# MEMORANDUM

April 7, 1993

TO: Eluid L. Martinez, State Engineer

THROUGH: Donald T. Lopez, Assistant State Engineer

FROM: Tom Morrison, Peggy Barroll, & Andy Core, Hydrology Section

SUBJECT: Proposed Saline Injection into the Capitan aquifer, Lea County, New Mexico

PART 1

## Introduction

In a letter to the State Engineer dated March 25, 1993, the Chief Engineer of the Oil Conservation Division of the Department of Energy, Minerals, and Natural Resources (OCD) advised that Pronghorn SWD System of Hobbs, New Mexico (applicant) has filed an application proposing the use of an existing oil and gas test well as a salt water disposal well. The well would be used to inject brine, taken from nearby oil producing wells, into the Capitan aquifer and dispose of that brine at depths from 3220 to 5050 feet. The maximum injection rate estimated by RE/SPEC, the environmental consultant for the applicant (consultant), is 588.5 acre-feet per year (AFY). The maximum concentration of total dissolved solids (TDS) within the brine to be injected was estimated by the consultant to be 250,000 parts per million (ppm). It was projected by the consultant that the injection operation would last for 50 years.

The proposed injection well is located within the Capitan Underground Water Basin. The applicant has requested several meetings with OCD and State Engineer Office (SEO) staff members to discuss this application. At the request of the OCD, the Hydrology Section agreed to review a model of the proposed injection site, prepared by the consultant, and make comment to the OCD staff on the methods employed.

**Location and Completion**

The proposed site of injection is an oil and gas exploration well known as Brooks Federal '7' Well No. 6. The well is located 660' FSL & 1926' FWL in Section 07, T20S, R33E, NMPM, Lea County, New Mexico. That site is approximately 25 miles east of Carlsbad and the Pecos River.

The well was originally drilled through the Capitan into the underlying Delaware Group rocks. It is proposed to cement the hole back to the Capitan horizon and inject into the entire aquifer thickness.

**Summary of Review**

1) Available data indicate two regions in the area of interest in which fresh water is located in the Capitan aquifer. One region is in the vicinity of the City of Carlsbad and the other is about 18 to 20 miles southeast of the proposed injection

site. At the proposed injection site, the average TDS concentration calculated from known data points within the Capitan aquifer is approximately 50,000 ppm.

2) Available data indicate that the Capitan aquifer is in hydrologic communication with the Pecos River.

3) Available data indicate that the Capitan aquifer at the proposed well site is in hydrologic communication with the two fresh water sources noted in comment 1.

4) A numerical groundwater flow and solute transport model was prepared by the consultant to estimate the hydrologic impacts due to the proposed injection activities. The consultant states in the study documentation that the modeling results indicate that the injected brine would occupy a relatively inconsequential volume of the Capitan and that the impact of this activity upon current water quality within the Capitan would be "practically undetectable". However, due to the exaggerated scale of the figures in which the results are provided, an assessment of the change in water quality in the fresh water zones could not be made.

5) A review of the model documentation and other available information indicates that a number of uncertainties exist in the consultants' investigation. Modeling limitations were also identified which raise concern as to the use of the results as a basis for approval by the OCD. Although several conservative aspects of the investigation were also noted, we are unable to agree with the authors' conclusions at this time due to the

uncertainties and modeling limitations identified.

6) The consultants' study results suggest the possibility that the hydraulic gradient may be reversed in the vicinity of the Pecos River which may eventually degrade the fresh water sources in the Capitan near the city of Carlsbad.

7) In the process of evaluating the consultants' investigation, we identified two other studies which quantified impacts on the Pecos valley due to withdrawals of Capitan water. These studies suggest that existing water rights could be impacted from injection of brine in to the Capitan aquifer.

## PART 2

### Hydrogeology

The Capitan aquifer (often referred to as the reef aquifer) is hosted by the Permian Capitan and Goat Seep Limestones and most of the Carlsbad facies of Meissner (Hiss, 1980). Hiss has divided the Permian facies of Guadalupian age into three aquifer groups (shelf, reef, and basin) as shown in Figure 1. The point of the three-fold division is to emphasize the very large contrasts in transmissivity (T) and salinity between the groups. East of the Pecos River, the Capitan aquifer is confined and the T is one to two orders of magnitude greater than either the shelf aquifers or the basin aquifers which surround it. Much of this increased T is probably due to solution cavities and fractures within the reef facies (Hiss, 1980). In essence, the Capitan may be visualized as a curved tube dipping to the east-northeast, carrying water from the surface in the Guadalupe Mountains of New Mexico and the Glass Mountains of Texas down into the subsurface near Hobbs. Figure 2 shows the changes in the flow of water through the Capitan aquifer, first as the Pecos River came into hydrologic connection with it, and then as the exploitation of water and oil resources impacted it.

With minor exceptions in the northeast portion of the reef, the salinity of the waters contained in the shelf and basin aquifers are one to two orders of magnitude greater than that within the Capitan aquifer (Hiss, 1975). The reason for this appears to be the higher T which allows rapid movement of fresh water through the Capitan which dilutes the salt content within that aquifer. One implication of Figure 2 is that the salinity of the north-central part of the aquifer has risen over time as the volume of fresh water reaching that portion of the aquifer has diminished. Figure 3, which was published by the NMBMMR as resource map 4, shows the zones of fresh water in yellow, as indicated by chloride values of less than or equal to 5000 ppm. In preparing the figure the assumption was made that chloride content accounts for 50% of TDS in solution, which is the same assumption made by the consultant in his report. Also shown are the Pecos River and the location of the proposed injection well.

The Capitan aquifer was incised by submarine canyons shortly after deposition which were then, presumably, filled with shelf aquifer materials. The effect was to create constrictions where the reef aquifer is thinned. The presence of several large submarine canyons between Ranges 26E and 30E apparently retards recharge from the modern Pecos River (Hiss, 1976). This retardation of recharge allows waters of higher salinity to pool in the area of Townships 19S and 20S, Ranges 29E through 33E. Much of this portion of the aquifer contains water with TDS of greater than 10,000 ppm (Hood and Kister, 1962, Hiss, 1975). However, there is no evidence of any loss of hydraulic connection between the Pecos River and the easternmost portions of the Capitan aquifer.

**Model Description**

The consultant prepared a model to simulate the injection of brine at the site noted above for a period of 50 years followed by a period of 1000 years during which no injection took place. The purpose was to estimate the transport of the brine pollutant constituents for 1000 years after injection into the Capitan aquifer.

The model was prepared to employ the two dimensional SUTRA subsurface flow and transport model code. The following assumptions were made in the preparation of the model: 1) a flat-lying model domain with a constant vertical thickness of 1000 feet and a constant width of 10 miles, 2) impermeable boundaries above, below, north, and south of the Capitan aquifer, 3) the Pecos River is treated as a constant head boundary that is fully penetrating into the Capitan aquifer, 4) a constant head boundary delimits the eastern end of the model, 5) the Capitan aquifer is treated as a homogenous, isotropic aquifer with a constant T of 5000 feet squared per day, 6) the Capitan aquifer is assigned a constant porosity of 18%, 7) the Capitan aquifer is assigned a constant longitudinal dispersivity of 100 meters and a constant transverse dispersivity of 10 meters, 8) the Capitan aquifer is assigned a coefficient of molecular diffusion of 5 times 10 to the minus 10 meters squared[1], 9) an initial distribution of brine, reflective of the chloride distribution of Hiss (1975), was assigned to the model elements, and no other sources of brine except the injection well were active during the simulation, 10) a constant brine injection rate of 588.5 AFY for 50 years, 11) a constant injection concentration of 250,000 ppm TDS. Specific comments concerning the implications of these assumptions and the nature of the model follow.

**Specific Comments**

The following comments are addressed to the draft report of the consultants' study (study) which was received on March 15, 1993. Some of the figures in that report were received by FAX later in that week. A copy of that draft report is attached.

1) In Section A, the zones in the Capitan aquifer which contain fresh water are described (fresh water is defined in the statutes and in the study as containing TDS less than or equal to

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[1]. We are of the opinion that the proper unit for coefficient of molecular diffusion is meters squared per second (see Mercer, et. al., 1982).

10,000 ppm). It was determined in the study that chlorides constitute an average of 50 percent of the TDS for the Capitan aquifer. Results of the study indicate that fresh groundwater exists near the Pecos River and extends westward. Wells owned by the City of Carlsbad produce from the Capitan in this area. In addition to this area, Townships 21 and 22 South, Range 35 East, were also identified in the study as containing fresh ground water in the Capitan. Those townships are located about 18 to 20 miles southeast of the proposed injection site, hydrologically down gradient from the injection well.

Based on the relationship between chlorides and TDS derived in the study, and on the chloride map developed by Hiss (1975), the SEO has determined that portions of the following townships in New Mexico may contain fresh water southeast of the proposed injection site: T20S R35E, T20S R36E, T21S R34E, T21S R35E, T22S R35E, T22S R36E, T23S R35E, T23S R36E, T24S R36E, T24S R37E, T25S R36E, T25S R37E, T26S R36E, and T26S R37E. These zones of fresh water are not acknowledged in Section A, Figure A2 or the discussion on page B5 with the exception of those noted above.

The omitted water quality data does not support the conceptual flow discussed in Section B. With respect to the fresh water zone in the Capitan located southeast of the injection well, it is stated on page B6 "It is important to note, that although the TDS concentrations at that location are below 10,000 ppm, the waters are nonpotable, having come from the San Andres, which contains major oil fields in that precise region."

It should be noted that fresh water and potable water are defined differently and the charge of the SEO is to designate areas of fresh water to the OCD. The data which was not included in the study suggests fresh water is entering the area due to recharge from the Glass Mountains in Texas (see Figure 3).

2) In Section B (page B2) and Section C.2 (page C2) it is stated that the Pecos River and Capitan are separated by over 500 feet of "Artesian Unit material". Available information indicates that these statements do not correctly describe the geology throughout the Carlsbad area. Bjorkland and Motts (1959) indicate in their Figure 20 that the alluvium and Capitan reef aquifer are in direct contact beneath the Pecos River in the vicinity of the City of Carlsbad well field.

3) In Section B (page B2) a discussion on the submarine canyons is provided and it is stated "Hiss has maintained that these canyons now function as significant barriers to the horizontal movement of water through the Capitan". The studies performed by Hiss indicate that the submarine canyons decrease the thickness of the Capitan aquifer thereby reducing the T of the aquifer in the vicinity of the submarine canyons. Hiss (1976) discusses the submarine canyons and indicates that the canyons "restrict" flow in the Capitan rather than producing an effective "barrier" to all flow as inferred on page B2 and also on page C2. Figure 4 (Hiss, 1980) indicates that groundwater flow in the Capitan proceeds from the Guadalupe Mountains toward Carlsbad and that flow continues on past the proposed injection

site in the Capitan to the New Mexico/Texas state line. Richey et. al. (1985) indicate on their Plate 2 (which is attached here as Figure 5) that a large portion of the Capitan reef facies rocks has an approximate thickness of 2000 feet. Also, near the Eddy-Lea County line a small portion of the reef is reduced to 500 feet thick by channel scouring. Based on this information, the injected brine would certainly be connected hydrologically to all other ground water resources in the Capitan aquifer.

The discussion on page B2 goes on to say that another feature that may act as a barrier to flow through the Capitan is an igneous dike that appears to have intruded through the reef's entire width. Hiss (1976) states on page 197 "the dike or dikes do not appear to act as restrictions or barriers to movement of ground water". As mentioned above, none of the figures prepared by Hiss indicate that a barrier to flow exists within the Capitan aquifer.

Further evidence that the Capitan is hydrologically connected over a relatively large area is also provided in the study in the last paragraph on page B2. It is stated "Over the past 60 years, significant quantities of water have also been withdrawn from the eastern arc of the Reef near the New Mexico/Texas border. These withdrawals....appear to have had significant impact on water levels throughout much of the Capitan."

4) At the bottom of page B2 it is stated that it appears that no official determination has been ever made of the impacts

of well withdrawals from the Capitan on the Pecos River. Studies have been performed which quantify the effects of Capitan wells on the Pecos River. P. D. Akin's memorandum to Steve Reynolds, dated January 20, 1965, makes reference to a paper by R. M. Brackbill and J. C. Gaines of Shell Oil Co., and Shell Pipe Line Corp., respectively, entitled "El Capitan source water system -- a step toward fresh water conservation." Mr. Akin indicates that review of the paper revealed rather blunt implications that the use of water from the Capitan in Texas could cause significant depletions of fresh-water supplies in the Pecos Valley, with possibly serious detrimental effects with respect to the City of Carlsbad's municipal water supply and Pecos River flows. Mr. Akin, who was then the Chief of the Hydrology Section at the SEO, goes on to say that "Any significant new developments in the Reef Complex in New Mexico would be expected to have a relatively greater effect (relative to withdrawals in Texas) on the fresh-water supplies in the Pecos Valley ...".

Impacts on the Pecos River due to the use of Capitan wells were also quantified in a 1985 SEO report by Deborah L. Hathaway. Both of these studies indicate that wells producing from the Capitan will impact the Pecos River.

5) In Section C.1 (page C1) it is stated that the use of a constant aquifer thickness of 1,000 feet is conservative and that much of the Capitan is greater than 2,000 feet thick. Transmissivity is the product of aquifer thickness and hydraulic conductivity. The choice of a smaller aquifer thickness will

result in a lower T which may decrease the transmission of impacts to distant locations in the aquifer. It is uncertain whether the selection of the 1,000 foot aquifer thickness will result in a conservative evaluation with respect to the impacts at the fresh water site located to the east of the proposed injection well.

6) In Section C.3 (page C2) it is stated that Hiss has estimated an average hydraulic conductivity for the Capitan of 5 feet per day. This value has been used in the groundwater model. The uncertainty of this value should be noted. Richey and others (1985) state on page 11 that aquifer test data for the Capitan is very sparse. Hiss (1976) provides hydraulic conductivities for seven wells completed in the Capitan aquifer in Lea and Eddy counties, the values range from 1 to 25 feet per day (Hathaway, 1985).

On page C2 it is stated that the use of a hydraulic conductivity of 5 feet per day for the Capitan is extremely conservative because it means that all the potential barriers to flow are completely ignored. As discussed in comment 3 above, Hiss does not indicate that the submarine canyons and igneous dike serve as barriers to flow. Furthermore, the use of 5 feet per day may not be conservative with respect to maximizing impacts at locations distant from the proposed injection especially with respect to the fresh water site in the Capitan aquifer located east of the injection well. As discussed in comment 5 above, the greater the T the greater impacts will be generally transmitted through the aquifer.

Hathaway (1985) reports on page 6 that the T of the Capitan aquifer east of the Pecos River should fall within the range of 2,000 to 50,000 feet squared per day. Through transient model calibration, Hathaway estimated a T of 25,000 feet squared per day for a majority of the Capitan including the area near the proposed injection site. A relatively small area within the Capitan representing the submarine canyon near the Lea-Eddy county line was estimated by Hathaway to have a transmissivity of 1,000 feet squared per day. In comparison to these values, the consultant has selected a T for the Capitan aquifer of 5,000 feet squared per day (this is the product of a aquifer thickness of 1,000 feet times a hydraulic conductivity of 5 feet per day).

Since the T of the Capitan in the area of the injection site may be greater than that represented in the model, it is not clear that the results of the study are conservative for the fresh water zone located to the east of the project. A reduction in T west of the injection site due to a submarine canyon may also result in greater impacts than estimated for the fresh water zone to the east.

7) In Section C.3 (page C2) it is stated that records of porosity for the Capitan are rare and that the value selected was obtained from values from a well log interpretation. Since this work was not provided, a determination of the validity of the estimate can not be made.

Furthermore, the draft report does not address the storage coefficient for the Capitan. The storage coefficient represents the volume of water released from storage in a unit prism of an aquifer when the head is lowered by a unit distance. A determination of the validity of the model results should not be made without consideration of the storage coefficient used in the calculations.

8) In Section C.3, it is stated that dispersivity values are assumed based on a range of values presented in Freeze and Cherry (1979). Dispersivity values represent how the solutes will mix as they flow through the aquifer, values selected will influence the estimates of how water quality will change due to the proposed injection. It is uncertain if the two values of dispersivity selected represent a conservative estimate. Freeze and Cherry (1979) indicate that studies of contaminant migration under field conditions require dispersivity measurements in the field. Measured dispersivity values for the Capitan are not available.

Furthermore, Mercer and others (1982) indicate that values of longitudinal dispersivity can range up to hundreds of meters for regional pollution problems and that dispersivity is scale dependent, the larger the area the larger the dispersion. It is indeterminate if the values presented in Freeze and Cherry are for a problem scale comparable to that being analyzed in the draft study.

An additional uncertainty in the dispersivity values assumed is that the reported values in Freeze and Cherry were selected by other investigators for modeling studies of large contaminant plumes in sandy aquifers. It is uncertain how conservative these values may be for flow in a heterogenous reef facies aquifer where solution cavities, fractures and rapid lateral facies changes are prevalent.

The difficulties in modeling solute transport in geologically complex media have been discussed by various investigators. Flow in the Capitan can be characterized as being very similar to that in a fractured media. Freeze and Cherry state that "Although contaminant transport in fractured geologic materials is governed by the same processes as in granular media ....the effects in fractured media can be quite different." Castillo et al. (1972) state "Although the basic theoretical aspects of...(dispersion)...have been treated at length for the case where the permeable stratum is composed of granular materials, the classical concept of flow through porous medium is generally inadequate to describe the flow behavior in jointed rock, and it becomes increasingly unsuitable for the analysis of dispersion." Due to the uncertainties discussed herein, we recommend that the estimates of solute increase be considered as very rough approximations.

9) In Section C.3 (page C3) it is stated that a likely reason for the brine zones in the Capitan is that recharge percolates through the Salado Formation which probably provides a constant source of brine to the Capitan just east of the Pecos River. The report indicates that the hydraulic gradient is

slightly to the east which results in the brine moving eastward toward the proposed injection well. It is stated on page C3 that this natural source of brine "does pose a much greater threat to Pecos River Basin water quality than any down-gradient injection activity".

We agree that injected brine from the proposed operation will not propagate to the area in the Capitan near the Pecos River unless the hydraulic gradient is reversed from the injection site to the stream. We also agree that the natural brine source located adjacent to the Pecos River probably poses the main threat to the fresh ground water in the Capitan from which the City of Carlsbad derives its supply. However, it has not been discussed in the study that brine injection could cause head changes that would "back up" or reverse the direction of saline flows into the fresh water zones used by the City of Carlsbad.

Information provided in the study suggests that the proposed injection could cause a reversal of groundwater flow in the Capitan adjacent to the Pecos to degrade fresh water zones. Figure D.4 in the study indicates that the hydraulic gradient is almost absent in the Capitan in the area immediately east of the Pecos River where the water quality interface exists (also see Figure 4). Recent work by the SEO indicates that it is difficult to establish if any head gradient exists in the Capitan in this area. Accordingly, relatively small increases in aquifer head on this relatively flat surface may cause changes in the direction of groundwater flow.

The model results shown in Figure D9.a indicate a predicted head change of about 1 foot of head increase for every mile from the Pecos due to the proposed injection. Based on the predicted head change in the study and the assumption of a level head distribution prior to injection, the proposed injection will induce saline flow toward the fresh water zones in the Capitan utilized by the City of Carlsbad. The predicted head change is based upon a constant T between the injection well and the Pecos River. If a constriction in the aquifer were included in the model, the predicted head change near the river would probably be reduced. However, this situation has not been modeled or discussed in the study.

10) On page D5 it is stated "if the heads at the east end are dropping, then the current assignments are conservative, since they minimize the gradient that is drawing water away from the Pecos". It should be noted that if the hydraulic head at the east end of the model is actually lower than was assumed, then the gradients will be larger and the solutes may flow more quickly to the east than predicted by the model. Also, the injected brine will probably increase gradients to the east which will increase the flow of solutes toward this area. The report correctly notes on page A2, item 4, that a zone in the Capitan with TDS concentrations less than 10,000 ppm exists east of the proposed injection site.

11) Model predictions showing increases in TDS are provided

in figures in which the TDS scale is greatly exaggerated. Although the report indicates on page D9 that it is extremely difficult to detect any impact at all upon the Capitan due to the proposed injection activities, it should be noted that this may be due to the scale chosen. On the figures provided in Section D showing predicted impacts, it is only possible to see large changes in TDS due to the scale chosen. It may be more appropriate in addressing the concerns of this proposal if the study provided the estimated increases in TDS to the nearest 10 ppm for the areas in which TDS concentrations are less than 10,000 ppm, including impacts to the Pecos River.

12) It is uncertain if the head rises computed in the study take into account the density of the injected water. The study does not address whether the heads have been corrected. Correcting heads for density would increase the mounding of the heads near the injection site computed relative to the mounding predicted uncorrected. If heads have been not been corrected for density, the results of the study could be in serious error.

Based on available information, we suspect that the heads have not been corrected for the density of the injected water. Figure D9 provides the estimated changes in head due to the injection well and indicate a maximum head rise of about 30 feet at the well after 23 years of injection. The results of the solute calculations indicate that TDS will increase at the well site from the present level of 50,000 ppm to 250,000 ppm at the end of the injection duration. Hiss (1973) provides adjustments of water levels due to water density for a number of wells in the Capitan aquifer. The adjustments increase the elevation of the head and range up to about 350 feet for water with a TDS of about 190,000 ppm. By performing calculations based on changing the density of water in a 1500 to 2000 foot thick aquifer from 50,000 to 250,00 ppm we estimated a change in fresh water head of between 200 and 300 feet. It is of interest to note that based on Figure D4 the head difference between the well site, prior to injection, and the Pecos River is less than 400 feet.

13) Two modeling scenarios were performed to estimate the impacts due to the proposed injection. In Scenario 1 a sloping hydraulic gradient was used in the model which does not closely approximate the actual observed gradient in the field for the entire modeled area. Because of this and the fact that the gradient can greatly influence the movement of solutes, the usefulness of this scenario is diminished. As an example of the limitations of Scenario 1, it is interesting to compare the physical system near the Pecos River with how the model represents this area. The head distribution based on available data indicates a near level potentiometric surface but the surface used in the model has a constant gradient of about 8.4 feet per mile. As discussed in comment 9 above, due to the relatively level nature of the potentiometric surface, small rises in head in this area could induce saline flows westward towards fresher water. Because the modeled surface has a much greater gradient to the east than actually observed, the model

does not simulate water quality changes well in this critical area. In addition, the modeled hydraulic gradient in Scenario 1 will cause the applied initial TDS concentration distribution to migrate eastward. The model does not distinguish between concentration changes due to this migration (or diffusion of the initial concentration distribution) from concentration changes caused by the brine injection.

The choice of a constant head boundary at the east end of the model may also induce a level of error into the calculations. If the head has not remained constant as assumed, the resulting gradient and solute movement as simulated in the model will differ from observed field conditions. The draft report indicates on page D5 that recent field data reflect the head is dropping in this area. If the head at the eastern boundary is actually lower than that simulated in the model, head gradients and solute movement toward the fresh water zone southeast of the site may be greater than estimated by the results of Scenario 1.

In Scenario 2, the impacts of the proposed injection are superimposed on to a level potentiometric surface. This scenario would not simulate the background movement of solutes in areas in which hydraulic gradients have been observed. As an example of the limitations imposed by this modeling decision, one can visualize a level potentiometric surface with no injection occurring. Movement of water and solutes will be occurring due to diffusion only (i.e. higher TDS water will migrate towards lower TDS water). Such a scenario does not model the transport of contaminant by background groundwater flow nor the dispersion of the contaminant by that flow. Also, model results from this scenario do not distinguish concentration changes due to diffusion from concentration changes due to the injection of brine.

**References**


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(From Hiss, 1980)

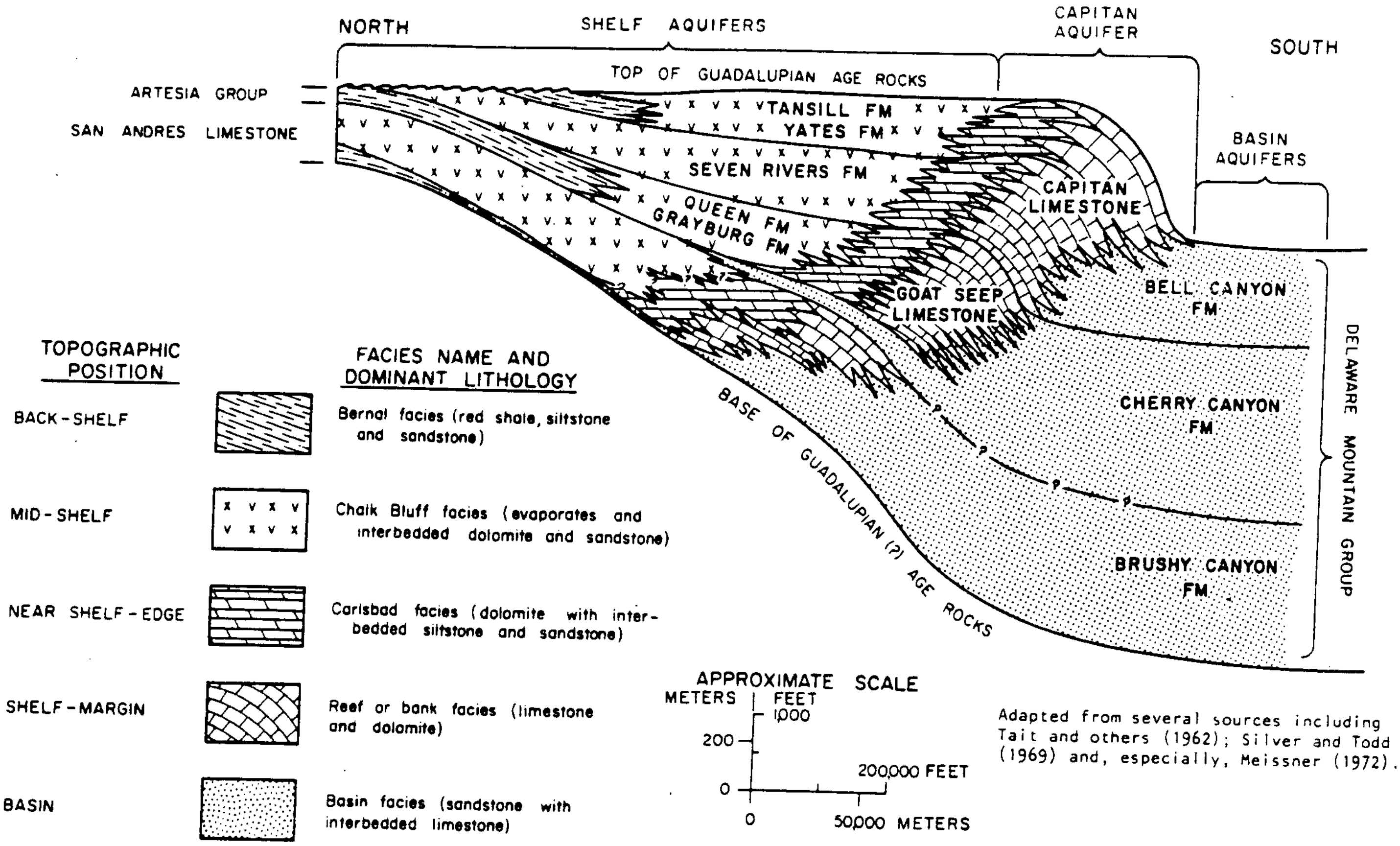
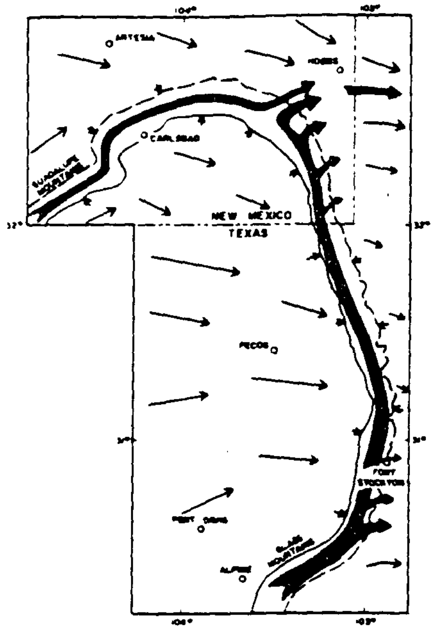
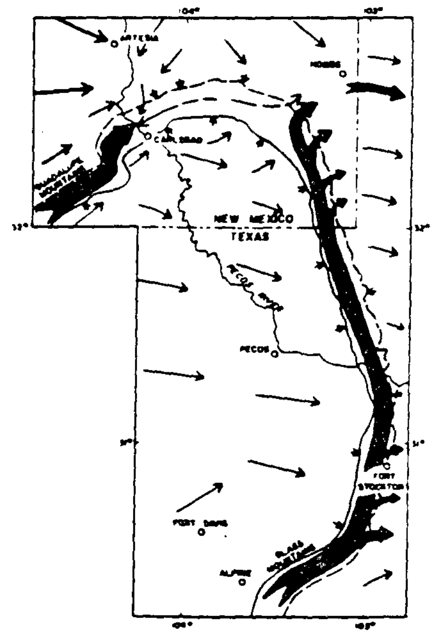



*Figure 1. Highly diagrammatic north-south stratigraphic section showing the positions and relationships of the major lithofacies in the rocks of Guadalupian age, eastern New Mexico.*

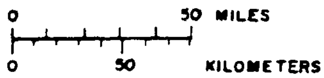
(From Hiss, 1980)




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




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

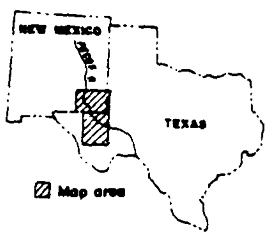



EXPLANATION

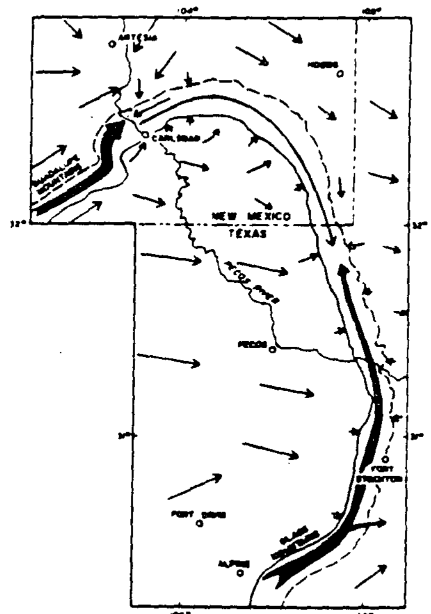
Capitan aquifer

Highly diagrammatic ground-water flow vectors:

1. Vector size indicates relative volume of ground-water flow.
2. Orientation indicates direction of ground-water movement.




INDEX MAP

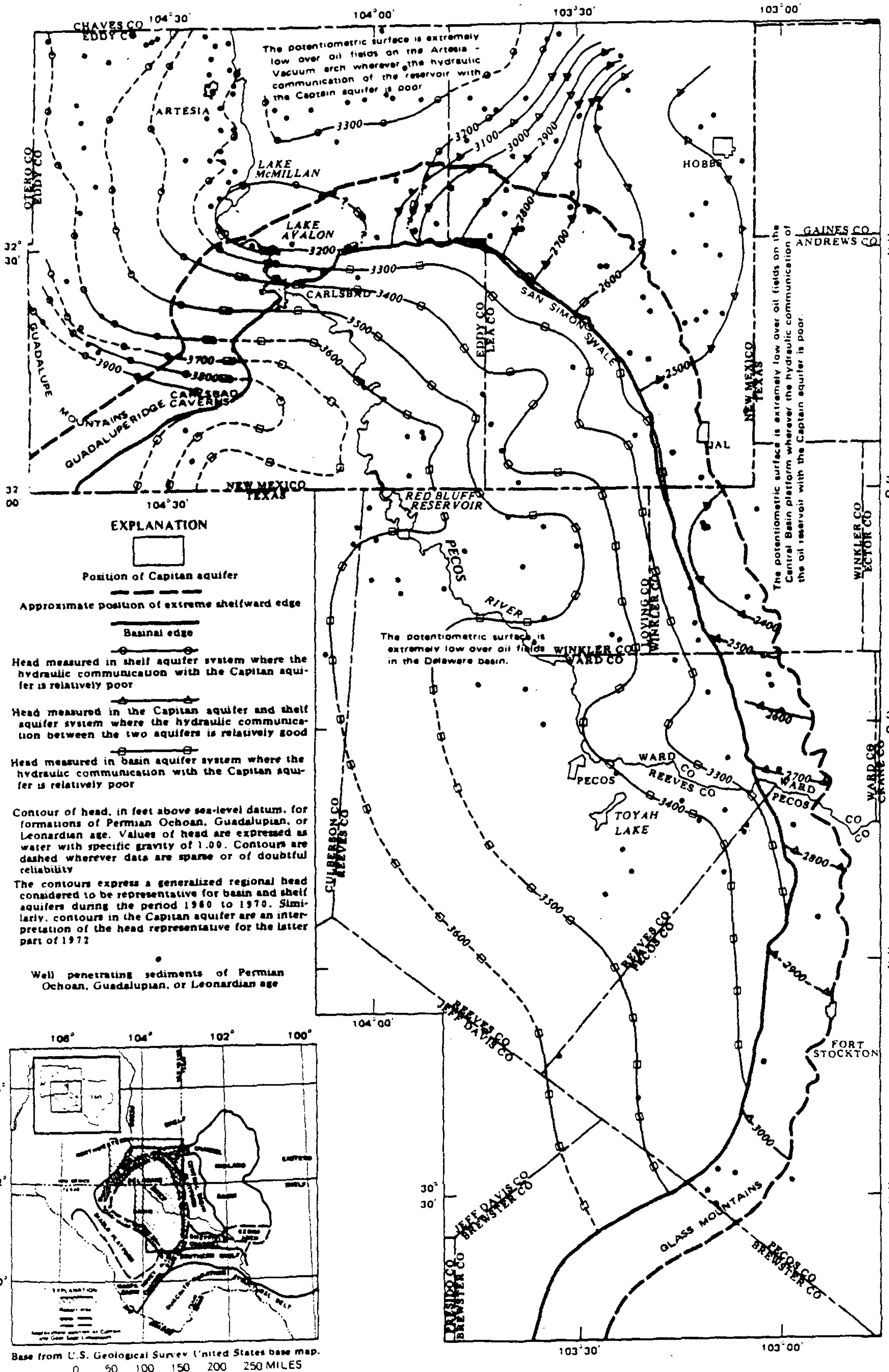



C. Regimen influenced by both communication with the Pecos River at Carlsbad and the exploitation of ground-water and petroleum resources.

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

Figure 2

(From Hiss, 1980)




*Post-development potentiometric surface.*

Figure 4