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NUCLEAR WASTE CONSULTANTS INC.
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009/3.1/DBS.001
RS-NMS-85-009
Communication No. 32

U.S. Nuclear Regulatory Commission
Division of Waste Management
Geotechnical Branch
MS-623-SS
Washington, DC 20555

Attention: **Mr. Jeff Pohle, Project Officer**
**Technical Assistance in Hydrogeology - Project B (RS-NMS-85-009)**

Re: **Salt Site Familiarization Report, Subtask 3.1**

Dear Mr. Pohle:

This cover letter transmits to the NRC staff the Site Familiarization Subtask Report for Salt, Subtask 3.1 of Contract No. RS-NMS-85-009. This report has been prepared by the Drs. Daniel Stephens and Fred Phillips and Mr. Robert Knowlton of Daniel B. Stephens and Associates (DBS), the site team for Salt, under subcontract to Nuclear Waste Consultants. The report has received a management and technical review by Mark Logsdon of Nuclear Waste Consultants.

Nuclear Waste Consultants calls to your attention three specific technical matters concerning the hydrology of the Palo Duro Basin that have been raised by DBS in their review of the data and of conceptual models of the hydrogeology in the Salt literature. These technical matters include:

1. The potential for horizontal flow in mudstone interbeds of the HSU-B aquitard under ambient horizontal gradients.

2. The potential for membrane filtration of brines to induce pressure anomolies within the basin that could affect interpretations of flow.

3. Significant differences in modeling assumptions and inputs between INTERA and TBEG which may have impacts on developing and evaluating conceptual models.

4. Apparent inconsistencies between hydrodynamically-based and geochemically-based estimates of residence and circulation times of waters within the basin. DBS considers that considerable additional effort will have to be applied to developing conceptual models that are consistent with the chemical as well as the physical characteristics of the system.



WM-Res
WM Record File
D1021
NWCI

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

Distribution:
J Pohle

(Return to WM, 623-SS)

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rec'd 3/14/86 to JPohle w/ltr dated 3/3/86 D102



The Statement of Work for all three tasks calls for comment on the NRC staff's hydrologic issues. DBS has already provided comment on the Salt issues, presented in the NWC letter report on the NNWSI issues hierarchy. Additional comment on the NRC issues is provided in this letter report, with particular comment on the potential significance of providing additional guidance in the issues on the roles of deterministic and stochastic models.

The submission of this letter report meets the contractual deliverable for Subtask 3.1 of Contract Number RS-NMS-85-009 and completes the Salt Site Familiarization subtask.

If you have any questions concerning this report or related matters, please contact me immediately.

Respectfully submitted,
NUCLEAR WASTE CONSULTANTS, INC.

Mark J. Logsdon

Mark J. Logsdon, Project Manager

Att: BWIP Site Familiarization Report, Subtask 2.1

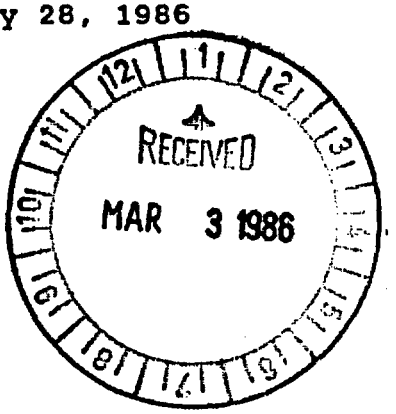
cc: US NRC - Director, NMSS (ATTN: PSB)
DWM (ATTN: Division Director) - 2
Barry Bromberg, Contract Administrator
WMGT (ATTN: Branch Chief)

bc: M. Galloway, TTI
R. Knowlton, DBS
L. Davis, WWL

DANIEL B. STEPHENS & ASSOCIATES, INC.
CONSULTANTS IN GROUND-WATER HYDROLOGY

• GROUND-WATER CONTAMINATION • UNSATURATED ZONE INVESTIGATIONS • WATER SUPPLY DEVELOPMENT •

February 28, 1986




Nuclear Waste Consultants, Inc.
8341 So. Sangre de Cristo Road
Littleton, Colorado 80127

Attention: Mark Logsdon, Project Manager

Re: Site Familiarization Report, Subtask 3.1

Dear Mr. Logsdon:

This letter serves as our report for Subtask 3.1, Site Familiarization, as required by our subcontract to Nuclear Waste Consultants. This correspondence also includes our comments regarding Hydrology Issues for the Palo Duro Bedded Salt Basin, Palo Duro STP-1.0, Draft, August 1984. After your review of this report, please forward it to Jeff Pohle at the U.S. Nuclear Regulatory Commission.

Background

Nuclear Waste Consultants, Inc. (NWC) was awarded NRC project RS-NMS-85-009 entitled "Technical Assistance in Hydrogeology - Project B - Analysis" on September 28, 1985. Daniel B. Stephens and Associates, Inc. (DBS) is subcontracted to NWC for review of hydrogeologic investigations of the Salt Repository Project (SRP). Robert G. Knowlton, Jr. (SRP Project Manager) and Daniel B. Stephens (SRP Technical Director) attended the project kickoff meeting at the NRC offices in Silver Spring, MD on October 22-25, 1985. As discussed in the October travel report for this trip, we were introduced to the NRC project officers and staff personnel, as well as personnel from Williams and Associates, contractors on the NRC project RS-NMS-85-008 entitled "Technical Assistance in Hydrogeology - Project A - Testing".

In addition to meeting personnel involved with the project we were given a copy of the NRC bibliography pertaining to SRP documents. We were given specific direction at this meeting to focus our familiarization and review activities on the Palo Duro Basin bedded salt sites in the Texas Panhandle. Attachment A contains a list of documents which we now have in our library. Documents recently requested but not yet received are listed in Attachment B.

## Document Data Base

The bibliography shown in Attachment A is part of a computerized data base cataloging the documents in our library. Document searches can be accomplished by entering complete or partial titles, author's name, document number, or some keyword. The bibliography will be modified shortly to include information pertaining to reviewed documents. Documents that have been reviewed formally or informally will be listed as such. The reviewers name, date of the review, and any other index information will also be included. This should aid us later for formal reviews and continued familiarization activities. Informal reviews and document readings are entered on a format such as that shown in Figure 1. These reviews are catalogued for future reference.

## Site Familiarization

Our current familiarization and understanding of the hydrogeology of the Palo Duro basin has been derived from numerous documents, including the following:

DOE, 1984, `Draft Environmental Assessment', Deaf Smith County Site, Texas

OF-WTWI-1983-4, `Identification of Recharge-Discharge Areas of the Palo Duro Basin, Texas Panhandle', 1983, R.K. Senger and B.C. Richter.

OF-WTWI-1984-22, `Geostatistical Analysis of Potentiometric Surface of the San Andres Formation, Texas Panhandle',1984, A.R. Dutton and E.D. Orr.

OF-WTWI-1984-30, `Stratigraphy of the Palo Duro Basin - A Status Report', 1984, Ruppel et al.

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OF-WTWI-1984-44, `Vertical Hydraulic Conductivity, Flux, and Flow in the Deep-Basin Brine Aquifer, Palo Duro Basin, Texas', 1984, E.D. Orr and R.K. Senger.

OF-WTWI-1984-54, `Hydrodynamic Development of the Palo Duro Basin and Other Mechanisms Creating Possible transient Flow Conditions', 1984, R.K. Senger

Figure 1 - Short-Form Document Reviews for NRC

Document Title:

Document Authors:

Document Number: Publication Date:

Document Read By: Reviewed Date:

Summary of Document:

Major Review Conclusions:

General Comments:

BMI/ONWI-578, `The Organic Chemistry of Deep Ground Waters from the Palo Duro Basin, Texas: Implications for Radionuclide Complexation, Ground-water Origin, and Petroleum Exploration', 1985, J.L. Means and N.J. Hubbard, Battelle Memorial Institute, ONWI.

ONWI/E512-02900/TR-31,410A-00G-17A, 1984, `Second Status Report on Regional Ground-water Flow Modeling for the Palo Duro Basin, Texas', INTERA, Inc.

`Hydrochemical and Isotope Hydrology Results for the Palo Basin, Texas Panhandle: A Summary Report of Material Presented at the June 5, 1984 Discussion Meeting, Columbus, Ohio', 1984, Prepared by Norman Hubbard/ONWI.

In reviewing these documents and others we have developed some initial impressions and concerns that may help guide our further study of the hydrogeology of the Palo Duro basin.

## The Conceptual Model

The hydrogeologic framework of the Palo Duro Basin is rather well established, particularly with regard to the stratigraphy and geologic structure. In a regional sense, details of the depositional environments and geologic history appear to be especially well developed. Although there are few control points (deep wells) near the proposed sites, there seems to be adequate control for developing a geologic framework for the conceptual model, owing to lateral uniformity within areally extensive strata.

The hydrologic data available are considered to be adequate at the regional scale to define general direction of ground-water flow within the principal hydrostratigraphic units.

In the conceptual model for ground-water flow which we have inferred from available data and reports, there are three regional hydrostratigraphic units (HSU). The shallow unit is HSU-A, which is an aquifer that includes the Ogallala formation and Triassic Dockum group. The middle unit, HSU-B, is an aquitard which is on the order of 4000 feet thick and includes relatively low permeable shale, anhydrite, carbonate, mudstones and siltstone of Permian age. The repository is to be located near the center of this sequence and within Unit 4 of the San Andres formation. The lower unit is HSU-C, a deep-basin brine-aquifer comprised of the lower Permian Wolfcamp carbonates and underlying units, including the granite wash. HSU-C overlies crystalline Precambrian basement rocks.

The shallow aquifer system, HSU-A, is recharged mostly by

infiltration of precipitation; and discharge is principally by wells and by springs. Ground water generally flows eastward and some is presumed to leak downward and flow vertically across the HSU-B aquitard. However, sparse data within the HSU-B San Andres formation indicate that there is also a horizontal flow component to the southeast. In the deep-basin brine aquifer HSU-C, ground water flow is to the northeast. Recharge to this unit is believed to occur mostly in outcrop areas to the west in New Mexico. Sources of discharge have not been clearly identified.

## General Comments on the Conceptual Model

Through the review of the available literature, general areas of relative weakness have been identified in the conceptual model. Some of our concerns may be addressed in forth-coming new documents or documents which we have ordered but have not received. Some of our concerns may diminish in importance to us as our understanding of the hydrogeologic system deepens through subsequent data-base management and quantification activities, whereas others may become the basis for additional, more detailed investigation. Below we present a brief discussion of our preliminary concerns regarding the information available to us at this time which pertains to hydrogeologic conceptual models.

DOE's conceptual model stresses vertical flow downward in the HSU-B aquitard toward the deep-basin brine aquifer. There are numerous layers of mudstone within the salt section which could have horizontal hydraulic conductivities that are much greater than that of the adjacent salt. Inasmuch as horizontal hydraulic gradients have been inferred from widely spaced wells in this unit, there is the possibility of lateral flow within mudstones of HSU-B that has not been addressed thoroughly. The implications of anisotropy in the HSU-B zone also have not been thoroughly discussed. High concentrations of brine across semi-permeable clay membranes may cause anoualous pressures within the basin that could affect interpretations of flow; this potential problem has not been addressed completely.

Numerical models have been applied as tools to understanding the conceptual model of the ground-water system. These modeling efforts were undertaken independently by the DOE subcontractor INTERA, Inc. and by the Texas Bureau of Economic Geology (TBEG). The models differ significantly in many respects, including the type of numerical model, choice of boundary conditions and parameterization, for example. We believe that differences between models should be closely examined for their implications to the conceptual model interpretations. Wherever possible, combined results of both efforts should be used in developing the conceptual model, and areas of contradiction should be identified and resolved with additional studies.

Another issue of concern is the rates of ground-water circulation through the salts and beneath the salts through the clastic and carbonate basin sediments. Preliminary numerical models of the basin by various groups (TBEG and INTERA) has produced roughly similar results, with cross-basin circulation times on the order of $10^6$ to no more than $10^7$ years. However recent geochemical dating of the ground-water by ONWI has produced much older age estimates, in fact they have implied a connate origin (i.e. Permian/Pennsylvanian) for the oldest waters. This discrepancy has cast doubt on the entire conceptualization of the flow system, and requires resolution. The problem of vertical transport through the salt section, although not so subject to conflicting interpretations, is equally ambiguous, given the state of knowledge concerning hydraulic conductivities in the salts. Geochemical evidence (e.g., isotopic dating) could yield considerable insight here. Also ground-water age dating and stable isotope analyses may be most useful in checking the rates of ground-water flow and sources of recharge.

We believe that additional effort is needed to present a conceptual model which is consistent with the chemical, as well as the physical, characteristics of the system.

Comment on Hydrology Issues

The draft NRC report on staff hydrology issues is a good, general guidance for organizing technical issues to be addressed for the Palo Duro Basin. Issues 1.1, 1.3, and 1.5 appear to be most relevant to our contract. However, there is one area we would like to comment on.

In regard to subissue 1.1.3, additional clarification on the types of models is suggested in order to establish the basis for model selection. Analytical or numerical models selected for application to the salt site will be either deterministic or probabilistic (stochastic). Deterministic models are usually most appropriate when there are few available data. Average hydraulic properties are assigned to large areas of the hydrogeologic system, and the predicted values of hydraulic head or velocity do not explicitly reflect the element of uncertainty in the input parameters. On the other hand, probabilistic models, which may, for example, include the spatial correlation structure of hydraulic properties or transient variability in boundary conditions, are usually most appropriate when there are sufficient data to statistically predict an outcome within specified confidence limits. Inasmuch as there are inherent uncertainties in the hydrogeologic parameters, the preferred modeling strategy would provide estimates of probabilities associated with a given model prediction. The probabilistic approach appears to be consistent with 10 CFR 60.122 (Siting Criteria) which requires that "the favorable conditions present are sufficient to provide

a reasonable assurance that the performance objectives...will be met".

Summary

The Site Familiarization subtask of the project has been successfully completed. The DBS team has developed a basic understanding of the hydrogeology of the Palo Duro basin, and along with our bibliographic data base, puts us in a good position for performing formal reviews and other tasks.

Sincerely,

Daniel B. Stephens & Assoc., Inc.

Robert G. Knowlton, Jr.

Robert G. Knowlton, Jr.
Project Manager

RGKJr/mt

ATTACHMENT A

SALT REPOSITORY PROJECT

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Memoirs, Vol. XVII, Parts 1 and 2, 'Hydrogeology of Rocks of Low Permeability', 1985, International Association of Hydrogeologists.

'Permian Potentiometric Analysis', 1983, J.L. Devary, Pacific Northwest Laboratories.

'Survey of Available Information with Respect to Sites Currently Under Consideration for Possible Development of a Repository for High-Level Radioactive Waste', 1983, enclosure of a letter from James R. Rollo of the USGS to Hubert J. Miller of the NRC.

'Report of the Panel on Evaluation of Ground-water Flow in Fractures at the Palo Duro Basin', Battelle.

'Hydrochemical and Isotope Hydrology Results for the Palo Basin, Texas Panhandle: A Summary Report of Material Presented at the June 5, 1984 Discussion Meeting, Columbus, Ohio', 1984, Prepared by Norman Hubbard/ONWI.

'The Composition and Stratigraphic Distribution of Materials in the Lower San Andres Salt Unit 4', N. Hubbard, D. Livingston, and L. Fukui, Battelle and Bendix Cooperative Report.

Geology, v. 12, p. 314-317, 1984, 'Deformation of Permian Strata overlying a zone of salt dissolution and collapse in the Texas Panhandle', A.G. Goldstein and E.W. Collins.

Draft Environmental Assessment, Deaf Smith County Site, Texas, 1984, DOE-OCRWM.

NRC Issues Comments on DOE's Nine Draft Environmental Assessments of Potential High-Level Waste Repository Sites.

NRC-10CFR Part 60, 'Disposal of High-Level Radioactive Wastes in Geologic Repositories; Technical Criteria'.

NRC-10CFR Part 60, 'Disposal of High-Level Radioactive Wastes in Geologic Repositories; Licensing Procedures'.

Nuclear Waste Policy Act, H.R.3809.

EPA-40CFR Part 191, 'Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule'.

WMGT Document Review, on BMI/SRP-5010, by Grant Buma, 1984.

WMGT Document Review, on Draft - ONWI-556, by Adrian Brown, 1984.

WMGT Document Review, on BMI/SRP-5011, by Adrian Brown, 1984.

WMGT Document Review, on ONWI-504, by Adrian Brown, 1984.

WMGT Document Review, on BMI/SRP-5010, by Williams and Associates, 1984.

WMGT Document Review, on BMI/SRP-5005, by Williams and Associates, 1984.

WMGT Document Review, on BMI/SRP-5020, by Williams and Associates, 1984.

WMGT Document Review, on Draft - ONWI-556, by Williams and Associates, 1984.

WMGT Document Review on OF-WTWI-1983-13, 'Hydrogeochemistry of the Palo Duro Basin, Texas Panhandle', and OF-WTWI-1984-36, 'Regional and Isotopic Hydrogeochemistry: Deep-basin Brine Aquifers, Palo Duro Basin, Texas Panhandle', review by Walton R. Kelly.

WMGT Document Review on OF-WTWI-1984-50, 'Amount and Nature of Occluded Water in Bedded Salt, Palo Duro Basin', review by Walton R. Kelly.

WMGT Document Review on OF-WTWI-1984-11, 'Host Rock Geochemistry of the Palo Duro Basin, Texas', review by Walton R. Kelly.

Letter from Adrian Brown to Eileen Poeter, Re: Data Review visit to Columbus, Ohio, May 14-18, 1984.

WMGT Document Review of `Test Plan for Multiple-Well Hydraulic Testing of Selected Hydrogeologic Units at the RRL-2 site, Basalt Waste Isolation Project, Reference Repository Location (DOE Doc. No. SD-BWI-TP-040) by Randolph Stone, P.M. Rogers, A.lt. Lu, and R.W. Bryce, Dated 1985, By Fred Marinelli, Michael Galloway, and Mark Logsdon.

ATTACHMENT B

SALT REPOSITORY PROJECT

DOCUMENTS REQUESTED

Documents Requested

| Report #/ Title | Author | Log # | Document Date |
|---|---|---|---|
| | Carpenter | 00108 | 780000 |
| Origin and Chemical Evolution of Brines in Sedimentary Basins (Oklahoma Geological Survey Circular 79) pp. 60-77 | | | |
| | DeBuchananne | 00013 | 810501 |
| USGS ltr to CHeath, DOE (w/cover ltr frm Neff, NWTS)-comparison of geologic and hydrologic characteristics of salt domes and salt beds. | | | |
| | DOE | 00034 | 830516 |
| U.S. DOE Transcripts from Public Hearings in Texas on Proposed Nomination of Sites for Site Characterization & Recommendations of Issues for Environmental Assessments & Site Characterization Plans, (Vol. 1 & 2), Hereford, TX (5/16/83) & Tulia, TX (5/17/83) | | | |
| | McCauley | 00075 | 840000 |
| Draft DOE Document - Expected Nuclear Waste Repository Near-Field, Perfomance in Three Salt Basins, Part II: Brine Migrations (Techinical Review by Walton Kelly) | | | |
| | McNulty | 00074 | 840200 |
| Draft DOE Cocument - Expected Nuclear waste Repository Near-Field, Perfomance in Three Salt Basins, Part 1: Thermal Conditions. | | | |
| | Wilson | 00014 | 801021 |
| Report of Trip to Asse and Konrad Mines, Federal Republic of Germany, by LBL. | | | |
| GLGYB | Roedder | 00107 | 811100 |
| Problems in Determination of the Water Content of Rock-Salt Samples and Its Significance in Nuclear-Waste Storage Siting, by Geology, Vol. 9 #11, pp. 525-530. | | | |
| NUTYB | | 00091 | 831200 |
| Letters to the Editor - Remarks on "Migration of Brine Inclusions in Salt", by Nuclear Technology Vo. 63 (pp. 507-510) | | | |
| NUTYB | Pigford | 00092 | 820200 |
| Migration of Brine Inclusions in Salt, by Nuclear Technology Vol. 56 (pp. 93-101) | | | |

Documents requested - continued

| Report #/ Title | Author | Log # | Document Date |
|---|---|---|---|
| ORNL-5774 Consolidation & Permeability of Salt in Brine, by Union Carbide Corporation for DOE | Shor | 00099 | 810000 |
| ORNL-5818 Brine Migration in Salt and Its Implications in theGeologic Disposal of Nuclear Waste, by ORNL for DOE | Jenks | 00077 | 811200 |
| ORNL-5950 The Effect of Water in Salt Repositories: Final Report, by ORNL for DOE | Baes Jr. | 00023 | 830900 |
| Report 98 Compilation of Results of Aquifer Tests in Texas, by Texas Water Development Board | Myers | 00046 | 690700 |
| Questions & Answers About the Potential Effects of a Repository on the Ogallala Aquifer. | Battelle | 01249 | 840501 |
| Quantitative Analysis of Regional gravity Data - Texas Panhandle Region, The University of Texas at Austin, Bureau of Economic Geology. | Goldstein | 00613 | 820000 |
| Selected Aspects of the Geology of the Palo Duro Basin, Texas Panhandle, Field Trip Guidebook, The University of Texas at Austin, Bureau of Economic Geology. | Gustavson | 00614 | 810500 |
| Regional Cross Section of the Texas Panhandle: Precambrian to Mid-Permian, The University of Texas at Austin, Bureau of Economic Geology | Handford | 00610 | 810000 |
| Palo Duro Basin Brine Samples (Tables 1-4) | Sewell | 01037 | 840000 |
| Thickness of Thick Salt Bed in Lower San Andres Unit 4 in Northern Palo Duro Basin (Sketch 13697-36-A-2) | Stone & Webster | 01058 | 831208 |
| Inferred Faults in Northern Palo Duro Basin (Sketch 13697-37-C-2) | Stone & Webster | 01059 | 831208 |

Documents requested - continued

| Report #/ Title | Author | Log # | Document Date |
|---|---|---|---|
| Zone of dissolution of Lower San Andres Unit 4 Salt (Sketch 13697-37-D-1) | Stone & Webster | 10160 | 831228 |
| Wolfcamp Potentiometric Surface after Culling Depressured, Overpressured, & Underpressured Data in Northern Palo Duro Basin (Sketch 13697-37-E-1) | Stone & Webster | 10161 | 831229 |
| Pennsylvanian Potentiometric Surface after Culling Depressured, Overpressured, & Underpressured Data in Northern Palo Duro Basin (Sketch 13697-37-F-1) | Stone & Webster | 10162 | 831229 |
| Wolfcamp Potentiometric Surface after Culling Depressured, Overpressured, & Underpressured Data in Palo Duro Basin (Sketch 13697-37-H-2) | Stone & Webster | 10163 | 840223 |
| Springs and Seeps in the Palo Duro Basin Area, Texas, Draft Report | SWEC | 01078 | 821200 |
| Forwarding aerial photographs for proposed sites in Swisher County & Deaf Smith County in Texas. | SWEC | 01109 | 841114 |
| Characterization Status Report entitled: (332 FJ) Host Rock Geochemistry (6.1), by University of Texas at Austin, Bureau of Economic Geology. | Univ. of Texas | 01077 | 840314 |
| Progress on Radiometric Dating of Wolfcamp Brines Using $^{4}He$ and $^{40}Ar$. | Zaikowski | 01044 | 000000 |
| BMI/SRP-5028 U, Th, and Ra Concentrations in Brines From Four Deep Wells in the Palo Duro Basin, Texas: Unanalyzed Data, Technical Report, by Bendix Field Engineering Corporation. | Bendix Eng. | 01122 | 850100 |
| DOE/NWTS-80(2) Geologic disposal of Radioactive Waste: Program Plan for Field Tests in Salt, by NWTS Program Office. | Battelle | 01247 | 810400 |

Documents requested - continued

| Report #/ Title | Author | Log # | Document Date |
|---|---|---|---|
| No. 102 Lower Permian Facies of the Palo Duro Basin, Texas: Depositional Systems, Shelf-Margin Evolution, Paleogeography, and Petroleum Potential, The University of Texas at Austin, Bureau of Economic Geology, Report of Investigations No. 102, for DOE. | Handford | 00606 | 800000 |
| OF-WTWI-1983-1 Tectonic History of the Palo Duro Basin, Texas Panhandle | Budnik | 01188 | 840709 |
| OF-WTWI-1983-10 Geomorphic Processes of the Texas Panhandle | Baumgardner | 01196 | 840718 |
| OF-WTWI-1983-11 Surface Geology of the Palo Duro and Dalhart Basins Area, Texas | Smith | 01197 | 840718 |
| OF-WTWI-1983-2 Tectonic Framework of the Palo Duro Basin, Texas Panhandle | Budnik | 01189 | 840709 |
| OF-WTWI-1983-3 Fracture Studies of the Palo Duro Basin, Texas Panhandle | Collins | 01190 | 840709 |
| OF-WTWI-1984-1 A Comparison of the Depositional Environment of the San Andres Formation in the Palo duro Basin to Recent Evaporitic Environments Geochemistry. | Chapman | 01160 | 840705 |
| OF-WTWI-1984-10 Late Quaternary Paleoclimatology of the Southern High Plains of Texas--Implications for Disposal of Nuclear Waste, by Bureau of Economic Geology for DOE | Caran | 01081 | 840000 |
| OF-WTWI-1984-16 Modern Eolian Processes on the Southern High Plains | Machenberg | 01175 | 840523 |
| OF-WTWI-1984-2 Uplift, Tilting and Subsidence of the Palo Duro Basin Area. | McGookey | 01161 | 840515 |
| OF-WTWI-1984-20 Jointing History of the Palo Duro Basin | Collins | 01179 | 840611 |
| OF-WTWI-1984-26 Geochemical Environment of the Evaporite Aquitard and Deep-Basin Brine Aquifer, Palo Duro Basin, Texas. | Fisher | 01184 | 840624 |
| OF-WTWI-1984-3 Salt Dissolution: Examples from Beneath the Southern High Plains, by the Bureau of Economic Geology for DOE | Gustavson | 01147 | 840000 |

Documents requested - continued

| Report #/ Title | Author | Log # | Document Date |
|---|---|---|---|
| OF-WTWI-1984-31 Composition of Unit 4 Halite in Deaf Smith and Swisher Counties, Texas Panhandle. | Hovorka | 01199 | 840723 |
| OF-WTWI-1984-36 Regional and Isotopic Hydrogeochemistry: Deep-Basin Brine Aquifer, Palo Duro Basin, Texas Panhandle (Technical Review by WKelly) | Fisher | 01207 | 840822 |
| OF-WTWI-1984-43 Stratigraphic Studies of the Palo Duro Basin: An Update | Ruppel | 01214 | 840919 |
| OF-WTWI-1984-48 Textural and Chemical Zones in Bedded Halite, Permian Lower San Andres Formation, Palo Duro Basin, Texas. | Fisher | 01169 | 841002 |
| OF-WTWI-1984-49 Quaternary Stratigraphy and Geologic Mapping, Western Rolling Plains of Texas. | Caran | 01170 | 841011 |
| OF-WTWI-1984-50 Amount and Nature of Occluded Water in Bedded Salt, Palo Duro Basin, Texas | Fisher | 01172 | 841029 |
| OF-WTWI-1984-53 Reconstruction of the Late Quaternary Paleoclimate of Northwestern Texas -- Progress Report | Caran | 01229 | 841219 |
| OF-WTWI-1984-55 Structural Geology and Tectonic History of the Palo Duro Basin, Texas Panhandle. | | 01227 | 841221 |
| OF-WTWI-1984-9 Structural Control of Physiography, Geomorphic Processes, and Lithofacies, Texas Panhandle. | Gustavson | 01168 | 840312 |
| OF-WTWI-1985-1 Radiocarbon Age of Quarternary Deposits, Western Rolling Plains of Texas. | Caran | 01230 | 850130 |
| OF-WTWI-1985-2 Hydrogeology and Hydrochemical Facies of the San Andres Formation in Easten New Mexico, West-Central Texas, & the Texas Panhandle. | Dutton | 01231 | 850206 |
| OF-WTWI-1985-7 Structure Control of the Development of the Canadian River Valley, Texas Panhandle: An Example of Regional Salt Dissolution and Subsidence. | Gustavson | 01235 | 850307 |

Documents requested - continued

| Report #/ Title | Author | Log # | Document Date |
|---|---|---|---|
| TP-83-133 Modeling the Deep Basin Hydrogeology of a Potential High-Level Radwaste Site in Texas - Presented at Association of Engineering Geologists Annual Meeting in San Diego, CA | Smith | 01052 | 831006 |
| 249 Analytical Study of the Ogallala Aquifer in Swisher County, Texas, Projections of Saturated Thickness, Volume of Water in Storage, Pumpage Rates, Pumping Lifts, and Well Yields, by Texas Department of Water Resources. | Bell | 01245 | 800700 |
| 288 Evaluating the Ground-Water Resources of the High Plains of Texas, Volume 1, by Texas Department of Water Resources | Knowles | 01251 | 840500 |
| 80-11 Climatic controls on Erosion in the Rolling Plains and Along the Caprock Escarpment of the Texas Panhandle, The University of Texas at Austin, Bureau of Economic Geology, Geological Circular 80-11, for DOE | Finley | 00601 | 800000 |
| 81-5 Lineament Analysis Based on Landsat Imagery, Texas Panhandle, The University of Texas at Austin, Bureau of Economic Geology, Geological Circular 81-5, for DOE | Finley | 00602 | 810000 |
| Properties of Salt Important in Radioactive Waste Disposal, The Geological Society of America, Inc., Special Paper 88. | Bradshaw | 00591 | 680000 |
| DOE/NWTS-80(2) Geologic Disposal of Radioactive Waste: Program Plan for Field Tests in Salt, prepared by Office of NWTS Integration, Battelle (Technical Review by RJohnson, MPendleton, JRhoderick) | NWTS | 00584 | 810400 |
| SAND81-7054 State-of-the-Art Review of Brine Migration Studies in Salt, by Sandie for DOE | Gnirk | 00587 | 810900 |
| UCRL-53476 Thermal Conductivity and Diffusivity Permian Basin Bedded Salt at Elevated Pressure and Temperature (fiche only) | | 01030 | 831000 |

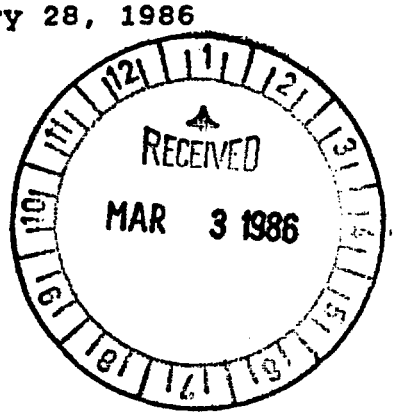
Documents requested - continued

| Report #/ Title | Author | Log # | Document Date |
|---|---|---|---|
| EEG-18 Origin Of The Brines Near WIPP From The Drill Holes ERDA-6 and WIPP-12 Based On Stable Isotope Concentrations Of Hydrogen And Oxygen, By Health And Environment Department, State of New Mexico | Spiegler | 01104 | 830300 |
| NUREG/CR-2324 o User's Manual for the Sandia Waste-Isolation Flow and Transport Model (SWIFT) Release 4.81 | | | 840100 |
| NUREG/CR-3490 o The Rold of Geochemical Factors in the Assessment and Regulation of Geologic Disposal of High-Level Radioactive Waste. | | | 840300 |
| NUREG/CR-3832 o Uncertainties in Long-Term Repository Performance Due to the Effects of Future Geologic Processes | | | 840800 |
| NUREG/CR-3847 o Climatic Calibration of Pollen Data | | | 840600 |
| NUREG/CR-4042 o A Three-Dimensional Computer Model to Simulate Fluid Flow and Containment Transport Thru a Rock Fracture System | | | 850100 |
| NUREG/CR-3612 o Prediction of Far-Field subsurface Radionuclide Dispersion Coefficients from Hydraulic Conductivity Measurement. | | | 840300 |

DANIEL B. STEPHENS & ASSOCIATES, INC.
CONSULTANTS IN GROUND-WATER HYDROLOGY

• GROUND-WATER CONTAMINATION • UNSATURATED ZONE INVESTIGATIONS • WATER SUPPLY DEVELOPMENT •

February 28, 1986




Nuclear Waste Consultants, Inc.
8341 So. Sangre de Cristo Road
Littleton, Colorado 80127

Attention: Mark Logsdon, Project Manager

Re: Site Familiarization Report, Subtask 3.1

Dear Mr. Logsdon:

This letter serves as our report for Subtask 3.1, Site Familiarization, as required by our subcontract to Nuclear Waste Consultants. This correspondence also includes our comments regarding Hydrology Issues for the Palo Duro Bedded Salt Basin, Palo Duro STP-1.0, Draft, August 1984. After your review of this report, please forward it to Jeff Pohle at the U.S. Nuclear Regulatory Commission.

Background

Nuclear Waste Consultants, Inc. (NWC) was awarded NRC project RS-NMS-85-009 entitled "Technical Assistance in Hydrogeology - Project B - Analysis" on September 28, 1985. Daniel B. Stephens and Associates, Inc. (DBS) is subcontracted to NWC for review of hydrogeologic investigations of the Salt Repository Project (SRP). Robert G. Knowlton, Jr. (SRP Project Manager) and Daniel B. Stephens (SRP Technical Director) attended the project kickoff meeting at the NRC offices in Silver Spring, MD on October 22-25, 1985. As discussed in the October travel report for this trip, we were introduced to the NRC project officers and staff personnel, as well as personnel from Williams and Associates, contractors on the NRC project RS-NMS-85-008 entitled "Technical Assistance in Hydrogeology - Project A - Testing".

In addition to meeting personnel involved with the project we were given a copy of the NRC bibliography pertaining to SRP documents. We were given specific direction at this meeting to focus our familiarization and review activities on the Palo Duro Basin bedded salt sites in the Texas Panhandle. Attachment A contains a list of documents which we now have in our library. Documents recently requested but not yet received are listed in Attachment B.

## Document Data Base

The bibliography shown in Attachment A is part of a computerized data base cataloging the documents in our library. Document searches can be accomplished by entering complete or partial titles, author's name, document number, or some keyword. The bibliography will be modified shortly to include information pertaining to reviewed documents. Documents that have been reviewed formally or informally will be listed as such. The reviewers name, date of the review, and any other index information will also be included. This should aid us later for formal reviews and continued familiarization activities. Informal reviews and document readings are entered on a format such as that shown in Figure 1. These reviews are catalogued for future reference.

## Site Familiarization

Our current familiarization and understanding of the hydrogeology of the Palo Duro basin has been derived from numerous documents, including the following:

DOE, 1984, `Draft Environmental Assessment', Deaf Smith County Site, Texas

OF-WTWI-1983-4, `Identification of Recharge-Discharge Areas of the Palo Duro Basin, Texas Panhandle', 1983, R.K. Senger and B.C. Richter.

OF-WTWI-1984-22, `Geostatistical Analysis of Potentiometric Surface of the San Andres Formation, Texas Panhandle',1984, A.R. Dutton and E.D. Orr.

OF-WTWI-1984-30, `Stratigraphy of the Palo Duro Basin - A Status Report', 1984, Ruppel et al.

OF-WTWI-1984-32, `Modeling the Effects of Regional Hydrostratigraphy and Topography on Ground-water Flow, Palo Duro Basin Texas', 1984, R.K. Senger and G.E. Fogg.

OF-WTWI-1984-44, `Vertical Hydraulic Conductivity, Flux, and Flow in the Deep-Basin Brine Aquifer, Palo Duro Basin, Texas', 1984, E.D. Orr and R.K. Senger.

OF-WTWI-1984-54, `Hydrodynamic Development of the Palo Duro Basin and Other Mechanisms Creating Possible transient Flow Conditions', 1984, R.K. Senger

Figure 1 - Short-Form Document Reviews for NRC

Document Title:

Document Authors:

Document Number: Publication Date:

Document Read By: Reviewed Date:

Summary of Document:

Major Review Conclusions:

General Comments:

BMI/ONWI-578, 'The Organic Chemistry of Deep Ground Waters from the Palo Duro Basin, Texas: Implications for Radionuclide Complexation, Ground-water Origin, and Petroleum Exploration', 1985, J.L. Means and N.J. Hubbard, Battelle Memorial Institute, ONWI.

ONWI/E512-02900/TR-31,410A-00G-17A, 1984, 'Second Status Report on Regional Ground-water Flow Modeling for the Palo Duro Basin, Texas', INTERA, Inc.

'Hydrochemical and Isotope Hydrology Results for the Palo Basin, Texas Panhandle: A Summary Report of Material Presented at the June 5, 1984 Discussion Meeting, Columbus, Ohio', 1984, Prepared by Norman Hubbard/ONWI.

In reviewing these documents and others we have developed some initial impressions and concerns that may help guide our further study of the hydrogeology of the Palo Duro basin.

## The Conceptual Model

The hydrogeologic framework of the Palo Duro Basin is rather well established, particularly with regard to the stratigraphy and geologic structure. In a regional sense, details of the depositional environments and geologic history appear to be especially well developed. Although there are few control points (deep wells) near the proposed sites, there seems to be adequate control for developing a geologic framework for the conceptual model, owing to lateral uniformity within areally extensive strata.

The hydrologic data available are considered to be adequate at the regional scale to define general direction of ground-water flow within the principal hydrostratigraphic units.

In the conceptual model for ground-water flow which we have inferred from available data and reports, there are three regional hydrostratigraphic units (HSU). The shallow unit is HSU-A, which is an aquifer that includes the Ogallala formation and Triassic Dockum group. The middle unit, HSU-B, is an aquitard which is on the order of 4000 feet thick and includes relatively low permeable shale, anhydrite, carbonate, mudstones and siltstone of Permian age. The repository is to be located near the center of this sequence and within Unit 4 of the San Andres formation. The lower unit is HSU-C, a deep-basin brine-aquifer comprised of the lower Permian Wolfcamp carbonates and underlying units, including the granite wash. HSU-C overlies crystalline Precambrian basement rocks.

The shallow aquifer system, HSU-A, is recharged mostly by

infiltration of precipitation; and discharge is principally by wells and by springs. Ground water generally flows eastward and some is presumed to leak downward and flow vertically across the HSU-B aquitard. However, sparse data within the HSU-B San Andres formation indicate that there is also a horizontal flow component to the southeast. In the deep-basin brine aquifer HSU-C, ground water flow is to the northeast. Recharge to this unit is believed to occur mostly in outcrop areas to the west in New Mexico. Sources of discharge have not been clearly identified.

## General Comments on the Conceptual Model

Through the review of the available literature, general areas of relative weakness have been identified in the conceptual model. Some of our concerns may be addressed in forth-coming new documents or documents which we have ordered but have not received. Some of our concerns may diminish in importance to us as our understanding of the hydrogeologic system deepens through subsequent data-base management and quantification activities, whereas others may become the basis for additional, more detailed investigation. Below we present a brief discussion of our preliminary concerns regarding the information available to us at this time which pertains to hydrogeologic conceptual models.

DOE's conceptual model stresses vertical flow downward in the HSU-B aquitard toward the deep-basin brine aquifer. There are numerous layers of mudstone within the salt section which could have horizontal hydraulic conductivities that are much greater than that of the adjacent salt. Inasmuch as horizontal hydraulic gradients have been inferred from widely spaced wells in this unit, there is the possibility of lateral flow within mudstones of HSU-B that has not been addressed thoroughly. The implications of anisotropy in the HSU-B zone also have not been thoroughly discussed. High concentrations of brine across semi-permeable clay membranes may cause anoualous pressures within the basin that could affect interpretations of flow; this potential problem has not been addressed completely.

Numerical models have been applied as tools to understanding the conceptual model of the ground-water system. These modeling efforts were undertaken independently by the DOE subcontractor INTERA, Inc. and by the Texas Bureau of Economic Geology (TBEG). The models differ significantly in many respects, including the type of numerical model, choice of boundary conditions and parameterization, for example. We believe that differences between models should be closely examined for their implications to the conceptual model interpretations. Wherever possible, combined results of both efforts should be used in developing the conceptual model, and areas of contradiction should be identified and resolved with additional studies.

Another issue of concern is the rates of ground-water circulation through the salts and beneath the salts through the clastic and carbonate basin sediments. Preliminary numerical models of the basin by various groups (TBEG and INTERA) has produced roughly similar results, with cross-basin circulation times on the order of $10^6$ to no more than $10^7$ years. However recent geochemical dating of the ground-water by ONWI has produced much older age estimates, in fact they have implied a connate origin (i.e. Permian/Pennsylvanian) for the oldest waters. This discrepancy has cast doubt on the entire conceptualization of the flow system, and requires resolution. The problem of vertical transport through the salt section, although not so subject to conflicting interpretations, is equally ambiguous, given the state of knowledge concerning hydraulic conductivities in the salts. Geochemical evidence (e.g., isotopic dating) could yield considerable insight here. Also ground-water age dating and stable isotope analyses may be most useful in checking the rates of ground-water flow and sources of recharge.

We believe that additional effort is needed to present a conceptual model which is consistent with the chemical, as well as the physical, characteristics of the system.

Comment on Hydrology Issues

The draft NRC report on staff hydrology issues is a good, general guidance for organizing technical issues to be addressed for the Palo Duro Basin. Issues 1.1, 1.3, and 1.5 appear to be most relevant to our contract. However, there is one area we would like to comment on.

In regard to subissue 1.1.3, additional clarification on the types of models is suggested in order to establish the basis for model selection. Analytical or numerical models selected for application to the salt site will be either deterministic or probabilistic (stochastic). Deterministic models are usually most appropriate when there are few available data. Average hydraulic properties are assigned to large areas of the hydrogeologic system, and the predicted values of hydraulic head or velocity do not explicitly reflect the element of uncertainty in the input parameters. On the other hand, probabilistic models, which may, for example, include the spatial correlation structure of hydraulic properties or transient variability in boundary conditions, are usually most appropriate when there are sufficient data to statistically predict an outcome within specified confidence limits. Inasmuch as there are inherent uncertainties in the hydrogeologic parameters, the preferred modeling strategy would provide estimates of probabilities associated with a given model prediction. The probabilistic approach appears to be consistent with 10 CFR 60.122 (Siting Criteria) which requires that "the favorable conditions present are sufficient to provide

a reasonable assurance that the performance objectives...will be met".

Summary

The Site Familiarization subtask of the project has been successfully completed. The DBS team has developed a basic understanding of the hydrogeology of the Palo Duro basin, and along with our bibliographic data base, puts us in a good position for performing formal reviews and other tasks.

Sincerely,

Daniel B. Stephens & Assoc., Inc.

Robert G. Knowlton, Jr.

Robert G. Knowlton, Jr.
Project Manager

RGKJr/mt

ATTACHMENT A

SALT REPOSITORY PROJECT

HYDROGEOLOGY BIBLIOGRAPHY
February 26, 1986

BMI/SRP-5002, 'Well Completion Report - Dissolution Zone Water Wells (PD-8,PD-11,PD-12,PD-13) Palo Duro Basin, Texas: Unanalyzed Data', 1984, Stone and Webster Engineering Corp.

BMI/SRP-5004, 'Well Completion Report - Harman No. 1 (PD-8) Well, Palo Duro Basin, Texas: Unanalyzed Data', 1984, Stone & Webster Engineering Corp.

BMI/SRP-5006, 'Well Completion Report - Sawyer No. 1 (PD-3) Well, Palo Duro Basin, Texas: Unanalyzed Data', 1984, Stone & Webster Engineering Corp.

BMI/SRP-5008, 'Well Completion Report - Detten No. 1 (PD-6) Well, Palo Duro Basin, Texas: Unanalyzed Data', 1984, Stone & Webster Engineering Corp.

BMI/SRP-5009, 'Well Completion Report - Zeeck No. 1 (PD-7) Well, Palo Duro Basin, Texas: Unanalyzed Data', 1984, Stone & Webster Engineering Corp.

BMI/SRP-5010, 'Pumping Test and Fluid Sampling Report - Sawyer No. 1 Well, Palo Duro Basin, Texas: Unanalyzed Data', 1984, Stone & Webster Engineering Corp.

BMI/SRP-5011, 'Well Completion Report - J. Friemel No. 1 (PD-9) Well, Palo Duro Basin, Texas: Unanalyzed Data', 1984, Stone & Webster Engineering Corp.

BMI/SRP-5012, 'Permeability Data Base - Palo Duro Basin: Texas, Oklahoma, and New Mexico: Unanalyzed Data', 1984, Stone and Webster Engineering Corp.

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ATTACHMENT B

SALT REPOSITORY PROJECT

DOCUMENTS REQUESTED

Documents Requested

| Report #/ Title | Author | Log # | Document Date |
|---|---|---|---|
| Origin and Chemical Evolution of Brines in Sedimentary Basins (Oklahoma Geological Survey Circular 79) pp. 60-77 | Carpenter | 00108 | 780000 |
| USGS ltr to CHeath, DOE (w/cover ltr frm Neff, NWTS)-comparison of geologic and hydrologic characteristics of salt domes and salt beds. | DeBuchananne | 00013 | 810501 |
| U.S. DOE Transcripts from Public Hearings in Texas on Proposed Nomination of Sites for Site Characterization & Recommendations of Issues for Environmental Assessments & Site Characterization Plans, (Vol. 1 & 2), Hereford, TX (5/16/83) & Tulia, TX (5/17/83) | DOE | 00034 | 830516 |
| Draft DOE Document - Expected Nuclear Waste Repository Near-Field, Perfomance in Three Salt Basins, Part II: Brine Migrations (Techinical Review by Walton Kelly) | McCauley | 00075 | 840000 |
| Draft DOE Cocument - Expected Nuclear waste Repository Near-Field, Perfomance in Three Salt Basins, Part 1: Thermal Conditions. | McNulty | 00074 | 840200 |
| Report of Trip to Asse and Konrad Mines, Federal Republic of Germany, by LBL. | Wilson | 00014 | 801021 |
| GLGYB Problems in Determination of the Water Content of Rock-Salt Samples and Its Significance in Nuclear-Waste Storage Siting, by Geology, Vol. 9 #11, pp. 525-530. | Roedder | 00107 | 811100 |
| NUTYB Letters to the Editor - Remarks on "Migration of Brine Inclusions in Salt", by Nuclear Technology Vo. 63 (pp. 507-510) | | 00091 | 831200 |
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| ORNL-5818 Brine Migration in Salt and Its Implications in theGeologic Disposal of Nuclear Waste, by ORNL for DOE | Jenks | 00077 | 811200 |
| ORNL-5950 The Effect of Water in Salt Repositories: Final Report, by ORNL for DOE | Baes Jr. | 00023 | 830900 |
| Report 98 Compilation of Results of Aquifer Tests in Texas, by Texas Water Development Board | Myers | 00046 | 690700 |
| Questions & Answers About the Potential Effects of a Repository on the Ogallala Aquifer. | Battelle | 01249 | 840501 |
| Quantitative Analysis of Regional gravity Data - Texas Panhandle Region, The University of Texas at Austin, Bureau of Economic Geology. | Goldstein | 00613 | 820000 |
| Selected Aspects of the Geology of the Palo Duro Basin, Texas Panhandle, Field Trip Guidebook, The University of Texas at Austin, Bureau of Economic Geology. | Gustavson | 00614 | 810500 |
| Regional Cross Section of the Texas Panhandle: Precambrian to Mid-Permian, The University of Texas at Austin, Bureau of Economic Geology | Handford | 00610 | 810000 |
| Palo Duro Basin Brine Samples (Tables 1-4) | Sewell | 01037 | 840000 |
| Thickness of Thick Salt Bed in Lower San Andres Unit 4 in Northern Palo Duro Basin (Sketch 13697-36-A-2) | Stone & Webster | 01058 | 831208 |
| Inferred Faults in Northern Palo Duro Basin (Sketch 13697-37-C-2) | Stone & Webster | 01059 | 831208 |

Documents requested - continued

| Report #/ Title | Author | Log # | Document Date |
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| | Stone & Webster | 10160 | 831228 |

Zone of dissolution of Lower San Andres Unit 4 Salt (Sketch 13697-37-D-1)

| | Stone & Webster | 10161 | 831229 |
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Wolfcamp Potentiometric Surface after Culling Depressured, Overpressured, & Underpressured Data in Northern Palo Duro Basin (Sketch 13697-37-E-1)

| | Stone & Webster | 10162 | 831229 |
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Pennsylvanian Potentiometric Surface after Culling Depressured, Overpressured, & Underpressured Data in Northern Palo Duro Basin (Sketch 13697-37-F-1)

| | Stone & Webster | 10163 | 840223 |
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Wolfcamp Potentiometric Surface after Culling Depressured, Overpressured, & Underpressured Data in Palo Duro Basin (Sketch 13697-37-H-2)

| | SWEC | 01078 | 821200 |
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| | SWEC | 01109 | 841114 |
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| | Univ. of Texas | 01077 | 840314 |
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| BMI/SRP-5028 | Bendix Eng. | 01122 | 850100 |
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U, Th, and Ra Concentrations in Brines From Four Deep Wells in the Palo Duro Basin, Texas: Unanalyzed Data, Technical Report, by Bendix Field Engineering Corporation.

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| OF-WTWI-1983-1 Tectonic History of the Palo Duro Basin, Texas Panhandle | Budnik | 01188 | 840709 |
| OF-WTWI-1983-10 Geomorphic Processes of the Texas Panhandle | Baumgardner | 01196 | 840718 |
| OF-WTWI-1983-11 Surface Geology of the Palo Duro and Dalhart Basins Area, Texas | Smith | 01197 | 840718 |
| OF-WTWI-1983-2 Tectonic Framework of the Palo Duro Basin, Texas Panhandle | Budnik | 01189 | 840709 |
| OF-WTWI-1983-3 Fracture Studies of the Palo Duro Basin, Texas Panhandle | Collins | 01190 | 840709 |
| OF-WTWI-1984-1 A Comparison of the Depositional Environment of the San Andres Formation in the Palo duro Basin to Recent Evaporitic Environments Geochemistry. | Chapman | 01160 | 840705 |
| OF-WTWI-1984-10 Late Quaternary Paleoclimatology of the Southern High Plains of Texas--Implications for Disposal of Nuclear Waste, by Bureau of Economic Geology for DOE | Caran | 01081 | 840000 |
| OF-WTWI-1984-16 Modern Eolian Processes on the Southern High Plains | Machenberg | 01175 | 840523 |
| OF-WTWI-1984-2 Uplift, Tilting and Subsidence of the Palo Duro Basin Area. | McGookey | 01161 | 840515 |
| OF-WTWI-1984-20 Jointing History of the Palo Duro Basin | Collins | 01179 | 840611 |
| OF-WTWI-1984-26 Geochemical Environment of the Evaporite Aquitard and Deep-Basin Brine Aquifer, Palo Duro Basin, Texas. | Fisher | 01184 | 840624 |
| OF-WTWI-1984-3 Salt Dissolution: Examples from Beneath the Southern High Plains, by the Bureau of Economic Geology for DOE | Gustavson | 01147 | 840000 |

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| OF-WTWI-1984-31 Composition of Unit 4 Halite in Deaf Smith and Swisher Counties, Texas Panhandle. | Hovorka | 01199 | 840723 |
| OF-WTWI-1984-36 Regional and Isotopic Hydrogeochemistry: Deep-Basin Brine Aquifer, Palo Duro Basin, Texas Panhandle (Technical Review by WKelly) | Fisher | 01207 | 840822 |
| OF-WTWI-1984-43 Stratigraphic Studies of the Palo Duro Basin: An Update | Ruppel | 01214 | 840919 |
| OF-WTWI-1984-48 Textural and Chemical Zones in Bedded Halite, Permian Lower San Andres Formation, Palo Duro Basin, Texas. | Fisher | 01169 | 841002 |
| OF-WTWI-1984-49 Quaternary Stratigraphy and Geologic Mapping, Western Rolling Plains of Texas. | Caran | 01170 | 841011 |
| OF-WTWI-1984-50 Amount and Nature of Occluded Water in Bedded Salt, Palo Duro Basin, Texas | Fisher | 01172 | 841029 |
| OF-WTWI-1984-53 Reconstruction of the Late Quaternary Paleoclimate of Northwestern Texas -- Progress Report | Caran | 01229 | 841219 |
| OF-WTWI-1984-55 Structural Geology and Tectonic History of the Palo Duro Basin, Texas Panhandle. | | 01227 | 841221 |
| OF-WTWI-1984-9 Structural Control of Physiography, Geomorphic Processes, and Lithofacies, Texas Panhandle. | Gustavson | 01168 | 840312 |
| OF-WTWI-1985-1 Radiocarbon Age of Quarternary Deposits, Western Rolling Plains of Texas. | Caran | 01230 | 850130 |
| OF-WTWI-1985-2 Hydrogeology and Hydrochemical Facies of the San Andres Formation in Easten New Mexico, West-Central Texas, & the Texas Panhandle. | Dutton | 01231 | 850206 |
| OF-WTWI-1985-7 Structure Control of the Development of the Canadian River Valley, Texas Panhandle: An Example of Regional Salt Dissolution and Subsidence. | Gustavson | 01235 | 850307 |

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| 249 Analytical Study of the Ogallala Aquifer in Swisher County, Texas, Projections of Saturated Thickness, Volume of Water in Storage, Pumpage Rates, Pumping Lifts, and Well Yields, by Texas Department of Water Resources. | Bell | 01245 | 800700 |
| 288 Evaluating the Ground-Water Resources of the High Plains of Texas, Volume 1, by Texas Department of Water Resources | Knowles | 01251 | 840500 |
| 80-11 Climatic controls on Erosion in the Rolling Plains and Along the Caprock Escarpment of the Texas Panhandle, The University of Texas at Austin, Bureau of Economic Geology, Geological Circular 80-11, for DOE | Finley | 00601 | 800000 |
| 81-5 Lineament Analysis Based on Landsat Imagery, Texas Panhandle, The University of Texas at Austin, Bureau of Economic Geology, Geological Circular 81-5, for DOE | Finley | 00602 | 810000 |
| Properties of Salt Important in Radioactive Waste Disposal, The Geological Society of America, Inc., Special Paper 88. | Bradshaw | 00591 | 680000 |
| DOE/NWTS-80(2) Geologic Disposal of Radioactive Waste: Program Plan for Field Tests in Salt, prepared by Office of NWTS Integration, Battelle (Technical Review by RJohnson, MPendleton, JRhoderick) | NWTS | 00584 | 810400 |
| SAND81-7054 State-of-the-Art Review of Brine Migration Studies in Salt, by Sandie for DOE | Gnirk | 00587 | 810900 |
| UCRL-53476 Thermal Conductivity and Diffusivity Permian Basin Bedded Salt at Elevated Pressure and Temperature (fiche only) | | 01030 | 831000 |

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| EEG-18 Origin Of The Brines Near WIPP From The Drill Holes ERDA-6 and WIPP-12 Based On Stable Isotope Concentrations Of Hydrogen And Oxygen, By Health And Environment Department, State of New Mexico | Spiegler | 01104 | 830300 |
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