Significant Developments in the Understanding of Culebra Hydrology at the WIPP Site

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INTRODUCTION

Understanding of the groundwater hydrology of the Culebra Dolomite Member of the Rustler Formation at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico, has significantly improved over the last decade due to the collection of additional field data, development of a more comprehensive conceptual model, and advances in numerical groundwater flow modeling. The Culebra is a 7-meter-thick fractured dolomite found in the Permian Delaware Basin in southeastern New Mexico and west Texas. Although the WIPP repository, located in bedded halite of the Salado Formation, is stratigraphically more than 200 m below the Culebra, the Culebra is considered the most likely groundwater pathway for radionuclides released from WIPP due to inadvertent human intrusion. Since 1998, when the Environmental Protection Agency (EPA) accepted the initial Compliance Certification Application [1], a great deal of geologic and hydrologic investigation on the Culebra has been done to refine and enhance our understanding.

SIGNIFICANT DEVELOPMENTS

Geologic Information

The Culebra geologic model has extensive stratigraphic information obtained from boreholes cored through the Culebra and hundreds of geophysical logs from oil wells drilled through the Culebra in search of deeper petroleum reservoirs. From this stratigraphy information, studies have been made about changes in the Permian depositional environment across the model domain [2,3]. In addition, Culebra transmissivity (T) has been shown to be related to overburden thickness, evaporite dissolution, and the distribution of secondary gypsum pore cements [4].

Hydrologic Information

Numerous slug and pumping tests have been conducted in the 90 monitoring wells completed in the Culebra over the past 30 years to estimate the local hydraulic properties. These tests indicate that Culebra T ranges over 10 orders of magnitude ($10^{-2.8}$ to $10^{-12.9}$ m^2/s) [4,5]. Additionally, seven long-term (19 to 121 days) pumping tests with observation wells up to 9.5 km away have been performed in the Culebra, revealing the formation to be highly heterogeneous, with T controlled by fracturing and other geologic factors. Tracer tests have also been conducted to verify that multi-rate diffusion from fractures into the Culebra porous matrix is a significant physical retardation mechanism occurring at the site [6,7].

The numerous single and multi-well tests performed at the site are interpreted using advanced modeling techniques including both pressure and characteristic (log derivative) curve matching, n-dimensional flow modeling (where n is not confined to the integer values 1, 2, and 3), 2D tomographic MODFLOW model calibration, Monte Carlo simulations are also used to understand uncertainties.

Model Integration

The geologic and hydrogeologic information mentioned above are integrated into the Culebra groundwater flow model. The numerical flow model domain is a 22.3 km × 30.6 km area approximately centered on the WIPP site (Fig. 1). The model is calibrated using observed steady-state and transient data for 100 realizations of Culebra T. These results are then used in performance assessment to estimate travel time from a point above the center of the WIPP disposal panels to the site boundary to support continued regulatory compliance.

ONGOING WORK

Recent Culebra investigations have also raised new questions about some aspects of the hydrologic system. Detailed monitoring of rainfall and pressure-head in Culebra wells has shown a correlation between major rainfall events and Culebra head fluctuations [8]. While the Culebra is at a depth of 120 m or more over the entire WIPP site and is sandwiched between

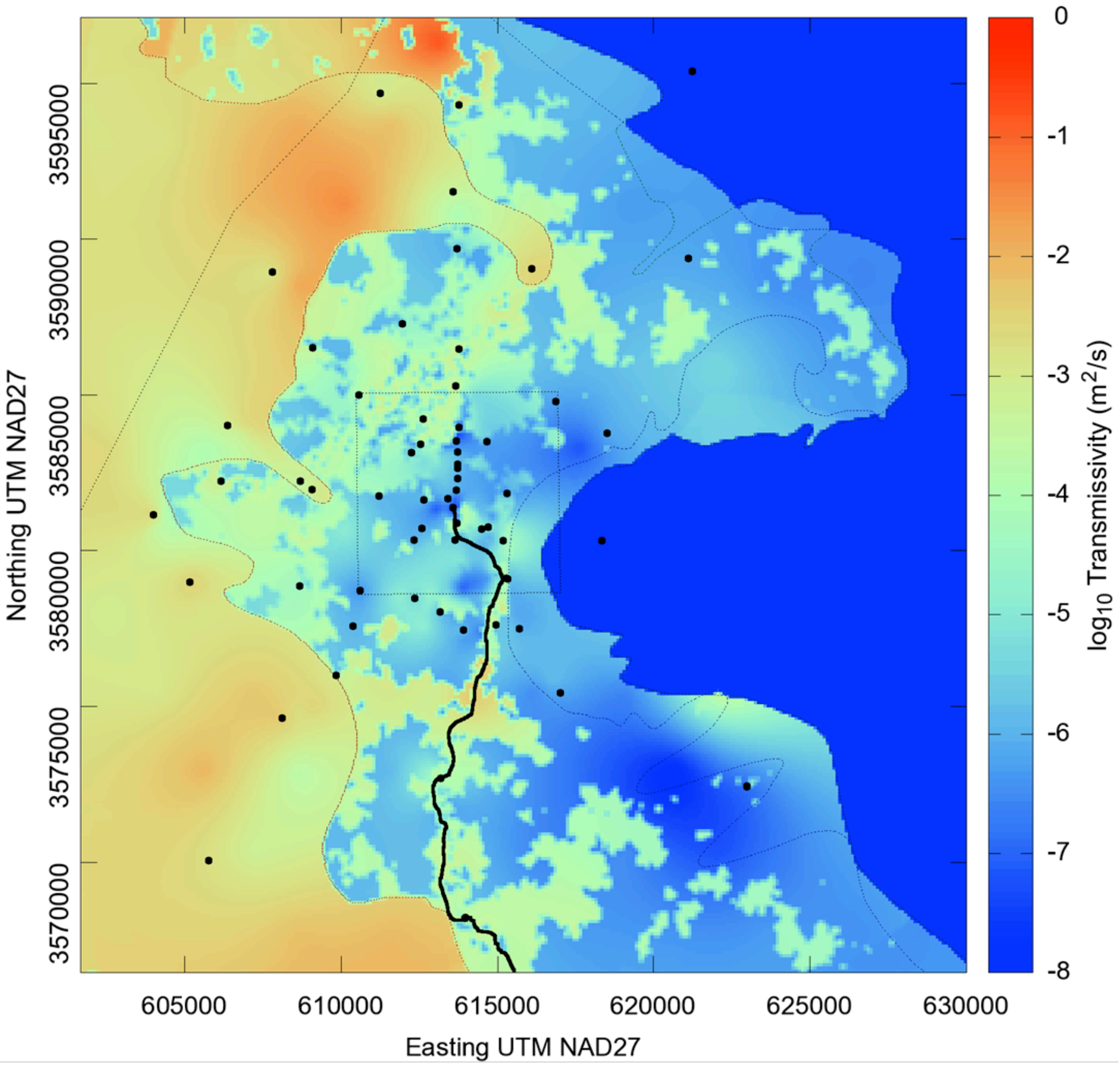

Fig. 1. Example Culebra T field used in flow and particle tracking model, with illustrative particle track from the center of the WIPP to the edge of the domain. Black dots are observation well locations.

surface and overlain by gypsum karst west of the WIPP site in Nash Draw, a subsidence trough created by dissolution of the upper Salado. Culebra wells in Nash Draw respond rapidly to major storms, and geochemical evidence suggests the Culebra is receiving recharge through the overlying gypsum karst. Some of the head responses observed, however, may represent a geomechanical response to localized loading of the overlying karst rather than recharge to the Culebra. Disentangling the geomechanical response of the Culebra from recharge effects, and identifying specific recharge locations, are new areas of active research.

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