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Integration of Thirty Years of Hydrogeological Investigations at the Waste Isolation Pilot Plant Site

H53E-1108

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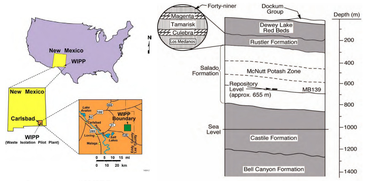
ABSTRACT

Hydrogeological research has been going on at the Waste Isolation Pilot Plant (WIPP), the U.S. Department of Energy's deep geological repository for transuranic and mixed waste in southeastern New Mexico, for over thirty years. The main focus of the research has been on the Culebra Dolomite Member of the Rustler Formation, a 7-m-thick fractured unit that would be the primary groundwater transport pathway for radionuclides released from the WIPP repository by inadvertent human intrusion. Since 1977, 90 wells have been completed to the Culebra on 63 drilling pads. Hydraulic tests have been performed in all of the wells, ranging from single-well slug and pumping tests to long-term (19-121 days) pumping tests with observation wells up to 9.5 km away. These tests have shown that Culebra transmissivity (T) varies over 10 orders of magnitude. Single-well injection-withdrawal, two-well recirculating, and multiwell convergent-flow tracer tests have been performed at six locations. Fluid electrical conductivity logging has been performed to identify the most transmissive sections of the Culebra, and a colloidal borescope has been used to identify specific flowing fractures. In addition to studies focused on groundwater flow and transport, geological, sedimentological, hydrogeochemical, and geophysical investigations have also been performed. Variations in Culebra T have been related to dissolution of the underlying Salado Formation, the presence/absence of gypsum cements, the presence or absence of halite in Rustler members above and below the Culebra, and overburden thickness. Different types of porosity (fractures, vugs, interparticle, intercrystalline) have been found to be significant for both flow and transport. Culebra water chemistry shows significant spatial variation, with total dissolved solids ranging from 3,000 to 300,000 mg/L. Five distinct hydrochemical facies have been identified, ranging from high ionic strength syndepositional Na-Mg Cl brines to low ionic strength $CaSO_4$ waters, thought to represent relatively recent recharge through gypsum karst, to brines contaminated with potash-processing effluent. Geophysical logs from an abundance of oil and gas wells around the WIPP site have been used to map facies boundaries within other Rustler members that can be related to Culebra hydrology. The results of these three decades of study have been integrated into a conceptual model for Culebra hydrology. Some of these studies have been carried out in collaboration with university researchers, and all of the data from these investigations are freely available.

OBJECTIVE

The objective of this study was to develop a conceptual model of Culebra hydrology that could be used to support modeling of flow and radionuclide transport. The conceptual model was developed by integrating data collected from a variety of studies conducted over 30 years.

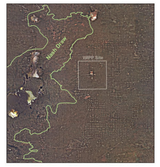


Location of WIPP

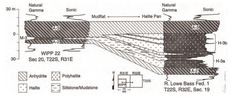
WIPP stratigraphy

GEOLOGY

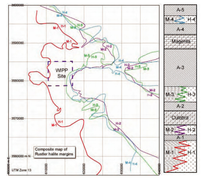
Geologic studies have focused on the depositional environment during the Permian, dissolution, and other factors affecting Culebra transmissivity such as overburden thickness and distribution of gypsum pore cements. Hundreds of oil and gas and potash exploration holes around the WIPP site provide extensive stratigraphic information.



Non-dolomite members of the Rustler Formation show transition from halite pan deposits to the east to mudflat facies to the west.

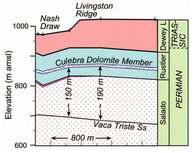


The WIPP site is located near the depositional margins of Rustler halite.

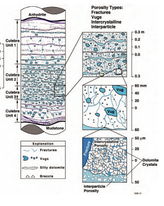


Culebra fractures and primary porosity are filled with gypsum to the east.

Dissolution of the upper Salado has created a subsidence trough west of the WIPP site known as Nash Draw.

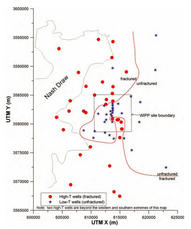


The Culebra is vertically heterogeneous, exhibiting different amounts of vugs and fractures, locally filled with sulfate and/or halite cements. It has multiple types of porosity at different scales.

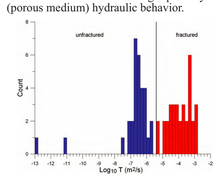


HYDROLOGY

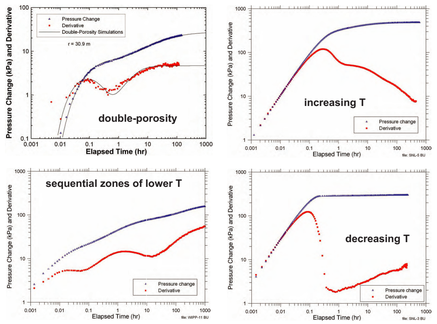
Hydrologic studies have focused on characterizing heterogeneity in the Culebra at all scales. Ninety wells have been completed to the Culebra to support extensive hydraulic and tracer testing programs. Additional specialized studies have been performed to understand flow through the Culebra.



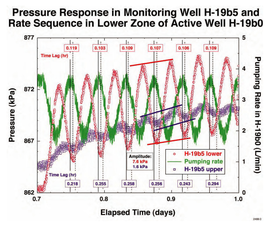
Hydraulic testing has shown that log10 T (m^2/s) values > -5.4 are associated with fractures and double-porosity hydraulic behavior. Lower T values are associated with single-porosity (porous medium) hydraulic behavior.



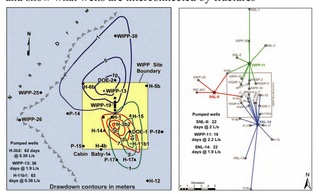
Log-log diagnostic plots show evidence of double-porosity and pronounced heterogeneity

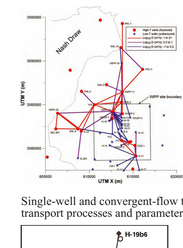


Sinusoidal pumping tests of the upper and lower Culebra were performed to characterize heterogeneity along tracer-test pathways.



Large-scale pumping tests provide information on heterogeneity and show what wells are interconnected by fractures

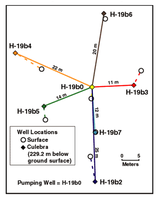


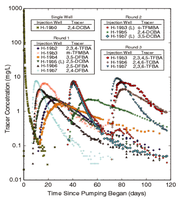


Diffusivity (D) values can be calculated from observation-well responses to pumping:

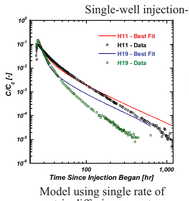
- Log_{10} D values < 0.2 reflect unfractured conditions
- Log_{10} D values ≥ 0.2 reflect fracture connections

Single-well and convergent-flow tracer testing provides insight into transport processes and parameters

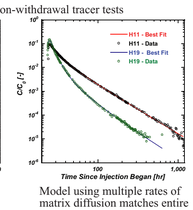




Single-well injection-withdrawal tracer tests

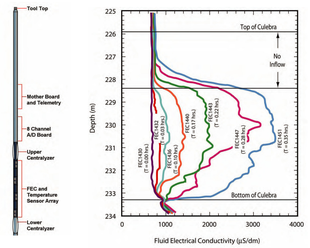


Model using single rate of matrix diffusion cannot capture tailing behavior

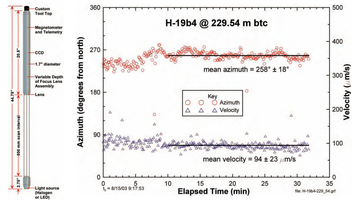


Model using multiple rates of matrix diffusion matches entire tracer-recovery curves

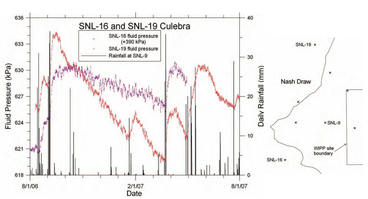
Fluid electrical conductivity logging showed that little flow occurs in the upper Culebra--later confirmed by tracer testing.



The colloidal borescope was used to locate flowing fractures and quantify the direction and rate of flow.

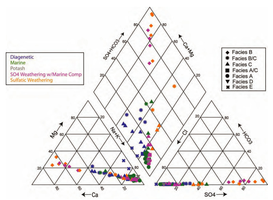


Continuous fluid-pressure monitoring in wells in Nash Draw, combined with rainfall monitoring, has shown some wells respond to rainfall where evaporite karst is present above Culebra. This provides a source of relatively fresh water to the Culebra important in interpretation of the hydrogeochemistry.

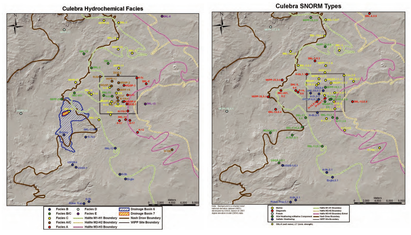


HYDROGEOCHEMISTRY

Groundwater samples have been collected from 59 Culebra locations. On the basis of major ion concentrations, five groundwater facies have been identified, with two additional transitional facies. The SNORM code (Bodine and Jones, 1986) has also been used to define the salt norm types of the Culebra waters.



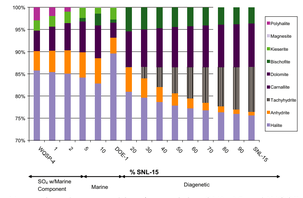
Piper diagram showing groundwater facies and SNORM types.



Facies	Characteristics
B	Dilute (ionic strength <0.1 molal) $CaSO_4$-rich groundwater, Mg/Ca ratio: 0.32 to 0.52
B/C	Ionic strength 0.18 to 0.29 molal Mg/Ca molar ratio 0.4 to 0.6
C	Variable composition waters, Ionic strength 0.3 to 1.0 molal Mg/Ca molar ratio 0.4 to 1.1
A/C	Ionic strength 1.1 to 1.6 molal Mg/Ca molar ratio 0.5 to 1.2
A	Ionic strength >1.66 molal, up to 5.3 molal Mg/Ca molar ratio 1.2 to 2.4
D	Ionic strength 3 molal, K/Na weight ratios of ~0.2
E	Ionic strength 6.4 – 8.6 molal, Mg/Ca molar ratio 4.1 – 6.6

Increasing Salinity

Salt Norm Type	Characteristics
Sulfatic-weathering solution	Waters with solutes originating primarily from weathering of sulfates
Sulfatic-weathering solution w/ marine component	Waters with a combination of sulfate-weathering and marine-derived solutes
Marine	Waters with marine-derived solutes
Diagenetic	Diagenetic (dolomitization) signature
Potash-contaminated	Waters contaminated with potash processing effluent



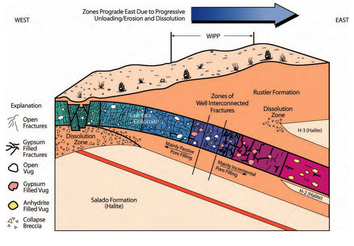
Mixing calculations show the feasibility of obtaining observed water chemistries by mixing of a few end members

Normative phases resulting from mixing SNL-15 and WQSP-4 waters. DOE-1 salt norm is also shown.

INTEGRATION

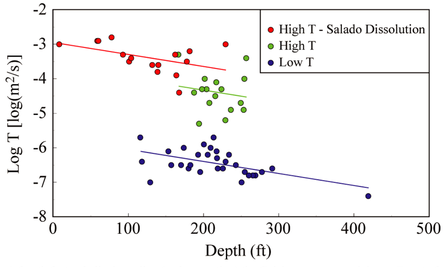
Culebra transmissivity was found to be related to three geologic factors:

- Salado dissolution
- Overburden thickness
- Gypsum cements



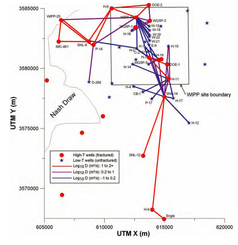
A linear correlation was developed relating T to these factors:

Log T = -5.7 - (3.5E-3 × depth) + (2.1 × gypsum indicator) + (0.7 × dissolution indicator)

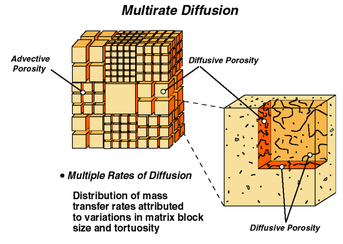


A fourth factor, halite bounding (and cementing) the Culebra, causes much lower T east of the Rustler mudstone-halite margins.

The presence or absence of fracture interconnections can be inferred from the responses observed during large-scale pumping tests. Log D (m^2/s) values > 0.2 generally reflect fracture interconnections. The continuous zone of low log D values extending from NE to SW across the WIPP site is consistent with the presence of gypsum pore fillings in that region, as well as with the local T values obtained from single-well hydraulic tests. A high log D zone is seen extending from the SE WIPP site to the south, consistent with model predictions.



Both hydraulic and tracer testing show that the Culebra behaves as a single-porosity (porous medium) system where T is low, and as a double-porosity (fractures + matrix) system where T is high. Solutes are transported rapidly through fractures, but are significantly retarded by matrix diffusion. The variability in scale and type of Culebra porosity leads to multiple rates of diffusion.



Most flow and transport occur in the lower Culebra.

Culebra facies B water (low ionic strength, sulfate-rich) coincides with the region where the Culebra is relatively shallow, is overlain by gypsum karst, and where wells respond to rainfall.

Culebra facies E water (saturated brine) coincides with the region where the Culebra contains halite cements and is bounded above and below by beds containing halite.

Mixing calculations show that all of the observed SNORM water types may be derived from three starting compositions:

primitive diagenetic -- sulfate weathering -- dilute diagenetic

Central WIPP area is characterized by low T, variable groundwater facies and SNORM types, and poikilotopic gypsum cements. Mixing of facies E brines with lower ionic strength (but still gypsum-saturated) waters (e.g., facies B or C) would have led to precipitation of gypsum, causing low T, and the variable water chemistry observed.

REFERENCES

Bodine, M.W., Jr., and B.F. Jones. 1986. *The Salt Norm: A Quantitative Chemical-Mineralogical Characterization of Natural Waters.* Water Resources Investigations Report 86-4086. Reston, VA: U.S. Geological Survey.

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