RECR - 10
Windmill Oil

Capitan Reef
Studies

Memo

From
WILLIAM OLSON
Hydrogeologist

To Bill,

This is the latest draft of the SEO - USGS work plan for the Capitan Reef study. Let me know if you have any comments. I have to get back to them next week with any comments.

Will

Need to collect Rw (log & measured analysis) data on water in Reef -- also changes vertically in Reef.
Bill

HYDROGEOLOGIC DATA FOR THE CAPITAN AQUIFER AND TANSILL FORMATION IN SOUTHEASTERN NEW MEXICO

Revised March, 1994

INTRODUCTION

The Capitan aquifer is the primary source of fresh water for the City of Carlsbad and several other communities in Eddy County, New Mexico. In addition, the Capitan aquifer is also a source for irrigation water in southeastern New Mexico. The Goat Seep and Capitan Limestones are composed of limestone and dolomite with minor amounts of siltstone and sandstone. These units appear to have similar hydraulic properties and are treated as the Capitan aquifer (Hiss, 1973, p7).

The Tansill Formation consists primarily of thin-bedded light-gray to grayish-brown dolomite in a carbonate facies and of gypsum and red clay and silt in an evaporite facies. The Tansill Formation is probably above the zone of saturation except near the Capitan reef and in the area between Lake Avalon and Carlsbad Springs (Cox, 1967, p16). Solution openings have formed in the dolomite of the Tansill Formation from the south shore of Lake Avalon to near Carlsbad Springs just north of Carlsbad. These solution openings are interconnected, and water moves from Lake Avalon through these solution channels mixes with water in the Capitan aquifer and becomes part of the discharge to Carlsbad Springs. Water that leaks from Lake Avalon has a specific conductance of greater than 5,000 micromhos and water from aquifers not influenced by Pecos River water has specific conductance of generally less than 1,000 micromhos (Cox, 1967, p. 39 and plate 5).

The study area includes Carlsbad and Jal, New Mexico in parts of Eddy and Lea Counties. The study is designed to compile and collect hydrologic data for the Capitan aquifer and the Tansill Formation, between Lake Avalon and Carlsbad, figure 1.

The Office of the New Mexico State Engineer (SEO) is interested in the Capitan aquifer and the Tansill Formation and need data compilation and data collection to support management of the water resources in the study area.

PROBLEM

Two problems which hinder water management of the Capitan aquifer are; (1) there has not been a comprehensive assessment of existing hydrogeologic data on the Capitan aquifer since 1973 and (2) the hydrogeologic data that has been collected since 1973 have not been compiled and typically are found in paper files at several locations. Hiss (1973) presents data for 12 observation wells. A comprehensive inventory of wells and data compilation have not been done. Therefore, the existing hydrogeologic data for the Capitan aquifer needs to be compiled, reviewed, and entered into a data base and data need to be collected to update existing data and to improve the areal extent of data collection. The improved data base can be used by water management officials and others involved in hydrologic studies of the study area.

Richey and others (1985, p 11) summarizing from Bjorklund and Motts (1959) report that water with dissolved solids concentrations of 3,000 to 10,000 milligrams per liter could be moving through the Tansill Formation and the Capitan Limestone from Lake Avalon to the vicinity of the north west parts of Carlsbad. Documentation of wells in the Tansill Formation, water levels in these wells, and the quality of water from the Tansill Formation is lacking. The compilation of historic and current hydrologic information will result in a better understanding of the water resources of the Capitan aquifer and the Tansill Formation.

PROJECT OBJECTIVES

The objectives of this investigation are: (1) to compile the existing water-level, water-quality, and aquifer test data and enter it into the USGS data base (2) evaluate the regional coverage of the compiled data and determine areas where data gaps exist or areas where further data collection is needed; and (3) update water-level and water-quality data for the Capitan aquifer in Eddy and Lea Counties and for the Tansill Formation between Lake Avalon and the City of Carlsbad.

PURPOSE

The purpose of this study is to provide updated comprehensive hydrogeologic data for the Capitan aquifer and Tansill Formation. This will help support sound management of the water resources of the Capitan aquifer and provide a foundation for future hydrogeologic studies.

APPROACH

This investigation is divided into two Phases. In general, phase I is designed to compile and enter existing data into the USGS data base. Phase II is designed to collect new data to update data collected in the past and to collect new data in areas where data have not been collected and to complete a report that presents the existing and new data.

Phase I

Phase I consists of reviewing and compiling existing hydrogeologic data at the SEO office in Roswell and from other agencies and organizations and entering these data into the USGS Ground-Water Site Inventory (GWSI) computer data base. Specific objectives of Phase I are given in the following section.

Objectives Of Phase I

1. Compile and review existing ground-water information on the Capitan aquifer and Tansill Formation.
2. Determine and assign aquifer designations to wells finished in the Capitan aquifer and Tansill Formation.
3. Update USGS GWSI data base with the data from objective 1
4. Evaluate the quality and quantity of the existing and new well information data and the regional coverage of this data.

Approach Of Phase I

The previously listed objectives for Phase I of this study will be accomplished by conducting the following work elements.

1. Literature search. Conduct a literature search for ground-water information, including aquifer test data, for the Capitan aquifer and Tansill Formation by reviewing publications from Federal and State agencies, and from NMSU library and inter-library loan data base of Master Thesis or Doctoral Dissertations. At the end of each Phase a preliminary ground-water bibliography will be compiled from the citations obtained. As part of the literature review, in the first quarter of the project, a base map will be prepared using the Geographic Information System (GIS). The map will be prepared from existing digital data of the area.

2. **Compile and review existing well record, water-level, and water-quality data.** There are approximately 400 wells completed in the Capitan aquifer that the SEO in Roswell collects water-level measurements from and about 150 to 200 of these wells are entered into USGS GWSI computer data base. Therefore, approximately 200 to 250 well record schedules with water-level measurements need to be compiled, reviewed, coded onto GWSI schedules, and entered into the GWSI computer data base. Review should include verification of well record data and aquifer assignment. As part of the direct services the SEO will be responsible for compiling, reviewing, and coding the SEO well records that have well location and construction information and water-level measurements onto GWSI forms. **To enter a well record into the USGS GWSI data base the following minimum information is required: Project number, Station name, Location map, Map scale, Altitude, Hydrologic unit code, Use of water, Water level and / or site status, Water level date, and if a water level is measured; Measuring point date, Measuring point height, Measuring point-description, Date of visit, and Name of Person. Any additional well information (i.e., owner, driller, depth of well, casing size, yield, SEO well identification #, etc.) can be and should be coded onto the form.** The USGS will train SEO staff in the interpretation of well location and completion data and water-level information as it pertains to coding the GWSI forms.

The following agencies have been contacted and either have sparse water-level data on the Capitan aquifer (these agencies stated that the SEO in Roswell also has their data) or they have no data: BLM, OCD, Soil Conservation Service (SCS), and the State Land Offices in Roswell, Hobbs, and Santa Fe. There will be continued contact with other agencies to determine if there is additional water-level information. Agencies that will be contacted during Phase I include the Bureau of Reclamation (BOR), County agencies, Roswell Geological Society, Texas Bureau of Economic Geology and any others suggested by the SEO.

Quality control restrictions limit the water-quality data that can be entered into the USGS water-quality data base (QWDATA). If the sample collection procedures cannot be verified to have met USGS standards and if the analyses were not performed in a USGS sanctioned laboratory the data cannot be entered into QWDATA. Existing data found in other agency files may not meet the quality control restrictions.

A search and compilation of existing USGS data, that is not in the data base will be made. Water-quality data prior to 1968 may not be in the data base but exists on card files in the USGS district office. If these data exist they will be entered into (QWDATA) by the USGS.

Existing hydrogeologic data for wells, found as a result of this work element, that are not in the USGS data base, or do not have an aquifer assigned to the units in which the well is finished, will be entered into the GWSI data base if there is reliable location information and adequate information is available so that an aquifer designation can be made. Wells that meet these criteria will be compiled and the existing data coded on the GWSI coding forms by SEO as part of the direct services credit. A map that shows the well location will be completed by the USGS after discussion with the SEO personnel. As part of this work effort the projection of the Capitan aquifer, figure 12 of Hiss (1975), and the Tansill Formation, plate 3 of Cox (1967), at land surface will be made on the base map using GIS. Well locations will be plotted on the resulting map along with well depth and the depth of the open section in the well. These data are needed to estimate the formation producing water pumped from the well. Well locations that are above the subsurface projection of the Capitan aquifer and the Tansill Formation and between Lake Avalon and the City of Carlsbad will have the aquifer designations assigned by the USGS. After the aquifer designations have been made, the GWSI coding sheets will be updated by the USGS with the aquifer information and these wells entered in GWSI.

3. **Collection of aquifer test data.** Aquifer test data will be collected and compiled during the ongoing literature search. At the end of each Phase aquifer test data will be compiled from the literature search conducted during that time period. This element will continue until the last quarter of 1996, when aquifer test data collection will stop. The data will be included in the final report.

4. **Evaluate existing data and plan the collection of new data.** Evaluate the regional coverage of the existing data by plotting well locations on a map or maps of the study area where water-level measurements, water-quality samples, aquifer designations, and aquifer test data have been obtained. This will provide a means of evaluating the areal coverage of water-level and water-quality data so future data collection (Phase II) can be planned according to the cooperators needs and available resources.

Schedule Of Work For Phase I (FY 95)

Note: [X refers to USGS activities and S refers to SEO activities. Work elements are specified by quarter and do not imply that effort will continue all quarter.]

	FY 95			
Quarter	**1**	**2**	**3**	**4**
	Jul Aug Sep	**Oct Nov Dec**	**Jan Feb Mar**	**Apr May Jun**
Work Element				
1. Literature search	X	X	X	X
2. Compile, review, and code existing water level and water-quality data	X	XS	XS	
3 Compile well data for mapping for aquifer designation		S	S	
4. Prepare map of wells for aquifer designation			X	
5. Determine aquifer designations			X	
6. Compile and code aquifer test data			X	
7. Enter coded data into GWSI and QWDATA			X	
8. Compile a preliminary table and maps of water level, aquifer test, and water quality data				X
8. Review and evaluation meeting with cooperator	X	X	X	X

Schedule Of USGS Man Days By Work Element For Phase I (FY 95)

	FY 95			
Quarter	1	2	3	4
	Jul Aug Sep	Oct Nov Dec	Jan Feb Mar	Apr May Jun
Work Element				
1. Literature search including generation of GIS base map	16	4	2	2
2. Compile, review, and code existing water-level and water-quality data	16	11;S	2;S	
3 Compile well data for mapping for aquifer designation		S	S	
4. Prepare map of wells for aquifer designation			4	
5. Determine aquifer designations			4	
6. Compile and code aquifer test data			4	
6. Enter coded data into GWSI and QWDATA			2	
7. Compile a preliminary table and maps of water level, aquifer test, and water quality data				9
8. Review and evaluation meeting with cooperator	2	2	2	2

Note: S refers to SEO activities

Products For Phase I

The primary product of phase I will be an updated GWSI and QWDATA data base. In addition a preliminary map or maps of the study area showing well locations; the availability of water-level, water-quality, aquifer-test data; and the aquifer designation will be produced. These maps will be used to design the data collection program during phase II.

USGS Personnel Requirements For Phase I

The following lists the estimated number of work days required for Phase I:

	FY95
Hydrologist	41
Hydrologic Technician	10
Hydrologic Aid	14
Geographer (GIS)	12
Computer Programmer (GIS)	7

SEO Personnel Requirements For Phase I

The following lists the estimated number of work days required for Phase I:

	FY95
Water Resource Specialist II	34

Project Costs

The estimated cost for Phase I is as follows:

New Mexico State Fiscal Year:

	FY95
Salaries	$30,400
Travel and per diem	3,400
Vehicles	2,900
Direct services	1,000
Total	$37,700

Phase II

Phase II of this investigation will focus on collecting new hydrogeologic data on the Capitan aquifer and Tansill Formation. Objectives and Approach for Phase II are given in the following sections.

Objectives Of Phase II

The specific objectives of Phase II are:

1. Evaluate present data and plan for new data collection as determined from discussions with the SEO.
2. Update GWSI with new water-level and water-quality data by measuring water levels and collecting water samples from selected wells in critical areas as determined from discussions with SEO. Update GWSI with aquifer-test data and with water-use data obtained from the SEO.
3. Update table 2 of Hiss (1973) with specific gravity data of water in the well bore of the original Hiss network wells. Update and add to the data in table 2 of Hiss (1973) by collecting water samples from wells selected in objective 1 of phase II from wells in the study area that are equipped with pumps. These samples will be analyzed for the same constituents as shown in table 2 of Hiss (1973)
4. Update and populate water-use data base using data from SEO files for calendar years 1995 and 1996.
5. Present historical and current hydrologic data in an Open-File data report.

Approach Of Phase II

The objectives for Phase II of this study will be accomplished by conducting the following work elements.

1. **Evaluate present data and plan for new data collection.** Using the maps and tables generated as a result of Phase I data compilation determine, with staff of the SEO, areas where new and additional data needs to be collected. Identify existing wells and the number of wells that can be utilized to collect water-level measurements and water-quality

samples. The observation well network of Hiss (1973) consisted of twelve wells, nine are abandoned oil and gas wells completed in the Capitan aquifer, two are owned by the City of Carlsbad, and one is owned by Forrest Miller. Continuous water-level data are presently collected at the two wells owned by the City of Carlsbad and one well owned by Forrest Miller. These three wells are located within 12 miles of the City of Carlsbad. The other nine abandoned oil and gas wells used as observation wells by Hiss are located on a southeasterly arcuate trend from the City of Carlsbad to the Texas state line, and have shelters over the wellhead.

2. **Collect new water-level and water-quality data**. Water levels will be measured during the winter of 1995-96 in the wells shown in Hiss (1973) and in wells selected by the SEO and the USGS. Water-level measurements made in the wells previously measured by Hiss (1973) will be made with steel tape coated with "color cut" which delineates oil floating on the water surface. The locations of each well visited will be determined with a Global Positioning System (GPS) and the data base updated, if needed, with the GPS determined locations.

An understanding of specific gravity changes of the fluid in the well bore will be determined by collecting water samples from the Hiss network wells. If the water-level measurement data indicates oil floating on the water surface a sample of the oil will be obtained using a thief sampler. Specific gravity of the sample will be determined in the field. Stratified water-quality sampling in wells will be completed using a thief sampler. These samples will be obtained at the same depths from which Hiss obtained samples. Specific gravity data will be used to adjust water-level measurements where specific gravity of the water is greater than one. Specific gravity of the formation water will be assumed to be similar to water from nearby production wells, if any, or to be the same as reported in Hiss (1973).

Water samples will be collected from selected production wells as determined with discussions of the staff of the SEO. Well locations will be checked with the GPS equipment. These production wells will be sampled in the summer of 1996. The samples will be analyzed for the following constituents:

Cations

calcium	**magnesium**
sodium	**sodium + potassium**
potassium	**boron**
iron	**silica**

Anions

bicarbonate	**carbonate**
sulfate	**chloride**
fluoride	**nitrogen**
bromide	

Physical Properties

total alkalinity as calcium carbonate

pH	**specific electrical conductance**
temperature	

total dissolved solids (residue on evaporation at 180 degrees Celsius).

3. **Data analysis.** Once the water-level measurements are collected and the water samples analyzed, the data will be compiled and entered into GWSI and QWDATA. Then construction of well record tables will begin and where applicable, table 2 of Hiss (1973) will be updated. Hydrographs for wells with long-term water-level records will be constructed. Current water-level data will be compared to historic data and where long-term water-level records exist a map showing water-level changes will be constructed. A current water-level map and total dissolved solids concentration map will be constructed for the Capitan aquifer and for the Tansill Formation if enough data are collected. The chloride ion concentration from existing data in wells completed in the Capitan aquifer (and Tansill Formation) along with the new chloride concentration data will be plotted

either graphically or on a map, similar to the Figure 8 in Hendrickson and Jones (1952).

4. **Collection of water-use data.** SEO will require that meters be installed on wells no later than January 1, 1994 in their Carlsbad and Capitan ground water basins, which essentially covers the extent of the Capitan aquifer in New Mexico. Therefore, ground water withdrawal data for the Capitan aquifer should be compiled at the end of the calendar year (1996) by the SEO as part of direct services and be a product of Phase II. The SEO will provide well locations, well owners, available meter readings or the amount of water used, and the water use category to the USGS. The USGS will present the data in table format in the data report.

5. **Continue collection of aquifer-test data.** During Phase II aquifer test data for the Capitan aquifer and Tansill Formation will be compiled from data acquired during the ongoing literature search.

6. **Final report preparation and publishing.** With maps, charts, and tables completed, a USGS Open-File data report will be prepared. The report will discuss methods used to collect the data. Water-level data will be adjusted to a specific gravity of 1 and the method used to make the adjustment will be briefly discussed Hiss (1973).

Schedule Of Work For Phase II (FY 96)

Note: [X refers to USGS activities and S refers to SEO activities. Work elements are specified by quarter and do not imply that effort will continue all quarter.]

FY 96

Quarter	1	2	3	4
	Jul Aug Sept	Oct Nov Dec	Jan Feb Mar	Apr May Jun
Work Element				
1. Evaluate existing data. Identify wells for collecting water level and water quality data	XS			
2. Measure water levels.			X	
3. Collect water quality samples				X
4. Collect and compile Water Use data			S	
5. Collect aquifer test data	X	X	X	X
6. Analyze data and enter into GWSI or QWDATA			X	X
7. Construction of well record tables, hydrographs, and maps				X
8. Review meetings with cooperator	X	X	X	X

Schedule Of Work For Phase II (FY 97)

	FY 97			
Quarter	**1**	**2**	**3**	**4**
	Jul Aug Sept	**Oct Nov Dec**	**Jan Feb Mar**	**Apr May Jun**
Work Element				
9. Compile and write text for draft of a USGS data report	X			
10. Colleague review of report		X		
11. Respond to reviewers comments			X	
12. District approval, and publish report				X
13. Review meetings with cooperator	X	X	X	X

Products For Phase II

The final report for this project will be a USGS Open-File data report. The report will contain no interpretation. It will contain the elements listed below.

1. A table with well record information. The following information will be included in the table if available; well location (Township, Range, Section, quarters) well name, owner, depth of well, casing diameter, date well was completed, historical and current water levels, dates water levels were measured, use of water, water-bearing unit, altitude of land surface, and well yield.
2. A map showing current, water-level data for the Capitan aquifer and Tansill Formation.
3. A map showing total dissolved solids and chloride ion concentration for water from wells

completed in the Capitan aquifer and Tansill Formation.

4. A map or graphical presentation showing historical and current chloride concentrations.
5. Hydrographs for selected wells completed in the Capitan aquifer and Tansill Formation, including the Hiss network wells, where there is sufficient period of record.
6. Data tables with historical and current water-quality results for water from selected wells completed in the Capitan aquifer and Tansill Formation. The Hiss network wells will not be sampled due to money constraints.
7. Updated aquifer test data (if available) to compliment Table 6 of Richey and others (1985).
8. Water use table showing well location, owner, water bearing unit, water use category, and amount of water used.

Schedule Of USGS Man Days By Work Element For Phase II (FY 96)

FY 96

Quarter	1	2	3	4
	Jul Aug Sept	Oct Nov Dec	Jan Feb Mar	Apr May Jun
Work Element				
1. Evaluate existing data. Identify wells for collecting water level and water quality data	2;S			
2. Measure water levels.		3	30	
Collect water quality samples		3		36
3. Collect and compile Water Use data			S	
4. Collect aquifer test data	2	2	2	2
5. Analyze data and enter into GWSI or QWDATA			10	10
6. Construction of well record tables, hydrographs, and maps				16
7. Review meetings with cooperator	2	2	2	2

Note: S refers to SEO activities

Schedule Of USGS Man Days By Work Element For Phase II (FY 97)

	FY 97			
Quarter	1	2	3	4
	Jul Aug Sept	Oct Nov Dec	Jan Feb Mar	Apr May Jun
Work Element				
8. Compile and write text for draft of a USGS data report	18			
9. Colleague review of report		7		
10. Respond to reviewers comments			3	
11. District approval, and publish report				8
12. Review meetings with cooperator	2	2	2	2

Personnel Requirements For Phase II

The following lists the estimated number:
of work days required for Phase II:

	FY96	FY97
Hydrologist	77	33
Hydrologic Technician	44	
Geographer	5	
Editor		2
Typist		4
Draftsman		5

SEO Personnel Requirements For Phase II

The following lists the estimated number of work days required for Phase II:

	FY96
Water Resource Specialist II	34

Project Costs

The estimated cost for Phase II is as follows:

New Mexico State Fiscal Year:

	FY96	FY97
Salaries	43,300	14,300
Travel and per diem	11,200	1,700
Vehicles	4,300	1,300
Printing and reproduction	0	19,100
Supplies and materials	700	0
Lab analysis (*1 sample / well =$440; this includes; analysis, supplies and postage) estimating 1 well/day + manpower estimate is for 15 wells =*	6,600	0
Equipment purchase	2,100	0
Direct services	1,000	0
Total	$69,200	$39,000

SELECTED REFERENCES:

Bjorklund, L.J., and Motts, W.S., 1959, Geology and water resources of the Carlsbad area, Eddy Count,. New Mexico: U.S. Geological Survey Open-File Report, 322p.

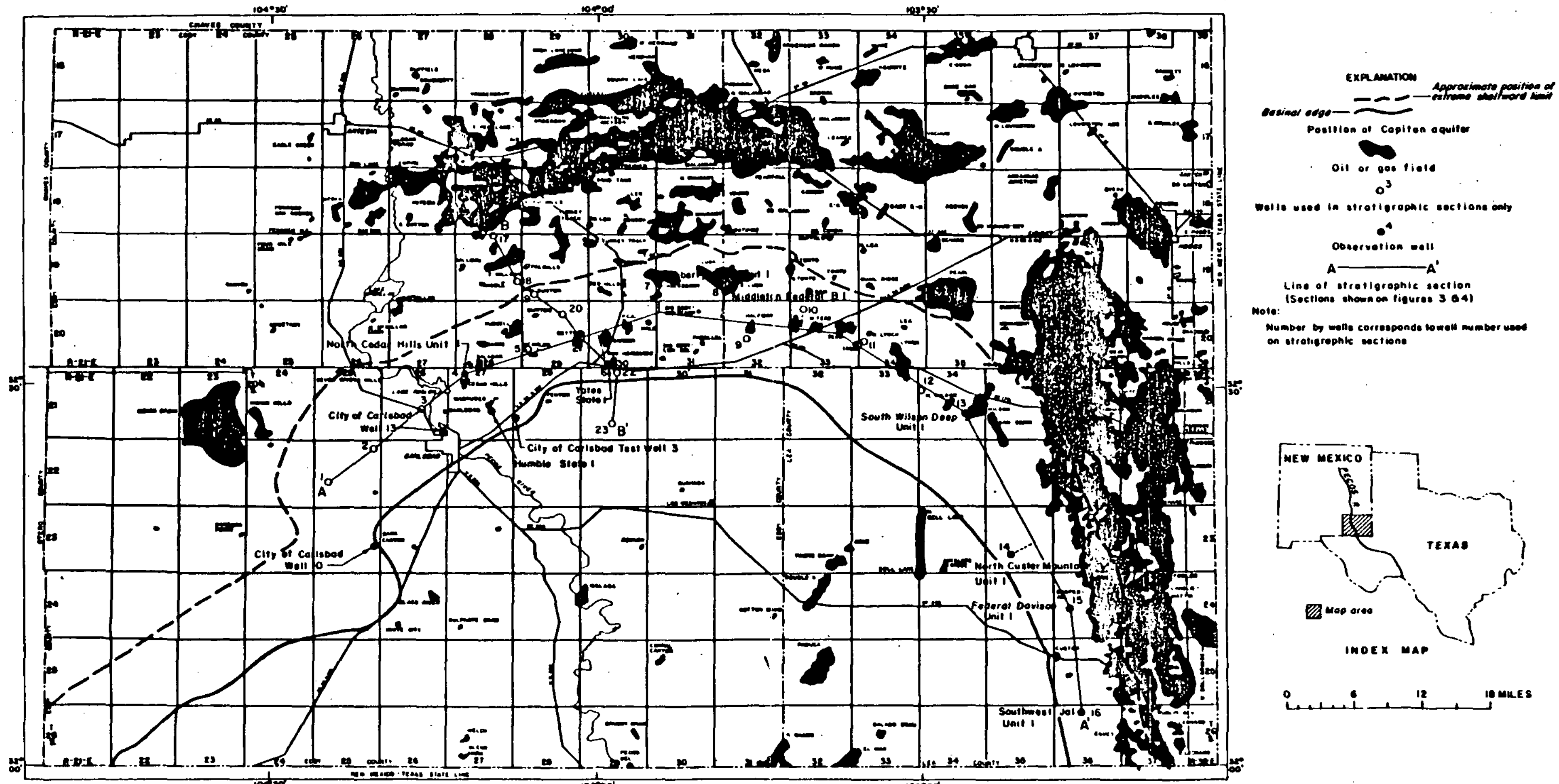
Cox, E.R., 1967, Geology and Hydrology between Lake McMillan and Carlsbad Springs Eddy Count, New Mexico: U.S. Geological Survey Water Supply Paper 1828, 47p.

Hendrickson, G.E., and Jones, R.S., 1952, Geology and ground-water resources of Eddy County, New Mexico: Socorro, New Mexico Bureau of Mines and Mineral Resources Ground-Water Report 3, 169 p.

Hiss, W.L. 1973, Capitan aquifer observation-well network Carlsbad to Jal New Mexico: New Mexico State Engineer Technical Report 38, 76p.

Hiss, W.L., 1975, Stratigraphy and ground-water hydrology of the Capitan reef and associated formations, southeastern New Mexico and western Texas: Boulder, University of Colorado, unpublished Ph.D. dissertation, 395 p., 12 pis.

Richey, Steven F., Wells, Jane G., and Stephens, Kathleen T., 1985, Geohydrology of the Delaware Basin and vicinity, Texas and New Mexico: U.S. Geological Survey Water-Resources Investigation Report 84-4077, 99p.



Base map modified from U.S. Geological Survey, Oil and Gas Branch Map No. Roswell 30, revised March 1967.

Figure 1.--Areal extent of the Capitan aquifer and the location of stratigraphic sections and Capitan aquifer observation wells in Eddy and Lea Counties, New Mexico From Hiss (1973).

SEO cooperative agreement with USGS to
study Capitan reef (2-3 yrs study)
Met last week with USGS

Phased approach 1 - water quality data update
throughout reef
2 - update last report on
Geohydro of Delaware Basin
USGS report WRIR 4077

After collection of data - look at need for more info
- ie freshwater/saline interface

will address - water quality
hydraulics porosity

Need to have - Carlsbad
OCD
BLM
Bureau of Mines

$15000 allocated by SEO for this fiscal yr.
Roswell SEO providing data
End result data report non interpretive

will have ongoing review meetings
possible interpretation by SEO of data
ie - basic interactions

HYDROGEOLOGIC DATA FOR THE CAPITAN AQUIFER AND TANSILL FORMATION IN SOUTHEASTERN NEW MEXICO

Revised March, 1994

INTRODUCTION

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Approach Of Phase I

The previously listed objectives for Phase I of this study will be accomplished by conducting the following work elements.

1. Literature search. Conduct a literature search for ground-water information, including aquifer test data, for the Capitan aquifer and Tansill Formation by reviewing publications from Federal and State agencies, and from NMSU library and inter-library loan data base of Master Thesis or Doctoral Dissertations. At the end of each Phase a preliminary ground-water bibliography will be compiled from the citations obtained. As part of the literature review, in the first quarter of the project, a base map will be prepared using the Geographic Information System (GIS). The map will be prepared from existing digital data of the area.

2. **Compile and review existing well record, water-level, and water-quality data**. There are approximately 400 wells completed in the Capitan aquifer that the SEO in Roswell collects water-level measurements from and about 150 to 200 of these wells are entered into USGS GWSI computer data base. Therefore, approximately 200 to 250 well record schedules with water-level measurements need to be compiled, reviewed, coded onto GWSI schedules, and entered into the GWSI computer data base. Review should include verification of well record data and aquifer assignment. As part of the direct services the SEO will be responsible for compiling, reviewing, and coding the SEO well records that have well location and construction information and water-level measurements onto GWSI forms. **To enter a well record into the USGS GWSI data base the following minimum information is required: Project number, Station name, Location map, Map scale, Altitude, Hydrologic unit code, Use of water, Water level and / or site status, Water level date, and if a water level is measured; Measuring point date, Measuring point height, Measuring point-description, Date of visit, and Name of Person. Any additional well information (i.e., owner, driller, depth of well, casing size, yield, SEO well identification #, etc.) can be and should be coded onto the form.** The USGS will train SEO staff in the interpretation of well location and completion data and water-level information as it pertains to coding the GWSI forms.

The following agencies have been contacted and either have sparse water-level data on the Capitan aquifer (these agencies stated that the SEO in Roswell also has their data) or they have no data: BLM, OCD, Soil Conservation Service (SCS), and the State Land Offices in Roswell, Hobbs, and Santa Fe. There will be continued contact with other agencies to determine if there is additional water-level information. Agencies that will be contacted during Phase I include the Bureau of Reclamation (BOR), County agencies, Roswell Geological Society, Texas Bureau of Economic Geology and any others suggested by the SEO.

Quality control restrictions limit the water-quality data that can be entered into the USGS water-quality data base (QWDATA). If the sample collection procedures cannot be verified to have met USGS standards and if the analyses were not performed in a USGS sanctioned laboratory the data cannot be entered into QWDATA. Existing data found in other agency files may not meet the quality control restrictions.

A search and compilation of existing USGS data, that is not in the data base will be made. Water-quality data prior to 1968 may not be in the data base but exists on card files in the USGS district office. If these data exist they will be entered into (QWDATA) by the USGS.

Existing hydrogeologic data for wells, found as a result of this work element, that are not in the USGS data base, or do not have an aquifer assigned to the units in which the well is finished, will be entered into the GWSI data base if there is reliable location information and adequate information is available so that an aquifer designation can be made. Wells that meet these criteria will be compiled and the existing data coded on the GWSI coding forms by SEO as part of the direct services credit. A map that shows the well location will be completed by the USGS after discussion with the SEO personnel. As part of this work effort the projection of the Capitan aquifer, figure 12 of Hiss (1975), and the Tansill Formation, plate 3 of Cox (1967), at land surface will be made on the base map using GIS. Well locations will be plotted on the resulting map along with well depth and the depth of the open section in the well. These data are needed to estimate the formation producing water pumped from the well. Well locations that are above the subsurface projection of the Capitan aquifer and the Tansill Formation and between Lake Avalon and the City of Carlsbad will have the aquifer designations assigned by the USGS. After the aquifer designations have been made, the GWSI coding sheets will be updated by the USGS with the aquifer information and these wells entered in GWSI.

3. **Collection of aquifer test data.** Aquifer test data will be collected and compiled during the ongoing literature search. At the end of each Phase aquifer test data will be compiled from the literature search conducted during that time period. This element will continue until the last quarter of 1996, when aquifer test data collection will stop. The data will be included in the final report.

4. **Evaluate existing data and plan the collection of new data.** Evaluate the regional coverage of the existing data by plotting well locations on a map or maps of the study area where water-level measurements, water-quality samples, aquifer designations, and aquifer test data have been obtained. This will provide a means of evaluating the areal coverage of water-level and water-quality data so future data collection (Phase II) can be planned according to the cooperators needs and available resources.

Schedule Of Work For Phase I (FY 95)

Note: [**X** refers to USGS activities and **S** refers to SEO activities. Work elements are specified by quarter and do not imply that effort will continue all quarter.]

	FY 95			
Quarter	**1**	**2**	**3**	**4**
	Jul Aug Sep	**Oct Nov Dec**	**Jan Feb Mar**	**Apr May Jun**
Work Element				
1. Literature search	**X**	**X**	**X**	**X**
2. Compile, review, and code existing water level and water-quality data	**X**	**XS**	**XS**	
3 Compile well data for mapping for aquifer designation		**S**	**S**	
4. Prepare map of wells for aquifer designation			**X**	
5. Determine aquifer designations			**X**	
6. Compile and code aquifer test data			**X**	
7. Enter coded data into GWSI and QWDATA			**X**	
8. Compile a preliminary table and maps of water level, aquifer test, and water quality data				**X**
8. Review and evaluation meeting with cooperator	**X**	**X**	**X**	**X**

Schedule Of USGS Man Days By Work Element For Phase I (FY 95)

			FY 95	
Quarter	**1**	**2**	**3**	**4**
	Jul Aug Sep	**Oct Nov Dec**	**Jan Feb Mar**	**Apr May Jun**
Work Element				
1. Literature search including generation of GIS base map	**16**	**4**	**2**	**2**
2. Compile, review, and code existing water-level and water-quality data	**16**	**11;S**	**2;S**	
3 Compile well data for mapping for aquifer designation		**S**	**S**	
4. Prepare map of wells for aquifer designation			**4**	
5. Determine aquifer designations			**4**	
6. Compile and code aquifer test data			**4**	
6. Enter coded data into GWSI and QWDATA			**2**	
7. Compile a preliminary table and maps of water level, aquifer test, and water quality data				**9**
8. Review and evaluation meeting with cooperator	**2**	**2**	**2**	**2**

Note: S refers to SEO activities

Products For Phase I

The primary product of phase I will be an updated GWSI and QWDATA data base. In addition a preliminary map or maps of the study area showing well locations; the availability of water-level, water-quality, aquifer-test data; and the aquifer designation will be produced. These maps will be used to design the data collection program during phase II.

USGS Personnel Requirements For Phase I

The following lists the estimated number of work days required for Phase I:

	FY95
Hydrologist	41
Hydrologic Technician	10
Hydrologic Aid	14
Geographer (GIS)	12
Computer Programmer (GIS)	7

SEO Personnel Requirements For Phase I

The following lists the estimated number of work days required for Phase I:

	FY95
Water Resource Specialist II	34

Project Costs

The estimated cost for Phase I is as follows:

New Mexico State Fiscal Year:

	FY95
Salaries	$30,400
Travel and per diem	3,400
Vehicles	2,900
Direct services	1,000
Total	$37,700

Phase II

Phase II of this investigation will focus on collecting new hydrogeologic data on the Capitan aquifer and Tansill Formation. Objectives and Approach for Phase II are given in the following sections.

Objectives Of Phase II

The specific objectives of Phase II are:

1. Evaluate present data and plan for new data collection as determined from discussions with the SEO.
2. Update GWSI with new water-level and water-quality data by measuring water levels and collecting water samples from selected wells in critical areas as determined from discussions with SEO. Update GWSI with aquifer-test data and with water-use data obtained from the SEO.
3. Update table 2 of Hiss (1973) with specific gravity data of water in the well bore of the original Hiss network wells. Update and add to the data in table 2 of Hiss (1973) by collecting water samples from wells selected in objective 1 of phase II from wells in the study area that are equipped with pumps. These samples will be analyzed for the same constituents as shown in table 2 of Hiss (1973)
4. Update and populate water-use data base using data from SEO files for calendar years 1995 and 1996.
5. Present historical and current hydrologic data in an Open-File data report.

Approach Of Phase II

The objectives for Phase II of this study will be accomplished by conducting the following work elements.

1. Evaluate present data and plan for new data collection. Using the maps and tables generated as a result of Phase I data compilation determine, with staff of the SEO, areas where new and additional data needs to be collected. Identify existing wells and the number of wells that can be utilized to collect water-level measurements and water-quality samples. The observation well network of Hiss (1973) consisted of twelve wells, nine are abandoned oil and gas wells completed in the Capitan aquifer, two are owned by the City of Carlsbad, and one is owned by Forrest Miller. Continuous water-level data are presently collected at the two wells owned by the City of Carlsbad and one well owned by Forrest Miller. These three wells are located within 12 miles of the City of Carlsbad. The other nine abandoned oil and gas wells used as observation wells by Hiss are located on a southeasterly arcuate trend from the City of Carlsbad to the Texas state line, and have shelters over the wellhead.

2. **Collect new water-level and water-quality data**. Water levels will be measured during the winter of 1995-96 in the wells shown in Hiss (1973) and in wells selected by the SEO and the USGS. Water-level measurements made in the wells previously measured by Hiss (1973) will be made with steel tape coated with "color cut" which delineates oil floating on the water surface. The locations of each well visited will be determined with a Global Positioning System (GPS) and the data base updated, if needed, with the GPS determined locations.

An understanding of specific gravity changes of the fluid in the well bore will be determined by collecting water samples from the Hiss network wells. If the water-level measurement data indicates oil floating on the water surface a sample of the oil will be obtained using a thief sampler. Specific gravity of the sample will be determined in the field. Stratified water-quality sampling in wells will be completed using a thief sampler. These samples will be obtained at the same depths from which Hiss obtained samples. Specific gravity data will be used to adjust water-level measurements where specific gravity of the water is greater than one. Specific gravity of the formation water will be assumed to be similar to water from nearby production wells, if any, or to be the same as reported in Hiss (1973).

Water samples will be collected from selected production wells as determined with discussions of the staff of the SEO. Well locations will be checked with the GPS equipment. These production wells will be sampled in the summer of 1996. The samples will be analyzed for the following constituents:

Cations

calcium	**magnesium**
sodium	**sodium + potassium**
potassium	**boron**
iron	**silica**

Anions

bicarbonate	**carbonate**
sulfate	**chloride**
fluoride	**nitrogen**
bromide	

Physical Properties

total alkalinity as calcium carbonate

pH	**specific electrical conductance**
temperature	

total dissolved solids (residue on evaporation at 180 degrees Celsius).

3. Data analysis. Once the water-level measurements are collected and the water samples analyzed, the data will be compiled and entered into GWSI and QWDATA. Then construction of well record tables will begin and where applicable, table 2 of Hiss (1973) will be updated. Hydrographs for wells with long-term water-le el records will be constructed. Current water-level data will be compared to historic data and where long-term water-level records exist a map showing water-level changes will be constructed. A current water-level map and total dissolved solids concentration map will be constructed for the Capitan aquifer and for the Tansill Formation if enough data are collected. The chloride ion concentration from existing data in wells completed in the Capitan aquifer (and Tansill Formation) along with the new chloride concentration data will be plotted either graphically or on a map, similar to the Figure 8 in Hendrickson and Jones (1952).

4. **Collection of water-use data.** SEO will require that meters be installed on wells no later than January 1, 1994 in their Carlsbad and Capitan ground water basins, which essentially covers the extent of the Capitan aquifer in New Mexico. Therefore, ground water withdrawal data for the Capitan aquifer should be compiled at the end of the calendar year (1996) by the SEO as part of direct services and be a product of Phase II. The SEO will provide well locations, well owners, available meter readings or the amount of water used, and the water use category to the USGS. The USGS will present the data in table format in the data report.

5. **Continue collection of aquifer-test data.** During Phase II aquifer test data for the Capitan aquifer and Tansill Formation will be compiled from data acquired during the ongoing literature search.

6. **Final report preparation and publishing.** With maps, charts, and tables completed, a USGS Open-File data report will be prepared. The report will discuss methods used to collect the data. Water-level data will be adjusted to a specific gravity of 1 and the method used to make the adjustment will be briefly discussed Hiss (1973).

Schedule Of Work For Phase II (FY 96)

Note: [X refers to USGS activities and S refers to SEO activities. Work elements are specified by quarter and do not imply that effort will continue all quarter.]

	FY 96			
Quarter	**1**	**2**	**3**	**4**
	Jul Aug Sept	**Oct Nov Dec**	**Jan Feb Mar**	**Apr May Jun**
Work Element				
1. Evaluate existing data. Identify wells for collecting water level and water quality data	XS			
2. Measure water levels.			X	
3. Collect water quality samples				X
4. Collect and compile Water Use data			S	
5. Collect aquifer test data	X	X	X	X
6. Analyze data and enter into GWSI or QWDATA			X	X
7. Construction of well record tables, hydrographs, and maps				X
8. Review meetings with cooperator	X	X	X	X

Schedule Of Work For Phase II (FY 97)

	FY 97			
Quarter	**1**	**2**	**3**	**4**
	Jul Aug Sept	**Oct Nov Dec**	**Jan Feb Mar**	**Apr May Jun**
Work Element				
9. Compile and write text for draft of a USGS data report	X			
10. Colleague review of report		X		
11. Respond to reviewers comments			X	
12. District approval, and publish report				X
13. Review meetings with cooperator	X	X	X	X

Products For Phase II

The final report for this project will be a USGS Open-File data report. The report will contain no interpretation. It will contain the elements listed below.

1. A table with well record information. The following information will be included in the table if available; well location (Township, Range, Section, quarters) well name, owner, depth of well, casing diameter, date well was completed, historical and current water levels, dates water levels were measured, use of water, water-bearing unit, altitude of land surface, and well yield.
2. A map showing current, water-level data for the Capitan aquifer and Tansill Formation.
3. A map showing total dissolved solids and chloride ion concentration for water from wells

completed in the Capitan aquifer and Tansill Formation.

4. A map or graphical presentation showing historical and current chloride concentrations.
5. Hydrographs for selected wells completed in the Capitan aquifer and Tansill Formation, including the Hiss network wells, where there is sufficient period of record.
6. Data tables with historical and current water-quality results for water from selected wells completed in the Capitan aquifer and Tansill Formation. The Hiss network wells will not be sampled due to money constraints.
7. Updated aquifer test data (if available) to compliment Table 6 of Richey and others (1985).
8. Water use table showing well location, owner, water bearing unit, water use category, and amount of water used.

Schedule Of USGS Man Days By Work Element For Phase II (FY 96)

	FY 96			
Quarter	**1**	**2**	**3**	**4**
	Jul Aug Sept	**Oct Nov Dec**	**Jan Feb Mar**	**Apr May Jun**
Work Element				
1. Evaluate existing data. Identify wells for collecting water level and water quality data	2;S			
2. Measure water levels.		3	30	
Collect water quality samples		3		36
3. Collect and compile Water Use data			S	
4. Collect aquifer test data	2	2	2	2
5. Analyze data and enter into GWSI or QWDATA			10	10
6. Construction of well record tables, hydrographs, and maps				16
7. Review meetings with cooperator	2	2	2	2

Note: S refers to SEO activities

Schedule Of USGS Man Days By Work Element For Phase II (FY 97)

	FY 97			
Quarter	**1**	**2**	**3**	**4**
	Jul Aug Sept	**Oct Nov Dec**	**Jan Feb Mar**	**Apr May Jun**
Work Element				
8. Compile and write text for draft of a USGS data report	**18**			
9. Colleague review of report		**7**		
10. Respond to reviewers comments			**3**	
11. District approval, and publish report				**8**
12. Review meetings with cooperator	**2**	**2**	**2**	**2**

Personnel Requirements For Phase II

The following lists the estimated number: of work days required for Phase II:

	FY96	FY97
Hydrologist	77	33
Hydrologic Technician	44	
Geographer	5	
Editor		2
Typist		4
Draftsman		5

SEO Personnel Requirements For Phase II

The following lists the estimated number of work days required for Phase II:

	FY96
Water Resource Specialist II	34

Project Costs

The estimated cost for Phase II is as follows:

New Mexico State Fiscal Year:

	FY96	FY97
Salaries	43,300	14,300
Travel and per diem	11,200	1,700
Vehicles	4,300	1,300
Printing and reproduction	0	19,100
Supplies and materials	700	0
Lab analysis (*1 sample / well =$440; this includes; analysis, supplies and postage) estimating 1 well/day + manpower estimate is for 15 wells =*	6,600	0
Equipment purchase	2,100	0
Direct services	1,000	0
Total	$69,200	$39,000

SELECTED REFERENCES:

Bjorklund, L.J., and Motts, W.S., 1959, Geology and water resources of the Carlsbad area, Eddy Count,. New Mexico: U.S. Geological Survey Open-File Report, 322p.

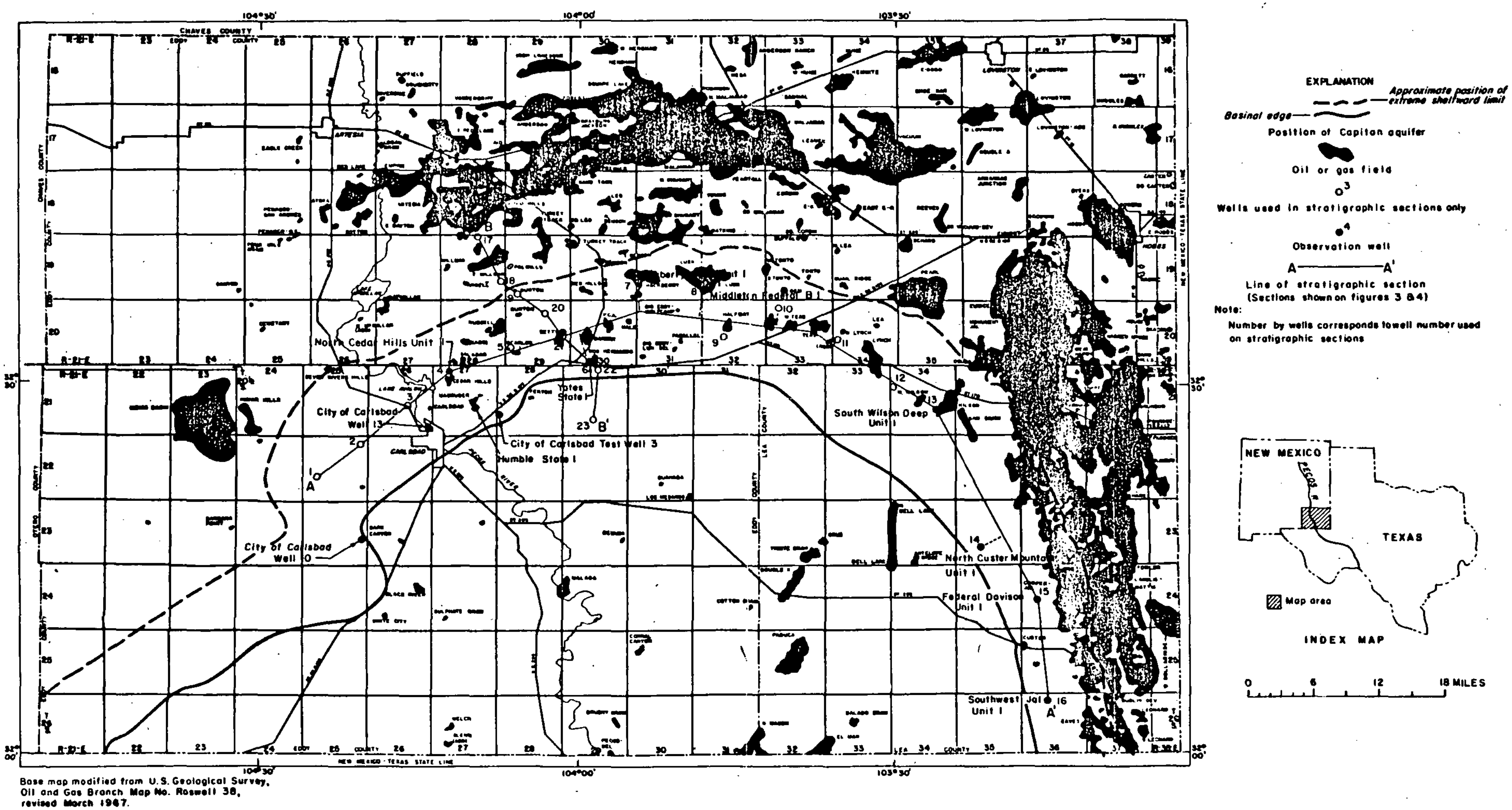
Cox, E.R., 1967, Geology and Hydrology between Lake McMillan and Carlsbad Springs Eddy Count, New Mexico: U.S. Geological Survey Water Supply Paper 1828, 47p.

Hendrickson, G.E., and Jones, R.S., 1952, Geology and ground-water resources of Eddy County, New Mexico: Socorro, New Mexico Bureau of Mines and Mineral Resources Ground-Water Report 3, 169 p.

Hiss, W.L. 1973, Capitan aquifer observation-well network Carlsbad to Jal New Mexico: New Mexico State Engineer Technical Report 38, 76p.

Hiss, W.L., 1975, Stratigraphy and ground-water hydrology of the Capitan reef and associated formations, southeastern New Mexico and western Texas: Boulder, University of Colorado, unpublished Ph.D. dissertation, 395 p., 12 pis.

Richey, Steven F., Wells, Jane G., and Stephens, Kathleen T., 1985, Geohydrology of the Delaware Basin and vicinity, Texas and New Mexico: U.S. Geological Survey Water-Resources Investigation Report 84-4077, 99p.



Base map modified from U.S. Geological Survey, Oil and Gas Branch Map No. Roswell 38, revised March 1967.

Figure 1.--Areal extent of the Capitan aquifer and the location of stratigraphic sections and Capitan aquifer observation wells in Eddy and Lea Counties, New Mexico From Hiss (1973).

State of New Mexico
ENERGY, MINERALS and NATURAL RESOURCES DEPARTMENT
Santa Fe, New Mexico 87505

STATE OF NEW MEXICO
OIL CONSERVATION DIVISION

MEMORANDUM OF MEETING OR CONVERSATION

☒ Telephone ☐ Personal	Time 1030	Date 1/13/94

Originating Party	Other Parties
Bill Olson - Envir. Bureau	Tom Morrison - SEO - 6140

Subject

Capitan Reef Study

Discussion

SEO awaiting final version of work plan
SEO provided comments on initial draft, had many problems with 1st draft
Expect final work plan in next 1-2 weeks

Conclusions or Agreements

SEO will send copy of their comments and final study proposal to OCD as they come in

Distribution

Signed Bill Olson

DRAFT

August 10, 1993

PROPOSED CAPITAN AQUIFER PROJECT

BASIC DATA STUDY

PROBLEM

The Capitan aquifer is the primary source of fresh water for the City of Carlsbad and several other communities in Eddy County, New Mexico. The Capitan is also an important source of irrigation water. The last comprehensive study of water level and water quality within the Capitan aquifer was performed by W.L. Hiss in the 1970s. Published materials by Hiss for the Capitan include State Engineer Office Technical Report 38 in 1973, a PhD dissertation in 1975, and NMBM Resource Maps 4, 5, and 6 in 1975 through 1976. Since that time, no new data compilations have been published.

Within the last year, the State Engineer Office has received several requests from private individuals, oil industry companies, and the Oil and Gas Conservation Division concerning the hydrology and water quality of the Capitan aquifer. In addition, the State Engineer Office has performed several evaluations recently of the impacts of proposed and existing Capitan wells on the Pecos River. During these investigations, it became evident that additional data collection and compilation were required to support management of the Capitan aquifer in New Mexico. With the Capitan aquifer serving as the primary source of domestic water for Carlsbad, Happy

Valley, and White's City; it is important for these communities and regulatory agencies to have the most current and complete data set available.

Richey and others (USGS Water Resources Investigations Report 84-4077) indicate on page 11 that moderately saline water is moving from the Lake Avalon area through the Tansill Formation to the Capitan aquifer. Limited data have been compiled for the Tansill Formation in the area from Avalon Lake southward towards the City of Carlsbad. Compilation of data for the Tansill in this area would be useful to help identify future data collection and investigative needs. [It is anticipated that few wells, if any, have been completed in the Tansill Formation. This could be verified by the USGS prior to this proposal being finalized. If no wells exist, the proposal should be revised by excluding references to the Tansill Formation.]

OBJECTIVES

The study goal is to provide historical and current water level and water quality data, including information on present water use for the Capitan aquifer in New Mexico and for the Tansill Formation in the Lake Avalon - Carlsbad area. Results of aquifer test data for the Capitan aquifer and Tansill Formation will be presented. The objectives of the study are listed below.

1. Identify all wells which have been completed in the Capitan

aquifer and Tansill Formation. Provide well record data, use, historical water level data, and current water level data for selected wells in to a table.

2. Produce a current water level map for the Capitan aquifer (point data can be plotted rather than contours to keep the project as a basic data study). Provide hydrographs for selected wells. Prepare a map showing water level declines since the Hiss studies. If sufficient data are available, provide a water level map for the Tansill Formation.

3. Update the water quality data for the observation wells listed in Table 2, Hiss, 1973 (SEO Technical Report 38). Include other historical water quality data for wells not listed in Table 2. Based on a review of this data, collect water quality data for selected wells to improve data coverage. [A relatively high degree of coverage should be obtained in the Carlsbad area eastward to the area where saline water begins to become present in the Capitan aquifer. At a minimum, chloride, sulfate and total dissolved solids should be collected. Assistance is needed from the USGS in determining whether all parameters listed in Table 2 (Hiss, 1973) should be collected and the associated costs for each parameter.] Provide all historical and current water quality data for the Capitan and Tansill in to a table.

4. Prepare a map showing the total dissolved solids concentration

at points in the Capitan aquifer (if possible, prepare map also for the Tansill Formation). If sufficient data are available, prepare graphs showing how water quality has changed in key wells.

5. Prepare a groundwater bibliography for the Capitan aquifer and Tansill Formation.

6. Quantify current well diversions from the Capitan aquifer and Tansill Formation.

7. Update Table 6 of USGS Water Resources Investigations Report 84-4077 by Richey and others summarizing aquifer tests for the Capitan aquifer. If available summarize aquifer test data for the Tansill Formation.

9/3/93
OCD/SEO meeting

PROPOSED SEO TESTIMONY

A. Provide education\work experience for qualification as expert witness.

B. Discuss what was done to gain familiarity with the application to inject brine.

**** ENTER APRIL 7, 1993 HYDROLOGY MEMO AS AN EXHIBIT

C. **** ENTER APRIL 7, 1993 LETTER BY ELUID AS AN EXHIBIT

Describe State Engineer conclusions presented in letter.

D. Discuss basis for State Engineer opinion.

a. Capitan aquifer contains fresh water ****ENTER EXHIBIT MAP SHOW LOCATION OF CAPITAN AND LOCATION OF FRESH WATER

b. Capitan aquifer is in hydraulic communication with two fresh water zones. ****ENTER EXHIBIT SHOWING THICKNESS OF THE CAPITAN

c. Cite reference to the fact that significant fresh water withdrawals for municipal, domestic and irrigation use are occurring from the Capitan aquifer near the City of Carlsbad. Indicate how much water is being withdrawn from the Capitan aquifer in NM.

d. Capitan aquifer is in hydraulic communication with the Pecos River. Studies performed by private consultants and the SEO revealed the possibility of significant depletions of the fresh-water zones in the Pecos Valley due to well diversions from the Capitan aquifer in NM and TX. Shortly after these evaluations were performed, the region was declared as the Capitan Underground Water Basin so the State Engineer could protect existing water rights. Proposed injection site is located in the Capitan Underground Water Basin.

e. Other evidence supports system is hydraulically well connected. Cite Hiss (1980), Capitan heads have changed significantly in response to groundwater and petroleum withdrawals during past 50 years. Cite Hathaway model of Capitan aquifer which indicates significant impact to the Pecos Valley due to wells producing from the Capitan aquifer.

Other topics? – weaknesses of their study
importance of other water users

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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:

CASE NO. 10693
Order No. R-9913

APPLICATION OF PRONGHORN SWD SYSTEM FOR SALT WATER DISPOSAL, LEA COUNTY, NEW MEXICO

ORDER OF THE DIVISION

BY THE DIVISION:

This cause came on for hearing at 8:15 a.m. on May 7, 1993, at Santa Fe, New Mexico, before Examiner Michael E. Stogner.

NOW, on this 16th day of June, 1993, the Division Director, having considered the testimony, the record, and the recommendations of the Examiner, and being fully advised in the premises,

FINDS THAT:

(1) Due public notice having been given as required by law, the Division has jurisdiction of this cause and the subject matter thereof.

(2) The applicant, Pronghorn SWD System, seeks authority to dispose of produced salt water into the Capitan Reef formation through the perforated interval from approximately 3220 feet to 5050 feet in the Brooks Federal "7" Well No. 6 located 660 feet from the South line and 1926 feet from the West line (Unit N) of Section 7, Township 20 South, Range 33 East, NMPM, Lea County, New Mexico. It presented its case with testimony and exhibits from a production engineer and a qualified expert hydrologist.

(3) The subject well, currently known as the Brooks Federal Well No. 6, is owned and operated by the J.F. McAdams Trust whereby the applicant has an option to purchase the leasehold interest and wellbore from the McAdams Trust with the understanding said well is to be converted into a disposal well. Said well is currently producing from the Salt Lake Yates Field at a depth of 3026 feet to 3052 feet. The well

was originally drilled in 1956 to a depth of 15,560 feet to test the Devonian formation. It was abandoned and then re-entered and completions were attempted at intervals of 4970 to 4975 feet and at 4620 to 4630 feet. Those intervals were squeezed with cement and the well was plugged back to its current completion.

(4) Applicant proposes to inject up to 10,000 barrels of water per day produced from the Delaware formation and gathered by an existing 20 mile, eight inch PVC pipeline. The proposed injection water contains in excess of 220,000 parts per million (ppm) dissolved solids. The only Capitan Reef sample presented contained approximately 105,000 ppm dissolved solids. Log analysis of the reef section of the proposed well suggests that the water contains between 50,000 and 80,000 ppm total dissolved solids.

(5) The New Mexico Oil Conservation Division ("Division") entered an appearance in this case and presented testimony by a petroleum engineer from its staff responsible for administration of the Federal Underground Injection Control (UIC) Program and a hydrologist from the Office of the State Engineer. The Division did not take a position at the beginning of the case, but at the conclusion of the case recommended that the application be denied and that the matter be considered in a rule making proceeding which could define rules for all applications for injection into the Capitan Reef.

(6) The Division is responsible for administering the UIC Program with respect to this application. That program was created under the Federal Safe Drinking Water Act to protect drinking water supplies.

(7) The State Engineer is responsible for managing the water resources of the State, including all fresh water which may or may not be usable for drinking water. The Division is required by statute to protect fresh water sources designated by the State Engineer.

(8) The Capitan Reef is a large Permian Age aquifer described by witnesses as a geologic tube which runs from the Guadalupe mountains west of Carlsbad to the Glass Mountains in Texas to the southeast. It is recharged primarily from the Guadalupe Mountains. The formation varies in thickness from 800 to more than 2,200 feet. The aquifer is hydrologically connected throughout its length. It is geologically complex, made up of canyons which act as restrictions to flow, fractures and solution channels; and the water qualities vary through different portions of the aquifer.

(9) The Capitan Reef has some connection to other Permian formations, including oil and gas producing formations. When the Division obtained primacy over the Underground Injection Control Program, several of those formations were exempted from the prohibition against injecting produced water into fresh water aquifers. The Capitan Reef was specifically not exempted.

(10) There is fresh water in the Capitan Reef to the west of the proposed location from which the City of Carlsbad, White's City and Happy Valley obtain water for municipal purposes. Substantial quantities of Capitan Reef water are also withdrawn for irrigation purposes in this area. The Capitan Reef is connected to the Pecos River in the area of the City of Carlsbad. There is also fresh water in the Capitan Reef starting 18 to 20 miles southeast of the proposed injection location and continuing into the State of Texas.

(11) The portions of the Capitan Reef aquifer which contain less than 10,000 ppm total dissolved solids are designated fresh water by the State Engineer and are required to be protected by statute. The Pecos River, as a surface stream, is also designated for protection.

(12) There have been and continue to be significant withdrawals of water from the Capitan Reef from the fresh water portions west and southeast of the proposed injection location.

(13) *Applicant's production engineer, who was not qualified as either a geologist or hydrologist, testified that he did not think that there was a practical hydrologic connection between the proposed injection well location and the fresh resources in the Carlsbad and Hobbs area. That testimony was not supported by any evidence or testing, and the witness did not quantify what he meant by "practical connection".*

Applicant's hydrologist testimony indicated that the Capitan Reef is in hydrologic connection and that there are saline zones and fresh water zones in the formation. He testified that there are canyons in the reef which act as barriers to flow between portions of the reef. His opinions were based primarily on the literature, and from the information he made various assumptions regarding the reef for the purpose of constructing his model.

The evidence presented by the hydrologist from the State Engineer's Office was not inconsistent with that provided by Applicant's hydrologist in that it noted the development of the canyons which constrict flow, the varying permeability and the presence of high TDS water in portions of the reef. Based upon review of much of the same literature, the witness *was of the opinion that the literature indicated that the canyons in the reef are restrictions but not barriers to flow; there was not any loss of hydrologic connection between the Pecos River and the eastern most portions of the Capitan Reef aquifer.*

FINDING: The evidence does not prove conclusively that the hydrological connection throughout the Capitan Reef is sufficiently restricted to prevent injected brine from impacting fresh water within the reef.

(14) *The applicant supported its application primarily with the testimony of its hydrologist who presented a two-dimensional SUTRA numerical simulator to attempt to model the impact of the injection of produced brine at this location.*

FINDING: The New Mexico Oil Conservation Commission has determined that while modeling can be useful as a tool, careful scrutiny will be made of the parameters used in the model to determine if they reflect actual conditions, and the model should be calibrated to determine the validity of the parameters.

(15) *Applicant's hydrologist made several assumptions in developing the model:*

(a) The model is built on a flat domain with a constant vertical thickness of 1,000 feet and a constant width of 10 miles.

(b) That there are impermeable boundaries above and below and to the north and south of the aquifer. The Pecos River fully penetrates the Capitan Reef, that it has a TDS concentration of 0.0 ppm and that there is a constant head boundary.

(c) The Capitan Reef is homogeneous and isotropic with a constant hydraulic conductivity of 5 ft. per day and a constant porosity of 18%. It is assigned a longitudinal dispersivity of 100 meters, a constant transverse dispersivity of 10 meters and a coefficient of molecular diffusion of $5 * 10^{-10}$ m^2.

(d) An initial distribution of brine exists in the model domain, constant throughout the thickness, and no additional sources of brine throughout time are present except the injection well.

(e) A constant source at the injection point with a rate of 12,500 bbls and a concentration of 250,000 ppm TDS for 50 years is assumed.

The assumptions used are taken from the literature or derived indirectly from information in the literature, and obtained from the U.S, Geological Survey and the State Engineer's Office. The hydrologist did no independent field work. The hydrologist testified that there is a lot of speculation about flow regimes.

The hydrologist from the State confirmed that there are very few aquifer tests which could be used to confirm aquifer parameters, which makes it difficult to obtain a realistic model.

<u>FINDING:</u> The model is based upon a simplification for the purpose of modeling of information which is contained in literature. The assumptions have not been verified against measured parameters. Therefore the parameter assumptions assumed in the model do not satisfy the Commission's requirement that modeling input be confirmed to be consistent with real data.

(16) *Applicant's hydrologist testified and his model report stated that the assumptions were very conservative, meaning that the model would predict that solutes injected would propagate the furthest distance away from the injection point.*

The State Engineer's hydrologist testified that the assumptions are not necessarily conservative. They may be conservative with respect to one fresh water zone but not with respect to the other. Further, because the witness testified that because of the amount of speculation about the flow regime, there is uncertainty in the assumptions.

<u>FINDING:</u> The conclusions reached in the model regarding the impact of the injection operation on fresh water cannot be assumed to be accurate or conservative. The model, without corroborating evidence, does not conclusively demonstrate the injection operation proposed will not have an adverse impact on fresh water.

(17) There has been no calibration or other confirmation that the model has a proper aquifer parameter distribution, and therefore the model does not satisfy the requirements for the use of modeling to predict how the injection will impact the fresh water in the Capitan Reef.

(18) The hydraulic gradient between the Pecos River and the proposed injection site is relatively flat. There is substantial disagreement between the Applicant's hydrologist and the State Engineer's hydrologist about whether or not the proposed

injection could reverse the gradient and cause degradation of the fresh water in and near the Pecos River and the City of Carlsbad. Because of the deficiencies of the model discussed in previous findings, the risk of gradient reversal must be considered.

(19) The Applicant's model assumptions regarding constant boundary conditions and zero permeability are not supported by any of the information, nor is the assumption of constant thickness or permeability.

(20) The model is based upon an assumption that the only influence upon flows at this site is the proposed injection well. Because there are significant withdrawals from the Capitan Reef at points east and west of the proposed injection, and because there is a hydrological connection throughout the reef, this assumption cannot be relied on to determine the actual impact of the injection operations.

(21) One of the advantages of modeling is the ability to change certain parameters and see how those changes affect the results, particularly when parameters used are based upon derived information or assumptions. The Applicant's hydrologist did not perform any such runs with different parameters.

(22) *The Applicant argued that this application must be considered as a stand alone application without consideration of any other possible applications for injection into the Capitan Reef. Applicant further suggested that if there were any subsequent applications for injection that those applicants should be required to present evidence of the impact of their operations with consideration of the cumulative impact of any prior injection operations, and the Division could at any point determine a limit of allowable injection, sort of a reverse appropriation. However, Applicant did not provide any guidance to the Division about how to make such a determination or set a limit. Applicant's engineer did testify that it might wish to conduct additional injection operations if the capacity of this well were exceeded by the demand for injection.*

The Division engineer testified that there has been one previous application for injection into the aquifer which was denied and that there have been other inquiries from operators about the possibility of obtaining approval to inject into the Capitan Reef. He recommended that if injection into the Capitan Reef is going to be allowed, a rule-making type of hearing should be conducted to determine what conditions, if any, should be imposed upon such operations.

<u>FINDING:</u> The Division has not allowed injection into the Capitan Reef up to this point in time because of the concern for protection of fresh water in the reef. Approval of any application will be precedent setting and additional applications are likely. Before injection is allowed into the Capitan Reef

the Division or the Commission should require that extensive studies be conducted and that such approval only be considered after a rule-making type of hearing in which all of the factors and impacts of such operations have been considered, and that such studies be conducted using actual reservoir information.

(23) Fresh water resources in this state are scarce and valuable, and this Division cannot risk the possibility of contamination of a major source of fresh water based upon conclusions derived from a model which has been constructed upon assumptions which have not been tested or validated. There are other alternatives available for water disposal, and therefore this application should be denied.

<u>IT IS THEREFORE ORDERED THAT</u>:

(1) The application of Pronghorn SWD System to dispose of produced salt water into the Capitan Reef formation through the perforated interval from approximately 3220 feet to 5050 feet in the J.F. McAdams Brooks Federal Well No. 6, located 660 feet from the South line and 1926 feet from the West line (Unit N) of Section 7, Township 20 South, Range 33 East, NMPM, Lea County, New Mexico is hereby **<u>DENIED</u>**.

(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

WILLIAM J. LEMAY
Director

SEAL

STATE OF NEW MEXICO
ENERGY, MINERALS AND NATURAL RESOURCES DEPARTMENT
OIL CONSERVATION DIVISION
2040 S. PACHECO
SANTA FE, NEW MEXICO 87505
(505) 827-7131

May 2, 1995

Mr. Thomas C. Turney
State Engineer
State Engineer Office
Bataan Memorial Bldg., Room 101
Santa Fe, New Mexico 87504-5102

RE: GROUND WATER STUDY OF CAPITAN REEF

Dear Mr. Turney:

The New Mexico Oil Conservation Division (OCD) is in receipt of the State Engineer Office's (SEO) March 21, 1995 correspondence which outlines the contributions that the OCD could provide to a cooperative study of the aquifer within the Capitan Reef.

The OCD agrees to allow geologists Bill Olson and Mark Ashley, as their schedules permit, to participate in developing a report concerning stratigraphic tops, lithologic characteristics and geochemistry of the Capitan Reef using readily available oilfield information.

The OCD looks forward to working with you in developing new information about the hydrogeology of the Capitan Reef. If you have any questions, please contact Bill Olson at 827-7154 or Mark Ashley at 827-7155.

Sincerely,

William J. LeMay
Director

xc: Roger Anderson, OCD Environmental Bureau Chief
Bill Olson, OCD Environmental Bureau
Mark Ashley, OCD Environmental Bureau

STATE OF NEW MEXICO
STATE ENGINEER OFFICE
SANTA FE

State Engineer

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RECEIVED
MAR 23 1995
Oil Conservation Division

March 21, 1995

Mr. William J. LeMay
Division Director, Oil Conservation Division
Energy, Minerals, and Natural Resources Department
P.O. Box 6429
Santa Fe, New Mexico 87505

RE: OCD participation in a Cooperative Program with the State Engineer Office and the USGS in studies of the groundwater aquifer within the Capitan Reef, Eddy and Lea Counties, New Mexico

Dear Mr. LeMay:

After discussions between staff members of the Oil and Gas Conservation Division (OCD) and the State Engineer Office (SEO), it appears that each agency can make a meaningful contribution to a cooperative study of the aquifer within the Capitan Reef. The SEO has recently initiated such a study with the Water Resources Division of the United States Geological Survey (USGS). The main purpose of this study is obtain new hydrogeologic data from the Capitan aquifer and update the publications of W.L. Hiss who studied the area in the late 1960's and early 1970's. Copies of the project outline have been made available to Bill Olson and Mark Ashley of the OCD Environmental Section staff.

The contribution that the OCD would make to this effort would consist of a basic data compilation report of any new information concerning the stratigraphic tops, lithologic characteristics and geochemistry of the Capitan Reef. That report would be an attachment to the report prepared by the USGS. An example of such a report has been provided to the OCD staff. The stratigraphic and lithologic data would come from recent electric logs and/or cuttings logs on file with the OCD or available through industry contacts. The geochemical data would come from OCD files, data collection carried out by the OCD staff as deemed necessary for their normal activities or available through industry contacts. It is envisioned that the majority of the OCD report would be data tables providing a compilation of new data. The time frame for the study would be between now and the end of 1996. At that point, the report would be submitted to the USGS for review and publication.

Briefly, the contribution of the other two agencies would be as follows: the SEO is providing funding for the project, personnel to carry out coding of aquifer units from well logs on file with the SEO and personnel to update the groundwater site inventory (GWSI) database, the USGS is providing the principal investigator, carrying out a data gathering program to obtain new water level and water chemistry data from the network of monitor wells developed in the Capitan Reef and updating the maps of W.L. Hiss in a Geographic Information System (GIS) format.

With your approval, the SEO is requesting your agreement that members of your staff may participate in this project on a part time basis as their schedule allows. If there are questions about this project, please contact Tom Morrison or Andy Core of the Hydrology Bureau at 827-6140. Thank you.

Sincerely,

Donald T. Lopez PE
Acting State Engineer

cc: Tom Morrison
Andy Core

3/7/95 SEO/OCD meeting on Capitan Reef

attendees - Bill Olson, Roger Anderson, Mark Ashley - OCD
- Andy Core - SEO
Rock Huff - USGS Las Cruces staff member on study

Nov 1996 need draft of companion paper

AQUIFER DESIGNATION FOR UIC:

PROTOTYPE STUDY IN SOUTHEASTERN NEW MEXICO

Submitted to:

Oil Conservation Division
Department of Energy and Minerals
State of New Mexico

Prepared by:

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Lee Wilson, Lee Wilson and Associates, Inc.
Mike Stahl, Lee Wilson and Associates, Inc.
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December, 17, 1979

Santa Fe, NM, 87501

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AQUIFER DESIGNATION FOR UIC:

PROTOTYPE STUDY IN SOUTHEASTERN NEW MEXICO

INTRODUCTION

The New Mexico Oil Conservation Division (OCD), in conjunction with Lee Wilson and Associates, has performed a prototype study to implement the aquifer designation regulations which are proposed as part of the Federal Underground Injection Control program. Designation criteria require protection of aquifers which are currently used for drinking water or which have a total dissolved solids (TDS) content of less than 10,000 mg/l. However, aquifers may be exempted from designation if they are or will be used for mineral, oil or geothermal energy production, or if they cannot provide drinking water for reason of economics, technology or gross contamination.

In New Mexico, state regulations already require that ground water with a TDS less than 10,000 mg/l be protected against virtually all types of pollutant discharge. UIC goes beyond the State programs by requiring explicit identification and mapping of the areas to be protected. However, aquifers protected under State regulations could be exempted from protection under UIC in areas of mineral, oil or geothermal energy production. Because the concept of designation or exemption is new, and standardized procedures are not available, the process of aquifer evaluation is potentially difficult, complex, and time-consuming; it may be expensive in terms of the commitment of resources for data gathering and interpretation. A prototype study is needed to develop procedures and evaluate the complexity and expense of the aquifer-designation process. The prototype reported here involved all steps in the process except for those related to a formal public hearing.

The project described here involved the mapping of aquifers in a 144-square-mile area near Artesia, in Eddy County (Figure 1). Characteristics of the area include the following:

1. Both artesian water and oil are produced from the same geologic unit, the San Andres Formation of Permian age. This situation is characteristic of much of Southeastern New Mexico and implies that boundary-setting in aquifer designation must be precise.

2. Injection into the San Andres is practiced both for secondary recovery and brine disposal; thus the

need exists for precision in aquifer designation in order to properly administer the federal UIC program.

3. Considerable information on the area has already been compiled by agencies or private companies, (for example, water-level maps). Additional data can be readily obtained, (for example, porosity values can be read from modern geophysical logs).

METHODS AND DATA

Geologic, hydrologic, and energy-resource data for the study area were gathered from published reports and the files of federal, state and local agencies concerned with water or energy resources. Information on salinity and porosity was developed in part from geophysical logs produced from new, deep gas wells which penetrated the Grayburg-San Andres interval. The Dual Laterlog and Compensated Neutron Log were utilized to determine resistivity of formation fluids and formation porosity. With proper borehole corrections, these logs provide an accurate assessment of fluid salinity. However, data are generally available only for deeper formations, since wells are required to be cased through formations known to contain potable water. The data were compiled into four tables (Tables

1 to 4), which include geohydrologic information, records of water wells, and records of oil, gas and injection wells (including geophysical data wells), and lithologic description. The tables were then interpreted to produce maps basic to the aquifer designation process (see Figures 2 through 9); the maps present structural contours, potentiometric surfaces, the location of shallow oil and gas pools, and the location of information wells.

The maps and tables were used to develop Figure 10, a cross-section of the study area. This cross-section portrays most of the information needed to make aquifer designations. The section shows the location of fresh water, oil and gas pools, geologic boundaries, potentiometric surfaces of shallow and artesian aquifers, and representative wells. Figure 10 is used as the base for the various designation options considered in the Results section.

The geology of the study area (see Figures 2, 3 and 4) reflects its position as a backwater depositional zone in the Permian Reef complex of New Mexico and Texas. Dolomites predominate, with limestone increasing southeastward toward the reef, and redbeds and evaporites increasing north and west onto the shelf. In general, the Permian units dip toward the southeast and thicken in the same direction.

The principal aquifer and hydrocarbon-producing zones both occur within the San Andres Formation, which lies between the Grayburg Formation of the Artesia Group, and the Glorieta Sandstone. This formation is therefore the critical interval for UIC protection. Two separate porosity horizons are situated within the San Andres. The upper horizon is a high-porosity (20 per cent) interval which contains an artesian aquifer and some isolated hydrocarbon development. The artesian aquifer underlies most of the area which includes much of the Grayburg as well as the upper, porous zone of the San Andres. The water contains less than 3000 mg/l dissolved solids, except in the southeastern part of the map area where oil is produced from the lower Grayburg.

The lower horizon corresponds to the Slaughter dolomite zone, where locally developed porosity contains oil and gas, and total dissolved solids exceed 10,000 mg/l. A zone of low porosity apparently acts as a confining horizon, or permeability barrier, which apparently separates the aquifer from the Slaughter zone and the oil pools.

Data on geohydrology and water quality in the area (see Tables 2 and 3, Figures 5, 6, 7) indicate that although fresh water is found to the base of the San Andres in some locations, there is no water production below the artesian aquifer. (However, fresh water is found beneath the San Andres in the Roswell Basin outside the study area; see Gross et al., 1978).

In most locations, fresh water is not found in wells which penetrate below the artesian aquifer. However, resistivity data indicate that fresh water may extend to the base of the San Andres in some locations (Arrow A, Figure 10). In all such cases, geophysical logs indicate that the fresh water occurs in rocks with low porosity (averaging less than 7 percent), suggesting that the water is interstitial. No fresh-water yield is obtained from any well which penetrates below the artesian aquifer. Water in the Glorieta exceeds 10,000 mg/l in all geophysical data wells.

In units east of the Pecos River, water contains more dissolved solids than in corresponding units west of the river. Most fresh-water production comes from the Yates Formation, with dissolved solids values which can be as low as 1,000 mg/l, but are generally above 4,000 mg/l.

A shallow aquifer extends from the western portion of the prototype area to the Pecos River (Figures 4 and 5). The aquifer includes the valley alluvial fill and upper portion of the Seven Rivers Formation. Little information is available for the lower Seven Rivers and Queen Formation, below the shallow aquifer, since they serve only as a minor source of water within the basin.

Shallow hydrocarbon development occurs primarily in the eastward-dipping Slaughter zone within the San Andres Formation (see Table 4; Figures 8 and 10). Six million barrels of oil have been pumped from over 400 wells in 10 pools which occur in the prototype area. Production has depleted to non-profitable levels in most wells and underground injection is applied for enhanced recovery in the Atoka San Andres, Atoka Grayburg, and Red Lake pools (Figure 8). Salt-water disposal is active in two wells.

Subtle changes of strike and dip and effective porosity development within the Permian units control regional pinchouts of hydrocarbon production, and separates many pools produced within similar horizons. Absence of vertical permeability development within the San Andres protects the artesian aquifer against oil migration from lower depths. Hence, contamination of the artesian aquifer by the underlying oil pool is unlikely. Local porosity along the Artesia Vacuum Arch within the Grayburg creates some oil production from facies above the Slaughter zone. Here also, absence of vertical permeability development protects the artesian aquifer. This trend continues east across the Pecos River in zones separated by permeability barriers. Most of these shallow pools have been depleted to production rates of less than one barrel per day per well.

Several points developed in the Methods section affect the four aquifer designation alternatives considered below. A considerable amount of fresh water which must be protected against contamination by underground injection is available in the study area. The shallow aquifers do not affect the designation process since they are underlain by the deeper artesian aquifer. Thus designation of the deeper aquifer will also protect the shallow aquifers. While oil production takes place as high as the top of the Grayburg, and fresh water is found to the base of the San Andres, no fresh-water production occurs below the artesian aquifer. There is a geologic basis in a large part of the study area for distinguishing between the upper porous horizon containing water and the lower porous horizon containing oil and gas.

RESULTS

Four alternatives were considered in the prototype study; three reflect a principle of designation (or exemption) contained in the UIC regulations, and the fourth is a combination containing the best overall approach.

Alternative 1. The entire stratigraphic interval to the base of the San Andres could be designated as an aquifer requiring UIC protection, with exemption for areas in which hydrocarbon production occur.

Alternative 2. The interval could be designated as an aquifer only where total dissolved solids are less than 10,000 mg/l.

Alternative 3. The interval could be designated as an aquifer only where production of fresh water is likely to be economically or technically feasible.

Alternative 4. A combination of options 2 and 3 could be used. This alternative is the one recommended for the prototype area.

Each alternative must be judged in terms of: a) its effectiveness in protecting drinking water; and b) its administrative efficiency. Figures 11-15 display the various aquifer designations which would result from each alternative.

Alternative 1 Full Designation with Exemptions for Hydrocarbon Production

If the lower limit of the aquifer were designated as the base of the San Andres (see Figure 11), all known fresh water in the study area would be protected since TDS exceeds 10,000 mg/l throughout deeper horizons. Upper and lateral boundaries of active oil pools would then be used to exempt areas of hydrocarbon production. The heavy dashed line in Figure 11 illustrates how such a boundary would appear in cross-section.

This approach promises good protection of drinking water. The available evidence indicates that hydrocarbon production (and hence potential injection zones) occurs within localized porosity zones (potential injection zones) which are unconnected to the artesian aquifer; further, fresh water has not been found beneath any oil pool. Therefore, wastes injected into areas exempted from designation would not be expected to commingle with fresh water in the protected aquifers. However, the approach would face severe administrative problems. Boundaries must be redrawn each time an oil pool is extended or a new pool developed, requiring a lengthy and expensive public review and hearing process on each boundary change. Further, determination of the exact location of pools (especially the upper limit) is quite time-consuming.

Alternative 2: Use of TDS Boundary

Use of a line to define the lower limit of water containing less than 10,000 mg/l solids would, by UIC definition, provide protection to all potential drinking water (see Figure 12). The major drawback to using this method throughout the study area is that there are no water-quality analyses available from the lower part of the San Andres, nor from many higher units east of the Pecos River. Instead, the determination that fresh water occurs to the base of the San Andres Formation involves the use of resistivity data from deep geophysical data wells. There are relatively few geophysical data wells; hence the boundary can only be approximate and the depth to which UIC protection should extend is uncertain. East of the river the line is drawn across the top of oil pools because elsewhere in the area TDS values in and beneath beneath pools are always greater than 10,000 mg/l. Administration of a designation based on approximate boundaries and uncertain depths would be difficult. In addition, evaluations of resistivity data from geophysical data wells is time-consuming and hence expensive. The approach may be the only one feasible in much of New Mexico, but in the prototype area a better procedure is available (see below).

Alternative 3: Boundary Based on Porosity.

The fresh water which lies between the base of the artesian aquifer and the base of the San Andres appears to be interstitial, trapped in pore spaces with little or no permeability. It is doubtful that usable quantities of water could be obtained by wells which tap this horizon. Therefore, the base of the artesian aquifer itself could be used as a UIC boundary in the study area since it effectively limits the depth at which fresh water resources are available (see Figure 13). The boundary is readily drawn based on the extensive well records available in the area. In practice it is preferable to place the base of the protected zone 100 feet below the aquifer to provide a margin of safety. This would be consistent with existing state regulations, which require casing of all oil wells from the land surface to a depth 100 feet below the artesian aquifer.

The historic use of this criteria in State regulations indicates that administrative difficulties would be minimal. Moreover, data are adequate to present the boundary in map form (Figure 14). However, the artesian aquifer does not extend east of the Pecos River; a different approach is needed to provide aquifer protection in that study area.

Alternative 4: Combination of Designation Techniques

To provide protection for fresh-water in the artesian basin as well as protection for those scattered sources outside the basin boundaries, a combination of designation techniques is necessary. A boundary placed 100 feet below the base of the artesian aquifer is feasible in the map area west of the Pecos River (Alternative 3). However, east of the river where the artesian aquifer does not occur, designation of boundaries would require careful scrutiny of well records and available geological data to determine zones productive of fresh water (using the procedures accounted with Alternative 2). The line given in Figure 14 is extrapolated from elsewhere in the area, and would need to be fixed in more detail if a UIC application were to occur east of the Pecos. This combination of options provides the best strategy for designating all potential sources of fresh water in this prototype area.

Figure 15 is a cross-section which identifies the boundary of the designated aquifer drawn according to Alternative 4. While this approach would require different types of administration in different parts of the zoning area, it also provides the most comprehensive protection. The administrative burden would not be significantly greater than that required for each technique above.

SUMMARY AND CONCLUSIONS

The prototype study has determined that boundaries can be set and aquifers identified under the UIC program. In the study area, existing state regulations can be used in coordination with UIC goals to carry out aquifer designations for the area west of the Pecos River. Designation of aquifers east of the Pecos requires use of geophysical data and available well records to determine apropriate boundaries based on total dissolved solids concentrations. This experiment provides many insights on the procedures to be used for UIC aquifer evaluations.

Geophysical data from oil and gas wells will be an important source of information, since they reveal conditions in deeper aquifers, which, while not currently in use as drinking water, should be protected under UIC. The TDS boundary method (Alternative 2) will be very useful in those areas which lack the geologically defined aquifer limit which occurs in the study area. The TDS method is likely to be used in much of New Mexico; however, the boundaries set will be less valuable than those established on a geologic basis, unless salinity is geologically controlled. A major administrative concern is that the procedures used in designating aquifers not change every time new data become available. This concern makes the exemptions of aquifers for hydrocarbon production an undesirable alternative.

The prototype study cost approximately $100 per square mile. This provides a basis for budget estimates for other mapping elsewhere in New Mexico. Less cost and time will be involved in mapping the remainder of the Roswell basin as a result of the experience and techniques developed in the prototype area. Costs elsewhere in the state will vary depending upon data availability and the complexity of geologic and hydrologic conditions. Since most of the state will have little or no data available from deep wells, costs will be lower (and results less reliable) than in the prototype area.

The estimated cost of aquifer designation in New Mexico, based on $100 per square mile, would be $12,166,000. Even if costs eventually approach $10/square mile, a considerable expense will be incurred by the UIC program. Where feasible, existing administrative procedures, such as New Mexico's state regulations, would reduce UIC costs considerably.

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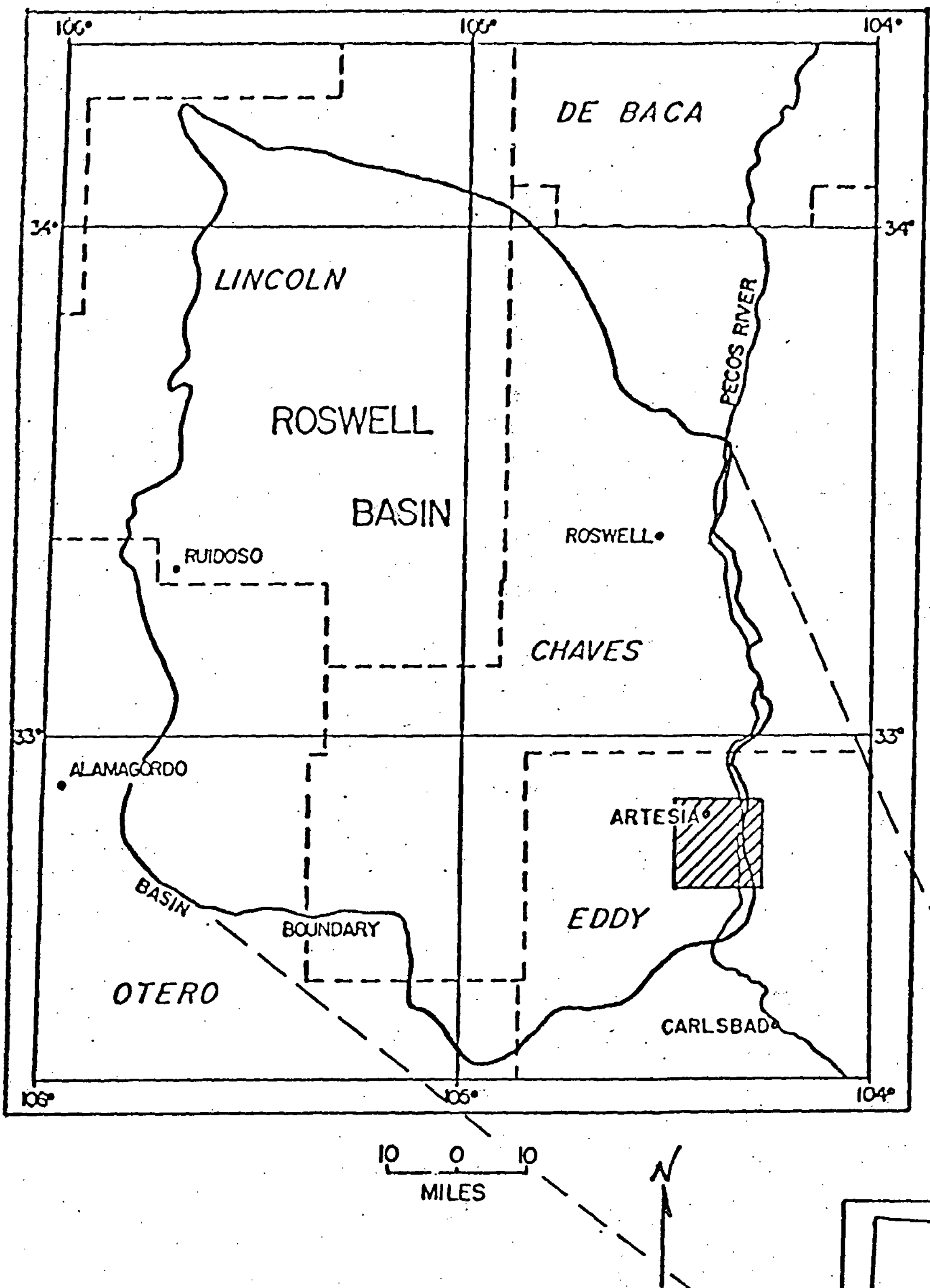


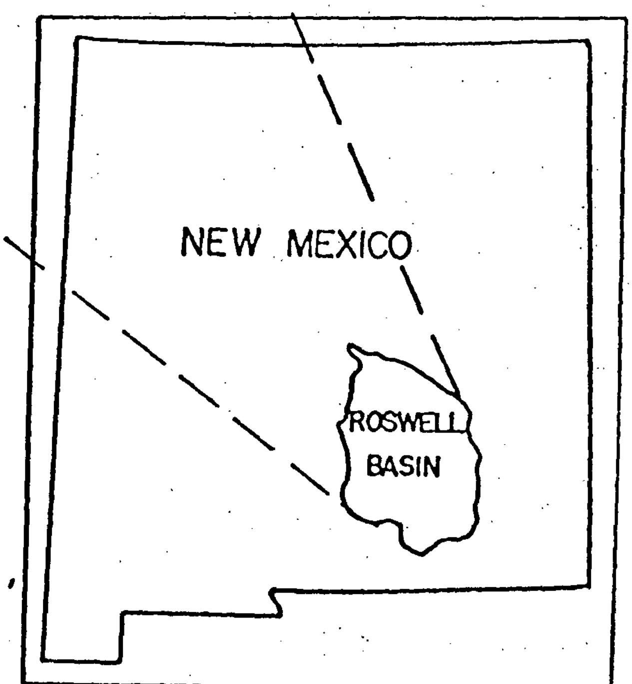


Figure 1: Location of Prototype Area.

Source: after Gross, et al., 1978.

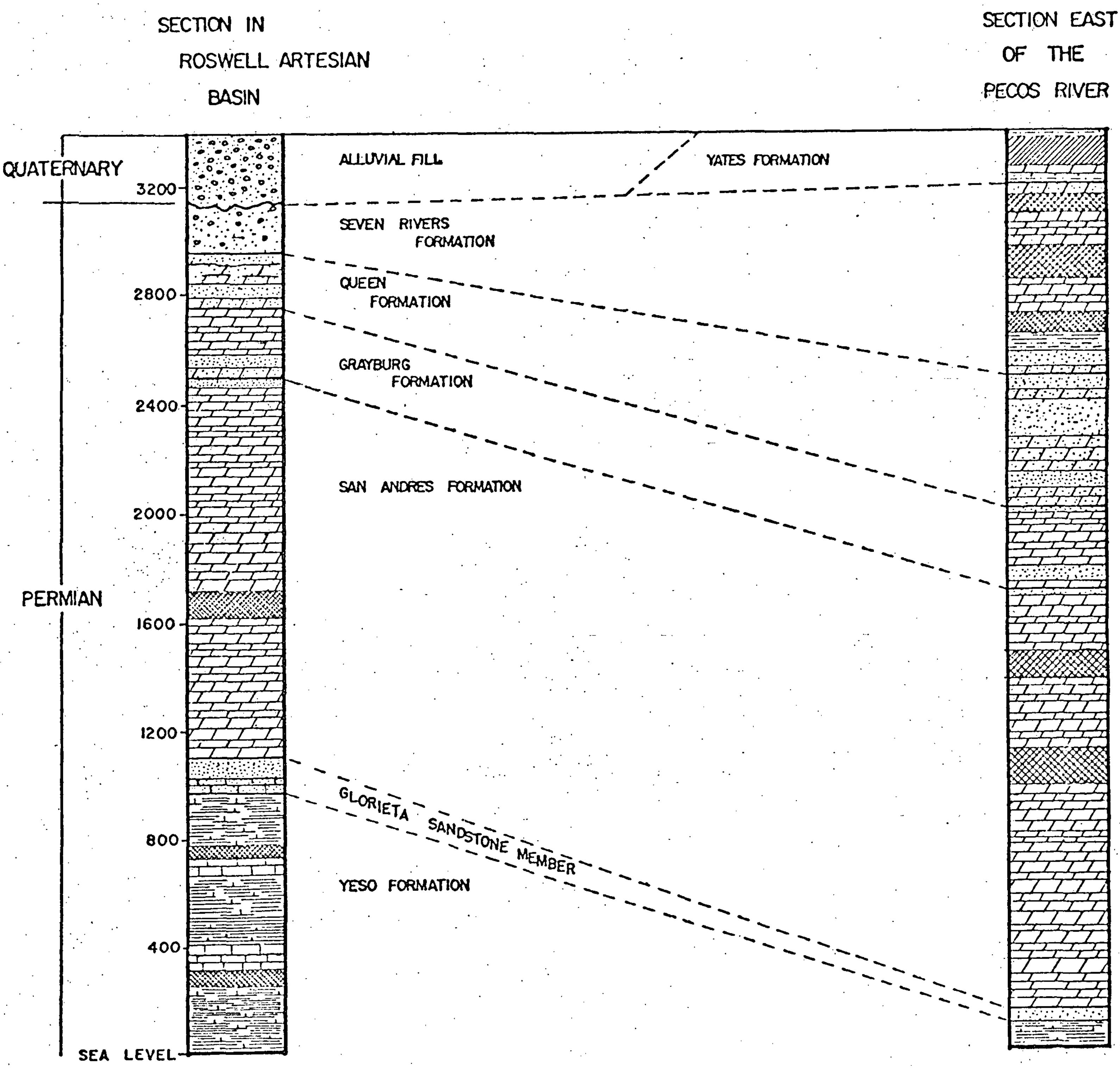


Figure 2: GENERALIZED STRATIGRAPHIC COLUMN ARTESIA AREA

Source: M. Holland, 1979.

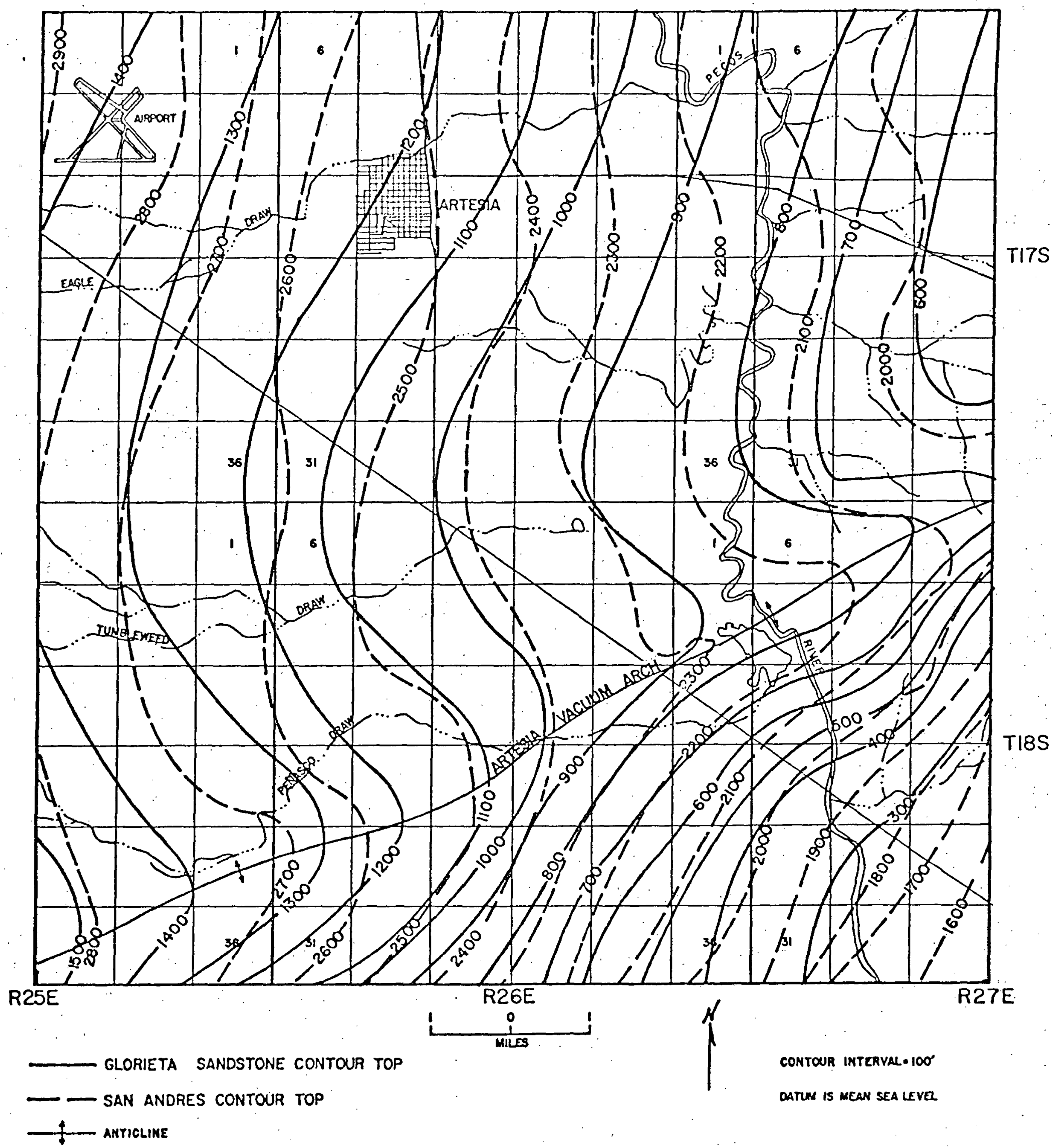


Figure 3: Structure Contour on San Andres Formation and Underlying Glorieta Sandstone Member.

Source: Modified after Maddox, 1969 by M. Stahl and M. Holland, 1979.

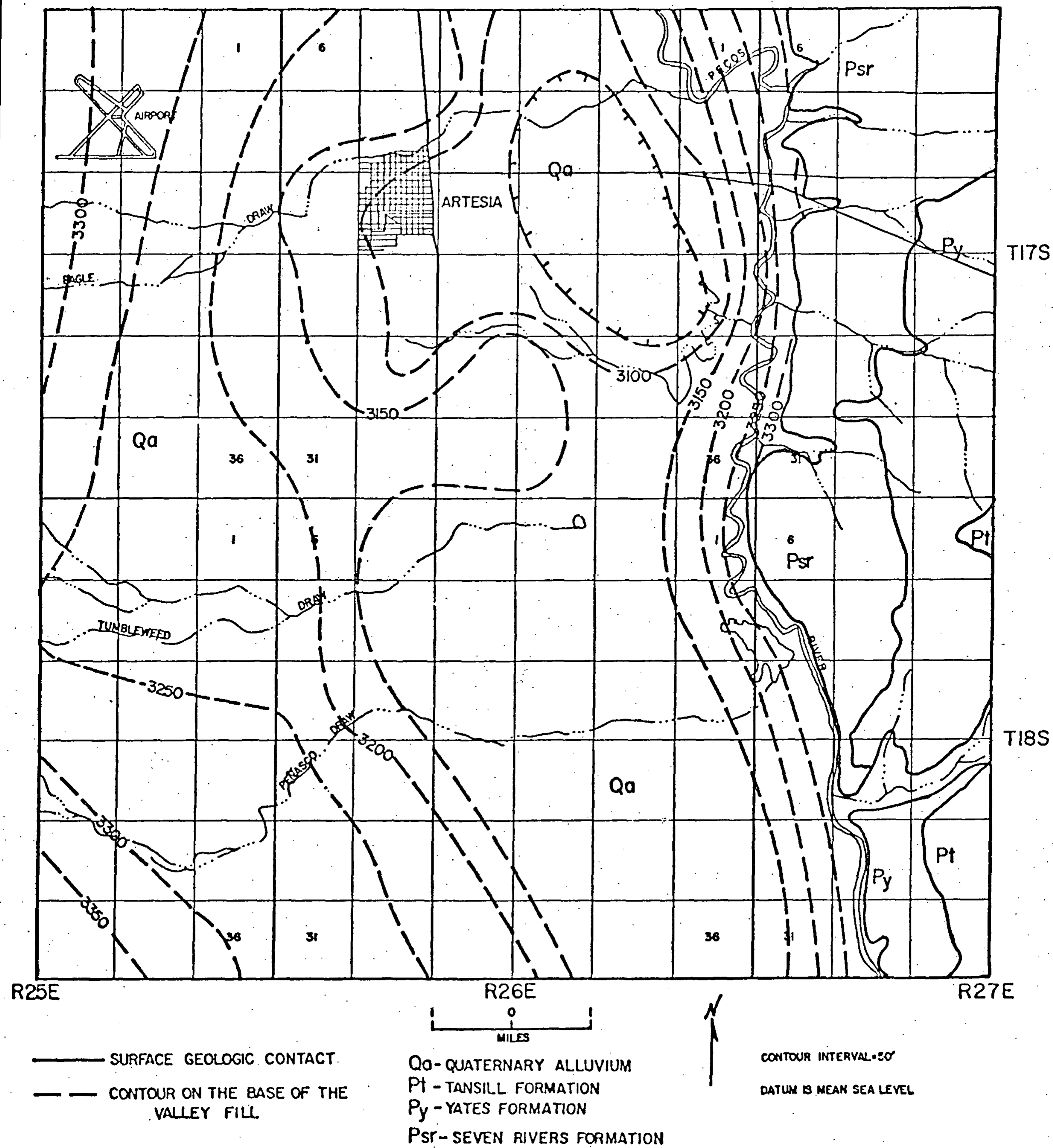


Figure 4: Surface Geology.
Source: Modified after Kelley, 1971 and Lyford, 1973 by M. Stahl.

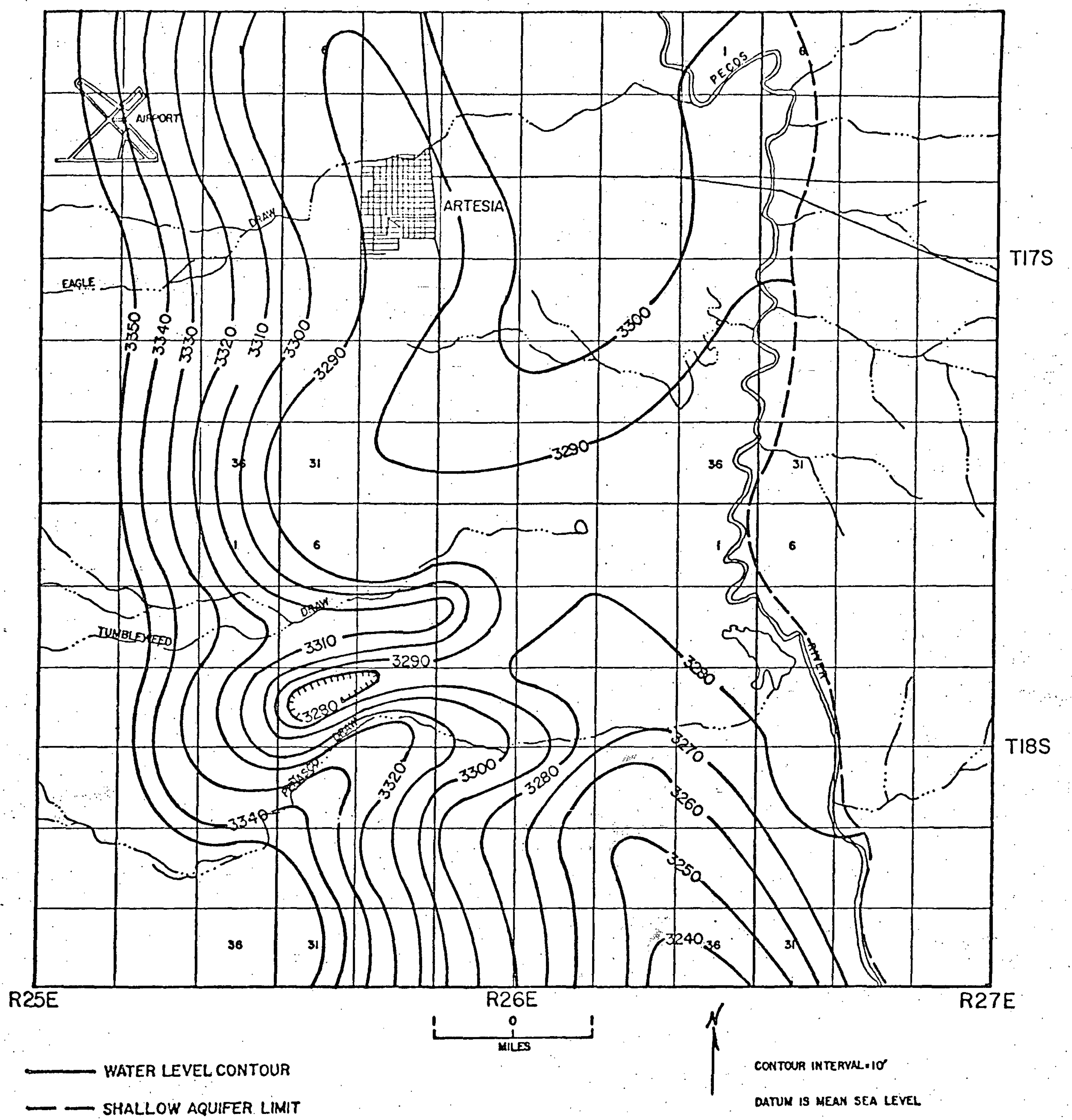


Figure 5: Potentiometric Surface of Shallow Aquifer.

Source: after E. Welder, 1977.

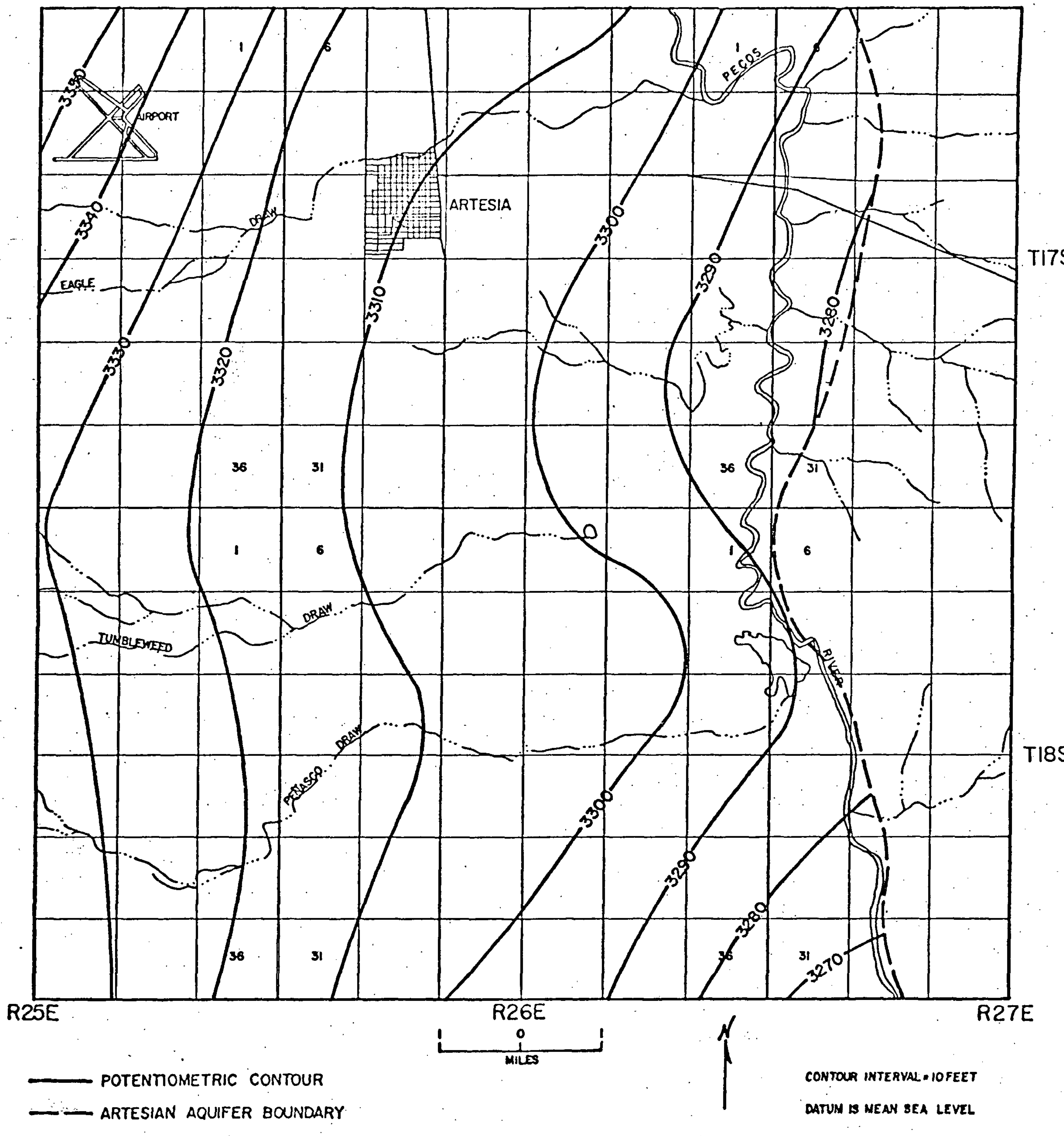


Figure 6: Potentiometric Surface of Artesian Aquifer.

Source: after E. Welder, 1977.

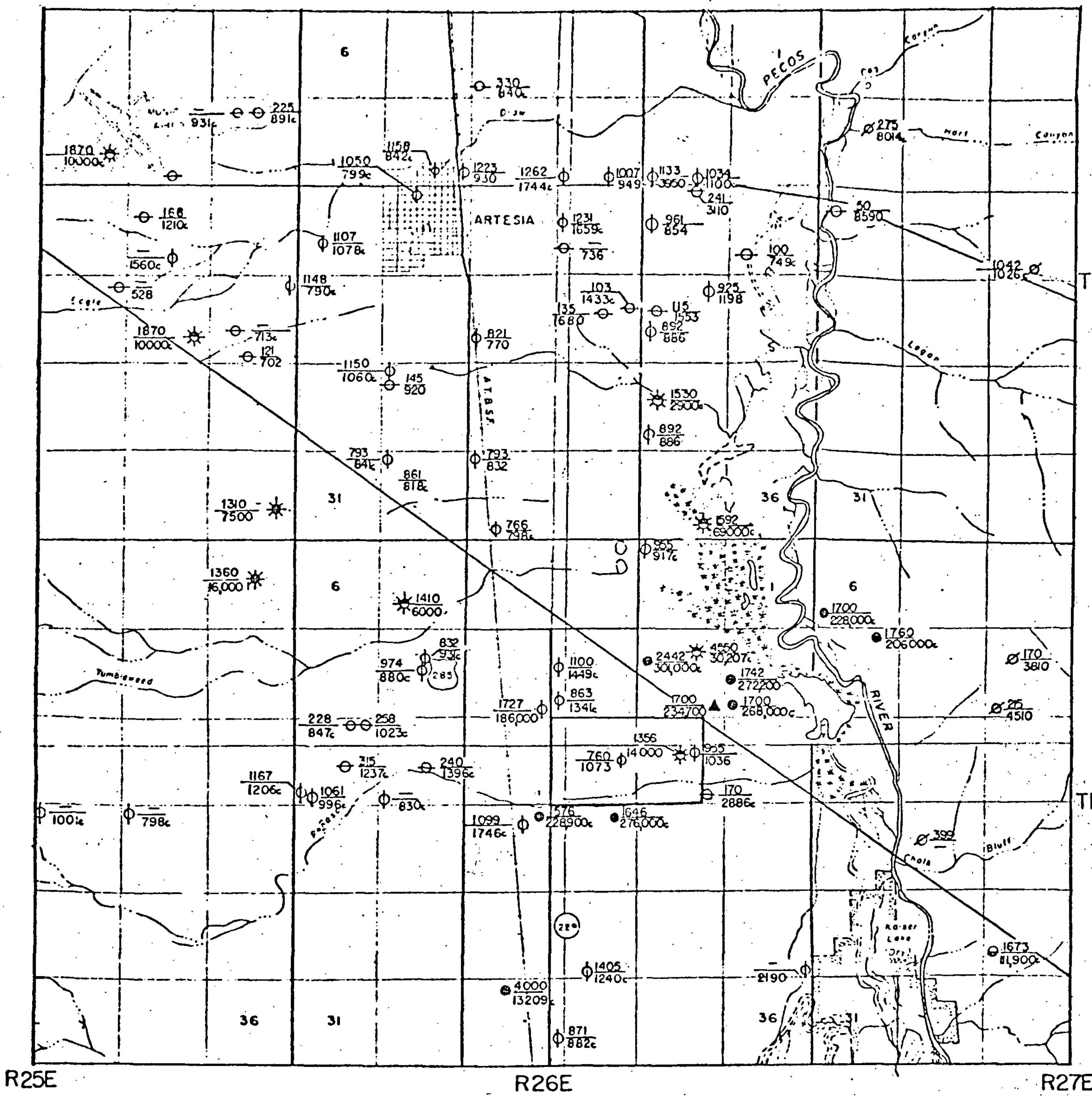


Figure 7: WATER QUALITY WELL PLOT

1 0 1
MILES

DEPTH OF ANALYSIS (FEET BELOW SURFACE)
TOTAL DISSOLVED SOLIDS IN PPM (c INDICATES CALCULATED FROM CHLORIDES)

- WATER WELL–SHALLOW AQUIFER
- WATER WELL–ARTESIAN AQUIFER
- WATER WELL–ARTESIA GROUP
- OIL WELL–SHOW OF WATER
- OIL WELL
- GEOPHYSICAL DATA WELL–DEEP GAS
- PENNSYLVANIAN GAS WELL

Source: M. Holland and M. Stahl, 1979.

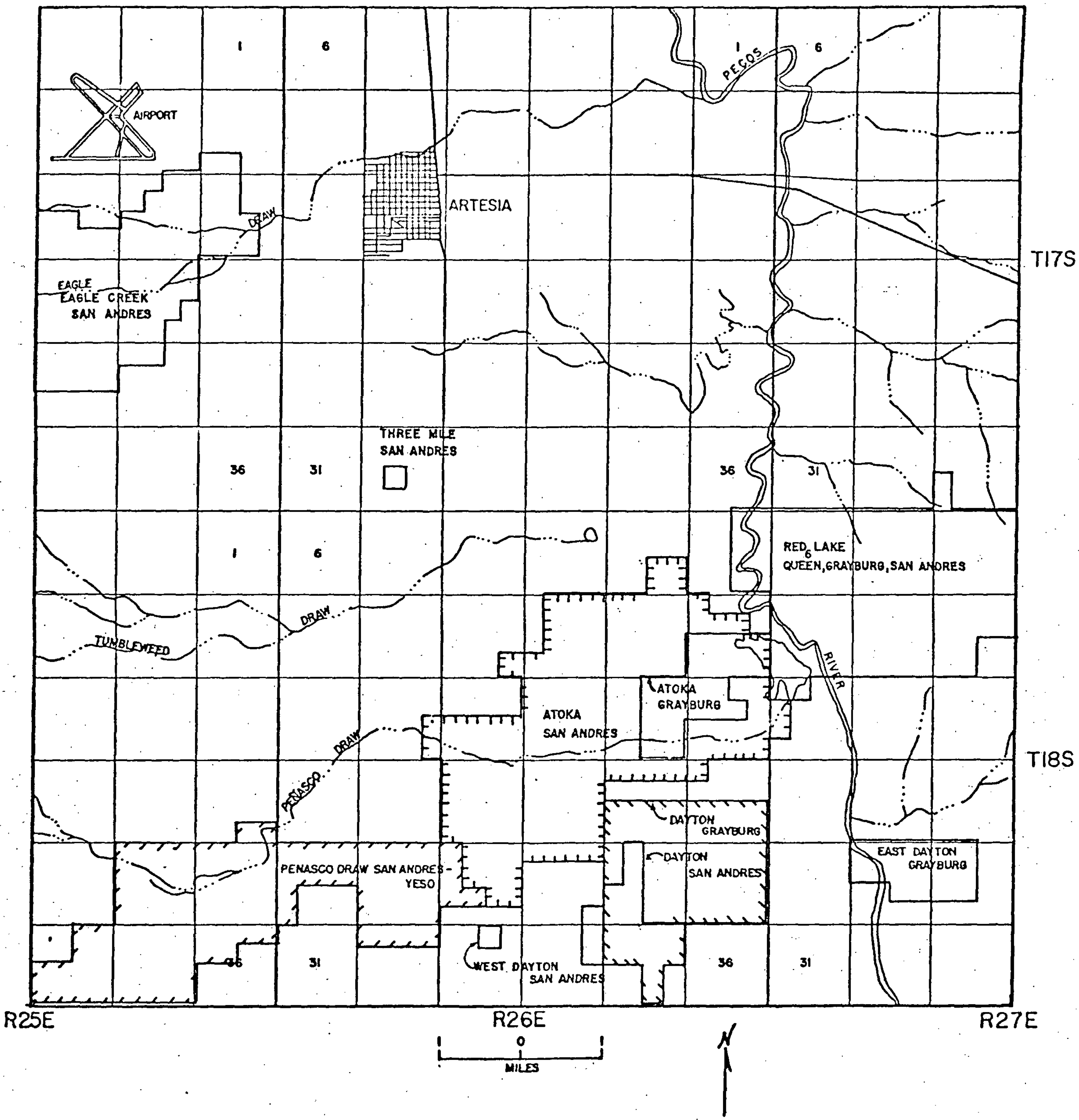


Figure 8: Location of Shallow Oil and Gas Pools.

Source: M. Holland, 1979.

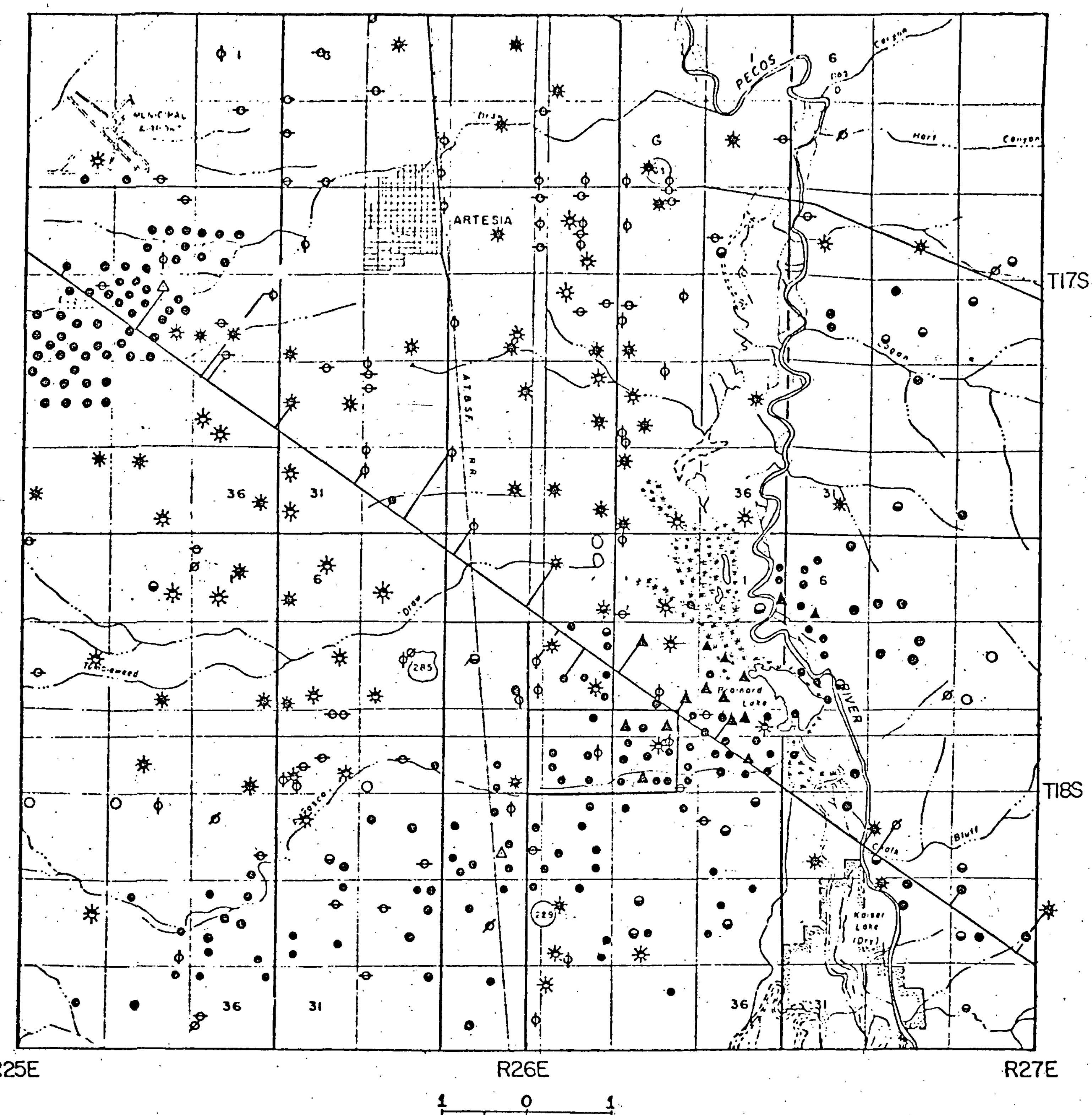


Figure 9: REPRESENTATIVE INFORMATION WELLS

(OIL, GAS, WATER, INJECTION)

NOTE: ALL WELLS IN AREA NOT DEPICTED
SOME WELLS WERE DRY HOLES BUT ARE DATA SOURCE
SOME WELLS NOW PLUGGED AND ABANDONED

- WATER WELL-SHALLOW AQUIFER
- WATER WELL-ARTESIAN AQUIFER
- WATER WELL-UPPER ARTESIA GROUP
- OIL WELL
- OIL WELL-SHOW OF WATER
- PENNSYLVANIAN GAS WELL
- GAS WELL-GEOPHYSICAL DATA
- GAS WELL-SHOW OF WATER
- INJECTION WELL
- SALT WATER DISPOSAL

Source: M. Holland, 1979.

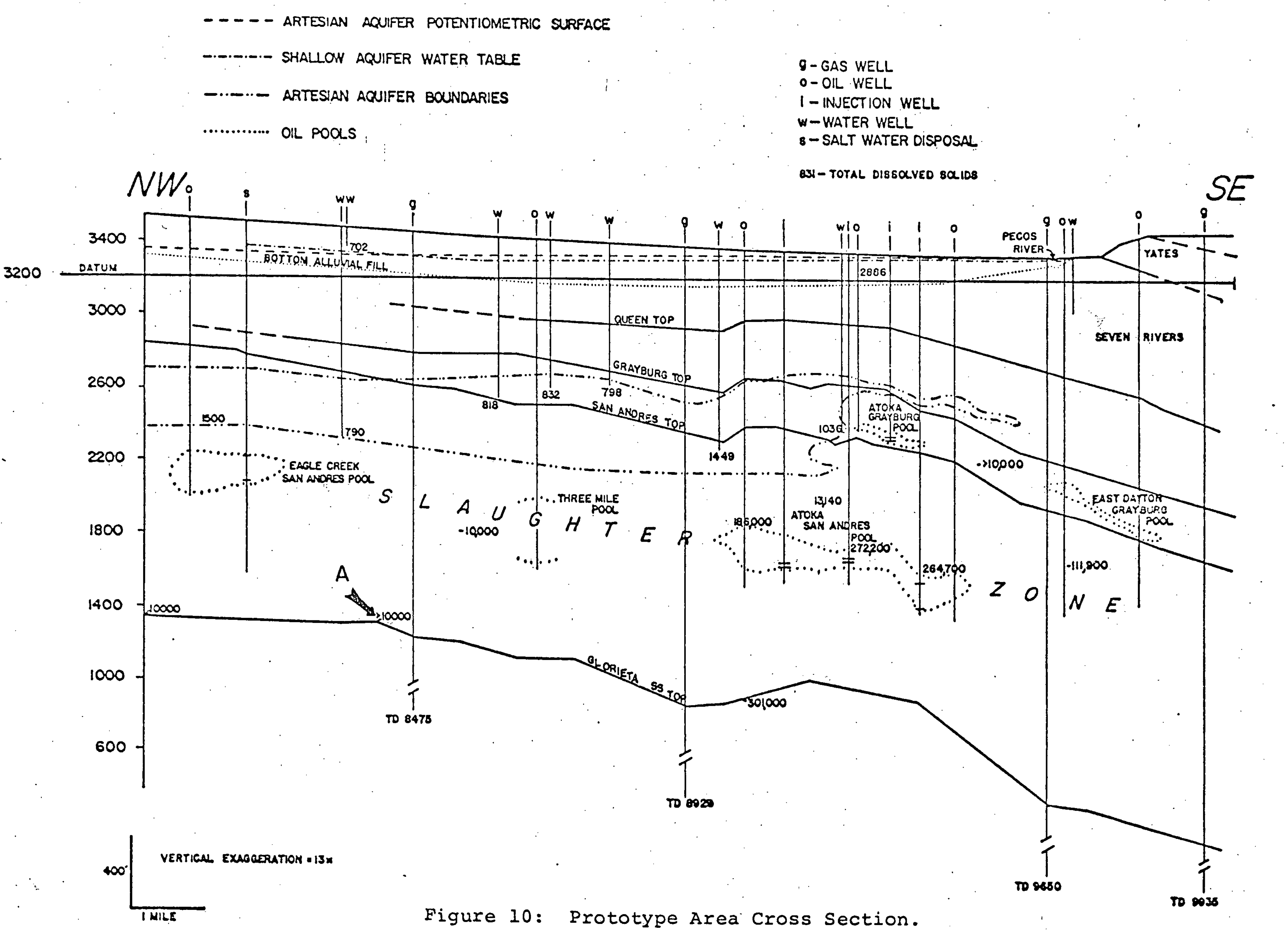


Figure 10: Prototype Area Cross Section.

Source; M. Holland, 1979.

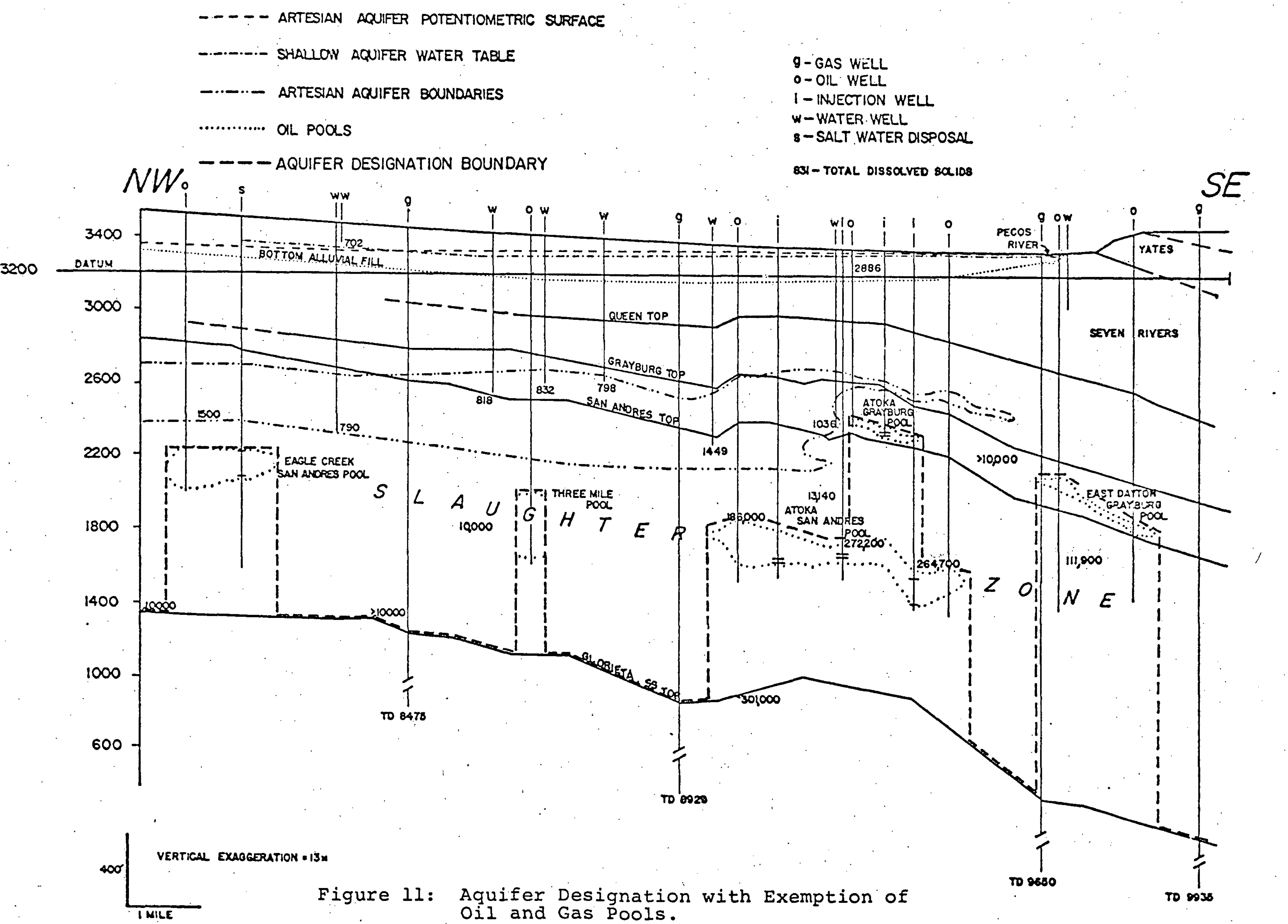


Figure 11: Aquifer Designation with Exemption of Oil and Gas Pools.

Source: M. Holland, 1979.

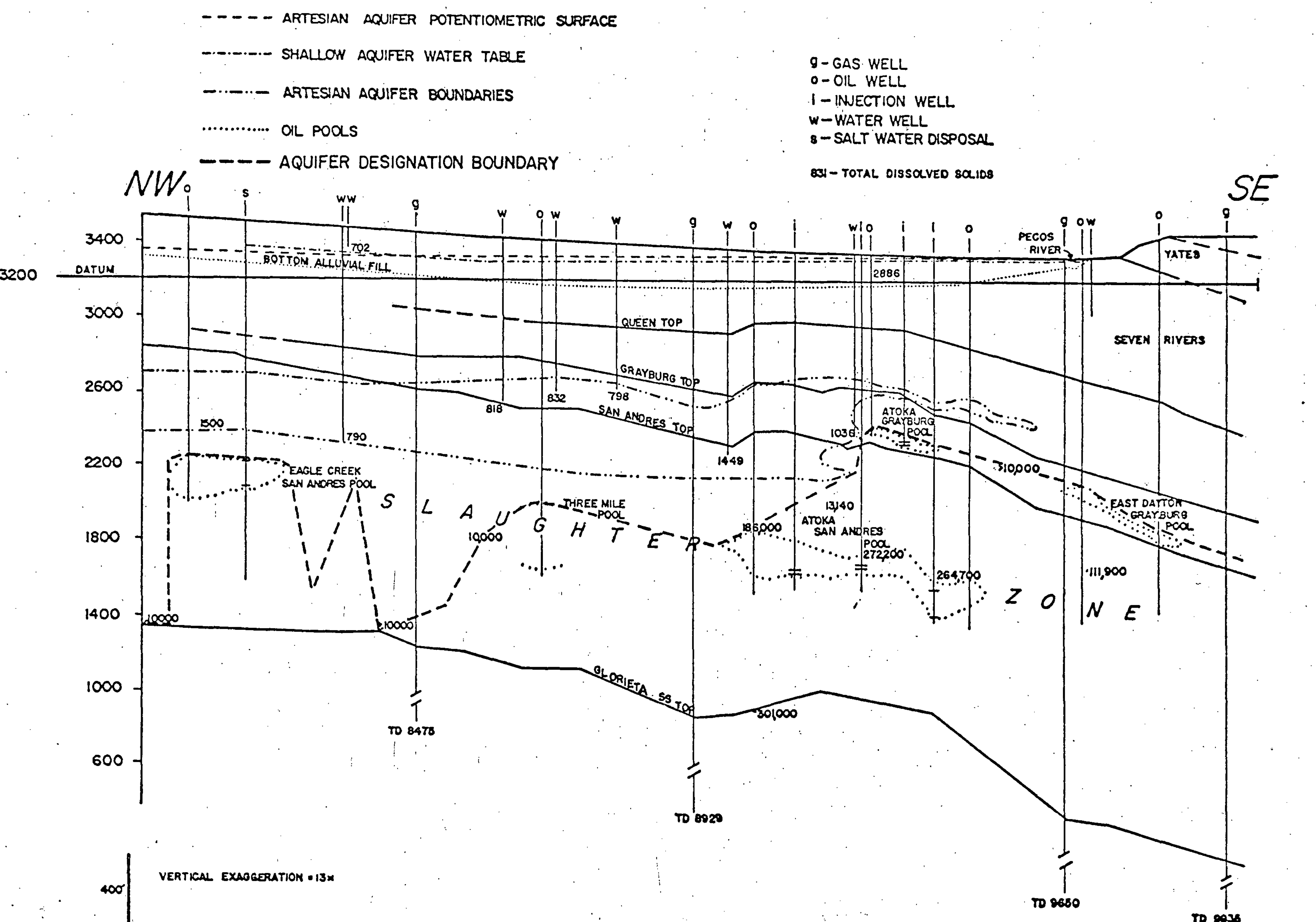


Figure 12: Aquifer Designation Utilizing TDS Data.

Source: M. Holland, 1979.

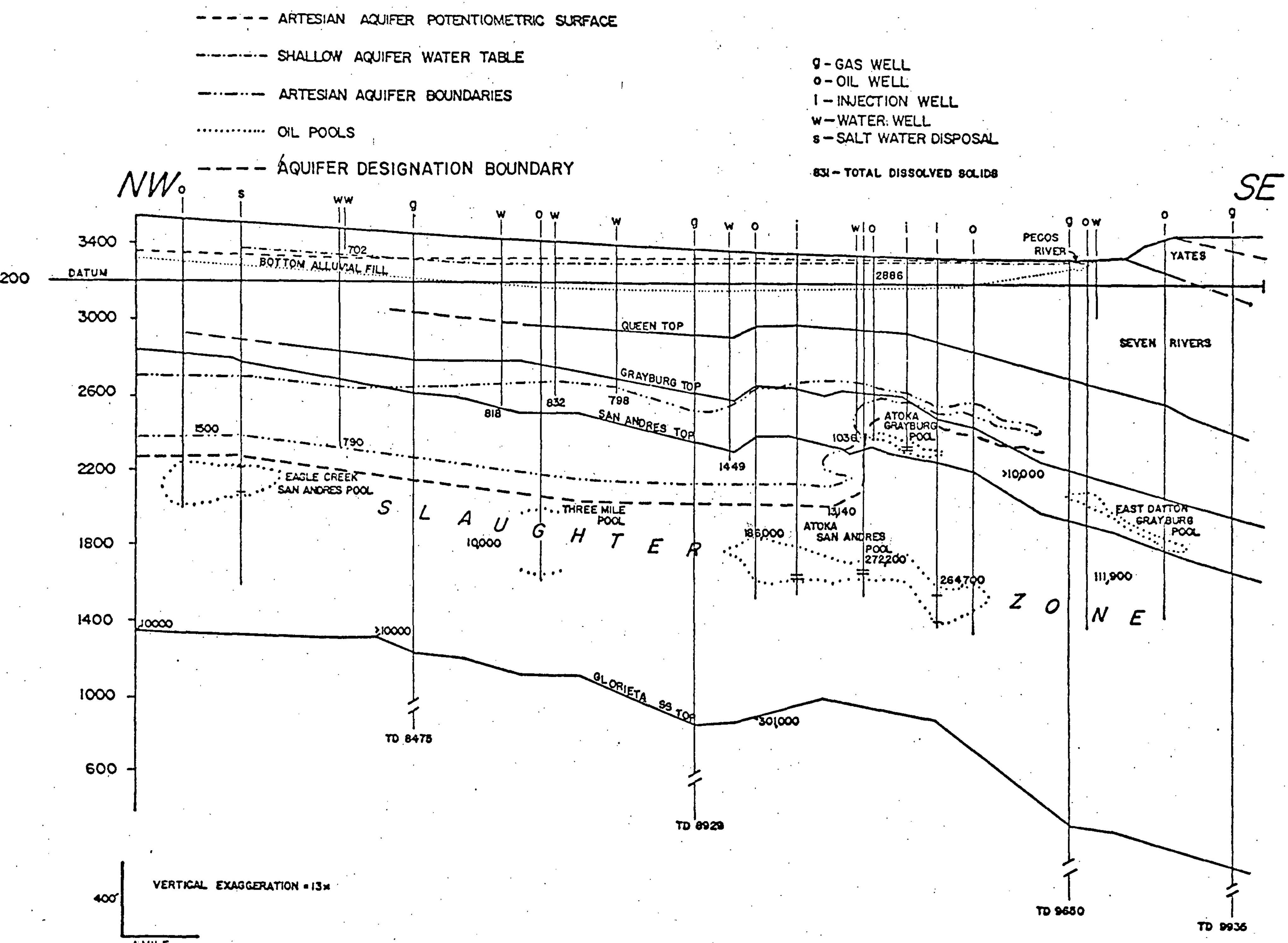


Figure 13: Aquifer Designation Based on Aquifer Porosity Limit.

Source: M. Holland, 1979.

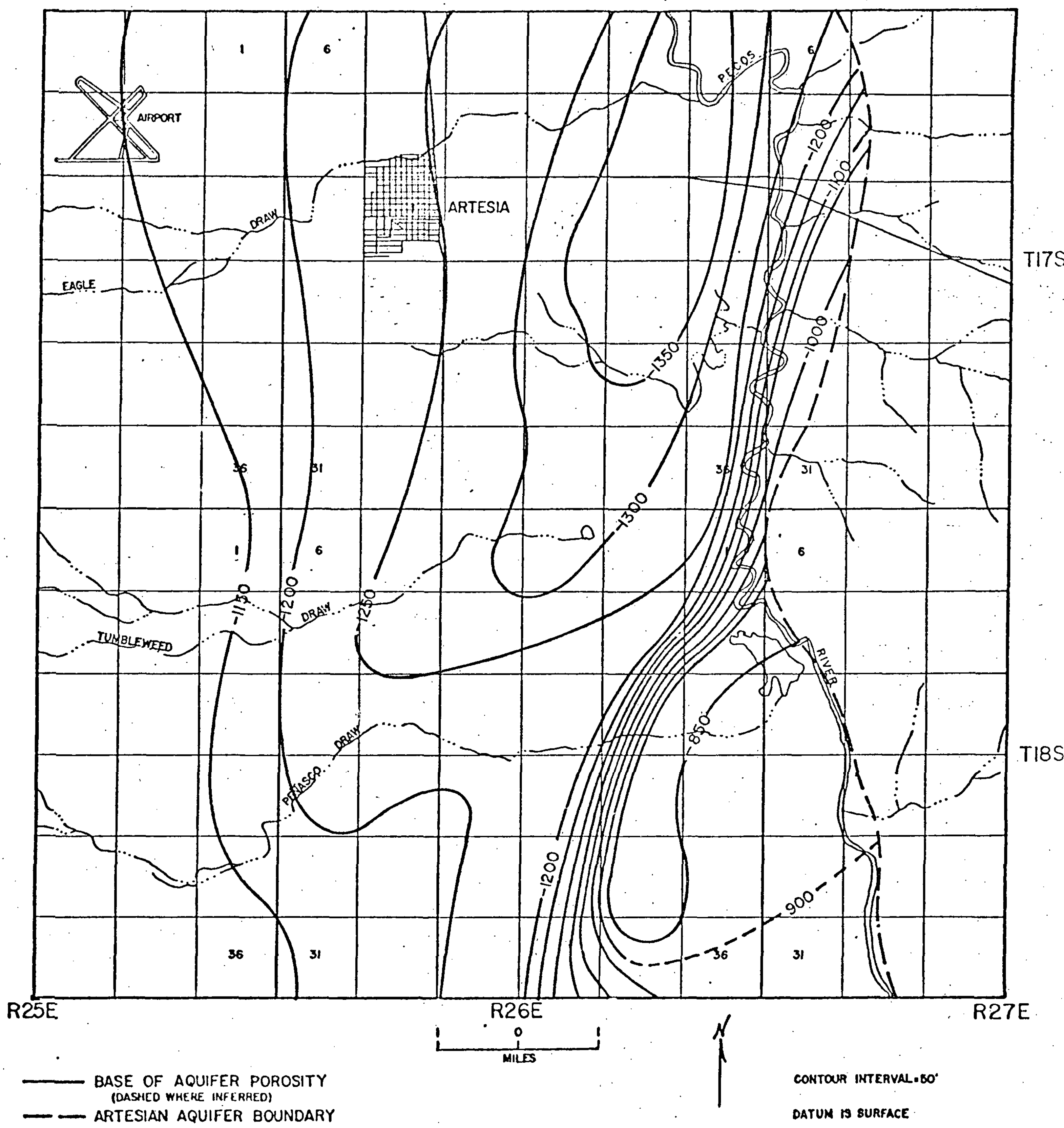


Figure 14: Base of Artesian Aquifer.

Source: M. Holland, 1979.

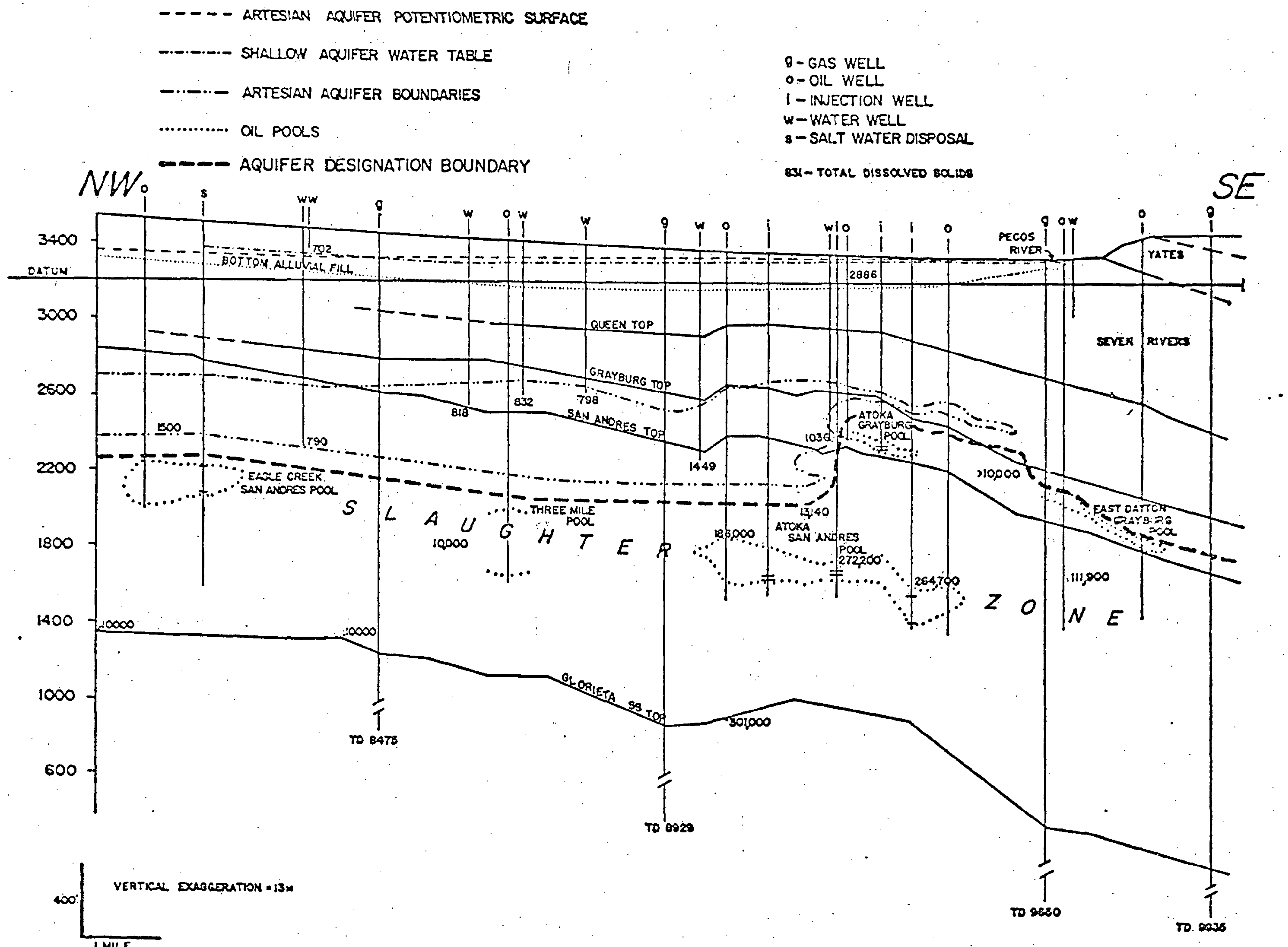


Figure 15; Aquifer Designation Based on TDS and Water Productivity.

Source: M. Holland, 1979.

Table 1. Geohydrologic Data.

Formation	Average Permeability (millidarcies)	Average Porosity %	Transmissibility gpd/ft	Storage Coefficient	Coefficient of Leakage (feet)
Alluvium			100,000	0.10	20,000
Yates	11.27c	10.21c			
Seven Rivers	2.47c	10.65c			
Queen	1.98c	9.21c	60,000k		
Grayburg	9.73	9.86			
Artesian Aquifer			150,000	.00005	25,000
Upper San Andres	up to 2.0	6.0	100,000		
Slaughter	up to 12.0	4.83			
Glorietta	0.28	21.0			
Yeso	2.02	1.29			

The values for porosity and permeability were calculated from data in USGS files, except for those marked with a "c" which are county-wide averages taken from Hiss (1975). The other parameters are taken from Hantush (1955) except those marked with a "k" which were taken from Kinney et.al. (1968).

Table 2. Water Wells Data.

Abbreviations used: Irr-Irrigation, Dom-Domestic, P.S.-Public Supply, Ind-industrial, S-Stock, Qal-Valley fill, Pya-Yates Fm, Psr-Seven Rivers Fm., Pq-Queen Fm, Pgb-Grayburg Fm, Psa-San Andres Fm, C in TDS column indicates calculated value, C.S. in comments column indicates well used in cross section. All water rights numbers have the prefix RA.

Location Number	Owner	Surface Elevation (feet)	Well Depth	Aquifer	Water Production (feet)	Diam. Casing (inches)	Bottom Depth of Casing (feet)	Driller	Date Drilled	Water Level (feet)
17.25.1.143	Fred Savoie	3,483	1,238	Psa	-	8	-	-	-	156.6
17.25.11.433	Haines	3,495	166	Qal	-	-	-	-	-	-
17.25.12.120	J.W. Collins	3,464	-	Qal	-	-	-	-	-	-
17.25.12.21141	Artesia Country Club	3,455	225	Qal	-	12	-	-	-	159
17.25.14.120	-	3,503	-	Qal-Psr	-	6	-	-	-	145.9
17.25.14.141	Artesia Country Club	3,505	-	Qal	-	-	-	-	-	-
17 25.14.220	-	3,496	-	Psa	-	-	-	-	-	-
17.25.14.430	-	3,479	-	Psa-Pgb	-	-	-	-	-	1133.2
17.25.22.220	N.T. Gissler	3,530	-	Qal	-	-	-	-	-	-
17.25.24.224	J. Park	3,442	1,148	Psa	-	-	-	-	-	136.3
17.25.24.321	N.T. Gissler	3,464	-	Qal	-	-	-	-	-	-
17.25.24.344	-	3,482	121	Qal	-	-	-	-	-	-
17.25.24.433	J.M. Jackson	3,465	-	Pgb	-	-	-	-	-	162.5
17.26.2.113	Fred Savoie	3,324	83	Qal	-	8	-	-	-	15.2
17.26.4.121	State of New Mexico	3,357	23	Qal	-	-	-	-	-	18.0
17.26.4.331	Joe Nunn	3,365	330	Qal-Pq	-	12.5	-	-	-	38.7
17.26.5.1111	T.J. Sivley	3,398	300	Qal-Pq	95-175 260-271	14	302	F. Osbourn	5-68	80
17.26.5.330	W.M. Simmons	3,403	188	Qal	88-133 147-155	12.25	190	D.N. Gray	2-55	35
17.26.6.1131	David Barret	3,449	241	Qal	180-186 227-238	7	241	Bristou	5-78	160
17.26.6.3333	Jack Garret	3,452	210	Qal	160-185	7	210	Osbourn	8-77	155
17.26.7.131	J.W. Collins	3,427	156	Qal	-	7	-	W.C. Gray	12-52	78.4
17.26.7.131113	Harvey Yates Co.	3,428	252	Qal	55-80 120-130 215-246	12.25	252	Yates Pet.	2-77	-
17 26.7.333	-	3,430	-	Qal	-	-	-	-	-	-
17.26.7.433	J.B. Champion	3,411	160	Qal	-	8	30	J. Hammond	8-68	115

(Second half of Table 2).

Date/ Sample Meas.	Yield (gpm)	Specific Conduct. (mmho)	Chloride (ppm)	Total Diss. Solids (mg/l)	Use	Water Rights Number	Comments
1-61	-	-	-	-	Irr	-	
-70	-	-	131	1,210C	-	-	C.S.
4-55	-	1,280	33	971C	Irr	-	
1-74	-	1,275	40	893C	Irr	-	
8-48	-	-	-	-	Dom	-	
7-40	-	946	18	904	Irr	-	
-	-	-	18	1,020C	-	-	
5-60	-	2,970	30	1,560C	-	-	
5-49	-	869	32	628	-	-	
1-64	-	1,129	14	790C	PS	-	C.S.
2-68	-	1,018	17	713C	-	-	
2-39	-	472	29	702	-	-	C.S.
1-63	-	-	-	-	Dom	-	
1-53	-	-	-	-	Irr	-	
1-58	-	2,540	133	2,060	Dom	-	
1-59	-	1,200	34	840C	Irr	-	
5-68	-	-	-	-	Irr	5,416	
12-55	-	-	-	-	-	1,513	
5-78	-	-	-	-	Dom	6,303	
8-77	-	-	-	-	Dom	6,167	
1-52	-	1,250	36	875C	Irr	2,991	
-	-	-	-	-	Irr	1,604	
2-39	-	1,220	53	954	-	-	
8-68	-	-	-	-	Irr	2,178	

Table 2 (continued).

Location Number	Owner	Surface Elevation (feet)	Well Depth	Aquifer	Water Production (feet)	Diam. Casing (inches)	Bottom Depth of Casing (feet)	Driller	Date Drilled	Water Level (feet)
17.26.8.244	Continental Oil Co.	3,364	1,123	Psa	-	12.5, 8.625	850	F. Osbourn	6-66	135
17.26.8.4314	City of Artesia	3,371	1,158	Psa	860-870 1015-1020 1140-1150	13.375 10.75	662	City of Artesia	5-46	-
17.26.8.4423	City of Artesia	3,367	1,223	Psa	365-388 980-993 1020-1076	13.375 10.75	658	Pearson Bros.	7-48	-
17.26.10.110	Heady	3,336	218	Qal	25-35 96-134	7	139	A.F. Smith	12-63	65
17.26.10.333	V.L. Gates	3,348	278	Qal	-278	13.375 10.75	278	Pearson Bros.	1-39	11.6
17.26.10.333a	V.L. Gates	3,348	294	Qal	280-92	12.5	294	W. Beaty	5-60	15.8
17.26.10.333b	V.L. Gates	3,348	1,262	Psa	1080-1106	12.5, 10	930	Pearson Bros.	6-26	-
17.26.10.433	Elizabeth Sullivan	3,341	1,007	Psa-Pgb	-	-	-	-	-	-
17.26.10.433a	Mrs. M.J. Sullivan	3,342	1,095	Psa	607-1095	13.375, 8	1,095	Pearson Bros.	2-54	-
17.26.10.433b	D.O. Sullivan	3,340	210	Qal	-	13	-	-	-	44.2
17.26.11.333	-	3,325	1,133	Psa	-	-	-	-	-	-
17.26.11.333a	William T. Halderman	3,325	955	Pgb	752-841 968-955	13.375 10.75	705	M. Brunig	2-46	-
17.26.11.433	Blaine Haines	3,313	1,034	Pgb	643-1034	13, 6.625	760	R. Johnson	4-47	-
17.26.11.4333	Blaine Haines	3,314	1,040	Pgb	864-931 975-1008	- -	- -	- -	- -	- -
17.26.12.244	George H. Settlemire	3,301	175	Qal	140-160	7	167	R. Monk	7-61	130
17.26.13.310	E.P. Bach	3,300	100	Qal	-	-	-	-	-	-
17.26.14.133	-	3,325	961	Pgb	-	-	-	-	-	-
17.26.14.211	G.E. Sharp	3,314	241	Qal	213-241	8, 7, 5	241	D.N. Gray	8-51	213
17.26.14.2112	G.E. Sharp	3,313	1,013	Pgb	806-879	10.75 8.75	990	M. Brunig	4-52	86.2

Date/ Sample Meas.	Yield (gpm)	Specific Conduct. (mmho)	Chloride (ppm)	Total Diss. Solids (mg/l)	Use	Water Rights Number	Comments
6-66	-	-	-	-	Ind	1,097	
-74	-	1,208	13	842C	PS	2,231	5th St. C.S. Well
-74	-	1,151	17	930	PS	2,397	Chisom St. Well
12-63	-	-	-	-	Dom	4,922	
3-59	1,000	2,980	135	2,500	-	1,341	
1-50	-	-	-	-	Dom Irr	4,196	
3-59	-	2,740	325	1,744C	-	307	plugged to 1150 ft.
8-64	-	1,355	37	948.5	Irr	-	
7-73	850	1,366	145	956C	-	397	
1-66	-	2,020	142	1,322C	Irr	-	
7-40	-	5,510	1,060	3,950	-	-	
7-63	-	2,402	310	1,595C	-	763	
1-59	1,000	420	80	1,100C	Irr	777	
-74	-	1,459	64	1,060C	-	-	
7-61	-	-	-	-	Dom	4,438	
6-54	-	1,070	17	749C	Irr	-	
3-59	-	1,120	15	854	-	-	
8-51	-	4,330	815	3,110	-	2,749	
1-74	600	-	171	1,277C	Irr	895	

Table 2 (continued).

Location Number	Owner	Surface Elevation (feet)	Well Depth	Aquifer	Water Production (feet)	Diam. Casing (inches)	Bottom Depth of Casing (feet)	Driller	Date Drilled	Water Level (feet)
17.26.15.111	Charles Allison	3,340	240	Qal	194-240	10, 8	240	Gray Bros.	1-36	-
17.26.15.133	Jackson/Mason	3,350	240	Qal	180-240	14	220.1	Black	10-44	-
17.26.15.133a	Jackson/Rowley	3,350	1,231	Psa-Pgb	586-1231	13.375 8.375	1,025	Schrock	4-55	42
17.26.15.211	J.M. Vogel	3,340	225	Qal	155-225	10	220	Gray Bros.	8-34	29.7
17.26.15.233	-	3,342	1,253	Psa	-	-	-	-	-	-
17.26.15.313	G.E. Sharp	3,353	-	Qal	-	-	-	-	-	-
17.26.15.411	W.M. Jackson	3,344	200	Qal	-	16	-	-	-	40.4
17.26.15.413	W.M. Jackson	3,342	850	Pgb	653-850	14	-	-	-	60.2
17.26.17.12111	City of Artesia	3,388	1,050	Psa	852-919 943-1050	15.5 12.5	849	M. Brunig	1-43	-
17.26.18.32131	City of Artesia	3,428	1,107	Psa	933-1068	13.375 10.75	825	E. Shrock	3-63	-
17.26.21.311	Dean and Taylor	3,377	821	Pgb	-	9,6	704	S. Butler	1-06	-
17.26.22.233	R.L. Paris	3,345	135	Qal	112-135	8,7	135	D.N. Gray	12-49	-
17.26.22.240	H.L. Greer	3,328	103	Qal	-	-	-	-	-	-
17.26.23.120	E.P. Bach	3,318	925	Pgb	786-925	13.375, 8	886	M. Brunig	4-46	-
17.26.23.130	G. Duncan	3,325	115	Qal	-	-	-	-	-	-
17.26.23.3111	Jim W. Berry	3,326	893	Pgb	755-762 805-893	10, 8	886	Pearson Bros.	6-35	-
17.26.26.211	L.R. Sperry	3,312	941	Pgb	-	14	-	-	-	29.5
17.26.26.331	-	3,321	892	Pgb	-	-	-	-	-	-
17.26.26.3311	G. Farmer	3,322	958	Pgb	820-880	12.5, 8	-	-	-	-
17.26.29.111	Don Menefee	3,400	1,150	Pgb-Psa	700-1150	12.5, 8	860	Pearson Bros.	5-52	-
17.26.29.113	-	3,406	145	Qal	-	-	-	-	-	-
17.26.29.131	C.E. Martin	3,407	201	Qal	8-23 132-198	20	-	Black Bros.	3-37	49.0
17.26.30.211	Don Menefee	3,423	200	Qal	152-167	16	200	Young and Montgomery	4-64	40
17.26.32.1111	Zeleny	3,405	793	Pgb	-	-	-	-	-	-

(Second half of Table 2).

Date/ Sample Meas.	Yield (gpm)	Specific Conduct. (mmho)	Chloride (ppm)	Total Diss. Solids (mg/l)	Use	Water Rights Number	Comments
5-75	600	-	145	1,234C	-	1,227	
7-73	900	-	215	1,290C	-	1,503F	
4-55	800	-	400	1,659C	-	2,050	
3-75	970	-	190	1,309C	Irr	1,183	
7-40	-	8,200	1,860	5,803	-	-	
2-39	-	969	13	736	-	-	
1-65	-	2,040	80	1,640	-	Irr	
1-65	-	-	-	-	-	1,578	Remarkable Chimney well.
-74	-	1,142	14	799C	P.S.	821	Standpipe well
-74	-	1,523	60	1,078C	P.S.	821-S	
7-40	1,494	981	14	770	-	-	
6-39	-	1,940	47	1,680	-	2,552	
11-54	-	2,510	70	1,433C	-	-	
6-54	-	1,710	124	1,198C	Irr	386	
11-54	-	2,820	84	1,553C	-	-	
3-66	-	1,190	18	833C	-	1,252	
1-66	-	1,100	24	864	Irr	1,199	
-	-	1,120	24	886	-	1,198-S17	
-74	-	1,332	17	976C	-	-	
-	1,000	-	50	1,060C	Irr	1,925-S	C.S.
7-40	-	1,140	30	920	-	-	
1-50	-	-	-	-	Irr	1,430	C.S.
4-64	250	-	-	-	-	1,826	
-69	-	1,202	17	841C	-	-	C.S.

Table 2 (continued).

Location Number	Owner	Surface Elevation (feet)	Well Depth	Aquifer	Water Production (feet)	Diam. Casing (inches)	Bottom Depth of Casing (feet)	Driller	Date Drilled	Water Level (feet)
17.26.32.1311	FLoyd Sherrill	3,405	861	Pgb	-	11.625, 8	758	Dayton Deep Well Co.	1-10	-
17.26.33.1111	*Adolph Zeleny*	*3,381*	*793*	*Pgb*	*714-730*	*8*	*707*	*Butler*	*6-10*	-
17.26.33.343	J.B. Snider	3,369	766	Pgb	730-745	8	729	Sperry & Lukas	2-11	-
17.26.33.343a	Bradshaw	3,369	800	Pgb	-	-	-	-	-	-
17.27.7.230	-	3,310	275	Psr	-	-	-	-	-	-
17.27.16.344	Moore & Stout	3,435	1,042	Pgr-Pq	370-380 630-640 1034-1042	5.5	934	W. Beaty	1-60	260
17.27.18.100	-	3,299	50	Qal	-	-	-	-	-	-
18.25.1.113	Pedro Lopez	3,466	200	Qal	155-165 175-195	7	200	W. Beaty	9-54	160
18.25.1.13113	Pedro Lopez	3,463	325	Pq	187-280	7	280	Tidwell	9-54	180
18.25.3.111	E.R. Powell	3,535	223	Qal	184-223	6.625, 5	223	D.N. Gray	5-57	184
18.25.10.310	E.R. Powell	3,526	300	Pgb	275-295	7, 5.5	300	D.N. Gray	8-59	168
18.25.22.111	Four Dinkas Ranch	3,537	-	Psa	-	-	-	-	-	-
18.25.23.111	Four Dinkas Ranch	3,503	-	Psa	-	-	-	-	-	-
18.25.23.111a	G.M. Phelps	3,503	-	Qal	-	-	-	-	-	117.8
18.25.23.210	Paul Haines	3,478	700	Pgb	-	-	-	Classen & Alford	5-05	-
18.25.24.100	G.W. Chisholm	3,463	588	Pgb	-	8.25,6,25	522	G.W. Chisholm	3-06	-
18.25.24.4234	David Fasken	3,344	204	Qal	155-203	7	205	F. Osbourn	12-70	158
18.25.26.440	Resler and Sheldon	3,480	1,400	Psa	860-980	7, 4.5	1,400	Waters Drlg.	6-57	-
18.25.36.310	Mark B. Kincaid	3,504	142	Qal	58-81	6.625	81	A. Beaty	11-62	81
18.25.36.313	Lee Drlg. Co.	3,509	430	Pgb	380-430	7	380	A.F. Smith	12-58	270
18.26.2.111	J.W. and W. C. Bradshaw	3,315	955	Pgb	770-792 837-887	3.375, 10.75	898	M. Bruning	1-50	29.8
18.26.2.333	S.O. Higgens	3,320	202	Qal	62-165	10	165	Gray Bros.	11-35	34.0
18.26.8.233	W.S. Miller	3,408	822	Pgb	666-224 822-875	8	704	S.A. Butler	7-07	-

(Second half of Table 2).

Date/ Sample Meas.	Yield (gpm)	Specific Conduct. (mmho)	Chloride (ppm)	Total Diss. Solids (mg/l)	Use	Water Rights Number	Comments
-74	1,667.2	1,169	18	818C	Irr	1,167	C.S.
-74	623	1,241	23	832	-	775	C.S.
3-59	1,539	1,140	31	798C	-	-	
-74	-	1,287	21	964C	-	-	C.S.
11-54	-	13,300	3,430	8,014C	-	-	
-74	-	1,424	38	1,026C	Dom	4,114	
10-39	-	12,000	2,910	8,590	-	-	
9-54	-	-	-	-	-	3,310	
9-54	12	-	-	-	Dom	6,077	C.S.
5-57	-	-	-	-	Dom	3,772	
8-59	-	-	-	-	Dom	4,068	
3-66	-	1,430	12	1,001C	-	-	
3-64	-	1,140	10	798C	-	-	
1-50	-	-	-	-	S	-	
-	960	-	-	-	-	-	
-	644	-	-	-	-	-	
12-70	-	-	-	-	-	5,620	
-	-	-	-	-	-	-	
11-62	-	-	-	-	Dom	4,722	
12-58	-	-	-	-	-	3,975	
1-65	-	1,310	17	917C	Irr	772-S	
1-75	-	-	-	-	Irr	1,288	C.S.
3-59	-	1,330	18	931C	-	-	

Table 2 (continued).

Location Number	Owner	Surface Elevation (feet)	Well Depth	Aquifer	Water Production (feet)	Diam. Casing (inches)	Bottom Depth of Casing (feet)	Driller	Date Drilled	Water Level (feet)
18.26.8.2333	L.F. Chumbley	3,397	974	Pgb-Psa	903-974	13.375	766	Shrock	8-59	86.9
18.26.9.444	Frank Waters & William Hudson	3,351	1,727	Psa	-	8.625, 5.5	1,727	Waters	6-56	-
18.26.10.133	-	3,350	1,100	Psa	-	-	-	-	-09	-
18.26.10.331	-	3,348	716	Pgb	-	-	-	-	-	-
18.26.10.331a	Borden Aaron & L.H. Johnson	3,348	863	Pgb	653-722 797-844	13.375	649	R. Johnson	5-48	-
18.26.11.431	Brainard Bros.	3,314	700	Pgb	27-58 545-563 657-690	10	520	D. Suiken	8-44	-
18.26.13.111	Donald Fanning	3,299	150	Qal	40-60 95-107	16, 14	150	A.F. Smith	1-59	16
18.26.14.232	Jones and MacArthur	3,307	955	Pgb-Psa	-	8.625	785	Mahres	7-56	2.7
18.26.14.443	Donald Fanning	3,310	170	Qal	45-94	16, 14	170	D.N. Gray	9-54	28
18.26.15.4211	J.H. Everst	3,331	760	Pgb	624-635	10	640	M. Brunig	2-38	16.4
18.26.17.322	T. Vandiver	3,400	240	Qal	90-240	16	230	A.F. Smith	7-60	70
18.26.17.3333	Tom Vandiver	3,418	-	Psa	-	-	-	-	-	-
18.26.18.212	Tom Vandiver	3,416	228	Qal	-	-	-	-	-	-
18.26.18.221	T. Vandiver	3,404	258	Qal	50-60 240-253	16	257	A.F. Smith	3-59	115
18.26.18.323	William McCrary	3,429	235	Qal	80-85	14	235	W.C. Gray	-37	56.8
18.26.18.332	T. Vandiver	3,428	1,167	Psa	-	-	-	-	-	-
18.26.18.3324	F.F. Thorpe	3,429	1,061	Psa-Pgb	600-1055	13.375	575	Shrock	3-62	-
18.26.18.411	T. Vandiver	3,414	315	Qal	220-240	12	240	A.F. Smith	4-57	115
18.26.20.441	Great Western Drilling	3,425	158	Qal	125-158	-	-	Abbott	8-60	125
18.26.21.2233	Joe Lee	3,355	1,099	Pgb-Psa	805-1049	13.375, 10.625	522	Shrock	5-55	61.7
18.26.22.313	Velma Lee Round	3,352	106	Qal	75-103	6	106	W. Beaty	8-57	40
18.26.24.131	Angelino Mackey	3,305	80	Qal	-	12.5	-	-	-	46.2
18.26.25.444	-	3,285	-	Pgb-Psa	-	-	-	-	-	-

(Second half of Table 2).

Date/ Sample Meas.	Yield (gpm)	Specific Conduct. (mmho)	Chloride (ppm)	Total Diss. Solids (mg/l)	Use	Water Rights Number	Comments
1-70	-	1,259	9	880C	Irr	1,895	C.S.
-59	-	-	108,000	186,000	Oil	-	
-	1,500	-	27	1,499C	-	1,029	C.S.
9-58	-	1,840	23	1,159C	-	-	C.S.
-73	-	2,172	102	1,341C	Irr	137	
-	1,050	-	-	-	-	277	
1-59	-	-	-	-	Irr	1,587-H	C.S.
1-75	-	1,487	24	1,036C	Irr	-	C.S.
9-54	-	5,160	700	2,886C	Irr	1,524-B	
1-63	-	1,590	24	1,073C	Irr	950	C.S.
7-60	-	-	56	1,396C	Irr	3,181-S8	
3-66	-	1,185	18	830C	-	-	
3-66	-	1,210	60	847C	-	-	
3-59	1,000	-	19	1,023C	Irr	1,381-S5	
1-50	-	-	-	-	Irr	-	
-	1,200	-	14	1,206C	-	1,496	
-74	1,100	1,404	10	996C	Irr	747	
4-57	1,000	-	46	1,237C	Irr	1,381-S6	
8-60	-	-	-	-	Dom	4,283	
1-66	-	2,967	248	1,741C	-	888	
8-57	-	-	-	-	Dom	3,771	
1-66	-	-	-	-	Irr	-	C.S.
-	-	4,250	290	2,190	-	-	

Table 2 (continued).

Location Number	Owner	Surface Elevation (feet)	Well Depth	Aquifer	Water Production (feet)	Diam. Casing (inches)	Bottom Depth of Casing (feet)	Driller	Date Drilled	Water Level (feet)
18.26.27.344	-	3,360	1,405	Psa	-	-	-	-	-	-
18.26.29.141	Noble Drilling Co.	3,428	160	Qal	130-155	7	160	W. Beaty	2-60	100
18.26.30.200	Gardener Bros.	3,445	205	Qal	150-160 195-205	7	205	A.F. Smith	3-63	190
18.26.32.110	M.A. Kincaid	3,419	152	Qal	120-145	6.625	152	W. Beaty	12-59	90
18.26.34.3132	E.G. Minton	3,356	871	Pgb	673-810	13, 10	642	Pearson Bros.	8-51	59.7
18.27.8.442	-	3,482	381	Psr	325-350	-	-	-	-	-
18.27.9.140	Humble Oil & Refining	3,545	-	Pya	160-170	-	-	-	-	-
18.27.9.334	Humble Oil & Refining	3,512	-	Pya	210-215	-	-	-	-	-
18.27.20.140	-	3,375	399	Psr	38-40 147-155	-	-	-	-	-
18.27.21.333	Moorhead Federal	3,372	1,622	Pgb-Psa	1190-1270	-	-	-	-	-
18.27.33.410	Yates Petroleum	3,392	-	Pgb-Psa	1258-1388 2940-2950	-	-	-	-	-

(Second half of Table 2).

Date/ Sample Meas.	Yield (gpm)	Specific Conduct. (mmho)	Chloride (ppm)	Total Diss. Solids (mg/l)	Use	Water Rights Number	Comments
-74	-	2,097	12	1,240C	-	-	
2-60	-	-	-	-	Dom	4,160	
3-63	-	-	-	-	Dom	4,784	
12-59	-	-	-	-	Dom	4,136	
1-75	-	1,260	15	882C	Irr	1,703	
-	-	-	-	-	-	-	
11-56	-	-	278	3,810	Ind	-	
11-56	-	-	384	4,510	Ind	-	
-	-	-	-	-	-	-	C.S.
-	-	-	-	-	-	-	
-	-	-	-	-	-	-	

Table 3. Oil, gas and injection well data.

Abbreviations.: SWD - salt water disposal, INJ - injection, QW - water quality, TDS - total dissolved solids, Cl - chlorides, SpC - Specific Conductance, c in TDS column indicates calculation from chlorides, CS - cross section, Pya - Yates Fm., Pq - Queen Fm, Pgb - Grayburg Fm., Psa - San Andres Fm., Pabo - Abo Fm. NOTE: Casing Depth indicates depth of casing string protecting fresh water. Most depths of formations interpreted by owners and given in well records, thus some discrepancy exists.

Location	Owner	Well Name	Well Elevation	Well Type	Total Depth	Depth of Casing	Depth to top Grayburg	Depth to top San Andres	Depth to top Glorietta	Depth to base Upper Porosity
17.25.10.4233	Yates Pet. Co.	Artesia Airport #2	3,526	Dry	8,080	1,136	455	690	1,975	1,150
17.25.15.344	Yates Pet. Co.	Federal EB #1	3,528	Oil	1,482	1,410	-	701	-	-
17.25.22.234	Yates Pet. Co.	J Lazy J #3	3,526	Oil	1,470	1,133	345?	719	-	-
17.25.22.224	Yates Pet. Co.	Federal BO #4	3,534	Oil	1,537	1,134	-	728	-	-
17.25.22.410	Yates Pet. Co.	J Lazy J #2	3,527	Oil	1,522	1,155	618	722	-	-
17.25.23.218	Yates Pet. Co.	Gissler AV #2	3,482	SWD	1,980	1,260	-	707	-	-
17.25.23.131	Yates Pet. Co.	Gissler AV #10	3,530	Oil	1,501	1,158	-	732	-	-
17.25.23.423	Yates Pet. Co.	Mitchell IN #2	3,480	Gas	9,500	1,262	-	-	-	1,440
17.25.25.310	Western Oil Co.	Flint #1	3,458	Gas	8,518	1,182	-	803	-	1,170
17.25.25.340	Western Oil Co.	Flint #2	3,442	Gas	10,243	1,261	-	-	2,180	-
17.25.35.431	Yates Pet. Co.	Powell DG #1	3,491	Gas	8,740	1,238	-	778	2,160	1,260
17.25.36.4213	Yates Pet. Co.	Arco E.C. State #2	3,446	Gas	8,594	1,263	615	820	-	1,180
17.26.15.1414	Yates Pet Co.	Hunter FL #1	3,345	Gas	8,589	1,374	-	964	2,225	1,310
17.26.15.430	Yates Pet. Co.	Caffall FD #1	3,336	Gas	8,662	1,404	750	948	2,357	1,420
17.26.21.3234	Yates Pet. Co.	Siegenthaller IC #1	3,364	Gas	8,627	1,420	730	910	2,350	-
17.26.22.124	Yates Pet. Co.	Tom Brown Com.	3,337	Gas	8,725	1,402	770	970	2,323	1,370
17.26.23.210	Morris R. Antwell	KD #1	3,315	Gas	8,818	1,500	800	1,230	-	1,365
17.26.26.1134	Yates Pet. Co.	Hnulik EJ #1 Com.	3,315	Gas	8,841	1,420	-	1,025	2,426	1,338
17.26.27.2231	Texas Pac. Oil Co.	J.H. Ansley #1	3,320	Gas	8,806	1,500	-	1,012	2,510	1,350
17.26.30.130	Yates Pet. Co.	Neller EO Com.	3,432	Gas	8,475	1,300	650	815	2,210	-
17.26.30.3413	Yates Pet. Co.	Caskey EV Com. #1	3,428	Gas	8,570	1,282	-	848	2,239	-
17.26.31.130	Yates Pet. Co.	Haldeman EN Com. #1	3,434	Gas	8,595	1,280	-	840	2,223	1,193
17.26.31.332	Yates Pet. Co.	Patterson El #1	3,442	Gas	8,640	1,269	622	826	2,220	-
17.26.32.3223	Floyd E. Sherrell	Floyd Sherrell #1	3,389	Oil	1,790	1,285	-	895	-	-
17.26.35.432	David Faskin	Marjorie Naylor #1	3,288	Dry	9,095	1,402	-	1,075	2,450	1,330

(Second half of Table 3).

Production or Injection Interval	QW Source	Depth	Cl (ppm)	TDS (mg/l)	Depth to base fresh Water	Comments
-	Psa	1,870	5,500	10,000C	1,870	
1,302-	-	-	-	-	-	
1,300-1,439	-	-	-	-	-	
1,289-1,518	-	-	-	-	-	C.S.
1,340-96	-	-	-	-	-	Water intervals 205-210, 720-730, top Slaughter 1260
1,260-1,410	-	-	-	-	-	
1,326-1,440	-	-	-	-	-	
-	Psa	1,870	5,500	10,000C	1,870	
-	Psa	1,280	2,100	4,500C	1,360	
-	Psa	-	-	-	2,150	
-	Psa	-	-	-	2,150	
-	Psa	1,310	3,900C	7,500C	1,320	
-	Psa	1,800	24,000C	41,000C	1,800	
-	Psa	-	-	-	1,420	
-	Psa	-	-	-	1,500	
	-	-	-	-	-	
-	Psa	1,540	18,000C	31,000C	-	
-	Psa	1,530	1,200C	2,900C	1,539	
-	-	-	-	-	1,570	
-	-	-	-	-	-	C.S.
8,015-8,166	-	-	-	-	-	
8,387-8,412	Psa	1,640	2,400C	5,000C	1,955	
8,002-30	Psa	-	-	-	1,630	
1,416-1,754	-	-	-	-	-	C.S.
-	Psa	1,592	41,000	69,000C	-	

Table 3 (continued).

Location	Owner	Well Name	Well Elevation	Well Type	Total Depth	Depth of Casing	Depth to top Grayburg	Depth to top San Andres	Depth to top Glorietta	Depth to base Upper Porosity
17.27.18.320	Mesa Retailers	Martin Fee #1	3,297	Dry	2,478	1,409	930	1,138	-	-
18.25.1.230	Coquina Oil Co.	Superior Federal #1	3,442	Gas	8,625	1,306	-	803	2,128	1,148
18.25.2.340	Coquina Oil Co.	Superior Johnson Com.	3,487	Gas	8,650	1,300	-	-	2,100	-
18.25.10.243	Amoco Prod. Co.	Johnson #1	3,498	Gas	8,720	1,200	549	790	-	-
18.25.27.421	Yates Pet. Co.	Scout Federal EH #2	3,502	Gas	9,090	1,205	-	742	2,082	-
18.26.2.432	David Fasken	Higgins Cahoon #1	3,288	Gas	9,074	1,908	-	1,025	2,385	1,302
18.26.3.141	David Fasken	Mary Brainard Com. #1	3,332	Gas	8,929	1,287	-	993	-	-
18.26.3.440	William Ross	Rogers Com. P#1	3,322	Gas	9,045	1,937	-	-	-	-
18.26.5.310		Armstrong S #1	3,393	Gas	8,853	1,318	-	900	-	-
18.26.6.230	Yates Pet. Co.	6 Federal #2	3,415	Gas	8,730	1,247	625	814	2,246	-
18.26.7.240	Yates Pet. Co.	Ferguson DY #1	3,408	Gas	8,901	1,313	613	922	-	1,252
18.26.7.3423	Yates Pet. Co.	Vandiver DO #1	3,423	Gas	8,906	1,305	578	887	-	-
18.26.8.332	Reading and Bates	Torrington #1	3,406	Dry	8,970	1,300	-	918	2,380	-
18.26.10.1410	Texas Pac. Oil Co.	Kissinger Com. #1	3,335	Gas	9,045	1,219	-	998	2,490	-
18.26.10.244	Gulf Oil Co.	(Stroup 4) #102	3,326	Inj	1,742	1,239	-	976	-	-
18.26.10.122	Collier & Collier	Kissinger #1	3,331	Oil	1,654	1,032	760	1,005	-	-
18.26.10.3240	Gulf Oil Co.	(Eva Hollond) #118	3,349	Oil	1,850	1,844	703	961	-	-
18.26.10.424	Gulf Oil Co.	(Ralph Rogers) #116	3,337	Oil	1,724	1,719	-	964	-	-
18.26.10.4232	David Fasken	Rogers IO #1	3,328	Gas	9,207	1,802	663	962	-	1,218
18.26.11.140	Gulf Oil Co.	#101	3,305	Inj	1,783	1,218	-	996	-	-
18.26.11.2144	Mobil Oil Co.	Brainard Gas Com. #2	3,307	Gas	9,000	1,497	713	1,008	2,333	1,220
18.26.11.3240	Gulf Oil Co.	(Standard Johnson) #114	3,326	Oil	1,714	1,186	-	968	-	-
18.26.11.3343	Gulf Oil Co.	(Standard Aaron) #120	3,330	Oil	1,696	1,178	-	956	-	-
18.26.11.413	Gulf Oil Co.	(Magnolia-Fanning) #113	3,316	Inj	1,797	1,225	720	1,020	-	1,220
18.26.11.433	Mobil Oil Co.	Reed-Brainard #1	3,315	Oil	1,736	802	700	1,010	-	-
18.26.11.440	Mobil Oil Co.	Reed-Brainard #2	3,308	Oil	1,749	840	743	990	-	-
18.26.11.441	Mobil Oil Co.	Brainard Gas Com. #1	3,320	Gas	9,181	1,256	-	1,045	2,366	-
18.26.12.133	Mobil Oil Co.	Fred Brainard #1	3,303	Oil	1,742	1,210	745	993	-	-
18.26.12.3314	Mobil Oil Co.	D.E. Fanning #3	3,301	Oil	1,800	-	-	1,052	-	-
18.26.12.423	Yates Pet. Co.	Gates Whatley Fed.#1	3,286	Oil	1,748	908	-	1,007	-	-
18.26.13.111	Maddox Energy Co.	Higgins Trust #1	3,287	Gas	9,342	950	-	1,042	2,424	-

(Second half of Table 3).

Production or Injection Interval	QW Source	Depth	CL (ppm)	TDS (mg/l)	Depth to base fresh water	Comments
-	Psa	-	-	-	4,409	top Queen 492
-	Psa	1,360	9,000	16,000	-	
-	-	-	-	-	2,150	
-	-	-	-	-	2,130	
-	-	-	-	-	2,050	
-	-	-	-	-	1,950	
-	Psa	1,300	7,500C	13,500C	-	C.S. - QW Doubtful
-	-	-	-	-	-	
-	Psa	1,410	3,000C	6,000C	1,415	
-	-	-	-	-	1,700	top Queen 440
-	Psa	1,335	12,000C	21,000C	-	QW doubtful
-	Psa	1,345	7,000C	12,000C	-	QW doubtful
-	-	-	-	-	1,850	
-	-	-	-	-	1,809	Water production to 876 ft.
1,672-82	-	-	-	-	-	
1,546-88	-	-	-	-	-	C.S., - top Queen 415
1,513-1,748	-	-	-	-	-	C.S., - water: 1107-1130
1,651-1,668	-	-	-	-	-	
-	Psa	1,893	13,000C	23,000C	-	
1,696-1,706	-	-	-	-	-	C.S.
8,853-8,888	-	4,550	17,500	30,207C	-	
1,646-1,678	-	-	-	-	-	
1,636-68	-	-	-	-	-	top Slaughter 1638
1,654-1,672	Psa	1,700	140,000	234,700C	-	C.S.
-	Psa	1,700	155,800	264,700C	-	Cored:1630-1803, Psa avg. Poros. 5.31%, avg. perm.
-	-	-	-	-	-	Cored: 967-986, Pgb avg. poros. 17.2%, avg. perm. Avg. perm. .1 md.
9,046-9,102	-	-	-	-	-	
-	Psa	1,742	160,100	272,200	-	
-	Psa	1,700	160,000	268,000C	-	
-	Psa	1,680	39,290	66,500C	-	top Slaughter 1649
-	-	-	-	-	-	Water zones: 225-430, 440-500, 540-810, top queen 310.

Table 3 (continued).

Location	Owner	Well Name	Well Elevation	Well Type	Total Depth	Depth of Casing	Depth to top Grayburg	Depth to top San Andres	Depth to top Glorietta	Depth to base Upper Porosity
18.26.13.124	Gulf Oil Co.	(Nat. Leavitt 11) #100C	2,995	Pgb, Inj	982	960	972	-	-	-
18.26.13.132	Gulf Oil Co.	(Nat. Leavitt 9) #138	3,300	Inj	1,770	1,770	970	-	-	-
18.26.13.114	Gulf Oil Co.	(Nat. Leavitt 2) #101	3,298	Pgb, Oil	978	960	967	-	-	-
18.26.13.132	Gulf Oil Co.	(J. Mac Leavitt 3) #103	3,300	Pgb, Inj	975	955	-	-	-	-
18.26.13.2523	Maddox Energy Co.	Leavitt Com. #1	3,295	Gas	9,355	1,952	-	-	2,441	-
18.26.13.312	Gulf Oil Co.	(Illamex Fanning 2)#143	3,304	Oil	1,772	1,100	695	993	-	-
18.26.13.321	Gulf Oil Co.	(Nat. Fanning 1) #142	3,297	Oil	1,826	1,103	-	1,032	-	-
18.26.13.411	Gulf Oil Co.	(Fanning A-2) #141	3,295	Inj	1,953	1,096	833	1,068	-	-
18.26.13.431	Gulf Oil Co.	(Kewanee 2) #153	3,290	Oil	2,020	2,015	908	1,134	-	-
18.26.14.131	Kewanee Oil Co.	Atoka Grayburg Unit #1	3,314	Oil	955	785	-	-	-	-
18.26.14.213	Dean A. Wolf	Jerry Nelson Com. #1	3,314	Gas	9,150	1,120	-	-	2,310	-
18.26.14.214	Gulf Oil Co.	(Illamex Terry) #131	3,305	Inj	1,700	1,100	-	-	-	-
18.26.14.222	Gulf Oil Co.	(Illamex 4) #130	3,300	Inj	1,742	1,100	950	-	-	-
18.26.14.224	Gulf Oil Co.	(Nat. Leavitt 10) #102	3,302	Pgb, Inj	965	950	960	-	-	-
18.26.14.233	Llano Inc.	Terry Com. #1	3,312	Gas	9,303	1,170	-	-	2,327	-
18.26.15.4132	Std. Oil of Texas	C.R. Martin et. al. #1	-	Gas	9,086	-	-	-	-	-
18.26.17.424	Yates Pet. Co.	Sears #1	3,385	Dry	1,678	1,219	-	990	-	Water: 1146-1208
18.26.18.1310	Maddox Energy Co.	Jones D #4	3,285	Oil	1,965	855	-	-	-	-
18.26.18.332	Yates Pet. Co.	Vandiver CN #1	3,427	Gas	8,900	1,212	-	848	2,201	-
18.26.18.441	Fundamental Oil	Thorpe Sears #1	3,412	Gas	8,959	1,210	-	883	-	1,218
18.26.19.141	Mtn. States Pet.	McCan Gas Com. #1	3,432	Gas	8,954	1,200	605	820	-	-
18.26.21.220	Mobil Oil Co.	Mildred Lee #1	3,358	Oil	1,685	1,125	695	920	-	-
18.26.26.341	Bassett & Birney	Kimbell #2	3,316	Oil	1,115	1,000	-	-	-	-
18.26.27.341	Ralph Nix	Hondo Kelly #1	3,360	Gas	9,385	1,250	775	1,107	2,540	-
18.26.34.113	Yates Pet. Co.	Wright J.A. #4	3,361	Oil	6,040	1,145	-	1,066	2,632	-
18.26.34.134	Magnolia Oil Co.	G.F. Wright #1	3,367	Oil	4,199	1,295	-	1,047	2,612	-

(Second half of Table 3)

Production or Injection Interval	QW Source	Depth	CL (ppm)	TDS (mg/1)	Depth to base fresh water	Comments
972-982	-	-	-	-	-	C.S., Cored: 977-986, Pgb avg. poros. 15.42%, avg. perm. .40 md.
1,712-1,722	-	-	-	-	-	Cored: 1645-1695, avg. poros. 4.08%, avg. perm. 0.16 md.
-	-	-	-	-	-	Water: 710-730
969-975	-	-	-	-	-	
9,031-9,093	-	-	-	-	-	Water: 225-526,636-675, 718-776
1,762-1768	-	-	-	-	-	top Queen 320' top Slaughter 1765
1,783-1,793	-	-	-	-	-	top Slaughter 1783
1,681-1,833	-	-	-	-	-	C.S.
1,758-1,914	-	-	-	-	-	top Queen 406'
1,670-1,680	-	-	-	-	-	top Slaughter 1670'
960-965	-	-	-	-	-	
1,650-1,664	-	-	-	-	-	
785-955	-	-	-	-	-	Open hole, no water below 788'
-	Psa	1,356	7,800	14,000C	-	
-	-	-	-	-	1,660	
-	-	-	-	-	-	
-	Psa	-	215,000	360,000C	-	
1,710-1,873	-	-	-	-	-	Water: 765-855, C.S.
-	-	-	-	-	2,190	
-	-	-	-	-	2,210	
-	-	-	-	-	-	
-	Psa	1,576	137,000	228,900C	-	
-	-	-	-	-	1,770	
-	-	-	-	-	1,790	
-	-	-	-	-	-	
-	Pya	2,994	175,000	293,000C	-	

Table 3 (continued).

Location	Owner	Well Name	Well Elevation	Well Type	Total Depth	Depth of Casing	Depth to top Grayburg	Depth to top San Andres	Depth to top Glorietta	Depth to base Upper Porosity
18.27.6.3314	Hondo Oil & Gas	W. M. Stirling Jr. #1	3,359	Oil	1,775	-	908	1,155	-	-
18.27.7.221	Atlantic Refining	Vandagriff Federal C #3	3,999	OIl	1,826	1,205	-	1,205	-	-
18.27.7.2132	Atlantic Refining	Vandagriff Federal A #2	3,388	Oil	1,824	1,200	-	1,150	-	-
18.27.7.4223	Hondo Oil & Gas	Gant Federal #2	3,359	Oil	1,824	-	-	1,125	-	-
18.27.18.131	Gulf Oil Co.	Jones D #4	3,285	Oil	1,965	955	860	1,084	-	-
18.27.18.222	Norwood Oil Co.	Gulf Jackson	3,280	Oil	1,785	1,000	-	1,448	-	-
18.27.19.340	British Amer. Oil	Pluma Unit #1	3,295	Dry	6,015	1,388	1,066	1,335	-	-
18.27.20.310	Parker Drilling	Kaiser #1	3,290	Oil	1,948	1,140	-	-	-	-
18.27.20.3124	Yates Oil Co.	Rio Pecos CB #2	3,290	Gas	9,650	1,558	-	-	3,008	-
18.27.27.130	ARCO	Trigg Federal #1	3425	Gas	9,935	2,500	-	1,875	3,580	-
18.27.28.131	John H. Trigg	Federal B-#3	3,416	Oil	1,666	-	1,382	1,661	-	-
18.27.28.222	Harlan Oil Co.	Federal B #2	3,405	Pgb, Oil	1,625	248-1336	1,368	-	-	-
18.27.28.3114	Yates Oil Co.	Gorman Federal JD #1	3,390	Pgb, Oil	1,680	1,678	1,389	1,675	-	-
18.27.28.320	John Trigg	Federal Resler #1	3,405	Dry	1,778	plugged	1,476	1,771	-	-
18.27.28.420	Yates Oil Co.	Federal GG #1	3,418	Dry	1,100	254	-	-	-	-
18.27.29.120	Yates Oil Co.	Rio Pecos BG Com. #1	3,305	Gas	9,768	1,448	1,190	1,455	3,079	-
18.27.29.222	Hondo Oil & Gas	Federal T #1			1,585	-	-	1,574	-	-

(Second half of Table 3).

Production or Injection Interval	QW Source	Depth	CL (ppm)	TDS (mg/l)	Depth to base fresh water	Comments
-	Psa	1,700	134,500	228,000C	-	Cored 1680-1716 Psa avg. poros 5.12%, avg. perm. 0.22 md.
-	Psa	1,760	119,800	206,000	-	
-	-	-	120,000	207,300	-	
-	-	-	-	-	-	Cored:1093-1101 Pgb avg porosity 6.82%, avg. perm. 0.22 md
1,710-1,873	-	-	-	-	-	Water: 765-855
1,048-1,578	-	-	-	-	-	
-	-	-	-	-	-	Top Queen 574
1,233-95	-	-	-	-	-	CS, Water 570-750
9,265-9,303	-	-	-	-	-	
9,781-95	-	-	-	-	-	Queen 1,065 CS
-	-	-	-	-	-	Cored: 1,595-1,666 avg. poros 8.94%, avg. perm. .15 md
1,578-1,591	-	-	-	-	-	CS Top Queen 885
1,604-1621	-	-	-	-	-	Water: 1,150-1,300
1,657-1,659	Pgb	1,673	66,970	$111,900_c$	-	Top Queen 915 Water:11,80-1360
-	-	-	-	-	-	Top Queen 994 Water: 1,250-1,430
-	-	-	-	-	-	Top Queen 1040
9,336-9,357	-	-	-	-	-	Top Queen 700
-	Pgb	1,570	160,000	$268,000_c$	-	

Table 4. Lithologic descriptions of units identified in Figure 2.

1. Alluvial Fill - unconsolidated sands, silts, and gravels.

2. Yates Formation - gypsum with minor dolomite and siltstone.

3. Seven Rivers Formation - anhydrite with shale, dolomite and sandstone.

4. Grayburg Formation - sandstone with some sandy dolomite.

5. San Andres Formation - limestone and dolomite, with a more sandy and porous upper portion. The lower portion, or Slaughter Zone, has several anhydrite horizons and irregular high porosity development; the area between the upper zone and Slaughter lacks good porosity development.

6. Glorieta Sandstone Member - sandstone and siltstone with calcareous cement.

7. Yeso Formation - dark gray shales with carbonate cemented siltstones, limestones and anhydrite.

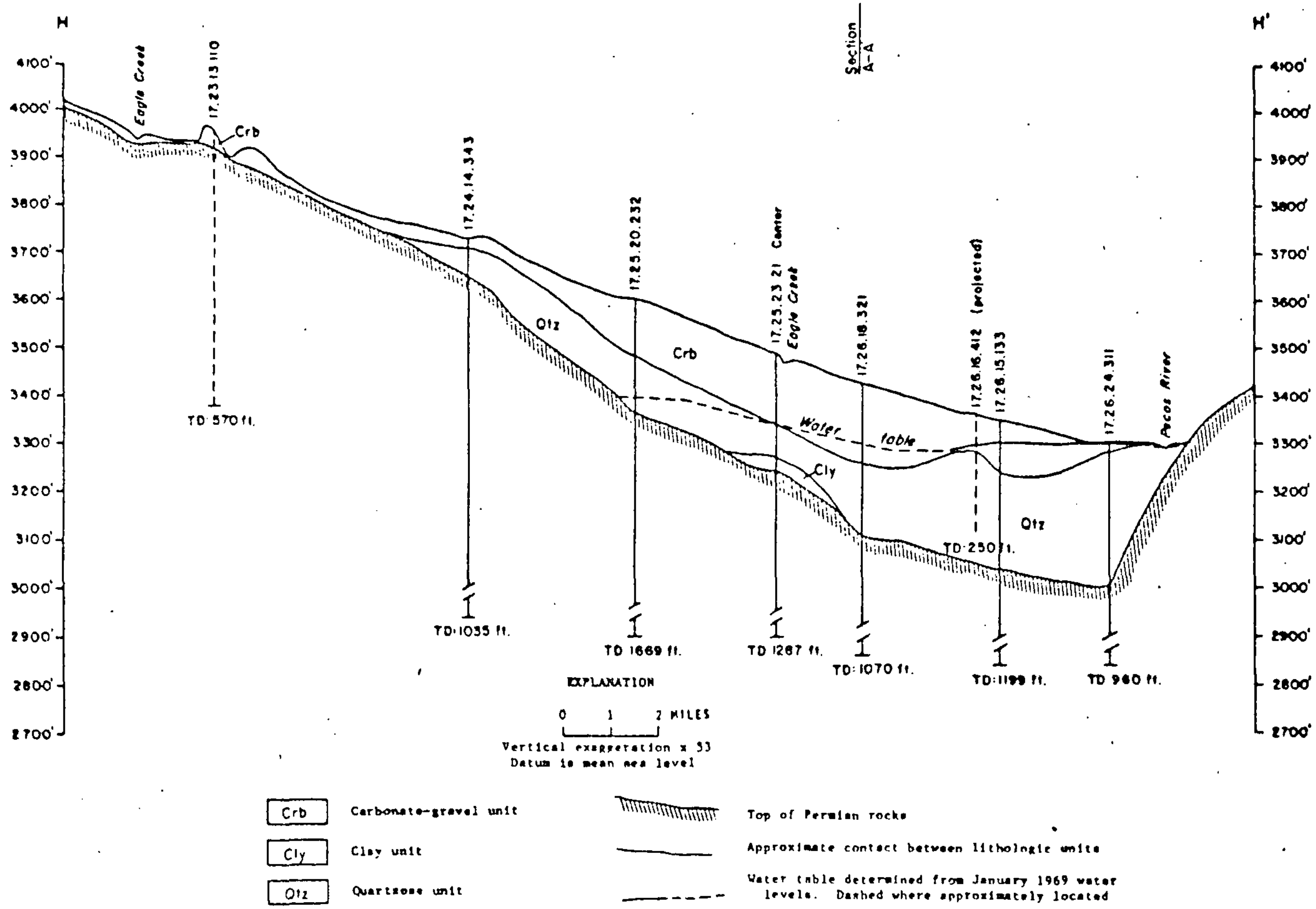


Figure 10.--Section H-H' showing the water table and the lithology of valley fill.

Lyford Op. F

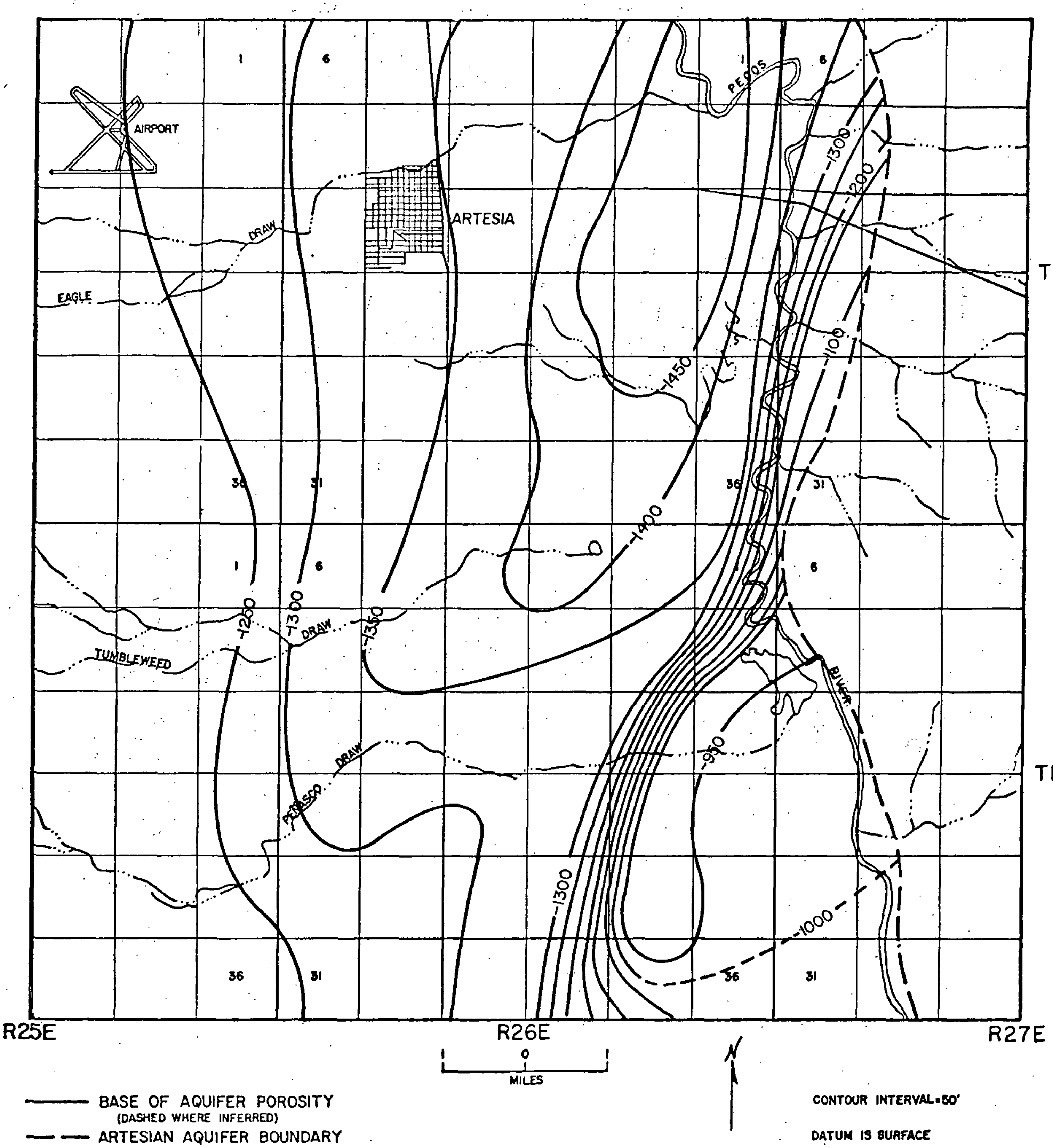


Figure 15: Base of Designated Aquifer.

Source: M. Holland, 1979.

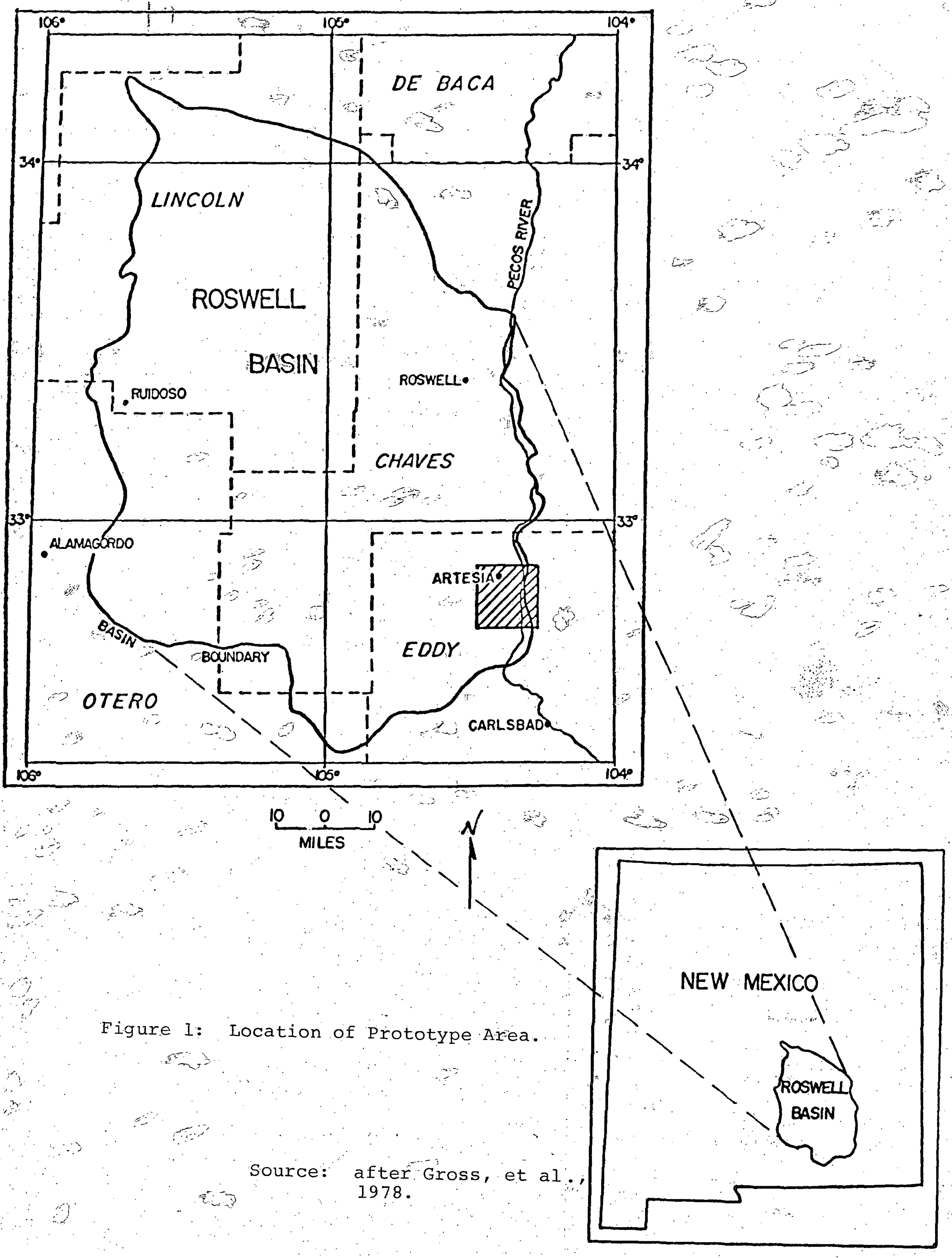


Figure 1: Location of Prototype Area.

Source: after Gross, et al., 1978.

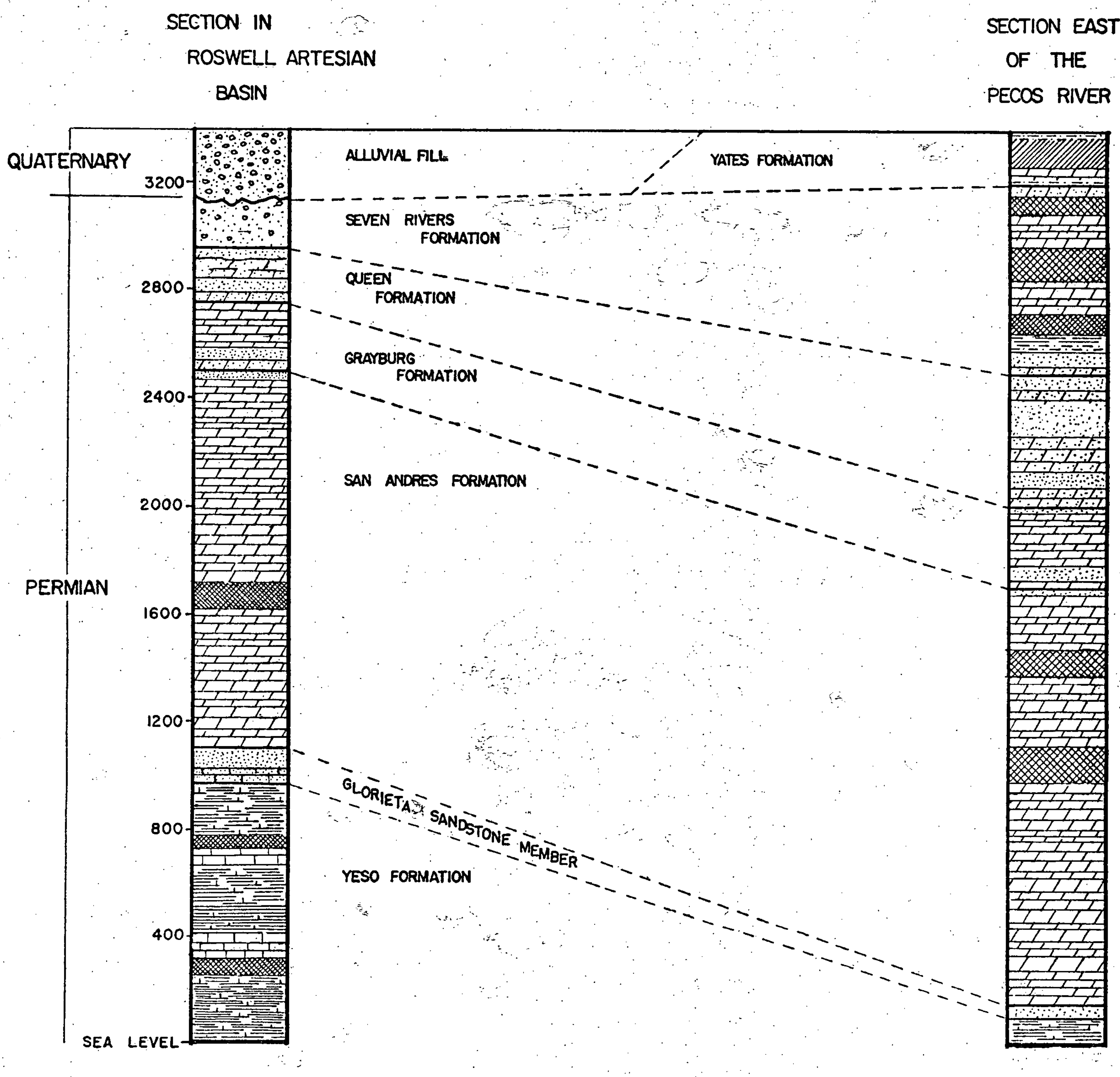


Figure 2: GENERALIZED STRATIGRAPHIC COLUMN ARTESIA AREA

Source: M. Holland, 1979.

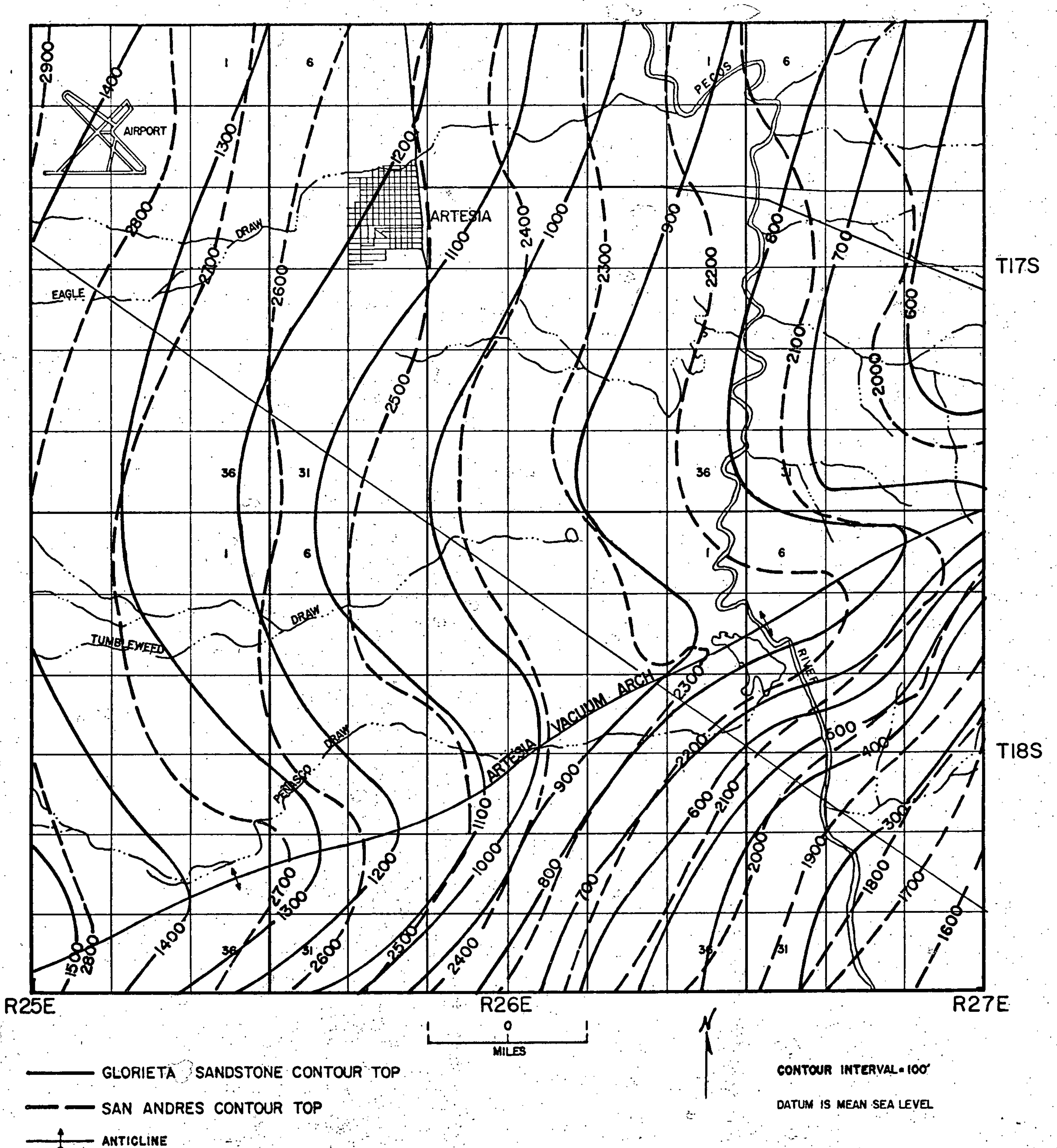


Figure 3: Structure Contour on San Andres Formation and Underlying Glorieta Sandstone Member.

Source: Modified after Maddox, 1969 by M. Stahl and M. Holland, 1979.

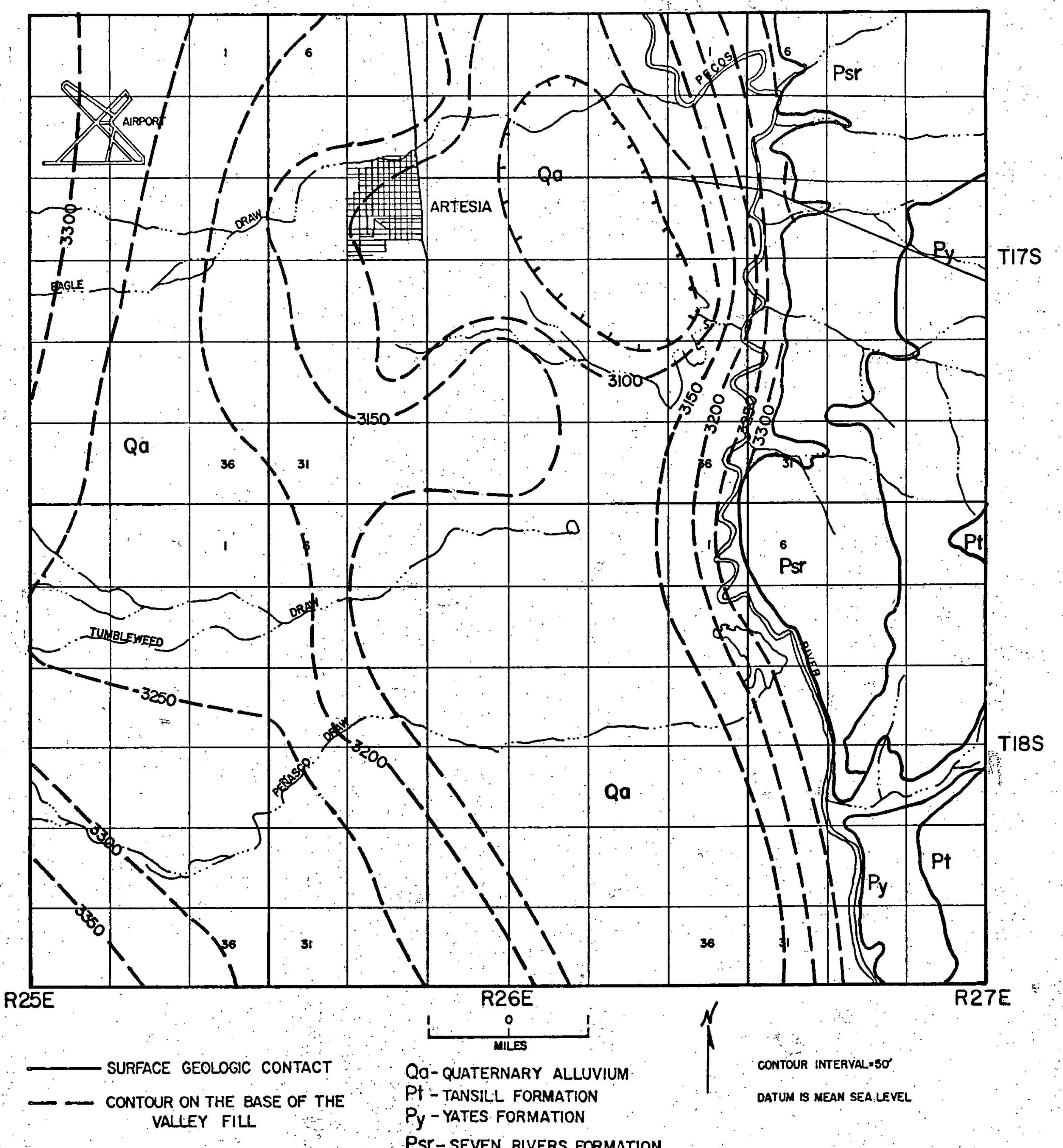


Figure 4: Surface Geology.
Source: Modified after Kelley, 1971 and Lyford, 1973 by M. Stahl.

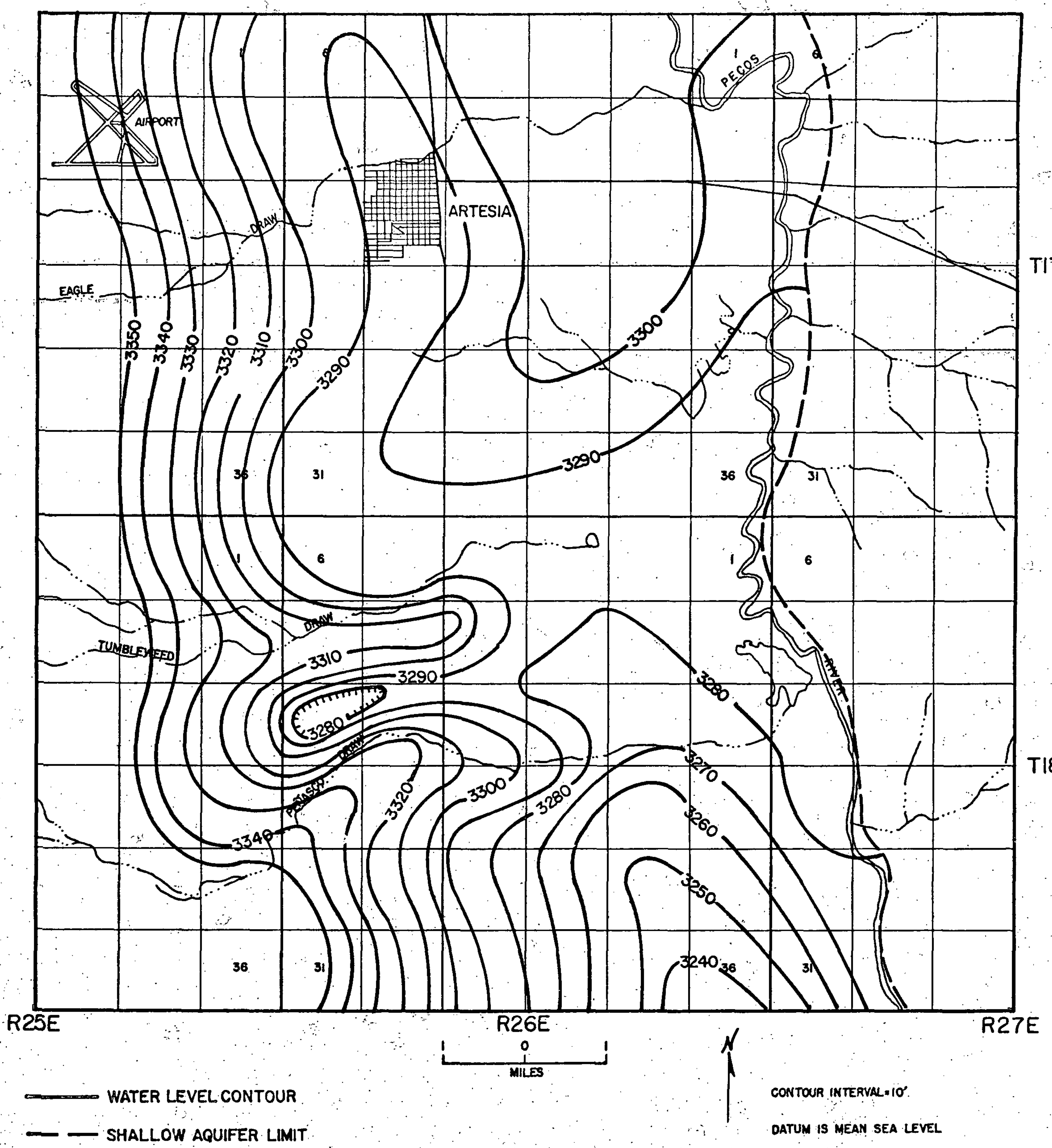


Figure 5: Potentiometric Surface of Shallow Aquifer.

Source: after E. Welder, 1977.

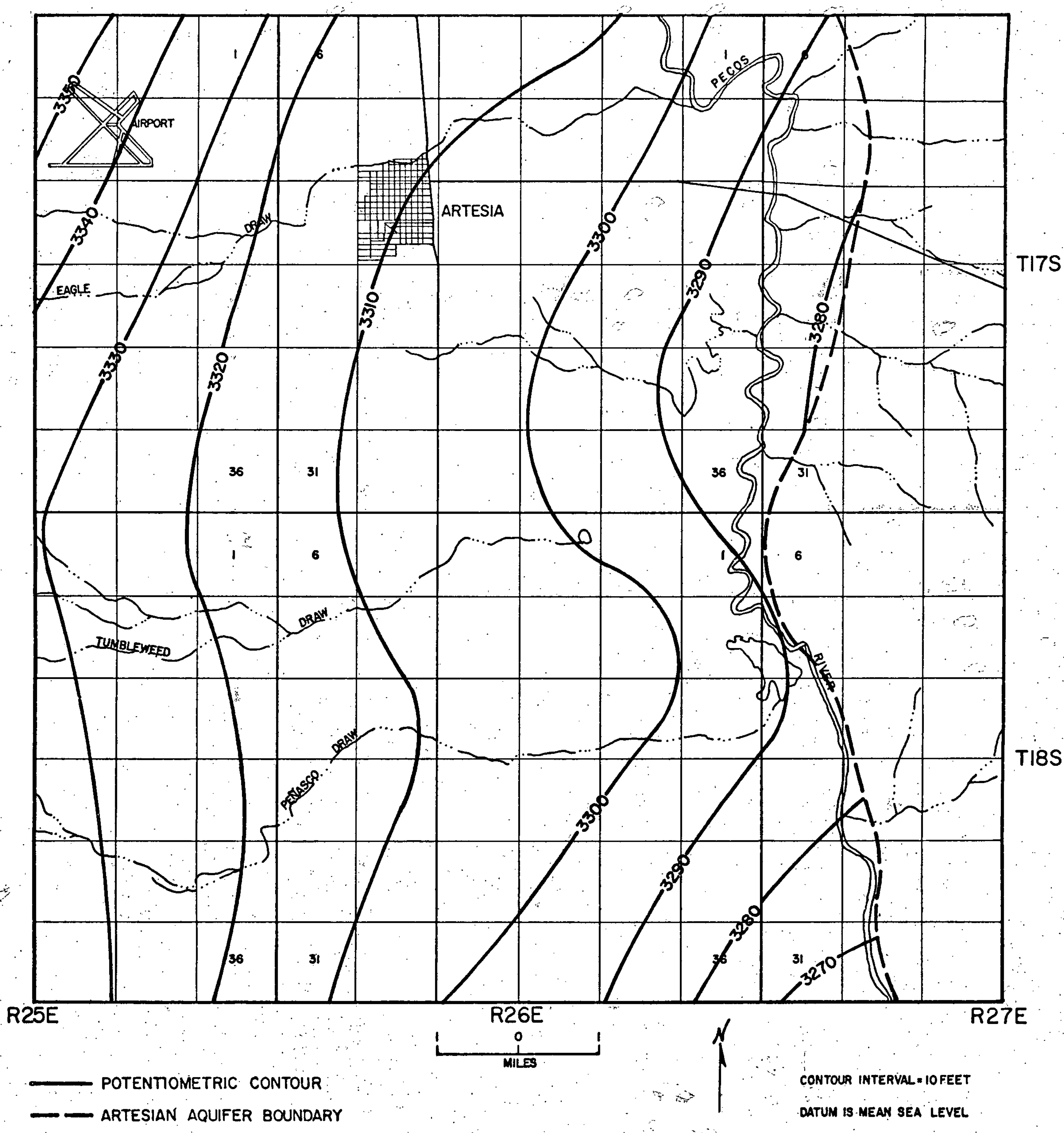


Figure 6: Potentiometric Surface of Artesian Aquifer.

Source: after E. Welder, 1977.

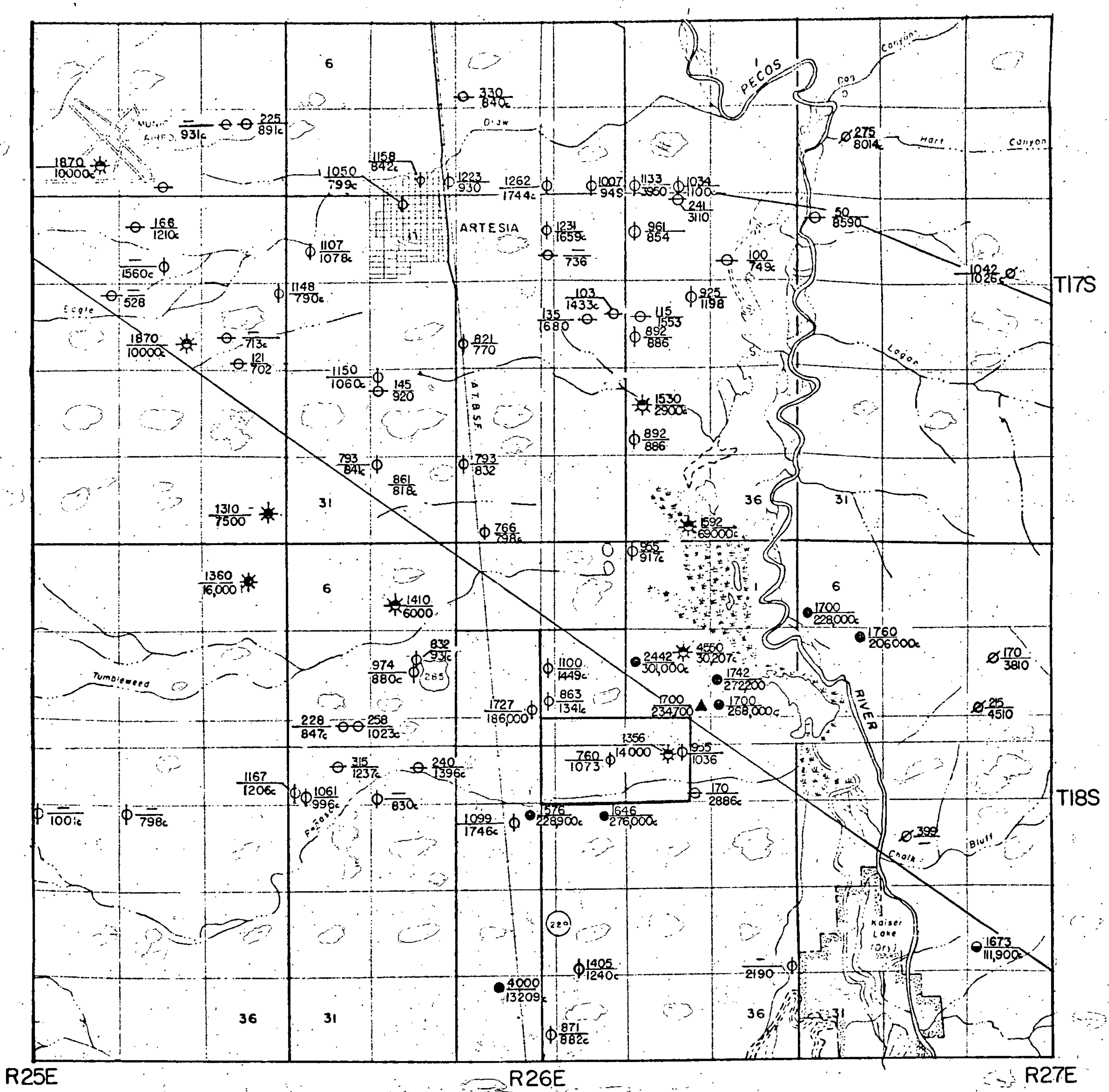


Figure 7: WATER QUALITY WELL PLOT

1 0 1
MILES

O DEPTH OF ANALYSIS (FEET BELOW SURFACE) / TOTAL DISSOLVED SOLIDS IN PPM (c INDICATES CALCULATED FROM CHLORIDES)

- WATER WELL-SHALLOW AQUIFER
- WATER WELL-ARTESIAN AQUIFER
- WATER WELL-ARTESIA GROUP
- OIL WELL-SHOW OF WATER
- OIL WELL
- GEOPHYSICAL DATA WELL-DEEP GAS
- PENNSYLVANIAN GAS WELL

Source: M. Holland and M. Stahl, 1979.

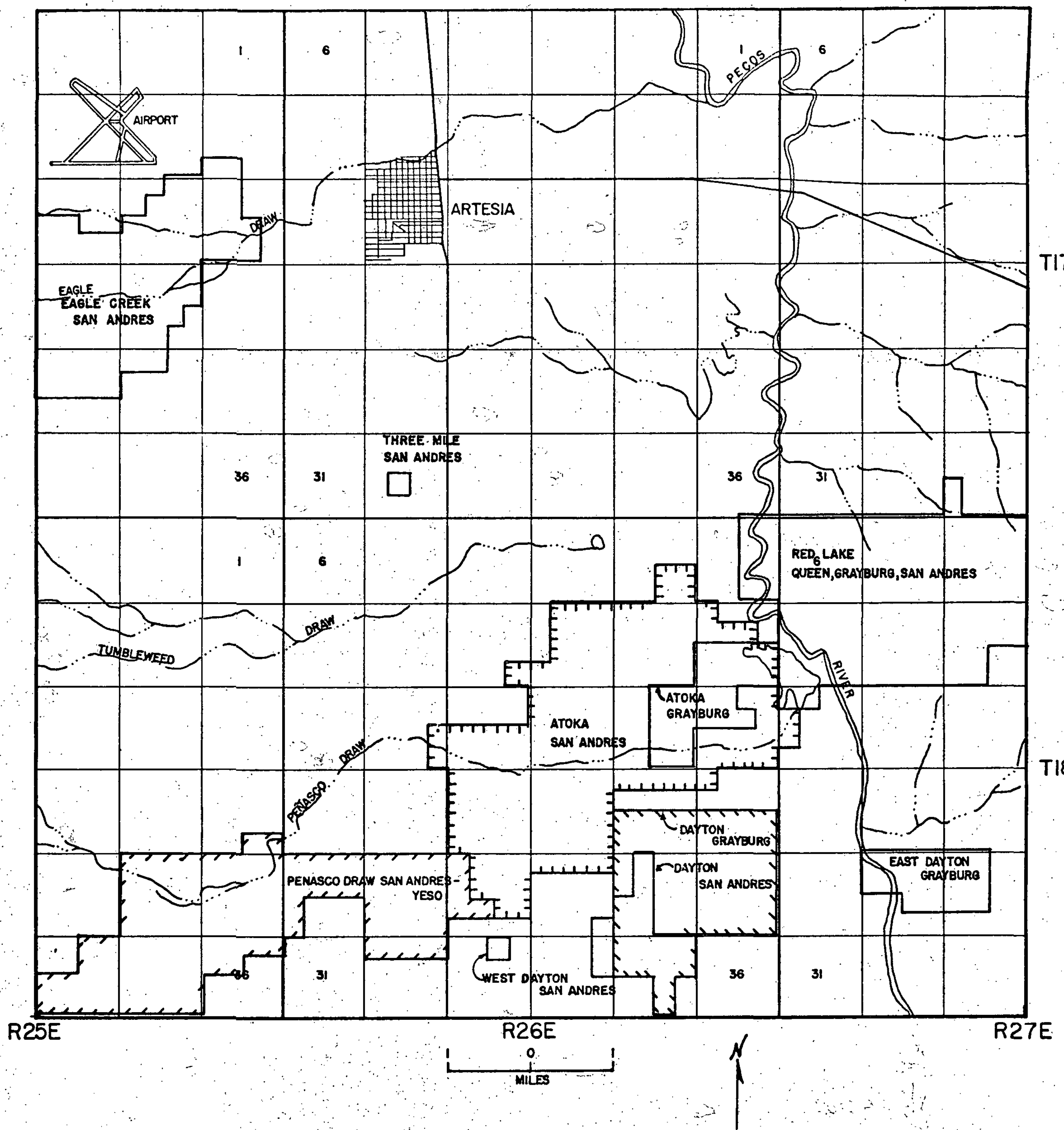


Figure 8: Location of Shallow Oil and Gas Pools.

Source: M. Holland, 1979.

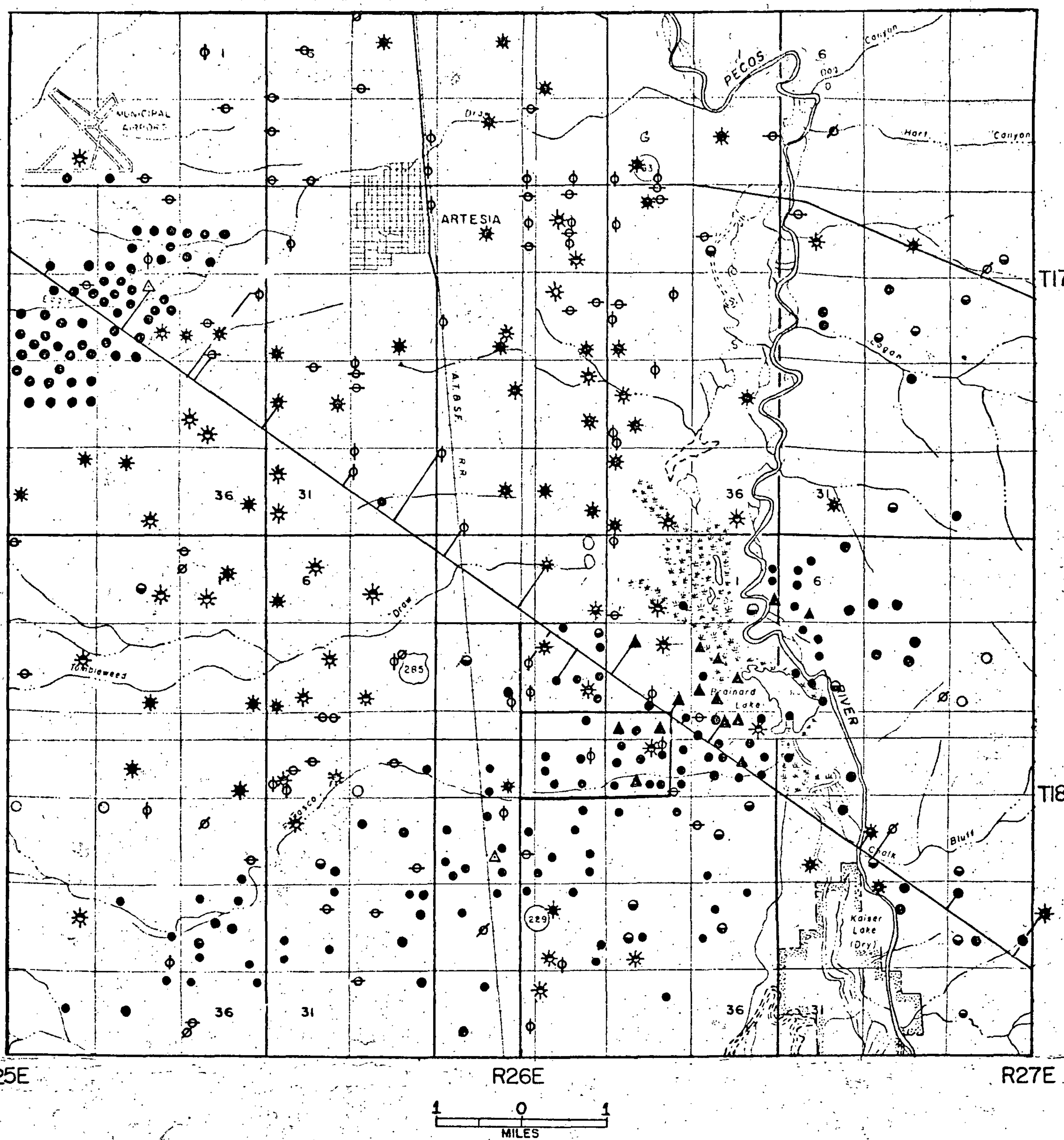


Figure 9: REPRESENTATIVE INFORMATION WELLS (OIL, GAS, WATER, INJECTION)

- WATER WELL–SHALLOW AQUIFER
- WATER WELL–ARTESIAN AQUIFER
- WATER WELL–UPPER ARTESIA GROUP
- OIL WELL
- OIL WELL–SHOW OF WATER
- PENNSYLVANIAN GAS WELL
- GAS WELL–GEOPHYSICAL DATA
- GAS WELL–SHOW OF WATER
- INJECTION WELL
- SALT WATER DISPOSAL

NOTE: ALL WELLS IN AREA NOT DEPICTED
SOME WELLS WERE DRY HOLES BUT ARE DATA SOURCE
SOME WELLS NOW PLUGGED AND ABANDONED

Source: M. Holland, 1979.

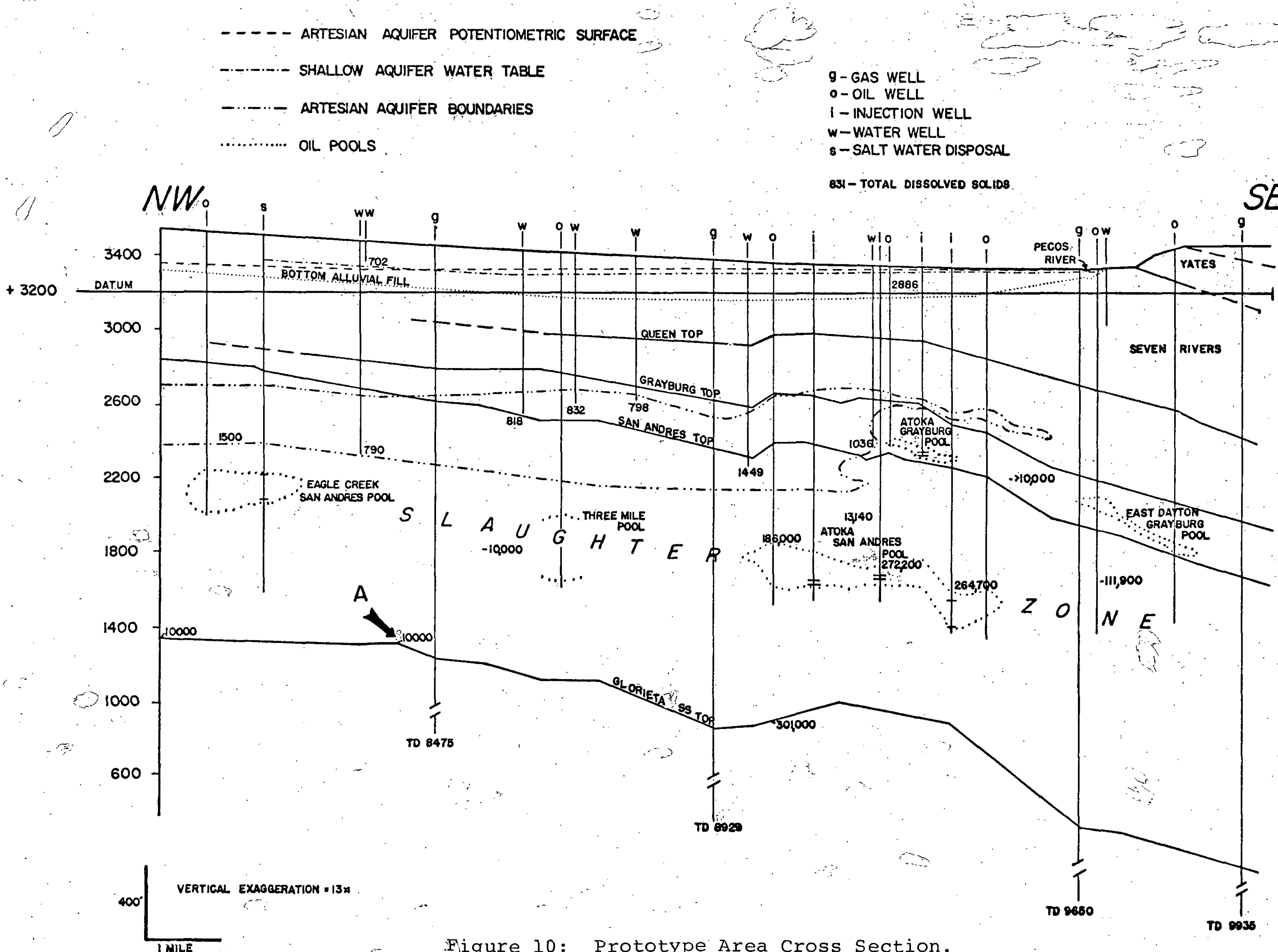


Figure 10: Prototype Area Cross Section.

Source: M. Holland, 1979.

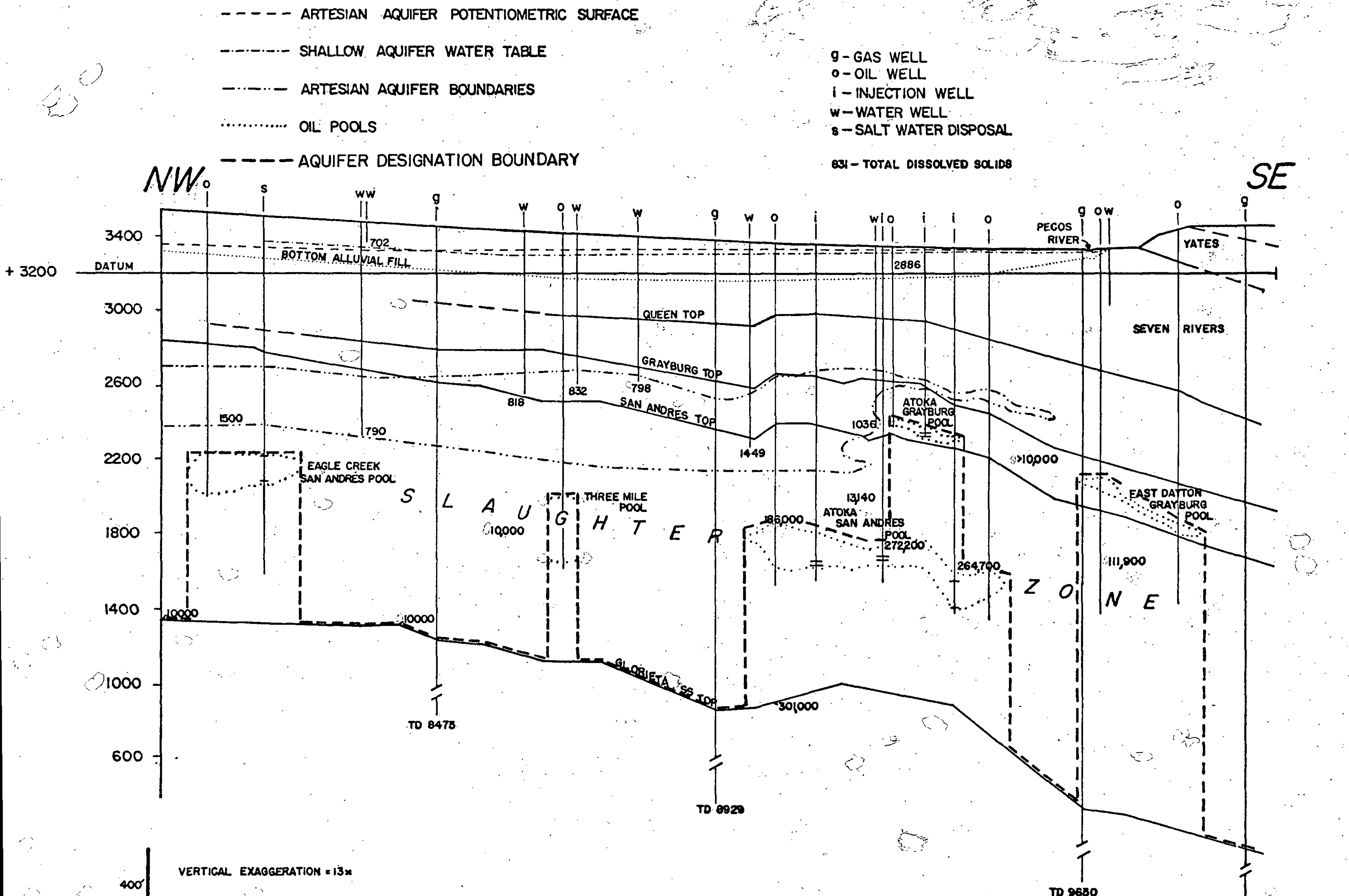


Figure 11: Aquifer Designation with Exemption of Oil and Gas Pools.

Source: M. Holland, 1979.

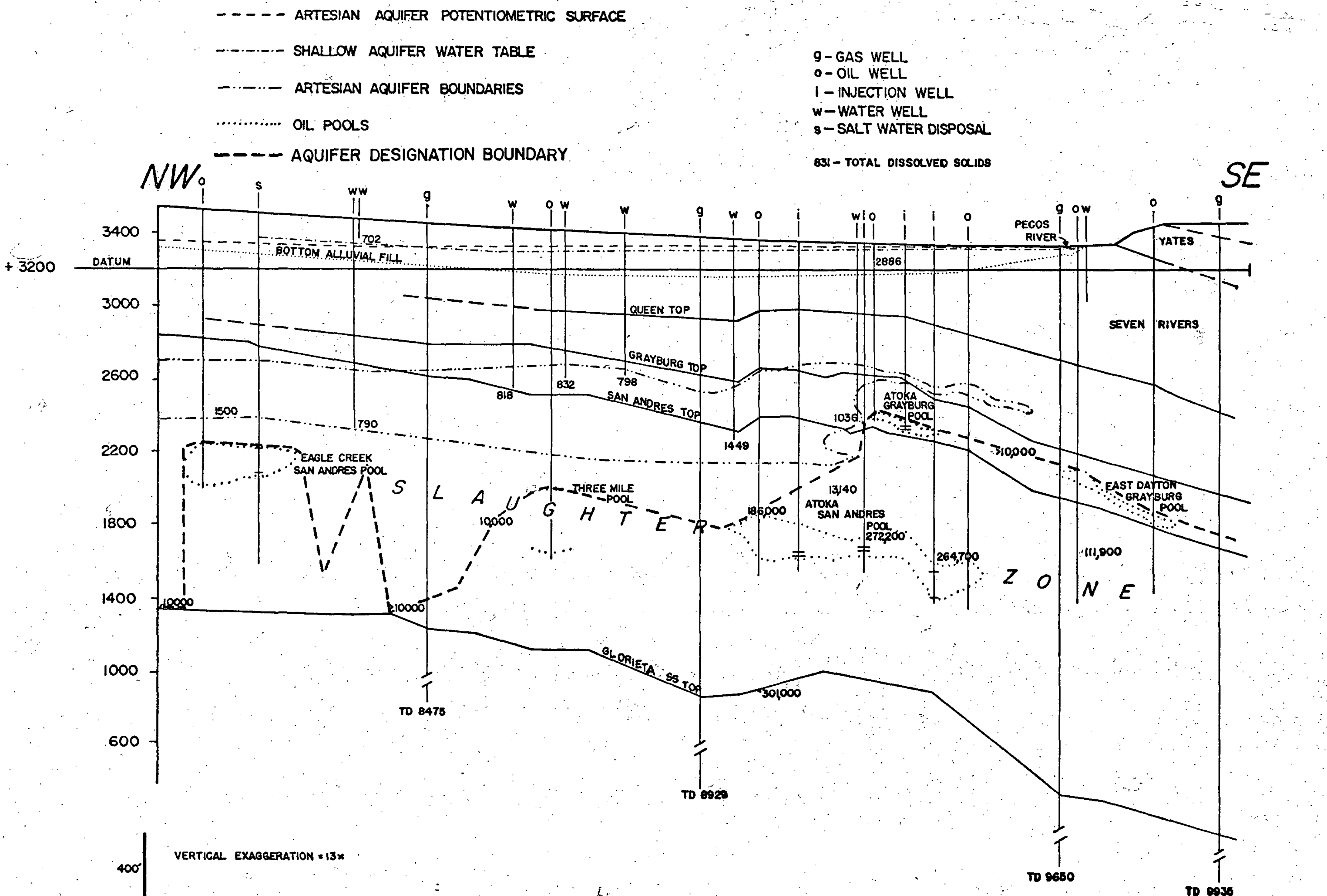


Figure 12: Aquifer Designation Utilizing TDS Data.

Source: M. Holland, 1979.

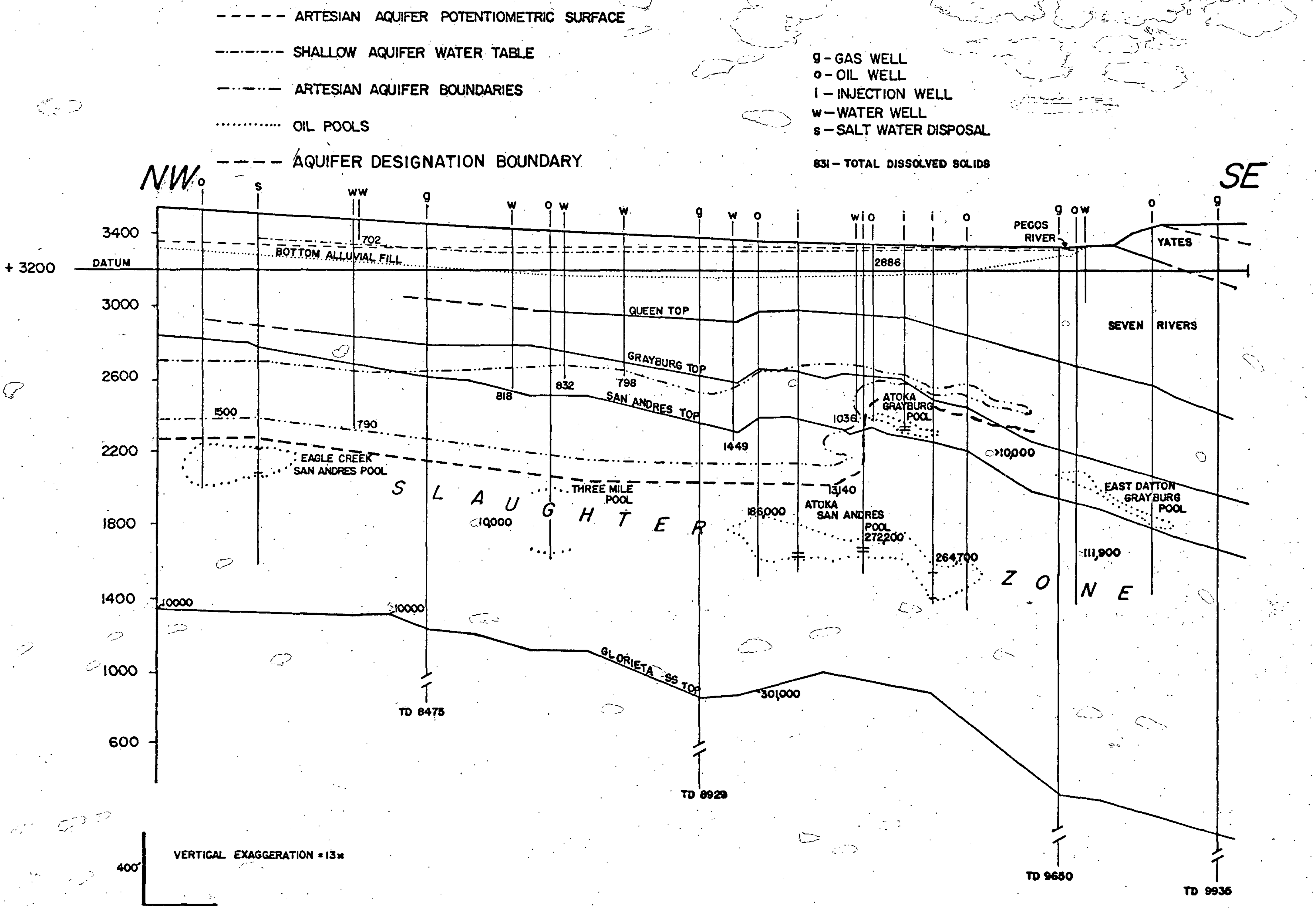


Figure 13: Aquifer Designation Based on Aquifer Porosity Limit.

Source: M. Holland, 1979.

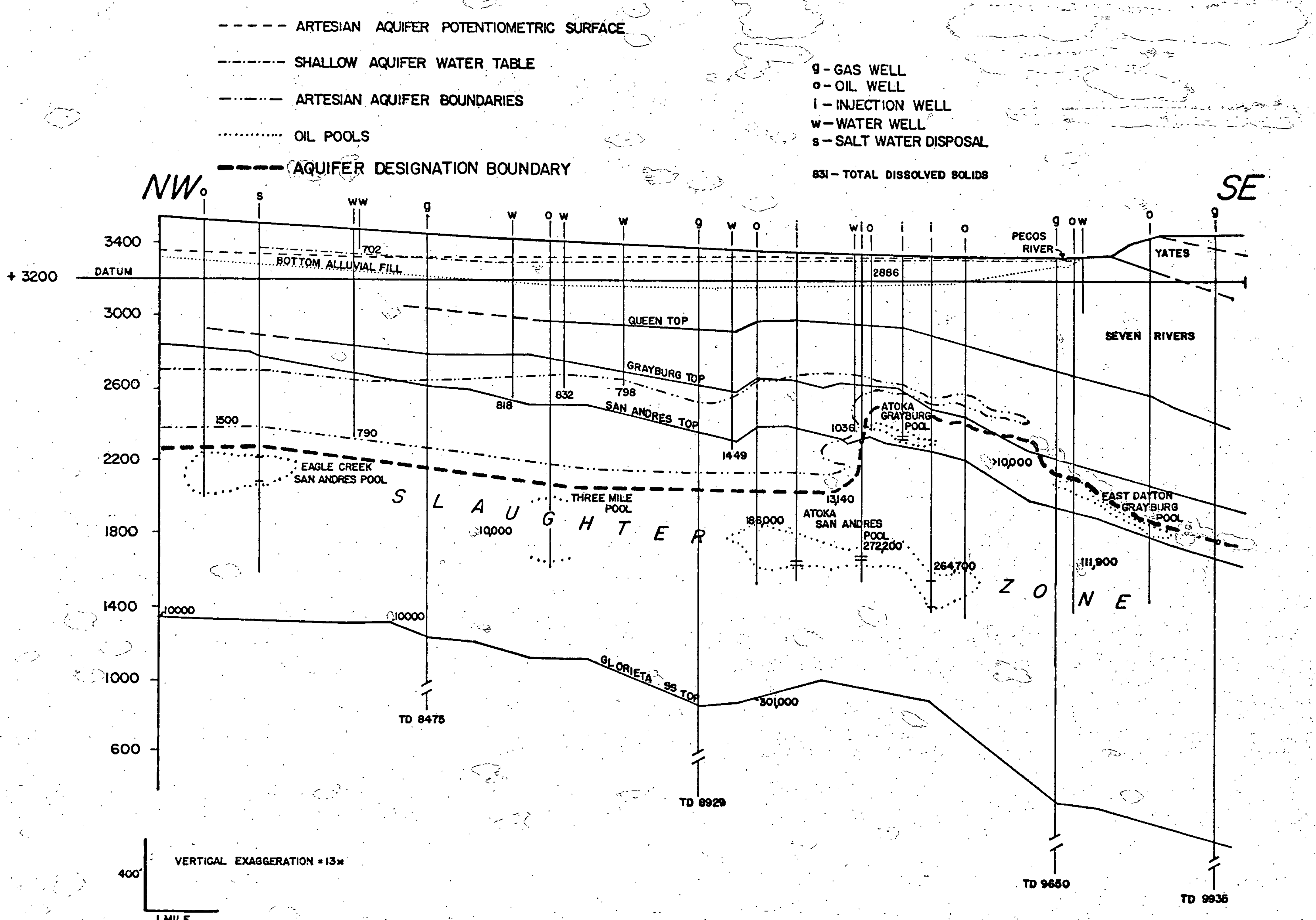


Figure 15: Aquifer Designation Based on TDS and Water Productivity.

Source: M. Holland, 1979.

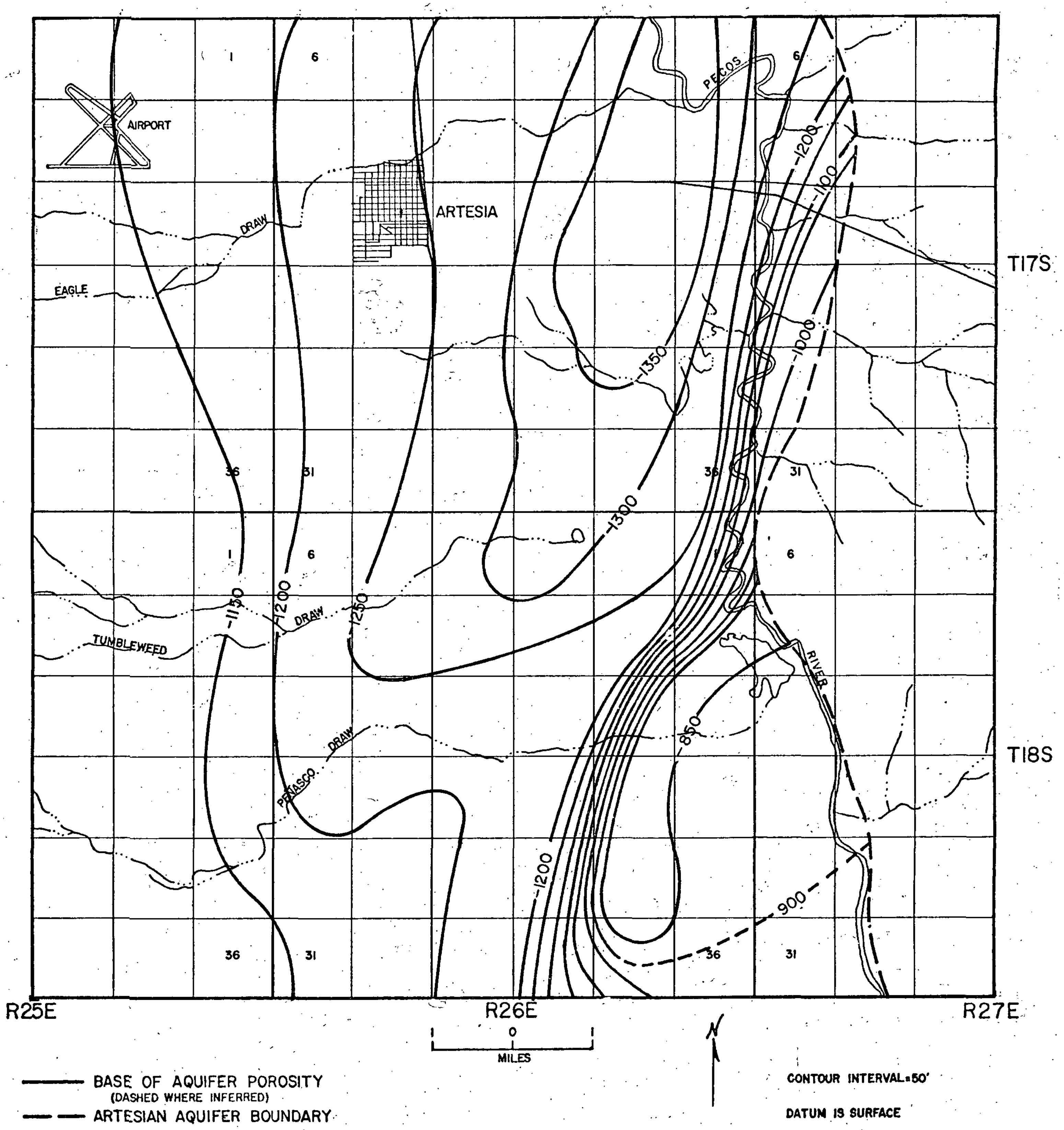
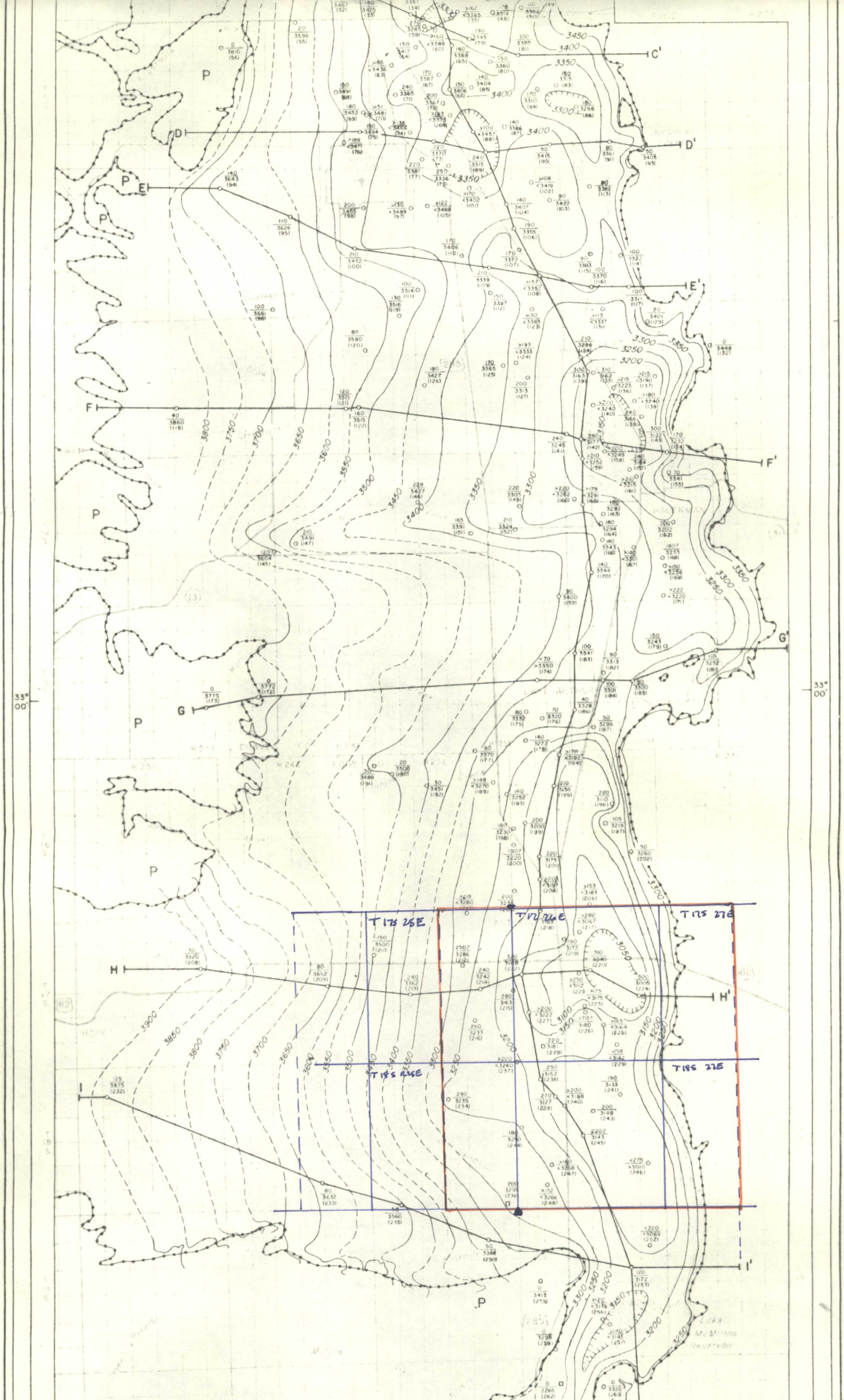


Figure 14: Base of Artesian Aquifer.

Source: M. Holland, 1979.



Base from U.S. Geological Survey
Roswell, 1962 and Carlsbad, 1954
Scale 1:250,000

Compiled by F.P. Lyford, 1973

FIGURE 12.--MAP SHOWING CONFIGURATION OF THE BASE OF THE VALLEY FILL, ROSWELL-ARTESIA AREA, NEW MEXICO

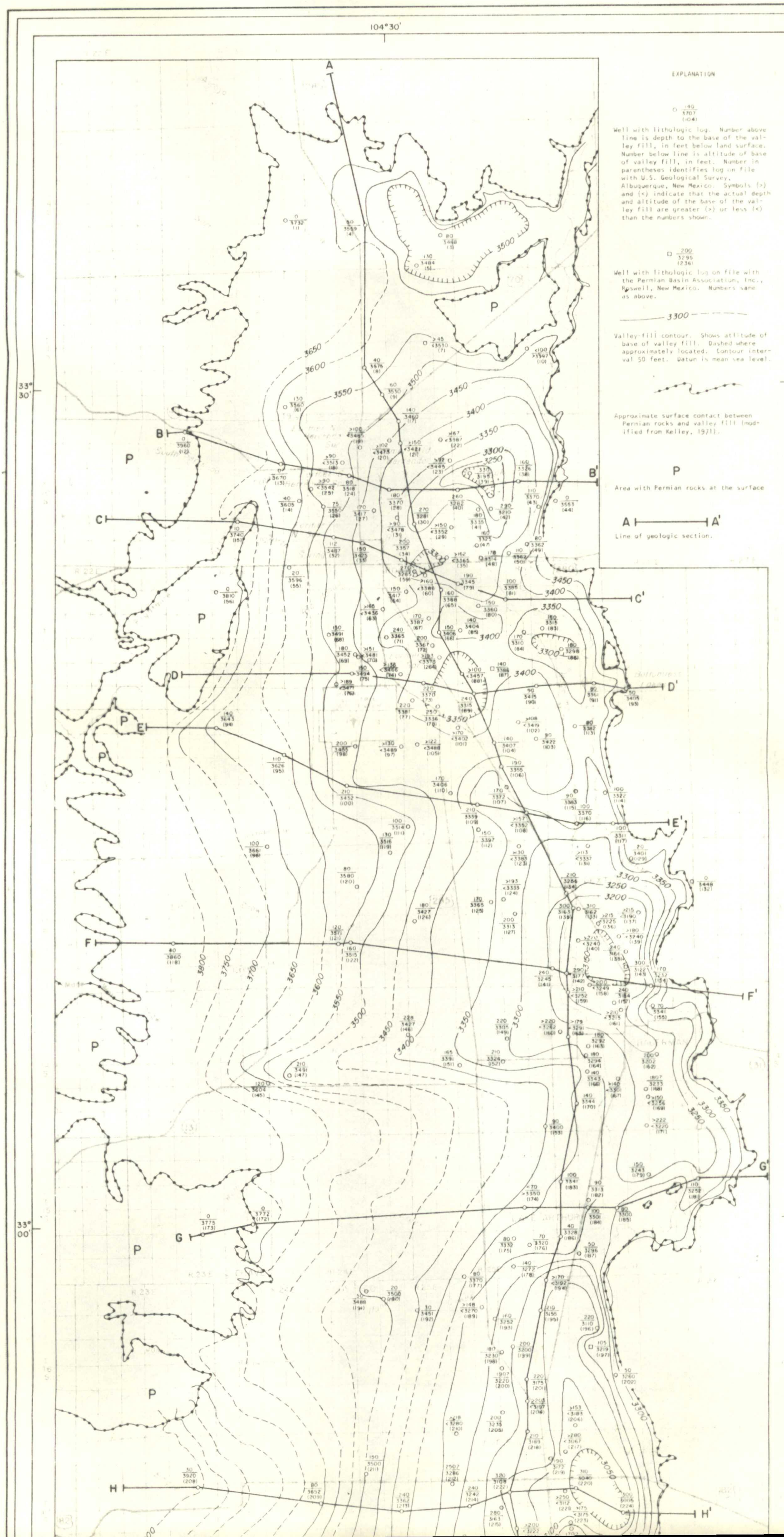
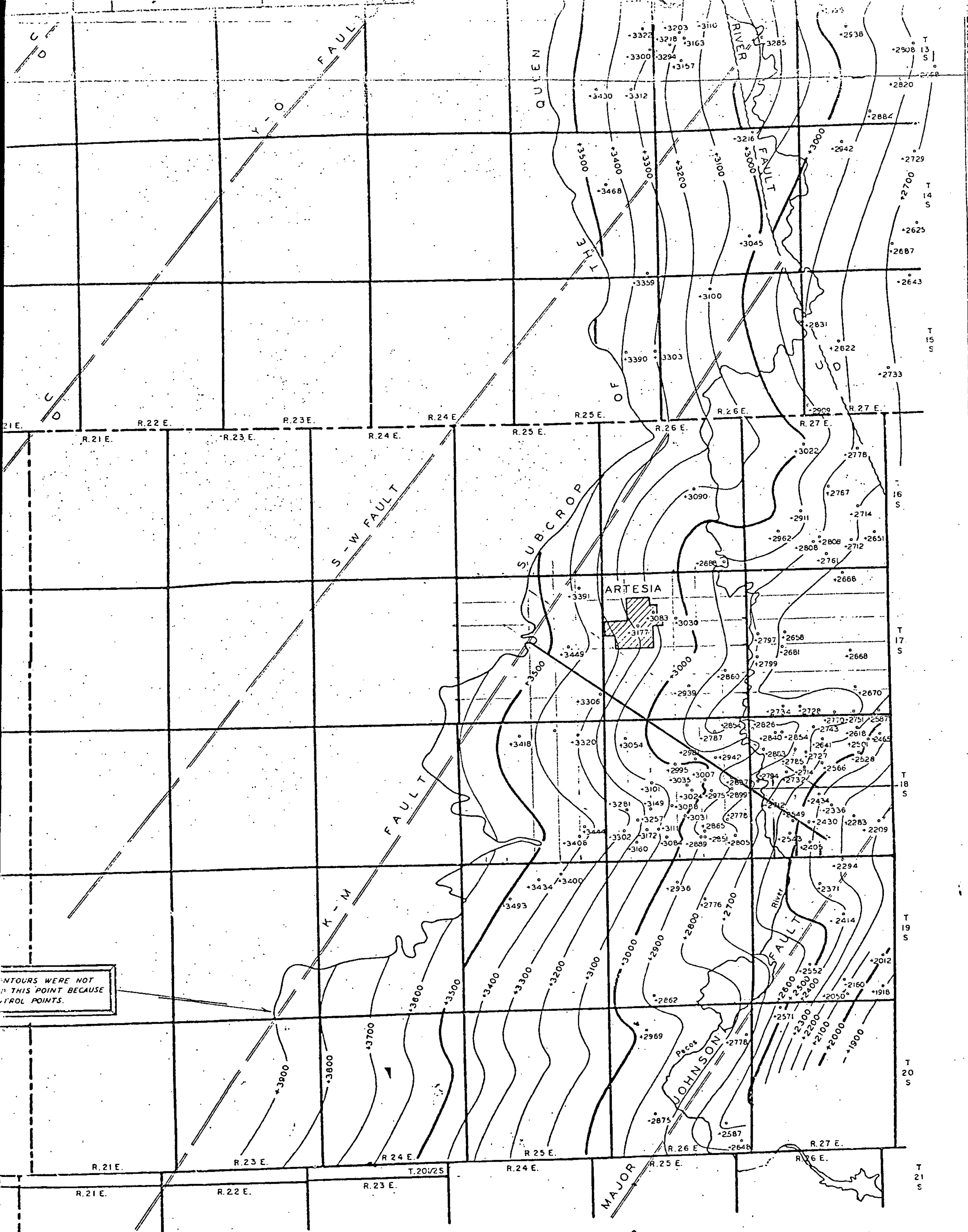
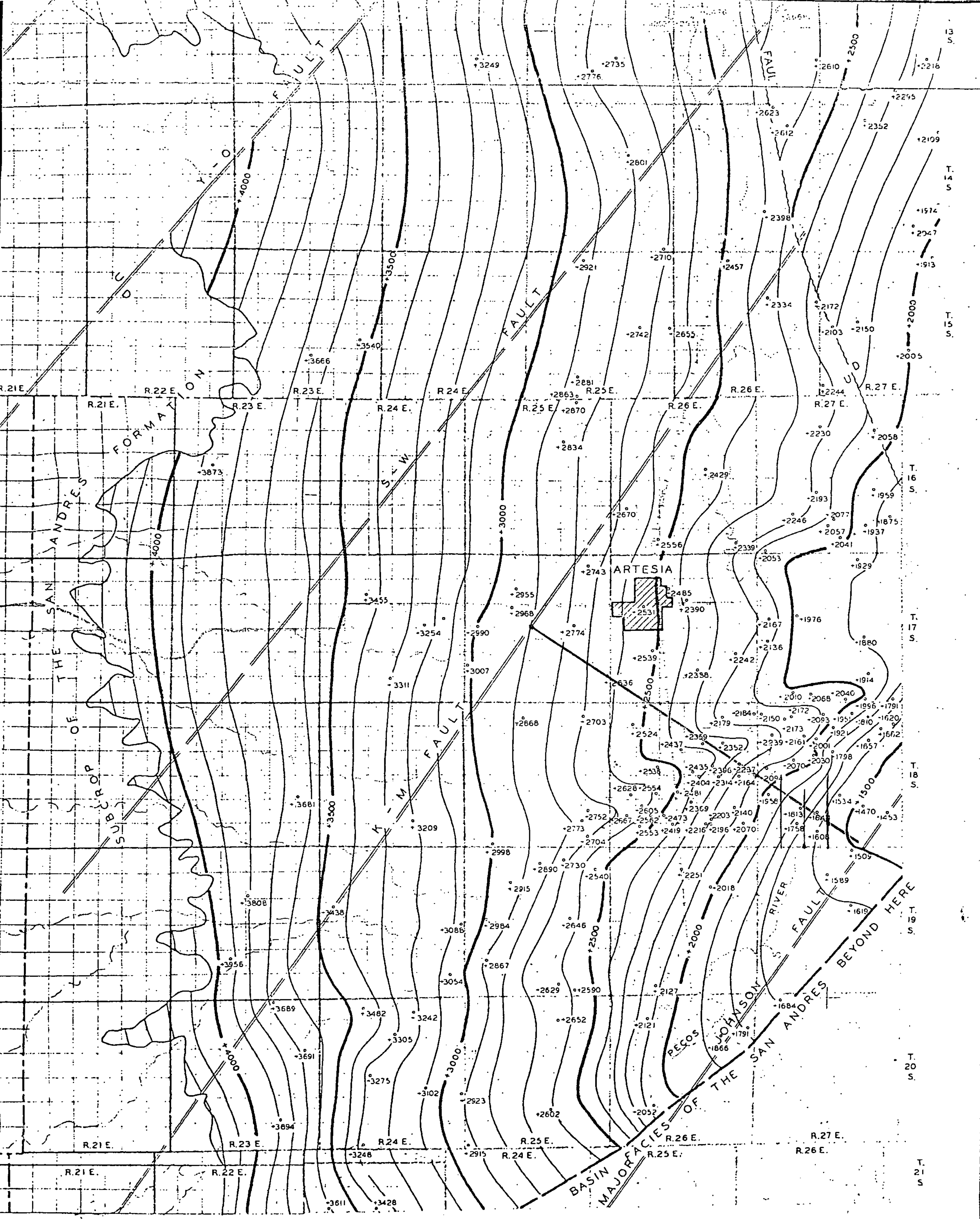

104°30'
33° 30'
33° 00'
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
G
G'
H
H'
P
EXPLANATION
>140
3707
(104)
Well with lithologic log. Number above line is depth to the base of the valley fill, in feet below land surface. Number below line is altitude of base of valley fill, in feet. Number in parentheses identifies log on file with U.S. Geological Survey, Albuquerque, New Mexico. Symbols (>) and (<) indicate that the actual depth and altitude of the base of the valley fill are greater (>) or less (<) than the numbers shown.
200
3295
(236)
Well with lithologic log on file with the Permian Basin Association, Inc., Roswell, New Mexico. Numbers same as above.
3300
Valley-fill contour. Shows altitude of base of valley fill. Dashed where approximately located. Contour interval 50 feet. Datum is mean sea level.
Approximate surface contact between Permian rocks and valley fill (modified from Kelley, 1971).
P
Area with Permian rocks at the surface
A A'
Line of geologic section.

FIGURE 12.--MAP SHOWING CONFIGURATION OF THE BASE OF THE VALLEY FILL, ROSWELL-ARTESIA AREA, NEW MEXICO.



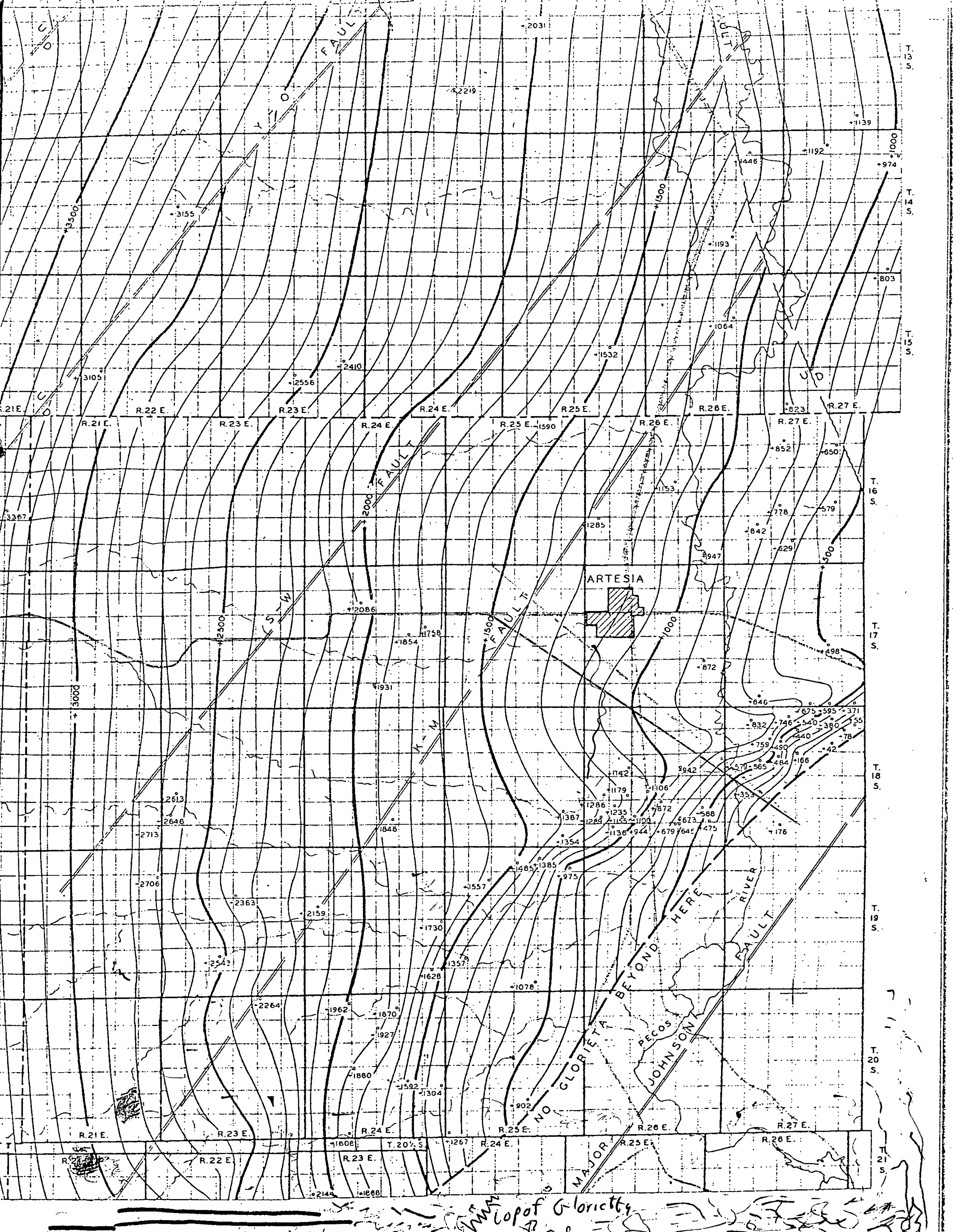
top of Queen

QUEEN FORMATION STRUCTURE MAP



top of SAN ANDRES FORMATION STRUCTURE MAP

ROSWELL ARTESIAN BASIN



GLORIETA SANDSTONE STRUCTURE MAP

Best regards
Lee

Aquifer Classification for the UIC Program: Prototype Studies in New Mexico

by Lee Wilson and Michael T. Holland

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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

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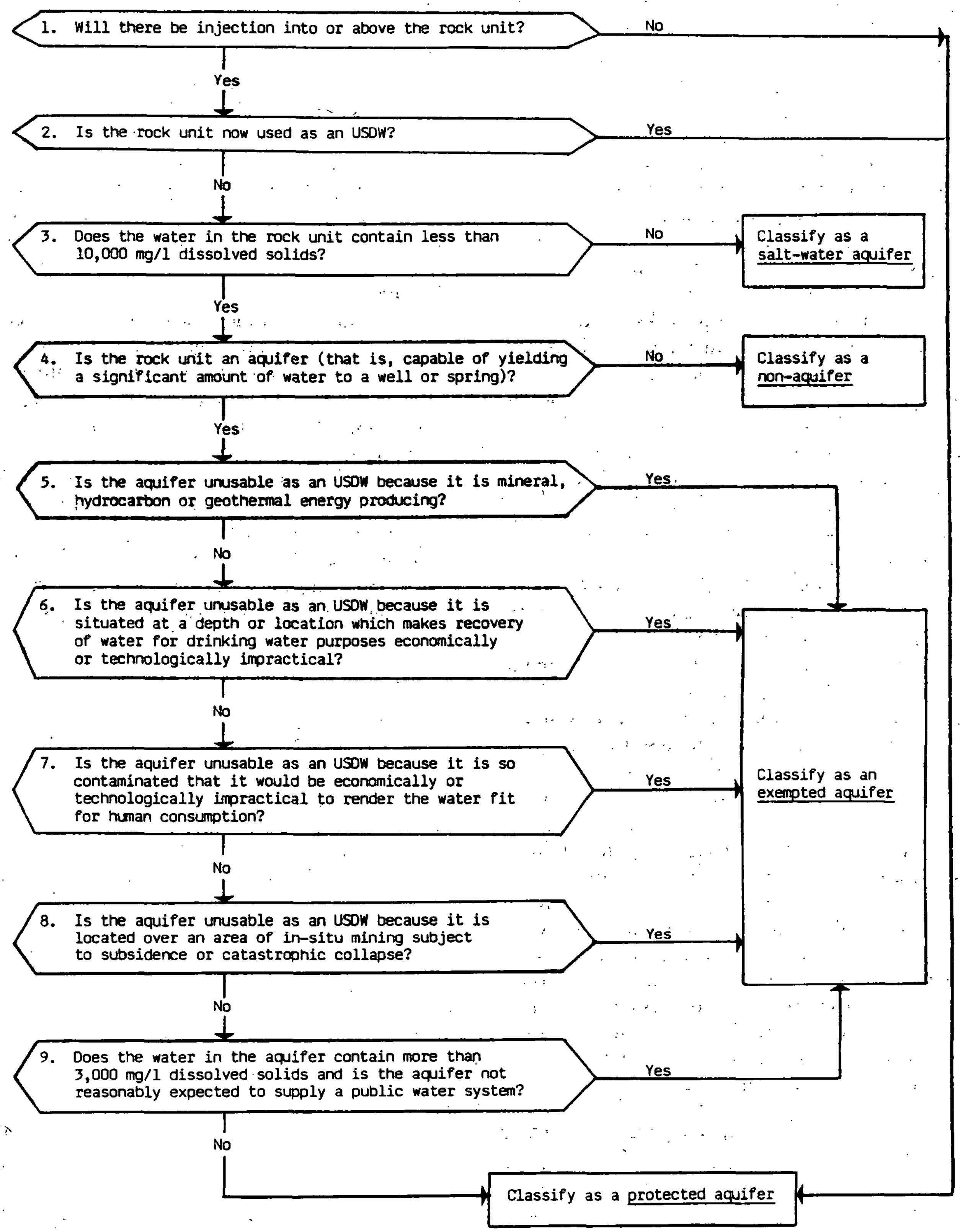

USDW = underground source of drinking water, defined as an aquifer or portion thereof which supplies any public water supply system or which supplies drinking water of less than 10,000 mg/l TDS for human consumption.

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

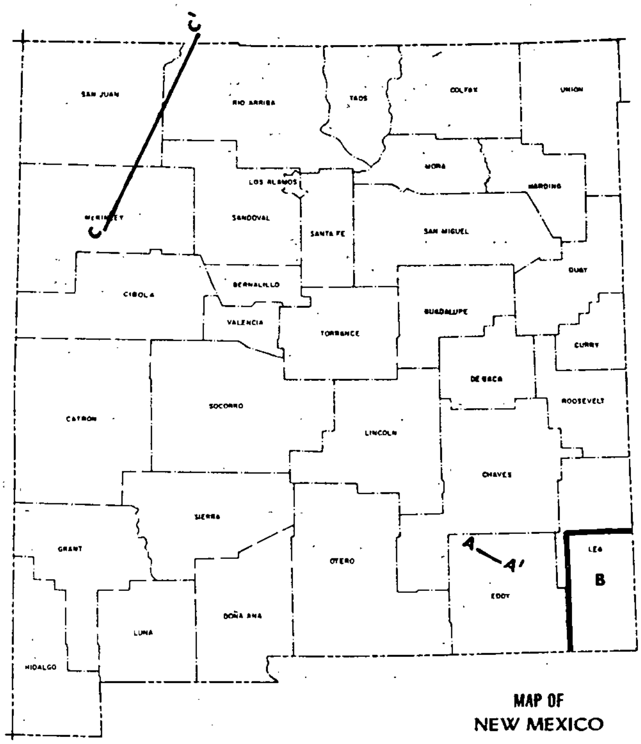

Fig. 2. Location of prototype study areas. Cross section A-A′ is in the Artesia area; see Figures 3 through 6. Area B is in southern Lea County; see Figure 7. Cross section C-C′ is in the San Juan Basin; see Figure 8.

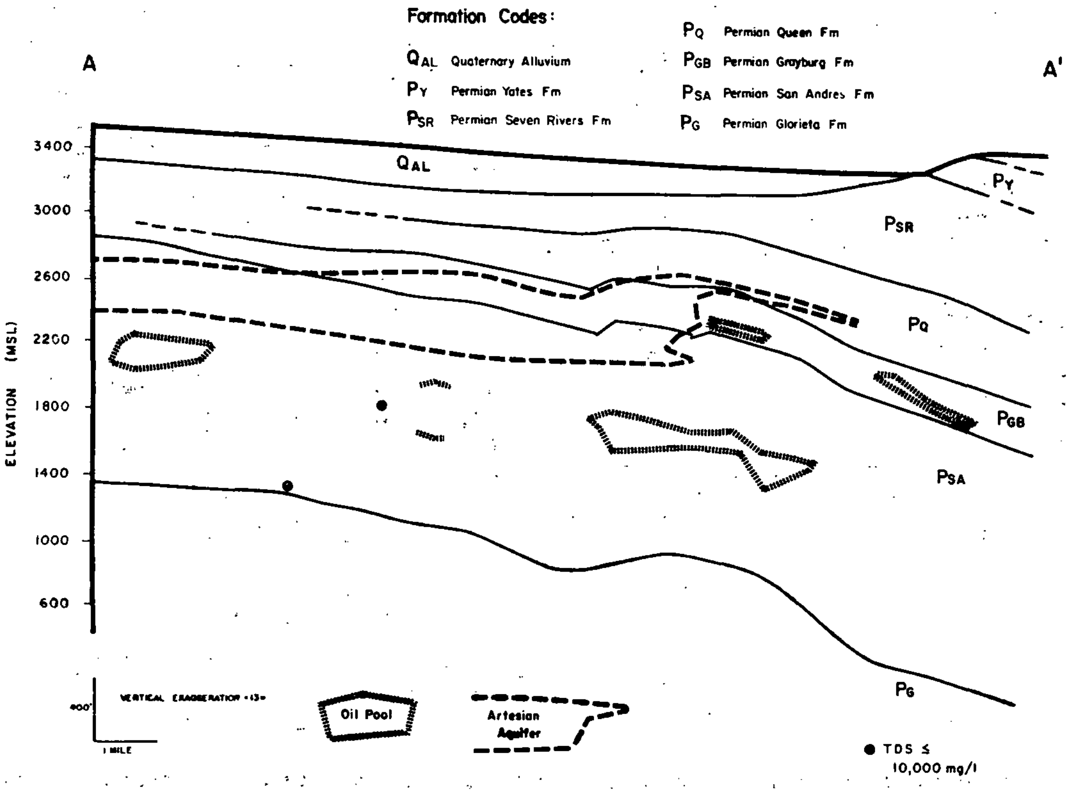

Fig. 3. Hydrogeologic cross section of the Artesia area, New Mexico. Primary oil-bearing zone is located 200-400 feet below the base of the artesian aquifer. The potentiometric surface of the artesian aquifer lies just beneath the land surface.

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

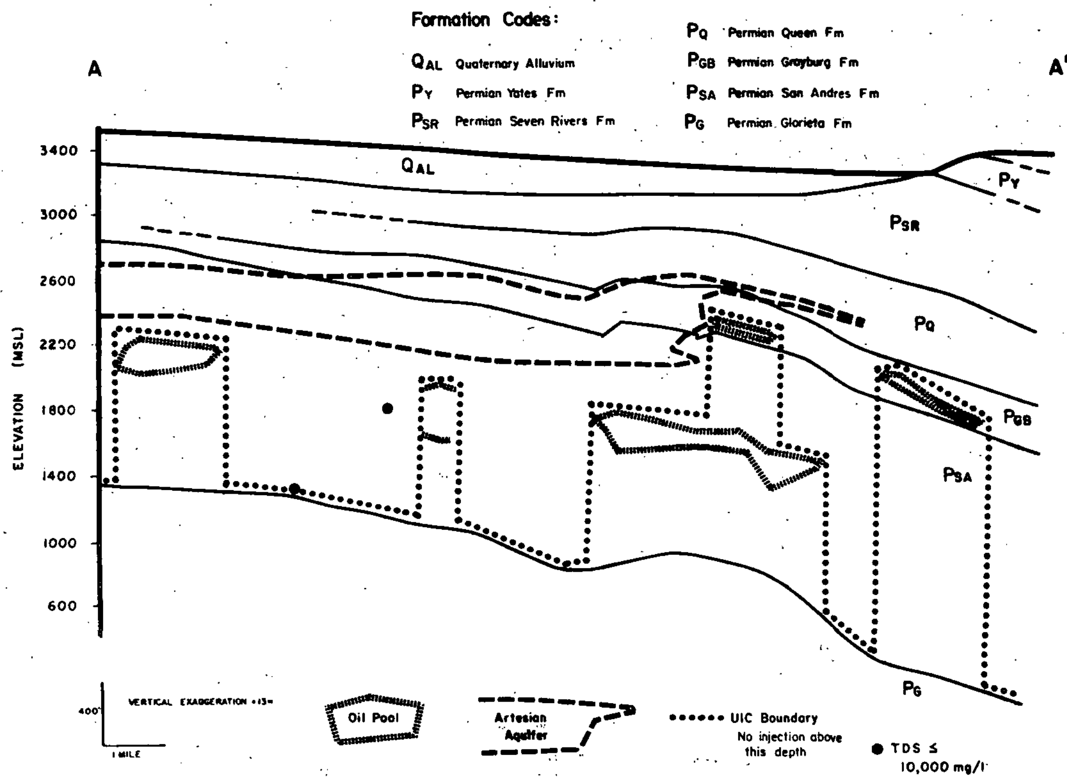

Fig. 4. Alternative UIC classification in which protection extends to base of San Andres Formation except for oil pools, which would be exempted per step 5 of Figure 1.

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 fresh-water 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

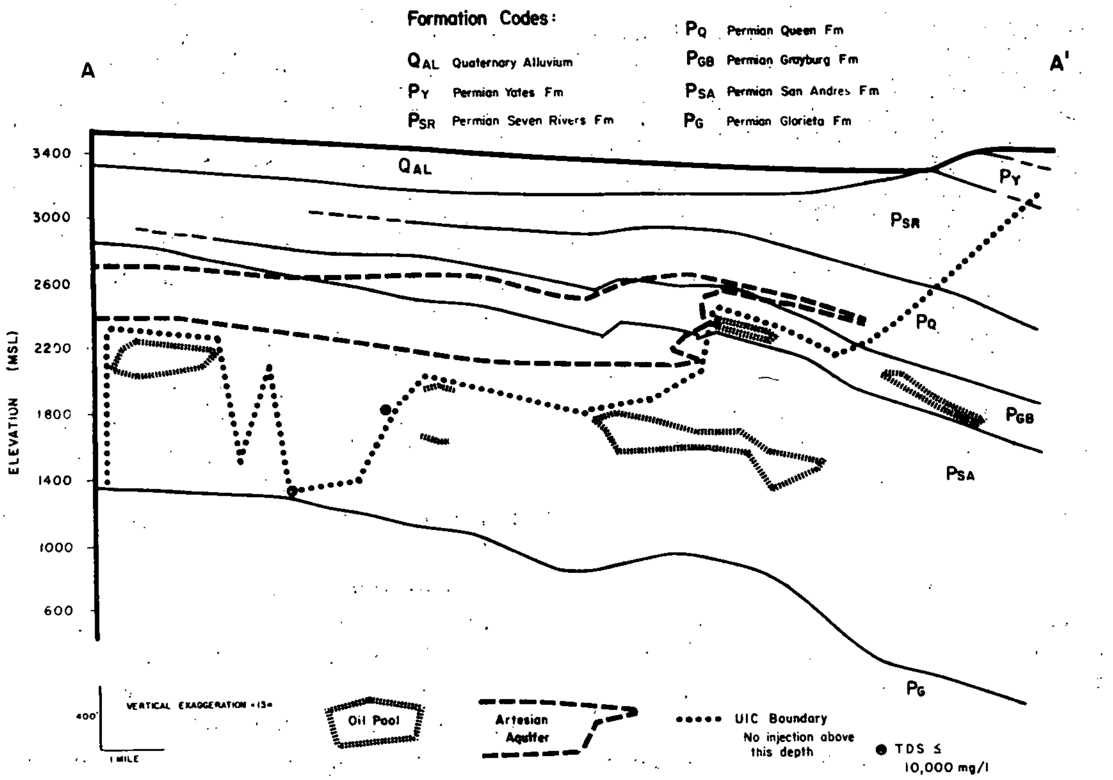

Fig. 5. Alternative UIC classification in which protection extends to base of water known to contain 10,000 mg/l total dissolved solids or less. Rock units below UIC boundary would be classified as nonaquifers.

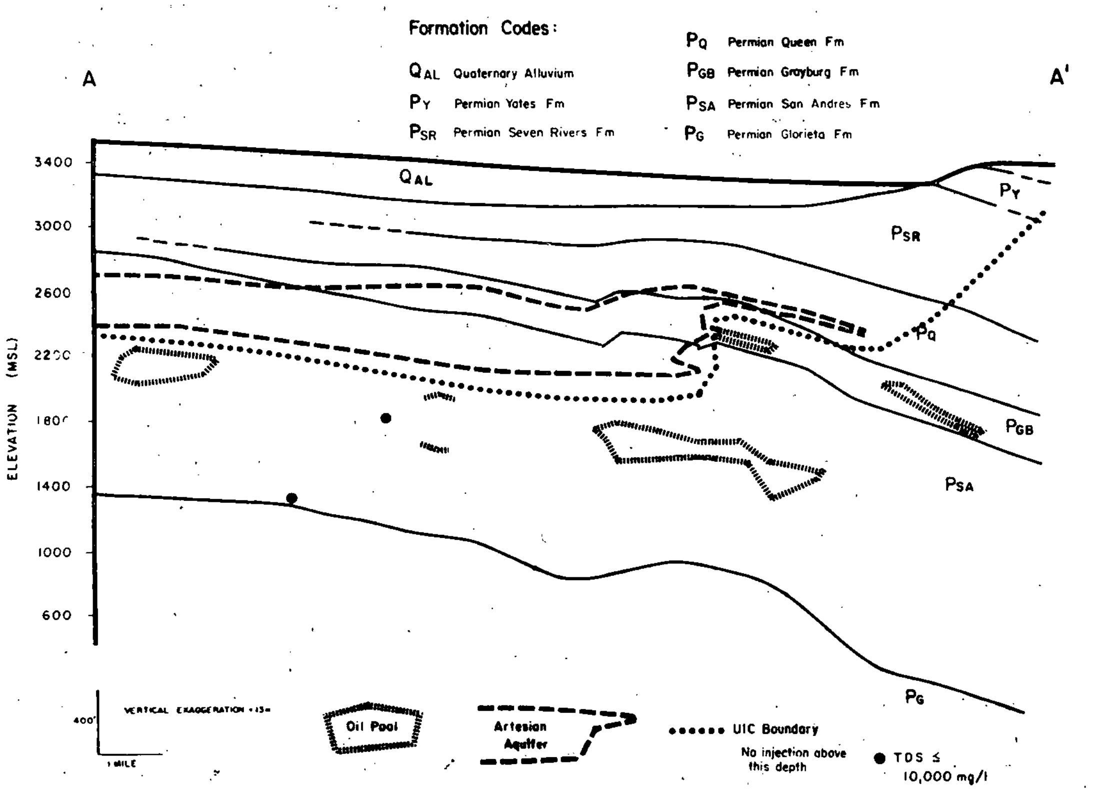

Fig. 6. Alternative UIC classification in which protection extends to base of formations known to be sufficiently permeable to yield significant amounts of water to wells and to contain water with 10,000 mg/l total dissolved solids or less. Rock units below UIC boundary would be classified as nonaquifers 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

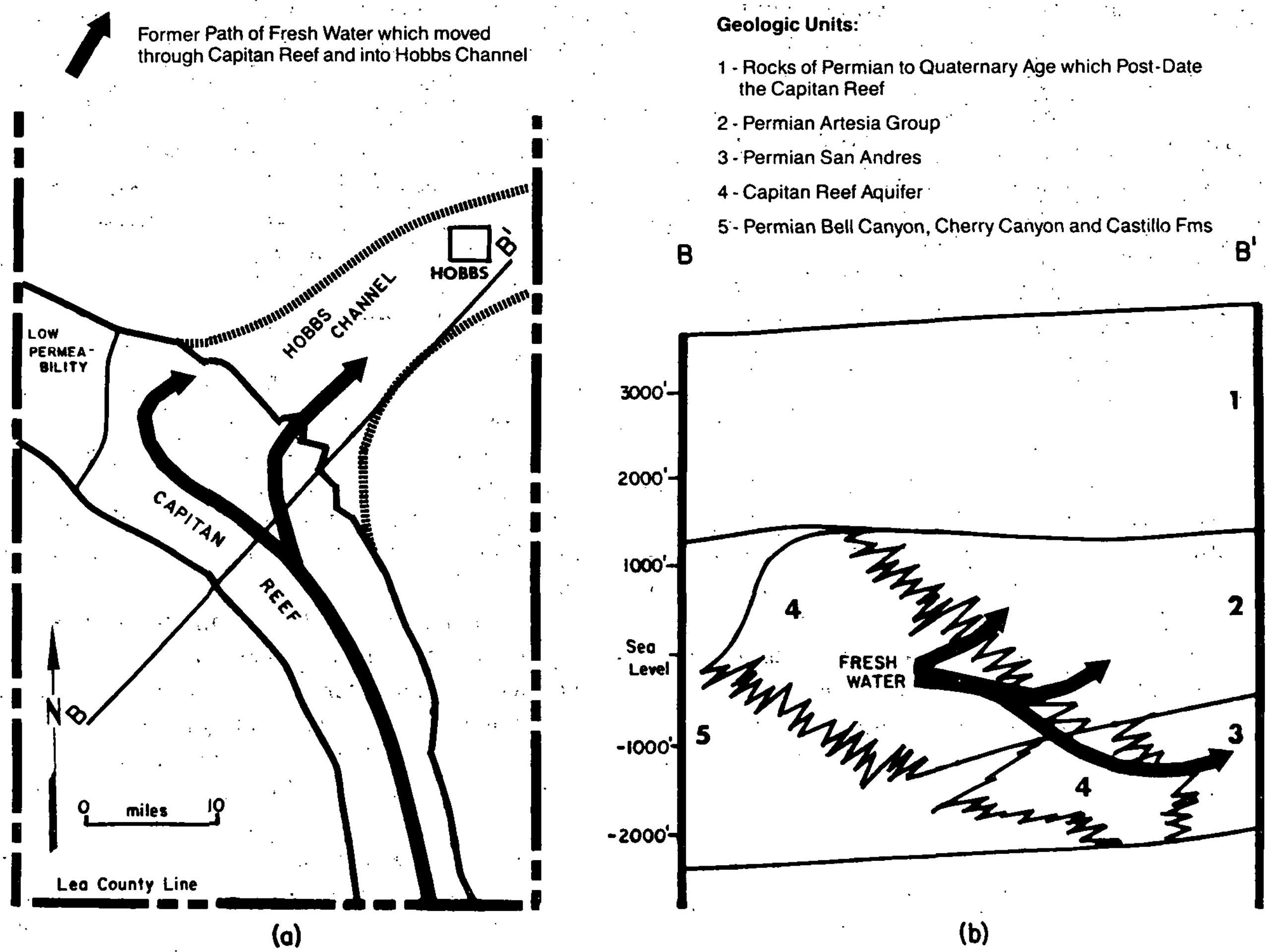

Fig. 7. Hydrologic features important to UIC classification in southern Lea County, New Mexico. The 10,000 mg/l TDS isocon inferred from the water-supply literature occurs in the upper part of unit 1, at about 3,000 feet elevation (msl).

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

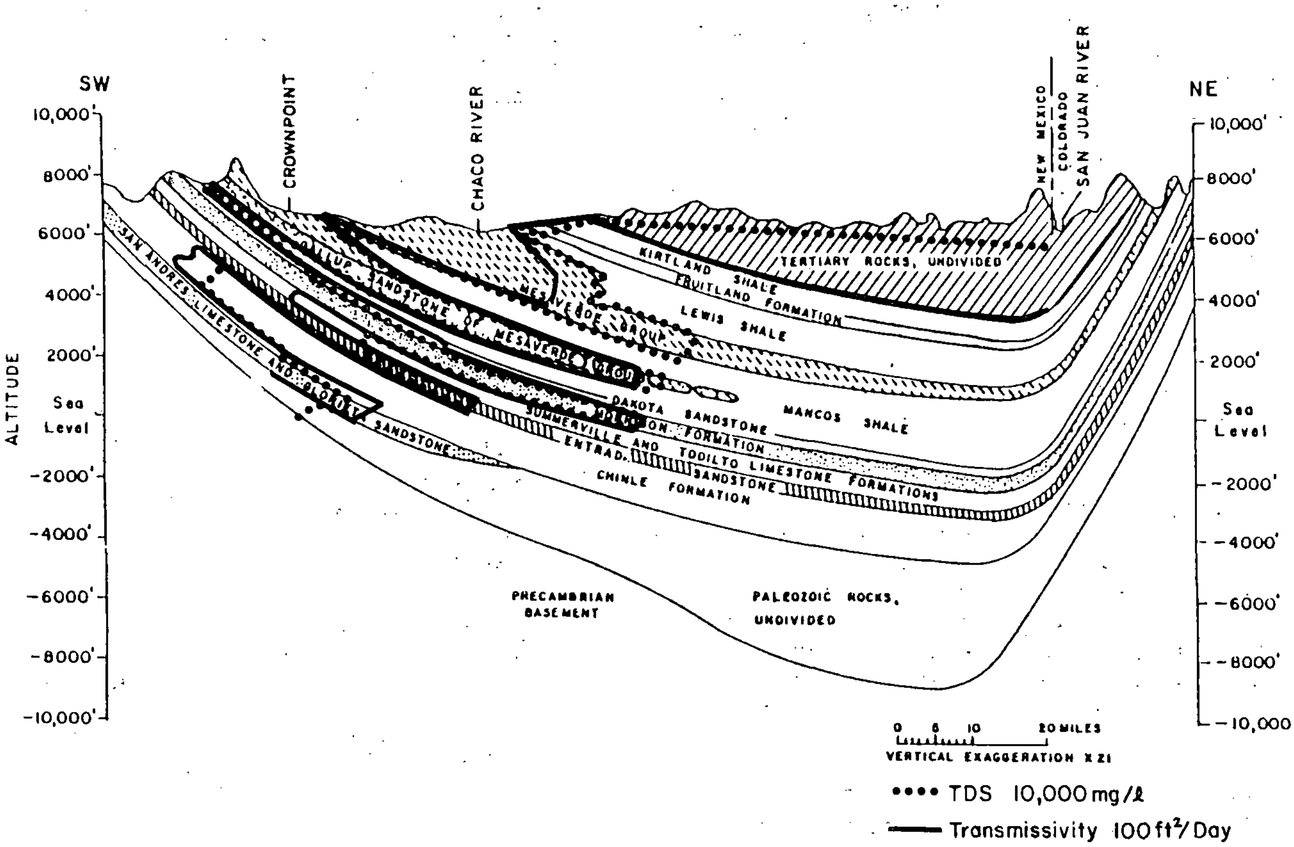

Fig. 8. Hydrogeologic cross section of the San Juan Basin, New Mexico. Water containing 10,000 mg/l or less total dissolved solids occurs above and to the west of heavy dotted line. Formations with a transmissivity of 100 ft^2/day or greater occur above and to the west of solid line. Section taken from 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.

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