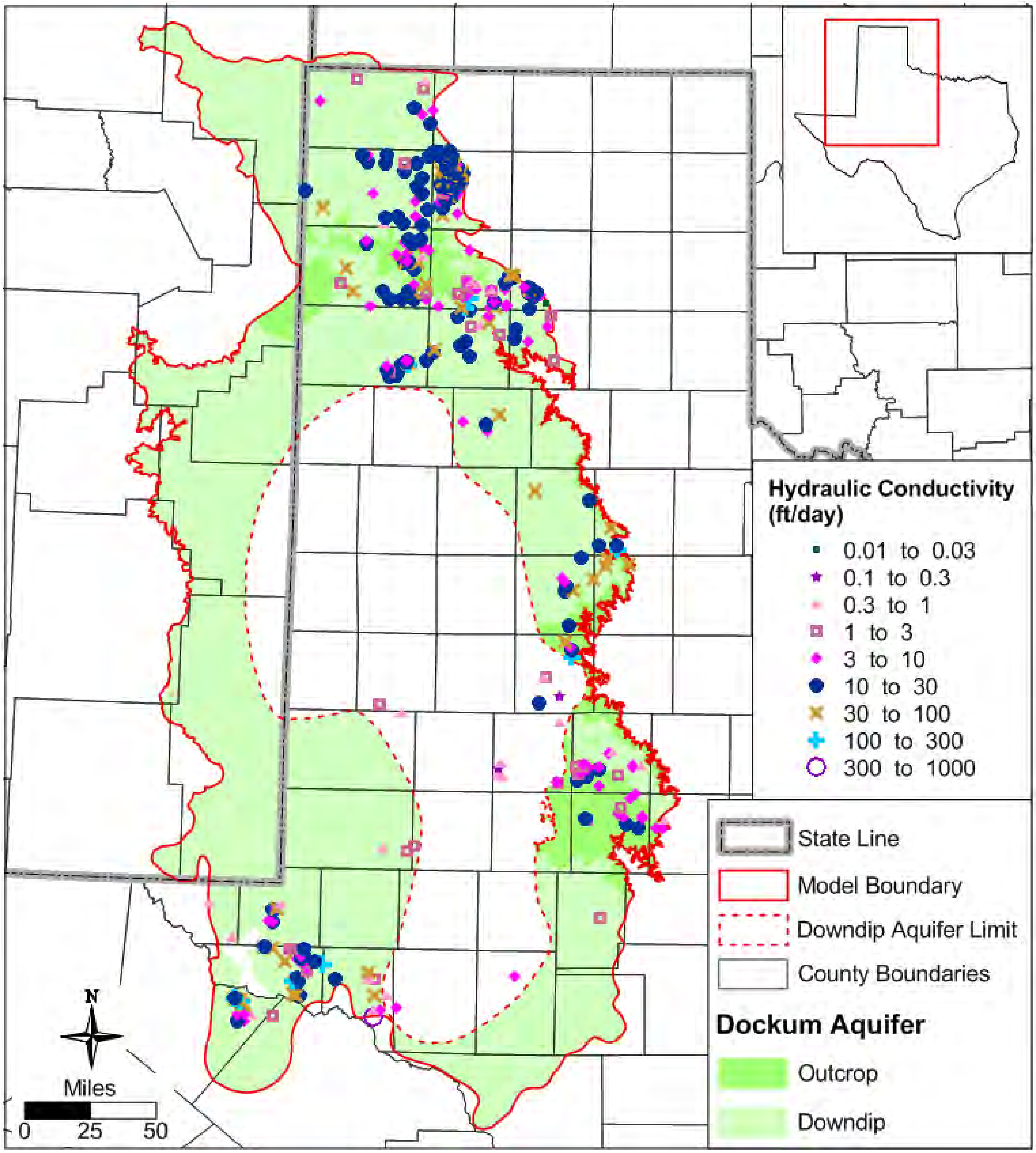


Figure 4.5.6. Hydraulic conductivity data for the Dockum Aquifer in Texas and New Mexico (from Ewing and others, 2008).

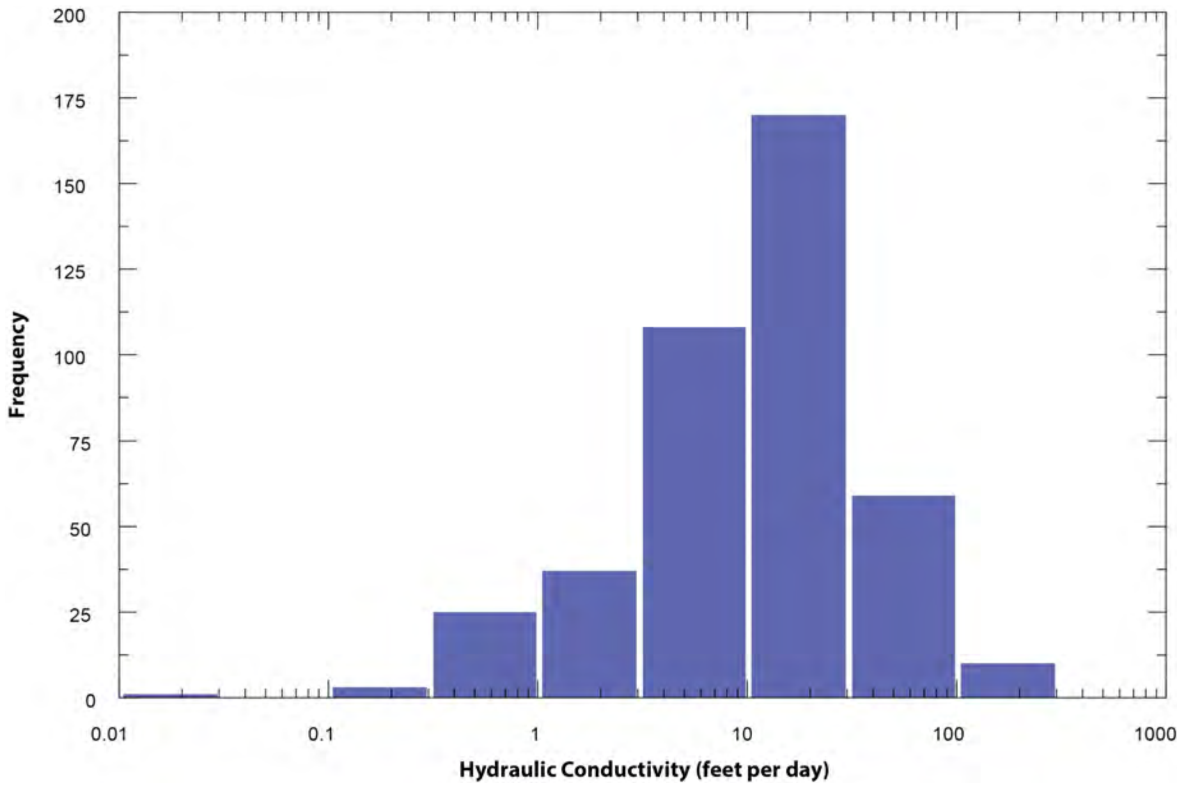


Figure 4.5.7. Histogram of hydraulic conductivity data in feet per day for the Dockum Aquifer (modified from Ewing and others, 2008).

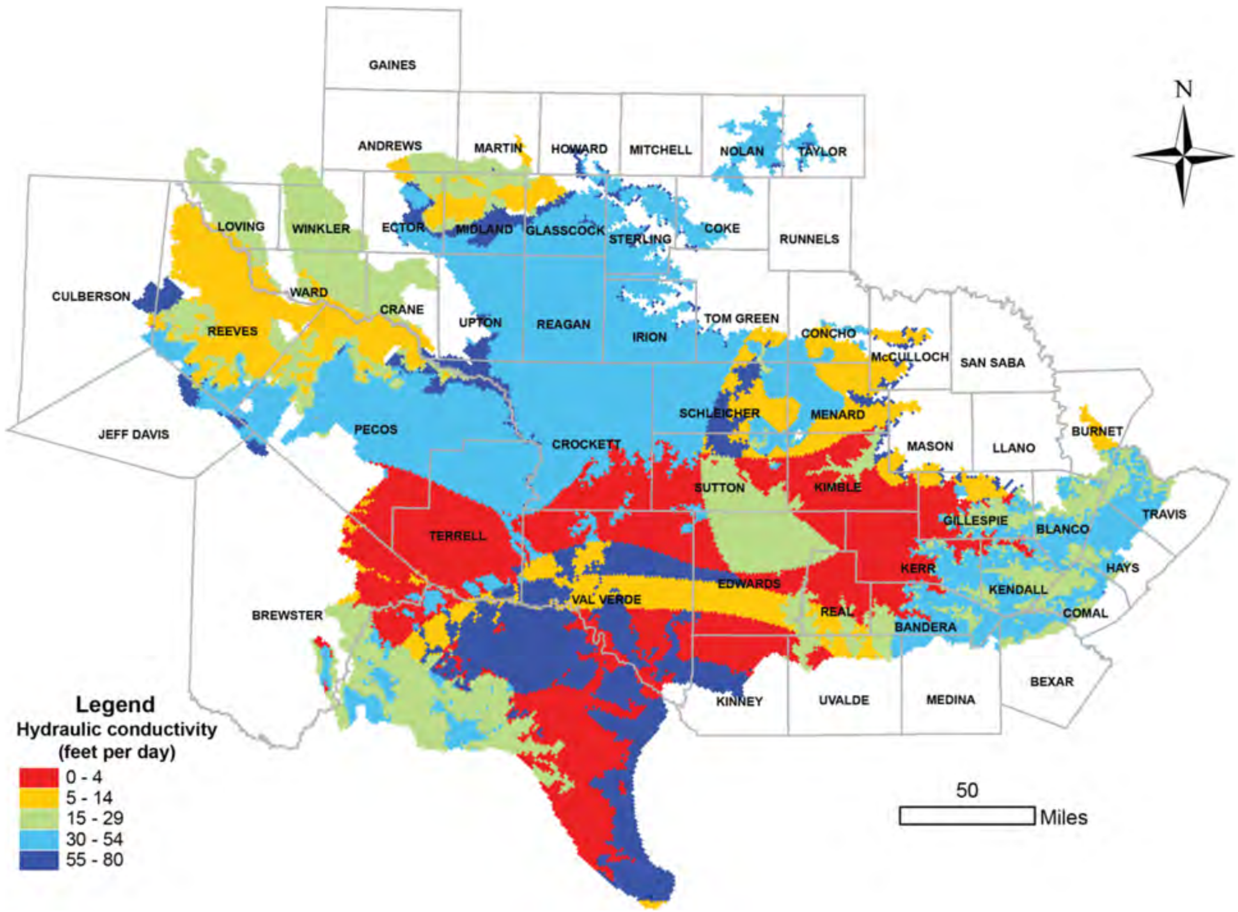


Figure 4.5.8. **Hydraulic conductivity data for the Edwards-Trinity and Pecos Valley aquifers in Texas and New Mexico (From Hutchison and others, 2011).**

4.6 Discharge

The term, discharge, refers to processes by which water leaves an aquifer. These processes include both natural and anthropogenic processes. Groundwater discharges from aquifers naturally to streams or springs, evapotranspiration, and cross-formational flow. Pumping wells are an anthropogenic form of discharge from aquifers.

4.6.1 Natural Aquifer Discharge

In a typical topographically-driven flow system, percolation of precipitation results in recharge at the water table, which flows from topographic highs and discharges at topographic lows through streams and springs and groundwater evapotranspiration. Water that moves down-dip eventually discharges upward through cross-formational flow. In the Capitan Reef Complex Aquifer, the most likely forms of discharge are spring discharge and cross-formational flow in the subsurface.

Discharge through spring discharge to Frijoles Spring and baseflow from the Capitan Reef Complex Aquifer to the Pecos River in New Mexico is discussed in Sections 4.4.1 through 4.4.3. This discharge limits eastward groundwater flow into the eastern arm of the Capitan Reef Complex Aquifer (Figure 4.2.2).

Discharge via cross-formational flow is mentioned in Section 4.2. Cross-formational flow is likely the largest form of discharge from the Capitan Reef Complex Aquifer considering the limited access to perennial streams and wetlands—sites for baseflow and evapotranspiration discharge from the aquifer—where the aquifer crops out. Evidence supporting cross-formational flow as the main form of discharge are: (1) few perennial streams crossing aquifer outcrops; (2) northward and southward flow paths converging in Winkler and Ward counties; (3) the occurrence of artesian wells and springs like the Diamond Y Spring that discharge water derived from underlying aquifers (Veni, 1991; Boghici and Van Broekhoven, 2001); and (4) Capitan Reef Complex Aquifer water levels that are consistently higher than water levels in overlying aquifers (Figures 4.2.1, 4.2.3, 4.2.6, 4.2.12). This cross-formational discharge is likely a combination of discharge to the back-reef Artesia Group and vertical discharge to overlying aquifers. The collapse structure that resulted from the dissolution of the overlying Salado Formation and resultant subsidence of the overlying stratigraphic units acts as a potential pathway for upward groundwater flow through—and mixing with—Rustler, Dockum, and Pecos Valley aquifer groundwater. This collapse structure is responsible for the formation of the Monument Draw Trough in the Pecos Valley Aquifer (Jones, 2001; 2004) and also approximately coincides with the eastern arm of the Capitan Reef Complex Aquifer (Figure 4.6.1).

4.6.2 Aquifer Discharge through Pumping

Estimates of groundwater pumping from the Capitan Reef Complex Aquifer throughout Texas for the years 1980 through 2008 were obtained from the Texas Water Development Board historical water use estimates. The six water-use categories defined in the Texas Water Development Board database are municipal, manufacturing, steam electric generation, irrigation, mining, and livestock. Rural domestic pumping is likely to be very small relative to the other pumping categories because of low population, poor water quality, aquifer depth, and the fact that the Capitan Reef Complex Aquifer is overlain by other aquifers that have better water quality and are consequently more attractive sources of groundwater. Water use estimates for the Capitan Reef Complex Aquifer indicate pumping from Brewster, Culberson, Hudspeth, Pecos, and Ward counties, and no pumping in Winkler County.

In the groundwater availability model for the Capitan Reef Complex Aquifer, pumping data for overlying aquifers—Rustler, Dockum, Edwards-Trinity (Plateau), and Pecos Valley aquifers—will be derived from the respective groundwater availability models (Ewing and others, 2008; 2012; Hutchison and others, 2011). It will be assumed that due to low groundwater yield and poor water quality issues that pumping from the non-aquifer stratigraphic units in the study area—the Artesia and Delaware Mountain groups, and the Castile and Salado formations—is insignificant.

The Texas Water Development Board water use survey indicates that mining pumpage is primarily attributable to oil and gas operations. Figure 4.6.2A shows the spatial distribution of oil and gas wells drilled since 1928 that penetrate the Capitan Reef Complex Aquifer. These wells—

mostly located on the eastern arm of the Capitan Reef Complex—were used to extract or explore for oil and gas in underlying stratigraphic units including the Wolfcamp, Spraberry, Canyon, Clear Fork, San Andres, and Grayburg formations (Nicot and others, 2012). In some cases, the Capitan Reef Complex Aquifer is used as a source of water for use in oil and gas well fields (Brackbill and Gaines, 1964). It is likely that petroleum-related pumping from the Capitan Reef Complex Aquifer will vary with oil and gas activity (Figure 4.6.2B). Figure 4.6.2B shows wide fluctuations in the number of oil and gas wells drilled per year. Over the period 2000 to 2010, the number of oil and gas wells penetrating the Capitan Reef Complex Aquifer per year varied from a high of 288 wells in 2006 to a low of 55 wells in 2002. However, there is a general trend towards increased drilling over time. Thus it is expected that petroleum-related pumping is gradually rising over time with the number of oil and gas wells in the area. Hiss (1975) estimated petroleum-related pumping from the Capitan Reef Complex Aquifer by decade and county. These estimates vary from average pumping of 10 acre-feet per year in Eddy County, New Mexico in the 1950s to about 15,000 acre-feet per year in Winkler County, Texas in the 1960s.

Nicot and others (2011; 2012) indicate that there are five categories of petroleum-related pumping—well completion in tight formations, enhanced oil recovery, waterflooding, drilling, and hydraulic fracturing. The term tight-formation completion refers to hydraulic fracturing of low permeability reservoir rock to increase oil and/or gas production. Enhanced oil recovery is a term for techniques that increase the amount of oil that can be extracted from an oil reservoir. Waterflooding is the injection of water into and oil or gas reservoirs in order to maintain pressure. The water used for drilling oil and gas wells that is reported in Nicot and others (2011) is an estimate based on informal discussions with practicing field engineers. Hydraulic fracturing refers to water used to fracture source rocks, such as shales, in order to extract gas. Hydraulic fracturing water use is subdivided into use and consumption. Water use refers to the amount of water used regardless of the water source, while water consumption excludes recycled and reused water. In the study area, there is no petroleum-related pumping in Brewster, Hudspeth, and Jeff Davis counties (Table 4.6.1). Overall, highest petroleum-related pumping occurs in Pecos County, although the highest rates of water consumption related to hydraulic fracturing occur in Ward County (Figure 4.6.3).

Irrigation pumping from the Capitan Reef Complex Aquifer is likely to be minimal considering issues of aquifer depth, groundwater quality, and the occurrence of alternative sources of irrigation water. Texas Water Development Board pumping data for the Capitan Reef Complex Aquifer indicate irrigation pumping up to 8,600 acre-feet per year—mostly in Culberson, Hudspeth, and Pecos counties (Figure 4.6.4; Table 4.6.2).

Livestock pumping was distributed using land cover data obtained from the National Land Cover Dataset (Vogelman and others, 1998a; 1998b). We assume that livestock pumping is associated with grassland and scrubland land cover (Figure 4.6.5A). These types of land cover account for almost all of the land cover over the Capitan Reef Complex Aquifer; however, livestock pumping is unlikely to occur much beyond the Capitan Reef Complex outcrops. Figure 4.6.5B shows the area most likely to be used for livestock pumping—where the depth to the Capitan Reef Complex Aquifer is less than 600 feet—the average depth of livestock wells pumping from the aquifer. Estimates of livestock pumping from the Capitan Reef Complex Aquifer are low, less than 100 acre-feet per year (Table 4.6.3).

Manufacturing and municipal pumping are spatially distributed based on known well locations (Figure 4.6.6). Texas Water Development Board pumping data indicates very little municipal pumping and almost no manufacturing and steam electric pumping from the Capitan Reef Complex Aquifer (Tables 4.6.4 and 4.6.5). Estimated pumping from the Texas Water Development Board water use survey indicates total municipal pumping from the Capitan Reef Complex Aquifer in the range of 1 to 20 acre-feet per year and no manufacturing pumping since 1982.

Rural domestic pumping—which consists primarily of unreported domestic water use—is assumed to: (1) be related to the population density in non-urban areas (Figure 4.6.7A), and (2) occur only in and adjacent to the Capitan Reef Complex Aquifer outcrops—in an area defined by an aquifer depth less than 900 feet which is the average depth of Capitan Reef Complex Aquifer domestic wells (Figure 4.6.7B). Capitan Reef Complex Aquifer rural domestic pumping is expected to be very small because most parts of the aquifer with this category of pumping have population densities of 0 to 1 persons per square mile (Figure 4.6.7). Rural domestic pumping estimates are based partially on per capita water usage rate estimates (Table 4.6.6). Estimates of per capita water use vary from 110 gallons per day to as high as 500 gallons per day. The highest estimates—based on county-wide municipal pumping and urban populations—are probably high because they also incorporate some commercial pumping that use “city water.”

Table 4.6.1. County-wide estimates of different categories of petroleum-related pumping in the Texas portion of the study area. The data was taken from Nicot and others (2011; 2012).

County	Tight Formation Completion (acre-feet)	Enhanced Oil Recovery (acre-feet)	Waterfloods (acre-feet)		Drilling (acre-feet)	Hydraulic Fracturing Use (acre-feet)	Hydraulic Fracturing Consumption (acre-feet)
	2008	1995	2008	2010	2008	2011	2011
Brewster	0	0	0	0	0	0	0
Culberson	12	0	115	160	0	166	33
Hudspeth	0	0	0	0	0	0	0
Jeff Davis	0	0	0	0	0	0	0
Pecos	183	162	267	315	206	110	22
Ward	67	9	13	15	84	568	114
Winkler	14	47	87	105	57	62	12

Table 4.6.2. Estimates of Capitan Reef Complex Aquifer irrigation pumping in the Texas portion of the study area. The data—expressed in acre-feet—was taken from Texas Water Development Board (2012c).

Year	County					
	Brewster	Culberson	Hudspeth	Pecos	Ward	Winkler
1980	0	60	2,800	0	0	0
1981	0	50	2,125	0	0	0
1982	0	41	1,449	0	0	0
1983	0	31	774	0	0	0
1984	0	21	98	0	0	0
1985	0	25	80	0	0	0
1986	0	19	37	0	0	0
1987	0	20	40	0	0	0
1988	0	19	46	0	0	0
1989	0	14	81	0	0	0
1990	0	9	42	0	0	0
1991	0	9	43	0	0	0
1992	0	11	33	0	0	0
1993	0	6	97	0	0	0
1994	0	0	2,797	0	0	0
1995	0	0	2,224	0	0	0
1996	0	0	2,084	0	0	0
1997	0	0	2,094	0	0	0
1998	0	0	2,436	0	0	0
1999	0	0	3,701	0	0	0
2000	0	0	3,532	0	0	0
2001	0	0	3,121	0	0	0
2002	0	0	2,769	0	0	0
2003	0	0	2,463	0	0	0
2004	0	3,151	2,828	918	0	0
2005	0	3,594	2,363	888	0	0
2006	0	3,366	1,522	1,337	0	0
2007	0	2,749	1,766	1,179	0	0
2008	0	5,651	1,713	1,229	0	0

Table 4.6.3. Estimates of Capitan Reef Complex Aquifer livestock pumping in the Texas portion of the study area. The data—expressed in acre-feet—was taken from Texas Water **Development Board (2012c).**

Year	County					
	Brewster	Culberson	Hudspeth	Pecos	Ward	Winkler
1980	0	41	11	0	0	0
1981	0	38	11	0	0	0
1982	0	36	10	0	0	0
1983	0	33	10	0	0	0
1984	0	30	9	0	0	0
1985	0	33	5	0	0	0
1986	0	28	3	0	0	0
1987	0	44	5	0	0	0
1988	0	47	5	0	0	0
1989	0	47	5	0	0	0
1990	0	46	5	0	0	0
1991	0	47	5	0	0	0
1992	0	31	6	0	0	0
1993	0	29	6	0	0	0
1994	0	26	8	0	0	0
1995	0	21	6	0	0	0
1996	0	23	5	0	0	0
1997	0	25	5	0	0	0
1998	0	34	9	0	0	0
1999	0	37	9	0	0	0
2000	0	33	8	0	0	0
2001	0	30	8	0	0	0
2002	0	47	8	0	0	0
2003	0	25	6	0	0	0
2004	21	50	6	14	0	0
2005	27	41	5	15	0	0
2006	25	47	6	17	0	0
2007	27	53	6	13	0	0
2008	30	55	6	15	0	0

Table 4.6.4. **Estimates of Capitan Reef Complex Aquifer manufacturing pumping in the Texas portion of the study area. The data—expressed in acre-feet—was taken from Texas Water Development Board (2012c).**

Year	County					
	Brewster	Culberson	Hudspeth	Pecos	Ward	Winkler
1980	0	0	1.00	0	0	0
1981	0	0	0.75	0	0	0
1982	0	0	0.50	0	0	0
1983	0	0	0.25	0	0	0
1984	0	0	0	0	0	0
1985	0	0	0	0	0	0
1986	0	0	0	0	0	0
1987	0	0	0	0	0	0
1988	0	0	0	0	0	0
1989	0	0	0	0	0	0
1990	0	0	0	0	0	0
1991	0	0	0	0	0	0
1992	0	0	0	0	0	0
1993	0	0	0	0	0	0
1994	0	0	0	0	0	0
1995	0	0	0	0	0	0
1996	0	0	0	0	0	0
1997	0	0	0	0	0	0
1998	0	0	0	0	0	0
1999	0	0	0	0	0	0
2000	0	0	0	0	0	0
2001	0	0	0	0	0	0
2002	0	0	0	0	0	0
2003	0	0	0	0	0	0
2004	0	0	0	0	0	0
2005	0	0	0	0	0	0
2006	0	0	0	0	0	0
2007	0	0	0	0	0	0
2008	0	0	0	0	0	0

Table 4.6.5. Estimates of Capitan Reef Complex Aquifer municipal pumping in the Texas portion of the study area. The data—expressed in acre-feet—was taken from Texas Water Development Board (2012c).

Year	County					
	Brewster	Culberson	Hudspeth	Pecos	Ward	Winkler
1980	0	10	2	0	0	0
1981	0	11	2	0	0	0
1982	0	11	2	0	0	0
1983	0	12	1	0	0	0
1984	0	12	1	0	0	0
1985	0	10	1	0	0	0
1986	0	8	1	0	0	0
1987	0	9	1	0	0	0
1988	0	9	1	0	0	0
1989	0	7	1	0	0	0
1990	0	5	1	0	0	0
1991	0	5	1	0	0	0
1992	0	5	1	0	0	0
1993	0	6	1	0	0	0
1994	0	0	1	0	0	0
1995	0	5	1	0	0	0
1996	0	5	1	0	0	0
1997	0	4	1	0	0	0
1998	0	5	1	0	0	0
1999	0	6	1	0	0	0
2000	0	4	1	0	0	0
2001	0	4	1	0	0	0
2002	0	4	1	0	0	0
2003	0	4	1	0	0	0
2004	3	12	4	0	0	0
2005	3	12	4	0	0	0
2006	3	13	4	0	0	0
2007	3	10	3	0	0	0
2008	3	11	3	0	0	0

Table 4.6.6. County-wide estimates of rural domestic pumping in the Capitan Reef Complex Aquifer study area. The data was obtained from the United States Department of Commerce (2013).

County	Rural Population (2000)	Rural Domestic Pumpage (2000) (acre-feet)
Brewster	2,085	257
Culberson	386	48
Eddy	10,091	1,243
Hudspeth	2,911	359
Jeff Davis	2,031	250
Lea	8,595	1,059
Loving	67	8
Otero	15,204	1,873
Pecos	6,587	811
Reeves	1,454	179
Ward	1,871	230
Winkler	215	26

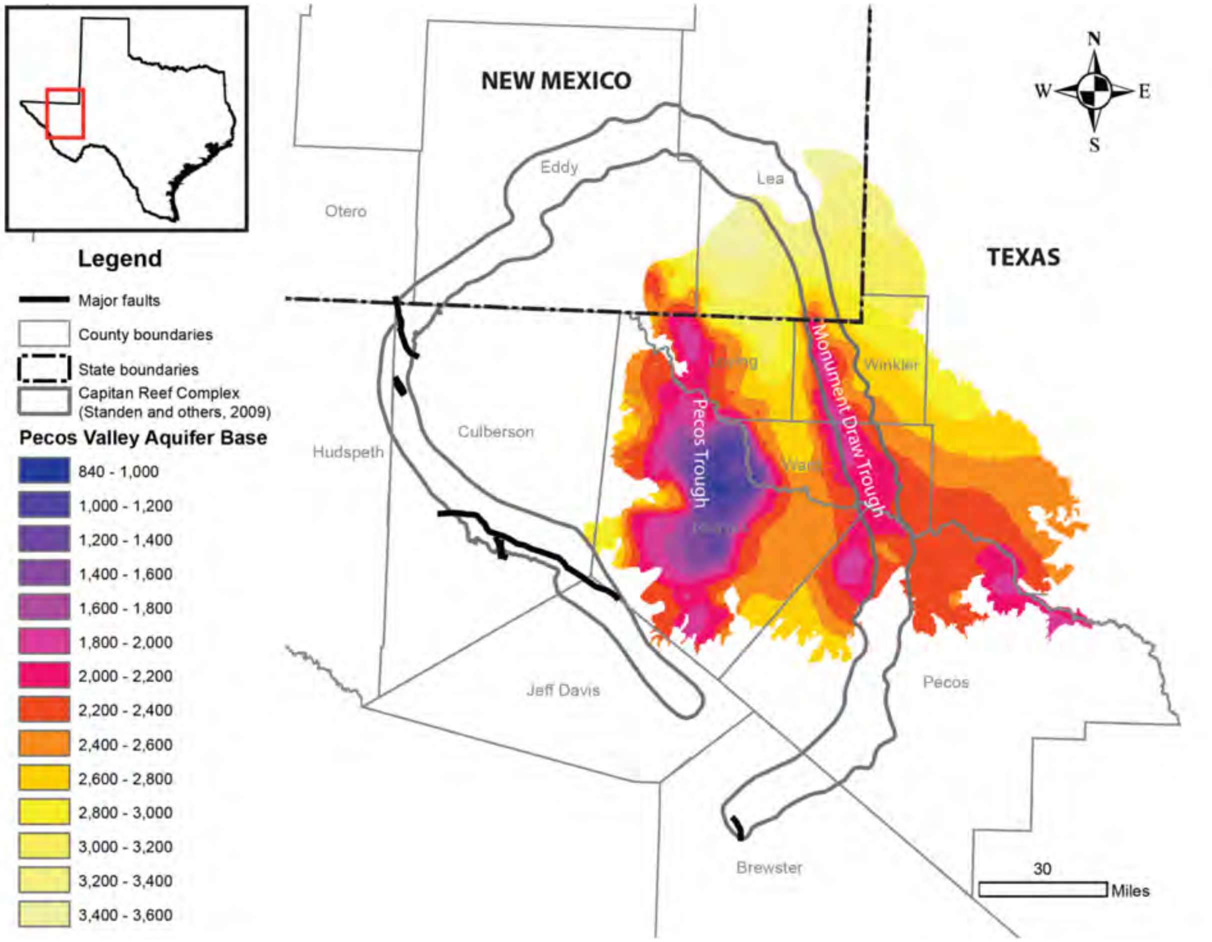
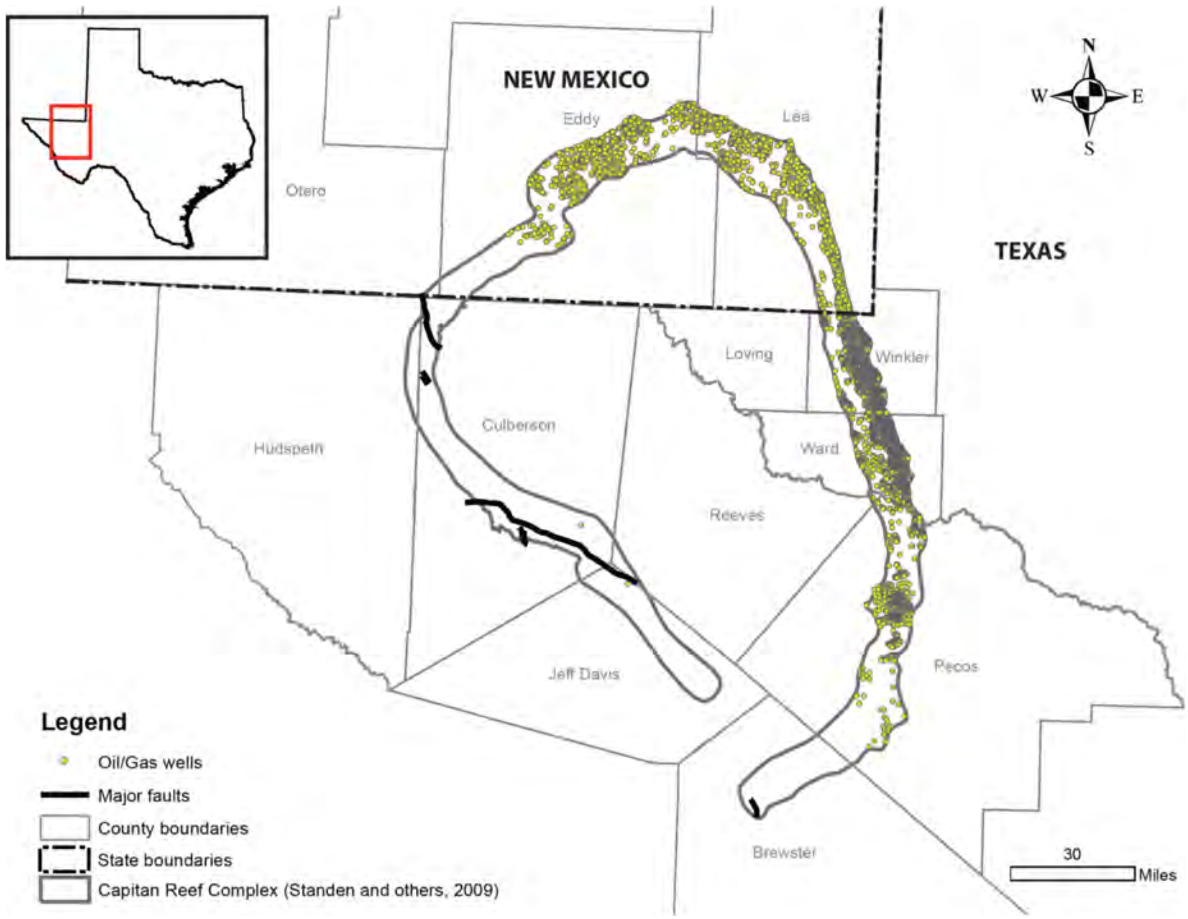
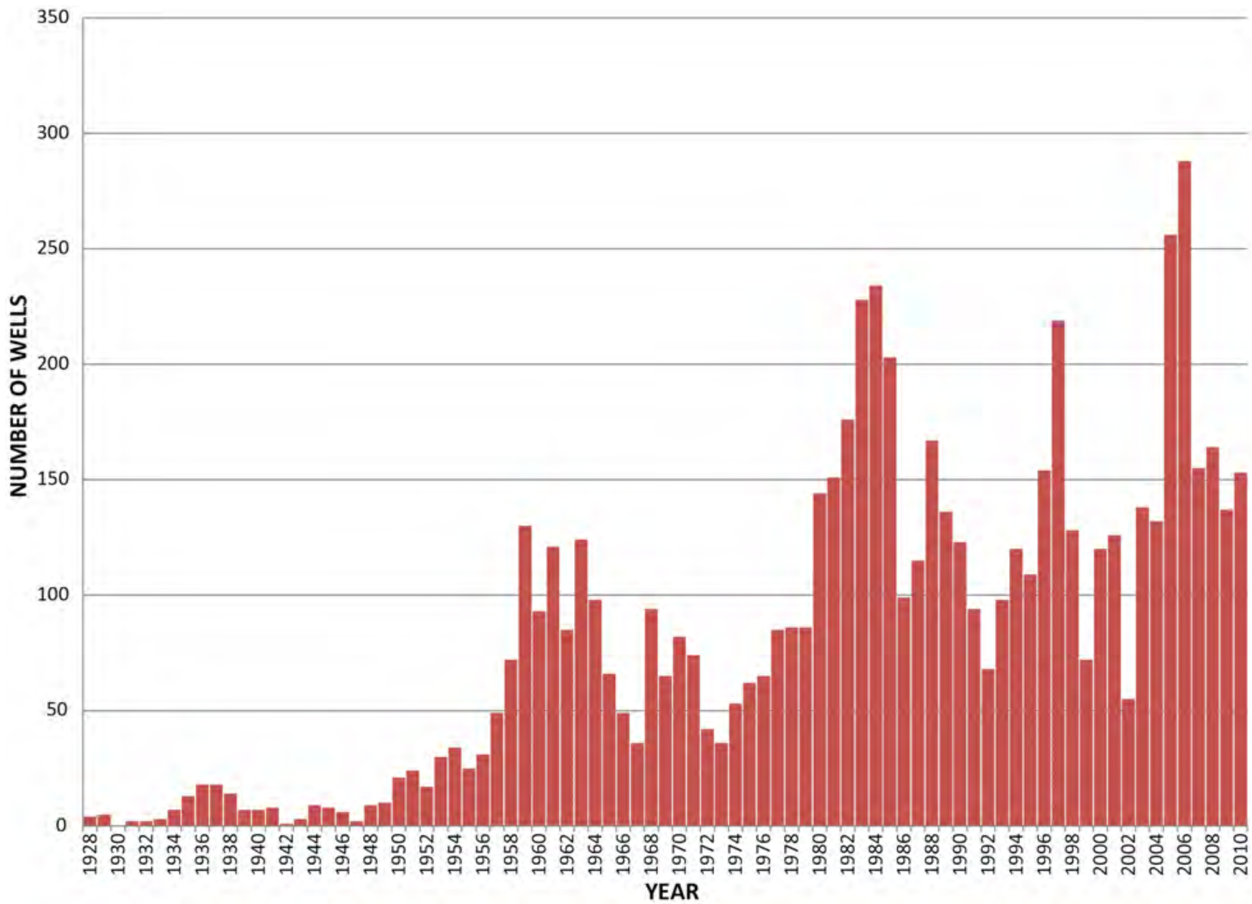


Figure 4.6.1. **The eastern arm of the Capitan Reef Complex Aquifer coincides with the Monument Draw Trough of the overlying Pecos Valley. The formation of the Monument Draw Trough is the result of dissolution of the Salado Formation—a stratigraphic unit overlying the Capitan Reef Complex—and consequent collapse of overlying stratigraphic units. This collapse structure potentially forms a pathway for upward discharge of groundwater. (Pecos Valley Aquifer base data from Hutchison and others, 2011).**



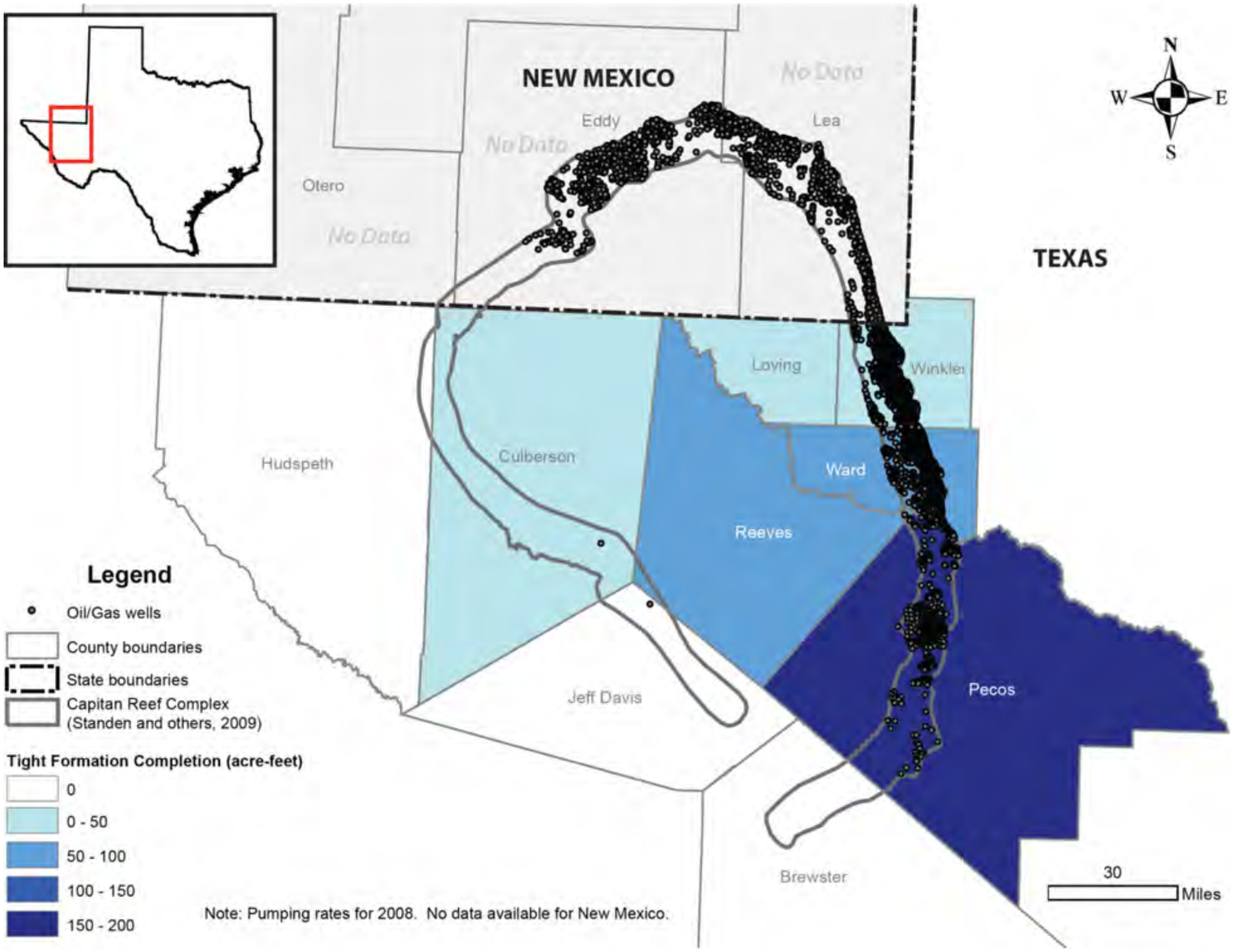
(A)

Figure 4.6.2. **Spatial (A) and temporal (B) distribution of oil and gas wells penetrating the Capitan Reef Complex Aquifer (Railroad Commission of Texas, 2012; New Mexico Energy, Minerals and Natural Resources Department, 2012).**



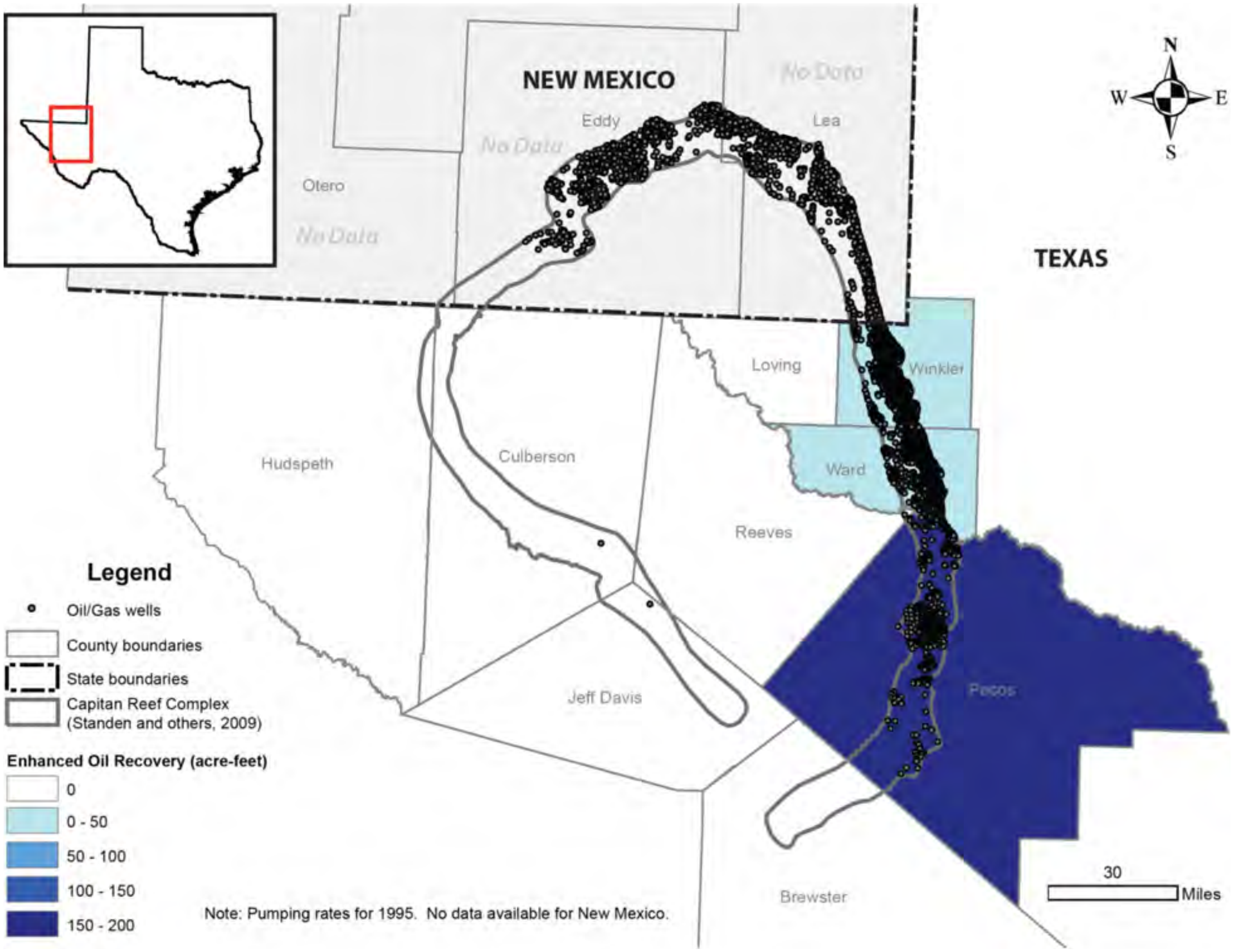
(B)

Figure 4.6.2. (continued)



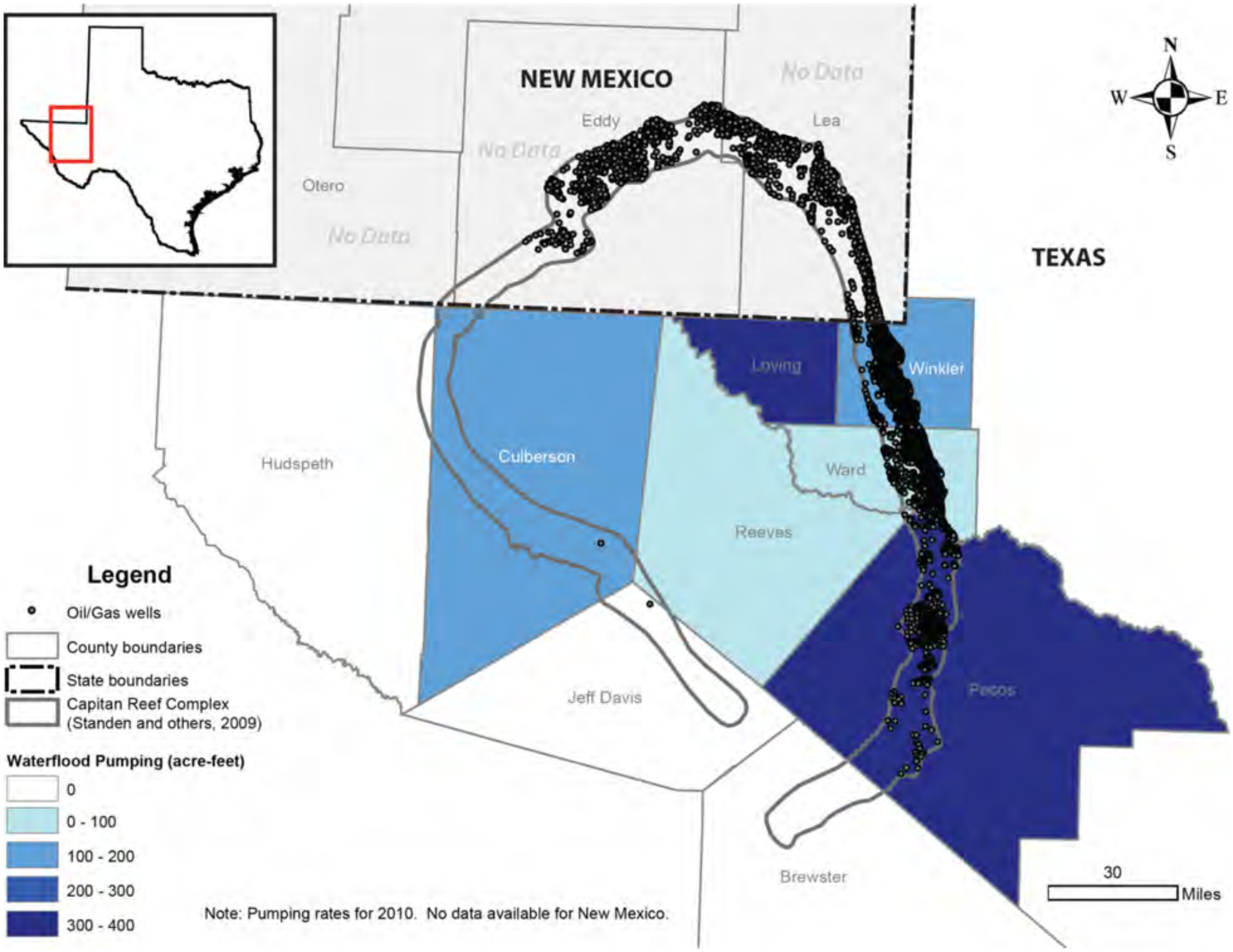
(A)

Figure 4.6.3. **Petroleum-related pumping in counties adjacent to the Capitan Reef Complex Aquifer from Nicot and others (2011; 2012). This pumping falls under five categories: (A) tight-formation completion, (B) enhanced oil recovery, (C) waterflooding, (D) drilling, and (E) hydraulic fracturing consumption.**



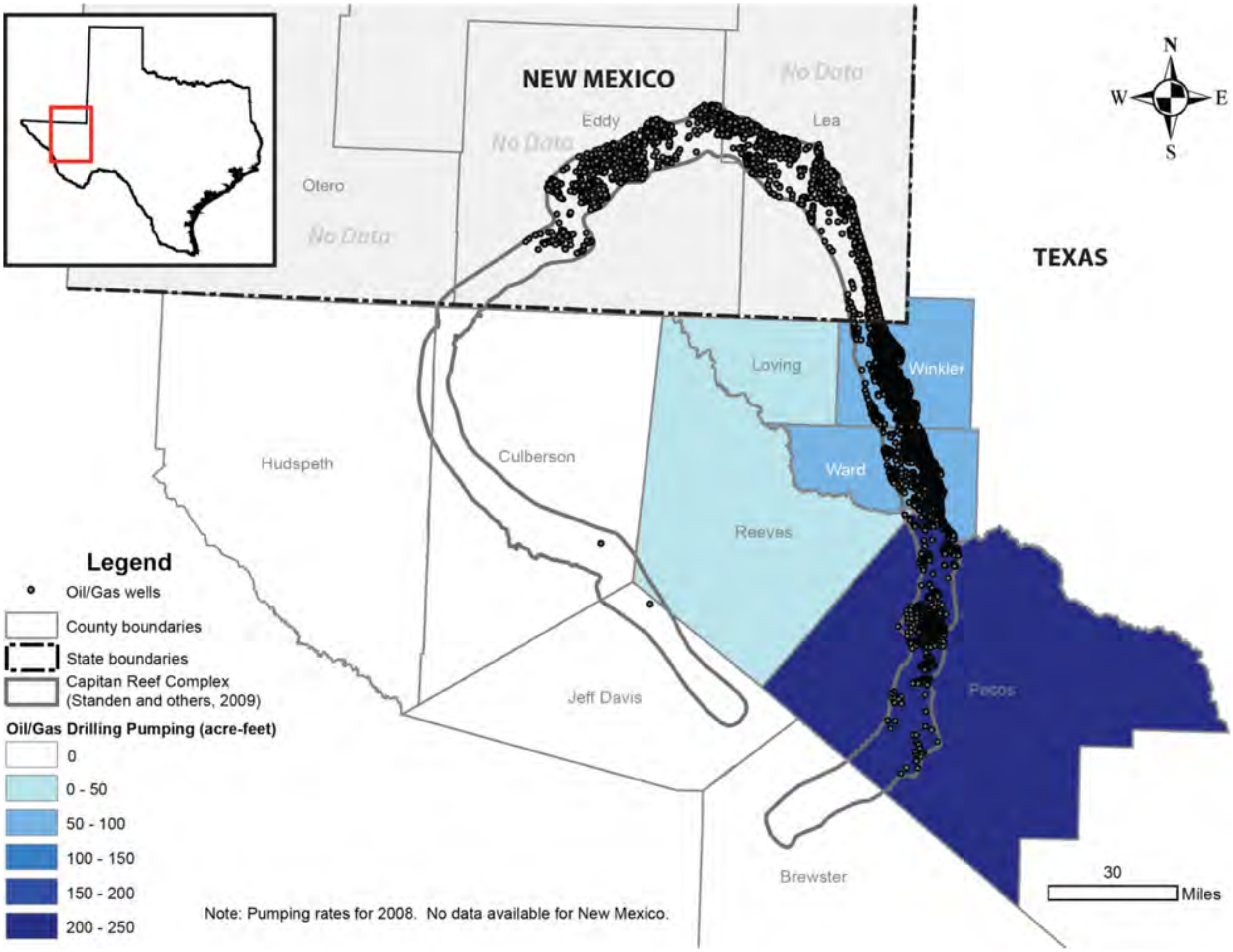
(B)

Figure 4.6.3. (continued).



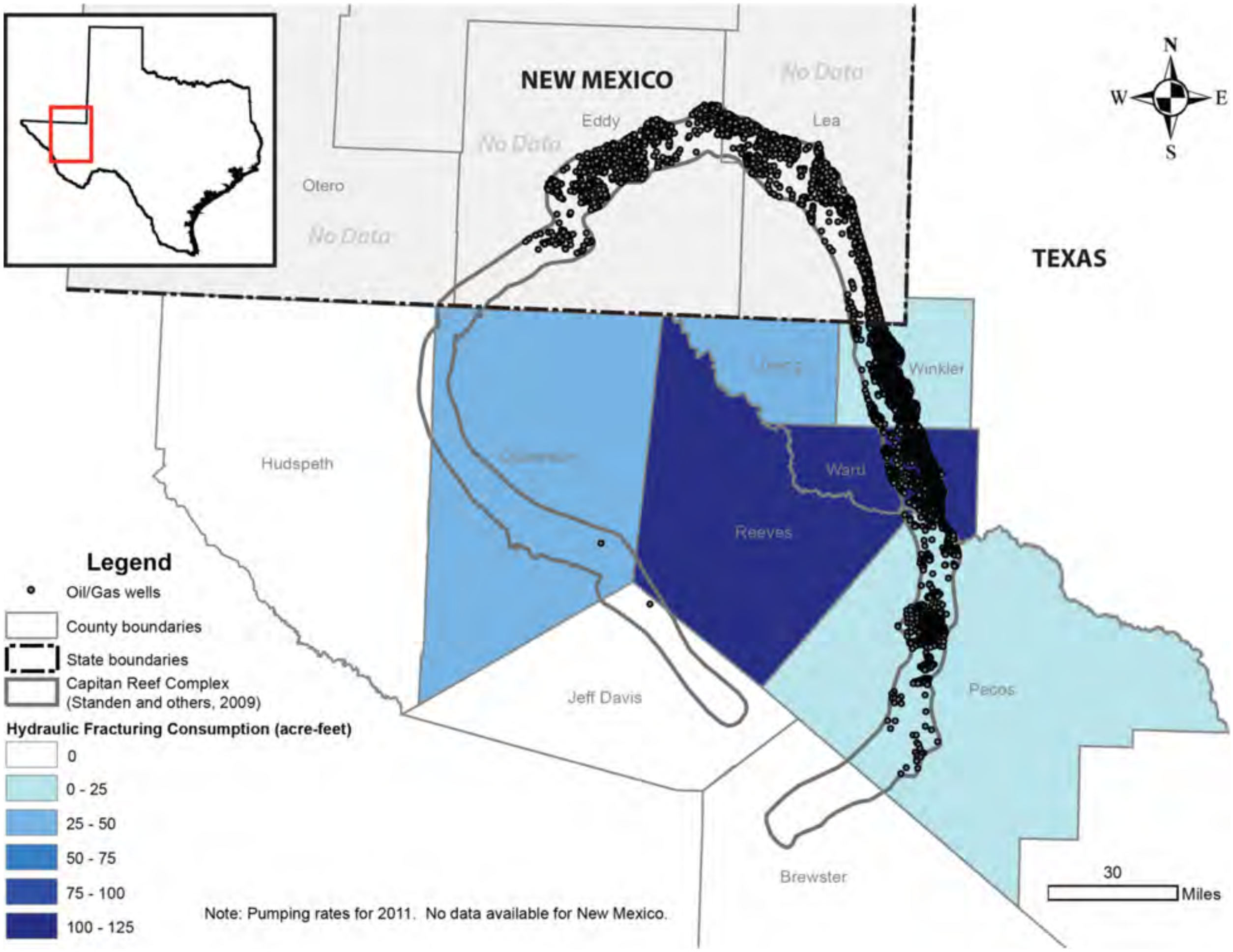
(C)

Figure 4.6.3. (continued).



(D)

Figure 4.6.3. (continued).



(E)

Figure 4.6.3. (continued).

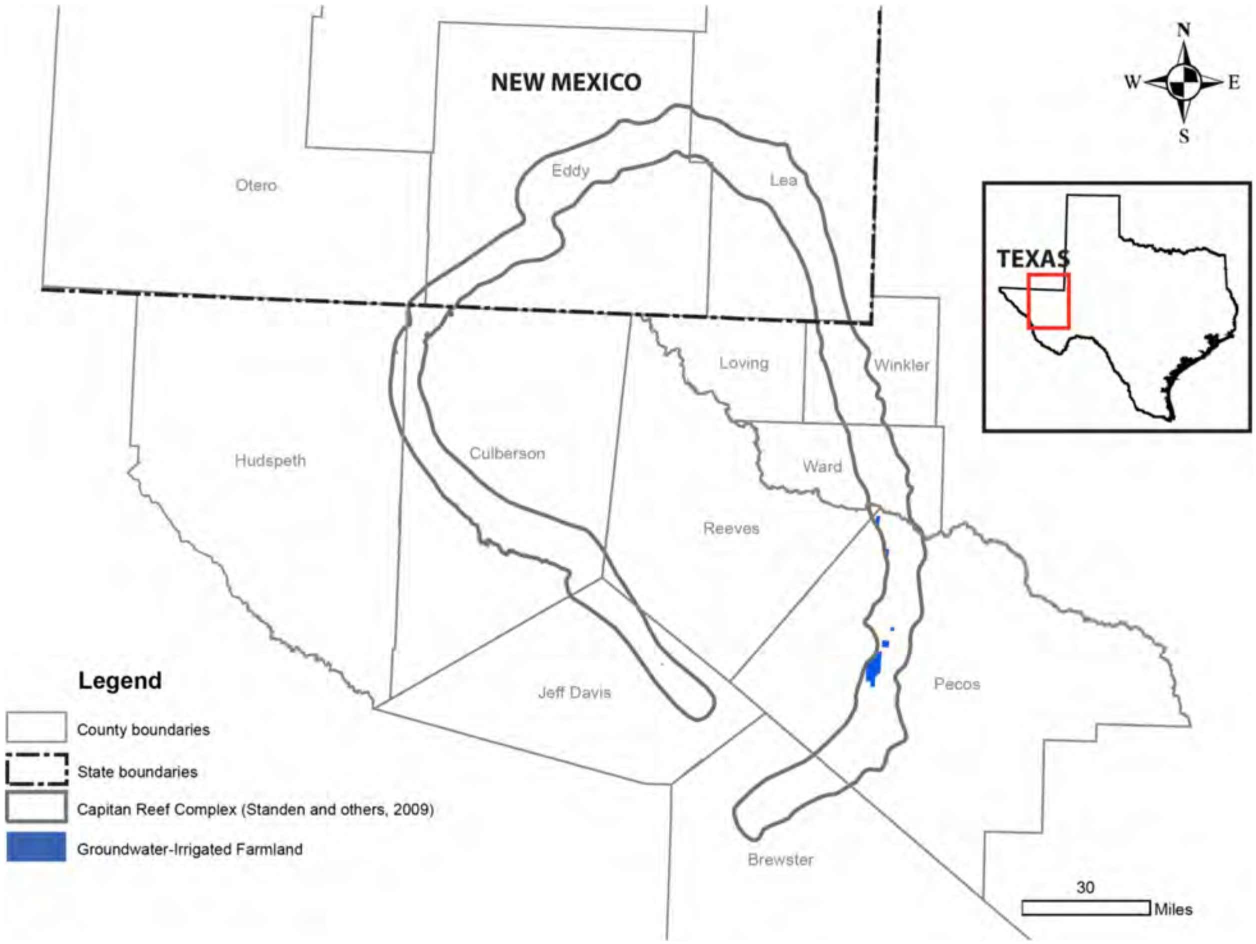
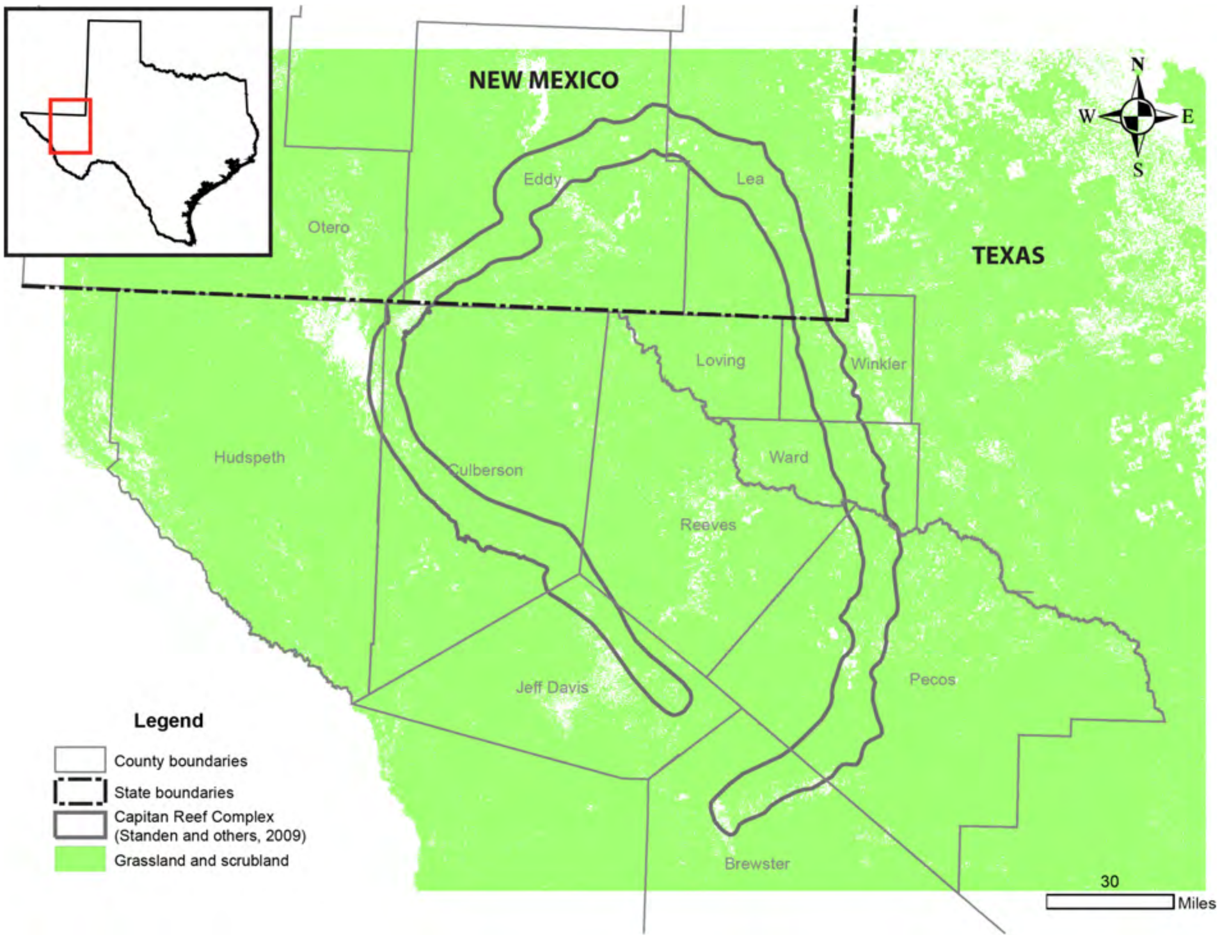
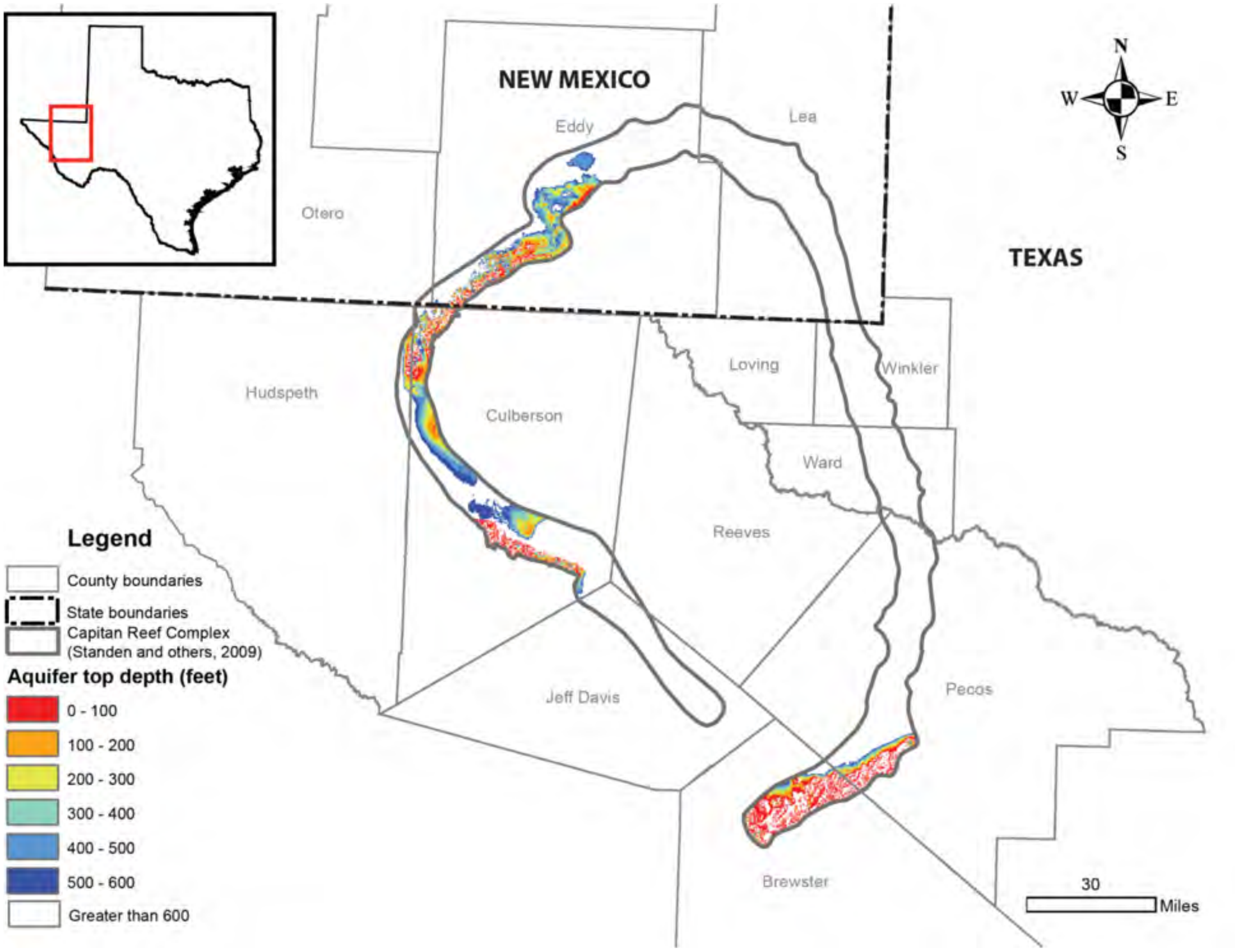


Figure 4.6.4. **Spatial distribution of groundwater-irrigated farmland overlying the Capitan Reef Complex Aquifer.**



(A)

Figure 4.6.5. **The spatial distribution of livestock pumping (A) based grassland and scrubland land cover from the National Land Cover Dataset throughout the study area (Vogelman and others, 1998a; 1998b) and (B) the portion of the Capitan Reef Complex Aquifer that would potentially be used for livestock pumping based on the combination of depth to the top of the aquifer and an average Capitan Reef Complex Aquifer livestock well depth of 600 feet. Livestock pumping will be distributed in model cells that include the shallow zones in (Figure 4.6.5B).**



(B)

Figure 4.6.5. (continued).

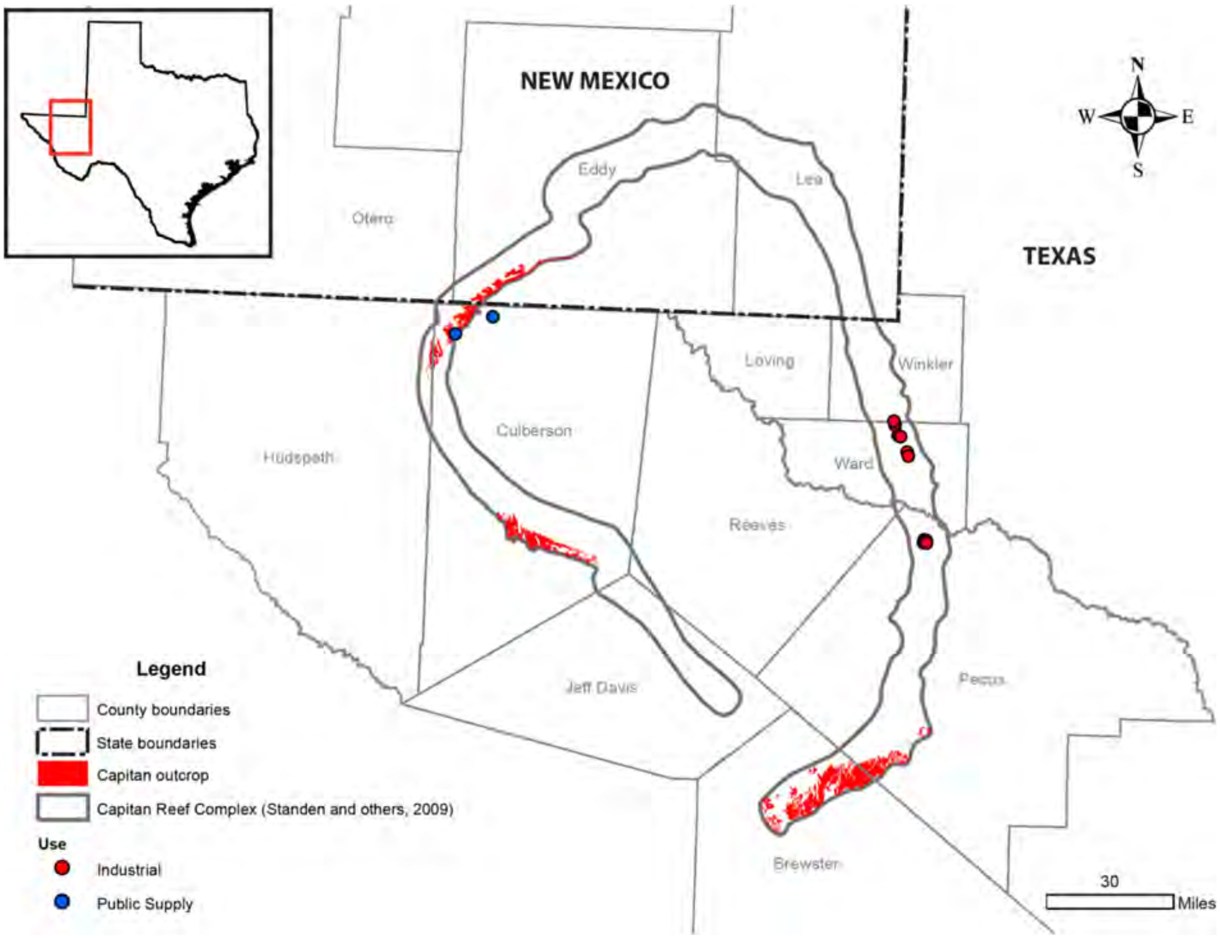
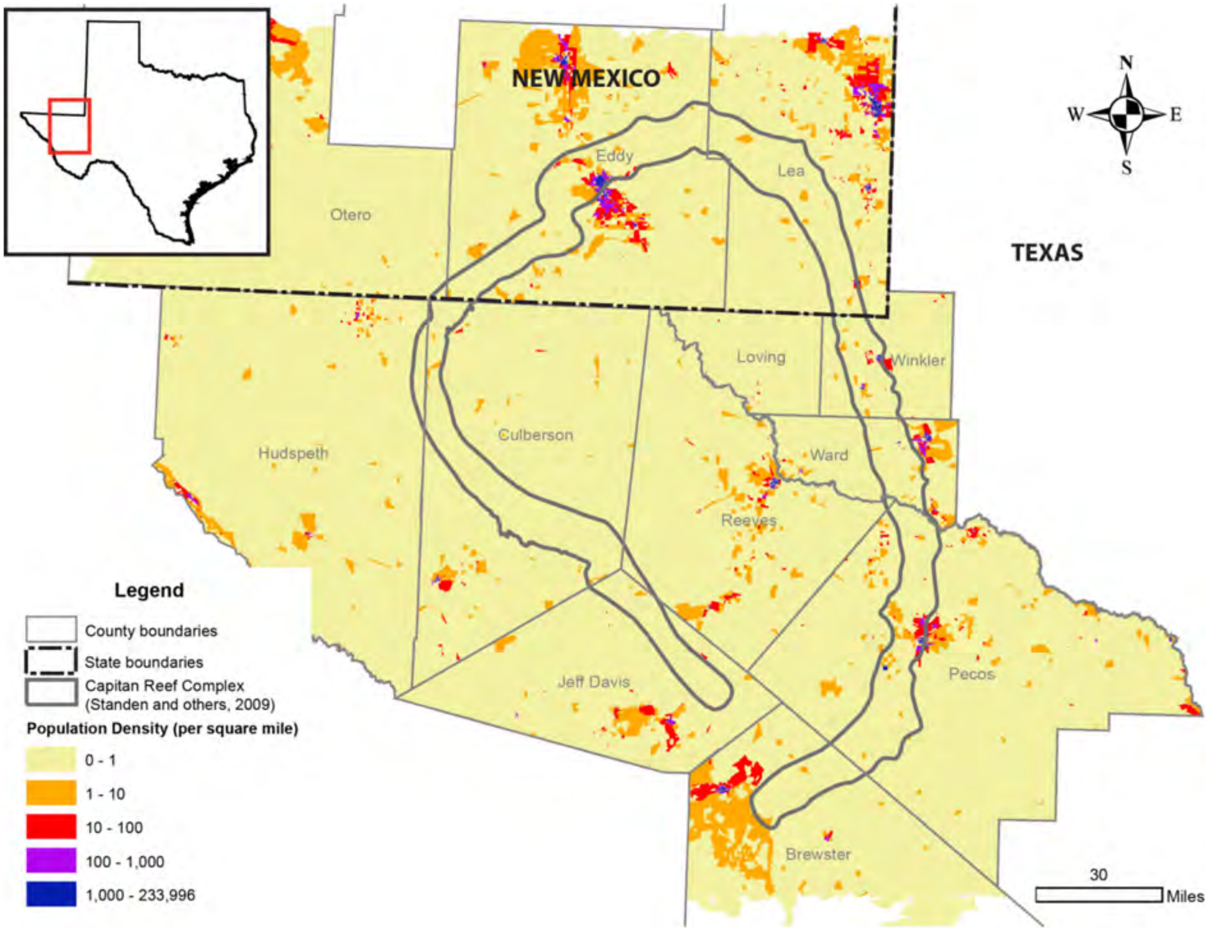
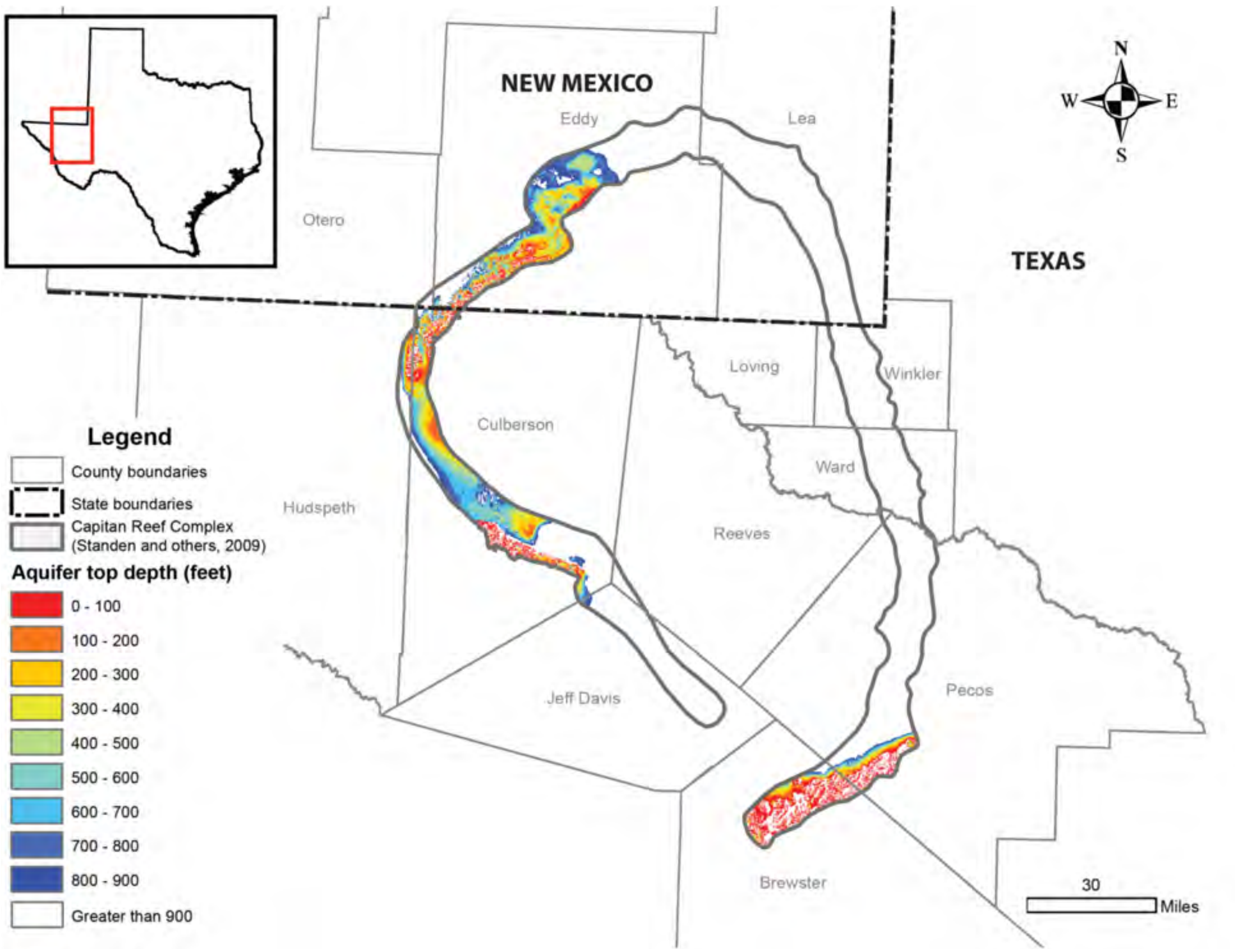


Figure 4.6.6. **The spatial distribution of manufacturing (industrial) and municipal (public supply) pumping. Manufacturing and public supply pumping will be distributed in model cells that coincide with the well locations.**



(A)

Figure 4.6.7. Population density in the Capitan Reef Complex Aquifer study area (A). Rural domestic pumping in the Capitan Reef Complex Aquifer is distributed based on the rural population over the aquifer and the combination of depth to the top of the aquifer and an average Capitan Reef Complex Aquifer domestic well depth of 900 feet (B). Rural domestic pumping will be distributed in model cells that include the shallow zones in (Figure 4.6.7B).



(B)

Figure 4.6.7. (continued).

4.7 Water Quality

The Capitan Reef Complex Aquifer generally has slightly to very saline groundwater (Brown, 1997).

4.7.1 Major Elements

In some parts of the Capitan Reef Complex Aquifer, concentrations of total dissolved solids, chloride, fluoride, and sulfate exceed applicable water quality standards. High concentrations of these constituents occur in both eastern and western parts of the aquifer in Texas, with especially high concentrations in Texas occurring in Pecos, Ward, and Winkler counties (Brown, 1997). Iron and manganese concentrations exceeding their respective water quality standards occur in the western extent of the aquifer.

Figure 4.7.1 shows total dissolved solids concentrations in Capitan Reef Complex Aquifer groundwater. The occurrence of fresh groundwater—total dissolved solids less than 1,000 milligrams per liter—is restricted to aquifer outcrops in Brewster, Culberson, Hudspeth, and Pecos counties and possibly also southern Eddy County. In areas where the Capitan Reef Complex Aquifer occurs at depth, groundwater varies from slightly saline to brine with a range of total dissolved solids of 1,000 milligrams per liter to greater than 100,000 milligrams per liter. The most saline groundwater occurs in Eddy and Lea counties in New Mexico. Groundwater salinity generally increases as groundwater flows away from the outcrops where recharge occurs, reaching a maximum in the northernmost parts of the aquifer.

Groundwater in the Capitan Reef Complex Aquifer displays a wide range of geochemical compositions (Figure 4.7.2). Groundwater compositions range from calcium-magnesium to sodium compositions and bicarbonate to sulfate to chloride compositions. These compositional ranges represent geochemical processes that take place as the groundwater flows through the aquifer interacting with aquifer rock and mixing with groundwater inflows from surrounding stratigraphic units (Figure 4.7.3). These compositions indicate groundwater interaction with calcite, dolomite, gypsum, and halite, minerals that occur within the Capitan Reef Complex and adjacent stratigraphic units. Groundwater interaction with dolomite and calcite would produce calcium-magnesium-bicarbonate compositions, gypsum would produce calcium-sulfate compositions, and halite would produce sodium-chloride compositions. In the Capitan Reef Complex Aquifer, groundwater with calcium-magnesium-bicarbonate compositions occur in or adjacent to Capitan Reef Complex outcrops in the Guadalupe and Glass mountains. Groundwater with calcium-magnesium-sulfate compositions occur in deeper parts of the aquifer in northern Pecos County while calcium-sulfate groundwater compositions occur adjacent to the Delaware Mountains in Culberson County. Groundwater with sodium-calcium-chloride and sodium-chloride-sulfate compositions occur in the New Mexico portion of the aquifer. Capitan Reef Complex Aquifer groundwater with sodium-chloride compositions are associated with some of the most saline groundwater in the aquifer—occurring in Eddy, Lea, and Ward counties. Figure 4.7.4 shows changes in groundwater composition that take place in the eastern arm of the

Capitan Reef Complex Aquifer extending from Brewster County, north through Pecos, Ward and Winkler counties in Texas and Lea County and eastern Eddy County in New Mexico. Northward, groundwater compositions change from calcium-magnesium-bicarbonate and calcium-magnesium-sulfate compositions in Brewster County and southern Pecos County to sodium-potassium-chloride compositions in Ward, Winkler, Lea, and Eddy counties. This pattern of geochemical composition changes suggests increasing inputs from halite dissolution as the groundwater flows away from the Glass and Guadalupe mountain recharge zones. These changes in groundwater compositions are also accompanied by increasing total dissolved solids concentrations.

4.7.2 Isotopes

Groundwater isotopic compositions can provide information about groundwater hydrology. Concentrations of different isotopes often change in response to processes such as evaporation, water-rock interaction, recharge processes, and the elapsed time since recharge.

Groundwater carbon-13 isotopic compositions ($\delta^{13}C$) represent the ratios of stable carbon isotopes—^{12}C and ^{13}C—in groundwater relative to the composition of a standard—PDB calcite (Clark and Fritz, 1997). These isotope ratios are expressed as the relative difference in parts per thousand—per mil. Groundwater carbon-13 isotopic compositions reflect relative carbon inputs from interaction with soil and aquifer rock. Groundwater near recharge zones tend to have more negative carbon-13 compositions reflecting recent contact with the soil. As the groundwater flows through the aquifer—away from the recharge zone—water-rock interaction results in the groundwater taking on more positive carbon-13 isotopic compositions reflecting those of the aquifer rock. This trend is most apparent in the eastern part of the Capitan Reef Complex Aquifer where carbon-13 isotopic compositions range from -10.7 per mil in the aquifer outcrop in Brewster County to -3.6 per mil in northern Pecos County (Figure 4.7.5). Negative groundwater carbon-13 compositions also indicate recharge in the Guadalupe Mountains outcrop but relatively little recharge in the Apache Mountains outcrop of the Capitan Reef Complex. On the other hand, low groundwater carbon-13 compositions in the subsurface adjacent to the southern margin of the Delaware Mountains in Culberson County suggest that recent recharge has occurred there.

Carbon-14 decays over time and, consequently, without a continuous influx of carbon-14 with recharging groundwater, the carbon-14 activity in groundwater will decrease over time. The result typically is that groundwater carbon-14 activity is higher in shallower parts of an aquifer where recharge is occurring. In the Capitan Reef Complex Aquifer, carbon-14 activity is generally highest—up to 100 percent modern carbon—where the aquifer crops out and recharge occurs, and lowest in the subcrop where there is no recharge and almost all of the groundwater carbon-14 has decayed (Figure 4.7.6). This figure shows the trend of decreasing groundwater carbon-14 activity northwards from the Glass Mountains outcrop of Brewster County and southern Pecos County. The spatial distribution of carbon-14 activity in the Capitan Reef

Complex Aquifer suggests that recharge zones occur in the aquifer outcrops in the Guadalupe and Glass mountains, and near the southern margin of the Delaware Mountains, while there is little recharge in the Apache Mountains outcrop—as suggested by groundwater carbon-13.

Groundwater tritium behaves like carbon-14. The difference is that tritium has a faster decay rate with a half-life of 12.3 years compared to 5,730 years for carbon-14 (Clark and Fritz, 1997). High tritium activity indicates the most recent recharge. In the Capitan Reef Complex Aquifer, the groundwater tritium activity ranges between 0 and 5 tritium units (Figure 4.7.7). However, except for a well in Culberson County with tritium activity in excess of 4 tritium units, most groundwater tritium activity is 0.1 tritium units or less. This indicates that there is very little recent recharge to the aquifer. This most recent recharge is limited to an area near the southern margin of the Delaware Mountains.

Groundwater stable hydrogen (δ^2H) and oxygen (δ^{18}O) isotopic compositions represent the ratios of stable hydrogen isotopes—H and ^{2}H—and stable oxygen isotopes—^{16}O and ^{18}O—in groundwater relative to the composition of standard mean ocean water (Clark and Fritz, 1997). These isotope ratios are expressed as the relative difference in parts per thousand—per mil. Groundwater stable hydrogen (δ^2H) and oxygen (δ^{18}O) isotopic compositions reflect the composition of the precipitation that recharged the aquifer. Consequently, the hydrogen and oxygen isotopic compositions of groundwater can be used as an indicator of the conditions under which recharge to the aquifer occurred. Figures 4.7.8 and 4.7.9 show groundwater hydrogen and oxygen isotopic compositions in the Capitan Reef Complex Aquifer. Groundwater stable hydrogen and oxygen isotopic compositions in the Capitan Reef Complex Aquifer lie in the ranges -71 to -43 per mil and -10 to -7 per mil, respectively. There are no apparent isotopic composition trends along groundwater flowpaths. The well located adjacent to the southern margin of the Delaware Mountains that is associated with recent recharge based on its groundwater carbon-13, carbon-14, and tritium compositions also has stable hydrogen and oxygen isotopic compositions that are more distinct—much higher—than other locations in the Capitan Reef Complex Aquifer. Stable hydrogen and oxygen isotope compositions generally lie along the Global Meteoric Water Line—the average relationship between stable hydrogen and oxygen isotopic compositions in precipitation around the world (Craig, 1961). Figure 4.7.10 shows Capitan Reef Complex Aquifer groundwater stable hydrogen and oxygen isotopic compositions relative to the Global Meteoric Water Line. The lowest stable hydrogen and oxygen groundwater isotopic compositions occur in the Guadalupe, Apache, and Glass mountains (Figures 4.7.8 and 4.7.9). The highest stable hydrogen and oxygen groundwater isotopic compositions occur just south of the Delaware Mountains. The range of groundwater stable hydrogen and oxygen isotopic compositions is narrower in the eastern arm of the Capitan Reef Complex Aquifer—Brewster, Pecos, Ward, and Winkler counties—than in the west—Culberson and Hudspeth counties (Figure 4.7.11).

4.7.3 Implications for Recharge Based on Groundwater Isotopic Compositions

The range of stable hydrogen and oxygen isotopic compositions can be influenced by temperature, altitude, amount of precipitation, and water-rock interaction effects (Dansgaard, 1964; Fontes and Olivry, 1977; Scholl and others, 1996; Gonfiantini, 1985; Fontes, 1980). The most likely effects influencing the range of groundwater stable hydrogen and oxygen isotopic compositions in the Capitan Reef Complex Aquifer are the altitude and amount effects. The altitude effect would result in groundwater with lower stable hydrogen and oxygen isotopic compositions—such as in the Guadalupe Mountains—due to recharge taking place at higher elevations. Conversely, recharge occurring at lower elevations would be characterized by higher stable hydrogen and oxygen isotopic compositions. Higher precipitation amounts produce more negative isotopic compositions in the precipitation and resultant groundwater. Note that more precipitation (Figure 2.1.6) also occurs at higher elevations (Figure 2.1.3) such as the Guadalupe Mountains; consequently, it would be difficult to differentiate between the impacts of the amount and elevation effects on groundwater stable hydrogen and oxygen isotopic compositions. The influence of these two effects can explain the difference in the ranges of groundwater stable hydrogen and oxygen isotopic compositions observed in the eastern and western arms of the Capitan Reef Complex Aquifer. The narrower range of groundwater stable hydrogen and oxygen isotope compositions in the eastern arm of the Capitan Reef Complex Aquifer can be explained as the product of a single recharge zone in the outcrops in the Glass Mountains. The wider range of compositions in the western side of the Capitan Reef Complex Aquifer—Culberson and Hudspeth counties—represent recharge under a range of conditions of climate and elevation. The relatively low groundwater stable hydrogen and oxygen compositions in northern Culberson County and Hudspeth County can be attributed to recharge in or adjacent to the Guadalupe Mountains—the highest mountains in Texas (Figure 4.7.12). The wide range of groundwater compositions in southern Culberson County represent a wide range of recharge conditions varying from recharge at higher elevations in the Apache Mountains—the lowest values—to recharge taking place at lower elevations in the valley between the Apache and Delaware mountains—the higher values (Figure 4.7.12).

An alternative explanation for the highest groundwater stable hydrogen and oxygen isotopic compositions in the western arm of the Capitan Reef Complex Aquifer is recent recharge in a climate that is warmer and drier than Pleistocene climate—a pattern that has been observed in other aquifers in the region (Darling, 1997). This explanation is supported by the carbon-14 and tritium data. These data indicate that about half of the groundwater samples collected from the Capitan Reef Complex Aquifer have apparent ages in excess of 10,000 years—carbon-14 of less than 25 percent modern carbon—suggesting recharge during the Pleistocene. Most groundwater carbon-14 apparent ages are in excess of 5,000 years. The highest groundwater stable hydrogen and oxygen isotopic compositions in the western arm of the Capitan Reef Complex Aquifer are associated with very high carbon-14 compositions—approaching 100 percent modern carbon—and the highest tritium concentration, indicating very recent recharge. This groundwater occurs in the subcrop part of the Capitan Reef Complex Aquifer near the southern margin of the

Delaware Mountains and is probably the result of recharge due to rapid infiltration down fractures.

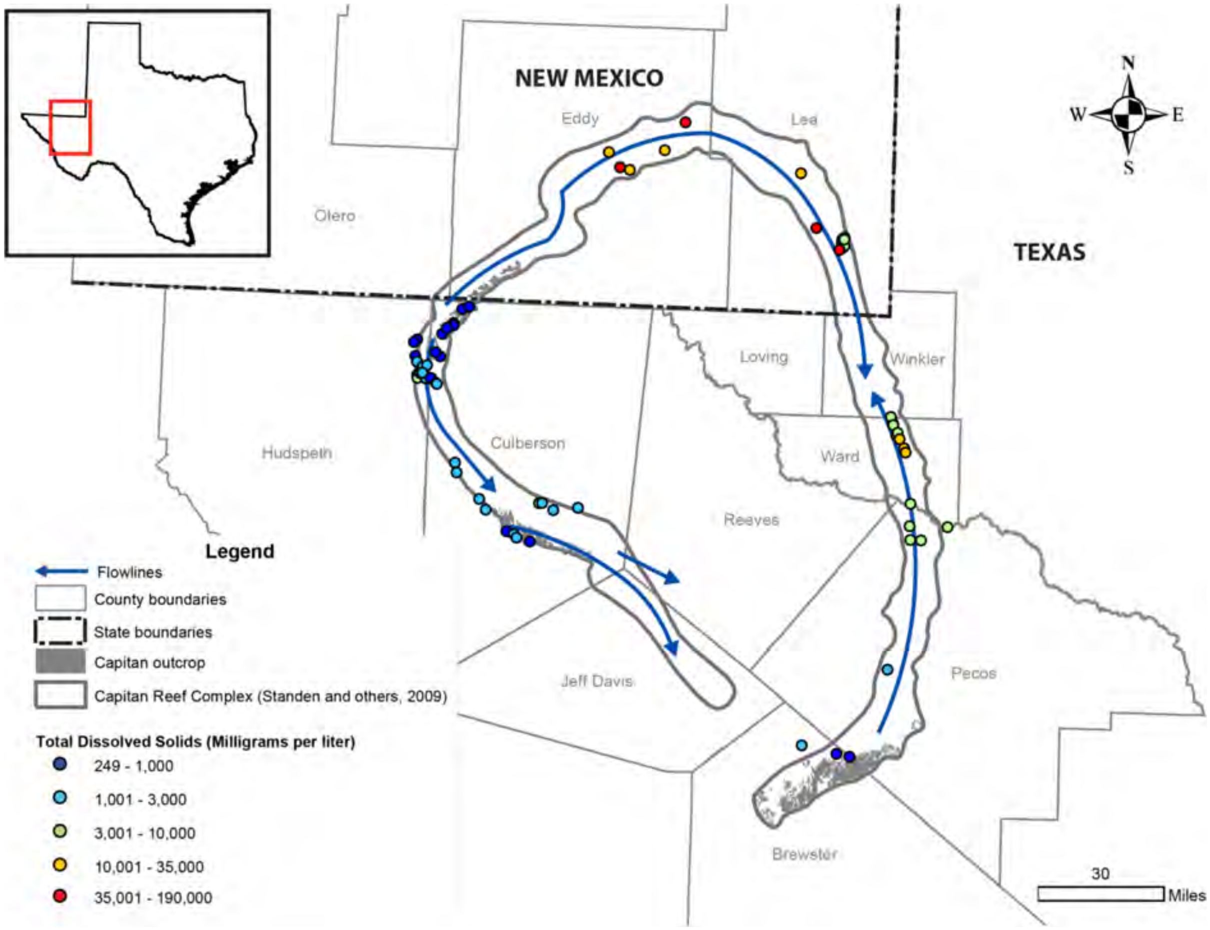


Figure 4.7.1. Total dissolved solids concentration (in milligrams per liter) in the Capitan Reef Complex Aquifer (Data from Hiss, 1973; Texas Water Development Board, 2012b; New Mexico Office of the State Engineer, 2014).

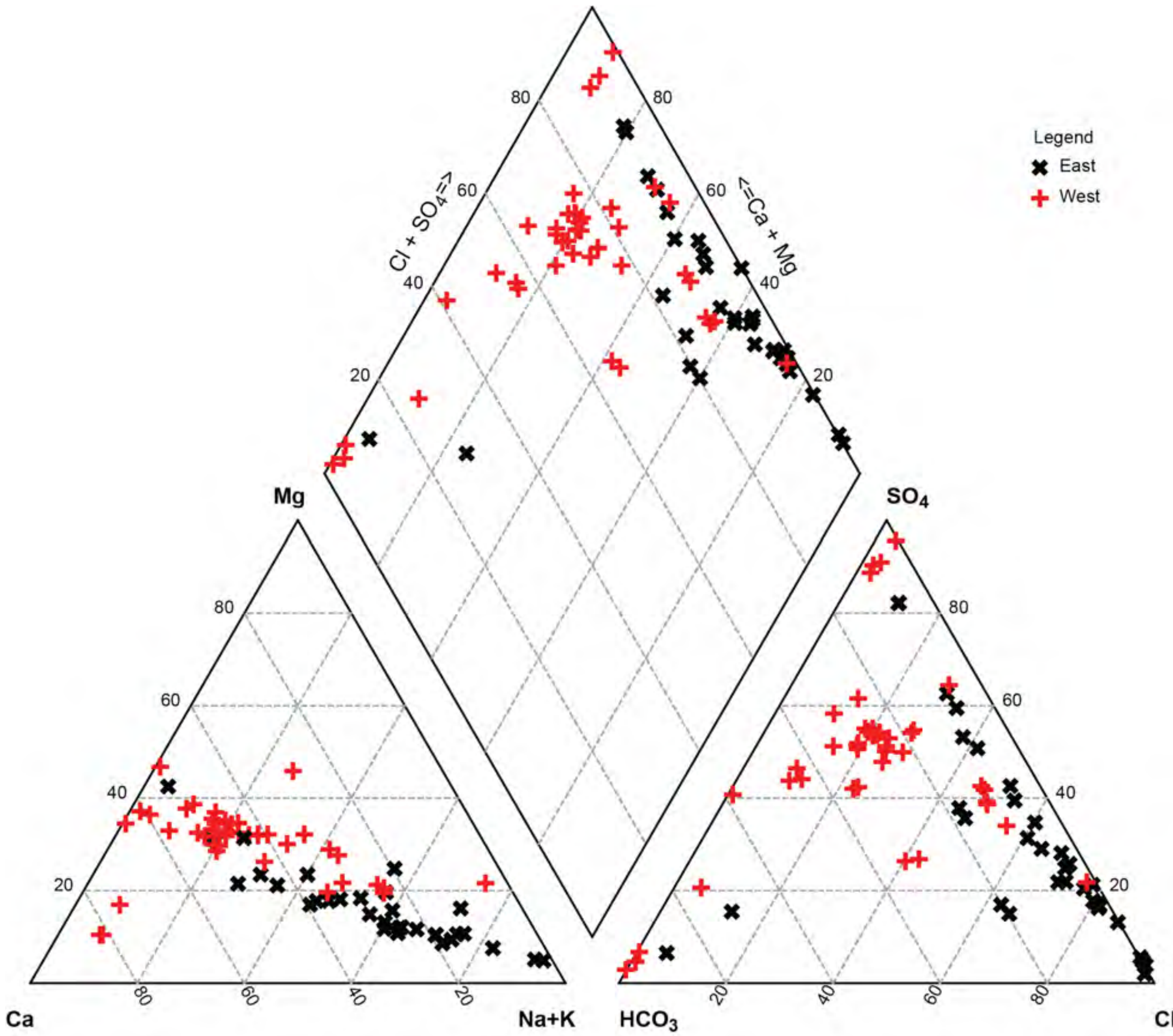


Figure 4.7.2. **A Piper diagram showing the range of groundwater compositions in the eastern (Brewster, Pecos, Ward and Winkler counties) and the western (Culberson and Hudspeth counties) parts of the Capitan Reef Complex Aquifer (Data from Hiss, 1973; Texas Water Development Board, 2012b; New Mexico Office of the State Engineer, 2014).**

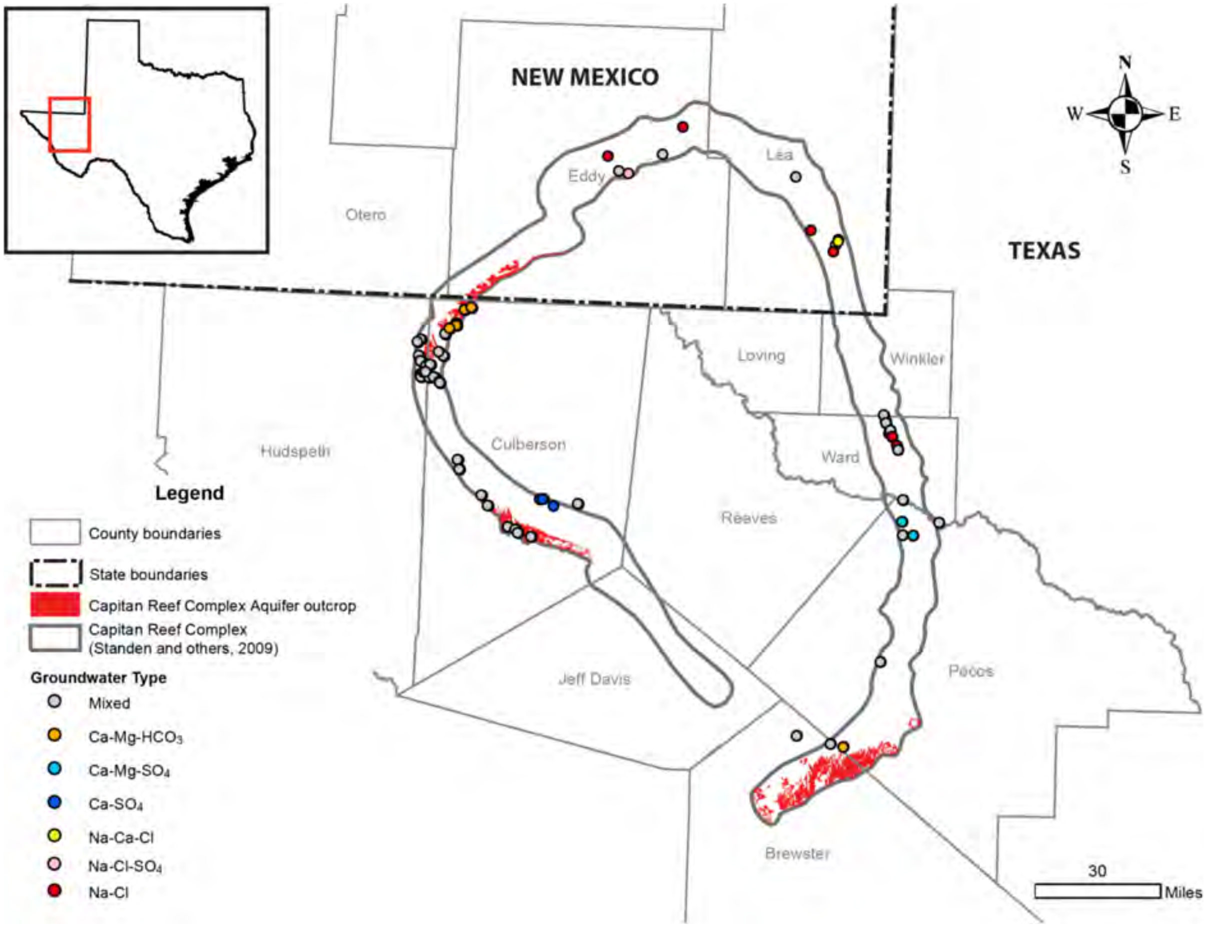


Figure 4.7.3. Groundwater types in the Capitan Reef Complex Aquifer (Data from Hiss, 1973; Texas Water Development Board, 2012b; New Mexico Office of the State Engineer, 2014).

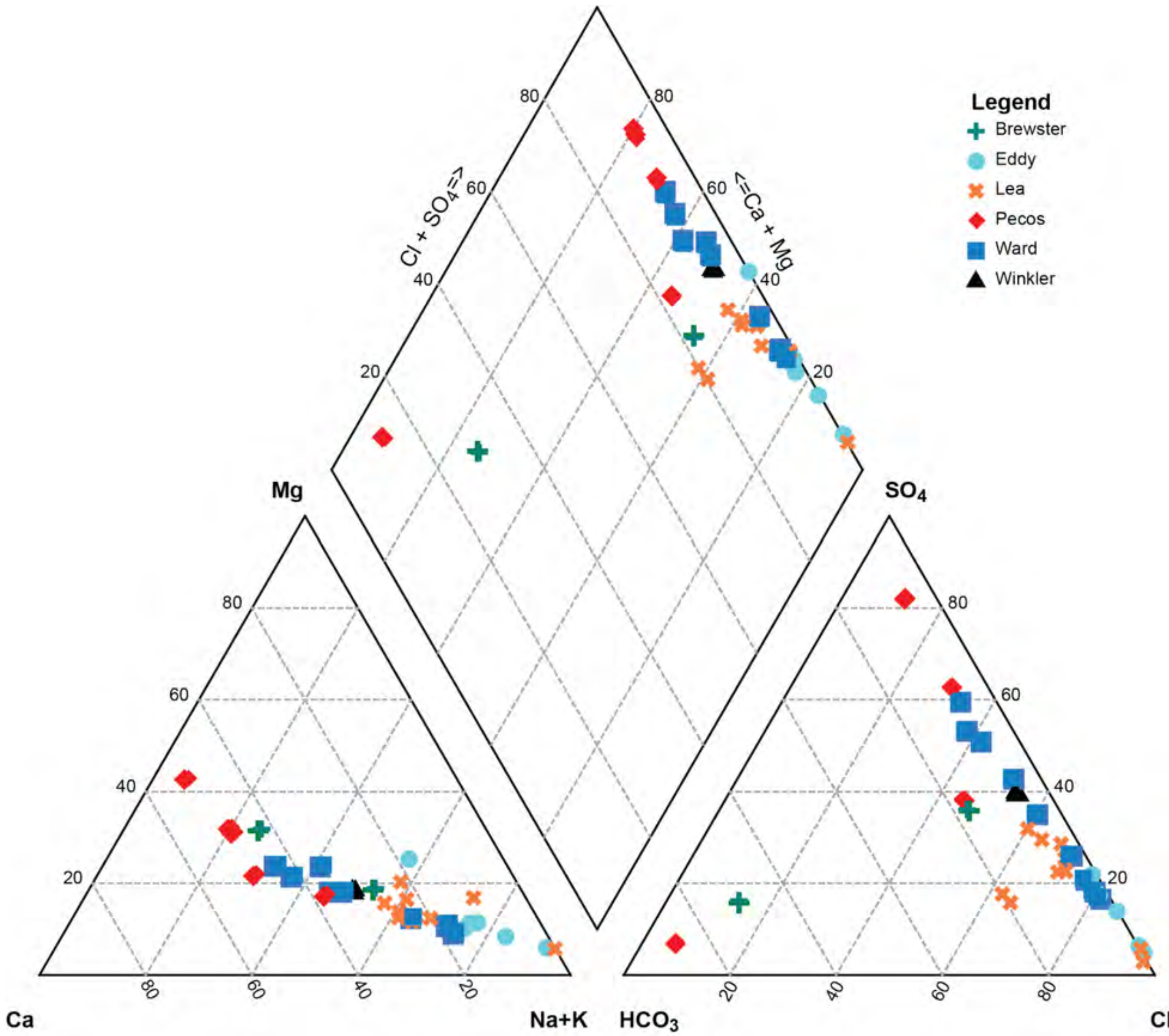


Figure 4.7.4. **A Piper diagram showing the range of groundwater compositions in counties of the eastern (Brewster, Pecos, Ward, and Winkler counties) part of the Capitan Reef Complex Aquifer (Data from Hiss, 1973; Texas Water Development Board, 2012b; New Mexico Office of the State Engineer, 2014).**

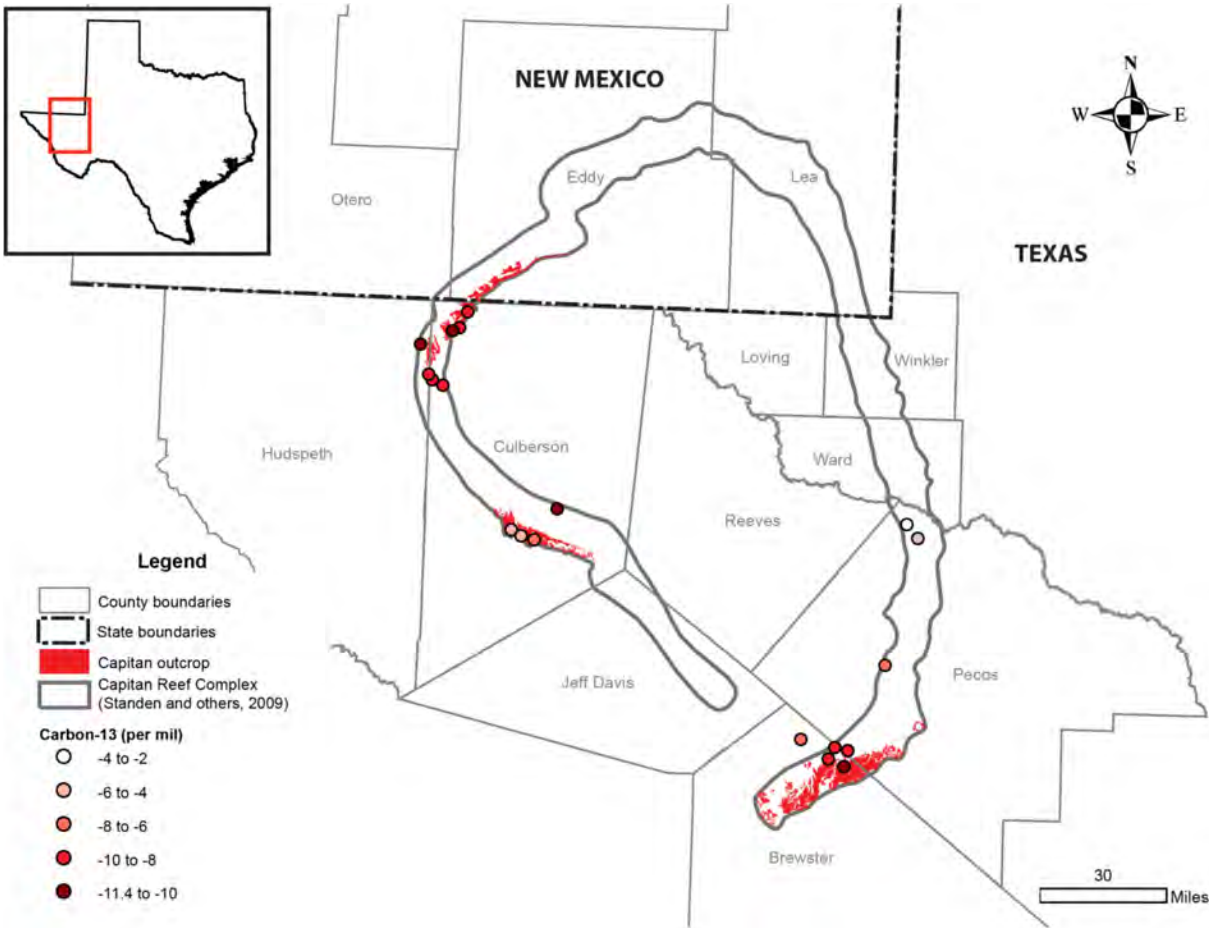


Figure 4.7.5. **Groundwater Carbon-13 isotopes (in per mil) in the Capitan Reef Complex Aquifer (Data from Texas Water Development Board, 2012b).**

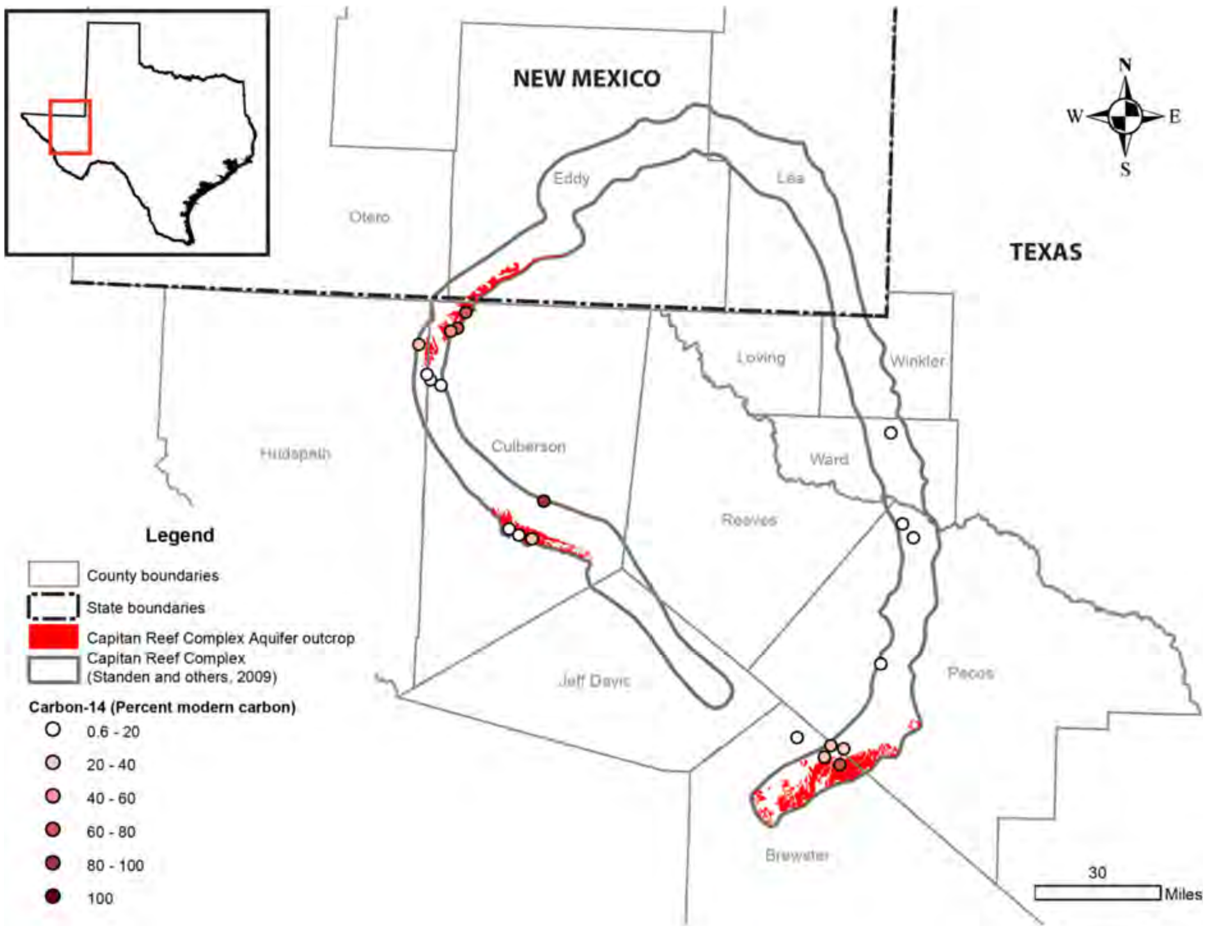


Figure 4.7.6. Groundwater Carbon-14 (in percent modern carbon) in the Capitan Reef Complex Aquifer (Data from Texas Water Development Board, 2012b).

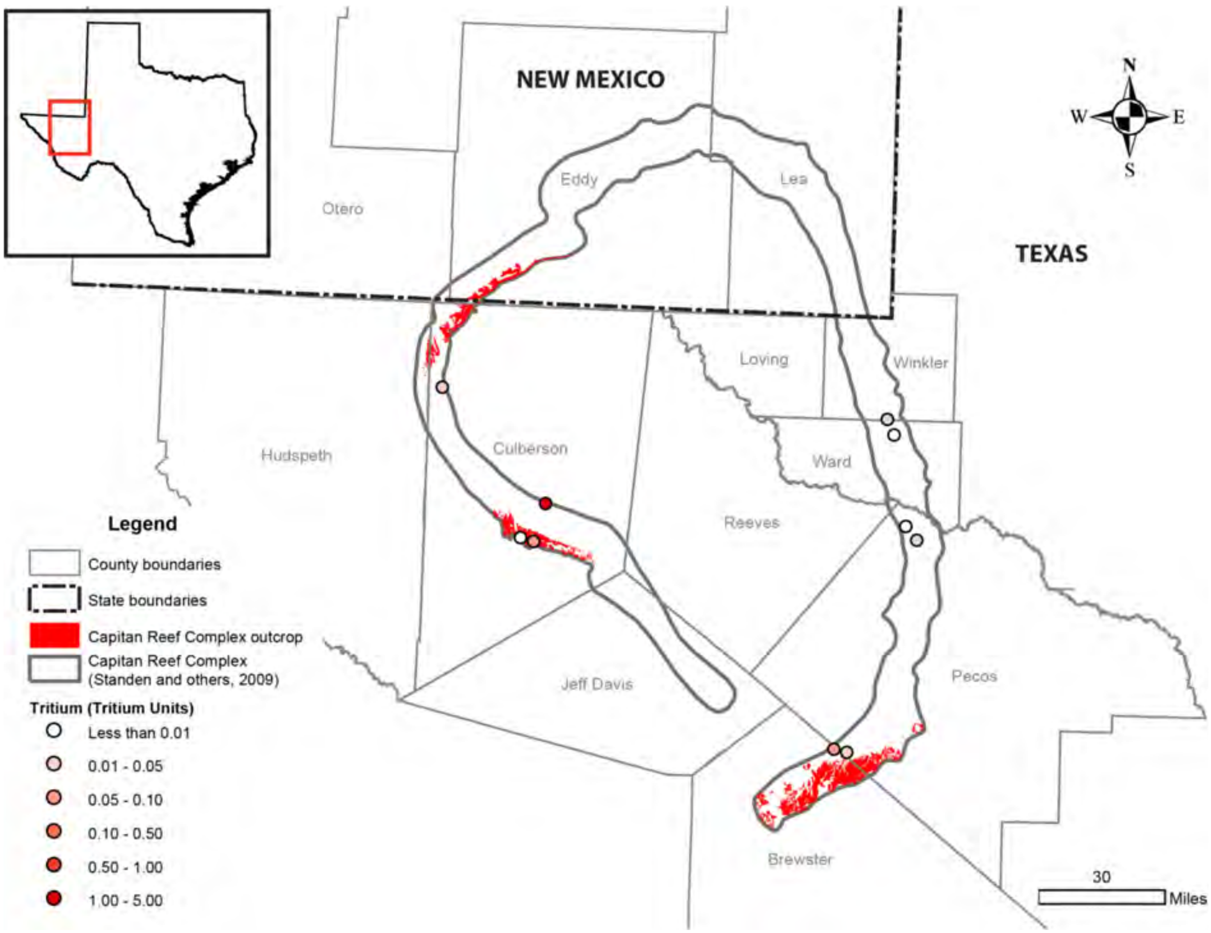


Figure 4.7.7. **Groundwater tritium (in Tritium Units) in the Capitan Reef Complex Aquifer (Data from Texas Water Development Board, 2012b).**

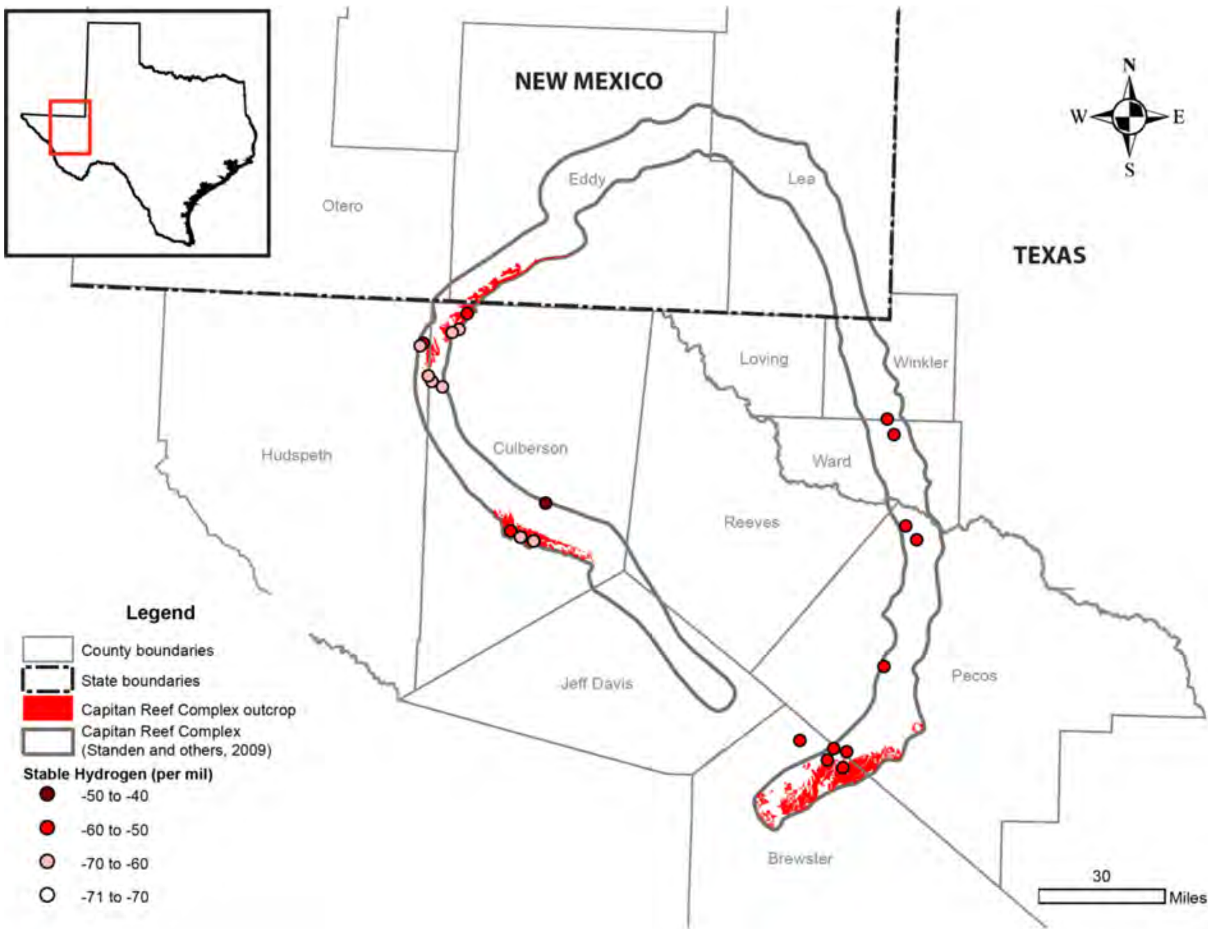


Figure 4.7.8. **Groundwater stable hydrogen isotopes (δ^2H, in per mil) in the Capitan Reef Complex Aquifer (Data from Texas Water Development Board, 2012b).**

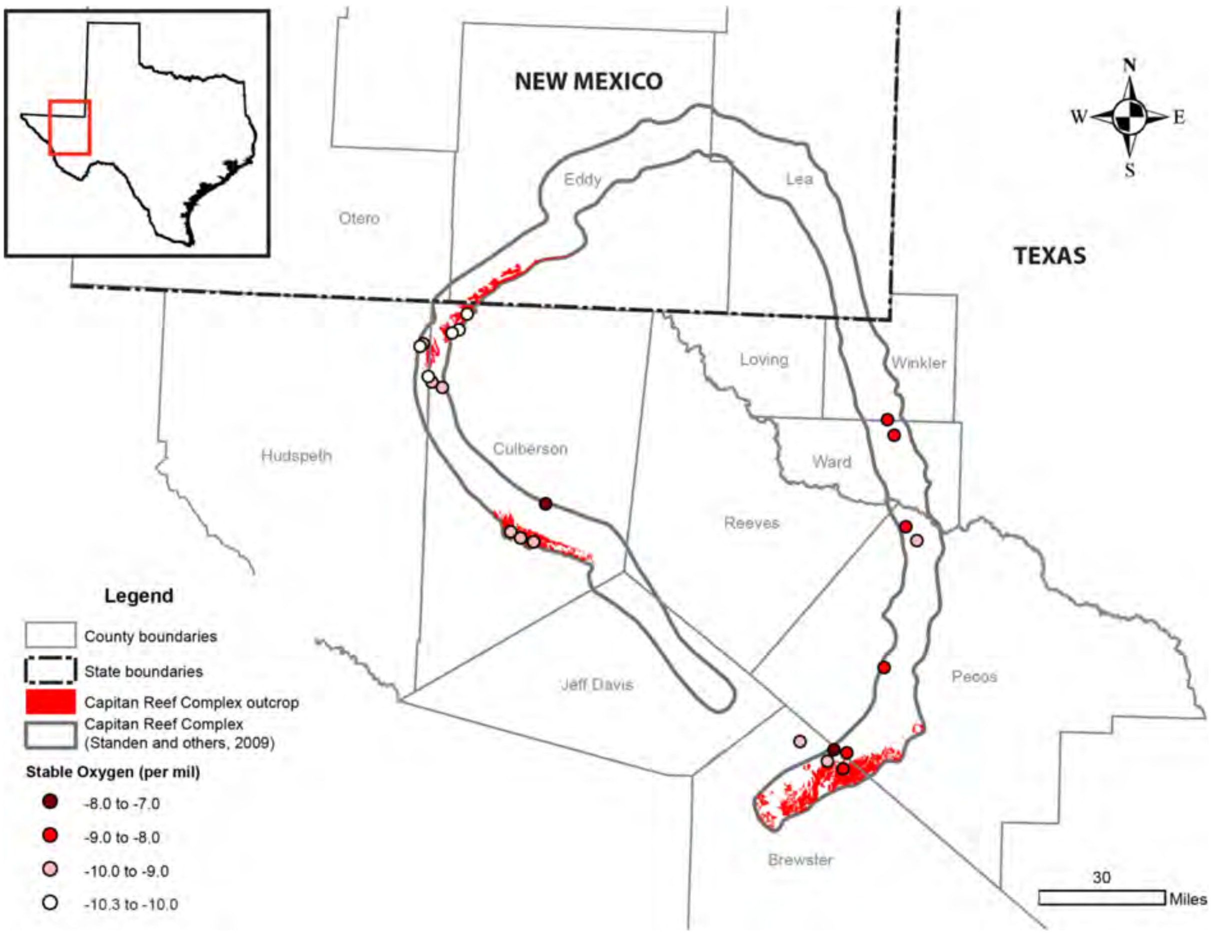


Figure 4.7.9. Groundwater stable oxygen isotopes ($\delta^{18}O$, in per mil) in the Capitan Reef Complex Aquifer (Data from Texas Water Development Board, 2012b).

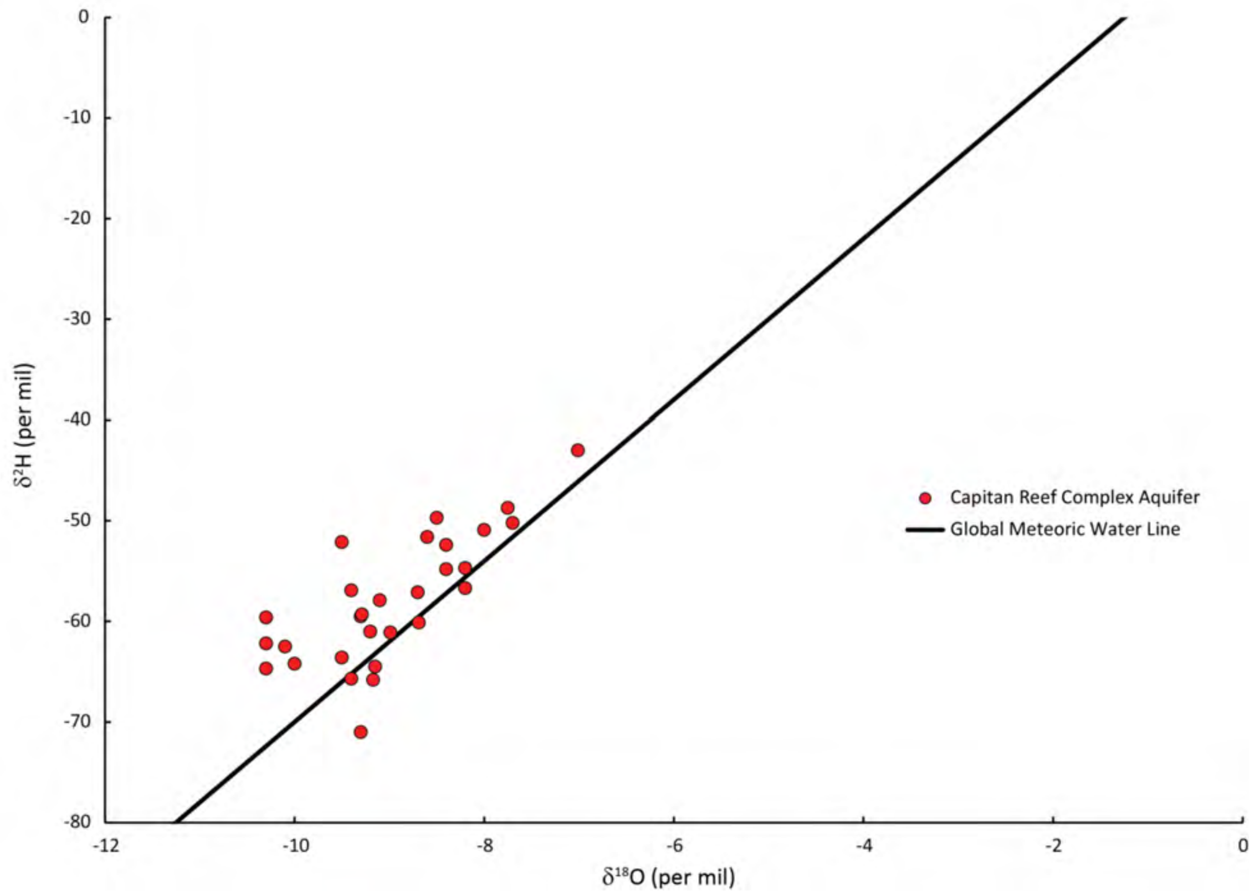


Figure 4.7.10. Capitan Reef Complex Aquifer groundwater stable hydrogen and oxygen isotopes (in per mil) relative to the Global Meteoric Water Line (Data from Texas Water Development Board, 2012b).

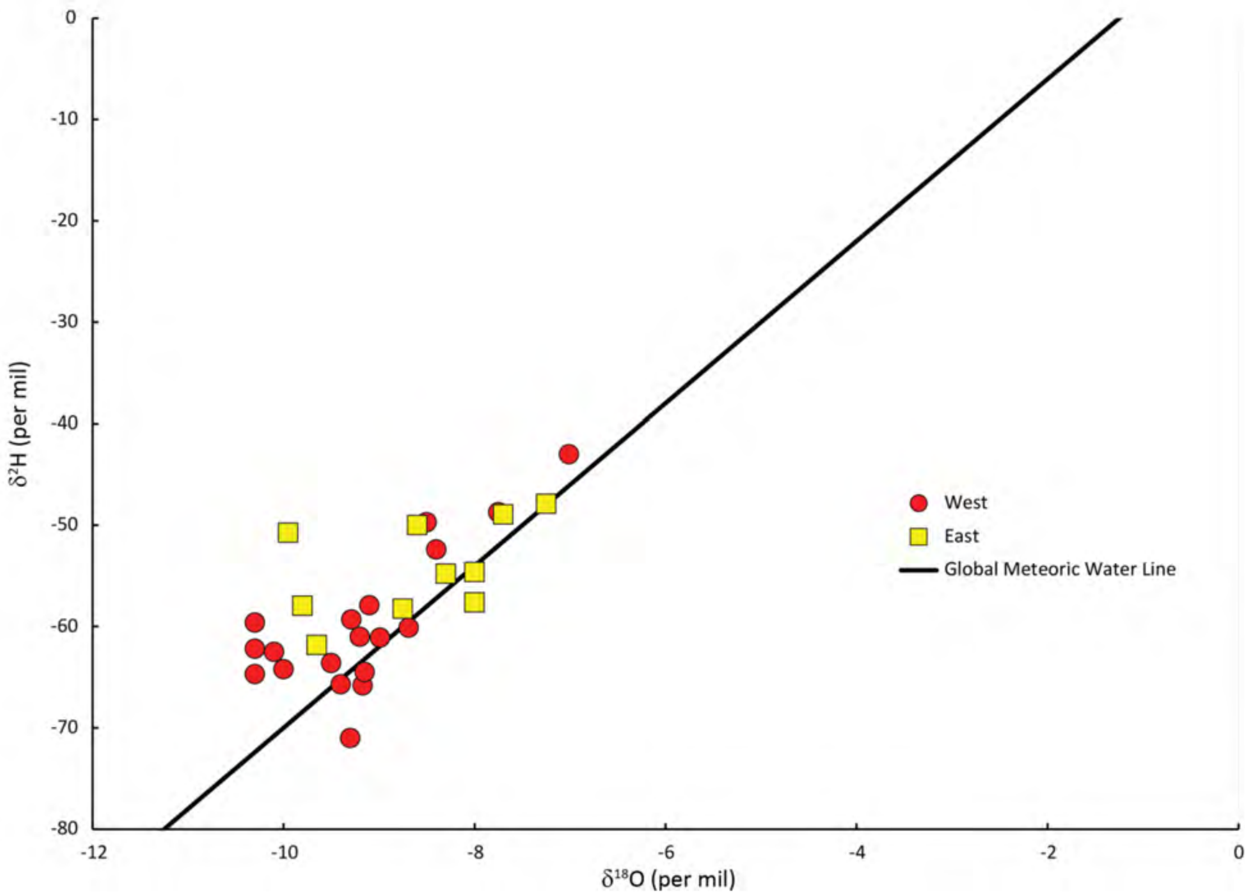
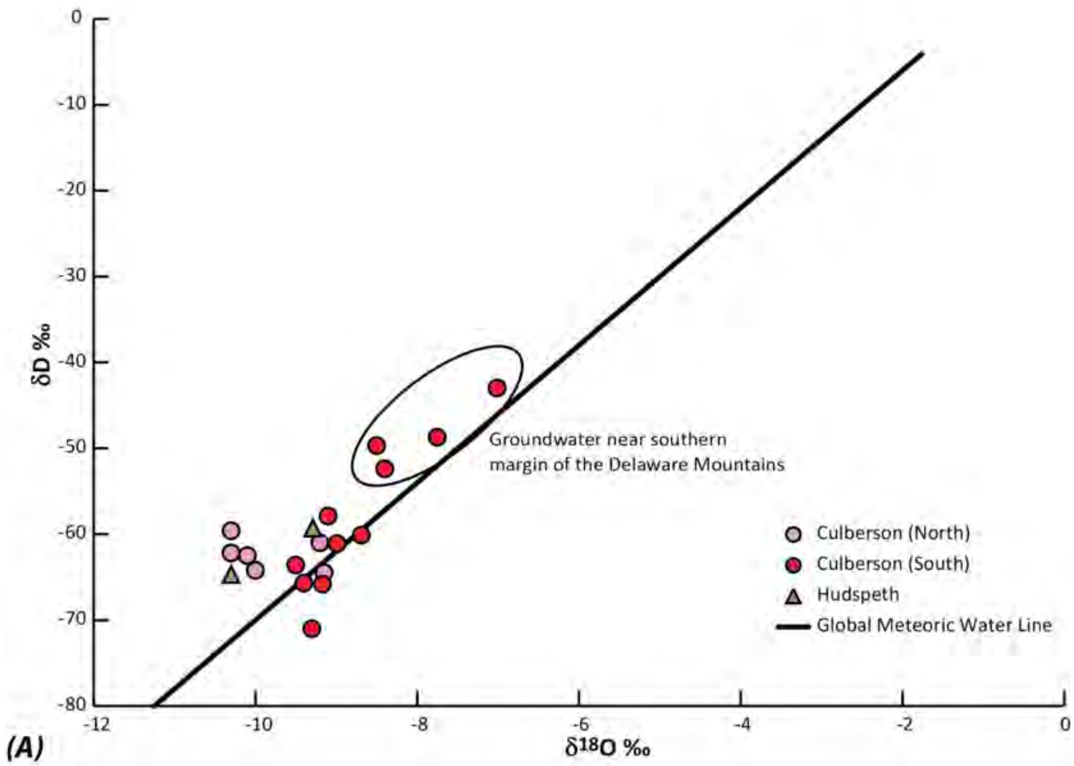


Figure 4.7.11. Comparison of groundwater stable hydrogen and oxygen isotopes (in per mil) in the eastern and western arms of the Capitan Reef Complex Aquifer of Texas (Data from Texas Water Development Board, 2012b).



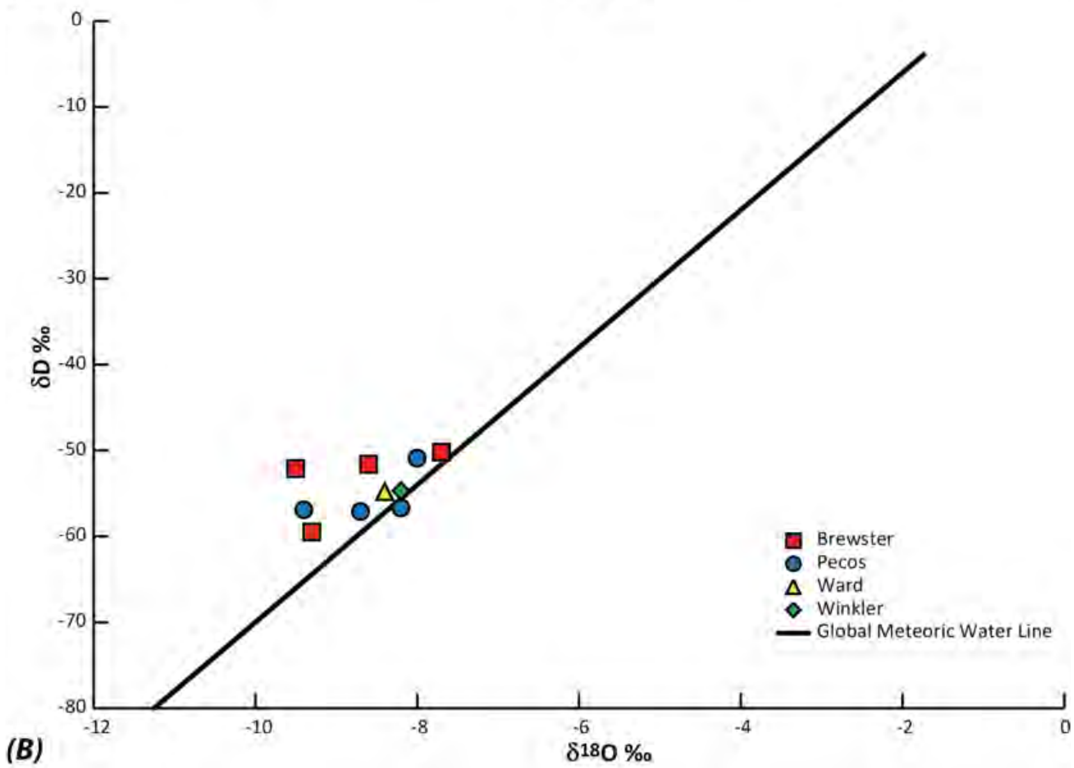


Figure 4.7.12. Comparison of groundwater stable hydrogen and oxygen isotopes (in per mil) in the eastern (A) and western (B) arms of the Capitan Reef Complex Aquifer of Texas by county (Data from Texas Water Development Board, 2012b).

5.0 CONCEPTUAL MODEL OF GROUNDWATER FLOW IN THE EASTERN ARM OF THE CAPITAN REEF COMPLEX AQUIFER

The conceptual model of groundwater flow in the eastern arm of the Capitan Reef Complex Aquifer is based on the hydrogeologic setting, described in Section 4.0. The conceptual model is a simplified representation of the hydrogeological features that govern groundwater flow in the aquifer. It includes the hydrostratigraphy, hydrogeologic framework, hydraulic properties, hydrologic boundaries, recharge, and discharge. In this study, only the eastern arm of the Capitan Reef Complex Aquifer is included in the conceptual model. The western arm of the Capitan Reef Complex Aquifer was excluded because parts of the western arm are included in the groundwater model of the Bone Spring-Victorio Peak Aquifer by Hutchison (2008).

The Capitan Reef Complex Aquifer is located in the Trans-Pecos region of western Texas and southeastern New Mexico. The boundaries of the eastern arm of the Capitan Reef Complex Aquifer used in this study were defined by Standen and others (2009) and differ slightly from the official Texas Water Development Board boundaries in Brewster and Pecos counties. The Capitan Reef Complex Aquifer is composed of the Capitan Limestone, Carlsbad Limestone, and Goat Seep Dolomite although of these stratigraphic units, only the Capitan Limestone occurs within the eastern arm of the aquifer (Figure 2.2.4).

The Capitan Reef Complex is bounded—vertically and laterally—by back-reef deposits of the Artesia Group and fore-reef deposits of the Delaware Group and Castile Formation. The Capitan Reef Complex is also overlain by the Salado Formation, a largely rock salt stratigraphic unit. The Salado Formation overlying the Capitan Reef Complex is thinned as a result of dissolution that resulted in the formation of the overlying Monument Draw Trough (Richey and others, 1985).

Work by Hiss (1976; 1980), Uliana (2001), and Sharp (2001) indicates groundwater flow through the Capitan Reef Complex Aquifer parallel to the reef trend and diverging from the main aquifer outcrops—the Guadalupe, Apache, and Glass mountains (Figure 4.2.1). Groundwater apparently converges in the northeastern part of the aquifer—possibly in Winkler County. Groundwater in the eastern arm of the Capitan Reef Complex Aquifer likely recharges by infiltration of precipitation where the aquifer crops out—the Glass Mountains—as noted in Section 4.7 (Figure 5.0.1). Discharge from the Capitan Reef Complex Aquifer likely takes the form of cross-formational flow through the back-reef stratigraphic units and overlying aquifers. Groundwater discharge by vertical cross-formational flow is supported by the fact that Capitan Reef Complex Aquifer water levels are generally higher than water levels in overlying aquifers, indicating an upward hydraulic gradient (Section 4.2). It is also possible for the Capitan Reef Complex Aquifer to discharge by cross-formational flow to adjacent fore- and back-reef deposits, especially the back-reef deposits which (1) have higher hydraulic conductivity values than the fore-reef deposits and (2) there is more evidence of hydrologic connections with the back-reef deposits than the fore-reef deposits (Figure 4.2.3).

In the aquifers overlying the eastern arm of the Capitan Reef Complex Aquifer, groundwater flow generally converges on the Monument Draw Trough which coincides with the Capitan Reef Complex (Figure 5.0.1; Ewing and others, 2008; 2012; Hutchison and others, 2011). Groundwater flow in the surficial Edwards-Trinity (Plateau) and Pecos Valley aquifers also converges on the Pecos River—a major discharge zone for both aquifers (Anaya and Jones, 2009; Hutchison and others, 2011).

The schematic diagram in Figure 5.0.2A is a conceptual block diagram illustrating aquifer contact relationships and sources and sinks of groundwater in the eastern arm of the Capitan Reef Complex Aquifer and overlying aquifers. Constructing the Groundwater Availability Model for the eastern arm of the Capitan Reef Complex Aquifer will require up to five model layers simulating groundwater flow through the Capitan Reef Complex Aquifer and the overlying aquifers and geologic formations within the Monument Draw Trough. The lowermost model layer would represent: (1) the Capitan Reef Complex Aquifer which is exposed at land surface in the Glass Mountains and (2) adjacent parts of the Artesia and Delaware Mountain groups (Figure 5.0.2B). Active cells in the model grid would extend from the Glass Mountains in the south and north to where the Capitan Reef Complex Aquifer footprint intersects with the Pecos River near Carlsbad, New Mexico. Other layers will simulate groundwater flow through the overlying Rustler, Dockum, Edwards-Trinity (Plateau), and Pecos Valley aquifers. There is the possibility that additional layers may be used to simulate the Artesia Group, and Salado, and Castile formations that act as confining units. In the eastern arm of the Capitan Reef Complex Aquifer, the Artesia Group pinches out and is absent along the western side of the aquifer. The Salado Formation and possibly the Castile Formation are thinned due to dissolution by groundwater discharging from the Capitan Reef Complex Aquifer in northern Pecos County and Winkler and Ward counties resulting in the formation of the Monument Draw Trough through collapse of overlying stratigraphic units and infilling by alluvial and eolian sediments (Figure 4.6.1; Synder and others, 1982; Jones, 2001; 2004). The Monument Draw Trough collapse structure would facilitate upward discharge of groundwater from the Capitan Reef Complex Aquifer through the Salado and Castile formations through breccia pipes (Figure 5.0.3; Hill, 1996; 1999a) that contributes to (1) saline groundwater discharging from Diamond Y Springs that is located directly over the Capitan Reef Complex Aquifer footprint and (2) pumping-induced deteriorating groundwater quality observed in the Pecos Valley Aquifer (Veni, 1991; Jones, 2004). An alternative strategy that can be used is to simulate the presence of the confining units by restricting vertical groundwater flow between the aquifers they separate.

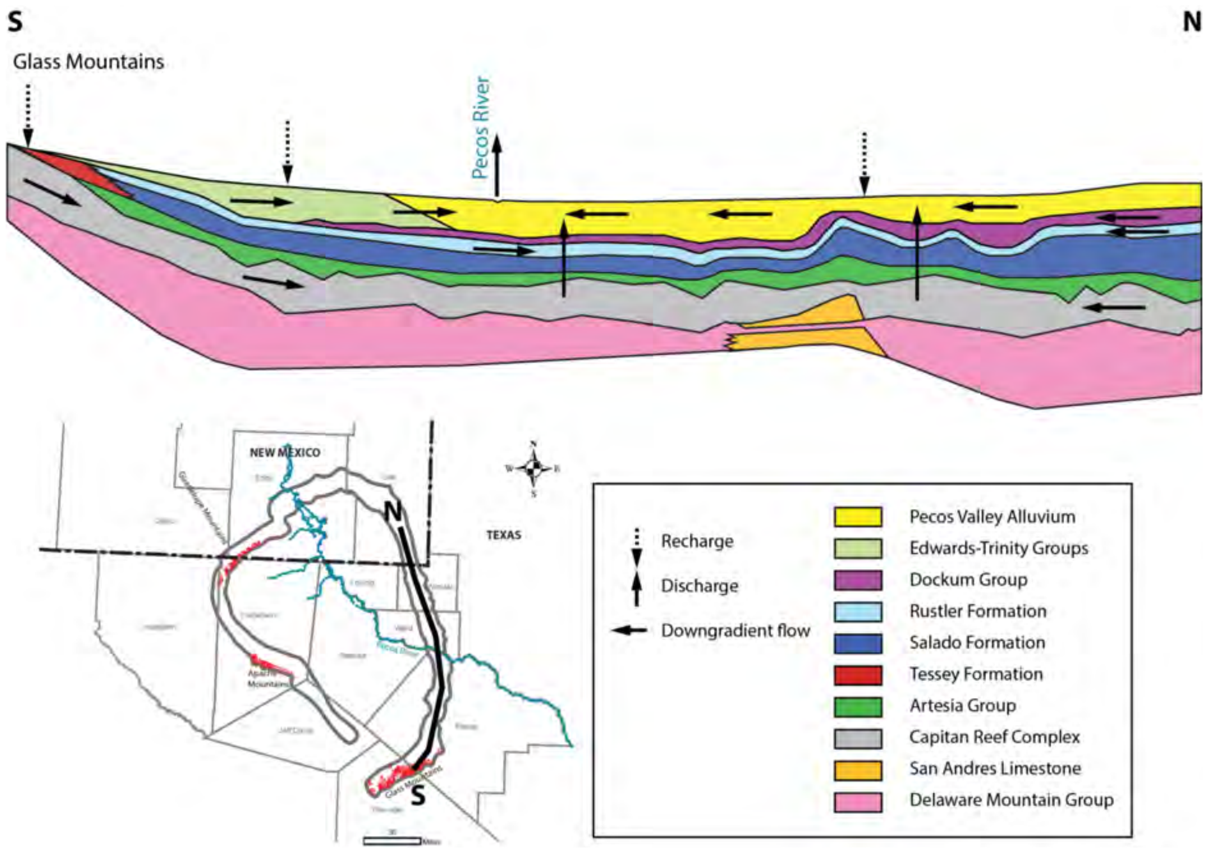
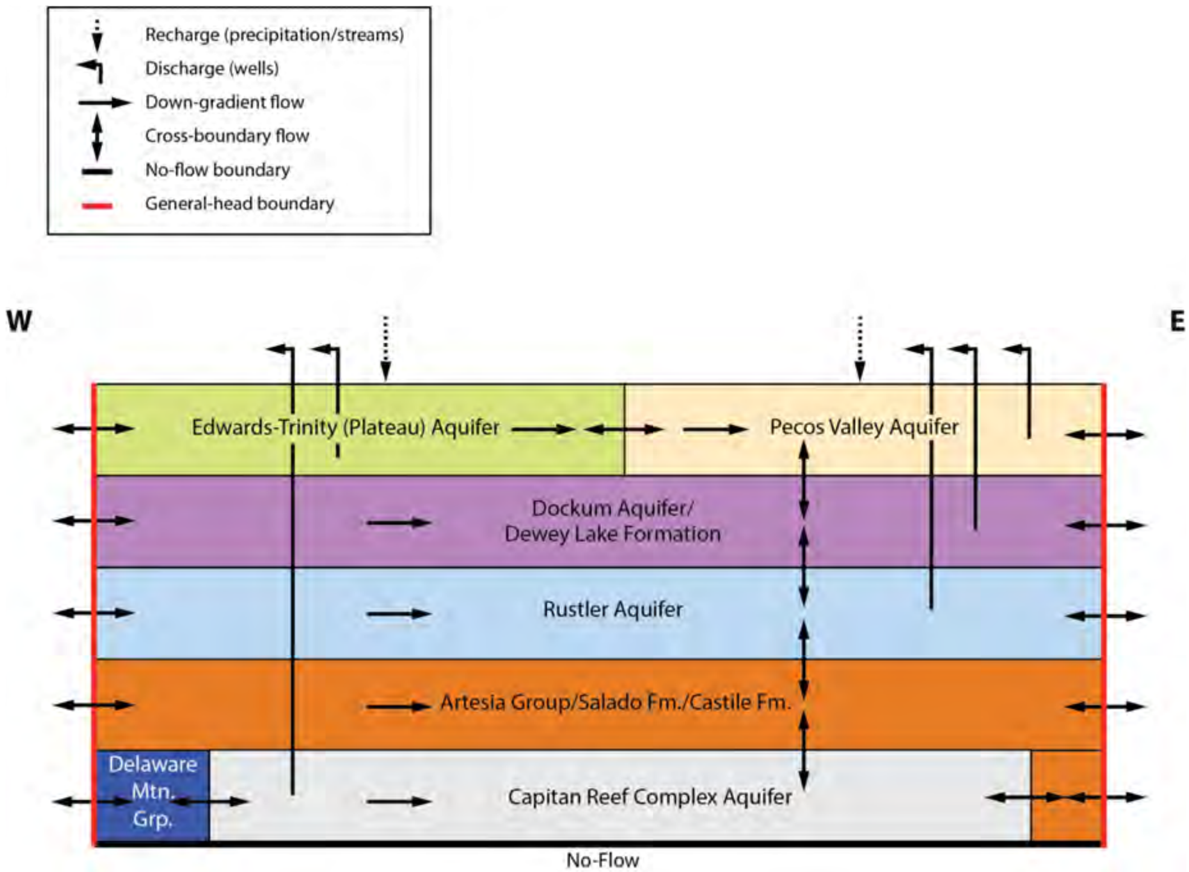
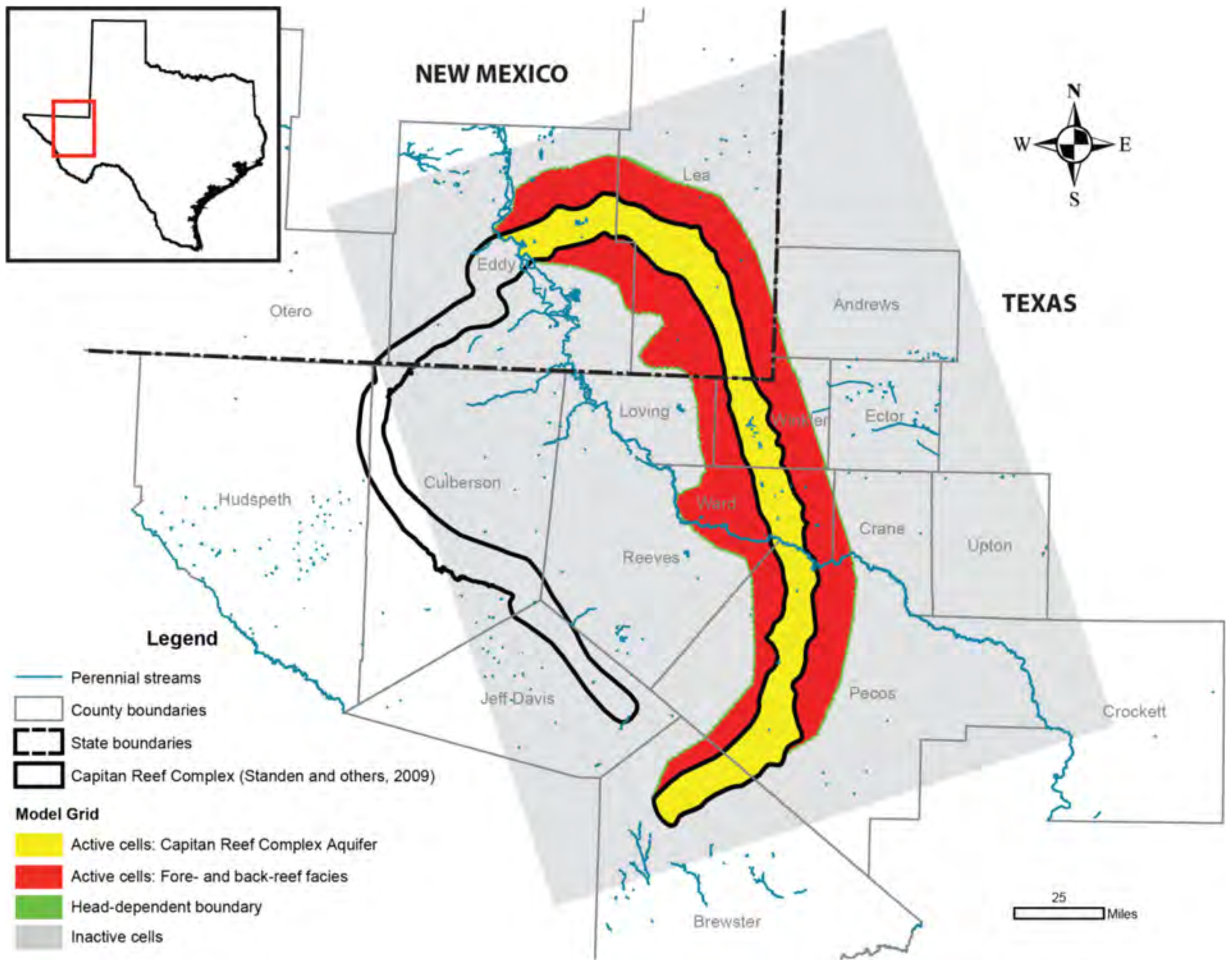


Figure 5.0.1. **Schematic cross-section through the Capitan Reef Complex Aquifer Groundwater Availability Model study area.**



(A)

Figure 5.0.2. **Conceptual groundwater flow model for the Capitan Reef Complex Aquifer Groundwater Availability Model. (A) cross-sectional view and (B) map view.**



(B)

Figure 5.0.2. (continued).

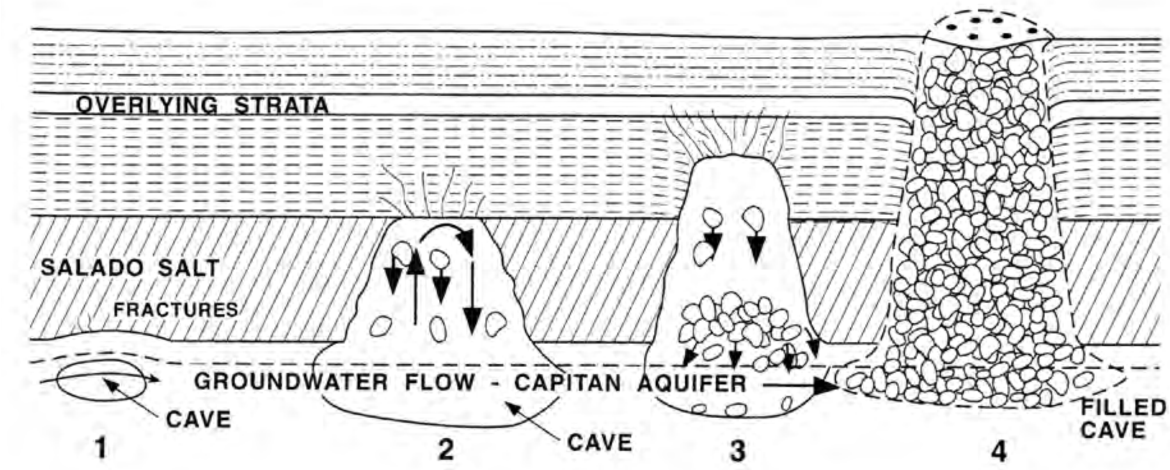


Figure 5.0.3. The development of breccia pipes through karstification in the Capitan Reef Complex Aquifer and subsequent collapse of overlying stratigraphic units produce potential pathways for upward cross-formational groundwater discharge from the Capitan Reef Complex Aquifer. (From Hill, 1996; 1999a).

6.0 ACKNOWLEDGEMENTS

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APPENDIX A. CONCEPTUAL MODEL REPORT COMMENTS AND RESPONSES

General Comments

1. It does not seem necessary to include detailed information in the conceptual model about the western arm of the Capitan Reef Complex Aquifer, if the Texas Water Development Board is only building a model of the eastern arm.

A conceptual model report for the entire Capitan Reef Complex Aquifer was done because (1) there is no conceptual model report for the western arm of the aquifer even though parts of it will be included in the groundwater availability model for the Bone Spring-Victorio Peak Aquifer, and (2) it provides the flexibility to allow us to extend the groundwater availability model for the eastern arm of the aquifer westward if deemed necessary at a later date.

2. Discharge is considered to occur as vertical flow from the confined Capitan Reef Complex Aquifer in Winkler County. This is in disagreement with Hiss (1975) and other studies, which describe discharge as occurring as lateral flow to the shelf margin aquifer. See comments below.

Discharge from the Capitan Reef Complex Aquifer in Winkler County is possible by both lateral cross-formational flow into the back-reef stratigraphic units as well as vertical cross-formational flow through overlying aquifers. The collapse structure formed by dissolution in the Salado Formation along with the resultant collapse of overlying stratigraphic units has formed a relatively high hydraulic conductivity pathway for upward discharge from the Capitan Reef Complex Aquifer. This high hydraulic conductivity is apparent in both groundwater availability models for the Rustler and Dockum aquifers.

3. The geologic framework from Hiss (1975) and Standen and others (2009) do not include the Tessey Limestone directly north and northeast of the Glass Mountains. Wilshire and others (1976) and other geologic studies provide the geologic analyses needed to modify the thickness and top and bottom elevations of the Capitan Reef Complex Aquifer north of the Glass Mountains. Adding the Tessey Limestone will significantly increase the recharge area, aquifer thickness, and storage in the unconfined portion of the Capitan Reef Complex Aquifer.

The Tessey Formation will be included in the model as a boundary condition influencing recharge to the Capitan Reef Complex Aquifer. Explicit inclusion of the Tessey Formation may be considered in future updates to the model.

4. The west to east trending fault zone defining the northern boundary of Subdomain 5 in Ewing and others (2012; Figure 4.2.10) is potentially a major boundary that limits groundwater flow from the unconfined portion of the aquifer to the down dip confined portion of the Capitan Reef Complex Aquifer. The fault system has also been identified by Bumgarner and others (2012; Figure 11).

There is no evidence to suggest that there is a regional-scale flow barrier to north-south groundwater flow in the Capitan Reef Complex or Edwards-Trinity (Plateau) aquifers. The Rustler Aquifer Groundwater Availability Model conceptual model shows groundwater from the Glass Mountains outcrop which includes the Tessey Limestone—a stratigraphic equivalent to the Rustler Formation—into the Rustler Aquifer.

Section 1.0 INTRODUCTION

Page 3. 1st paragraph, bullet (3): Implying the Capitan Reef Complex Aquifer has poor quality water throughout the aquifer may be misleading, as the Capitan Reef Complex Aquifer is known to have potable groundwater in the unconfined portions at or near the formation outcrop.

Added the phrase "in most parts of the aquifer" to indicate that potable groundwater exists in some parts of the aquifer.

Page 3. 1st paragraph, 2nd sentence: As determined from Hiss (1975), historical total pumping from 1954 to 1970 was 306,500 acre-feet (18,039 acre-feet per year average).

Revised the sentence to specify that the pumping rates applied only to the Texas portion of the aquifer for the period 1980 through 2008.

Figure 1.0.2 should show the entire Capitan Reef Complex Aquifer outline.

Figure 1.0.2 only shows the Texas portions of the respective minor aquifers.

Section 2.1 Physiography and Climate

Page 18: 3rd and 4th paragraphs would benefit from an analysis of daily precipitation and evaporation statistics. Daily data are extremely important for understanding and calculating recharge.

Daily data would probably not be applicable to the spatial and temporal scale of the proposed groundwater availability model which will be regional-scale with 1-year stress periods.

Section 2.2 Geology

Consider restructuring Section 2.2 so it contains the following:

- 2.2.1 Structural Setting
- 2.2.2 Surface Geology
- 2.2.3 Delaware Basin Stratigraphy
- 2.2.4 Capitan Reef Complex
- 2.2.5 Geologic units overlying Capitan Reef Complex Aquifer

The section does not include discussion of overlying geologic units.

Recommended Section 2.2.5 would be extremely important for understanding recharge and discharge for the Capitan Reef Complex Aquifer.

Discussion of the overlying stratigraphic units can be found in other reports referenced throughout this report.

Section 2.2.1 Structural Setting

No time periods are given for the various structural elements discussed in this section. The Delaware Basin is the primary structural feature that influenced the formation of the Capitan Reef Complex Aquifer, however, there are several structural elements that formed after the Delaware Basin that should be discussed (Monument-Belding Trough, tectonic event that formed the Glass Mountains, major fault zones, and Sierra Madera astrobleme). Some of the written parts of Section 2.2.3 belong in 2.2.1.

The Monument Draw Trough is discussed in Section 4. and, the uplift that resulted in the formation of the Capitan Reef Complex Aquifer outcrops including the Glass Mountains and major fault zones are discussed in Section 2.2.3. The Sierra Madera astrobleme is small relative to the model area. We will have to investigate the effects of the astrobleme on the regional flow system during model construction and calibration.

Section 2.2.3 Capitan Reef Complex Aquifer and Delaware Basin Stratigraphy

This section should be divided into two sections: Delaware Basin Stratigraphy and Capitan Reef Complex. Furthermore, several paragraphs in Section 2.2.3 belong in Section 2.2.1.

This section has been subdivided as suggested and several paragraphs moved to the Structural Setting section.

The Delaware Basin stratigraphy from oldest to youngest should discuss Permian carbonates of Leonardian (prior to deposition of Capitan Reef) and Guadalupian periods (during deposition of Capitan Reef), and post deposition of Capitan Reef and filling of Delaware Basin with evaporates, Rustler Formation, Triassic red beds, Cretaceous rocks, and alluvium.

The primary focus of this report is on the Capitan Reef Complex; consequently, other stratigraphic units—especially underlying units—are discussed in limited detail.

Page 30: The discussion of geologic units confuses formations from different areas. The formation names that make up the Capitan Reef Complex Aquifer are different for the Capitan, Glass, and Apache Mountains. The formations that consist of the Capitan Reef Complex Aquifer from the Glass Mountains and the eastern arm of the Reef include Capitan Limestone, Tessey Formation, Gilliam Formation, Vidrio Formation, and the Word and San Andres Formations (where hydraulically connected).

Figure 2.2.4 has been revised to clarify the relationships between the various formations that occur in the Glass Mountains. Please note that even though they may be hydraulically connected, we do not consider the Tessey Formation—an equivalent to the Castile and Salado formations, Gilliam, Vidrio, Word and San Andres formations to be part of the Capitan Reef Complex Aquifer. Interaction between these formations and the Capitan Reef Complex Aquifer will be simulated in the model.

The compositional differences between the formations that make up the Capitan Reef Complex Aquifer are not discussed. For example, the Tessey Formation is a massive limestone lacking fossils that grades northward from the Glass Mountains into the Rustler, Salado, and Castile Formations. The Capitan Formation is fossiliferous reef mound. Both formations have undergone karstification and are hydraulically connected.

At the regional scale, compositional differences among the stratigraphic units that make up the Capitan Reef Complex Aquifer and adjacent units such as the Tessey Formation is of secondary importance considering the variability over short distances that are small compared to the likely cell size that will be used in the groundwater flow model.

Figures 2.2.2, 2.2.4, 2.2.5, 2.2.6, and 2.2.7 should use formation colors standardized by the United States Geological Survey.

The colors used in Figure 2.2.2—a simplified surface geology map—are loosely based on the United States Geological Survey colors; however, exceptions are made in some cases to provide contrast necessary for important stratigraphic units to be distinguishable from other stratigraphic units of similar age on such a small map. It is not practical to use the standardized colors in Figures 2.2.4 through 2.2.7 because almost all of the stratigraphic units in the cross-sections are Permian and would therefore have very similar colors that may not be distinguishable.

Figure 2.2.3 lists the Bissett Conglomerate as Triassic, but it has been designated as Cretaceous (see Fort Stockton Sheet, and Wilcox (1989)).

Figure 2.2.3 is now Figure 2.2.4. As a result of revisions, the Bissett Conglomerate no longer appears on this figure.

Cross sections and fence diagrams from Wilshire and others (1972) should be considered in the Capitan Reef Complex Aquifer conceptual model report.

The report by Wilshire and others (1972) is highly localized and does not include information that does not appear elsewhere.

Section 3.0 PREVIOUS WORK

Page 41, 2nd and 3rd paragraphs: The report accurately describes the previous modeling work by both Barroll et al. (2004) and INTERA and Cook-Joyce (2012). However, missing from this discussion is mention of the calibrated groundwater flow model developed for the eastern limb of the Capitan aquifer described by INTERA (2013).

We revised the text to include mention of this model.

The report states on page 41 that the Board's interest is to "..simulate groundwater flow between the Glass Mountains outcrop in Brewster County and where the Pecos River interacts with the aquifer near Carlsbad, New Mexico—a study area that includes the areas of interest of both models." Given this interest, the model described in INTERA (2013) is brought to the Boards attention because it is a model that simulates flow between the Glass Mountains and the Pecos River and does so by adopting the model described by Barroll and others (2004) to evaluate impacts on the Pecos River. Because the Board's objective and area of interest is directly in line with the objective and area of interest of the model described in INTERA (2013), a discussion of this previous work would be an important addition to the section that describes previous work. Though Appendix B of INTERA (2013) is referenced in Section 4.3 of the subject report on recharge, in Section 3.0 there is no mention of the model described in the body of INTERA (2013). Therefore, the Board may wish to add to Section 3.0 a discussion of the model described in INTERA (2013) to recognize a calibrated groundwater flow model that has recently been developed for the eastern limb of the Capitan Reef Complex Aquifer.

Based on figures in the INTERA (2013) groundwater flow model report, the model domain does not include the Glass Mountains that occur in southern Pecos County and extend into Brewster County. Instead the model uses a specified flux boundary to simulate recharge inflow from the Glass Mountains. The Texas Water Development Board requirements for a groundwater availability model is to explicitly simulate groundwater flow within the official aquifer boundaries in Texas, part of which is excluded from the INTERA (2013) model.

It should be noted that the work by Hill (1996) is the most comprehensive summary of geology, stratigraphy, structure, hydrology, and formation of caves and karst in the Capitan Reef Complex Aquifer.

Hill (1996) is referenced in this report.

More information on the model by INTERA and Cook-Joyce (2012) should be presented if this model will be relied on to complete the Capitan Reef Complex Aquifer Groundwater Availability Model (GAM).

The model by INTERA and Cook-Joyce (2012) is listed only as an example of existing models in the study.

Section 4.0 HYDROLOGIC SETTING

This section would benefit from a discussion of karst features in the Capitan Reef Complex Aquifer. A good reference would be Hill (1996). Hill (1996) states *"Water moves through the Capitan primarily along the upper and basinward sides of the carbonate aquifer units where a zone of high porosity exist (Gail, 1974). This zone is located along the contact of the reef and fore-reef facies exactly in the same position as are many of the cave passages in the Guadalupe Mountains… Breaks in drilling have indicated true cavernous zones in some places."*

Mention of karstification in the Capitan Reef Complex Aquifer occurs throughout the text. We revised the text slightly to include additional information on karst processes in the Capitan Reef Complex.

Section 4.1 Hydrostratigraphy

Page 43, 2nd paragraph, 3rd sentence: The fore-reef and back reef formations are reversed. The fore-reef is the Delaware Mountain Group, and the back-reef is the Artesia Group. Furthermore, it should be clarified that the aquitards overlying the Capitan Reef Complex Aquifer do not exist in the Capitan Reef Complex Aquifer outcrop area and directly down dip, and that the formations overlying the Capitan Reef Complex Aquifer changes from the Glass Mountains down dip to the north. In Pecos County, from south to north, the Capitan Reef Complex Aquifer is overlain by the Bissett Formation, Rustler Formation, salt beds of the Castile formation, and then the Artesia Group.

The text has been revised in response to this comment.

The Artesia Group along the northern portion of the eastern arm is not considered an aquitard, but rather part of the shelf aquifer with similar hydraulic properties to the Capitan Reef Complex Aquifer (Hiss, 1975).

Text has been added to clarify that the hydraulic connection between the Capitan Reef Complex Aquifer and back-reef stratigraphic units observed west of the Pecos River also exists to the east.

Page 43, 3rd and 4th paragraphs: It has been discovered that the Tessey Formation was not included when Standen and others (2009) defined the top elevation and thickness of the Capitan Reef Complex Aquifer. Hiss (1975) used geophysical logs to pick the top of the Capitan Formation and did not include the Tessey Formation as part of the Capitan Formation (see Hiss, 1975; Figure 6). Standen and others (2009) carried over this same approach. The Tessey Formation needs to be included in defining the Capitan Reef Complex Aquifer framework for the model to be representative.

The Tessey Formation will be simulated as a boundary condition in the groundwater availability model for the Capitan Reef Complex Aquifer. Explicit simulation of the groundwater flow *through the Tessey Formation is not considered at this time because of the absence of aquifer property, water-level, and other hydrologic data.*

Figure 4.1.1: The title should state Hydrostratigraphic chart of the Capitan Reef Complex Aquifer for the down dip portion of the eastern arm.

The figure caption has been revised in response to the comment.

Figures 4.1.2 through 4.1.4 do not include the Tessey Limestone. Slight modifications to the geologic structure of the Capitan Reef Complex Aquifer are needed south of Belding to include the Tessey Limestone. Aquifer thickness of the Capitan Reef Complex Aquifer will increase by more than 500 feet when the Tessey Limestone is included.

As mentioned before in response to other comments, the Tessey Formation will be simulated as a boundary condition in the groundwater availability model for the Capitan Reef Complex Aquifer and may be incorporated in future updates of the model.

4.2 Water Levels and Regional Groundwater Flow

In the last paragraph on page 58, the report suggests that the post-development potentiometric surface that shows a convergence of groundwater flow in Winkler County may be caused by either discharge into the Central Basin Platform or to overlying aquifers. It is suggested the Board also consider the effects of groundwater pumping from well fields in Winkler County that resulted in an excess of 700 feet of drawdown in the Capitan aquifer. INTERA (2013) conceptualizes the pumping in Winkler County to have reversed the flow in the aquifer between Winkler County and the northern end of the aquifer from a northerly to a southerly flow direction. It seems more likely that this convergence in Winkler County is primarily a result of pumping over several decades in the mid-20th century, although some discharge to the back-reef units and/or overlying aquifers under non-pumping conditions is also possible, though less likely the cause based upon our analysis.

We are unsure of the source of water-level data that Hiss used to develop the flow regimes in Figure 27 of INTERA (2013). It is therefore speculative where the point of convergence between eastward groundwater flow from the Guadalupe Mountains and Pecos River and northward groundwater flow from the Glass Mountains would be located before and after the Pecos River incision and if it moved in post-development times. One would question whether pumping in one of many well fields in the Capitan Reef Complex Aquifer would have the ability to completely change the aquifer flow system.

The report states on Page 59 that "[t]here are only two wells in New Mexico—both in Eddy County—and no water-level measurements in Lea County, New Mexico…" please also consider the water levels measured in groundwater wells ICP-WS-01 (CP-01056) and ICP-WS-02 (CP-

01057), which are discussed on page 5 of INTERA (2013). These water-supply wells were drilled in early 2012 by ICP in Lea County, NM as part of the Ochoa Project.

That statement refers to the data available at the time the draft report was written. These additional wells do not change the fact that water-level data is sparse and therefore an issue in model calibration.

In addition to the data mentioned in the previous comment, water levels have been measured on a quarterly basis since November 2012 from seven wells previously described in Hiss (1975). These measurements have been collected by the U.S. Geological Survey for the Bureau of Land Management Carlsbad Field Office. Measurements have been recorded from the North Cedar Hills Unit 1, City of Carlsbad Well 13 (La Huerta East Well), City of Carlsbad Test Well 3 (Miller-Nix-Yates 1), South Wilson Deep Unit 1, North Custer Mountain Unit 1, Federal Davison 1, and Southwest Jal Unit 1 monitoring wells described in Hiss (1975). The data show that the water levels in wells east of the West Laguna Submarine canyon have rebounded hundreds of feet since some of the last measurements were recorded in 1980. Given the importance of these data, the Board is encouraged to contact Mr. David Herrell of the BLM Carlsbad Field Office to discuss the data. Mr. Herrell can be reached at (575) 234-5972 and has been provided with a copy of these comments.

We will contact the Bureau of Land Management to obtain this water-level data and incorporate as appropriate.

It is assumed that the water-level measurements presented in Figure 4.2.3 are from during or before the 1980's, closer in time to when this area of the Capitan Reef Complex Aquifer was stressed due to pumping to supply water flooding projects. Since pumping has stopped, recent observations (e.g., United States Geological Survey/Bureau of Land Management measurements) indicate a rebound in water levels in Lea County as far south as the Southwest Jal Unit 1 well near the Texas-New Mexico state line. The report shows a rapid rebound in well 46-32-309 in Figure 4.2.14, also after records indicate pumping of the Capitan Reef Complex Aquifer for water flooding projects ceased. The convergence that is evident in the data presented by Hiss (1980) seems more likely to be caused primarily from pumping rather than the two options suggested in this draft report based upon our analysis. We would recommend that the Board consider and discuss this third option as well.

Figure 4.2.3 is modified from Hiss (1980) but the original map appeared in Hiss (1975; Figure 23). The water levels in Figure 4.2.3 were measured over a period of time ranging from the 1950s through the early 1970s. It is difficult to make inferences on regional-scale changes in aquifer water levels based on a single well. The water-level rebound observed on well 46-32-309 during the late 1970s does not correspond with a period of increasing oil and gas drilling but it does coincide with similar water-level responses observed in overlying aquifers that correspond to changes in non-petroleum related pumping. The available water-level and pumping data are *insufficient to support groundwater convergence due to pumping in an aquifer that has no surficial discharge zone and therefore must discharge through cross-formational flow.*

Figures 4.2.13 and 4.2.14: Please consider adding to these figures information presented in Figure 28 and Appendix C in INTERA (2013) for additional wells with transient data in Lea County and Eddy County, New Mexico.

We add these water-level data if they provide additional information to the figures.

Figure 4.2.2 and the 3rd paragraph on Page. 58 do not seem pertinent to the conceptual model. Figure 4.2.3 presents the post development water levels in the Capitan Reef aquifer modified from the work originally developed by Hiss (1975, Figure 23). Hiss (1975) divided the water levels into various groups: 1) head measured in basin aquifers where the hydraulic communication with the Capitan Reef was poor, 2) head measured in the Capitan and shelf aquifers where the communication is good between Capitan Reef Complex Aquifer and shelf aquifers, and 3) head measured in shelf aquifer where hydraulic communication is poor with the Capitan Reef Complex Aquifer. These are important hydraulic distinctions that have been removed in Figure 4.2.3.

Figure 4.2.2 and the associated discussion in the text discuss the influence of the Pecos River—the proposed northern boundary of the groundwater availability model—on the groundwater flow system of the Capitan Reef Complex Aquifer and is therefore relevant to the conceptual model. Hiss classified the water-level contours into three groups. The modified map only shows water levels in the Capitan Reef Complex Aquifer and surrounding shelf and basin stratigraphic units and is not intended to indicate hydraulic connectivity. Hydraulic connections between the Capitan Reef Complex Aquifer and the basin and shelf stratigraphic units are discussed in the text.

Hiss (1975) and Hill (1996, p. 263) discuss the potentiometric trough in the northern part of the eastern arm of the Capitan Reef Complex Aquifer. Groundwater west of the trough flows toward the Pecos River, and groundwater east of the trough flows toward the Hobbs channel where groundwater discharges from the Capitan Reef Complex Aquifer.

In the text, we discuss groundwater discharge by lateral cross-formational flow in addition to vertical cross-formational flow.

It is important to note that the post development water levels are about 200 feet lower than predevelopment water levels (Hiss, 1975). Therefore, it is recommended to include the predevelopment water levels for the Eastern Arm of the Capitan Reef Complex Aquifer developed by Hiss (1975, Figure 22).

The pre-development water levels shown in Figure 22 of Hiss (1975) are identical to the post-development water levels in Figure 3 in Hiss (1980)—the source of Figure 4.2.3 in this report.

Including the pre-development water levels from Figure 2 in Hiss (1980) is not appropriate due to numerous errors such as intersecting contours and numerous contours that are not based on actual water-level data.

Page 58, 4th paragraph: The convergence of groundwater elevation contours in Winkler County is a result of lateral eastward flow (discharge) to the shelf aquifer, and Capitan Reef Complex Aquifer pumping from Winkler and Ward Counties that occurred between 1960 and 1970. There is no evidence that discharges from the Capitan Reef Complex Aquifer occurred through 2,000 feet of aquitard into the overlying Monument Draw Trough collapse feature in Winkler County. However, it may be possible that some vertical flow occurs from the Capitan Reef Complex Aquifer to the Rustler Formation locally where sink holes have formed (see discussion in Hill, 1996).

The convergence of southward and northward groundwater flow in the Capitan Reef Complex Aquifer in Winkler County results from multiple factors. Vertical cross-formational flow cannot be ruled out considering: 1) the amount of subsidence that took place due to the dissolution of the overlying Salado Formation (Jones, 2001; 2004; 2008), 2) the coincidence of the Capitan Reef Complex Aquifer and the Monument Draw Trough, 3) the relatively high hydraulic conductivity zones in the overly Rustler and Dockum aquifers (Ewing and others, 2008; 2012) that coincide with the Monument Draw Trough and would provide a pathway for upward groundwater flow, and 4) the vertical hydraulic gradients between the Capitan Reef Complex Aquifer and overly aquifers.

The cited references (Jones, 2001, 2004, and 2008) stated *"Cross-formational flow from underlying saline Permian aquifers is also enhanced due to increasing municipal and industrial pumpage in the Monument Draw Trough portion of the Pecos Valley Aquifer (Jones, 2004)."* This statement is in reference to municipal pumping in central Ward County, where there appears to be a correlation between increasing total dissolved solids with pumping over time. Under heavy pumping conditions at the City of Pecos Ward well field, the total dissolved solids increased about 150 milligrams per liter over a 12-year period (see Jones, 2004, Figure 6-13). A review of water quality data from the area of wells used to construct Jones (2004) Figure 6-13 suggests these slight increases in total dissolved solids could also be attributed to capture of shallow groundwater directly east or south of the pumping wells. This captured groundwater may be elevated in total dissolved solids resembling sodium-chloride type water from oil field brine impacts.

It is difficult to conclude that groundwater salinity changes over time that have a direct relationship with water-level decline are related to oil field brine contamination based on only three wells and without enough spatially distributed data to indicate shallow sources of oil field brine contamination.

Hill (1996, p. 263) states “Some of the water in the Capitan Aquifer of the Glass Mountains moves eastward before reaching a point west of Fort Stockton, and the remainder of the water apparently moves northward along the reef to finally exit the basin via the Hobbs channel.” Researchers have performed a detailed analysis of geophysical logs (API 49532997, 49532160, and 49532177) from wells drilled into the Winkler County portion of the Monument Draw Trough and found that several thousand feet of evaporate beds overlie the Capitan Reef Complex Aquifer, thereby reducing the likelihood for vertical flow into the Santa Rosa Sandstone (Dockum) or Pecos Valley alluvium aquifers. Furthermore, there are no water quality data in the shallow aquifers to support the concept of discharge from the Capitan Reef Complex Aquifer via vertical cross formational flow.

The Monument Draw Trough collapse structure extends into New Mexico and coincides with the Capitan Reef Complex. The Monument Draw Trough is described as a series of coalesced collapse features—breccia pipes—similar to sinkholes (Meyer and others, 2012). These breccia pipes can transmit groundwater vertically from the Capitan Reef Complex Aquifer through the Salado Formation to overlying aquifers and are apparent in the structure of the Rustler Formation (Hiss, 1976). Over the Capitan Reef Complex Aquifer the Salado Formation is much thinner than elsewhere due to dissolution by groundwater derived from the Capitan Reef Complex Aquifer. Because of the occurrence of these breccia pipes, the occurrence of several hundred feet of evaporite beds over the Capitan Reef Complex Aquifer is unlikely to prevent vertical groundwater discharge. The concept of vertical groundwater flow from the Capitan Reef Complex Aquifer to overlying aquifers is also supported by other authors, such as Hiss (1976) and Veni (1991) who associated this flow with surface discharge from Diamond Y Springs. Additional evidence of extensive cross-formational flow can be seen in the overlapping geochemical and isotopic compositions of groundwater in the Capitan Reef Complex and overlying aquifers.

Figure 4.2.12(a) compares water level elevations between the Edwards-Trinity (52-32-701) and Capitan Reef Complex Aquifer (52-40-101) aquifers. Well 52-40-101 is a hand dug well on a hillside at the old Sanderson Camp on the La Escalera Ranch; researchers performed a field check of this well during April 2014 and found it to be related to a localized perched groundwater system. The aquifer designation for 52-32-701 is not accurate. Based on researchers’ field check, this well is located on the mapped portion of the Capitan Reef Complex Aquifer and drilled into the Capitan Reef Complex Aquifer, and is therefore not an Edwards Trinity well. The water level from 52-32-701 (owner’s name is Pump Jack Well, also JJ-17 in B6016) is representative of the Capitan Reef Complex Aquifer.

We deleted Figure 4.2.12(a) and adjusted the other associated figures as appropriate.

Figure 4.2.12(a-e): It is difficult to see the difference in head due to the y-axis scale.

We revised these figures using a smaller y-axis range.

4.3 Recharge

Page 78, 2nd paragraph: This section should include the concept of recharge to karst terrains, and present some type of analysis and estimate of recharge that relates to the observed conditions in the Glass Mountains and Sierra Madera. Based on researchers' analysis of precipitation data for the area, recharge is not significantly controlled by topography as stated in this paragraph.

We added text mentioning karst features as potential pathways for recharging water to the aquifer. Topography plays a role in recharge to the Capitan Reef Complex Aquifer because the aquifer outcrops—potential recharge zones—all coincide with mountains, such as the Guadalupe, Apache, and Glass mountains. One would expect that the role played by topography in influencing amounts of recharge would be greater in the high relief of the Guadalupe Mountains than in the Glass Mountains. We also revised the text to incorporate recharge estimates from Finch (2014).

Page 79, 1st paragraph: There is a lot of reliance on age-dating of groundwater to make inferences about recharge to the Capitan Reef Complex Aquifer. The validity of isotope analysis depends on well construction and representative section of aquifer sampled.

In this case, groundwater isotopes are used qualitatively—comparing changes in the groundwater isotopic composition in different parts of the aquifer. This indicates relatively ages of groundwater and conditions under which recharge occurred. Comparison of groundwater isotopic compositions in the Capitan Reef Complex and overlying aquifers indicate overlapping composition ranges in all of the aquifers in the study area.

INTERA (2013) and Ewing and others (2012) recharge estimates are weakly supported by data and analysis. Researchers' analysis of recharge for the Glass Mountain area uses daily precipitation statistics and outcrop characteristics.

We revised the text to incorporate recharge estimates from Finch (2014).

4.4 Rivers, Streams, Springs, and Lakes

Page 81, Section 4.4.1: It is suggested the Board consider the discussion presented on page 14 of Barroll et al. (2004), which indicates that groundwater still flows from the Capitan Reef Complex Aquifer into the alluvial aquifer and into the Pecos River. It is further suggested the Board also consider the influence of discharge through pumping for municipal, industrial, and irrigation uses along this reach in addition to the presence of Lake Avalon.

Please note that the Pecos River near Carlsbad, New Mexico is peripheral to this project which is primarily focused on the Texas portion of the aquifer. Groundwater discharge from underlying aquifers, including the Capitan Reef Complex Aquifer, is discussed in Section 4.4.2.

4.5 Hydraulic Properties

Page 88, Section 4.5.1: There are estimates of specific capacity, transmissivity, hydraulic conductivity and storativity presented in INTERA (2012) that are not mentioned in this section. Estimates for each property are provided in INTERA (2012) based on both single well tests and aquifer testing. It is suggested that the number of estimates for each property be updated and that the statement in the last paragraph of this section ".. no estimates of storativity were found for the Capitan Reef Complex Aquifer." be revised It is also suggested that Figure 4.5.1 and Table 4.5.1 be updated to include the data presented in INTERA (2012), as they represent recent results for hydraulic property data in the area of interest.

The text and applicable figure and table have been revised to include these hydraulic property data.

Page 88, Section 4.5.2: Please consider adding to this section the estimate of horizontal hydraulic conductivity presented in INTERA (2012). This estimate, which was obtained from an aquifer test that was completed using two wells that fully penetrated the thickness of the Capitan Reef Complex Aquifer, could be useful to both the conceptual and numerical models of this aquifer.

The report states on page 89 that "A model by INTERA and Cook-Joyce (2012) used a uniform horizontal hydraulic conductivity of 20 feet per day and a vertical hydraulic conductivity of 2 feet per day." In place of this statement, it is suggested that the Board consider discussing the more recent approach described in INTERA (2013) where eight (8) zones of hydraulic conductivity were established through model calibration. Doing so would acknowledge the variability in hydraulic conductivity recognized in previous modeling work for the CRCA.

The text was revised to replace discussion of the INTERA and Cook-Joyce (2012) model with INTERA (2013).

Page 91, Section 4.5.3: As stated a comment above, the storativity value discussed in INTERA (2013) and presented in INTERA (2012) can be referenced as a Capitan Reef Complex Aquifer storativity value based on recent field tests.

The text was revised to include the storativity data.

There is a reported transmissivity for a well in Pecos County (45-49-203, Enstor-Waha WW Site) that is not listed in Table 4.5.2 (horizontal hydraulic conductivity is about 24.8 feet/day).

We added this well to Table 4.5.1 and Figure 4.5.1.

Between 1955 and 1970 significant volumes of water were pumped from the Capitan Reef Complex Aquifer in Lea County, New Mexico and Winkler and Ward Counties, Texas. The pumping caused widespread drawdown from Lea County to the Glass Mountains (Hiss, 1975). This type of aquifer response would imply high transmissivity in a confined karst type aquifer.

The hydraulic property data in this report suggest that the transmissivity in the Capitan Reef Complex Aquifer is much higher than in the surrounding fore- and back-reef stratigraphic units.

There is a good description of regional hydraulic conductivity distribution by Hiss (1975), where he states "hydraulic conductivity of the Capitan aquifer probably averages 5.0 feet/day in most of Southern Lea County, New Mexico, but appears to increase progressively southward to an estimated 10.0 feet/day near the Pecos-Brewster County line. The hydraulic conductivity in the Glass Mountains is probably very high because of the numerous small caverns developed in this area."

The data in Figure 4.5.2 do not support the Hiss (1975) statement; however, we will take it under consideration during model calibration.

4.6 Discharge

Page 102-123, Section 4.6.2: Because historic records indicate that pumping of groundwater from the Capitan Reef Complex Aquifer for water flooding projects began in earnest in the 1950's (see Figure 38 of Hiss, 1975), it is suggested that the report discussion be expanded to capture these pre-1980 uses. To our knowledge, pumping-rate data are not available outside of Hiss (1975) for many of the major groundwater well fields in Lea County, New Mexico and Ward and Winkler Counties that supplied water for secondary oil recovery projects. For example, major groundwater well fields developed in the Capitan Reef Complex Aquifer included the Jal, Dollarhide, El Capitan, Grisham-Hunter, Wink, O'Brien, and Wicket well fields. Though pumping data are not available, Hiss (1975) does provide hydraulic heads associated with these stresses, with data available from 1967 through 1972. Although the discussion of this early period may be lacking specificity in terms of pumping volumes, we believe the potential importance of pumping in the pre-1980 period warrants discussion.

Because the domain of the conceptual model includes Eddy and Lea County, New Mexico, it is suggested that the discussion in this section be expanded to include discharge through pumping that occurs in New Mexico. Expanding the discussion to include New Mexico would be appropriate given the extent of the model and the different uses of the Capitan Reef Complex Aquifer compared to Texas. For example, the report states "Irrigation pumping from the Capitan Reef Complex Aquifer is likely to be minimal considering issues of aquifer depth, groundwater quality, and the occurrence of alternative sources of irrigation water." It is assumed that this statement is intended to only apply to a discussion of pumping in Texas, but suggest clarification given that much pumping from the Capitan Reef Complex Aquifer for irrigated agriculture occurs in Eddy County, New Mexico. Consider, for example, the present water uses for the Capitan Underground Water Basin discussed in the Lower Pecos Valley Regional Water Plan (PVWUA, 2001).

We added mention of the pumping estimates from Hiss (1975) to the text.

4.6.1 Natural Aquifer Discharge largely discusses upward discharge through cross formational flow, and neglects the data and analysis by Hiss (1975) supporting lateral cross formational flow from the Capitan Reef Complex Aquifer to the shelf aquifer to the east. Hiss (1975) wrote "Stratigraphically, the Capitan Aquifer is adjacent to, and partly enclosed by, the basin and shelf aquifers. Because of the position and the relatively higher transmissivity, it functions either as a drain or as a source of water for the shelf and basin aquifers, depending on the relative differences in head between the aquifers….. Water in the Capitan Aquifer on the east side of the ground-water divide moved eastward toward a point northeast of Eunice, where it then flowed into the San Andres Limestone and other formations in the Artesia Group as noted above."

Term 'cross-formational flow' refers to groundwater discharge from the Capitan Reef Complex Aquifer to adjacent stratigraphic units irrespective of whether that flow is lateral or vertical. Discharge by lateral cross-formational flow is discussed in Section 4.2. Figure 4.2.3 indicates little interaction between the Capitan Reef Complex Aquifer and basin stratigraphic units and data supporting interaction between the Capitan Reef Complex Aquifer and the shelf stratigraphic units is limited to the New Mexico portion of the study area. However there is a lot of hydrologic, structural geologic, and geochemical data supporting vertical cross-formational flow discharge.

See comments for Section 4.2.

See response above.

4.6.2 Aquifer Discharge through Pumping

The report only includes pumping from 1980 to 2008, when the heaviest pumping occurred from Ward and Winkler County between 1950 and 1970. Researchers have compiled pumping and water level data to assist with model development and calibration.

We would welcome any pumping and water-level data that you have to aid in model development and calibration. The period—1980 through 2008—is the period for which the most readily available pumping data is available. However, we will not restrict the model calibration period to this period of time.

4.7 Water Quality

It is suggested the publically available groundwater quality data from the Jal Water System of Lea County, New Mexico be added to the discussion. The system consisted of seven wells that once supplied water for oil flooding projects and are now plugged and abandoned.

We included New Mexico groundwater quality in Figures 4.7.1 through 4.7.4 and revised the text where appropriate.

Fresh water in the Capitan Reef Complex Aquifer is not restricted to the outcrop area, but instead to the unconfined aquifer area. Researchers have developed a map showing the distribution of water quality in the Capitan Reef Complex Aquifer using data from Hiss (1976) and John Shomaker and Associates Inc. (2014).

In this report, we assume that outcrop and unconfined areas of the Capitan Reef Complex Aquifer are synonymous.

Figure 4.7.2 nicely separates data points between east and west Capitan Reef Complex Aquifer. A plot of sulfate versus chloride for the east Capitan Reef Complex Aquifer data points would further support the change in chemistry along the groundwater flow path down dip from the Glass Mountains to Ward County.

A plot of sulfate versus chloride would not provide additional information that is not apparent in Figure 4.7.2.

Page 125, 2nd paragraph: It would appear that using Carbon isotopes for analysis of age dating the Capitan Reef Complex Aquifer would be complicated by carbonate rocks and carbonate geochemistry.

We are not using carbon-14 for quantitative age dating. That would require complex corrections to address the issues that you pointed out in this comment. Instead, we are using carbon-14 qualitatively to compare carbon-14 concentrations at different locations along flow paths. We assume the principle of decreasing carbon-14 with increasing average groundwater residence time in the aquifer.

5.0 CONCEPTUAL MODEL OF GROUNDWATER FLOW IN THE AQUIFER

Page 140: It is acknowledged that communication is possibly occurring between the Capitan Reef Complex Aquifer and overlying aquifers in the area of the Monument Draw Trough where the Salado Formation is absent. However, a more important control on historical groundwater flow direction that would explain this convergence of flow in Winkler County is the large volume of pumping that occurred in that area before and during those water-level measurements (e.g., see Brackbill and Gaines, 1964; Hoestenbach, 1982).

The interpretation of sparse data throws a lot of certainty on the location(s) of flow convergence in the Capitan Reef Complex Aquifer inferred in Hiss (1975). One needs to ask whether pumping over the past 50 years was enough to dramatically change the flow system in the Capitan Reef Complex Aquifer.

Page 142, Figure 5.0.1.: An explanation in the legend of what each arrow indicates is currently missing for dashed vs. solid lines. Assuming that the arrows indicate the direction (and magnitude?) of groundwater flow, the vertical flow of water through the Salado Formation into the overlying Rustler, Dockum, and Pecos Alluvial Aquifers is questionable. For example, Beauheim et al. (1991) report that the hydraulic conductivity of the overlying halite and anhydrite intervals of the Salado Formation are extremely low compared to other rock types, interpreted to be on the order of 1.2×10^{-9} to 3.5×10^{-6} m/day. However, the graphic shows water moving through the Salado with arrows the same size or larger than some of the arrows that depict horizontal movement. The size of the arrows may mislead readers to believe that size corresponds to flow rate, which is presumably not the intention of this figure.

We revised the figure in response to this comment. Groundwater discharge through the Salado Formation likely occurs through breccia pipes which would have hydraulic conductivity values much higher than undisturbed halite and anhydrite. The arrows in this figure indicate general directions of flow and should not be interpreted to indicate flow magnitudes.

Perhaps the section title should be rephrased to CONCEPTUAL MODEL OF GROUNDWATER IN THE EASTERN ARM OF THE CAPITAN REEF COMPLEX AQUIFER.

We revised the title of this chapter to "The Conceptual Model of Groundwater Flow in the Eastern Arm of the Capitan Reef Complex Aquifer".

Page 140, 2nd paragraph: The boundaries and geometry of the Capitan Reef Complex Aquifer on the north end of the Glass Mountains will change from Hiss (1975) and Standen and others (2009) if the Tessey Limestone is included with the Capitan Formation. The eastern arm does not contain Carlsbad Limestone or Goat Seep Limestone.

The Standen and others (2009) boundaries for the Capitan Reef Complex Aquifer include the Tessey Formation.

Page 140, 4th paragraph: The primary path for discharge is stated as upward cross formational flow. However, this conclusion is not fully supported by the data and analysis from Hiss (1975) and Hill (1996).

We revised this paragraph slightly, but it already included discussion of cross-formational flow discharge through back-reef stratigraphic units. Evidence for vertical cross-formational flow discharge is discussed in this paragraph.

Figure 5.01 is a great depiction of the conceptual model, but the formation thicknesses are not proportional making the flow paths misleading. It would help to illustrate the aquitards in Figure 5.01 and the transition from unconfined to confined aquifer system.

We revised Figure 5.0.1 based on Figure 2.2.9 to better represent formation thicknesses.

Page 141, 2nd paragraph, 5th sentence: Geophysical log analysis has shown that the salt beds of Salado and Castile are not absent in the Monument Draw Trough. The Dewey Lake redbeds act as a significant aquitard separating groundwater flow in the Permian rocks from the overlying formations. It is my understanding that dissolution of the Castile Formation happened slow enough for contemporaneous subsidence and filling of the Monument Draw Trough. As a result, the overlying Salado salt beds and Dewey Lake redbeds remained intact (deformed without faulting and fracturing), and continued to act as confining layers.

We revised the paragraph to more accurately describe the Salado Formation and the mechanism for vertical cross-formational flow from the Capitan Reef Complex Aquifer to the overlying aquifers through the formation of breccia pipes through the Salado and Castile formations. Please note: that in the Monument Draw Trough, the overlying aquifers—the Rustler and Dockum aquifers—are characterized by relatively high hydraulic conductivities probably caused by fracturing associated with subsidence (Ewing and others, 2008; 2012). Also, because of the subsidence the Rustler Formation within the Monument Draw is disconnected from the rest of the formation (Ewing and others, 2012).