AQUIFER EVALUATION FOR UIC:

SEARCH FOR A SIMPLE PROCEDURE

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INTRODUCTION

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

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

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

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

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

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

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

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

INITIAL CLASSIFICATION

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

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

IN-DEPTH STUDY

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

REVISED CLASSIFICATION

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

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

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

DELINEATION OF FRESH WATER

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

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

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

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

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

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

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

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

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

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

NEED TO CONSIDER EXEMPTIONS

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

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

EVALUATION OF EXEMPTION CRITERIA

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

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

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

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

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

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

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

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

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

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

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

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

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

FINAL CLASSIFICATION

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

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

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

SUMMARY OF IN-DEPTH STUDY

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

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

APPENDIX 1. SUMMARY OF GEOHYDROLOGY OF LEA COUNTY.

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

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

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

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

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

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

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

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

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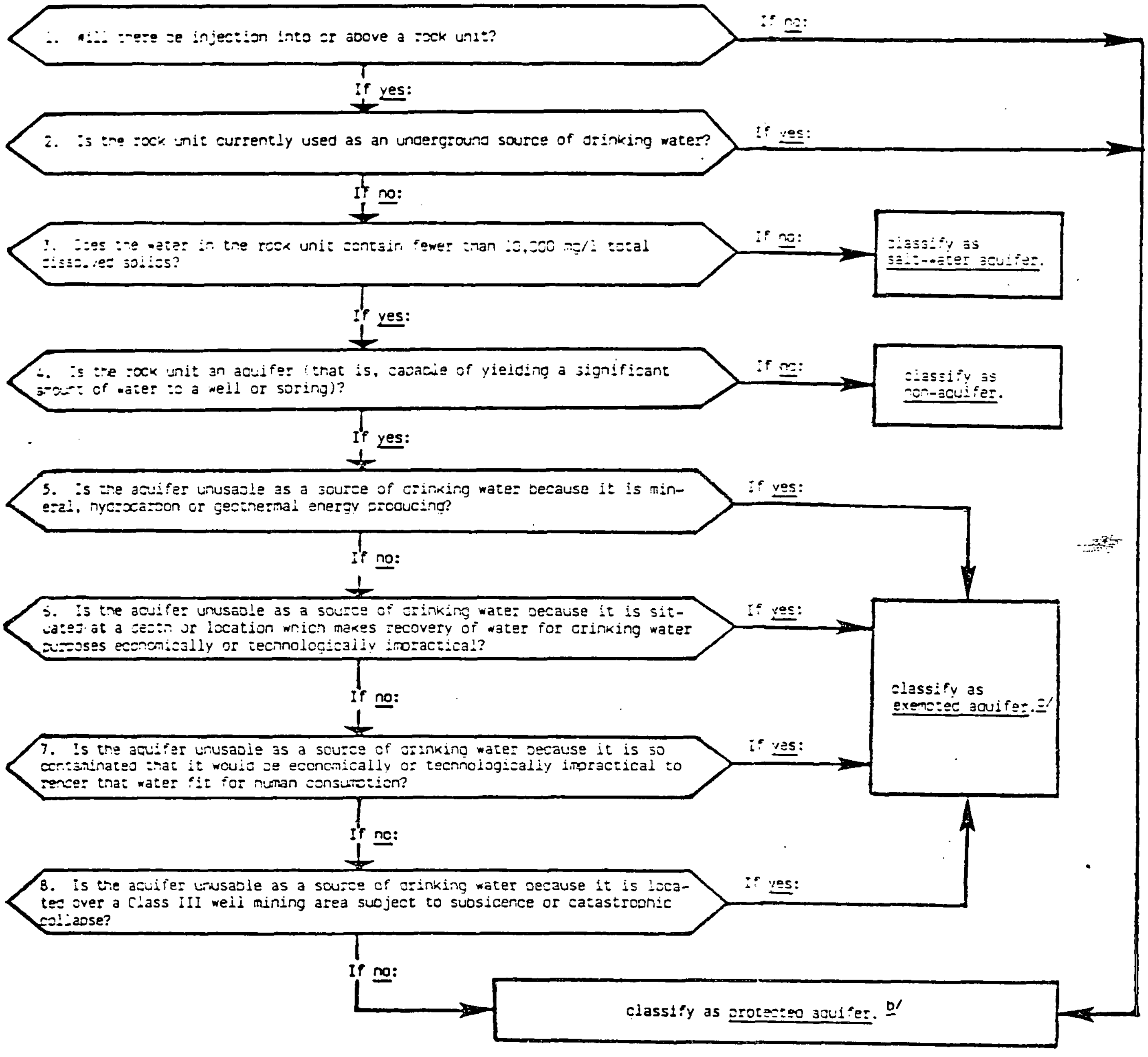
FIGURE 1. AQUIFER EVALUATION PROCESS, UNDERGROUND INJECTION CONTROL PROGRAM

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



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

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

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

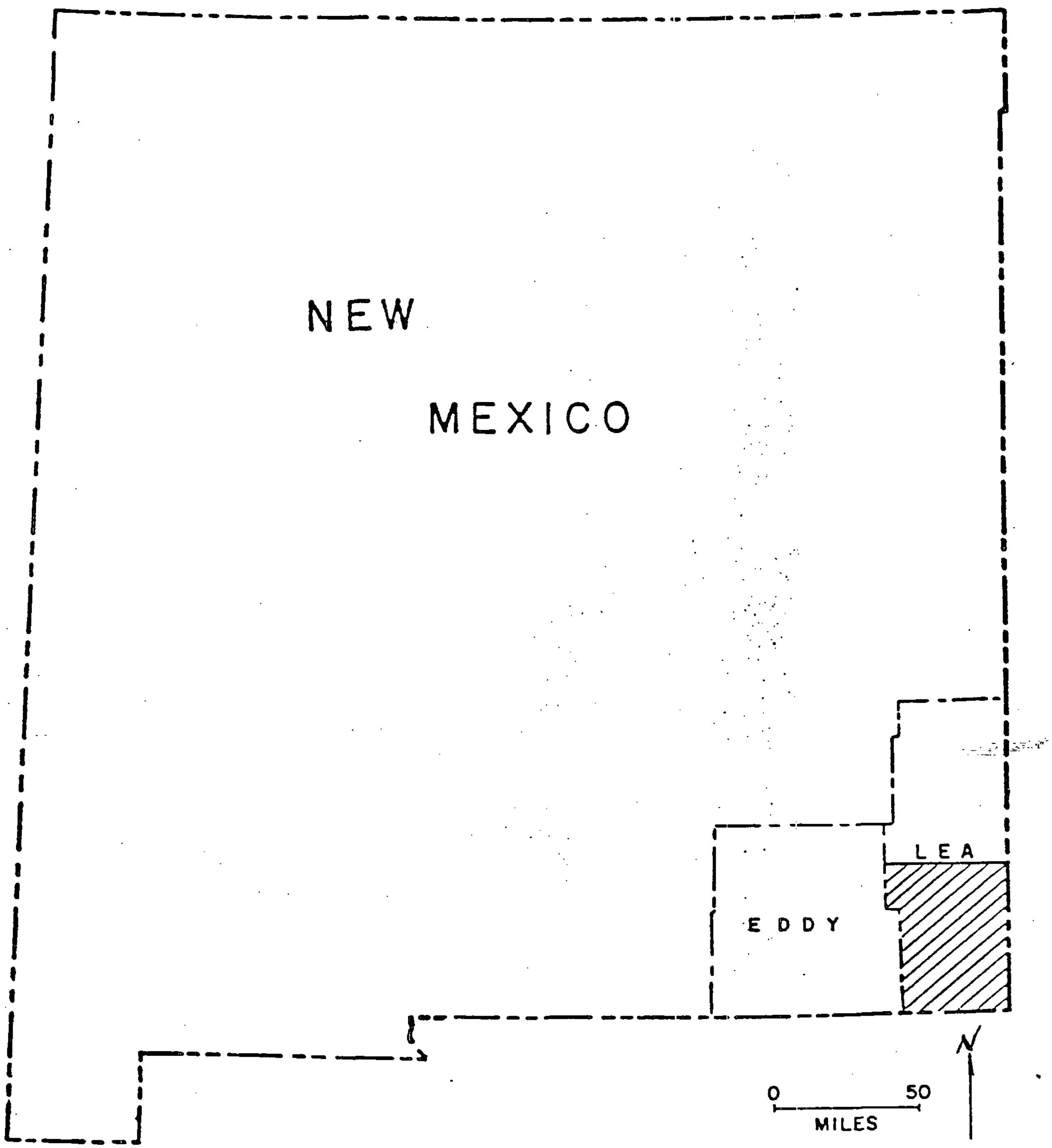


FIGURE 2. LOCATION OF STUDY AREA (LEA COUNTY, NEW MEXICO).
Slanted lines show area of intensive study.

Source: M. Holland, 1980.

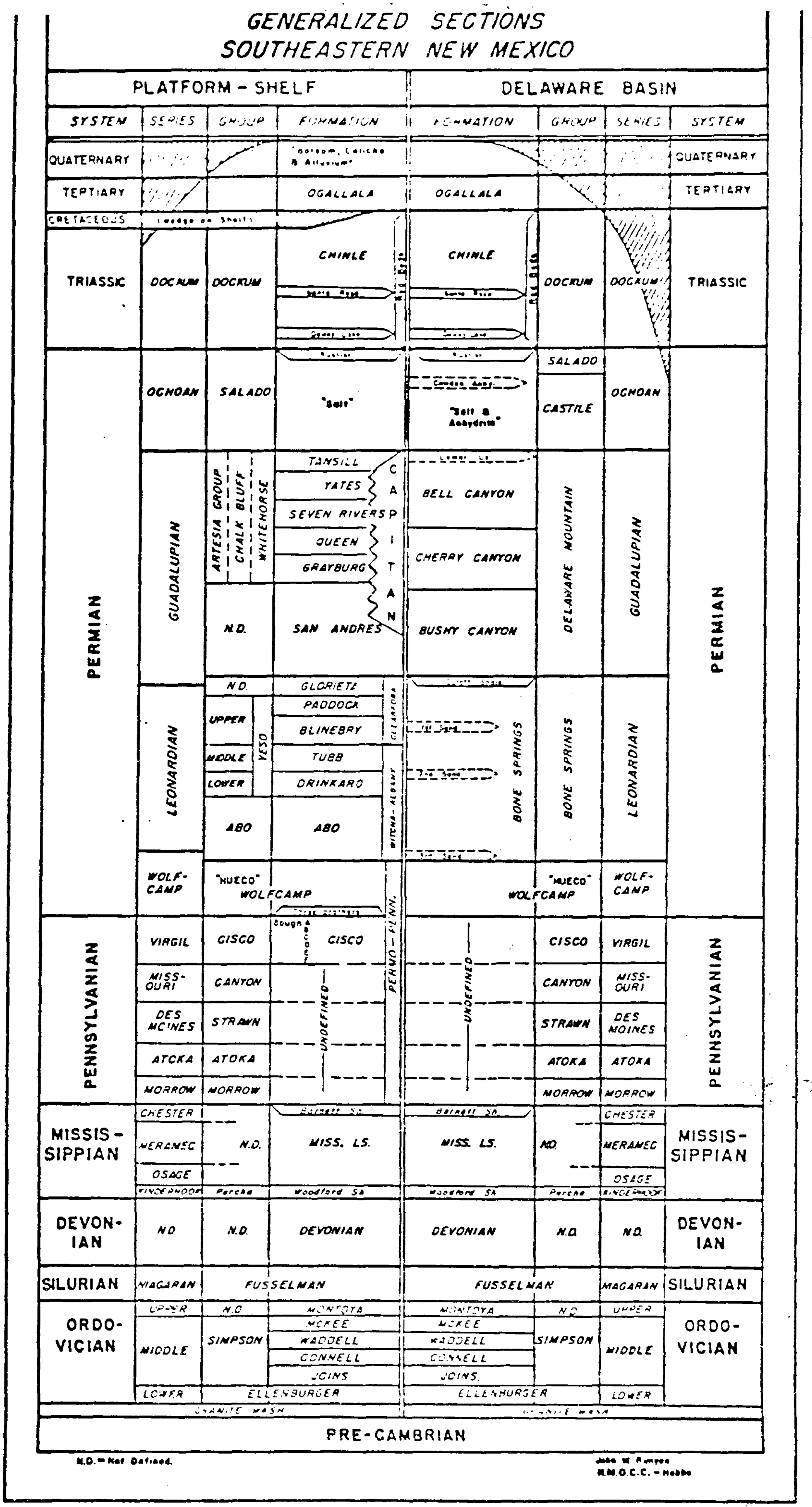
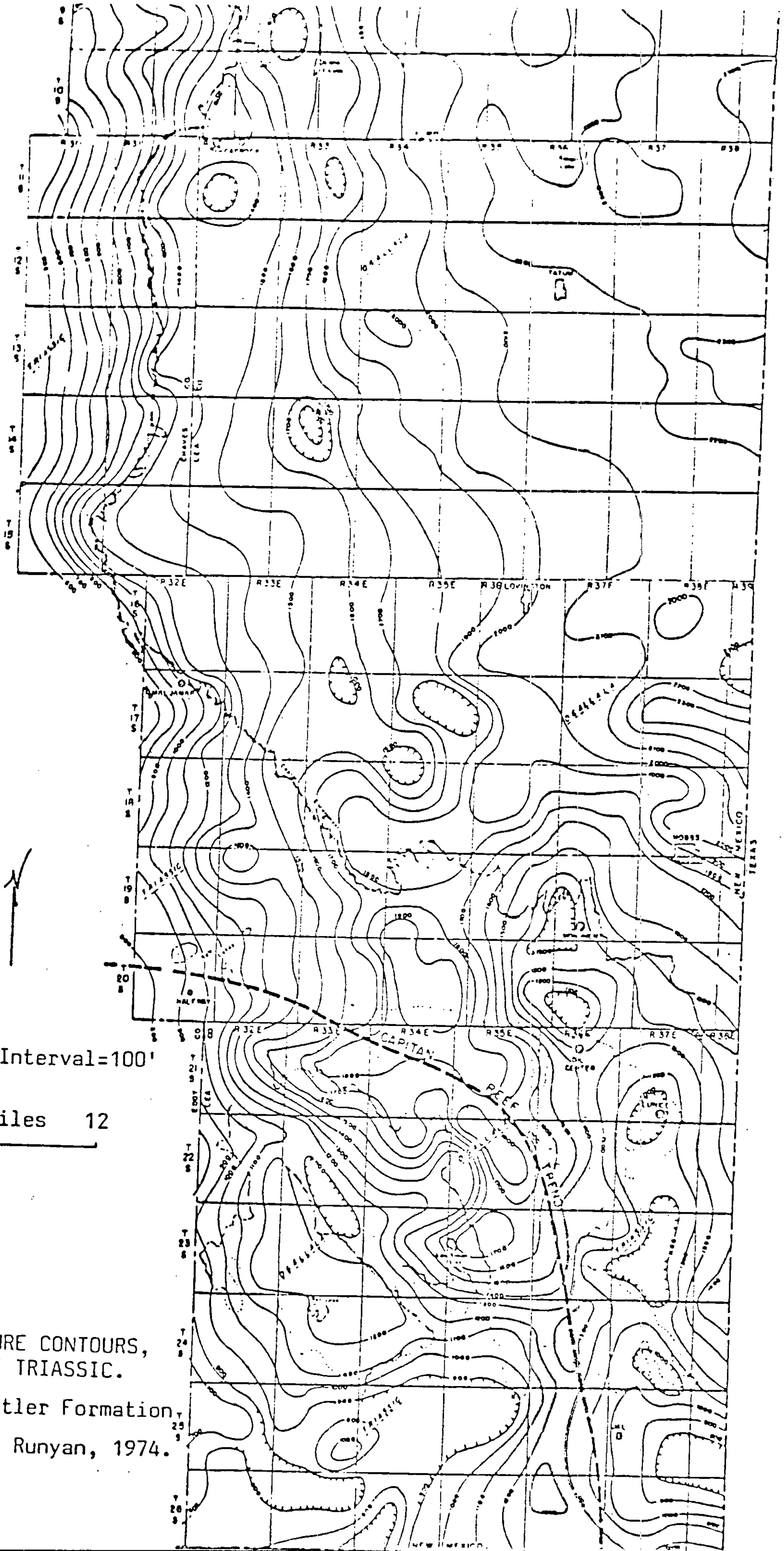


FIGURE 3. STRATIGRAPHIC COLUMN FOR THE STUDY AREA.



Contour Interval=100'

0 Miles 12

FIGURE 4. STRUCTURE CONTOURS, BASE OF TRIASSIC.

Top of Permian Rustler Formation.

Source: Runyan, 1974.

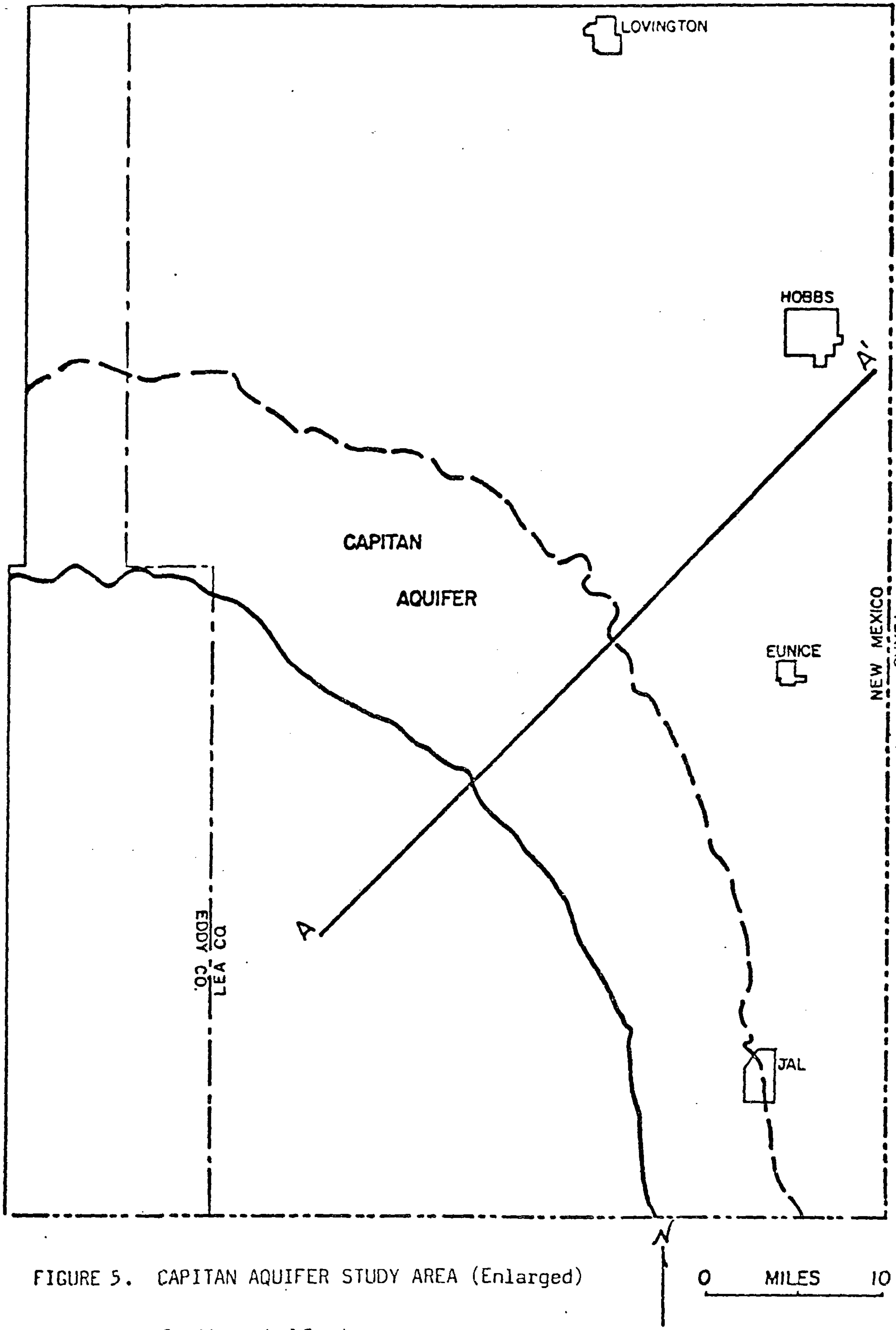


FIGURE 5. CAPITAN AQUIFER STUDY AREA (Enlarged)

0 MILES 10

Capitan shelf edge

Capitan basinal edge

Source: After W. Hiss, 1975.

FIGURE 6. AQUIFER STUDY REFERENCE FORM

Observer: ______________________ Date: ________________________

Citation:

Area:

Geologic Time:

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

General level of detail/insight:

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

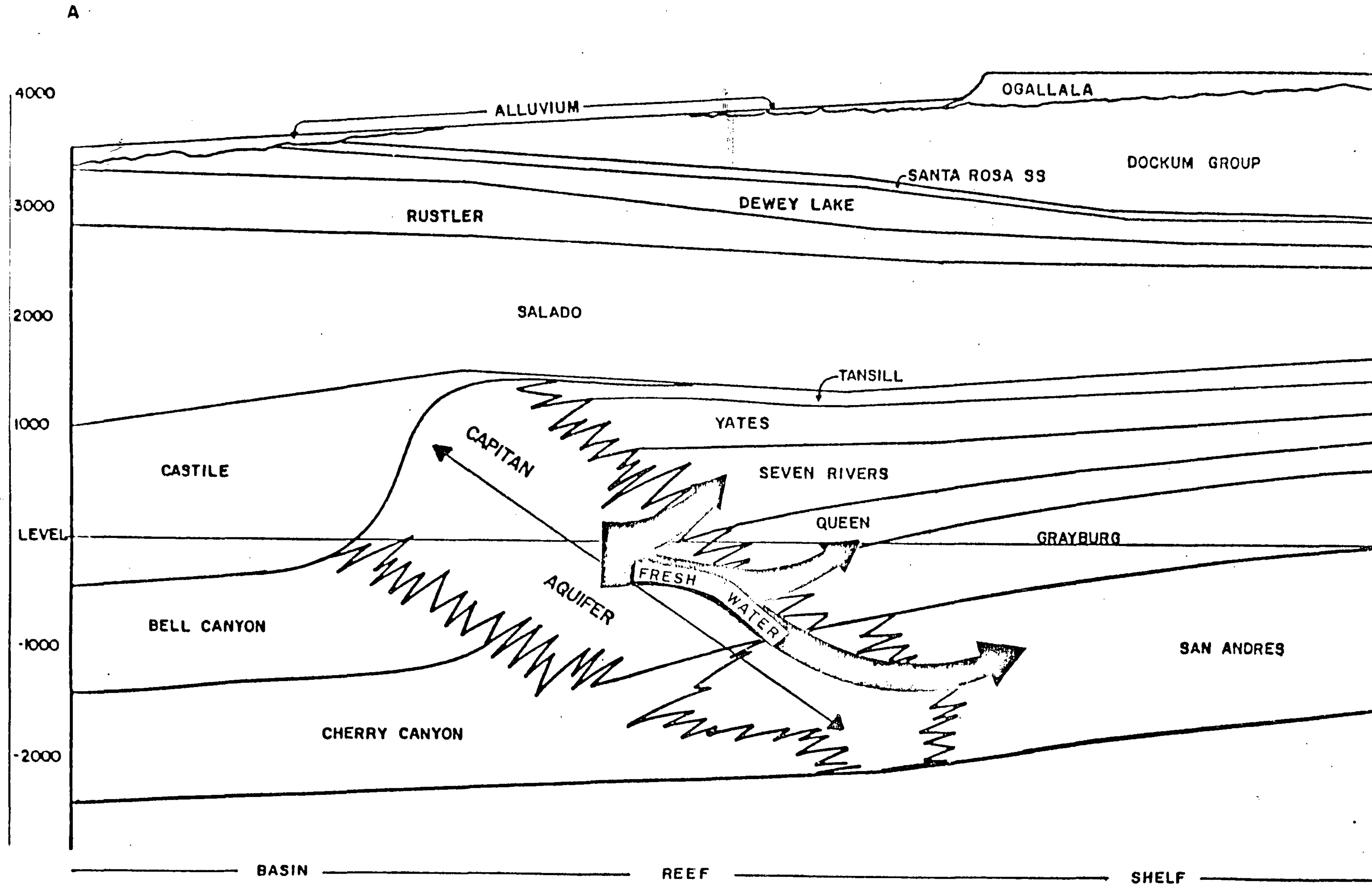


FIGURE 7. SCHEMATIC GEOLOGIC CROSS-SECTION OF THE STUDY AREA.

Source: M. Holland, 1980.

ACTUAL DATA

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

Good References:

Items Xeroxed and Attached:

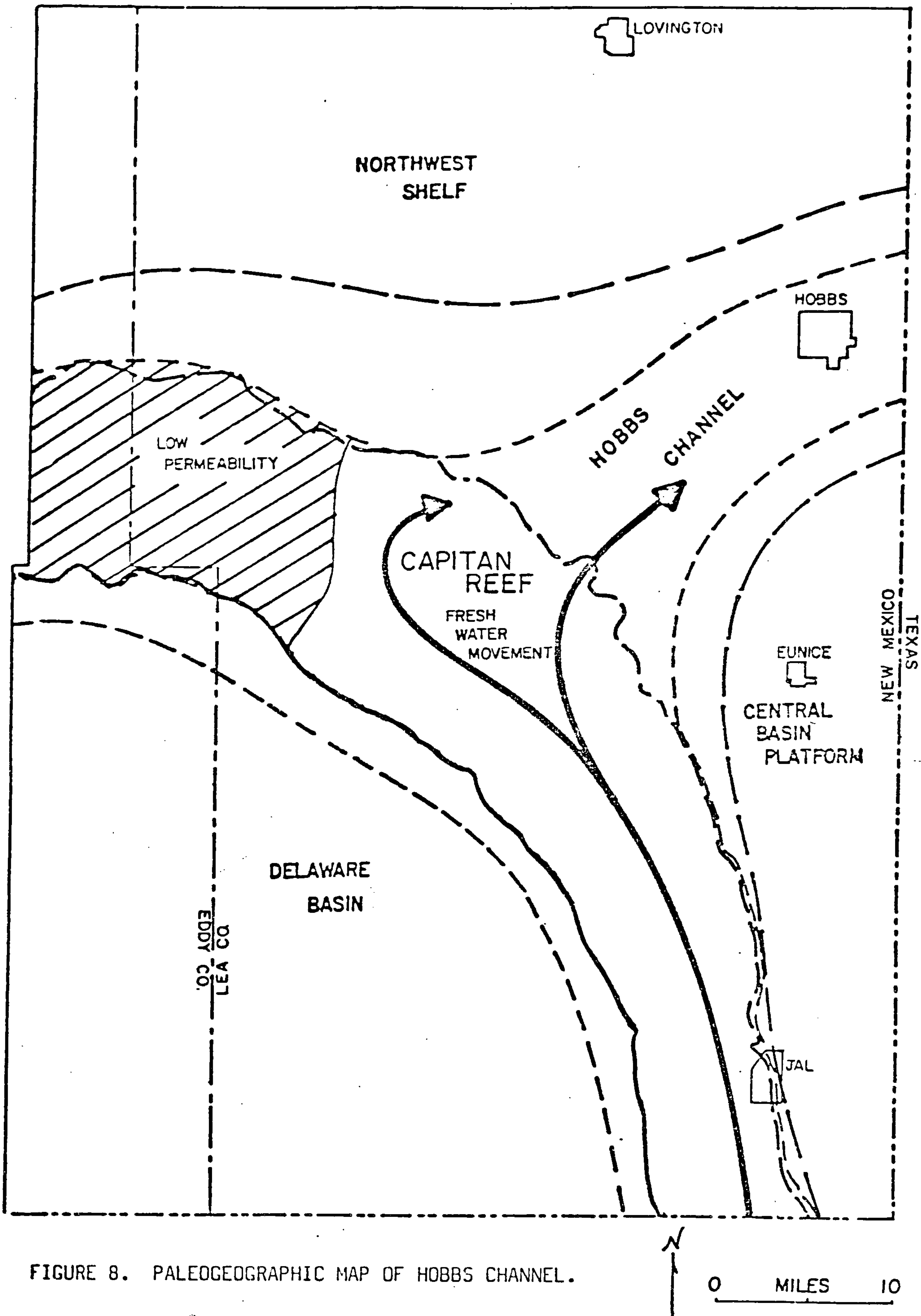
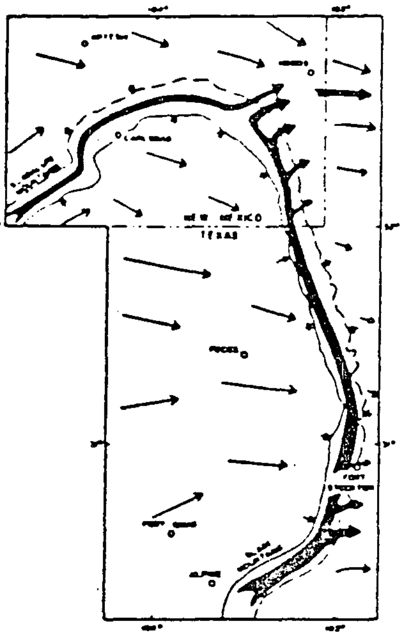
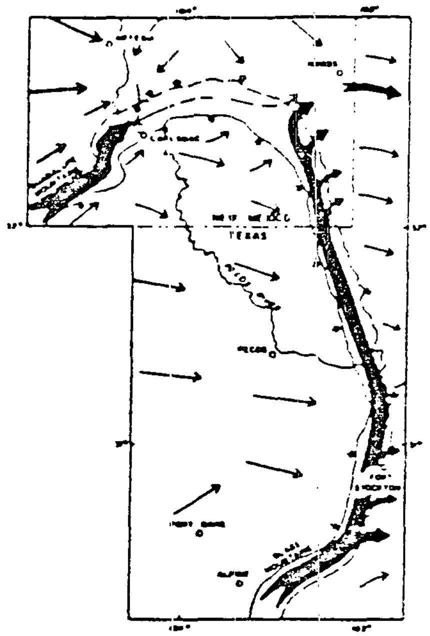


FIGURE 8. PALEOGEOGRAPHIC MAP OF HOBBS CHANNEL.

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



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



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

0 50 MILES

0 50 KILOMETERS

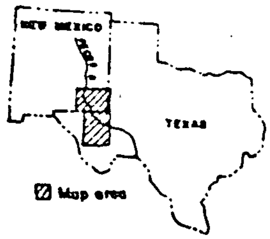
EXPLANATION

Capitan aquifer

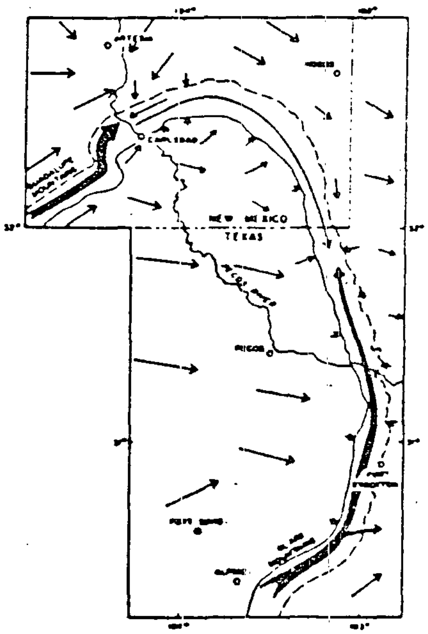
Highly diagrammatic ground-water flow vectors:

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

2. Orientation indicates direction of ground-water movement.



INDEX MAP



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

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

Source: W. Hiss, 1974.

TABLE 1.

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

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

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

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

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

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

A. DRINKING WATER

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

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

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

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

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

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

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

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

E. INJECTION

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

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

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

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

NOTES TO TABLE 2.

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

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