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P.O. Box 48, Viola, Idaho 83872 (208) 883-0153 (208) 875-0147

Hydrogeology • Mineral Resources Waste Management • Geological Engineering • Mine Hydrology

March 4, 1986
Contract No. NRC-02-85-008
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Communication No. 34

Mr. Jeff Pohle
Division of Waste Management
Mail Stop SS-623
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

'86 MAR 13 A11:11

WM DOCKET CONTROL CENTER

RE: SALT

Dear Jeff:

I am enclosing a review of each of the following documents:

1. Conti, R.D., Herron, M.J., Senger, R.K., and Wirojanagud, P., 1985, Stratigraphy and Influence of Porosity on Ground-Water Flow in the Wolfcamp Brine Aquifer, Palo Duro Basin, Texas Panhandle. Texas Bureau of Economic Geology, OF-WTWI-1985-19.

2. Senger, R.K., and Fogg, G.E., 1984, Modeling of the Effects of Regional Hydrostratigraphy and Topography on Ground-Water Flow, Palo Duro Basin, Texas. Texas Bureau of Economic Geology, Austin, Texas.

3. Bair, E.S., O'Donnell, T.P., and Picking, L.W., 1985, Hydrogeologic Investigations Based on Drill-Stem Test Data: Palo Duro Basin Area, Texas and New Mexico. Office of Nuclear Waste Isolation Technical Report BMI/ONWI-566.

If you have any questions concerning these reviews, please call.

8603310075 860304
PDR WMRES EECWILA
D-1020 PDR

Sincerely,

Gerry Winter /sl

Gerry V. Winter

WM-RES
WM ~~Record File~~
D1020
W4A

WM Project 10, 11, 16
Docket No.
PDR ✓
LPDR ✓ (B, N, S)

GVW:sl

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Pohle

(Return to WM, 623-SS)

2894

WMGT DOCUMENT REVIEW SHEET

FILE #:

TEXAS BUREAU OF ECONOMIC GEOLOGY #: OF-WTWI-1985-19

DOCUMENT: Conti, R.D., Herron, M.J., Senger, R.K., and Wirojanagud, P., 1985, Stratigraphy and Influence of Porosity on Ground-Water Flow in the Wolfcamp Brine Aquifer, Palo Duro Basin, Texas Panhandle: Texas Bureau of Economic Geology, OF-WTWI-1985-19.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: February 28, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E Williams

The report under review describes the lithology of the Wolfcamp strata in the Palo Duro Basin. The role of tectonics and sedimentation are described with respect to the development of the Palo Duro Basin.

Geophysical log data (neutron-density log responses) are used to determine the distribution of porosity in the Wolfcampian Series and the Brown Dolomite. The Brown Dolomite is an informal term for the facies at the top of the Wolfcamp section. The neutron-density log responses are crossplotted with porosity values obtained from laboratory analyses of core. The results of the study are used as an indicator of petroleum reservoir potential: the results also are used to enhance the calculation of groundwater travel time through the Palo Duro Basin in the strata noted.

Our major concern about the report under review is the extrapolation of a few point sources of data to very large areas. The crossplotted geophysical logs and core analyses are used to extrapolate porosities over the entire basin. Secondary porosity features cannot be incorporated into this analysis.

BRIEF SUMMARY OF DOCUMENT:

The report states two main objectives. "The first is to characterize and define stratigraphic boundaries of the Wolfcamp within the Palo Duro Basin... The second objective is to stratigraphically delineate the upper Wolfcamp Brown Dolomite (fig. 2) for the purpose of studying its thickness, stratigraphic correlation, and reservoir potential" (p. 3). The main sources of data for this report are geophysical logs and lithological descriptions from sample logs. Core descriptions from four U.S. Department of Energy test holes were used.

The report states that "Wolfcamp" is an informal subsurface lithostratigraphic unit. The Wolfcamp overlies the Pennsylvania/Permian boundary and underlies the Wichita Group. The "Lower Wolfcamp strata consist of marine carbonate and terrigenous clastic sediments that were deposited in marine, shallow-shelf, and deltaic environments... Upper Wolfcamp strata are composed of dolomitized shallow-water carbonates which grade upward into Leonardian evaporitic rocks" (p. 5).

The report states that the present hydraulic conditions were initiated during Cenozoic tectonism which initiated regional tilting of the sedimentary strata to the east. The higher elevations in the Sacramento and Sierra Grand Uplifts are zones of potential recharge to the flow systems. The Hardeman Basin is a candidate area for potential discharge. There is evidence of fault displacement of Middle Permian strata; some faulting probably occurred as recently as the Triassic (p. 8).

The report states that the contact between the Pennsvlvania and Permian systems is a source of confusion. The contact varies regionally and exhibits both unconformable and apparently conformable relationships. The boundarv between the Wolfcamp Series and the Wichita Group "is characterized by a large upward decrease in apparent matrix porosity and a gradational change in lithology from porous, coarsely crystalline dolomite to non-porous anhydritic dolomite" (p. 12). The changes in porosity and lithology cause characteristic log responses in neutron- and density-porosity and resistivity logs. The boundary is distinct in the northern part of the basin but is difficult to detect due to the lack of anhydrite in the Wichita Group in some areas of the southern most part of the basin.

The Brown Dolomite is an informal stratigraphic term. The dolomite is an important hydrocarbon reservoir. The Brown Dolomite is a diagenetic facies at the top of the Wolfcamp Series. The Brown Dolomite can be traced across the Palo Duro Basin. The Brown Dolomite is composed of "fairlv massive dolomitic mudstones, wackestones, and some packstones" (p. 14).

The report states "that much of the Brown Dolomite represents shelf-margin carbonates that were subsequently dolomitized" (p. 15).

Maps are presented in the report under review that were constructed based on cross plotted neutron-density log responses. The lithology evaluations were made by cross plotting and comparison with macroscopic core analyses. The report states that the log derived porosity values accurately reflect porosity similar to that determined through laboratory analyses of core. The report further states that no distinction was made between fracture induced porosity (secondary) and primary porosity (matrix). The cross plotting technique was applied to the logs of 26 wells that penetrate Wolfcamp Series strata. The density-porosity and neutron-porosity values were resolved from two to ten feet. "Plotting density-porosity against neutron-porosity responses yields relative percentages of dolomite/limestone, limestone/silica (undifferentiated chert, sandstone or granite wash), the presence of anhydrite and each lithology's corresponding porosity" (p. 17). Shaley intervals were interpreted to have a high total but very little effective porosity. The porosities of these shaley intervals was interpreted to equal 0%.

The "geographic distribution of average effective porosity within the Palo Duro Basin" was determined for each well in the Brown Dolomite interval and the entire Wolfcamp Series using a weighted average porosity technique. The technique was employed by using 5% ranges in porosity and the thickness represented for that 5% range. The weighted average porosity distributions are presented in the report as figures.

The report addresses the hydrologic implications of the porosity distribution in the Palo Duro Basin. The report notes that porosity is in the denominator of the groundwater velocity equation. A smaller denominator (smaller porosity) results in a higher velocity and hence a shorter groundwater travel time. The report cites a numerical modeling study by Wiroganagud and others (1984). The report under review states that the modeling study presents the same head distributions regardless of the porosity used in the simulation. Porosity is used only to calculate groundwater travel times. The report states (p. 21) that "Fluid velocities derived from incorporating log-derived average porosities are almost twice as great as the velocities derived from using typical porosity values." Travel times for the flow lines developed using the previously noted model range from 2.1 million years in the southeastern part of the basin to 0.25 to 0.8 millions years along the northwesternmost area of the basin.

The report addresses the relationship of permeability to air and porosity. Forty-two one inch diameter cylindrical core plugs were tested in the laboratory to determine permeability to air. The report states that "Generally, the common logarithm of permeability (to air) increases linearly with increasing porosity" (p. 27). The predictable relationships between porosity and permeability for the three lithologies tested are evidenced by correlation coefficients of 0.81 for sandstone, 0.84 for limestone, and 0.87 for dolomite. The report states that the permeability is higher in sandstone than it is for limestone with equivalent porosities.

The report addresses the differences between in-situ derived hydraulic conductivity values as opposed to laboratory derived permeabilities. The report states that permeabilities measured in the core plugs are distributed about the values of permeabilities measured via downhole transient pressure tests. The report states that the large variance of permeabilities derived from core plug analyses suggests extreme heterogeneity within the intervals that were analyzed by in-situ transient pressure tests. The report further states that the higher permeabilities derived from the in-situ tests may be caused by fracture permeability which is not discernable in core plugs.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The report is important to the Waste Management Program because this report outlines a procedure for attempting to determine porosity in-situ via an indirect means (geophysical logs). The approach is progressive in that it proposes an advancement in the use of different methods of in-situ characterization of hydrogeologic parameters. The porosity values derived using the crossplotting techniques must be used with caution because these values may be higher than true effective porosities (perhaps secondary) that control the rate of groundwater movement.

PROBLEMS, DEFICIENCIES, OR LIMITATIONS OF REPORT:

A major problem exists with the report because of the use of essentially point values of porosity and permeability. The geophysical logs have a small radius of influence although not as small as the core. Geophysical logs and core analyses encompass very small volumes of the strata. Secondary porosity such as fractures or solution features are not detected at all using these indirect means of characterization. Hence, the values derived for porosity probably will be higher than expected for an equivalent volume of material. Only field tracer tests will approach the value of effective porosity that is appropriate for calculating groundwater travel time. The values of permeability derived from core analyses in the report are limited to the core plug. Questions as to the validity of the data derived from laboratory analyses of core are also questionable due to the in-situ stress conditions which were relieved upon coring and may have not been adequately reinstituted during testing. A core plug represents only a small volume of the strata sampled. In-situ large-scale transient type tests provide a representative value for a much larger volume of material tested. Larger scale in-situ tests provide information on both matrix and secondary permeability-porosity under many circumstances, even though difficulties may arise when interpreting data derived from in-situ tests in a dual porosity system.

Our concern regarding the porosity values and the representativeness of the porosity values for large volumes of material carries over into the use of these data for constructing large scale porosity distribution maps. The extrapolation of the data to this basinwide scale is questionable for purposes of estimating groundwater travel time. The attempt to calculate groundwater travel time seems to be a secondary product; the original objective of the report was to ascertain the reservoir potential in the Wolfcamp Series and in the Brown Dolomite. The report addresses the question of the reservoir potential; the report also addresses groundwater travel time by using the porosity distributions derived in this report.

The report states (p. 33) that total porosity is assumed equal to effective porosity for purposes of the report. The results of the travel time calculations must be assumed to be non-conservative because effective porosity can be equal to total porosity but it probably is less than total porosity. A smaller effective porosity results in a shorter travel time to the accessible environment.

This report is similar in many respects to Conti and Senger(1985). Our review of Conti and Senger (1985) points out the inconsistency in referring to the "Deep-Basin Brine Aquifer" which is assumed to be the entire Wolfcamp Series while at the same time splitting the series into hydrostratigraphic units. The limitations of core analyses and geophysical logs noted in the review of Conti and Senger (1985) also are appropriate to the document under review.

<u>REFERENCES CITED</u>:

Conti, R.D., and Senger, R.K., 1985, Hydrostratigraphy of the Wolfcamp Aquifer, Palo Duro Basin, Texas Panhandle. Texas Bureau of Economic Geology, Austin, Texas, OF-WTWI-1985-38.

WMGT DOCUMENT REVIEW SHEET

FILE #:

TEXAS BUREAU OF ECONOMIC GEOLOGY #: OF-WTWI-1984-32

DOCUMENT: Senger, R.K., and Fogg, G.E., 1984, Modeling of the Effects of Regional Hydrostratigraphy and Topography on Ground-Water Flow, Palo Duro Basin, Texas: Texas Bureau of Economic Geology, Austin, Texas.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: February 28, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E Williams

The report under review discusses a cross-sectional groundwater flow model of the Palo Duro Basin. The model was constructed to analyze available hydrogeologic data and to better understand the causes of the underpressuring below the evaporite aquitard. The report also discusses the mechanisms of recharge and discharge to and from the "Deep-Basin Brine Aquifer".

The model states that the subhydrostatic pressures beneath the evaporite aquitard are caused by the segregation of the deep and shallow flow systems by the evaporite aquitard. In addition, the deep system is drained by the relatively permeable granite wash deposits. The Pecos River also contributes to the underpressuring beneath the evaporite aquitard. The report states that about 26% of the groundwater in the "Deep-Basin Brine Aquifer" originates from leakage through the evaporite aquitard. This assumes that the vertical hydraulic conductivity of the aquitard is restricted to an upper limit of 2.8×10^{-4} md.

This report is limited by a lack of data. Numerous modeling units are assigned assumed permeability values based on measured values for similar materials or on calculated mean values. Assumed values for the ratio of horizontal to vertical permeability are used for the modeling units. Assumed porosity values are used to estimate groundwater velocities.

BRIEF SUMMARY OF DOCUMENT:

The report discusses a two-dimensional groundwater flow model that was constructed along a cross section through the Palo Duro Basin. The report simulates the underpressuring below the evaporite aquitard and the mechanisms of recharge and discharge to and from the "Deep-Basin Brine Aquifer". The model simulates steady state flow conditions using data for various hydrogeologic units in the section and hydraulic head and recharge rates along the boundaries of the model.

The report describes the geologic setting and geologic history of the Palo Duro Basin. The physiography and climate of the Texas Panhandle and the high plains are discussed in the report. Elevations range from 3,000 to 4,700 feet along the cross section. The elevation of the Manzano Mountain Range (New Mexico) reaches approximately 7,000 feet. The high plains region is characterized by a semi-arid climate with a mean annual precipitation of 12 inches in the west to 23 inches east of the High Plains.

Recharge to the Ogallala aquifer is variable and is estimated to range from 0.058 to 0.833 inches per year depending upon several factors including climate and soil type. The recharge values assigned to the high plains are presumed to be a minimum of 0.058 inches.

The data base includes hydraulic head and pressure data. The hydraulic head and pressure data indicate that shallow groundwater in the Ogallala aquifer is moving east and southeast. Heavy pumping has caused groundwater level declines since 1940. The heavy pumpage has not caused significant changes in the potentiometric surface of the Ogallala from pre-pumpage days. The heavy pumping has not been incorporated in this modeling effort.

The hydraulic head data for the "Deep-Basin Brine Aquifer" were derived from drill stem tests. The hydraulic head data were developed by converting the drill stem test data into equivalent fresh water heads. The report states that a comparison of the unconfined and confined hydraulic heads shows that the heads are lower in the "Deep-Basin Brine Aquifer" than in the upper aquifer.

The Ogallala Formation consists primarily of fluvial clastics. The average hydraulic conductivity of the Ogallala is approximately 8.0 m/day (reference cited in the report under review as Myers, 1969). The report assumes that vertical hydraulic conductivity is an order of magnitude less than the horizontal hydraulic conductivity.

The Dockum Group is a fluvial and lacustrine depositional system. The average hydraulic conductivity for the Dockum is assumed to be about 0.8 m/day (report cites Myers, 1969). The report states that most modeling approaches assume that the potentiometric surface of the Ogallala Aquifer and the Dockum Group are equivalent. The report under review states that there is evidence that heads in the Dockum Group are 100 to 300 feet lower than the heads in the Ogallala Aquifer. References are cited to support this statement. The report states that the water chemistry and the O^{18} and H^{2} concentration in the Dockum is different than that in the Ogallala aquifer. Again references are cited for the statement. The report states that these two pieces of evidence suggest that the two aquifers are not well connected. The report states that the vertical permeability has to be at least four orders of magnitude lower than the horizontal permeability based on the head difference between the Ogallala and the Dockum. The report states that this difference in hydraulic conductivity is substantiated by a simulation in the report under review.

The Permian evaporite section includes evaporites and deposits of the inner shelf system. The aquitard consists mainly of thick layers of salt deposits, anhydrite, red beds and peritidal dolomite. A vertical permeability of 0.00028 md is assumed for the evaporite aquitard. This value is derived by calculating the harmonic means of permeabilities using "typical and measured values of permeability for each sub-strata" (p. 9). The report notes that this value is a rough estimate and does not incorporate possible fracture flow.

The "Deep-Basin Brine Aquifer" consists of the Lower Permian, Pennsylvanian, and Pre-Pennsylvanian Formations. The Lower Permian and Pennsylvanian depositional environments were similar; these environments consisted of a fan delta, shelf and shelf margin, and a basinal system. The fan delta system is arkosic sand and conglomerate. "Open marine shelf carbonates and terrigenous muds comprise the shelf and basinal system" (p. 9). The vertical permeabilities of the Lower Permian and Pennsylvanian strata are assumed to be approximately two orders of magnitude lower than the horizontal permeability. Permeability values were converted to hydraulic conductivity values by using an average fluid salinity and temperature (127,000 mg/L and 46°C). The report states that permeability data indicate an extremely heterogeneous distribution of values. The data also indicate a relatively small data base. The report states that the proximal granite wash deposits apparently have higher permeabilities than the distal granite wash deposits in the center of the basin. The report states that five pumping tests were conducted in the proximal granite wash in the J. Friemel #1 well.

A generic value of permeability of 70 md was used for the mud flat and alluvial fan delta systems in the Permian/Pennsylvanian strata. A generic value was used because measured permeability data are not available. The report states that the value used for the mud flat alluvial fan delta systems creates a model computed discharge rate to the Pecos River that is commensurate with measured stream flow increases along the river in the area of the cross section.

Permeability values for the units in the salt dissolution zones were "conservatively estimated to be 70 md ..." (p. 11). The report states that recent data indicate a high hydraulic conductivity, approximately twice that used in the model.

The report uses FREESURF, a model developed by Neuman and Witherspoon (1970). FREESURF was used to solve two-dimensional steady state groundwater flow in porous media. The finite element mesh extends from New Mexico into Oklahoma. The report states that the large node spacing differences between the horizontal and vertical directions does not create a significant problem with the calculation of head values. A sensitivity study was conducted to ascertain this conclusion. Several hydrogeologic units are distinguished within the model. These units consist of the carbonate shelf and shelf margin systems, mud filled basin and slope system, and the fan delta system (granite wash) within the "Deep-Basin Brine Aquifer". The thick aquitard (Permian evaporite sequence) separates the "Deep-Basin Brine Aquifer" and the Ogallala Aquifer and the Dockum Group. The salt dissolution zones to the east and west of the High Plains are designated in the model; the Permian mud flat system also is designated. The Permian/Pennsylvanian mud flat and alluvial fan delta systems are designated in New Mexico.

The model prescribes heads and flux. The water table is represented as a prescribed head boundary. A recharge value of 0.058 inches is assigned to the High Plains of the Texas Panhandle. The recharge value was increased to 0.250 inches in the New Mexico area. The report states that hydraulic conductivities had to be reduced by one order of magnitude in the Ogallala Aquifer and the Dockum Group in the western High Plains in New Mexico to account for the observed water levels within the Ogallala Aquifer. The lower boundary of the mesh was assumed to impervious be and corresponds to the contact between the "Deep-Basin Brine Aquifer" and basement rock. Heads are assumed to be uniform with depth on the eastern boundary of the mesh.

Several simulations were run for the report. The results are compared to hydraulic heads derived from a kriged head map of the deep aquifer.

The report notes the limitations of the model. A major potential source of error is noted as being the assumed anisotropy of the different units. Also a major error could lie in the values of hydraulic conductivity assigned to the units. Lateral and vertical permeability trends are ignored in the deep section. The large values of variance in measured permeabilities suggest heterogeneity within the unit. The report also notes that this is a steady state model which assumes that there are no transient conditions affecting the hydrodynamics of the Palo Duro Basin. The report suggests that uplift and tilting of the basin, erosion and retreat of the caprock escarpment, and extensive hydrocarbon production could affect the results of the model. The model also assumes that the fluid is homogeneous throughout the basin.

Several simulations were run for the report. Simulations A-1 and A-2 test various spatial, permeability variations of the granite wash deposits. Permeabilities for the different units were assigned according to the attached Table 4. The results of Simulation A-1 indicate that a shallow flow system exists as well as a deeper flow system. The aquitard separates these two flow systems. The report states that the heads in the deep section become progressively higher, by up to 246 feet, than heads in the unconfined section. These simulated heads are unrealistic.

Simulation A-2 assigns higher permeabilities to the proximal granite wash deposits. A permeability of 100 md was assigned to the proximal granite wash east of the caprock escarpment. The report states that modification of granite wash permeabilities allows the computed heads in the eastern half of the cross section to show good agreement with kriged head data in the deep aquifer. The report states that granite wash permeabilities do not affect heads in the deep aquifer in the western part of the section. The report notes that there is a significant discrepancy between computed heads and kriged heads in the western half of the section. The report notes that the excess heads in the western half of the section could be created due to the fact that the high permeability proximal granite wash deposits are not considered in the western part of the section of the model. The proximal deposits that are not considered are located to the north of the section of this model.

Simulation A-3 incorporates the possible draining effect of the proximal granite wash deposits along the Oldham Nose and Amarillo Uplift which lies to the north of the cross section. This simulation inserts artificially high values of granite wash permeability along the entire east-west cross section. The granite wash permeability values were increased from 8.6 md to 100 md for the distal facies to the west. The permeabilities were increased from 100 md to 250 md for the proximal granite wash deposits to the east of the caprock escarpment. The report states that the computed hydraulic heads in the deep aquifer are significantly lower in the western part of the cross section compared to Simulation A-2. The report further states that the heads in the deep section agree reasonably well with the kriged heads. The report states that leakage through the evaporite aquitard increased from 0.0094 in Simulation A-2 to 0.0116 cubic meters/day in Simulation A-3. This increase in leakage was created by the increased hydraulic gradient across the aquitard. The report states that the groundwater flow pattern indicates two important aspects of the hydrology of the Palo Duro Basin. The first aspect is the role of the evaporite aquitard and the second aspect is the discharge to the Pecos River.

Simulation B-1 and B-2 test the hypothesis that subhydrostatic conditions in the deep aquifer are created in large part by the evaporite aquitard. These simulations vary the aquitard permeabilities. The report states that increasing the aquitard permeability from 2.8×10^{-4} md to 2.8×10^{-3} md results in a significant increase in hydraulic heads in the deep section. The increase in heads (up to 250 m) is unrealistic. The second simulation (B-2) decreased the aquitard permeability by five orders of magnitude from 2.8×10^{-4} md to 2.8×10^{-8} md. The heads decrease in the deep basin aquifer by up to 50 m in the central part of the cross section. Heads from this simulation are slightly lower than kriged heads in the eastern part of the cross section.

Simulation C tests the effect of the Pecos River on the distribution of heads. The mesh was modified in this simulation to eliminate the Pecos River Valley. Results of this simulation indicate that the facies contrast is more important than the topography in creating an upward flow of groundwater beneath the Pecos Valley.

Simulation D tests the interconnectedness of the Ogallala and Dockum aquifers. The vertical hydraulic conductivity of the Dockum was lowered in successive runs of the model until a minimum observed head difference occurred between observed and simulated values. The vertical hydraulic conductivity for the Ogallala was assumed to be 8×10^{-2} m/d. The vertical hydraulic conductivity for the Dockum was assumed to be 8×10^{-8} m/d. The simulation resulted in computed heads that are up to 40 m (130 ft) lower than those derived from Simulation A-2. The change in vertical hydraulic gradient in the shallow aquifer system results in a change in the leakage through the evaporite aquitard. The reduction in gradient creates a reduction in leakage rate of approximately 19% under the leakage rate from Simulation A-2.

The report states that Simulation A-2 represents the most realistic model which incorporates permeability values for granite wash deposits that are supported by presently available data on permeability. The report states that the maximum groundwater flow velocities in the shelf carbonates of the "Deep-Basin Brine Aquifer" are 1.1×10^{-4} m/d. The maximum groundwater velocities in the proximal granite wash are 4.4×10^{-4} m/d. These velocities are equivalent to 400 m and 1,600 m for 10,000 years, respectively. Average porosities were assumed to be 8% and 23% for the shelf carbonates and proximal granite wash, respectively. The report states that the contribution to the deep aquifer through vertical leakage is approximately 26% of the water passing through the "Deep-Basin Brine Aquifer".

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

This report is significant to the program because the results of the modeling are significant with respect to groundwater travel time calculations and determination of the direction of groundwater flow. The report indicates that the Ogallala Aquifer may not be well interconnected with the Dockum Group. The reduction in gradient across the evaporite aquitard due to the consideration of the separate aquifers (Ogallala and Dockum) above the aquitard may reduce leakage to the deep aquifer. The variability of the simulated heads in the deep aquifer emphasize the point that the deep aquifer may be more than a single aquifer. A number of factors are incorporated into this point including the stated heterogeneity of the formations. All of these factors result in various considerations of groundwater flow direction and travel time calculations.

PROBLEMS, DEFICIENCIES, OR LIMITATIONS OF REPORT:

The report uses the phrase "Deep-Basin Brine Aquifer". We objected to the use of this phrase in our review of Orr and Senger (1984). We will not comment further on our objection to the use of the phrase "Deep-Basin Brine Aquifer".

The hydraulic head data for the "Deep-Basin Brine Aquifer" are based on a conversion of drill stem test data; the data were converted into equivalent freshwater heads. The use of equivalent freshwater heads for the model must be used with extreme caution. The use of freshwater heads is supposedly restricted to consideration of lateral flow within a hydrostratigraphic unit (Lusczynski, 1961). In contrast, the hydraulic head data are used to compare vertical gradients in the report under review. This use of the data is not appropriate based on the conclusions stated by Lusczynski.

This report, as many modeling reports, uses assumed values of permeability or hydraulic conductivity where test values are missing. This report is no exception. The report, for instance, assumes that vertical permeability is one order of magnitude less than horizontal permeability in the Ogallala Formation. The vertical permeability of the Dockum Group is assumed to be four orders of magnitude lower than the horizontal permeability based on simulations using the model in the report under review. The vertical permeability for the evaporite aquitard was derived from the harmonic means of permeabilities using "typical and measured values of permeability ..." (p. 9). One must assume that the measured values represent horizontal permeability although the report under review does not so state. The vertical permeabilities for the Lower Permian and Pennsylvanian strata are assumed to be two orders of magnitude lower than horizontal permeability. A generic value of permeability was used for the Permian/Pennsylvanian strata referred to as mud flat and alluvial fan delta systems. A permeability for the units representing the salt dissolution zones is approximately one-half the value derived from recent tests in the dissolution zone. The dissolution zone test report was in preparation prior to the completion of this report.

Other problems exist with modeling this heterogeneous system. The fluids are of varying salinity and temperature; single values for salinity and temperature are used for converting permeability to hydraulic conductivity values. The report states that the large variance suggests an extremely heterogeneous distribution of permeabilities and a relatively small data base (p. 10). In conclusion, we reiterate our point that modeling studies such as this are fraught with severe restrictions due to the lack of data and the necessity to assume values.

The report compares computed hydraulic head values to those derived from a kriged head map. The kriged head maps have appeared in a succession of reports prepared by the Texas Bureau of Economic Geology. We are reviewing these documents.

The report under review points out that outside influences could affect the supposed steady state flow conditions simulated by the model. These flow conditions include uplift and tilting of the basin, erosion and retreat of the caprock escarpment, and extensive hydrocarbon production. The report under review does not address these factors; a second report does address these factors (Senger, 1984).

The report states that Simulation B-1 infers that a generically derived permeability value of 2.8×10^{-4} md represents an upper limit of the possible permeability value of the evaporite aquitard. The report fails to state that increasing the horizontal hydraulic conductivity of the "Deep-Basin Brine Aquifer" could also lower the heads below the aquitard while still sustaining a higher vertical hydraulic conductivity in the aquitard. The approach used to simulate the required heads in the "Deep-Basin Brine Aquifer" is limited by apparently preconceived notions about the horizontal hydraulic conductivity of the deep aquifer (p. 9).

The "Deep-Basin Brine Aquifer" groundwater velocities are based on assumed average porosities. These porosities are 8% and 23% with respect to shelf carbonates and the proximal granite wash. Again, we note that these values are assumed and are not supported by in-situ testing. Lower values of effective porosity would increase the groundwater velocity and hence decrease the groundwater travel time. Obviously, tests must be conducted to obtain representative values of porosity.

<u>REFERENCES CITED:</u>

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Senger, R.K., 1984, Hydrodynamic Development of the Palo Duro Basin and Other Mechanisms Creating Possible Transient Flow Conditions: Texas Bureau of Economic Geology, Austin, Texas, OF-WTWI-1984-54.

Smith, A., and Orr, E.D., 1982, Use of Kriging to Estimate the Wolfcampian and San Andres Potentiometric Surfaces, Palo Duro Basin, Texas Panhandle: Texas Bureau of Economic Geology, Austin, Texas, OF-WTWI-1982-3.

Smith, D.A., Akhter, S., and Kreitler, C.W., 1985, Ground-Water Hydraulics of the Deep-Basin Aquifer System, Palo Duro Basin, Texas Panhandle: Texas Bureau of Economic Geology, OF-WTWI-1985-16.

Table 4. Assigned hydraulic conductivity values for the major hydrologic systems.

Hydrologic Unit		Hydraulic Conductivity (m/day) horizontal (K_x)	vertical (K_z)
1.	Ogallala fluvial system[1]	8.0×10^{0}	8.0×10^{-1}
2.	Triassic fluvial/lacustrine system[1]	8.0×10^{-1}	8.0×10^{-2}
3.	Permian (salt dissolution zone)[3]	8.2×10^{-2}	8.2×10^{-4}
4.	Permian sabkha system[4]	3.2×10^{-7}	3.2×10^{-7}
5.	Permian mudflat system[2]	8.2×10^{-5}	8.2×10^{-5}
6.	Permian/Pennsylvanian shelf carbonates[4]	1.3×10^{-2}	1.3×10^{-4}
7.	Permian/Pennsylvanian basinal systems[4]	1.1×10^{-7}	1.0×10^{-7}
8.	Permian/Pennsylvanian mudflat and alluvial/fan delta system[2]	8.2×10^{-2}	8.2×10^{-4}
9.	Permian/Pennsylvanian fan delta system (granite wash)[4]	1.0×10^{-2}	1.0×10^{-4}

Sources of data:

1. K_x from Myers (1969); assumed $K_x/K_z = 10$
2. typical value of geologic material (Freeze and Cherry, 1979)
3. K_x from U.S. Geological Survey open-file data; assumed $K_x/K_z = 100$
4. after Table 2

WMGT DOCUMENT REVIEW SHEET

FILE #:

OFFICE OF NUCLEAR WASTE ISOLATION #: BMI/ONWI-566

DOCUMENT: Bair, E.S., O'Donnell, T.P., and Picking, L.W., 1985, Hydrogeologic Investigations Based on Drill-Stem Test Data: Palo Duro Basin Area, Texas and New Mexico: Office of Nuclear Waste Isolation Technical Report BMI/ONWI-566.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: February 28, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E Williams

Potentiometric surface maps are presented for the aquifers associated with the Wolfcamp Series and the Pennsylvanian System in the Palo Duro Basin of Texas and New Mexico. Only one homogeneous aquifer is assumed to exist in each of the two stratigraphic sequences. Drill-stem test data were selected and used to produce initial potentiometric surface maps and two more sets of maps were produced following extensive data culling procedures. Linear regression analysis was performed on the data to evaluate culling effectiveness. Data regression statistics improved with each culling stage.

Questions arise regarding the validity of the potentiometric surface maps produced because of the limited data base used to produce the maps, the use of initial shut-in pressure as representative of true formation pressure, the process of comparing anomalous data values to values from "adjacent wells", and the method of potentiometric surface generation which involves conversion of irregularly spaced data points into data on a regular grid spacing. Potentiometric surfaces may not necessarily represent conditions within either the Wolfcamp Series or the Pennsylvanian System because the assumption that each sequence is a single hydrostratigraphic unit probably is invalid. Potentiometric surfaces probably represent some average of head from a group of aquifers for each sequence.

BRIEF SUMMARY OF DOCUMENT:

The report under review is an attempt to develop meaningful potentiometric surface maps of aquifers associated with the stratigraphic sequences of the Lower Permian Wolfcamp Series and Pennsylvanian System within the Palo Duro Basin and surrounding areas. This report was reviewed in draft form by Williams and Associates, Inc., on November 16, 1984. The report has now been released in final form following revision. This review is of the revised final version.

The objective of the study (p. 5) "...is to produce regional potentiometric surfaces of the Wolfcamp and Pennsylvanian aquifers, the two regionally important down gradient aquifers that underlie the proposed repository host rock." The report is presented in three principal sections. The first section describes data collection and selection procedures. The second section describes the process used in generating three different sets of potentiometric surfaces. The third section describes statistical analyses as related to the culling procedures used on the data in generation of the different potentiometric surfaces.

The data consist exclusively of drill stem test (DST) data obtained from a petroleum information clearing house. The data used are from forty-three counties in the Palo Duro Basin area of Texas and New Mexico; the original tests were conducted between the 1940's and mid-1981. The data are of variable quality and, as a result, each test is grouped into one of four classes based on quality. Class 1 data are those for which a complete pressure curve is available and from which a Horner plot could be constructed. Class 2 data are those for which the length of time between initial and final shut-in was one hour or longer, and for which the initial and final shut-in pressures does not vary by more than 5% of the initial shut-in pressure. Class 3 data are similar to the Class 2 data except that the length of time between initial and final shut-in is between 30 minutes and one hour. Class 4 data are everything else which does not meet the criteria of the other three classes. Of the 5202 DSTs obtained 80% were determined to be in Class 4; less than 0.5% were considered Class 1 data. Only data of the first three classes were used for preparation of potentiometric surface maps.

Initial shut-in pressures were assumed to be representative of equilibrated, predisturbance formation pressures for data of Classes 2 and 3, because pressure curves from which Horner plots could be developed were not available. According to the report under review (p. 22), initial shut-in pressures were less than formation pressure values extrapolated from Horner plots and greater than final shut-in pressure values. Comparison of initial shut-in pressure values with extrapolated values in the

Class 1 data set indicated that initial shut-in pressure values were an average of 97 feet less than the extrapolated value. As a result initial shut-in pressure values also were used for Class 1 data to insure agreement with data of Classes 2 and 3.

Once values of pressure were selected they were converted to equivalent fresh-water heads by dividing each pressure value by the unit weight of freshwater. No correction for salt water density was attempted. Once these head values were obtained, a potentiometric surface contour map was prepared and assumed to be representative of the entire Wolfcamp Series. A similar map was prepared and assumed to be representative of the entire Wolfcamp Series. A similar map was prepared for Pennsylvanian System. Each potentiometric surface exhibits considerable relief; in some locations differences in head between two adjacent wells may be as much as 10,000 feet. As a result of this extreme variation, a culling procedure was developed to remove data anomalies. The culling procedure involved two stages. First, on the assumption that much of the underpressured data came from areas of oil production, "depressured" values obtained from areas of known oil production were removed. Second, grossly overpressured and underpressured values which remained following the first phase were compared with values from adjacent wells which tested the same geologic horizon. In cases where these values were significantly different, the anomalous value was discarded.

Three sets of potentiometric contour maps are presented in the report under review. Each set contains a map of the Wolfcamp Series and a map of the Pennsylvanian System. One set of maps presents potentiometric data prior to any data culling procedures; a second set presents potentiometric surfaces following removal of depressured data; and a third shows such surfaces after "depressured", "grossly underpressured", and "grossly overpressured" data were removed. Potentiometric surface maps were computer generated for each data set using a program that takes data at irregularly spaced intervals and produces values on a grid of regular spacing. The interpolated values are then contoured.

Statistical analysis of the culling procedures was performed by means of linear regression analysis of pressure-depth data. DST data were plotted on pressure-depth diagrams and a regression coefficient and correlation coefficient determined for each group. Results of this analysis indicate that regression coefficients more closely approached the slope of hydrostatic conditions on the pressure-depth diagrams; the correlation coefficient was improved with each culling procedure. It was recognized also that topographic variation probably was responsible for scatter within data groups after culling. Consequently a hypothetical plane generated through trend surface analysis was produced. Once depth measurements were corrected to this plane, both regression and correlation coefficients improved markedly.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

Definition of potentiometric surfaces of aquifers which underlie a proposed high-level waste repository is of paramount significance to predicting travel path and travel time. Potentiometric surfaces are used to develop values for hydraulic gradient which is a key component of travel time calculations. Accurate knowledge of fluid potential distribution within affected aquifer systems is of fundamental importance to the NRC. In this particular case these data may or may not affect the decision as to whether the Wolfcamp Series can be treated as a single aquifer.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

Questions of uncertainties exist with regard to data selection and potentiometric surface construction. These uncertainties in turn produce questions regarding the accuracy of the potentiometric surfaces produced.

Regarding the data selection process, page 22 states that "heads calculated from ISIP (initial shut-in pressure) will be less than those based on extrapolated formation pressures..." Comparison of 17 DSTs for which Class 1 data, as well as initial shut-in pressure values were available, indicated that heads calculated from initial shut-in pressure values were an average of 97 feet less than heads calculated from extrapolated formation pressure. No discussion is presented to indicate the range of variation among the 17 samples. In the absence of evidence to the contrary, it seems probable that some percentage of the initial shut-in pressure values used in construction of the potentiometric surface maps may deviate significantly from actual formation pressures. In the absence of any statistical comparison among these 17 values, it is impossible to ascertain whether or not initial shut-in pressures are representative of actual formation pressures.

The problem is exacerbated further by the fact that neither Horner plots nor any other graphics of the Class 1 data are presented. Lacking these supporting data independent review of the correlation between Class 1 and Class 2 is not possible. As a result, questions about whether or not the initial shut-in pressures are representative of actual formation pressures cannot be answer or even addressed.

Another problem involves the lack of specificity regarding the culling procedure in which anomalous values are compared to pressure values from drill stem tests (DST) in adjacent wells at similar depth intervals. Initially the procedure employed seems quite reasonable; however, once the distribution of wells is apparent, questions arise regarding the definition of "adjacent well". The geographical and vertical distribution of wells used in this study is very irregular. In many instances, "adjacent wells" might be tens of miles or more apart. It is evident that comparison of values between wells over long distances may result in the removal of a value which only appears to be anomalous in order to produce a much more uniform potentiometric surface. In fact the value deleted may not be "anomalous". It may be high or low for a legitimate reason. Two such wells might be in different groundwater flow systems or they might be in different hydrostratigraphic units.

Several points are important with regard to the potentiometric surface maps. First, a very large area (735,000 square miles) was contoured based on a relatively small amount of widely spaced data. Of the 5202 DST values originally collected, only 117 were used for the first potentiometric surface map of the Wolfcamp Series; 257 were used for the initial map of the Pennsylvanian System. Subsequent to culling of the data, even fewer DST values were used in preparation of the second and third potentiometric surfaces. In the set of maps prepared from data remaining after culling out "depressured", "grossly overpressured", and "underpressured" values, only 83 DST values were used for the potentiometric surface of the Wolfcamp Series; 145 DST values were used to contour the Pennsylvanian System. This data distribution reduces to an average of one data point for every 350 square miles of area mapped.

To compound the problem data points are not distributed evenly throughout the study area. In the final set of maps, the potentiometric surface map of the Wolfcamp Series contains only one data point in Deaf Smith County and only two are present in Swisher County. No data points are present in Deaf Smith County for preparation of the Pennsylvanian System potentiometric surface map.

Initially, the problem of data distribution does not appear particularly severe because of the scale of the maps presented in the report under review. The area under study contains substantial parts of two states; the mapped part of Texas alone is greater than 25,000 square miles. When the size of the study area is appreciated properly it is apparent that 100 data points irregularly distributed throughout such an immense area constitutes very minimal control. The scale of the map becomes even more significant in the context that each well location dot represents an actual diameter of 2.5 miles and that even a single potentiometric line represents a width of about one-half mile. We recognize that the amount and spacing of data are beyond the control of the authors; however, it is important to appreciate the limited extent of the data base upon which these potentiometric surface maps are based.

Uncertainties also exist regarding the method of contour map development. A computer program was used which extrapolated head values over large, regularly spaced intervals throughout the mapped area. Despite sophisticated error analysis routines which are designed to reduce the possibility of the creation of anomalous values, the limited data base and the sheer distance between individual data points produce several curiosities. The formation of closed contours in areas where no data exist are most noticeable. An example of this situation occurs in the south-central part of Figures 4-18 and 4-19 on pages 59 and 60. The existence of such features illustrates how limited the data base is. Considerable question arises as to how accurately these maps reflect the various potentiometric surfaces.

The accuracy of the potentiometric surface maps generated in the report under review is of particular interest as a result of discussion presented in section 4.10 of said report. In this section discussion is presented on comparison of the potentiometric surface maps produced in previous reports with those developed in the report under review. The report suggests that previously generated potentiometric surface maps are less precise than those produced in the report under review. The report points out that potentiometric levels in the vicinity of Deaf Smith and Swisher Counties are several hundred feet lower than those reported in earlier papers. The report suggests that the reason for this change is that earlier efforts did not restrict pressure values to initial shut-in pressures. Instead, extrapolated formation pressure, initial shut-in pressures and final shut-in pressures were used together. No explanation is presented to illustrate how this combination of values could produce such a marked difference; without such an explanation the reason presented is difficult to believe. In fact, the statement implies that differences between extrapolated formation pressures and initial shut-in pressures may be very large, which raises serious question about the accuracy of potentiometric surfaces based exclusively on initial shut-in pressures. Finally we pointed out above that the final map for the Wolfcamp Series contains only one data point in Deaf Smith County and two data points in Swisher County. Fewer data points for the Pennsylvanian rocks are available in either county. Many interpretations are possible with such a limited distribution of data points.

An important question raised by this study involves the definition and conceptualization of the number of aquifers present within the zone that has been referred to as the "Deep Basin Brine Aquifer". A key assumption in the report under review is that the units associated with the Wolfcamp Series behave as a homogeneous hydrostratigraphic unit. A similar assumption is applied to the Pennsylvanian System. This assumption is not discussed in the report; but it must be present for at least two reasons. First, pressure data were not corrected for vertical density differences when they were converted to hydraulic head values. Instead the values were converted to equivalent freshwater heads. Conversion to freshwater head values is valid only for lateral comparison and is not valid for evaluation of vertical head variation. Second, no attempt was made to delineate data points further with respect to either their elevation or stratigraphic position within either the Wolfcamp Series or the Pennsylvanian System. Once it is determined that a test was run within the Wolfcamp Series it is assumed to be directly correlative with all others within the Wolfcamp Series regardless of whether the tested interval is stratigraphically higher of lower than other test values with which it is being compared. This assumption is convenient for purposes of data assembly and insures a minimum amount of data points. Such an assumption probably does not reflect hydrogeologic reality within either the Wolfcamp Series of the Pennsylvanian System. The thickness of each sequence is on the order of 1500 to 2000 feet and it is probable that more than one zone of sufficient enough permeability to constitute an aquifer exists within each sequence. As a result the potentiometric surfaces that are produced may be an average of more than one aquifer within either the Wolfcamp Series or the Pennsylvanian System.