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July 23, 1986
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Mr. Jeff Pohle
Division of Waste Management
Mail Stop 623-SS
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

RE: SALT

Dear Jeff:

A copy of the review of the following document is enclosed.

1. Wirojanagud, P., Kreitler, C.W., and Smith, D.A., 1985, Numerical Modeling of Regional Ground-Water Flow in the Deep-Basin Aquifers of the Palo Duro Basin, Texas Panhandle. Texas Bureau of Economic Geology, Open-File Report, OF-WTWI-1984-8, Revision 1, 37 p.

Please contact me if you have any questions concerning this review.

Sincerely,

Gerry Winter/sl

Gerry Winter

GW:sl

enclosures

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WM Project 10, 11, 16
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WMGT DOCUMENT REVIEW SHEET

FILE #:

TEXAS BUREAU OF ECONOMIC GEOLOGY #: OF-WTWI-1984-8

DOCUMENT: Wirojanagud, P., Kreitler, C.W., and Smith, D.A., 1985, Numerical Modeling of Regional Ground-Water Flow in the Deep-Basin Aquifers of the Palo Duro Basin, Texas Panhandle. Texas Bureau of Economic Geology Open-File Report, OF-WTWI-1984-8, Revision 1, 37 p.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: July 16, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E. Williams

A finite element, steady state, two dimensional model of a confined aquifer receiving vertical leakage was run for part of the Palo Duro Basin. Two sets of simulations were run: one using only the Wolfcamp rocks as a single aquifer and the other using the Permian and Pennsylvanian rocks as a single aquifer termed the Deep-Basin Brine aquifer. Input head data were derived from kriging of values obtained from various qualities of drill stem test data. Input permeability values were obtained from drill stem tests, pumping tests, core permeability measurements and values derived from the literature.

Numerical simulations indicate that measured head values of the Wolfcamp rocks are most closely approximated when a vertical permeability value of 8×10^{-5} md is used for describing leakage through the aquitard and when values of 260 md and 50 md are used for the granite wash deposits and for the high-porosity carbonate rocks, respectively. Simulations of the Deep-Basin Brine aquifer indicate that permeability variations in the Pennsylvanian rocks are less important than those of the Wolfcamp rocks.

Model procedures and results appear reasonable but limited knowledge of actual head, boundary conditions and of hydrologic properties make evaluation of the validity of model results impossible. Head data generated by the model and concomitant calculations may or may not represent actual groundwater flow conditions accurately.

BRIEF SUMMARY OF DOCUMENT:

The report under review presents information on the generalized hydrogeologic setting of the Palo Duro Basin. Three hydrogeologic units are designated. The lower unit is identified as the Deep-Basin Brine aquifer; it consists of the sequence of rocks from the top of the Precambrian upward to and including the lower Permian (Wolfcamp) rocks. The water bearing sequences within this lowermost unit generally are carbonate and arkosic sand (granite wash) facies. The lithology of this lower unit consists mainly of carbonate although a substantial sequence of shale is present in the central part of the Palo Duro Basin. Carbonates of Pennsylvanian and lower Permian age are the most extensive and are the predominant aquifers. Permeable arkosic sand deposits are present near structural features that were positive during Pennsylvanian and Permian depositional periods. These features include the Amarillo Uplift and the Bravo Dome on the basin's north side. Carbonates of the Wolfcamp Series vary in thickness from 120 to 580 m and are thickest along shelf margins. High porosity trends also follow shelf margins.

The middle unit is called the Permian Evaporite aquitard; it consists of the sequence from the top of the Wolfcamp strata upward to and including rocks of the Permian Ochoan Series. This sequence is characterized by low permeability evaporite and red bed deposits; it is estimated to range in thickness from 650 to 1550 m.

The upper aquifer consists of units of the Triassic Dockum Group and the Tertiary Ogallala Formation. Both sequences can be significant water-bearing units but generally the Ogallala has a higher transmissivity and better water quality than does the Dockum Group.

The report combines the above hydrogeologic information into a generalized conceptual model on which subsequent numerical modeling efforts are based. The conceptual model is virtually identical to that proposed by Bassett and Bentley (1983); it envisions lateral flow within the Deep-Basin Brine aquifer and the upper aquifer, with predominantly vertical flow through the Evaporite aquitard. Total flux through the aquitard is assumed to be small. The upper aquifer and the Deep-Basin Brine aquifer are conceptualized as nearly isolated from one another by the Evaporite aquitard.

Recharge to the Deep-Basin Brine aquifer is presumed to occur in updip areas in western Texas and in New Mexico where Paleozoic geologic units are at or near land surface. Some recharge is believed to occur also from leakage through the Evaporite aquitard. Amount and location of discharge from the brine aquifer is unknown but discharge is conceptualized as occurring east of the Palo Duro Basin.

Flow in the upper aquifer is believed to be more typical of local or intermediate flow systems with recharge occurring over much of the high plains area. Natural discharge is believed to occur in the form of springs in the Caprock Escarpment area. Significant amounts of discharge from the system occurs through irrigation well pumpage.

Values for various hydrogeologic properties used as model inputs were obtained from a variety of sources. Horizontal permeability values for units of the Deep-Basin Brine aquifer were obtained from tests run in U.S. Department of Energy test wells as well as from drill stem tests (DSTs) and from core sample tests run on cores obtained from oil exploration wells. Although multiple pumping test values are presented in the report, the test values represent repeat tests run on the same lithologic interval in the same test well. Thus only one Wolfcamp unit, one granite wash unit and one Mississippian carbonate unit were analyzed by pumping test. Many of the DST and core permeability tests were obtained from wells in developed oil fields in the Anadarko, Midland, and Dalhart basins. To determine a permeability value for each aquifer the (p. 8) "geometric mean of these point quantities is then used as an effective permeability value for the aquifer based on the assumption that the medium consists of discontinuous layers of homogeneous K." Once values of aquifer permeability were determined for various units of the Deep-Basin Brine Aquifer, they were converted to hydraulic conductivity values using a conversion of 1 md = 1.2×10^{-5} m/day. This conversion is based on an average total dissolved solid content of the brine of 127,000 mg/L and an average temperature of 46 degrees C. Mean permeability values for the Deep-Basin Brine aquifer range between 3 and 18 md (3.6×10^{-5} to 2.2×10^{-4} m/day).

Determination of vertical hydraulic conductivity of the Evaporite aquitard is somewhat confusing. The report states (p. 10) that the "vertical permeability of 2.8×10^{-4} md for the Evaporite aquitard was derived from the harmonic means of permeabilities of its substrata in two typical cross sections through the evaporite strata." The precise meaning of this statement is not clear to us, but it appears that published values of permeability for similar lithologies were assigned to those lithologies in the cross sections and the harmonic mean calculated from these values. Measured permeability values for these units within the Palo Duro Basin apparently were not available.

The basin-wide fluid potential (head) distribution was determined by creating potentiometric maps for the Deep-Basin Brine aquifer and for the aquifer associated with rocks of the Wolfcamp Series. Data for these maps were derived from DSTs run in wildcat oil exploration wells within the basin. The data are of highly variable quality and ultimately only 160 DST head values were used in the preparation of the Deep-Basin Brine aquifer potentiometric map. To compensate for the limited number and variable distribution of these head data a kriging process was used to produce estimates of head at locations within the basin where head data were not present. Results of the kriging analysis indicate "a random error in the head data of about 52 m" (p. 14).

A potentiometric map of the Wolfcamp rocks prepared by Smith (1983) also was used in the numerical simulation. This map was prepared from DST data with a wide range in quality; it is believed to have greater random error than the map prepared for the Deep-Basin Brine aquifer (52 m).

The numerical model used is a finite-element, steady state, two-dimensional model of a confined aquifer with vertical leakage from above. Two principal layers were included in the model: the Evaporite aquitard and the Deep-Basin Brine aquifer. The "Wolfcamp aquifer" (upper part of the Deep-Basin Brine aquifer) also used as the lower layer in some simulations. The Deep-Basin Brine aquifer was subdivided into three subunits: the Wolfcamp rocks, the Pennsylvanian rocks, and pre-Pennsylvanian strata. "The Wolfcamp and the Pennsylvanian strata were further subdivided into carbonates, granite wash and shales" (p. 17). Transmissivity values input at each node point are simply the summation of the products of hydraulic conductivities times the assumed thickness of each subunit. Constant head boundaries were assumed on the western and eastern edges of the model area. A no-flow boundary was established on the south along the Matador Arch. Boundary conditions associated with the Amarillo Uplift to the north are more complicated and are varied in several model simulations.

Some numerical simulations were run using the Wolfcamp rocks as the lower layer; another group of simulations was run using the Deep-Basin Brine aquifer as the lower layer. Eight separate simulations of the Wolfcamp rocks were conducted. Simulations A-1 and A-2 used identical input parameters except that in simulation A-1 the entire northern boundary was treated as a no-flow boundary. In simulation A-2 the western half of the northern boundary was a constant head boundary with the eastern half remaining a no-flow boundary. Results from these simulations showed little resemblance to known head distributions. Simulation A-3 used the same boundary conditions as simulation A-1 but transmissivities of the granite wash deposits in the northeastern part of the model area were increased significantly. The major conclusion from the A series of simulations was that the creation of a zone of high transmissivity in the northeast part of the model area was necessary in order to begin to match head distribution as it is known currently in the Wolfcamp rocks.

Simulations B and C were used to evaluate the effects of leakage through the Evaporite aquitard. Simulation B assumed no leakage through the aquitard while simulation C assumed leakage through an aquitard with a vertical permeability of 8×10^{-5} md. The vertical permeability value used for simulation C is less than the value of 2.8×10^{-4} md developed from the harmonic means of permeability values derived from the literature. Results of these simulations indicate that leakage through the aquitard must be small in order to simulate known head conditions in the Wolfcamp and Pennsylvanian rocks beneath the evaporite rocks.

In simulation D-1 a constant head boundary was assumed to exist along the western part of the northern boundary of the modeled area; this constant head boundary permitted flow to occur over part of the Amarillo Uplift. This boundary condition (configuration) appeared to improve the correlation of model generated heads with measured head values. Simulation D-2 used the same parameters as simulation D-1 except that a smaller average effective porosity value was used which produced shorter travel times. Results of this simulation indicate (p. 22) that the "time it takes for ground water to flush through the modeled section of the basin within the Wolfcamp aquifer is computed to be about 1.4 to 1.8 million years."

Simulation E retains the same boundary conditions as those of the D simulations but porosity and permeability values of the carbonate sequence were increased. Simulation E appears to approach the known head distribution for the Wolfcamp aquifer most closely.

Three simulations were conducted that treated the Deep-Basin Brine aquifer as a single unit. For each simulation the boundary conditions were the same as those used for simulation E of the Wolfcamp rocks except that prescribed head values were composites of values assumed or measured for the Deep-Basin Brine aquifer. Differences among the three simulations consisted of various transmissivities applied to the granite wash deposits near the Amarillo Uplift and various transmissivities applied to the Wolfcamp and Pennsylvanian carbonate rocks. Results of the three simulations suggest that with higher transmissivity values heads generated by the model approximated measured values of head more closely.

Conclusions derived from the modeling effort include that vertical permeability of the Evaporite aquitard and horizontal permeability of the higher permeability layers within the rocks of the Wolfcamp Series are critical factors for matching measured head values in the Wolfcamp rocks. Results indicate that simulations using a value of 8×10^{-5} md for the vertical permeability of the aquitard and values of 260 md and 50 md for the granite wash deposits and high-porosity carbonate rocks, respectively produce the closest approximation to observed head conditions. Travel time estimates for the movement of water through the modeled part of the basin range from 1.2 to 2.0 million years.

Simulations of the Deep-Basin Brine aquifer indicate that variations in the permeability distribution within the Pennsylvanian rock sequence are of lesser importance than that of the Wolfcamp sequence for controlling model results. In other words the model is less sensitive to variations in the hydraulic properties of the Pennsylvanian rocks than to variations in the hydraulic properties of the Wolfcamp rocks.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The geometry and rate of groundwater flow within the Palo Duro Basin is critical to the feasibility of high-level waste disposal within the basin. This study is of major importance to the NRC licensing effort because it develops models of groundwater flow and estimates of concomitant travel times.

PROBLEMS, DEFICIENCIES, OR LIMITATIONS OF REPORT:

We recognize few significant problems in the methodology of the study. The model used appears appropriate and the simulations produce results that are reasonable given the input parameters and boundary conditions used. However, some comments regarding the conceptual model are warranted.

Williams and Associates, Inc. (Communication #33) has pointed out that a conceptual groundwater model is still not well defined for the Palo Duro Basin. Sufficient data on head distribution of the Deep-Basin Brine rocks necessary to permit precise definition of a potentiometric surface, either for the Wolfcamp rocks or for the entire Deep-Basin Brine aquifer still do not exist. In addition, no data exist on vertical permeability of the Evaporite aquitard or on areal variations in vertical permeability for this unit. This dearth of permeability data is evidenced by the use of values derived from the literature for permeabilities used in this study. The weakness of such an approach also is evidenced by the fact that the values had to be altered significantly to obtain potentiometric distributions from the model that would approximate measured or kriged head values.

The report states that the results of the kriging analysis indicate "a random error in the head data of about 52 m" (p. 14). The report further states that this error is "significant." Harper and Furr (1986) reported an error of standard deviation of 148 feet (45 m) from their analysis of the potentiometric data of the Wolfcamp aquifer. Williams and Associates, Inc. has pointed out (Communication #63) that a portion of the error may be attributed to the continuing consideration of the Deep-Basin Brine aquifer or the Wolfcamp aquifer as single aquifers. The continuing reference to a single aquifer was addressed by Williams and Associates, Inc. in Communication #33.

Similarly, relatively little is known about the hydrogeologic conditions along the north boundary of the Palo Duro Basin. In this modeling effort it was found that best results were obtained when the western half of the north boundary was treated as a prescribed head boundary (thereby permitting flow over the Amarillo Uplift) and the eastern half as a no-flow boundary. No field evidence exists to confirm the validity of these boundary conditions. The only justification for generating flow over the Amarillo Uplift along the western half of the model's northern boundary is that the brown dolomite of the Wolfcamp Series is not offset completely by faulting; consequently it may be rational to assume that some degree of lateral hydraulic continuity exists over the uplift. Whether such continuity exists or whether the hydrogeologic effect of the faults which offset the dolomite is real is not known at this time.

The validity of the use of a two layer model has yet to be substantiated. The entire Wolfcamp series and the entire Pennsylvanian rock sequence may or may not behave as a single hydrostratigraphic unit. Field data are not yet available that would substantiate the absence of vertical head gradients in these units. This issue has not been addressed to date. For additional comments on this issue the reader should refer to Williams and Associates, Inc. communication numbers 26, 33, 34, and 63.

Therefore, while the modeling procedure may be valid and while the model results may be useful for future investigative purposes, the results of the model may or may not be accurate. The dearth of potentiometric data for the Pennsylvanian rocks, the absence of data on vertical hydraulic conductivities of the Evaporite aquitard, the unsubstantiated assumption that the Wolfcamp and Pennsylvanian rocks constitute a single hydrostratigraphic unit, and the uncertainty regarding the validity of model boundaries produce a high degree of uncertainty regarding model results. Behavior of the modeled system may not represent the behavior of the prototype; consequently the travel times predicted may not be realistic. Additional refinement of the model as new field data become available should be encouraged.

REFERENCES CITED:

Bassett, R.L., and Bentley, M.E., 1983, Deep Brine Aquifers in the Palo Duro Basin: Regional Flow and Geochemical Constraints. Texas Bureau of Economic Geology Report of Investigations No. 130, 59 p.

Harper, W.V., and Furr, J.M., April 1986, Geostatistical Analysis of Potentiometric Data in the Wolfcamp Aquifer of the Palo Duro Basin, Texas. Office of Nuclear Waste Isolation, Columbus, Ohio.

Smith, D.A., 1983, Permeability of the Deep-Basin Aquifer System, Palo Duro Basin, in Gustavson, T.C., and others, Geology and Geohydrology of the Palo Duro Basin, Texas Panhandle. Texas Bureau of Economic Geology Circular 83-4.