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January 30, 1986
Contract NRC-02-85-008
Fin. No. D-1020
Communication No. 26

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

RE: SALT

Dear Jeff:

I have enclosed a review of each of the following documents:

1. Kaiser, W.R., 1985, Cross-formational Flow in the Palo Duro Basin, Texas Panhandle: Texas Bureau of Economic Geology, Austin, Texas, OF-WTWI-1985-33.

2. Orr, E.D. and Senger, R.K., 1984, Vertical Hydraulic Conductivity, Flux and Flow in the Deep-Basin Brine Aquifer, Palo Duro Basin, Texas: Texas Bureau of Economic Geology, Austin, Texas, OF-WTWI-1984-44, 19 p.

3. Senger, Rainer 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.

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

Sincerely,

Jeffrey C. Brown

JCB:sl

enclosures

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PDR WMRES EECWILA
D-1020 PDR

WM Record File WM-RES D1020 W&A

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

Distribution:
JPohle

(Return to WM, 623-SS)

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WMGT DOCUMENT REVIEW SHEET

FILE #:

TEXAS BUREAU OF ECONOMIC GEOLOGY #: OF-WTWI-1985-33

DOCUMENT: Kaiser, W.R., 1985, Cross-formational Flow in the Palo Duro Basin, Texas Panhandle: Texas Bureau of Economic Geology, Austin, TX.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: January 30, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E Williams

The report under review discusses several pieces of information which are collated into a position on the movement of groundwater through the evaporite sequence in the Palo Duro Basin. The report cites evidence derived from head distributions, numerical modeling, water chemistry, isotopic data, and core analyses to support a finding that there is little vertical flow through the evaporite sequence.

We do not have any major concerns regarding the report under review. We do have a few minor questions which are expressed below.

BRIEF SUMMARY OF DOCUMENT:

The report states that the known head distribution and numerical modeling indicate the potential for downward, vertical flow of groundwater through the evaporite aquitard. The report expresses the possibility that some lateral diversion of groundwater flow may occur in permeable carbonate rocks contained within the evaporite aquitard. One major piece of evidence cited for the presence of leakage is the isotopic signature of brines found in northwestern Palo Duro Basin. These brines have a meteoric isotopic signature. Two explanations are provided in the report under review for the presence of this meteoric isotopic signature. One explanation assumes that there is leakage down through the evaporite aquitard. The second explanation assumes that the isotopic signature could have been derived by the eastward movement of meteoric water from the shallow subsurface of eastern New Mexico. The salinity would have been acquired due to dissolution of salt early in the flow history using this latter scenario.

Groundwater flow through the evaporite aquitard would create movement of dissolved ions into the deep basin flow system. The report states that such a transfer is not reflected in the chemical composition of San Andres and Wolfcamp brines. Chlorinites (term not defined in text) are used to illustrate the lack of movement through the evaporite aquitard (data are not included in the report). The chlorinites in the San Andres are approximately twice those found in the underlying Wolfcamp. Chlorinites increase with depth below the salt in the deep basin flow system. San Andres brines are believed to represent modified marine connate brines.

The report states that aquitard permeability (assumed vertical) values are estimated to range from 8×10^{-5} md to 2.8×10^{-4} md or approximately 10^{-4} md based on numerical groundwater model studies (p. 15). The report states that these values are in general agreement with laboratory measurements; the report states that these values should be considered an upper limit due to stress differences that occur between insitu and laboratory test techniques. The report states that in-situ measurements of permeability and porosity of competent salt as well as argillaceous and anhydritic salt at the WIPP site resulted in values of less than 10^{-8} md an approximate porosity of 0.001 respectively. The report states that with a permeability of salt of 10^{-4} md the contribution of leakage to the Wolfcamp geologic series could represent 50% of the flow within the Wolfcamp geologic series. The report also states that a permeability of 10^{-5} md would result in a contribution of only 5% of the Wolfcamp series flow. The report notes that the latter contribution would not be reflected in the brine chemistry.

The report states that significant matrix flow is unlikely due to the low matrix permeability of salt. The alternate mode for possible cross-formational flow is fracture flow. The report states that the "Evaluation of that possibility awaits future research" (p. 15). The report states that almost all fractures in the aquitard are filled by mineral deposition.

The report states that bromide values in the fracture fill and non vein halite are similar and do not support the possibility of distinct post Permian dissolution events. The report states further that the high bromide levels in the bedded salt and the "dominance of halite textural types assigned syndepositional or early diagenetic origins, and absence of gypsum show that only the Salt Dissolution zone has experienced post-Permian dissolution" (p. 16).

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

This document is important to the Waste Management Program because the evaporite aquitard would contain the high-level radioactive waste. The hydraulic conductivity and direction of groundwater flow through the evaporite aquitard are important to determinations of direction and rate of movement of groundwater for travel time considerations. This report considers several pieces of evidence for the formulation of concepts regarding the movement of groundwater within and through the evaporite aquitard.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

We have commented in previous reviews of Texas Bureau of Economic Geology reports and associated documents produced by the Office of Nuclear Waste Isolation (ONWI) about the continual referal to the "Deep-Basin Brine Aquifer". We wish to point out that we believe the terminology is incorrect; this groundwater flow system should not be referred to as an aquifer. The Wolfcamp is a geologic series. We will not elaborate on our concerns which have been expressed in previous reviews. We also observed in this report the acknowledgment that the so-called "Upper aquifer" is "two separate aquifers" (p. 3). This statement raises a question as to the validity of referring to an upper aquifer which consists of the Ogallala Formation and the Dockum Group.

Chemical and isotopic data are not included in the report under review. Only graphical representations of Na/Cl and Cl/Br ratios versus depth and bromide content in bedded and recrystallized halite and vein halite are included. An independent assessment of the 'data' is limited.

We do not wish to express any concern but to reiterate points made in this document regarding the relationship of in-situ measurements versus laboratory measurements of permeability of salt. Insitu values of permeability are more valid with respect to the actual characteristics of the material than those derived from laboratory testing. This difference in values is due partially to the stress redistribution that occurs between testing at depth and testing in the laboratory.

The report discusses the abundance of fractures in the Palo Duro Basin Permian strata. The report states that "Almost all fractures in the aquitard are probably filled..." (p. 9). We wish to point out that these fractures had to have been open at one time in order for the fractures to become filled with different minerals precipitated from groundwater. The fact that these fractures were open and that they now are filled suggests that there was movement of groundwater through them. This suggests that the permeability attributed to possible fracture flow could be a temporal phenomena which is not acknowledged in the report under review. The concept of temporal hydraulic conductivity has been raised by Williams and Associates in previous discussions with the NRC.

The discussion regarding brine composition lends significant support to the concept that there is little vertical flow through the evaporite aquitard. We wish to point out that the sampling density for this discussion is not comprehensive in areal and vertical extent at this time. Additional sampling is needed to further support the conclusions derived in this report.

The report cites as evidence results of modeling studies of the Palo Duro Basin. The modeling studies must be used with caution as noted in the panel report on evaluation of groundwater flow in fractures. We wish to point out that this panel report, which was prepared for ONWI, states that "The frequency of reference to these models in many publications and figures could mislead readers into an incorrect interpretation of the real flow system" (Parizek and others, 1985, p. 10). We are not concerned that the information derived from the modeling studies is used inappropriately in this document; we wish to point out that such information must be used with caution.

<u>REFERENCES</u>:

Parizek, R.R., Mink, L.L., Domenico, P., and Robertson, J.B., July 1985, Report of the Panel on Evaluation of Ground-Water Flow in Fractures at the Palo Duro Basin.

WMGT DOCUMENT REVIEW SHEET

FILE #:

TEXAS BUREAU OF ECONOMIC GEOLOGY #: OF-WTWI-1984-44

DOCUMENT: Vertical Hydraulic Conductivity, Flux and Flow in the Deep-Basin Brine Aquifer, Palo Duro Basin, Texas, by E.D. Orr and R.K. Senger, 1984, Texas Bureau of Economic Geology, Austin, Texas, 19 p.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: January 30, 1986

BRIEF SUMMARY OF DOCUMENT: APPROVED BY: Roy E Williams

INTRODUCTION:

The document under review is one of several produced by the Texas Bureau of Economic Geology (TBEG) which examines fluid potential distribution in the so-called Deep-Basin Brine aquifer of the Palo Duro Basin in Texas. This document deals specifically with the determination of vertical fluid potential gradients and the evaluation of these gradients with respect to the possibility of cross-formational flow in various locations within the Palo Duro Basin. The objective of the document is (p. 1):

> "to evaluate the significance of these potential components of vertical flow by (1) estimating vertical head gradients for the Deep-Basin Brine aquifer by normalizing vertical pressure gradients, (2) estimating vertical hydraulic conductivities and vertical fluxes across the basin, and (3) comparing the estimated volumes of horizontal and vertical flow for different areas in the basin."

METHOD:

Part of the research effort described in the reviewed report involves trying to characterize non-hydrostatic conditions accurately within the Palo Duro Basin. The report recognizes (p. 1) that because of the "confined nature of the aquifer (assumed to be the entire Wolfcamp Series) and geographic spread of data, differences between observed vertical pressure gradients and the estimated brine hydrostatic gradient (.466 psi/ft) for the entire basin (Orr, 1984) may not accurately reflect non-hydrostatic conditions." In an attempt to deal with the problem of validity and accuracy of fluid potential relationships, pressure vs. depth graphs are presented for certain areas within the basin. The report recognizes (p. 2) that vertical pressure gradients are affected by such things as "lateral variation in head, structural dip of the aquifer, and topographic elevations within each area." The effects of the items just noted are eliminated by subtracting the computed hydrostatic gradient from the observed vertical gradient. The resulting value is "the magnitude of the gradient attributable to the vertical hydraulic gradient" (p. 2). These values are normalized by adding each gradient magnitude value to the estimated brine hydrostatic gradient of the aquifer. This estimated gradient is assumed to be 0.466 psi/ft based on the specific weight of the brine.

The normalized pressure gradients are then converted to vertical hydraulic head gradients by subtracting 1 from the product of the reciprocal of specific weight of the brine and the normalized pressure gradient. Conversion of fluid potential data to hydraulic head gradients permits calculation of flow volumes after calculating hydraulic conductivities.

Vertical hydraulic conductivities are calculated for each of 405 nodes of a finite element mesh. These conductivities were calculated assuming that each lithologic layer is homogeneous and isotropic. The permeability data are found in Wirojanagud and others (1984). The vertical hydraulic conductivity was computed for each node using

$$K_z = \frac{d}{\sum_{i=1}^{n} d_i/k_i}$$

where: d = total thickness of all lithologies at node,
d_i = thickness of each individual lithology,
K_i = permeability of each individual lithology (m/day), and
n = total number of lithologies at node (p. 3).

Hydraulic conductivity values used in this calculation consist of a single weighted value for each lithologic unit associated with the Deep-Basin Brine aquifer. Once vertical and horizontal hydraulic conductivities are calculated for each node, calculation of vertical and horizontal fluxes and flow volumes are made for specific areas.

RESULTS:

Results are presented in the form of a contour map of vertical hydraulic conductivity of the "Deep-Basin Brine aquifer," maps showing areas of horizontal versus vertical flow within the basin, and estimates of vertical and horizontal flow volumes within the "Deep-Basin Brine aquifer." Vertical conductivities range from 0.2 x 10^{-6} m/day to greater than 1.0 x 10^{-6} m/day. K_v is controlled primarily by the total shale thickness present at each node. Comparison of vertical and horizontal fluxes calculated at each node indicate that horizontal fluxes are "two to three orders of magnitude greater than vertical fluxes" (p. 6), and are highest in the granite wash areas along the northeastern part of the basin. The ratio of horizontal to vertical flux is determined for each node and the ratios are contoured for the entire Palo Duro Basin. Results of this contouring effort indicate that generally horizontal flow predominates and that it is most significant along the north and northeastern parts of the basin.

Calculation of vertical and horizontal flow volumes indicates that significant vertical flow occurs in the south, west, and central parts of the basin. It is reported (p. 6) that within these areas "nearly as much water flows vertically within the Deep-Basin Brine aquifer as moves laterally out of this area along the eastern boundary." Estimates of yearly water volumes through the eastern boundary range between 1,080,000 m^3 to 1,335,000 m^3.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The path that a radioactive contaminant will follow away from a repository and the relative rate of movement along that path are two of the most critical concerns in site characterization. Because the path and the rate ultimately are controlled by hydraulic gradient and hydraulic conductivity along with effective porosity, investigations of these parameters are very significant to the waste management program.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF THE REPORT:

The report under review is relatively brief but it covers topics of major significance. The brevity of the document leaves unanswered some questions regarding methods and/or assumptions;

the questions arise because some methods and assumptions are not explained.

The first assumption that is not explained is that the entire Wolfcamp Series is an "aquifer". The Wolfcamp is a Series. A series consists of a number of super groups. A supergroup consists of a number of groups. A group consists of a number of formations. A formation may consist of a number of aquifers. At the BWIP site, for example, the Wanapum Formation consists of at least 8 aquifers and 8 aquicludes or aquitards. We cite the BWIP site because we believe some consistency is essential in the NRC position among sites. On this basis we might expect a series to consist of many aquifers unless evidence is presented to the contrary. Evidence to the contrary is not presented in the document under review or in any document cited in the references cited section of the document under review. Several definitions of an "aquifer" are presented below.

1. "An aquifer is a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs" (Lohman and others, 1972).

2. "A primary unit in groundwater-resource studies is the aquifer, a lithologic unit or combination of units capable of yielding water to pumped wells or springs" (Domenico, 1972).

3. "An aquifer is best defined as a saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients" (Freeze and Cherry, 1979).

4. "An aquifer is a saturated bed, formation, or group of formations which yields water in sufficient quantity to be of consequence as a source of supply" (Walton, 1970).

5. "Only a small fraction of most phreatic zones will yield significant amounts of water to wells. The water-bearing portions are called aquifers" (Davis and DeWiest, 1966).

None of these definitions leads one to believe that it is probable that an aquifer is equivalent to a stratigraphic series. This assertion is not to say that it is impossible for an entire series to constitute one aquifer but it certainly is improbable. The report under review offers no evidence to support the assumption that the entire Wolfcampian Series is a single aquifer. Consequently the pressure vs. depth graphs (discussed below) may not reflect the model that is conceptualized in the report under review. If an authentic permeable aquifer existed at a critical elevation in the Wolfcampian Series then the pressure vs. depth graphs presented in the report under review would have a different, and perhaps more definitive, meaning.

This point is critical to the entire purpose and objective of the paper under review; consequently we believe that it should be addressed in the report or in a subsequent document.

In the initial discussion the statement is made (p. 2) that "pressure-depth regression lines were computed for flow parallel to the dipping structure of the aquifer for small geographic areas (fig. 1a)." Several uncertainties surround this statement. First, no pressure vs. depth graphs are presented nor is any reference made to other sources which might contain them. An independent evaluation cannot be made because these graphs are unavailable; consequently the conclusions drawn from the graphs must be accepted at face value if they are to be accepted at all. Second, the above statement indicates that these graphs were prepared for "small geographic areas" and yet some of the areas shown on the cited figure are quite large, including all or parts of several counties and areas of thousands of square miles. It is not clear from the statement and related discussion whether only one pressure vs.. depth graph was produced for each of the areas and/or how many values were incorporated into each graph. Second, no discussion is presented to indicate how area boundaries were determined and if any particular data selection process was used in preparing pressure vs. depth graphs. Third, the report states that pressure vs. depth regression graphs were prepared for flow parallel to the dip of the structures incorporating the aquifer. In addition, we repeat that it is not clear how many locations were selected for the preparation of pressure vs.depth regression graphs. It also is not clear how many locations exist within the basin at which the dip of the "aquifer" is significant. Finally, "computed hydrostatic gradients" and the comparison between these gradients and "observed" gradients are cited and discussed. But nowhere in the paper is either type of gradient defined nor is any discussion presented that explains how computed gradients were derived.

We raise similar concerns regarding values of vertical hydraulic conductivity as used in the document. The permeability data used in this document were not generated for this report but are cited from Wirojanagud and others (1984). Examination of the cited document indicates that most of the data were taken from Smith (1983). These data were derived from some 25 drill stem tests (DST), and 70 core sample tests derived from tests in oil fields in the Anadarko, Midland and Dalhart basins. No discussion of the accuracy and/or reliability of these data are presented in any of the documents. In addition, the document under review states (p. 3) that "vertical and horizontal core plug permeability tests have not indicated significant anisotropy in carbonate, dolomite, and sandstone lithologies"; however, no reference is presented and no mention of vertical permeability is made in either Wirojanagud and others (1984) or in Smith (1983). We note that the above quotations mention nothing about shale units within the aquifer and yet the report under review assumes that isotropy is valid for all units for calculation of an average vertical hydraulic conductivity at each node. The report under review uses "permeability" and "hydraulic conductivity" as equivalent terms (see p. 3). These terms are not equivalent; fluid density and viscosity are not used in this apparent conversion of terms. The report should use these terms in the correct manner.

Finally, the validity of extrapolation of a few data into basin wide contour maps is questionable. Vertical hydraulic conductivity values calculated using the assumptions discussed above from a data base that is restricted areally and possibly of questionable quality ultimately are presented for each of 405 nodes throughout the Palo Duro Basin. Similarly a contour map of vertical hydraulic conductivity is produced for the entire basin. In addition, values of horizontal and vertical flux are generated for each node using these manufactured conductivity values and related vertical gradient calculations. It is improbable that the numbers generated by subsequent basin-wide calculations are very meaningful or useful. Contouring conductivity values over the entire basin requires a level of control that does not exist.

REFERENCES CITED:

Davis, S.N., and DeWiest, R.J.M., 1966, Hydrogeology: John Wiley & Sons, Inc., New York, p. 463.

Domenico, P.A., 1972, Concepts and Models in Groundwater Hydrology: McGraw-Hill Book Co., New York, 405 p.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 604 p.

Lohman, S.W., Bennett, R.R., Brown, R.H., Cooper, H.H., Jr., Drescher, W.J., Ferris, J.G., Johnson, A.I., McGuinness, C.L., Piper, A.M., Rorabaugh, M.I., Stallman, R.W., and Theis, C.V., 1972, Definitions of Selected Ground-Water Terms--Revisions and Conceptual Refinements: U.S. Geological Survey, Water Supply Paper 1988, 21 p.

Orr, E.D., 1984, Investigation of Underpressuring in the Deep-Basin Brine Aquifer, Palo Duro Basin, Using Pressure/Depth Profiles: The University of Texas at Austin, Bureau of Economic Geology, Open-file Report OF-WTWI-1984-6, 20 p.

Smith, D.A., 1983, Permeability of the Deep Basin Aquifer System, Palo Duro Basin, <u>in</u> Gustavson, T.C., and others, Geology and Geohydrology of the Palo Duro Basin, Texas Panhandle, a Report on the Progress of Nuclear Waste Isolation Feasibility Studies (1982): The University of Texas at Austin, Bureau of Economic Geology, Geological Circular 83-4, p. 89-93.

Wirojanagud, P., Kreitler, C.W., and Smith, D.A., 1984, Numerical Modeling of Regional Ground-Water Flow in Deep-Brine Aquifers of the Palo Duro Basin, Texas Panhandle: The University of Texas at Austin, Bureau of Economic Geology, Open-file Report OF-WTWI-1984-8, 118 p.

WMGT DOCUMENT REVIEW SHEET

FILE #:

TEXAS BUREAU OF ECONOMIC GEOLOGY #: OF-WTWI-1984-54

DOCUMENT: Senger, Rainer K., 1984, Hydrodynamic Development of the Palo Duro Basin and Other Mechanisms Creating Possible Transient Flow Conditions: Texas Bureau of Economic Geology, Austin, Texas.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: January 30, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E. Williams

The report under review describes the investigation of transient flow conditions that were modeled to identify possible flow patterns that could result from changing hydrologic conditions with time. Several sources were used to supply data for the modeling. A significant portion of these data were derived from generic references rather than from testing. In addition, the ratios of horizontal to vertical hydraulic conductivity are assumed for several modeled strata.

BRIEF SUMMARY OF DOCUMENT:

The report under review provides a basic description of the geology and hydrogeologic factors that are believed by TBEG to affect groundwater flow in the Palo Duro Basin. A finite element cross-sectional model was constructed along an east-west section extending from New Mexico across the Texas Panhandle into Oklahoma. The finite element model incorporates the San Andres dolomite as an individual hydrologic unit within the evaporite aquitard. The model FLUMPS was used to simulate hydrologic conditions under various boundary conditions.

Only constant head boundary conditions were used in the model. The upper surface of the finite element mesh corresponds to the water table. The lower boundary of the model corresponds to the contact between the deep basin brine aquifer and basement rocks.

The model assumes that hydraulic head is uniform with depth along the eastern boundary; a reference supporting this assumption is in preparation.

The effects of modifying the topography, which would be a result of tectonic and geomorphologic activity, is simulated by varying prescribed heads at specific nodes in the model. Similarly, hydrocarbon production was simulated by reducing heads at particular node locations in the model representing a hydrocarbon reservoir. The geometry of the finite element mesh is preserved in all runs. The simulation of topographic changes was simulated by changing head conditions at specific nodes within the finite element mesh.

Hydrogeologic properties of the individual units were assumed to remain constant with time for all simulations. Horizontal hydraulic conductivity values, vertical hydraulic conductivity values and specific storage values are presented in Table 2 of the report. A copy of this table is appended to our review. Values for these hydrogeologic parameters were obtained from other references including generic values and previous modeling studies. The vertical hydraulic conductivity value assigned to the evaporite aquitard was derived from the harmonic means of permeabilities using "typical and measured values" (p. 5). The term "typical" is not explained in the document under review. The report notes that a previous study by Senger and Fogg (1984) suggests that a vertical hydraulic conductivity of 3.2×10^{-7} m/day represents an upper limit of possible hydraulic conductivities for this evaporite aquitard.

This model incorporates the San Andres cycle 4 dolomite as an individual hydrogeologic unit. The hydraulic conductivity for cycle 4 unit is based on limited permeability data derived from pumping tests and drill stem tests. The reference cited for the Cycle 4 hydraulic conductivity is in preparation. The hydraulic conductivities assigned to shelf carbonates and granite-wash deposits represent geometric means of permeabilities obtained from analyses of pumping tests, drill-stem tests and data compiled from laboratory tests. The values assigned for hydraulic conductivity and specific storage are shown in Table 2 as are the references cited.

The report assumes that granite-wash deposits in the vicinity of the sediment source have a permeability which is approximately one order of magnitude higher than the distal granite-wash deposits. The report considers the geometric mean of the compiled data to represent distal granite-wash deposits. The report states that the assumed higher permeabilities for the proximal granite-wash deposits are supported by recent test data from the J. Friemel #1 well and by previous modeling efforts. A specific storage value of 1×10^{-4} 1/m was used for all hydrologic units. The report states that this value is comparable to the values used by similar research efforts.

Six simulations were run using the model described. The first five model runs were designated T-1 through T-5. Each simulation output became the head distribution at the beginning of the subsequent simulation. The T-1 simulation approximates steady state hydrodynamic conditions prior to the uplift of the basin. Simulation T-2 describes the uplift and tilting of the basin. Simulation T-3 simulates the deposition of the Ogalalla Formation. Simulation T-4 investigates the possible effects created by the erosion of the Pecos River Valley. Simulation T-5 approximates the westward retreat of the Caprock Escarpment. The sixth simulation is designated H-1. This simulation produces the possible effects of hydrocarbon production from a simulated reservoir.

The report under review states that the uplift and tilting of the basin caused increased flow rates in the Palo Duro Basin. The erosion of the Pecos River Valley and the retreat of the Caprock Escarpment in combination with the vertical and lateral distribution of the permeable granite-wash deposits contribute to the underpressuring which is observed in the deep basin brine aquifer. The report also concludes that the westward retreat of the Caprock Escarpment resulted in a drop in the water table in the shallow aquifer and significantly affected hydraulic heads in the deep section. The report states that head declines of up to 250 m occurred in the deep section. The simulation of the retreat of the Caprock Escarpment implies that significant underpressuring occurred within the last one to two million years. The final simulation suggests that hydrocarbon production affects hydraulic heads only locally. It does not influence regional groundwater flows in the deep basin brine aquifer.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

This document is important to the NRC Waste Management Program because this document investigates the possible transient effects of various factors on the potentiometric distribution in the Palo Duro Basin. Transient effects on the potentiometric distribution are important for considerations of direction of groundwater flow and travel time estimations.

PROBLEMS, DEFICIENCIES, OR LIMITATIONS OF REPORT:

Hydraulic conductivity values used in the report under review are derived from several sources. These sources range from a local publication (Myers, 1969) to a textbook (Freeze and Cherry, 1979). Values used in the model include values derived from other modeling efforts and values derived based on assumed ratios of horizontal to vertical hydraulic conductivity.

We wish to express a minor concern regarding the value of specific storage (1×10^{-4} 1/m) used in the model. The report has used a value obtained from various sources other than field testing. The report states that this value is comparable to a value used by Toth and Millar (1983) for a similar study in the Red Earth Region of the Alberta Basin. We believe that this value mav be high with respect to anticipated specific storage values that may be derived from in-situ testing. Higher values of specific storage result in higher values of storativity. Higher values of storativity result in smaller areal extents of the cone of depression which would be created by hydrocarbon production. Similarly, the effects of different transient conditions such as erosion and increased recharge will be reduced in areal extent for a given period of time by the use of a larger specific storage. We suggest that this value may be higher because the values of specific storage have not been derived from appropriate field tests at this time. The report does point out an item of potential controversy regarding the isolation versus non-isolation of the Panhandle Oil and Gas Field from the Palo Duro Basin. The report states (p. 22) that alternate interpretations of the hydrologic regime exist. Insufficient data exist at this time to indicate whether or not the oil and gas field is hydraulically isolated from the fluid pressures in the surrounding formations.

REFERENCES:

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Prentice-Hall, Englewood Cliffs, New Jersey, 604 p.

Myers, B.N., 1969, Compilation of Results of Aquifer Tests in Texas: Texas Water Development Board Report No. 98, 532 p.

Senger, R.K., and Fogg, G.E., 1984, Modeling the Effects of Regional Hydrostratigraphy and Topography on Ground-Water Flow, Palo Duro Basin, Texas: University of Texas at Austin, Bureau of Economic Geology Open-file Report OF-WTWI-1984-32.

Toth, J., and Millar, R.F., 1983, Possible Effects of Erosional Changes of the Topographic Relief on Pore Pressures at Depth: Water Resources Research, vol. 19, no. 6, p. 1585-1597.

Table 2. Assigned Hydraulic Conductivity Values for the Major Hydrologic Systems.

Hydrologic Unit	Hydraulic Conductivity (m/day) Horizontal (K_x)	Vertical (K_z)	Specific Storage[6] (m^{-1})
1. Ogallala fluvial system[1]	8.0×10^{0}	8.0×10^{-1}	10^{-4}
2. Triassic fluvial/lacustrine system[1]	8.0×10^{-1}	8.0×10^{-2}	10^{-4}
3. Permian (salt dissolution zone)[3]	8.2×10^{-2}	8.2×10^{-4}	10^{-4}
4. Permian sabkha system[4]	3.2×10^{-7}	3.2×10^{-7}	10^{-4}
5. Permian mudflat system[2]	8.2×10^{-5}	8.2×10^{-5}	10^{-4}
6. Permian/Pennsylvanian shelf carbonates[4]	1.3×10^{-2}	1.3×10^{-4}	10^{-4}
7. Permian/Pennsylvanian basinal systems[4]	1.1×10^{-7}	1.0×10^{-7}	10^{-4}
8. Permian/Pennsylvanian mudflat and alluvial/fan delta system[2]	8.2×10^{-2}	8.2×10^{-4}	10^{-4}
9. Permian/Pennsylvanian fan delta system	$1.0\text{-}12. \times 10^{-2}$	$1.0\text{-}12. \times 10^{-4}$	10^{-4}
10. Inner shelf and coastal sabkha systems (San Andres Cycle 4 dolomite)[5]	1.2×10^{-4}	1.2×10^{-4}	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 Wirojanagud and others (1984).
5. After Dutton (1983).
6. After Toth and Millar (1983).