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Discussion of Capitan Reef Aquifer Salinity

Introduction

The nature of the Capitan Reef and the salinity of its groundwater became items of significant interest in the August 5, 2008 Santa Fe discussion between Mesquite SWD, Inc., and the New Mexico Oil Conservation Division (OCD). The meeting was a discussion of Mesquite's application/amendment to the produced water disposal permit for the Exxon State #8 well in Section 15, T21S-R27E, Eddy County, New Mexico.

The major points of interest in the meeting focused upon the stratigraphy of the Exxon State #8's injection interval (574' - 698'), its potential relationship to the Capitan Reef, and the water quality of the reef aquifer. The question as to the salinity (in TDS) of the Capitan Reef aquifer appeared to be based, in part, upon the written BLM objections to future injection into the Exxon State #8, or in the area.

Geological correlation of the Exxon State #8 zones of injection (574 - 694') has been previously demonstrated to be in the lower Yates Formation with its total depth (TD) at least 50 feet above the highest reasonable projection of the base of the formation. Similarly, the dip of the Artesia Group has been demonstrated to be southeast.

Additional Review and Rebuttal of BLM Reef and Groundwater Quality Statements

In the original report accompanying Mesquite's C-108 application, several justifications for the Carlsbad Field Office of the BLM's June 9, 2008 objections to Mesquite's application were not addressed. Those objections dealt with groundwater flow and salinity.

The BLM letter, page 2, notes that Capitan Reef water flows to the east, "and it is too saline to warrant protection under New Mexico State regulations" which, as originally noted, is a correct statement. In the next sentence the letter indicates "Water in overlying formations flows to the south/southwest (towards the Pecos River)." The overlying formations must include those of the Artesia Group and Castile in this area. Those formations clearly dip east to east-southeast, as does the underlying back-reef San Andres Formation. The structural dips are definitively shown in Welder's (1983) Figure 3, in numerous cross-sections in the Bjorklund and Motts (1959) study of the Carlsbad area, and in the Figure 3, page 6, map on top of the Magruder (Yates) zone by Havenor (June 17, 2008) accompanying the Mesquite C-108 application.

In addition to having the groundwater flow approximately perpendicular to the structural

dip, the BLM states "Ground water quality improves down-gradient outside the Salado outcropping . . ." Without obvious and significant fresh water dilution it is hydrogeologically highly improbable to impossible for groundwater to move through back-reef evaporitic deposits and improve in quality. As to the dissolved salt in any such water, there is no known water-rock reaction that will *remove* NaCl from groundwater. The BLM correctly indicates there are no water wells within 2.5 miles of the Exxon State #8. Similarly, there are no wells within 2.5 miles (or greater) of the Exxon State #8 that can be used to support their statements as to a west-southwest gradient and/or improved quality.

BLM concedes that groundwater in the reef east of the Pecos River was of poor quality before the advent of oil and gas operations, "but there was probably a larger area that contained usable (<10,000 ppm tds) water." The BLM did not indicate where or what utilization could presently be made of water in the 5,000 to 10,000 TDS range, nor do they indicate where or how large that area actually might be. Without the direct influx of fresh, low TDS recharge–such as naturally occurs on the south-bound eastern flank of the Capitan Reef south of Hobbs, there can be no reduction of TDS within the reef complex.

The BLM's seemed implication is that oil and gas operations have been the cause of high salinity in the reef aquifer east of Carlsbad and west of Hobbs. Irrigated lands were in cultivation in the Pecos River Valley long before oil and gas operations arrived. It was well know before oil and gas development that water quality in the limestone aquifer around Carlsbad rapidly deteriorated to the east of the Pecos River. Had the water quality been usable, even marginally, farmers would have developed it for irrigation. Some portions of the Pecos River have salinities close to the 10,000 mg/l TDS, but farming is not practical above about 5,000 mg/l TDS.

The BLM suggests that reef water may become an important resource as new water treatment technologies are developed. Treatment technologies are currently available to remove salts from the Dead Sea, however, the costs are extremely high and the environmental consequences of 62.5% concentrate that is 50% *more* saline than the source water (Clarke, 2007) are substantial.

The BLM also states that "If the natural ground water chemistry is restored, it will make treatment options more viable." This statement presupposes that the water chemistry of the Capitan Reef has been worsened by human operations. The BLM fails to recognize that the original waters in the Capitan Reef were Permian sea waters with salinities similar to modern ocean water (35,000 mg/l TDS). Where the western Capitan Reef yields potable water today, those porosities within the reef were flushed as a result of structural uplift and enhanced by fresh water solution to form an aquifer transmitting groundwater millions of years before the industrialization of the area by humans. The flushing process is natural and is continuing today, just as it is west of the Pecos River in Permian formations to the north in the Roswell groundwater basin. Restoring the "natural ground water chemistry" is not possible or desirable.

Examination of Known Capitan Reef Characteristics and Salinities East of Carlsbad

Salinity (TDS) has long been recognized as increasing in the Capitan Reef eastward from the Pecos River. Domestic and irrigation wells confirm this known increase. High salinity waters found in shallow oil well tests within a few miles to the east of the Pecos River have been known since oil drilling began in the area. The shallow wells that can be used to identify both specific lithologic units as well as source of water, were drilled with cable tools during the era of shallow oil exploration. Most wells today have deeper objectives that exclude the Capitan Reef from close observation because of rapid rotary drilling and cemented casing strings through the zones of our current hydrologic interest. Although geophysical logs are available through some of the shallow horizons of our present interest, the casing prevents running any resistivity logs that might assist estimations of the salinity of water in a particular zone.

Huff (2004) summarized the availability of Capitan Reef hydrogeologic data:

> Hydraulic conductivity of the Capitan aquifer in New Mexico ranges from 1 to 25 ft/d west of the Pecos River and averages about 5 ft/d east of the river. Transmissivities may be as much as 10,000 ft^2/d in thicker parts of the aquifer that have well–developed porosity (Hiss, 1975). The portion of the aquifer containing saline water may yield up to 500 gpm to wells (Kelly 1973). Huff (1997) summarized available porosity, permeability, and aquifer test data for the Capitan aquifer of New Mexico.

Hiss (1973) provides the most definitive stratigraphic and salinity information available through the T-21S, R-27E and R-28E area of concern in this report. This report has been reviewed in two forms, 1) the USGS "subject to major revision" review draft Hiss (1975), 374 pages, dated 4/7/1975, and 2) the official NM OSE Technical Report 38 (1973) of 76 pages.

In the review draft version, Hiss (1975, p. 191) states: "The 5,000 mg/l (milligrams/liter) isochlore in the Capitan aquifer extends only a few miles east of Carlsbad . . ." Unfortunately, the figure 26 Hiss references has been removed from the available copy of the report and is not present in the published 76 page 1973 version. Nevertheless, this confirms the rapid increase of reef salinity immediately east of Carlsbad.

Hiss (1975, p. 177) also describes the flushing of the Capitan Reef aquifer:

> Apparently, the volume of fresh water that flowed eastward from the Guadalupe Mountains was not adequate to flush the original brines from the Capitan aquifer in Eddy and the northern part of southern Lea Counties, New Mexico. The comparatively higher salinity of water in the Capitan aquifer east of Carlsbad can be attributed to three factors: (1) an inadequate volume of water moving eastward due to lower transmissivity of the aquifer, (2) the establishment of hydraulic communication between the aquifer and the Pecos River very early in the geomorphic evolution of the

> Carlsbad area and consequent reduction in the total amount of water that flowed eastward from the Guadalupe Mountains and (3) the subsequent leakages of higher salinity water into the Capitan aquifer from adjacent aquifers.

The first sentence of the above statement reminds us that the northern-most leg of the Capitan Reef, the essentially west to east portion, naturally contains high salinities that nature has not flushed during the past 50 million years of uplift and erosion in this region, including the approximately 12 million year presence of the Pecos River system.

In the meeting of August 5th, mentioned above, the subject of the inter-tonguing of Artesia Group formations, including the Yates Formation, with the Capitan Reef, was of great importance in understanding the hydrologic and geochemical relationships in the area. Hiss (1973, p. 7) succulently describes the relationships surrounding the Mesquite properties in Section 15, T21S-R27E.

> The Capitan aquifer is underlain by sandstones, siltstones, and limestones of the Delaware Mountain Group and is overlain by the Artesia Group and the Salado Formation. It is bounded on the basinward side by impermeable anhydrite of the Castile Formation and grades shelfward into the interbedded dolomite, limestone, sandstone, and anhydrite of the Artesia Group and San Andres Limestone. The basinward edge of the Capitan aquifer is abrupt and can be sharply defined, whereas the shelfward edge is gradational and cannot be easily defined (fig. 4). ***The rock units surrounding the Capitan aquifer generally have significantly less permeability than the Capitan and, in most places, act as partial hydrologic barriers to movement of water into or out of the aquifer.*** (Emphasis added)

Hiss' (1973) figure 4, shown below as Figure 1, p. 5, is roughly ten miles east of a generally south-southeast line through the Magruder (Yates) field, but would exhibit the same stratigraphic and lithologic relationships with the reef environment as a line through the Magruder (Yates) field. As discussed in our August 5th meeting, it is important to emphasize that the cross-section shelf to reef demarcation lines are not geologically instantaneous boundaries, but are wide transition zones of back-reef lithologies into reef deposited carbonates. *Sharply defined* in this environment probably means about one or two miles, more or less. That delineation, in turn, is highly dependent upon which (vertical) tongues of the reef in the back-reef environment are being represented in any specific line of cross-section.

The significance of Hiss' (1973) quotes, above, to the Magruder (Yates) discussion, is that effectively impermeable anhydrites, clays, sandstones, and some of the dolomites, are substantially less permeable than the Capitan Reef *aquifer*. The *aquifer* is usually in the uppermost Capitan Reef and positioned close to the basinward margin of the reef. The massive reef body lithologies, as also discussed by Hiss and others, is typically dense, low porosity to

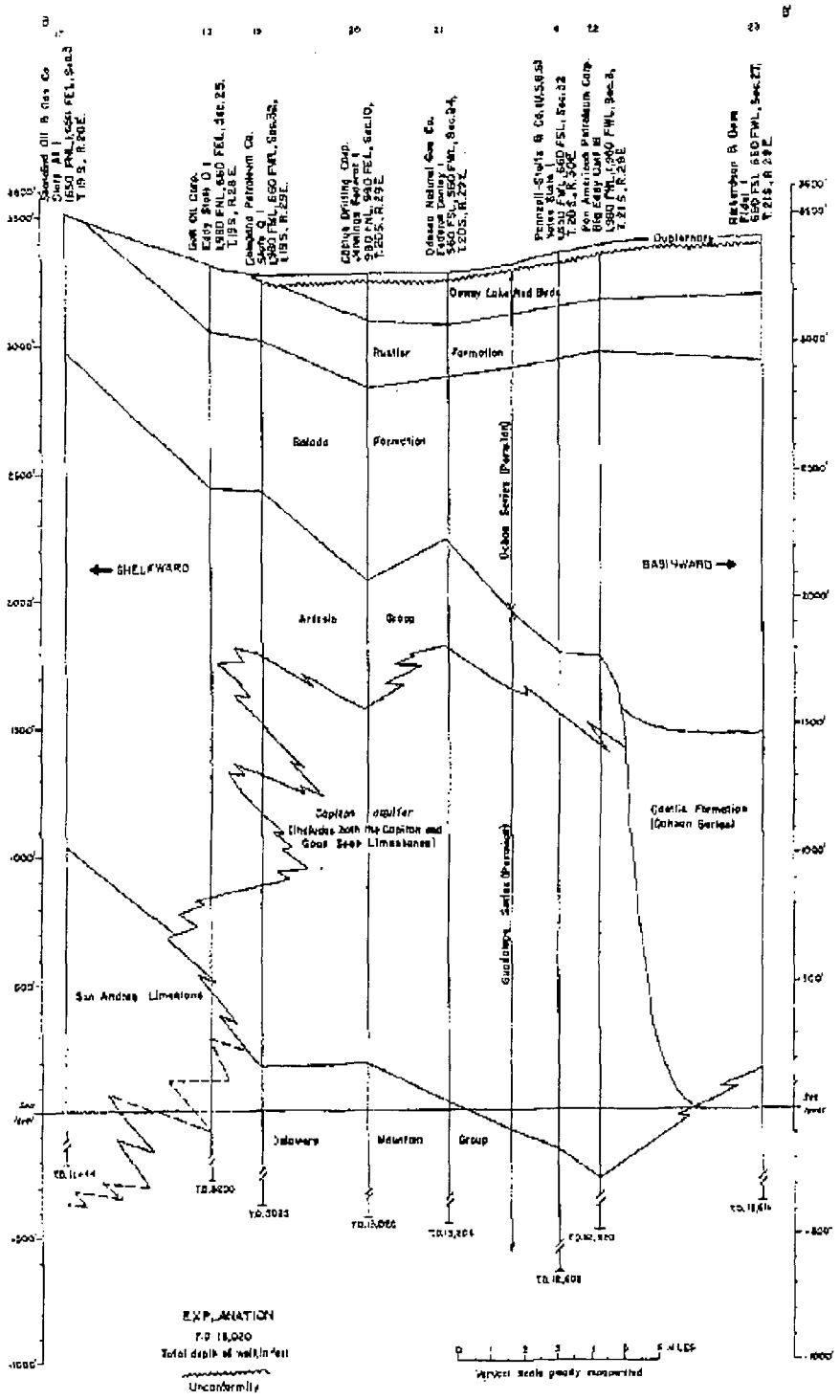

Figure 4.--Transverse stratigraphic section B-B' showing the position of the Capitan aquifer, Eddy County, New Mexico.

Figure 1 Reef cross-section from Hiss (1973).

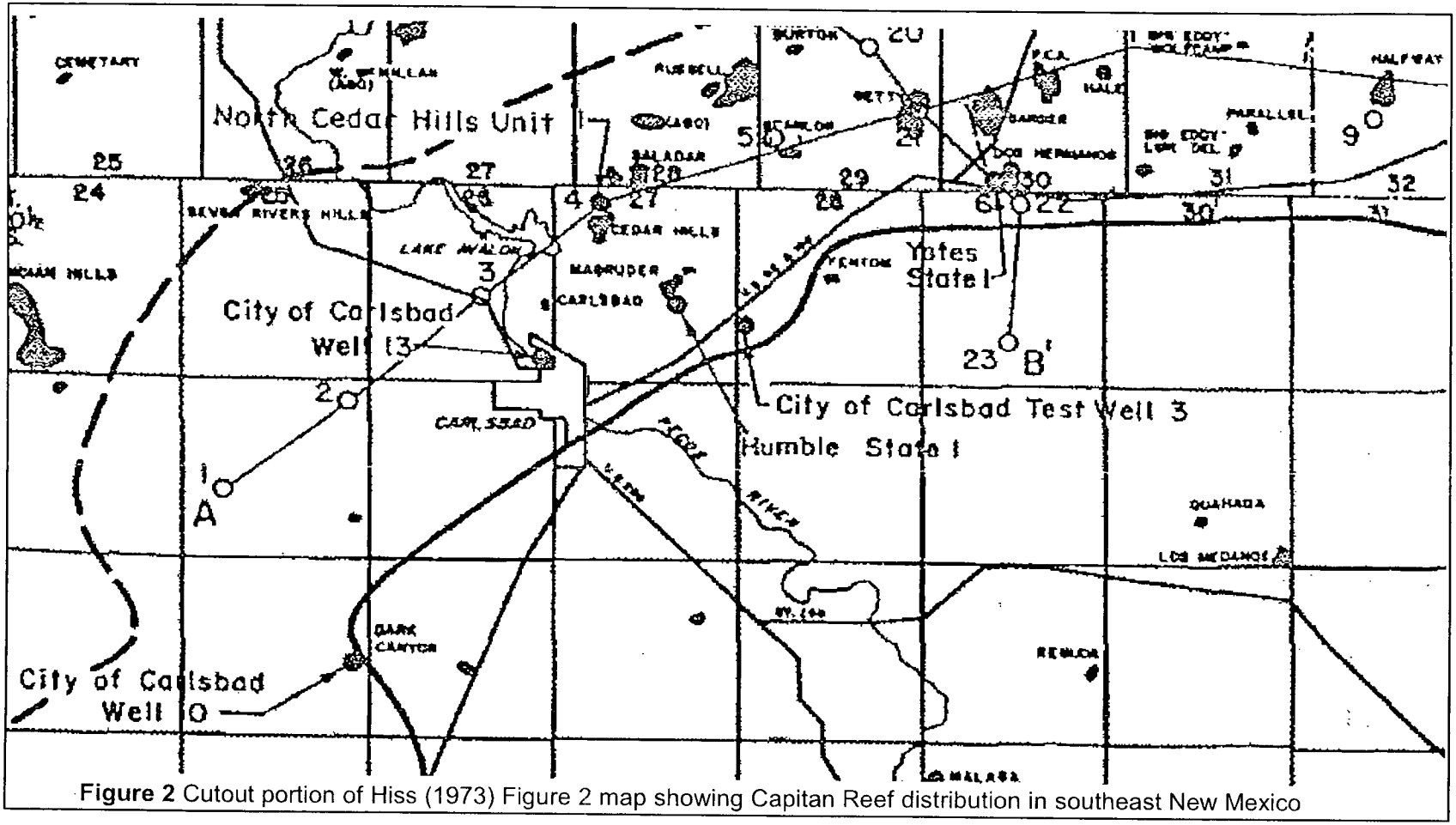

Figure 2 Cutout portion of Hiss (1973) Figure 2 map showing Capitan Reef distribution in southeast New Mexico

impermeable limestones. It is for these reasons that the back-reef lime mud depositional environment produces lithologies that act as ". . .hydrologic barriers to movement of water into or out of the (reef) aquifer."

Figure 2, p. 6, is an enlarged clip from Hiss (1973, Figure 2) regional depiction of the spatial position of the Capitan Reef in southeastern New Mexico. Two reference points are of special importance. The City of Carlsbad Test Well 3 is identified in the center of Figure 2. Approximately 8 miles east of test well 3, please note the well location identified as 23 B', the south end of the cross-section displayed above in Figure 1, p. 5.

Salinity Tests of the Greater Capitan Reef

The City of Carlsbad Test Well 3 is located 2.85 miles southeast of the Mesquite #8 Exxon State. Test well 3 is located in the Capitan Reef aquifer along the basinward edge of the reef. Test well 3 was originally drilled as the Miller Nix-Yates #1 Federal in the early 1950's (personal comm. w/Ralph Nix, 8/8/2008). There are no records of this well in the OCD files, the OSE well files, or in any scout tickets examined. Mr. Nix did confirm the well was an exploratory 1,060 ft dry hole conveyed (somehow) to the City of Carlsbad which then later allowed the USGS to sample the well. The current status of the hole is unknown. Mr. Nix will attempt to located some records.

The City of Carlsbad Test Well 3 is of particular importance in this study because it is included in Hiss' (1973) Table 2 tabulation of reef salinity tests and is actually in the Capitan Reef aquifer. At a depth of 900 ft Hiss (1973) reports TDS 23,800 mg/l. No description of sampling techniques are provided. Water at 60 ft tested 22,400 mg/l.

The Humble #1 North Cedar Hills Unit well is shown on Figure 2, p. 6, as well 4 on the roughly west to east cross-section line. The North Cedar Hills Unit #1 the is in the NW corner of Section 5, T21S-R27E, northwest of the Exxon State #8 (Section 15). This well was also sampled from 1,007 to 1,170 ft depths and had a TDS measurement of 28,000 mg/l (Hiss, 1973). This sample depth would be below the upper Yates, the Magruder equivalent, and is probably in the Seven Rivers Formation. The zones tested are in the back-reef facies and are within Hiss' (1973) "Capitan Reef" shown above, a comprehensive inclusion of reef and back-reef facies.

The Humble State #1 is shown on Figure 2, p. 6, immediately southeast of the Magruder (Yates) field, and is reported by Hiss (1973, Table 2, p. 18) as being in the center of SW/SW of Section 23, T21S-R27E (API 30-015-20012). Three of the water samples collected were from 250, 500, and 750 ft depths with TDS values of 48,310, 49,780, and 55,000 mg/l respectively. These depth intervals cover the upper Yates, middle to lower Yates, and possibly Seven Rivers/Capitan Reef limestone at 750 ft. It should be noted that these salinities predate the drilling of the Exxon State #8 or any water disposal. The lower most samples collected from this well were from 2,500 ft and the salinity at that depth was 46,004 mg/l TDS. This deepest sample illustrates the significant vertical differences that can and do occur in the back-reef.

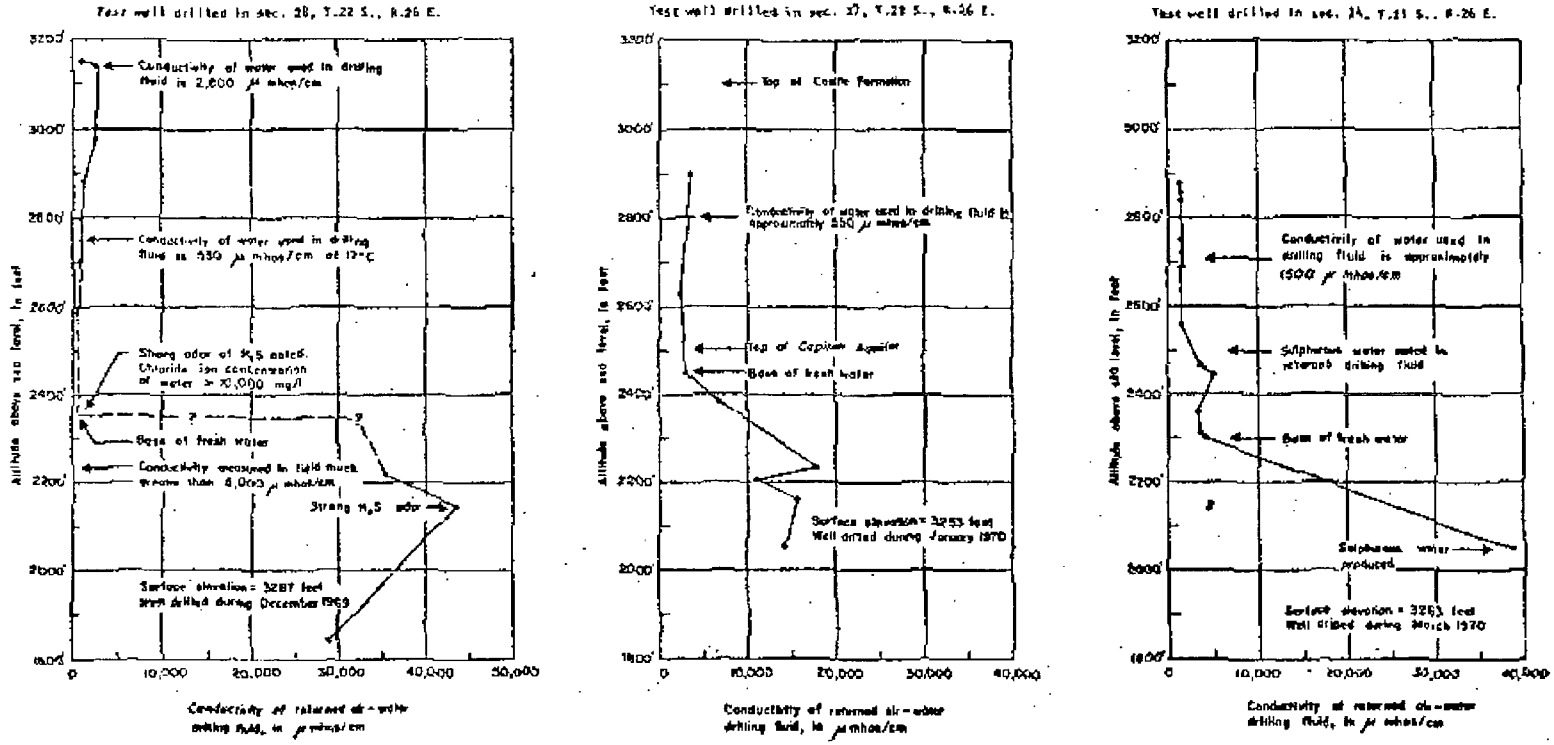

Figure 27.--Altitude of the fresh-saline water interface in the vicinity of Carlsbad, N. Mex.

Figure 3 Conductivity of waters in 3 USGS test wells (Hiss, 1975, Fig. 27, p. 198)

In Hiss' (1975) USGS preliminary report it was shown that three wells were drilled by the USGS (rotary tools using air - water) in which the conductivity of the returned drilling water was monitored. For a reasonable approximation, μ mhos/cm conductivity represents mg/l TDS. Figure 3, p. 8, is a reproduction of Hiss' (1975, p. 198, Figure 27) showing the curves recorded opposite depth for each of three wells. The wells 1 and 2 were drilled in Sec. 28 and 27 of T22S-R26E, and well 3 was located in Sec. 34, T21S-R26E.

The apparent intent of Figure 3 (Hiss, 1975, Figure 27) is to portray the base of the fresh water and top of the saline water. No support information is available, such as lithology, e-logs, penetration rates, etc. The two wells drilled in Sec. 28 and 27 of T22S-R26E are located southwest of Carlsbad and in a different geological situation than the Mesquite or the Carlsbad Test Well 3 areas. This method yields general information as to salinity, but is subject to the influence of fresh water added for air-water drilling.

The test well in Section 34, T21S-R26E (Figure 3, p. 8) is located on the west side of the Pecos River, in Happy Valley, on the west side of Carlsbad. Only one shallow water well (domestic) is reported in Section 34, whereas 55 water wells are present in Section 35. The top of the artesian aquifer (reef) in Section 35 is approximately 100 ft. Most of the wells in the Section 35 are alluvial aquifer domestic. The Section 34 USGS test well is not in the records of the OSE or the OCD.

OCD reports only one well (gas) in Section 34. No sample log was filed, but the hole was circulated, ran 13-3/8" surface casing set at 425 ft, and circulated cement (475 sacks). Experience in this area suggests the fresh water aquifer is a short distance above hard limestone picked by drilling for the casing point. The USGS conductivity log for the Section 34 well in Figure 3, shows a distinct conductivity peak at approximately 425 ft depth, also accompanied by a sulphur odor in the water. Sulphur odor does not necessarily indicate high salinity water. The USGS well continued to TD about 850 ft. The deepest conductivity reading indicated water TDS in the range of 38,000 mg/l. The 850 ft depth would be in the dense limestones beneath the potable water aquifer. This is another illustration of the lack of vertical hydraulic conductivity through the massive limestones of the reef.

Conclusions

The BLM objection comments should be summarily dismissed as not having any basis in known geological history, surface, and subsurface information, hydrogeological, hydrogeochemical data, or scientific examination.

References in the Mesquite C-108 application/amendment for water disposal in the Exxon State #8 well referenced sulphur and/or saline waters in the back-reef facies of the Artesia Group. The data presented in this report documents high salinity values throughout the entire greater area, including beneath the fresh water aquifer of the Capitan Reef. The values in the Capitan Reef and the back-reef facies range from 22,400 mg/l in the reef aquifer from the City of Carlsbad Test Well 3 located 2.85 miles southeast of the Exxon State #8, to 55,000 mg/l in the

Humble State #1, about 1.21 miles south-southeast of the Exxon State #8.

Present day lithologies in the Capitan Reef are of two general types: 1) the porous, crest region mostly along the leading edge of the buried reef, and 2) the massive reef body composed of relatively dense limestones, many of which were lithified lime muds deposited in and along the back-reef side. These limestones gradually grade northward into the dolomites and anhydrites of the San Andres Formation and the overlying Artesia Group.

The lithologies of the Seven Rivers and Yates Formations of the Artesia Group in the greater area surrounding the Exxon State #8 are back-reef facies deposits. These are the deposits referred to above, p. 4, by Hiss (1973) as having ". . . significantly less permeability than the Capitan and, in most places, act as partial hydrologic barriers to movement of water into or out of the aquifer." They are also the deposits observed in the sample descriptions and geophysical logs of the wells studied for the C-108 disposal application/amendment by Mesquite dated June 17, 2008.

Salinities and geological examination documented in the Mesquite's studies confirm, with strong support from other authorities, that

1) the TDS concentrations in the Capitan Reef aquifer dramatically and rapidly increase eastward from the Pecos River,
2) the salinities of the back-reef formations of the Artesia Group are naturally both variable and as high–or higher–than the waters within the Capitan Reef aquifer (proper),
3) the back-reef deposits of the Artesia Group and San Andres Formation are hydrologically and lithologically not conducive to groundwater communication with the Capitan Reef aquifer,
4) the Capitan Reef aquifer waters in their west to east groundwater flow are, for the most part, saline to, or well above, that of present-day sea water,
5) the flushing of the Capitan Reef aquifer of saline water is an ongoing geological process over millions of years, and
6) the Hiss' (1973) report predates any artificial human interference (water disposal) in the greater area.

Approval of produced water disposal into the Exxon State #8 well has not, and will not, have deleterious effects upon the Capitan Reef aquifer, or any other potable or protected groundwater source in the region, or upon Pecos River.

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