Sandia National Laboratories
Technical Baseline Report

WBS 1.3.5.3:
Compliance Monitoring;
WBS 1.3.5.4:
Repository Investigations

Milestone RI 03-210

January 31, 2003

Prepared for the United States Department of Energy
Carlsbad Field Office

Sandia
National
Laboratories

WIPP:1.3.5.3.1.1:1.3.5.4.1.1:1.3.5.4.3.1:1.3.5.4.1.1:QA-L:DPRPI:Package#523933

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January 29, 2003

Sandia National Laboratories
Carlsbad Programs Group – Project Milestone
Milestone: RI 03-210
Date: 1-30-03

Dr. Inés Triay, Manager
U.S. Department of Energy
Carlsbad Field Office
P.O. Box 3090
Carlsbad, NM 88221

Attn: Cynthia Zvonar, Manager, Office of Regulatory Compliance

Subject: Transmittal of Sandia Level Three Milestone No. RI 03-210 entitled, Technical Baseline Report

Dear Dr. Triay:

Please find enclosed the Sandia National Laboratories Level Three Milestone RI 03-210, Technical Baseline Reports. This document includes up-to-date status reports for Sandia programs including:

Compliance Monitoring
Geochemistry
Engineered Barriers
Rock Mechanics

This report is structured to match FY2003 BOEs.

An executive summary compiles abstracts for each chapter in the main text. Although this document is not intended as a QA record, Sandia has subjected each contribution to a technical and QA review. As noted, these tasks are likely to result in publications or cited reference documents. When technical papers are prepared for the open literature, they will receive complete review as required by NP 6-1, Document Review Process.

UNIQUE #	DOE UFC	DATE REC'VD	ADDRESSEES
0300606	1000.00	FEB 0 3 2003	I. Triay C. Zvonar S. Casey D. Mercer E. Nuckols R. Patterson

Exceptional Service in the National Interest

Please note the completion of this milestone in your records.

If you have any questions or comments regarding this information, please contact me.

Sincerely,

Paul E. Shoemaker

Paul E. Shoemaker

Enclosure

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Sandia National Laboratories
Technical Baseline Report

WBS 1.3.5.3:
Compliance Monitoring;
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WIPP:1.3.5.3.1.1:1.3.5.4.1.1:1.3.5.4.3.1:1.3.5.4.1.1:QA-L:DPRPI:Package#523933

Sandia National Laboratories Technical Baseline Report

WBS 1.3.5.3: Compliance Monitoring; WBS 1.3.5.4: Repository Investigations

Milestone RI 03-210

January 31, 2003

The contents of this report follow the WBS structure for Sandia National Laboratories' FY 2003 program. Subject matter includes compliance monitoring and repository investigations, and follows the WBS numerically. The intent of this organization is to facilitate direct comparison between the BOEs and progress, thereby providing the U.S. Department of Energy's Carlsbad Field Office with current technical status and program tracking information.

TABLE OF CONTENTS

CONTENTS

1 EXECUTIVE SUMMARY,
L. H. Brush, T. W. Pfeifle, and F. D. Hansen

2 COMPLIANCE MONITORING

3 GEOCHEMISTRY

CONTENTS (cont.)

4 ENGINEERED BARRIERS

5 ROCK MECHANICS

1 EXECUTIVE SUMMARY

1 EXECUTIVE SUMMARY

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1.1 Introduction

This report by Sandia National Laboratories' (SNL's) Carlsbad Programs Group fulfills the requirements of Milestone RI 03-190. It is the fifth in a series (SNL, 2001a, 2001b, 2002a, and 2002b) describing repository investigations carried out for the U.S. Department of Energy's (DOE's) Waste Isolation Pilot Plant (WIPP) Project. This report describes SNL activities relevant to Compliance Monitoring (Section 2), Geochemistry (Section 3), Engineered Barriers (Section 4) and Rock Mechanics (Section 5) from July 2002 through December 2002.

1.2 Compliance Monitoring

Section 2, Compliance Monitoring, describes WIPP hydrological activities conducted by the SNL during the current reporting period. The emphasis on hydrology stems from recent groundwater-monitoring data that indicate regional head levels in the Culebra Member of the Rustler Formation are rising and, at some locations, exceed the uncertainty ranges established for assumed steady-state heads used in the WIPP Compliance Certification Application (CCA). As a result, the DOE's Carlsbad Field Office has directed SNL and Washington TRU Solutions, the WIPP Management and Operating Contractor (MOC), to develop a fully integrated hydrology program designed to investigate the cause(s) of the rising water levels and their effects on the long-term performance of the WIPP. Current efforts supporting this plan include: (1) testing and monitoring of wells recompleted to the Magenta Member of the Rustler, (2) comprehensive Culebra water-level-rise investigations, and (3) development and/or revision of analysis plans and test plans to control the efforts outlined for the hydrology program.

Subsection 2.1 describes continuous water-level measurements made in six existing monitoring wells (DOE-2, H-11b2, H-14, H-15, H-18, and WIPP-18) recently recompleted to the Magenta (see also Subsection 2.4), and a seventh well (C-2737), located directly above the WIPP waste panels and completed to the Culebra and the Magenta as a replacement for a plugged and abandoned well (H-1). Continuous water-level measurements are made using TROLLS, electronic pressure transducers that measure the pressure of the water column directly above the transducers. In addition, this section presents the results of slug tests performed in H-9c to characterize the transmissivity (T) and flow dimension of the Magenta at this location. Eventually, all recompleted Magenta wells and C-2737 will be tested to obtain data for the development of a Magenta hydrological flow model to assist in evaluating hypotheses proposed to explain the observed Culebra water-level rises (e.g., vertical flow from the Magenta to the Culebra through leaking boreholes).

Subsection 2.2 describes the status of various Culebra water-level-rise investigations for the WIPP Integrated Hydrology Program. In particular, this subsection discusses: (1) data from continuous monitoring of precipitation at two wellpads (H-7 and H-9), (2) data on Culebra and other relevant water levels using TROLLS, (3) data from periodic monitoring of fluid injection by the oil and gas industry near the H-9 wellpad, (4) development and documentation of state-of-the-art well-test analysis software (nSIGHTS), (5) preparation of a comprehensive draft program plan for the WIPP Integrated Hydrology Program (including all Culebra investigations), (6) development of viable explanations for the observed Culebra water-level rises, and (7) a preliminary analysis of the effects of rising Culebra water levels on the calibration of Culebra T fields used for the performance-assessment (PA) modeling for the CCA (see also Subsection 2.3).

Subsection 2.3 is a revised analysis plan for the evaluation of the effects of head changes on the calibration of Culebra T fields. The Culebra T fields used in the CCA PA were originally calibrated to heads assumed to represent steady-state conditions, as well as to transient heads arising from hydraulic testing and shaft activities. Monitoring since the CCA has shown heads at many WIPP wells to be outside of the uncertainty ranges for steady-state conditions, raising questions about the validity of the T-field calibration. The analysis plan, as originally written, addressed these issues by describing: (1) the generation of new base T fields using newly developed correlations between observed T at individual wells and known geologic metrics (such as thickness of overburden and presence of upper Salado Fm. dissolution), (2) conditioning these base T fields to assumed equilibrium heads at 10-year intervals (1980, 1990, and 2000) and to the heads used for the CCA, (3) the generation of a cumulative distribution function (CDF) for groundwater travel times from a point above the center of the waste-disposal panels to the WIPP site boundary for each time interval to determine the effect of head differences on the resulting T fields, (4) comparison of the four CDFs, (5) comparison with the CDF for the CDF for the CCA transient-calibrated T fields, (6) calibration of at least one of the sets of equilibrium-head-conditioned T fields to transient stresses affecting Culebra heads over the WIPP site, and (7) comparison of the travel-time CDF from these new transient-calibrated T fields with the travel-time CDF from the CCA transient-calibrated fields. This analysis plan was revised to include evaluation of the effects of future potash mining scenarios on Culebra flow and transport.

Subsection 2.4 is a revised test plan that describes well recompletion and testing activities to characterize the hydrological properties of the Magenta to support the development of a Magenta hydrological flow model. The original test plan, effective June 2000, identified 11 locations where Magenta well data are needed (i.e., fluid density, head, and T), and described a two-phase approach for recompleting existing Culebra monitoring wells to the Magenta at these locations. Six wells were to be recompleted during Phase 1, and the remaining five were to be recompleted only if the data from the first six wells were insufficient to develop a reliable Magenta model. In April 2001, SNL recompleted the first six wells (DOE-2, H-11b2, H-14, H-15, H-18, and WIPP-18). These wells are now ready to be tested. In November 2001, data from a twelfth location (H-9c) were considered important to the Magenta modeling effort. The WIPP MOC recompleted H-9c as a Magenta well in February 2002; water-quality sampling and slug testing were conducted recently by SNL. The test plan revision provided in this report incorporates changes necessary to accommodate the H-9c recompletion and testing efforts.

Subsection 2.5 is a new test plan that describes the acquisition of laboratory data for characterization of the mineralogy and diagenesis of the Dewey Lake Fm. Important variables to be measured from drillhole cores are the presence, relationships, and locations (i.e., depths in a particular drillhole) of natural mineral cements and matrix materials. Techniques to be used in the study include X-ray diffraction and petrography to determine the relative abundance of mineral phases and petrography, and scanning electron microscopy to establish diagenetic relationships among minerals. The studies will support the development of a conceptual geohydrological model of the Dewey Lake, and will provide information useful to the WIPP Integrated Hydrology Program. Scoping studies were recently completed to guide the development of this test plan. The study will begin soon at the SNL lab in Carlsbad.

Subsection 2.6 is another new test plan that discusses the equipment and field methods to be used in the testing of WIPP wells at the WIPP site. Data acquired from the tests will include hydraulic parameters (flow dimension, storativity, and T), transient head responses from observation wells during long-term pumping, direct measurement of the rates and directions of groundwater flow through wells, fluid specific gravity (or density), and water-quality parameters. The study directly supports the Culebra water-level-rise investigations identified in the WIPP Integrated Hydrology Program Plan.

1.3 Geochemistry

Section 3, Geochemistry, describes a re-evaluation of microbial gas-generation rates in the WIPP and three laboratory studies of near-field chemistry relevant to the actinide source term, the time-dependent concentration of actinides under conditions expected in the repository after filling and sealing.

Subsection 3.1 describes new microbial gas-generation rates for possible use in WIPP PA calculations after the CRA. This subsection contains a preliminary evaluation of the long-term lab study of microbial gas generation under humid and inundated conditions at Brookhaven National Laboratory (BNL), which strongly supports significant reductions in these rates relative to those used in the CCA in 1996 or the EPA's Performance Assessment Verification Test (PAVT) in 1997. A new lab study under humid conditions will be carried out at SNL in Carlsbad to simulate these conditions more realistically than the humid experiments at BNL, which were carried out with small but potentially significant quantities of water added during inoculation.

Subsection 3.2 is a new test plan for a laboratory study of the chemical behavior of bromine (Br) in the WIPP. This study will be conducted at SNL in Carlsbad. Hypochlorite (OCl^-) and other byproducts of α radiolysis of WIPP brines could oxidize dissolved bromide (Br^-) to species such as bromate (BrO_3^-), which could in turn oxidize Pu from the relatively insoluble +III and +IV oxidation states to the relatively soluble +V and +VI oxidation states and thus affect the dissolved actinide source term. This study will identify the important reactions that could produce and consume oxidized Br species under realistic repository conditions, and quantify the rates of these reactions. It will also quantify the mobility of Br_2, which could migrate as a gas in the repository. It will use nonradioactive materials such as OCl^- to simulate the possible effects of α radiolysis.

Subsection 3.3 is a revised test plan for ongoing lab studies of the possible formation of colloids from the MgO engineered barrier, and the behavior of humic acids in the WIPP. Both colloids and humic acids could affect the suspended actinide source term.

Subsection 3.4, a presentation at a recent conference, describes the approach used to obtain data for actinide complexes with organic ligands for use in Pitzer activity-coefficient models of the speciation and solubilities of the important actinides in TRU waste. Actinide complexation by organics was not included in the actinide-solubility models used for the CCA PA or the PAVT, but will be included in the actinide solubilities for the CRA PA.

1.4 Engineered Barriers

Section 4, Engineered Barriers, describes studies of MgO and cement, two materials that could also significantly affect near-field chemical conditions and the actinide source term. It also describes SNL support of a field test of Salado Mass Concrete (SMC), included in the current design of the WIPP Panel Closure System (PCS).

Subsection 4.1 is a revised test plan for an ongoing laboratory study of the efficacy of the MgO engineered barrier. MgO, the only WIPP engineered barrier certified by the EPA, is being emplaced in the WIPP to decrease actinide solubilities by consuming CO_2 from possible microbial activity. This study comprises: (1) characterization of Premier Chemicals MgO, the material currently being emplaced in the WIPP; (2) quantification of MgO hydration rates and identification of MgO hydration reactions; (3) quantification of MgO carbonation rates and identification of the metastable, solid, carbonation products that will control P_{CO_2} in the repository; and (4) determination of the effect(s) of possible lithification on MgO hydration and carbonation.

Subsection 4.2 and 4.3 describe recent results on MgO hydration and carbonation, respectively. These ongoing experiments have shown that MgO hydration is slow, and that the hydration rate decreases as the ionic strength of the solutions increases from low (experiments started with de-ionized water) to high (4 M NaCl), and as the composition of the solutions becomes more complex (ERDA-6, representative of Castile-Fm. brines, and GWB, typical of intergranular Salado brines). The hydration rate also increases with temperature. MgO carbonation is even slower than hydration, and also decreases as ionic strength increases and the solutions become more complex. Nevertheless, the carbonation rates observed in this study are significantly greater than microbial CO_2 production rates from lab studies for the WIPP.

Subsection 4.4 is a revised test plan for a lab study to develop a thermodynamic model for brine-cement interactions under expected WIPP conditions and a kinetic model for the degradation of cementitious borehole plugs. Currently, experiments are underway to quantify the effects of brine-cement interactions on brine chemistry and to identify the solid phases formed by these reactions. SNL is also reviewing the literature and assembling thermodynamic data for these solids, and for dissolved Al and Si species.

Subsection 4.5 discusses temperature measurements carried out by SNL to support a large-scale test of the placement and curing of SMC, the primary component of the WIPP PCS. SNL successfully designed, assembled, and deployed a data-acquisition system (DAS) comprising temperature sensors and a stand-alone measurement and control unit capable of interfacing and communicating with the sensors. This subsection discusses the DAS and presents the results obtained for the large-scale SMC test and two small-scale tests that preceded it.

1.5 Rock Mechanics

Rock mechanics contributions this reporting period include the work on the Clay Seam G structural analysis, the disturbed-rock-zone (DRZ) investigations, and a contribution to the panel closure re-design submittal. The Clay Seam G analyses have the greater immediate emphasis, as they are expected to be part of the technical baseline migration underlying the CRA PA calculations. Structural assessment includes the effects of raising the repository horizon by 2.43 m, as already approved by the EPA. The DRZ work compiles a large amount of observational information from the WIPP site and compares this information with other research in German salt-repository sciences. This research constitutes a significant contribution to an upcoming treatise on the WIPP DRZ. The technical work involved with panel closures was compiled along with the redesign effort and was included in submittals to the regulators.

The analysis plan describing Clay Seam G structural evaluations included in this progress report involves several steps, beginning with qualification of the finite-element code. The original compliance certification included a calculation of a porosity surface, which was calculated using a qualified code called SANTOS. This code was executed on a Cray J916 machine. For the current analyses the code is being run on a Linux P4 Intel workstation. The first step in the requisite analyses is to replicate the CCA calculation of the porosity surface. These calculations verify that identical results can be obtained today, despite use of a new computational platform. Concomitantly, the verification and validation test problems will be run to verify SANTOS functionality. Then, the porosity surface will be calculated at the new repository horizon. Preliminary results suggest that the porosity surface is unchanged. Further structural assessments will investigate anhydrite marker bed fracture and evolution of the DRZ. These phenomena will be considered and incorporated into the CRA PA.

References

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2.1 Magenta Hydrological Flow Model[1]

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Abstract

The Magenta Dolomite Member of the Rustler Formation is a saturated, laterally extensive, geohydrological unit located within a stratigraphic section of southeastern New Mexico that also contains the Waste Isolation Pilot Plant (WIPP). The WIPP, operated by the U.S. Department of Energy (DOE) near Carlsbad, NM, is a geologic repository for disposal of defense-related transuranic waste. (The waste also contains chemically hazardous constituents.) The disposal horizon is located at a depth of 2,150 ft and is sited in the massive salt beds of the Salado Formation that lies directly below the Rustler. At the location of the WIPP shafts, the Magenta is approximately 1,450 ft above the repository horizon or ~ 700 ft below ground surface. The Magenta could potentially provide a flow path for transport of radionuclides escaping the repository; however, a groundwater flow model of the Magenta has never been developed for use in transport modeling because previous studies have shown that the Culebra Member (located below the Magenta and also within the Rustler) is more transmissive than the Magenta and, thus, would be the preferred transport pathway should radionuclides reach the Rustler.

A flow model of the Culebra has been developed based on extensive geologic and hydrologic characterization of the WIPP site. One assumption in the Culebra flow model is that hydraulic heads in the Culebra are in static equilibrium and, therefore, are not expected to change with time unless some anthropogenic event occurs. Results of recent water-level measurements in wells completed to the Culebra have shown that these water levels are not static, but instead are rising. To explain these rising water levels, DOE has implemented an aggressive investigation of WIPP site hydrology, including reassessment of the Culebra flow model, development and testing of recharge-discharge scenarios, and additional field activities (well testing, geological-geophysical investigations, etc.). One plausible scenario explaining the rising water levels in the Culebra is vertical leakage from the Magenta to the Culebra through existing or abandoned boreholes. Testing of this scenario requires the development of an accurate Magenta flow model.

Sandia National Laboratories' Carlsbad Programs Group, the WIPP Scientific Advisor, has implemented a plan to recomplete and test up to 11 existing WIPP groundwater monitoring wells to acquire the data necessary to develop the required Magenta flow model. This report presents the status of these Magenta well-recompletion activities. The status report is subdivided into two general sections: (1) monitoring of Magenta wells; (2) Magenta Well H-9c slug testing and data analysis.

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[1] This work is covered by WBS #1.3.5.3.1.1 and 1.3.5.3.1.2

Background and Introduction

Previous hydrological and transport calculations for the Waste Isolation Pilot Plant (WIPP) Compliance Certification Application have shown that no radionuclides reach the Magenta during any plausible scenarios but instead enter only the Culebra Member of the Rustler Formation. Therefore, most early studies concentrated on hydrological characterization and groundwater monitoring of the Culebra. Recently however, some of the focus has returned to the Magenta Member of the Rustler, and activities are planned and currently under way to develop a groundwater flow model for the Magenta to evaluate scenarios explaining rising Culebra water levels and to understand better the hydrology in the region for evaluation of compliance monitoring hydrological data.

The development of the Magenta flow model requires a variety of spatial and temporal hydrological data for the Magenta, including depth and thickness, transmissivity, storativity, hydraulic head, and fluid density. Depth and thickness have been well characterized through the drilling of approximately 100 wells and exploratory holes under previous studies; however, the other properties are not well established. Therefore, a plan for collecting additional hydrological data has been developed and implemented (Beauheim, 2000). The plan calls for the following activities: (1) recompletion of up to 11 wells to the Magenta, (2) water quality and density measurements, (3) selective slug tests and/or drill-stem tests, (4) selective pumping tests, and (5) long-term water-level monitoring.

In addition to these activities, water-level data from wells already completed to the Magenta are being assembled to supplement the data expected from the recompleted wells. To date, the Magenta well-recompletion activity has been initiated and historical water-level data from nine existing Magenta wells have been assembled.

The status of the Magenta flow model development is presented below under separate headings including: (1) monitoring of Magenta wells, and (2) Magenta well H-9c slug testing and data analysis.

Monitoring of Recompleted Magenta Wells and Well C-2737

The development of a Magenta flow model requires, among other activities, the recompletion of wells to the Magenta so that water levels can be monitored and hydrological tests can be performed. Recompletion is being considered for 11 wells selected because they are in locations where Magenta data are sparse. In addition to plans for Magenta well recompletion, the Washington TRU Solutions, the WIPP Management and Operating Contractor (M&OC) drilled well C-2737 in 2001 to replace well H-1, which was plugged and abandoned by the M&OC when holes were discovered in its casing. Well C-2737 is a dual-completion well with screened intervals through the Magenta and the Culebra.

Recompletion of the 11 wells was scheduled to occur in two phases. In the first phase, the six wells considered most important for the model development (i.e., DOE-2, H-11b2, H-15, H-18, P-15, and WIPP-18) were to be recompleted and instrumented to collect pertinent data. These data would then be evaluated to determine whether the database was adequate for construction of a reliable Magenta model, or whether additional data were needed from some or all of the remaining five wells (i.e., DOE-1, ERDA-9, H-14, H-17, and WIPP-13). If additional data were required because of large differences (several orders of magnitude) in transmissivity across the site or large uncertainty in predicting transmissivity at untested locations, recompletion of the remaining five wells would occur during the second phase of the effort. The locations of all 11 wells are shown in Figure 1.

Early in 2001, six wells were recompleted to the Magenta during the first phase of this activity including DOE-2, H-11b2, H-14, H-15, H-18, and WIPP-18. Recompletion of P-15 rather than H-14 was scheduled for the first phase of the activity; however, while attempting to set the bridge plug in P-15, scale build-up in the casing was so extensive that the plug could not be positioned properly. The well casing was subsequently scraped to remove the scale, but the scraping revealed a hole in the casing near the ground surface. As a result, recompletion activities for P-15 were abandoned in favor of H-14.

Following the bailing of the recompleted wells under Phase I, water-level recovery in each of the six wells was characterized using both a sounder tape referenced to the top of casing and a submersible TROLL[2]. The water levels measured using the tape are plotted in Figure 2, which shows the recovery responses for all six wells. Sounder tape and TROLL data for individual wells are presented in Figures 3 through 8 and discussed below. TROLL data are referenced to the primary ordinate axis and sounder tape data to the secondary ordinate axis. The TROLL data are plotted as "head above TROLL" as recorded directly in the field rather than in elevations because no water-density information is currently available to correct the heads to freshwater elevations. When water densities are available, the water levels will be plotted as freshwater elevations. Offsets in the TROLL data represent occasions when a TROLL is removed from the well for calibration, well work, or troubleshooting and then either reset or replaced/reset in the well at a later time and, in some cases, at a different depth than was used for the previous placement.

WELL DOE-2

The water level in DOE-2 (Figure 3) has recently leveled off at about 3,069 ft. (All of the water levels in this subsection refer to elevation above mean sea level.) The Magenta wells nearest to DOE-2 are H-5c and H-6c (Figure 1). Based on December 2002 data, the steady-state water levels in these wells are 3,157 ft and 3,065 ft, respectively so the steady-state water level at DOE-2 is expected to lie between these two values. Although the water level in DOE-2 appears to have stabilized at about 3,069 ft, monitoring at this location will continue for several months to determine if the water level changes with time. Water density will also need to be determined.

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[2] A TROLL is an electronic transducer that is positioned below the water level in a well and measures the fluid pressure of the column of water standing above the transducer.

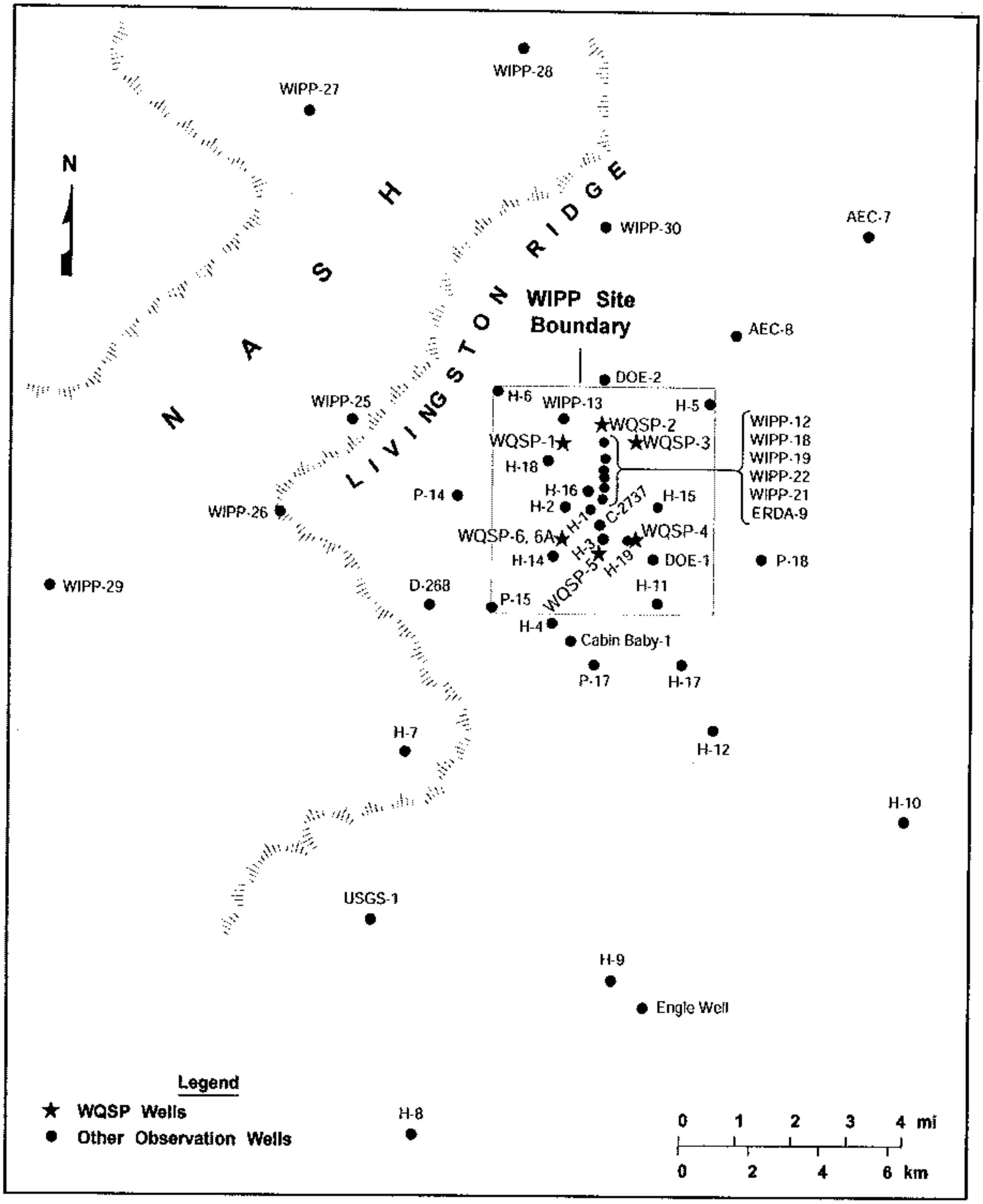


Figure 1. Locations of WIPP monitoring wells.

WELL WIPP-18

Following the bailing of WIPP-18, the water level in the well (Figure 4) recovered to a steady value of 3,140 ft. In July 2001, the water level began to drop at a steady rate of approximately 6 ft/month. The trend reversed in January 2002 and the water level in WIPP-18 is rising and is currently 3,140 ft. The drop in water levels was attributed to a leaky bridge plug placed between the Magenta and Culebra; however, the current trend is unexplained but could represent the arbitrary self-seating of the plug and subsequent recovery. Assuming the well condition is good and the current trend continues, the water level in the well will likely continue to rise consistent with other known hydrologic conditions in the area. However, because of the anomalous behavior of the water levels in this well, Sandia has recommended to the WIPP M&OC that WIPP-18 be added to the well logging and integrity testing priority list. During logging, the bridge plug will be removed and eventually reseated, and well-casing integrity will be examined.

WELL H-18

The Magenta water level in H-18 (Figure 5) reached a peak shortly after the well was bailed, then monotonically decreased to a constant value of 3,078 ft. The current Magenta water level in H-18 is about 18 ft higher than the water level in the Culebra at this location. Northwest of H-18 at H-6, the Magenta water level is 13 ft higher than the Culebra water level, but to the south and east of H-18, the Magenta water level is approximately 100 ft higher than the Culebra water level. Because of this strong change in gradient from southeast to northwest, the difference in water levels between the Magenta and Culebra at H-18 is not well known. Pressure-density data from H-18 would be helpful in assessing the water levels at this location.

WELL H-15

The Magenta water level in H-15 (Figure 6) has stabilized at approximately 3,113 ft. The current water level is consistent with the closest other wells completed to the Magenta (e.g., H-2, H-3, and H-5) and is approximately 100 ft higher than the water levels at adjacent Culebra wells, consistent with previous knowledge about the hydraulic gradient between the Magenta and Culebra. As such, Sandia plans to initiate its well-testing activities including water-quality serial sampling and slug or pumping tests.

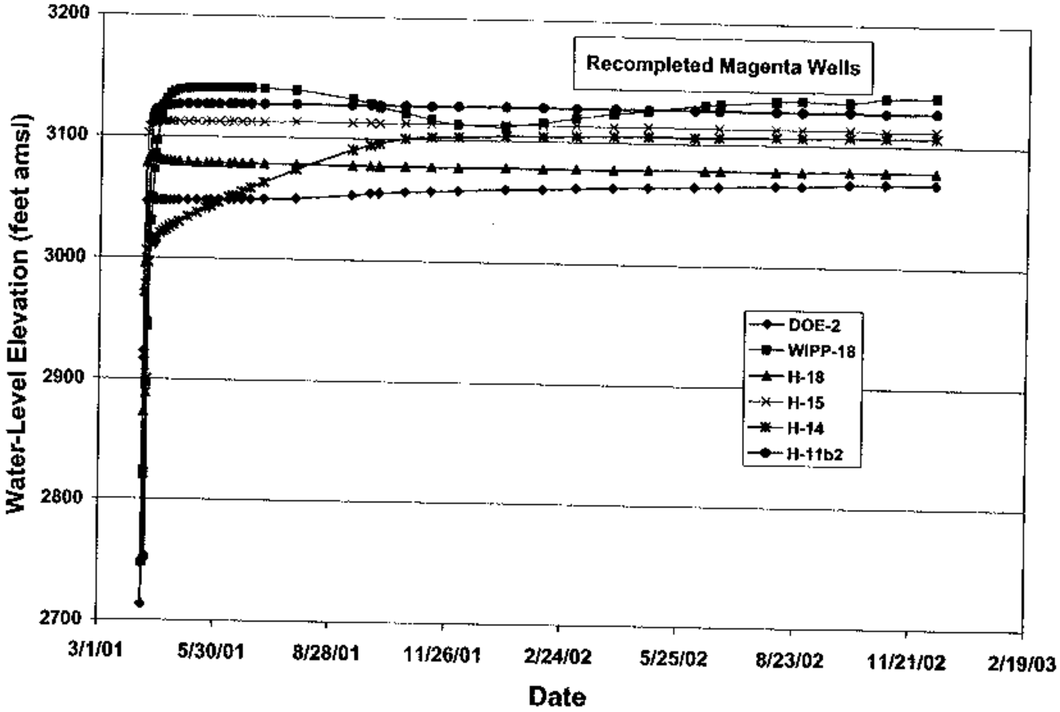


Figure 2. Water-level recovery for bailed wells re-completed to the Magenta based on sounder-tape measurements.

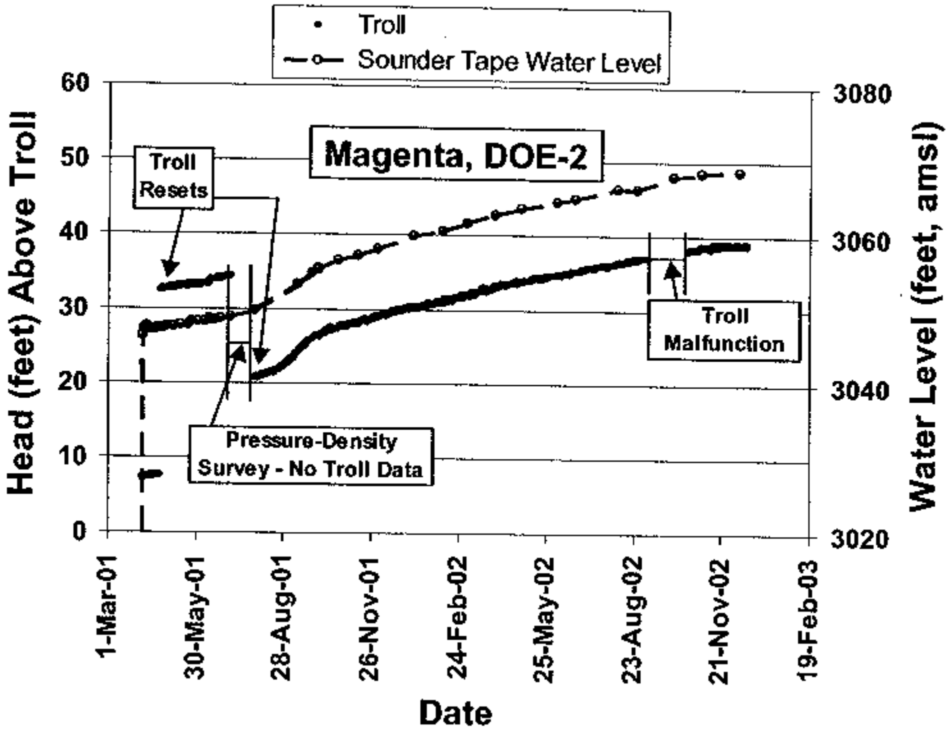


Figure 3. Magenta head levels measured at DOE-2.

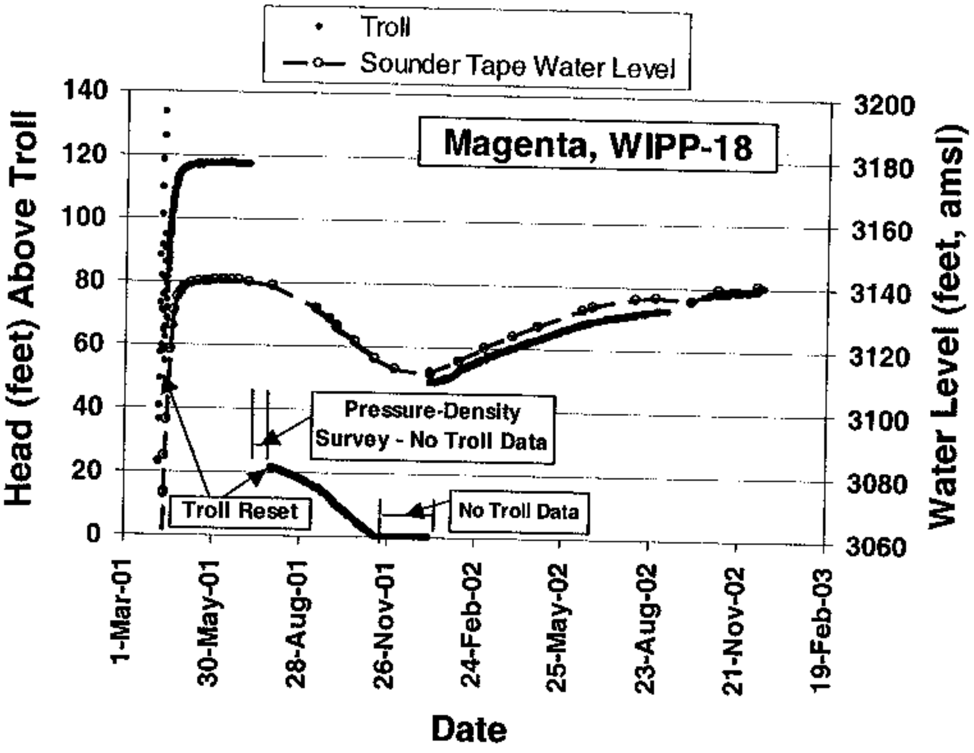


Figure 4. Magenta head levels measured at WIPP-18.

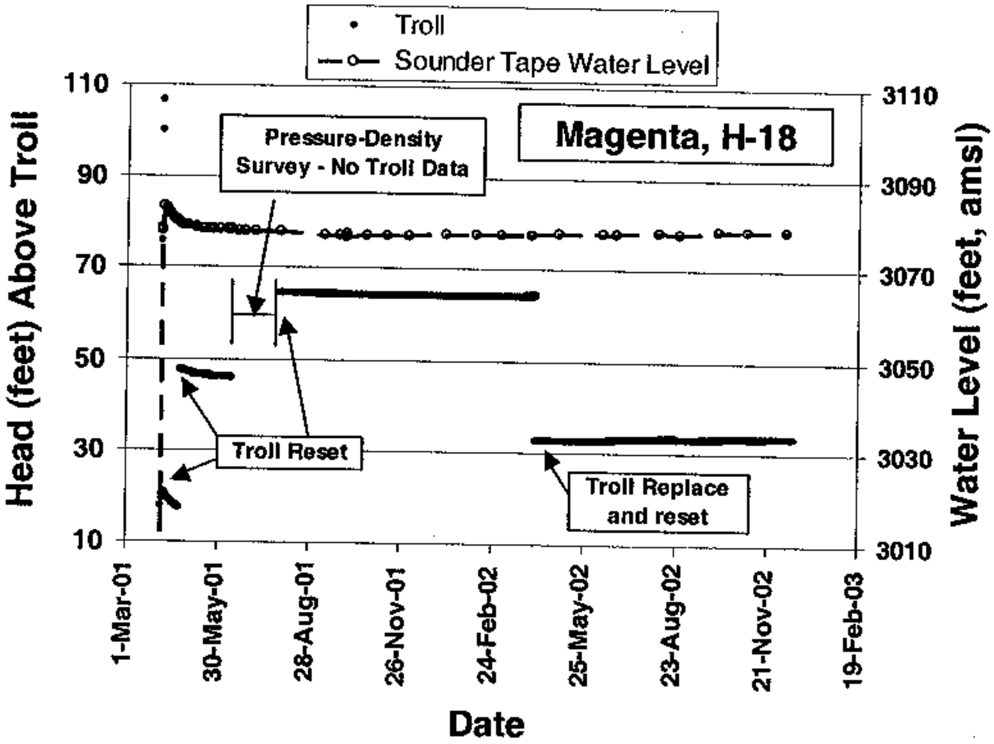


Figure 5. Magenta head levels measured at H-18.

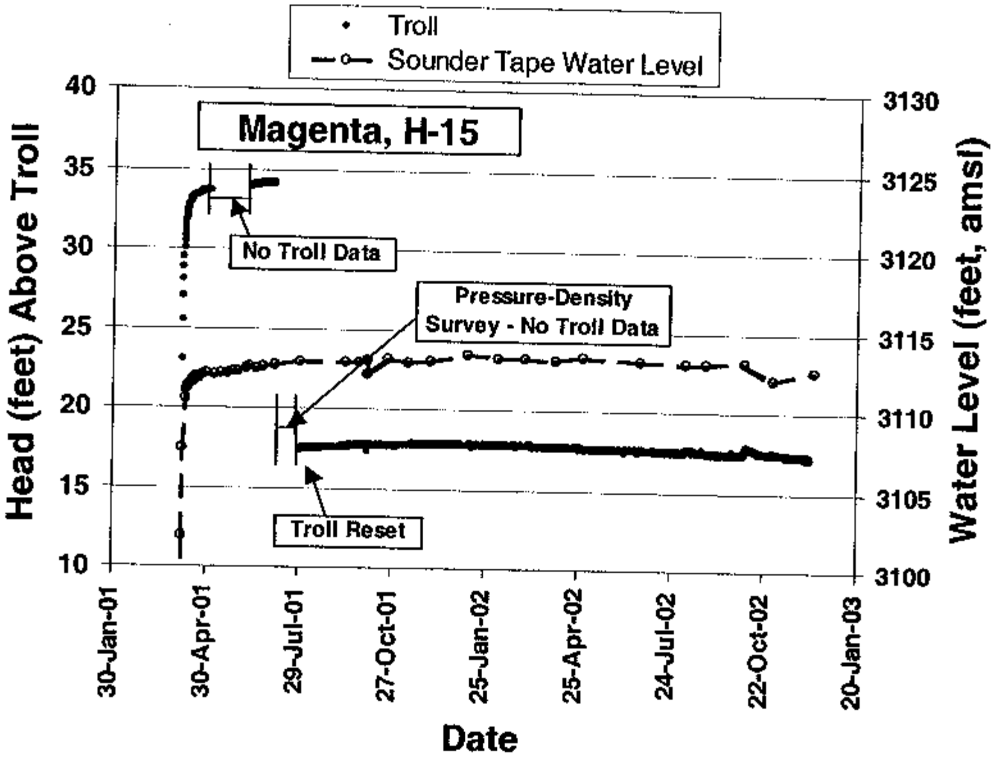


Figure 6. Magenta head levels measured at H-15.

WELL H-14

From April 2001 through October 2001, the Magenta water levels in H-14 rose steadily at a rate of approximately 15 ft/month (Figure 7). As shown in Figure 2, this rate is somewhat slower than the recovery rates in the other five recompleted Magenta wells, possibly because of lower transmissivity of the Magenta in this location. Since November 1, 2001, the water level rise has slowed considerably (1 ft /month) indicating well recovery is nearly complete. The current water level is 3,107 ft. The stabilized water level is expected to be between 3,100 and 3,120 ft, a range consistent with previous hydrological knowledge. Because data collected to date indicate the Magenta water levels in H-14 are representative of the site conditions, Sandia plans to initiate its well-testing activities including water-quality serial sampling and slug or pumping tests.

WELL H-11B2

The Magenta water level in H-11b2 (Figure 8) recovered quickly after the bailing activity and has essentially stabilized at 3,128 ft, a value consistent with previous hydrological knowledge at this location. Because data collected to date indicate the Magenta water levels in H-11b2 are representative of the site conditions, Sandia plans to initiate its well-testing activities including water-quality serial sampling and slug or pumping tests.

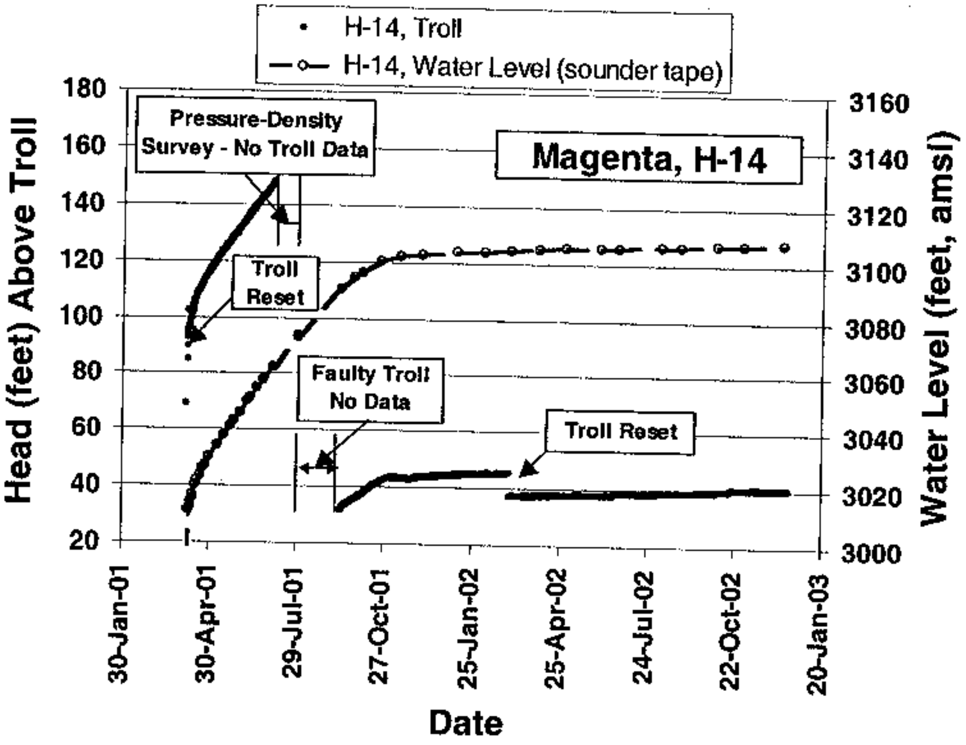


Figure 7. Magenta head levels measured at H-14.

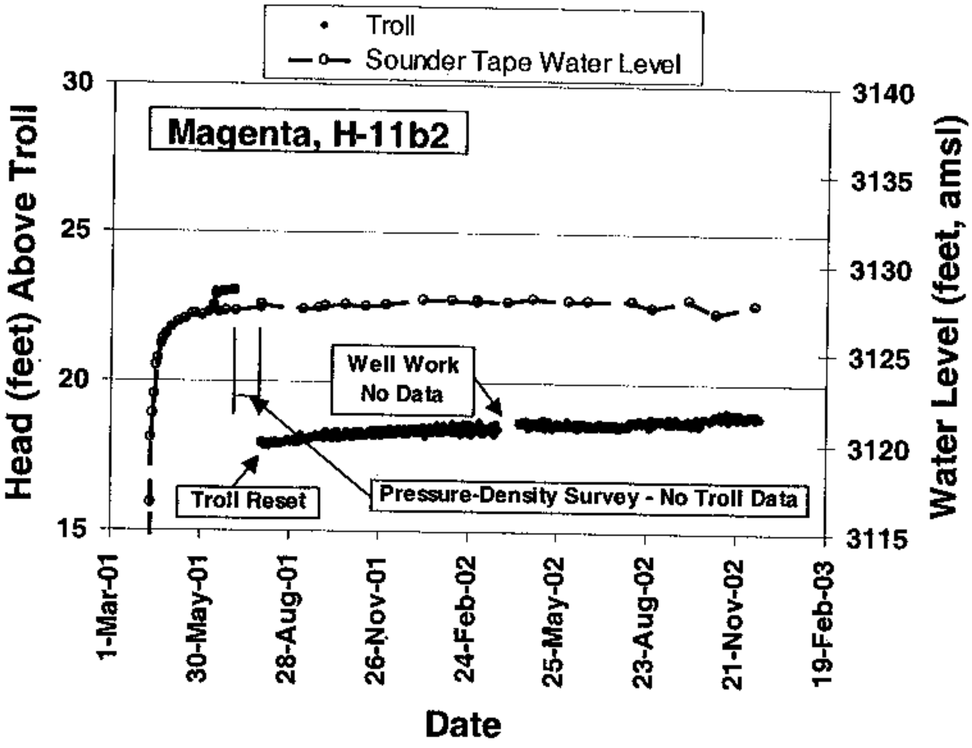


Figure 8. Magenta head levels measured at H-11b2.

WELL C-2737

As described previously (SNL, 2002), well C-2737 Magenta water-level measurements were initiated on May 29, 2002, as part of a remote monitoring system demonstration. Figure 9 presents the water-level measurements recorded by the TROLL installed in the Magenta. As shown, the Magenta water level at C-2737 has steadily decreased by about 1 ft since the remote monitoring system was installed. This decrease could be a result of re-equilibration of the water levels after the instrumentation was placed in the well or could represent some longer-term trend. On December 9, 2002, a sounding tape was used to establish the elevation of the C-2737 Magenta water level at 3,143 ft. Over the same monitoring period, the Magenta water levels in wells H-2b1 and H-3b1 have dropped by 0.4 ft and 1.1 ft, respectively, indicating that the Magenta water level in C-2737 may be responding to a regional trend.

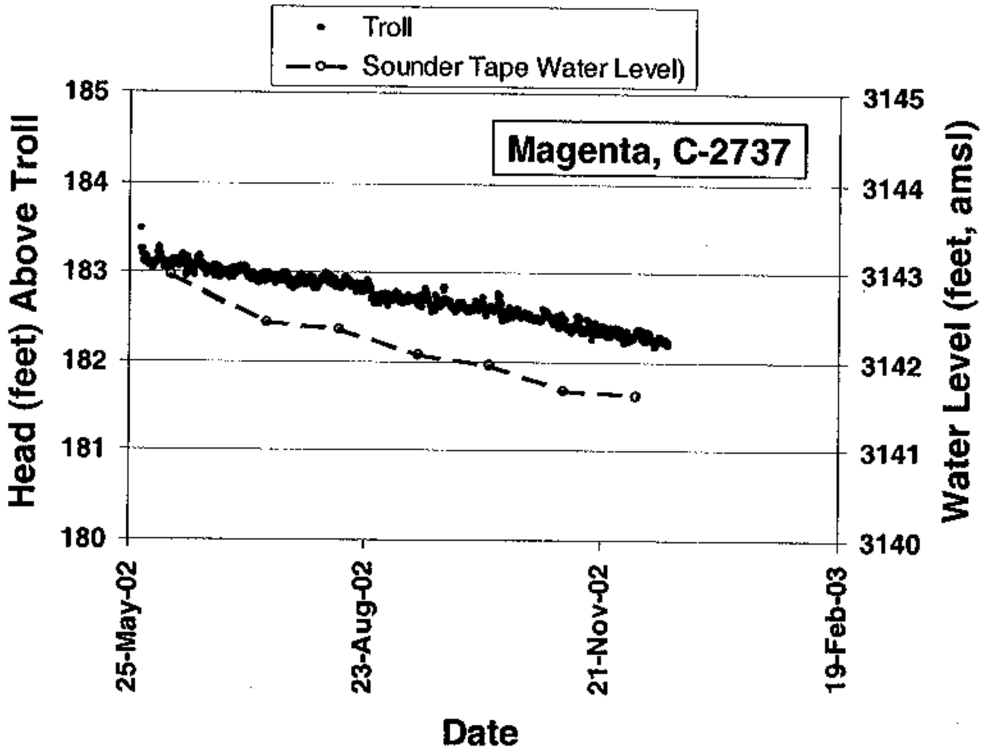


Figure 9. Magenta head levels measured at C-2737.

Hydraulic Testing and Analysis in Well H-9c

H-9C HYDRAULIC TESTING

Following the recompletion and water quality sampling performed in well H-9c, reported in Chace et al. (2002), hydraulic testing was performed in order to provide hydraulic parameter estimates associated with the Magenta at this location. The hydraulic parameters of interest include transmissivity (T) and flow dimension (n). Hydraulic testing at well H-9c began on October 15, 2002, with the installation of the Access Port Valve (APV) tool into well H-9c to isolate the Magenta. Figure 10 shows the location of well H-9c.

Hydraulic testing activities at well H-9c consisted of both slug-injection and slug-withdrawal tests. The pressure response measured during the water-quality-sampling activities described in Chace et al. (2002) indicated that it would be feasible to perform a 50-h pumping test at this location assuming that the well could sustain a flow rate of approximately 1 gpm. Limitations associated with currently available equipment were such that this 1-gpm flow rate could not be sustained for the desired 50-h test. Therefore, it was decided that slug tests would be performed. Table 1 provides information relevant to the H-9c hydraulic testing activities. The H-9c testing and analysis activities described here are governed by a test plan prepared by Beauheim (2000).

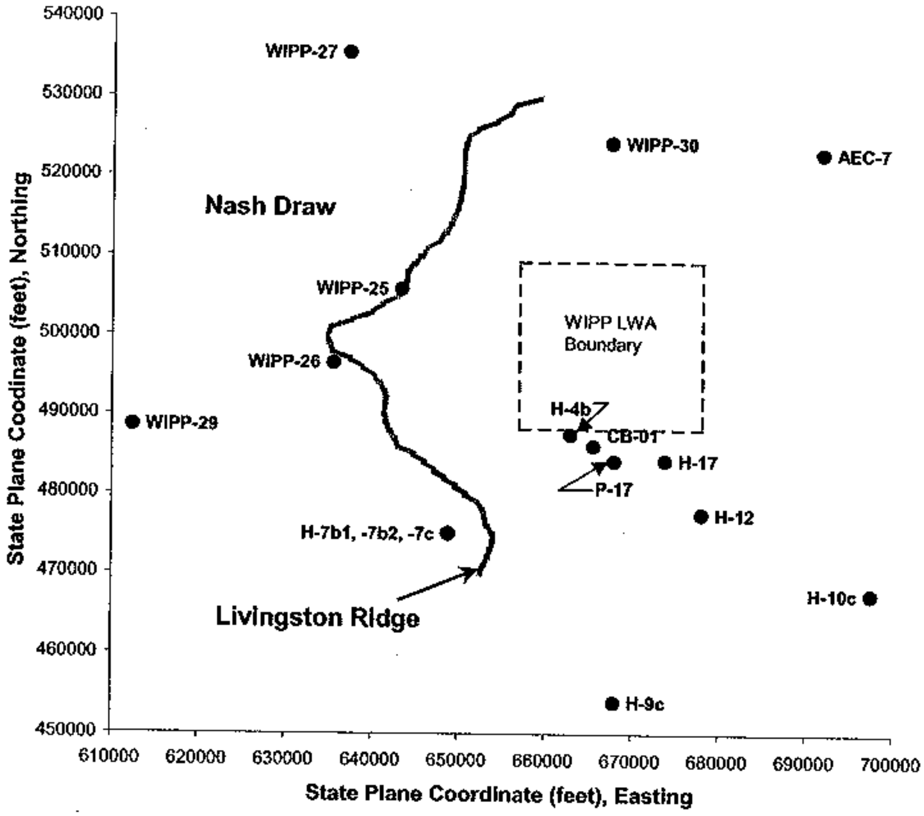


Figure 10. H-9c well location.

Table 1. H-9c Hydraulic Testing Activities

Operation	Date Completed	Time Completed (h:min)
Remove pump from well	October 15, 2002	09:45
Install APV tool	October 15, 2002	12:30
Inflate packer	October 15, 2002	12:40
Perform slug-withdrawal test	November 20, 2002	11:52
Perform slug-injection test #1	November 25, 2002	11:30
Perform slug-injection test #2	December 5, 2002	11:39

Figure 11 shows the APV tool in detail and Figure 12 shows the H-9c well configuration associated with the hydraulic testing activities. The pressure response associated with the sequence of hydraulic tests described above is shown in Figure 13.

H-9C HYDRAULIC TEST ANALYSIS

Equipment

The equipment used during the hydraulic testing activities, along with calibration information, is given in Table 2. This list represents the standard equipment that will be used to perform slug tests in wells C-2737 (Magenta), DOE-2, H-11b2, H-14, H-15, H-18, and WIPP-18.

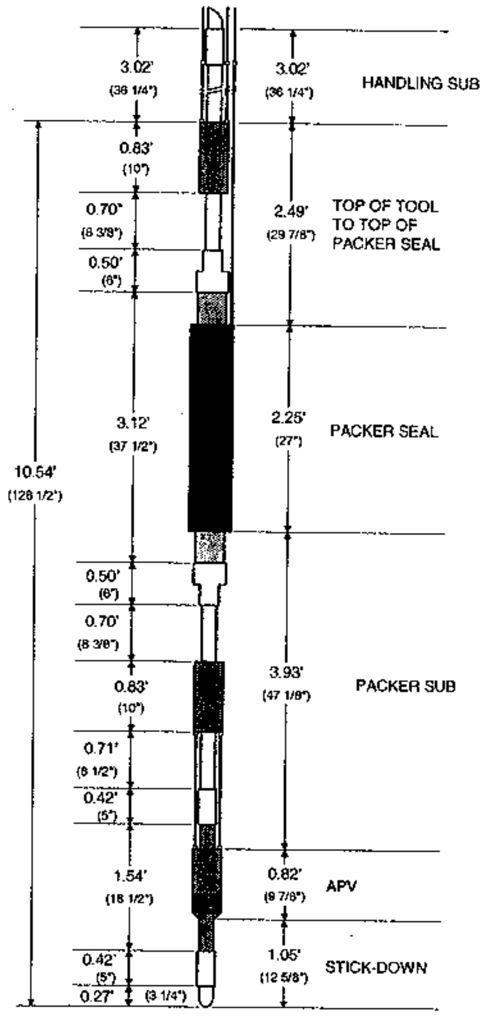
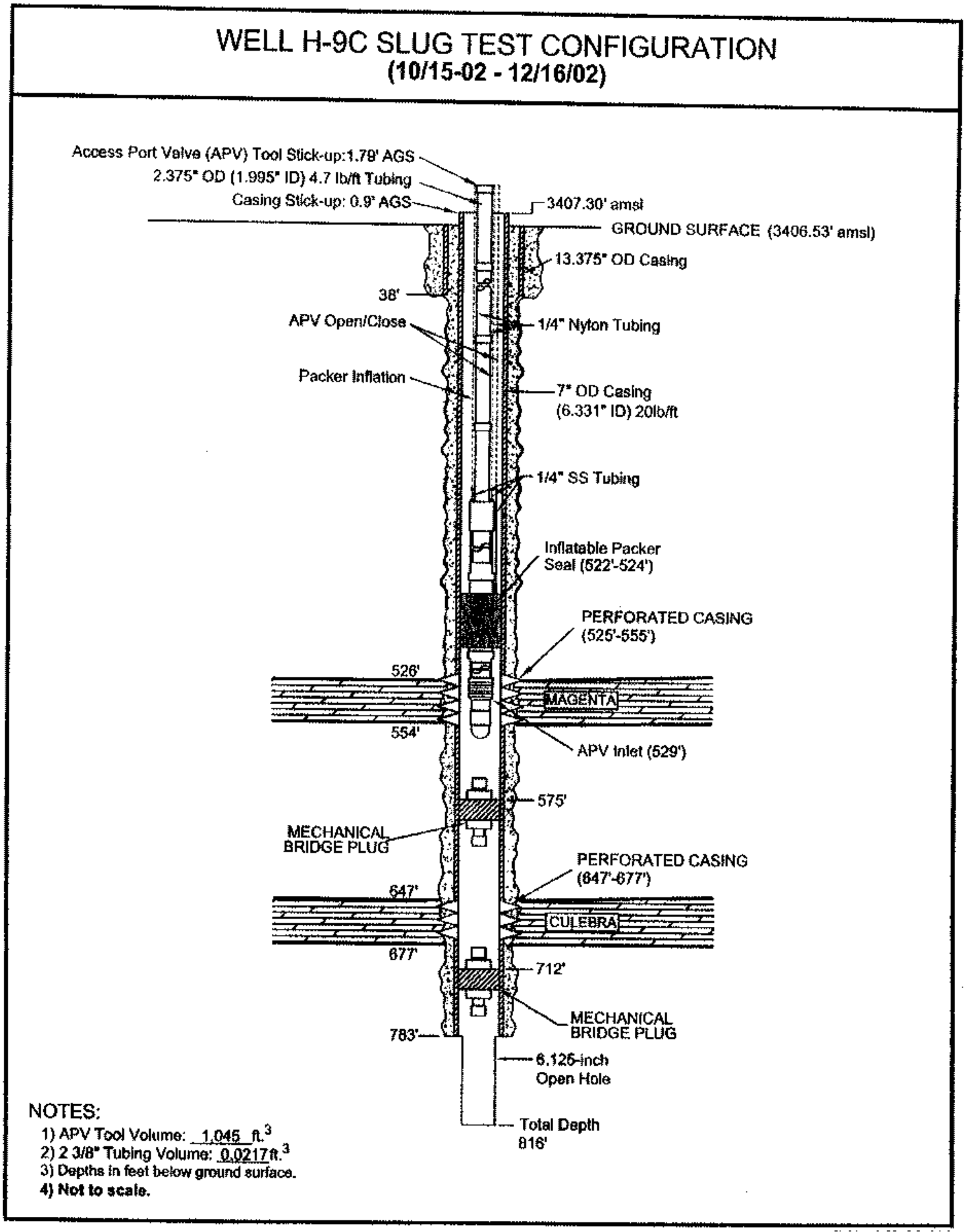


Figure 11. APV tool diagram.



NOTES:
1) APV Tool Volume: 1.045 $ft.^3$
2) 2 3/8" Tubing Volume: 0.0217 $ft.^3$
3) Depths in feet below ground surface.
4) Not to scale.

Figure 12. Current H-9c well configuration.

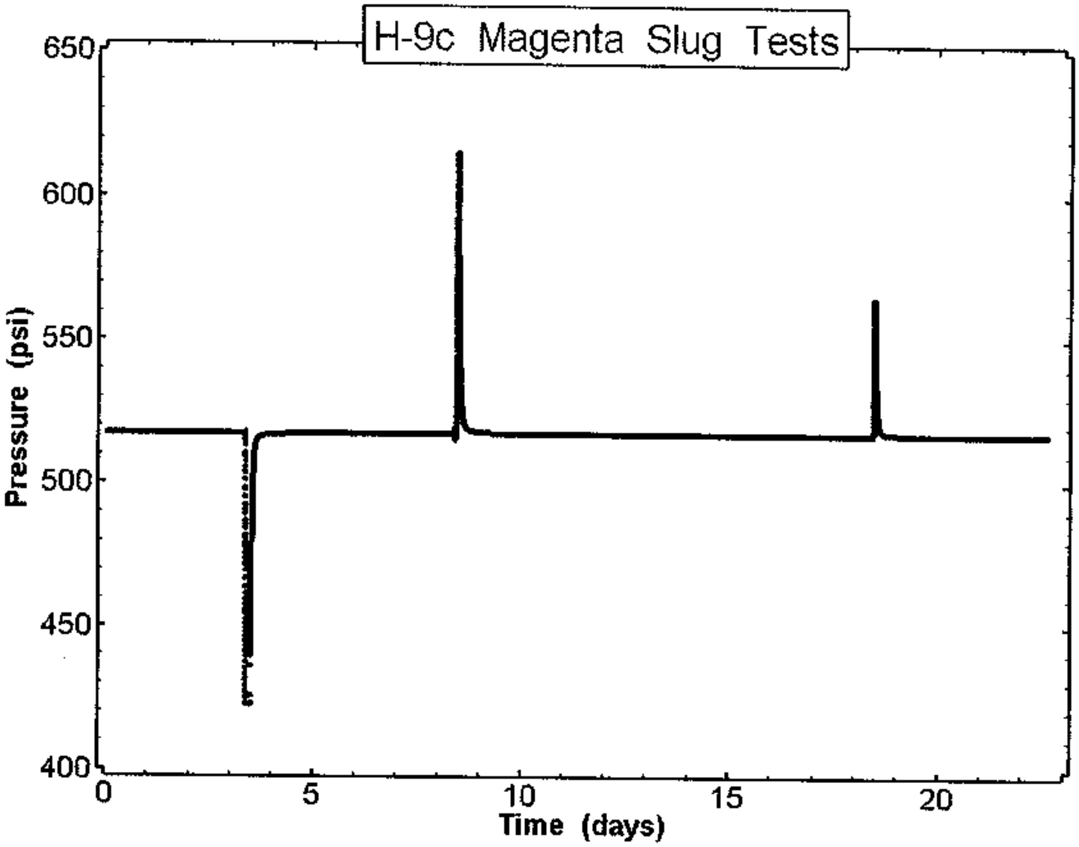


Figure 13. Well H-9c hydraulic testing sequence.

Table 2. Hydraulic Testing Equipment

Equipment	Serial No.	Purpose	Calibration Date (mm/dd/yy)	Calibration Due (mm/dd/yy)
Access Port Valve	20568	Instantaneous isolation of and access to the Magenta	N/A	N/A
In-Situ miniTROLL water monitoring probe	8276	Electronic pressure and temperature measurement in annulus	4/22/02	4/22/04
In-Situ miniTROLL water monitoring probe	4558	Electronic pressure and temperature measurement in Magenta	2/5/01	2/5/03

The Sandia well-test analysis code nSIGHTS was used to analyze three slug tests performed in borehole H-9c as described above (Figure 13). These slug tests were performed to estimate the transmissivity and the flow dimension of the Magenta at this location. A transmissivity estimate of 0.56 ft^2/day (6×10^{-7} m^2/s) and a flow dimension estimate of 2 were obtained by matching the three slug responses simultaneously. The flow dimension of 2 indicates that the flow system behaves radially at this location. The results of the simulation and analysis are shown in Figure 14. The slug-test responses in Figure 14 are shown as a log-log plot of the normalized pressure response and its derivative (d(normP)/dlog(t)), a standard presentation format in well-test analysis. Also shown is a linear plot of pressure versus time. The transmissivity estimate was constrained by matching each of the three slug responses up to an elapsed time of approximately 0.3 days. After approximately 0.3 days, the barometric effects became relatively large. Sensitivity analysis indicated that the estimate of transmissivity was well constrained (small uncertainty), so the additional effort of correcting the pressure data for barometric effects appeared to be unwarranted.

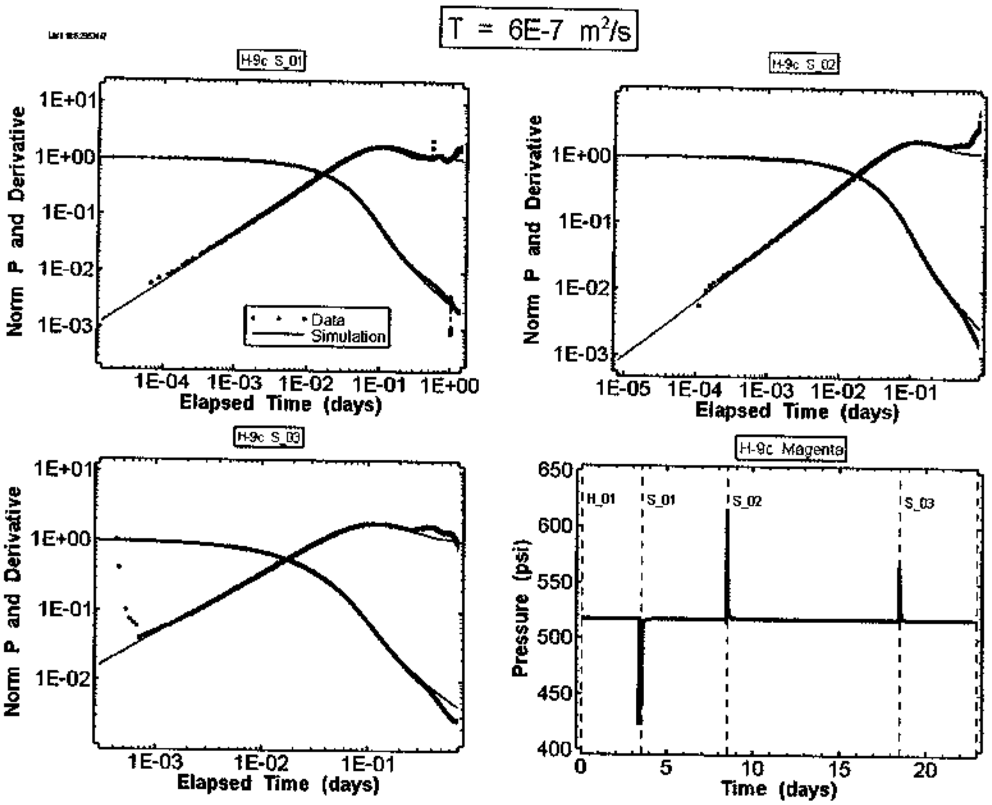


Figure 14. Well H-9c slug test simulation/analysis results.

References

Beauheim, R.L. 2000. "Compliance Monitoring Program: Recompletion and Testing of Wells for Evaluation of Monitoring Data from the Magenta Member of the Rustler Formation on the WIPP Site." Unpublished test plan, TP-00-03. Carlsbad, NM: Sandia National Laboratories.

Chace, D.A, T.W. Pfeifle, and T.L. MacDonald. 2002. "WIPP Hydrologic Data Assessment," "Sandia National Laboratories Technical Baseline Reports, WBS 1.3.5.3, Compliance Monitoring; WBS 1.3.5.4, Repository Investigations, Milestone RI130, July 31, 2002." Carlsbad, NM: Sandia National Laboratories. 2.3-1 to 2.3-23.

2.2 Culebra Water-Level Rise Investigations[1]

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Abstract

Water-level rises in the Culebra Member of the Rustler Formation have resulted in the implementation of an extensive program to identify the cause(s) of the rises and the effects such rises might have on assumptions and conceptual models used by the U.S Department of Energy (DOE) to obtain certification of the Waste Isolation Pilot Plant (WIPP) as the nation's first nuclear waste repository. As part of this program, supplemental groundwater-monitoring activities have been initiated to obtain continuous water-level measurements in selected wells, continuous meteorological (rainfall) data at selected locations, and injection well metrics (e.g., pressure, injection volumes, etc.) from industry (oil and gas) operators performing work near the WIPP site. Based on a review of historical WIPP hydrological data and related events that have or are occurring on and near the site, scenarios are being developed to explain the water-level rises and additional information is being gathered to test these hypotheses. In addition, the impact of current Culebra water-level rises on assumptions and conceptual models used by DOE is being analyzed and new transmissivity (T) fields are being developed using a geologically-based model. Other activities include the development of new well-test analysis software needed to quantify uncertainty in well-test analysis. The Culebra investigations make use of a phased approach so that work completed in one phase supports subsequent phases. The full Culebra water-level rise investigation is expected to require a multiyear effort.

Background and Introduction

The Waste Isolation Pilot Plant (WIPP) Compliance Certification Application (CCA) calculations of flow and transport in the Culebra used transmissivity (T) fields for the Culebra that were calibrated to hydraulic heads measured at 32 wells located within or near the WIPP site. Calibrations were conducted iteratively by adjusting the T values until the simulated hydraulic heads predicted from the calibration model matched, within defined ranges of uncertainty, both the steady-state and transient (arising from hydraulic testing and shaft constructions and leakage) heads observed at the wells. In its certification of the WIPP, the US Environmental Protection Agency (EPA) required the U.S Department of Energy (DOE) to monitor heads (groundwater levels) to provide assurance that assumptions used in the flow and transport modeling were valid. In response to this requirement, the DOE implemented a groundwater-monitoring program (GWMP) to measure water levels in approximately 70 WIPP wells. An additional subprogram of the DOE GWMP requires water-quality sampling and

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[1] This work is covered by WBS #1.3.5.3.1.1 and #1.3.5.3.1.2

analyses from seven wells included in the monitoring network in response to both EPA and New Mexico Environment Department requirements.

In recent years, water levels observed in many of the wells used in the T-field calibrations have exceeded (risen outside) the ranges of uncertainty established for the steady-state heads used in the CCA. Based on these observations, questions about the continued validity of the T-field calibrations and the flow and transport calculations based on those T fields have been raised by EPA and others. In addition, the assumption that the Culebra is at steady-state has also received scrutiny. In response to the questions raised by the rising Culebra water levels, DOE has directed Sandia National Laboratories, its Scientific Advisor, to investigate the cause for the water-level rises, re-assess the assumptions and models used in the CCA flow and transport calculations, recalculate T-fields, and, if required, revise the hydrologic conceptual model of the Culebra for use in future recertification performance assessment calculations utilizing newly acquired data.

As directed by DOE, Sandia has developed and implemented an extensive investigation into the cause for the rising Culebra water levels. The major elements of the investigation (Powers, 2001) are as follows:

- Document hydrograph features and contributing events.
- Develop scenarios and hypotheses potentially explaining the Culebra water level rises.
- Review field and drillhole evidence for relevant events and processes.
- Conduct sensitivity analyses.
- Perform scenario and hypothesis testing.

Documents controlling the Culebra investigations include Chace (2003a; 2003b), Powers (2001; 2003), and Jepsen (2000).

In addition to the elements described above, the controlling documents describe the need to characterize the Magenta Member of the Rustler Formation and the Dewey Lake Formation, collect water-level measurements and rainfall data more frequently than currently done by Washington TRU Solutions (WTS), the WIPP Management and Operating Contractor (M&OC), and investigate the influence of brine injection around the site. The information collected will be used directly in the development and testing of scenarios/hypotheses explaining the observed water-level rises. The Culebra investigations are expected to be completed within 3 to 5 years using a multi-phased approach.

The DOE has also directed Sandia to evaluate the effects of the observed water-level changes on the calibration of Culebra T fields and to recalculate T-fields using a geologically-based model. The scope and technical approach for this evaluation are described in Beauheim (2002). This evaluation is expected to be completed in early FY03.

This report presents a status review of ongoing Culebra investigation activities during the period July 1, 2002 through December 31, 2002. Activities specifically addressed include:

- Ongoing monitoring of WIPP-site hydrological conditions:
    - continuous water-level monitoring in selected wells,
    - meteorological monitoring at select well locations,
    - injection well monitoring near the H-9 well pad.
- Development of well-test data interpretation software nSIGHTS (**n**-dimensional **S**tatistical **I**nverse **G**raphical **H**ydraulic **T**est **S**imulator).
- Observed water level changes and potential causes.
- Development of a WIPP integrated hydrology program plan.
- Reassessment of Culebra T fields.

Each of these activities is discussed below under separate headings. Magenta hydrological activities are described in a separate section of this report (i.e., Section 2.1).

WIPP-Site Hydrological Monitoring

CONTINUOUS WATER-LEVEL MONITORING IN SELECTED WELLS

At present, the M&OC measures the water levels in the WIPP monitoring wells on a monthly basis using manually operated water-level sounder tapes. The locations of these monitoring wells are shown in Figure 1. Although this frequency is adequate for assessing the long-term regional changes in water levels, it does not necessarily give the resolution required to evaluate the effects of short-term transients (e.g., injection, precipitation, etc.) on water levels in specific wells. Therefore, submersible TROLLs[2] have been placed in some monitoring wells to record, on a more or less continuous basis, the water levels in the Bell Canyon Formation and the Culebra (TROLLs are also being used to measure Magenta water levels – see Section 2.1 of this report).

In 1999, TROLLs were placed in six wells including four wells completed to the Culebra, i.e., H-9a, P-17, WIPP-13, and WIPP-30, and two wells completed to the Bell Canyon, i.e., AEC-8 and Cabin Baby-1. In March 2001, the TROLL used to monitor the Culebra water levels in WIPP-13 was moved to monitor Culebra water levels in H-7b1, while in October 2001, the TROLL monitoring Culebra water levels in H-9a was removed in preparation for the plugging

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[2] A TROLL is an electronic transducer that is positioned below the water level in a well and measures the fluid pressure of the column of water standing above the transducer.

and abandonment of the well. As described by SNL (2002a), a remote water-level monitoring system was installed at C-2737 (a replacement well for H-1) in May 2002 to evaluate this new technology for possible future use at the WIPP site. The system comprises TROLLs for monitoring Culebra and Magenta water levels, a solar panel and gel-cell battery for power, and a cellular modem and associated interface hardware/software to provide real-time access to the down-hole equipment. Thus, TROLL measurements are currently being made in four Culebra wells and two Bell Canyon wells, in addition to the Magenta wells described in Section 2.1 of this report. The Culebra and Bell Canyon TROLL data are shown in Figures 2 through 7.

The TROLL measurements are expressed as head above the current position of the TROLL. Head for each well is calculated from the measured TROLL pressure and a constant water density of 1.0 g per cubic centimeter rather than the actual density of the water in each well. In future calculations, freshwater heads will be determined using well-specific water densities based on values determined from ongoing pressure-density (P-D) surveys being conducted by WTS. The gaps in time and the vertical offsets in heads shown in some of the TROLL data of Figures 2 through 7 indicate a TROLL was either removed (i.e., for calibration or some specific well activity) or re-positioned to ensure that a positive hydraulic pressure within the dynamic range of the instrument is maintained on the TROLL throughout the monitoring period, respectively.

In addition to the TROLL data described above, water level elevations (above mean sea level, amsl) determined by WTS from monthly surveys are also shown in Figures 2 through 7. The water levels shown for the Culebra wells have been adjusted to freshwater elevation heads by WTS using historical values for water density. In contrast, the water-level elevations shown for the Bell Canyon wells have not been corrected for water density because historical density data are not available for these wells.

Culebra Well P-17

The Culebra water levels measured in P-17 (Figure 2) show a 2-ft linear rise over the period May 1999 through December 2002. The TROLL measurements and the WTS manual measurements compared well during this monitoring period with two exceptions. During December 1999 to January 2000, the TROLL recorded a drop of 6 ft in the Culebra water level of P-17 in comparison to the constant water levels measured by WTS during this same time. The difference in measurements was attributed to a malfunction in the TROLL, which was subsequently replaced in March 2000. During October 2000 to January 2001, the WTS measurements showed a 2-ft perturbation, while the TROLL measurements indicated no such change. No explanation for this difference is currently available.

Culebra Well WIPP-30

The TROLL measurements of Culebra water levels in WIPP-30 (Figure 3) were generally constant from May 1999 through January 2000. In early 2000, the TROLL was repositioned several times accounting for the offsets in the data. The TROLL was removed completely in July 2000 to allow for well work by WTS. Therefore, no TROLL data were acquired during July and August 2000. When the TROLL was returned to the well in September 2000, water levels rose rapidly in response to recovery from the well work and continue to rise at a rate of about 0.25 ft/month. The TROLL measurements and the WTS manual measurements compare well throughout the monitoring period. The WTS manual measurements indicate the Culebra water level in WIPP-30 is currently about 4 ft higher than the water levels measured immediately before the well work was initiated.

Culebra Well H-7b1

The TROLL measurements of Culebra water levels in H-7b1 were initiated in March 2001 using the TROLL removed from WIPP-13. These TROLL measurements, together with manual water-level measurements made by WTS in H-7b1 and H-7b2, are shown in Figure 4. H-7b1 and H-7b2 are two of the four wells located at the H-7 well pad and are separated horizontally by approximately 100 ft. The four wells are configured in a diamond pattern with wells located at the corners. The other wells at the H-7 well pad are H-7a (plugged and abandoned) and H-7c (inactive). From late March through early April 2002, the TROLL in H-7b1 was removed while WTS logged the wells on the well pad. This logging activity likely affected the water levels in the wells, but little evidence of the activity is seen in Figure 4. During the past six months, the water levels at the H-7 well pad exhibited a slight downward trend initially but now seem to be stable or, perhaps, are rising slightly.

Culebra Well C-2737

As discussed briefly above, TROLL measurements of Culebra water levels in C-2737 are now being acquired using a remote monitoring system. Figure 5 provides these measurements for the six-month period since the system was installed. Initially, the water levels increased approximately 1.5 ft, but have stabilized at a freshwater head elevation of 3017 ft. The TROLL measurements are consistent with the WTS sounder tape measurements.

Bell Canyon Wells AEC-8 and CB-1

The Bell Canyon water levels measured in AEC-8 (Figure 6) and Cabin Baby-1 (Figure 7) show contrasting trends over the May 1999 through December 2002 monitoring period. Although the Bell Canyon water level in Cabin Baby-1 rose initially in response to recovery from previous well work, it has been stable for more than three years at a level of 3015 ft, amsl. In early May 2002, the TROLL in Cabin Baby-1 was removed to permit access for other well activities, and then replaced in the well six days later. At AEC-8, the Bell Canyon water level has risen steadily at a rate of about 1.6 ft/month or more than a 60-ft rise since the TROLL monitoring was initiated. At the end of December 2002, the Bell Canyon water level in AEC-8 was approximately 3062 ft amsl. The rise in AEC-8 water levels may be related to a problem with the well (possibly, a split casing). The TROLLs are in good agreement with the manual water-level measurements made in both wells except for the large offsets in head attributable to re-positioning of the TROLL and/or malfunctioning of the TROLL (April 2002, AEC-8).

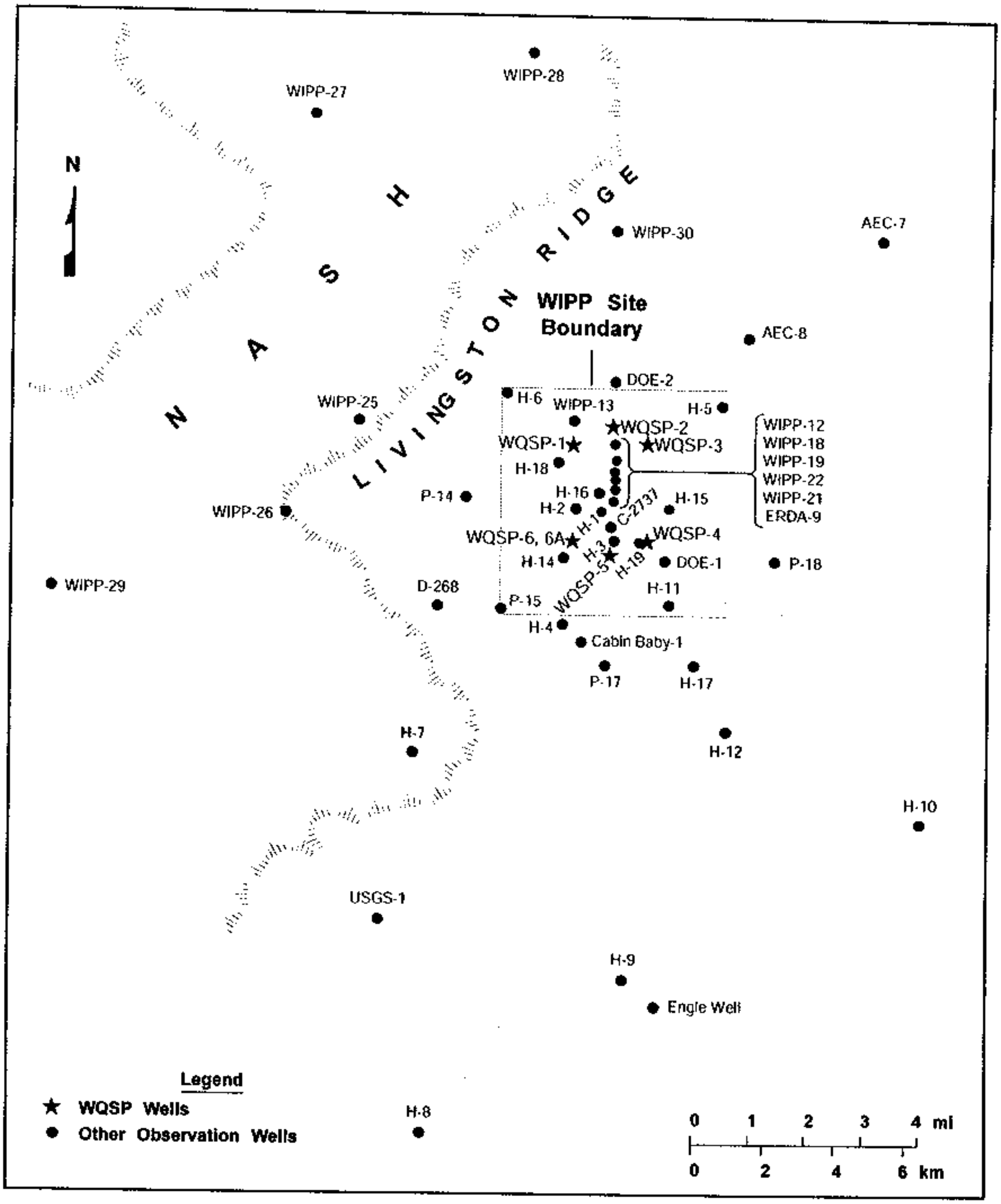

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Figure 1. Location map for WIPP monitoring wells.

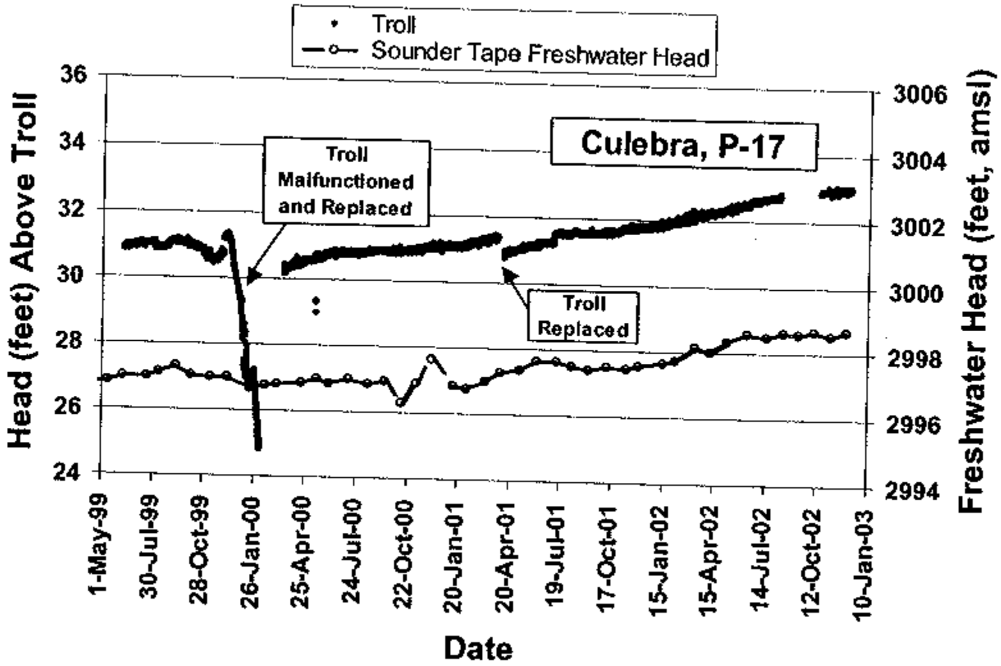


Figure 2. Culebra head levels measured in P-17.

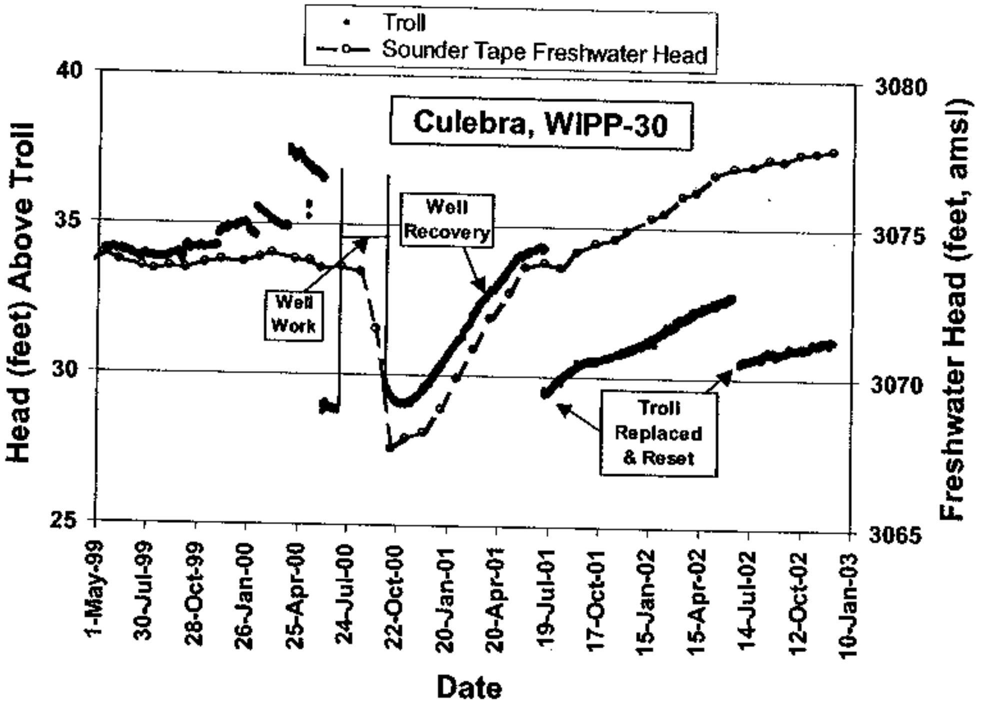


Figure 3. Culebra head levels measured in WIPP-30.

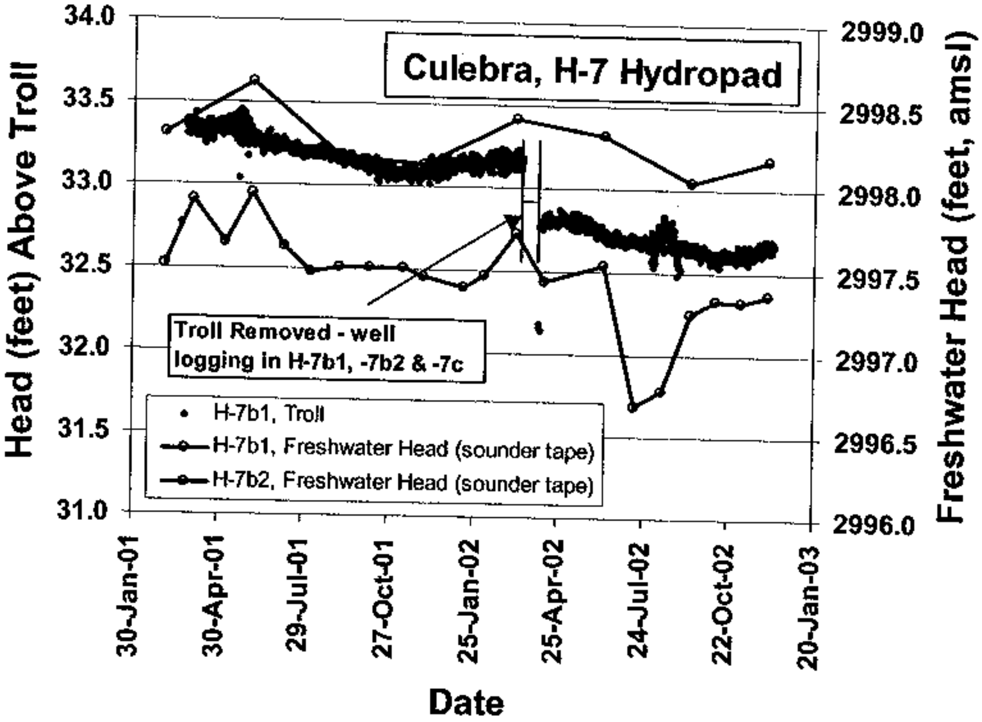


Figure 4. Culebra head levels measured at the H-7 well pad.

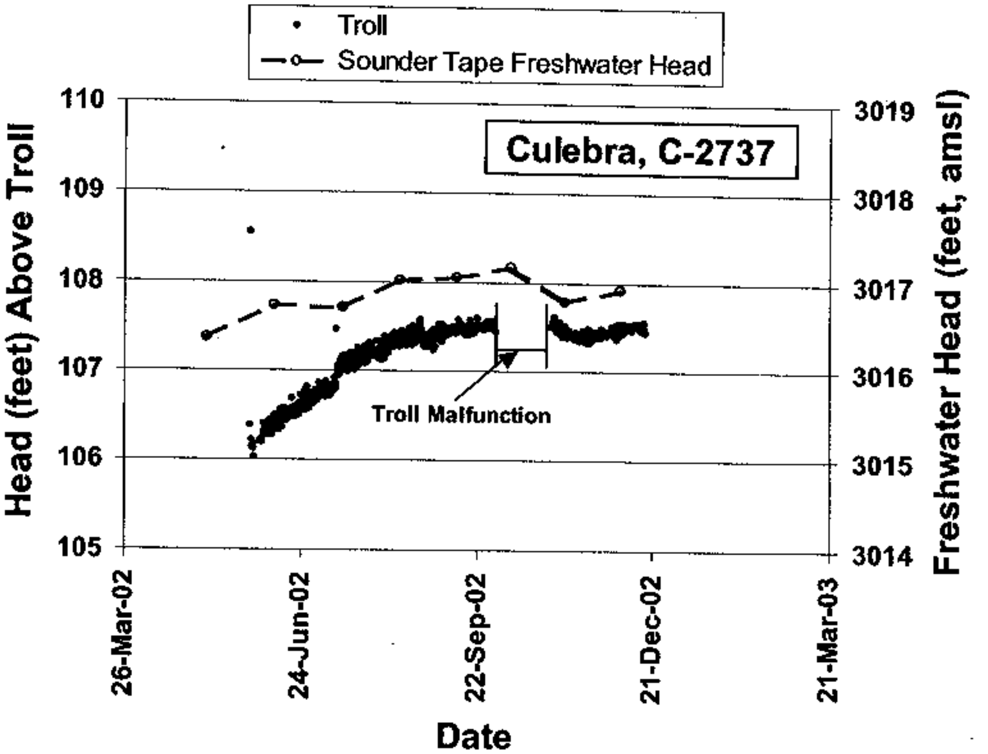


Figure 5. Culebra head levels measured in C-2737.

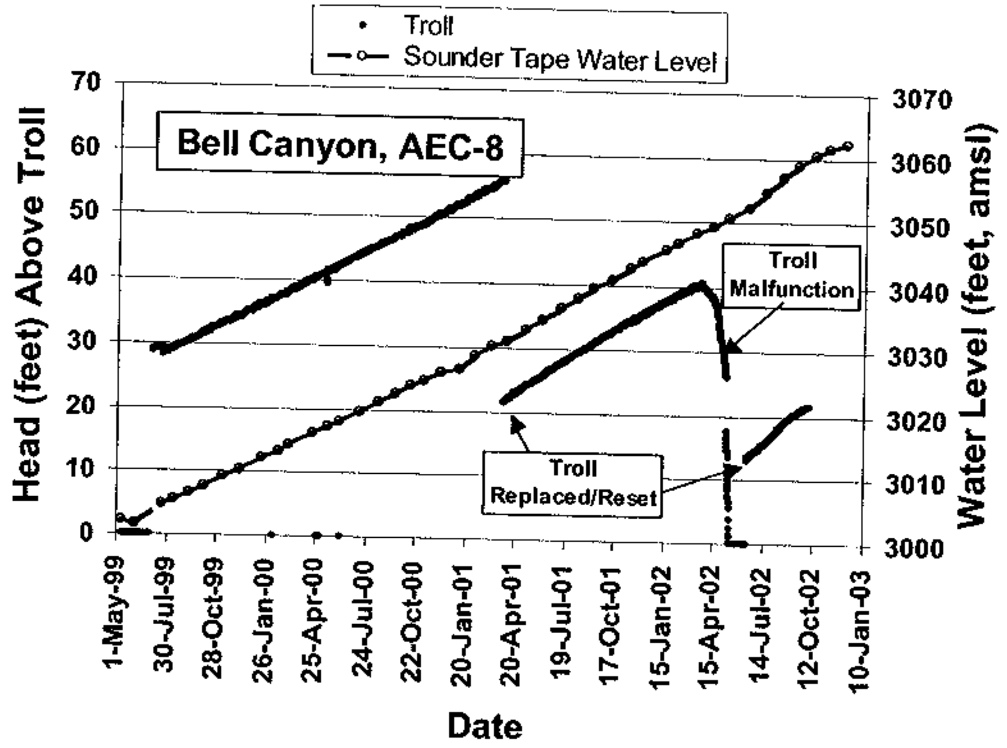


Figure 6. Bell Canyon head levels measured in AEC-8.

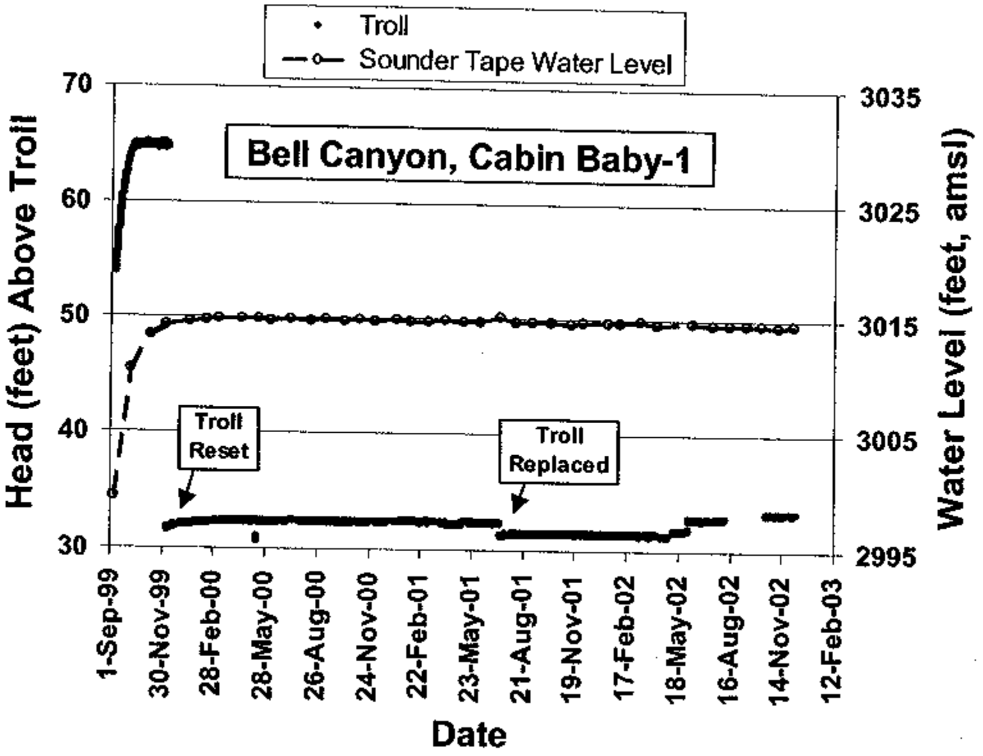


Figure 7. Bell Canyon head levels measured in CB-1.

METEOROLOGICAL DATA

Although the WIPP site comprises only 16 square miles, the WIPP well monitoring network encompasses an area of approximately 250 square miles. Weather patterns within this relatively large area can produce significant variability in precipitation on a local scale. Precipitation recharge has been postulated as a possible mechanism to explain changes in Culebra water levels so measurement of precipitation at or near individual monitoring wells is necessary to determine if such a mechanism is important. The H-7 and H-9 well pads are two monitoring locations considered to be good candidates for testing the precipitation recharge postulate; however, the nearest meteorological station to the H-7 and H-9 well pads is located at the center of the WIPP site, approximately 5 miles and 8 miles from the H-7 and H-9 well pads, respectively. Therefore, Sandia instrumented both the H-7 and H-9 well pads with stand-alone, remote tip-bucket rain gauges and data loggers to record precipitation directly at the well pads. The H-9 well pad was instrumented in late February 2000, while the H-7 well pad was instrumented in mid-May 2001.

Monthly precipitation totals measured at the H-9 well pad from March 2000 through December 2002 are shown in Figure 8. Precipitation at this site is highly variable ranging from 0 to more than 5 in/month. Monthly precipitation totals measured at the H-7 well pad from June 2001 through July 2002 are also shown in Figure 8 and range from near 0 to approximately 2.2 in/month. For comparison, the differences in monthly precipitation totals at the two sites range from approximately 8 to 100 % of the average rainfall at the two sites.

As described previously (SNL, 2002a), the Culebra groundwater-monitoring well (i.e., H-9b) located on the H-9 well pad was lost (inadvertently plugged with cement while H-9a was being plugged and abandoned) so a direct comparison of rainfall and Culebra water levels is not possible. A second well, H-9c, located on the H-9 well pad was recently re-completed as a Magenta groundwater monitoring well; however, water levels in this well have been disturbed because of the re-completion and well development activities and water-quality sampling and slug testing that occurred subsequent to re-completion. Therefore, correlation between rainfall and Magenta water levels was not attempted. Figure 9 plots rainfall events at the H-7 well pad and Culebra water levels in H-7b1 from April 2001 through December 2002. No clear correlation between rainfall and water levels is apparent from this comparison; however, this apparent lack of correlation could also mean head levels in the Culebra lag rainfall events. Longer-term data are needed to investigate possible correlations including the effect of time lag.

Precipitation measurements will be continued at least through the next reporting period.

INJECTION WELL MONITORING NEAR THE H-9 WELL PAD

Private resource exploration companies are currently involved in deep-well injection activities (specifically, injection of produced oil-field brines into the Bell Canyon Formation) that are being conducted outside, but near, the WIPP site boundary area. WIPP stakeholders have suggested that a hydrological connection may exist between these injection activities and the changes in water levels measured in some of the Culebra monitoring wells. The premise for such a hydrological connection is vertical flow from the Bell Canyon to the Culebra induced by a change in hydraulic gradient between the two formations during brine injection. Possible vertical flow paths include:

- poorly cemented and/or leaking injection wells,
- old abandoned wells that extend through the Culebra to the Bell Canyon or deeper, and
- porous media flow from the Bell Canyon up through the Castile and Salado Formations (a highly unlikely scenario given the low hydraulic conductivity of the Castile and Salado and the relatively long flow path, a distance of more than 3,600 ft).

To investigate the various hydrological connection scenarios, inflow data for six injection wells located near the H-9 well pad are being collected by WTS for comparison with the water levels measured at the H-9 well pad. The location of the H-9 well pad is approximately 6.5 miles south of the WIPP site boundary as shown in Figure 1.

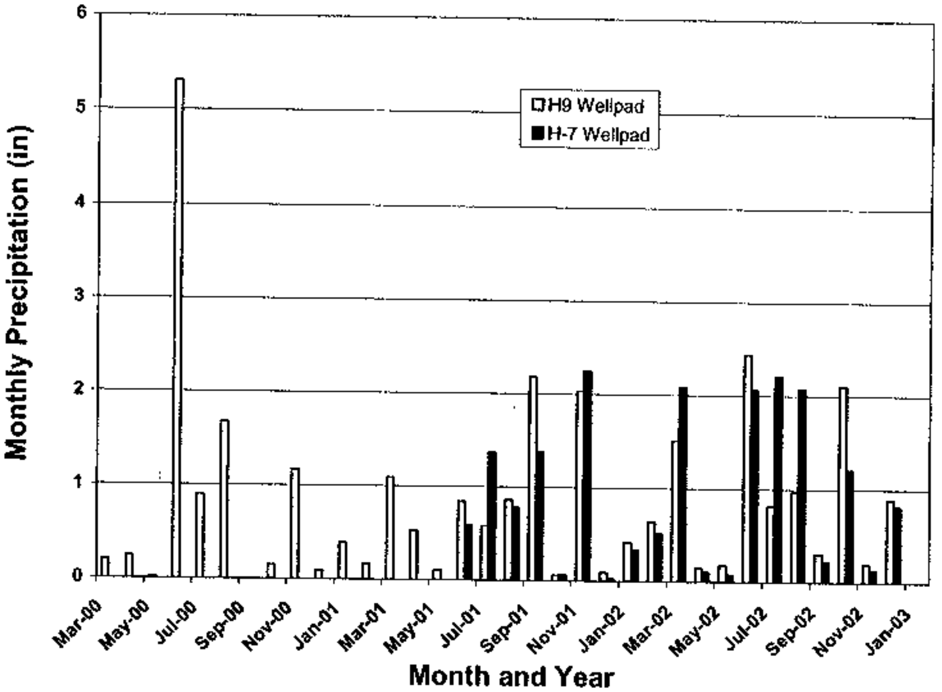


Figure 8. Monthly precipitation totals for the H-7 and H-9 well pads.

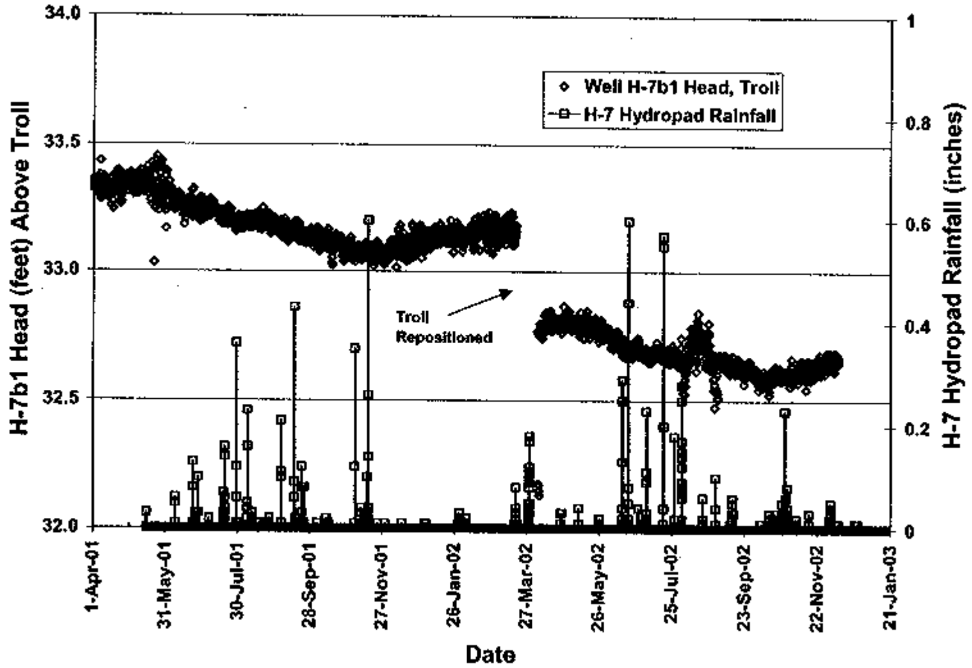


Figure 9. Temporal comparison of rainfall events and Culebra water levels at the H-7 well pad.

The six injection wells monitored by WTS are Cal Mon #5, Sand Dunes 28F#1, Pure Gold B F#20, Todd 26F#2, Todd 26F#3, and Todd 27F#16. These wells are located from 1.5 to 3 miles northeast of the H-9 well pad (Figure 10). The injection zones for all six wells are shown in Table 1. With the exception of Pure Gold B F#20, the injection zones are located in the Bell Canyon Formation at depths typically between 4,500 to 5,500 ft (below ground surface, bgs). The injection zone for Pure Gold B F#20 is in the Brushy Canyon Formation at a depth of 7,740 to 7,774 ft bgs. Injection data for the wells are being collected daily by WTS during non-weekend and non-holiday periods (except during August 23, 2001, through October 8, 2001, when no data were collected). The data collected include total cumulative injection volume as read on the injection meter for each well, well injection pressure, and the date and time each meter was read.

As part of the current investigations, an average daily injection rate for each well was calculated by dividing the difference in injection volumes for consecutive meter readings by the elapsed time (in days) between readings. With the exception of the Pure Gold B F#20, the average daily injection rates for each of the six wells are shown in Figure 11 for the entire monitoring period beginning in July 1999. Pure Gold B F#20 was recently added to the injection well cluster so the data for this well are shown only for the period from June 1, 2001, through December 31, 2002.

The current average daily injection rate for Todd 26F#2 is approximately 600 barrels/day, a rate slightly less than reported in July 2002. The average daily injection rate for Todd 26F#3 has recovered to a rate of about 900 barrels/day after having dropped consistently over the previous year. The average daily injection rate for Todd 27F#16 has risen to about 2,500 barrels/day, an increase of about 700 barrels/day since July 2002, but is still below a high of 2,800 barrels/day recorded in April and May 2000. With the exception of a few short time intervals, the average daily injection rate for Cal Mon #5 ranges from 500 to 1,000 barrels/day.

The injection rates for Sand Dunes 28F#1 have stabilized within the past year and are now about 400 barrels/day. At the beginning of June 2001, Pure Gold B F#20 was added to the Sand Dunes 28F#1 brine manifold. As a result, the injection rate at Sand Dunes 28F#1 dropped to zero and the initial injection rates for Pure Gold B F#20 ranged between 1,000 and 1,500 barrels/day. The injection rates at Sand Dunes 28F#1 remained zero until October 2001 when they increased to 500 to 1,000 barrels/day. During this same time, the injection rates at Pure Gold B F#20 were highly variable with rates as high as 2,500 barrels/day and as low as 500 barrels/day. Over the past year, the rates of injection at Pure Gold B F#20 have stabilized at about 750 barrels/day. The sum of the injection rates for Sand Dunes 28F#1 and Pure Gold B F#20 is currently equivalent to the rates for Sand Dunes 28F#1 immediately before Pure Gold B F#20 was added to the brine manifold.

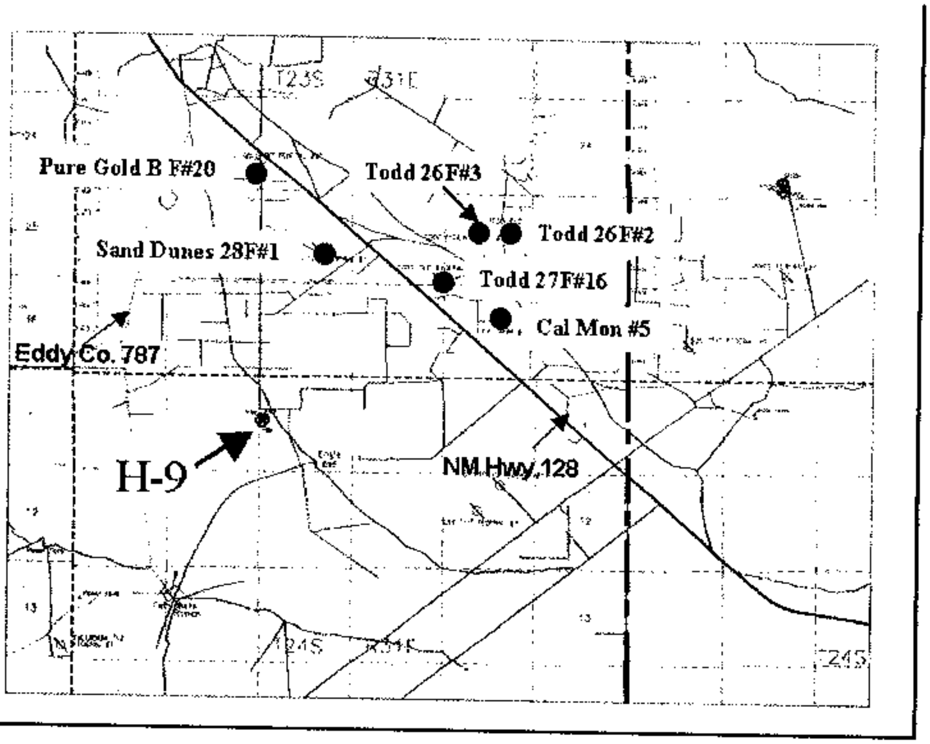


Figure 10. Location of injection wells relative to the H-9 well pad.

Table 1. Injection Zone Depth Intervals for the Injection Wells Located Near the H-9 Well Pad.

Well No.	Injection Zone Depth, ft[(a)]
Cal Mon #5	4484 – 5780
Sand Dunes 28F#1	4295 – 5570
Pure Gold B F#20	7740 – 7774
Todd 26F#2	4460 – 5134
Todd 26F#3	4390 – 6048
Todd 27F#16	4694 – 5284

(a) below ground surface, bgs

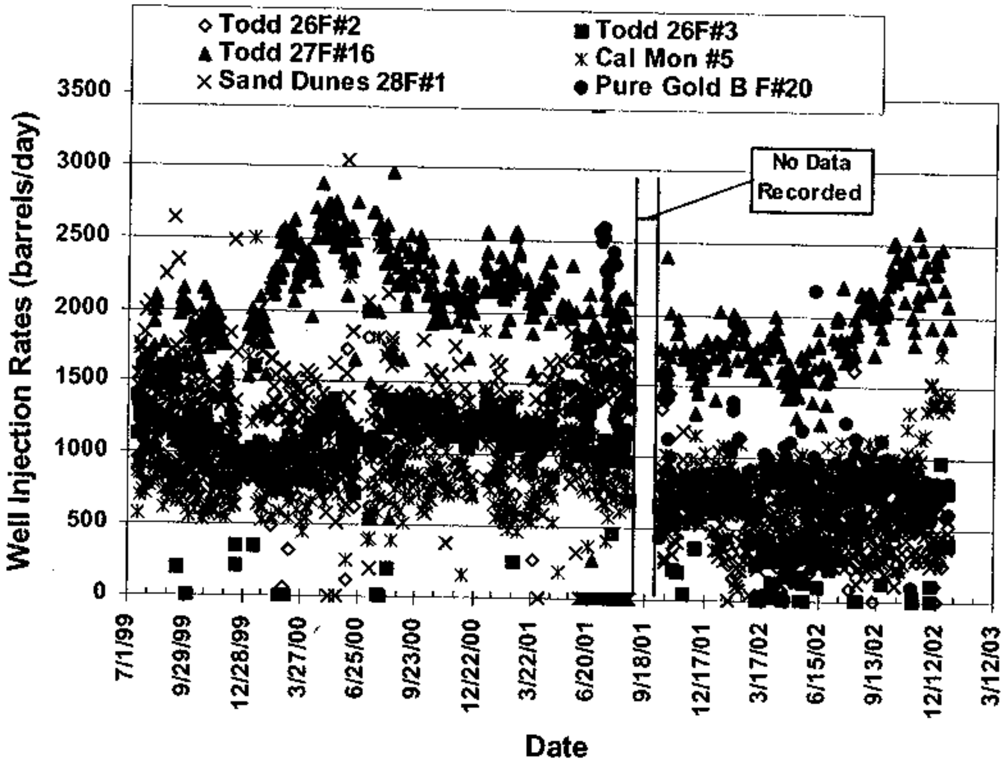


Figure 11. History of daily injection rates for six wells located near the H-9 well pad.

As shown previously in Table 1, the injection zones for five of the six wells cover approximately the same depth interval (between 4,500 and 5,500 ft bgs). In addition, because the wells are located near one another (1 to 3 miles) in a horizontal plane, the injection can be approximated as a point source on the regional scale. Using this assumption, the total injection rate at the point source is simply the cumulative total of the injection rates of the five individual wells. Figure 12 gives the total cumulative injection rate as a function of time both for these five wells and for all six wells.

Because of the large variability in the cumulative rates, two running-average injection rates were calculated. One running average included the data from all six wells, while the second included data only from the five wells injecting at the same depth interval. Both of these running-average injection rates are plotted in Figure 12 for comparison with the measured cumulative rate. Each running-average rate is calculated as the average total injection rate for all of the data falling inside a sliding "time window." Subsequent rates are determined by simultaneously adding and dropping a data point from either end of the time window, until all of the data have eventually been included in one of the time windows. The average rates are then plotted at the midpoints of their respective time windows. As shown in Figure 12, this technique "smooths" the measured data so that local trends and/or peaks and valleys become obvious. The running-average injection rates for the six wells parallel the rates for the five wells, but are offset in magnitude as expected. Both the five-well and six-well cumulative daily injection rates have fallen steadily for nearly a year and in March 2002 were about half of what they were in July 2001; however, since March 2002, the cumulative rates have steadily increased.

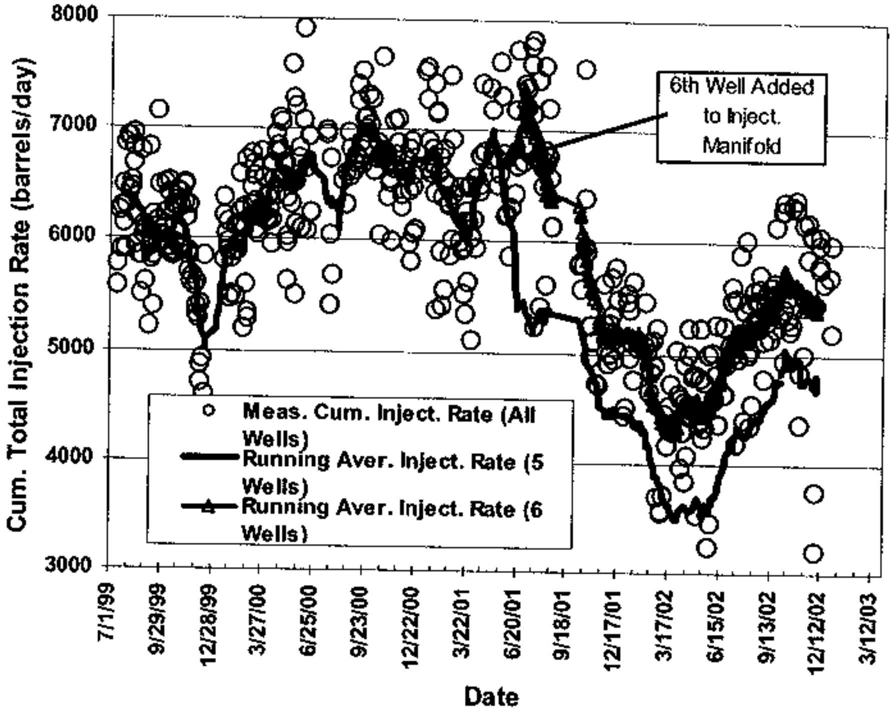


Figure 12. History of cumulative daily injection rates for injection wells located near the H-9 well pad.

Because of the apparent loss of the Culebra groundwater monitoring well (i.e., H-9b) at the H-9 well pad (Sandia, 2002a), no Culebra water levels are currently available for comparison with injection rates. Injection rate monitoring will continue at least through the next reporting period, while a plan is developed to assess if valid Culebra water levels can once again be measured at the H-9 well pad.

ANNUAL COMPS ASSESSMENT

Sandia conducts a formal assessment of WIPP monitoring data to evaluate if the disposal system continues to perform as expected. Ten monitoring parameters are used as metrics in this assessment and are termed compliance monitoring parameters or COMPs. Of these 10 parameters, 5 are geotechnical (e.g., creep closure of underground openings, surface subsidence, etc.), 2 are hydrological, 2 are drilling-related (e.g., drilling rate in the Delaware Basin), and 1 is related to waste activity. Current values for each COMP are evaluated based on data obtained in various WIPP monitoring programs and compared annually against a set of derived trigger values (SNL, 2002b). If a current COMP value falls below the derived trigger value or within a trigger value range, then no further action is required beyond reporting the result. In contrast, if the current value exceeds the trigger value or falls outside the trigger value range, then the impact of such a finding on expected repository performance or related factors such as features/events/processes (FEP) screening, modeling assumptions, etc., must be investigated. For the latter condition, exceeding a trigger value does not mean that the repository no longer meets regulatory requirements, but that additional investigations may need to be performed.

Results of the 2002 annual COMPs assessment have been provided by SNL (2002c) with a summary of the 2002 hydrological COMPs assessment provided below.

The hydrological COMPs include: (1) changes in Culebra groundwater flow as manifested by freshwater heads at 32 well locations, and (2) Culebra groundwater composition at six well locations. Assessment of the "Changes in Culebra Groundwater Flow" COMP involves trigger values derived from the steady-state freshwater heads estimated for Culebra flow modeling in the CCA. Assessment of the "Culebra Groundwater Composition" COMP involves trigger values derived from statistical analyses of ten rounds of baseline water-quality sampling at the six well locations.

Table 2 provides a summary of the Culebra water-level changes and freshwater heads reported for the 2002 "Changes in Culebra Groundwater Flow" COMP assessment and includes well identification number, relevant water-level measurements, change in water level, and trigger values based on the CCA uncertainty ranges. As shown, only 28 of the original 32 wells used in the CCA analyses are still being monitored. Of this total, one has been plugged and abandoned during the reporting period (i.e., H-1) and five have been recompleted as Magenta wells, so Culebra water levels for only 22 of the original 32 wells are available for direct comparison with the trigger values. Table 2 also shows water levels in 13 other wells located around the WIPP site but not used in CCA analyses. Of the 35 water levels reported for 2000 and 2001, 29 levels were higher in 2001 than in 2000, while only 6 were lower. In addition, 17 Culebra water levels exceed the CCA trigger value range including 13 that lie above the range and 4 that lie below the range. The predominant trend of rising water levels in the Culebra was first observed in the 2000 annual COMPs assessment and, as shown in Table 2, continues through the current assessment. These rising Culebra water levels are the impetus for the multiyear groundwater hydrology program described in this report.

Table 3 provides a summary of the 2002 "Culebra Groundwater Composition" COMP assessment. Major ion concentrations are presented for two rounds of sampling (Rounds 12 and 13) from six Culebra wells, along with a set of trigger value ranges for each concentration and well. Major ion species evaluated included Na, Ca, Mg, K, Cl, SO_4, and HCO_3. The trigger value ranges, as defined by Sandia (2002b), represent the 95% confidence interval (CI) for each species based on ten rounds of baseline sampling for each well. For a given concentration to exceed the trigger value, the sample and duplicate analytical result must both fall outside the 95% CI for three consecutive sampling rounds. As shown in Table 3, most concentrations observed in Rounds 12 and 13 for each of the six samples and duplicates fall within the 95% CI, indicating water composition stability; however, Mg and K concentrations for WQSP-1 and WQSP-2 and Cl concentration for WQSP-6 fell outside the 95% CI. In the case of WQSP-1, the high charge-balance error, implying either that the analysis of one or more ions is inaccurate (most common) or that a significant ion has been overlooked (rare), makes the Round 12 and 13 sampling values suspect; thus, the results do not warrant further action even though they exceed the trigger values. However, in the case of WQSP-2, the charge-balance errors are acceptable so analytical inaccuracies cannot be assumed and the results are significant. In keeping with the definition of when a trigger value is exceeded (concentrations exceeding trigger values for three consecutive sampling rounds), the results of the current Round 13 analyses, as well those obtained in Rounds 11 and 12, were examined and subsequently indicated that the trigger values

Table 2. Summary of 2001 Culebra Water-Level Changes and Freshwater Heads

Well I.D.	12/00 W.L. (ft AMSL)	12/01 W.L. (ft AMSL)	2001 Change (ft)	12/01 FWH (ft AMSL)	CCA Range (ft AMSL)	Outside CCA Range?
AEC-7	3038.22	3038.29	0.07	3061.25	3055.1-3060.4	Y
CB-1	3245.85	3274.28	28.43	3287.21	2986.9-2991.5	Y
DOE-1	2975.04	2976.71	1.67	3005.19	2992.5-3013.8	N
DOE-2	3040.80	Recompleted to Magenta well (April 2001)			3061.7-3071.5	N/A
ERDA-9	3007.53	3008.60	1.07	3024.05	N/A	N/A
H-1	3035.57	Plugged and Abandoned (February 2001)			3017.1-3030.2	N/A
H-2b2	3036.63	3037.60	0.97	3039.95	3033.8-3040.0	N
H-3b2	2997.81	2998.94	1.13	3010.29	2995.1-3007.5	Y
H-4b	3000.30	3001.07	0.77	3004.66	2988.2-2992.1	Y
H-5b	3028.30	3028.57	0.27	3073.47	3060.4-3069.6	Y
H-6b	3051.70	3052.50	0.80	3064.68	3054.5-3061.0	Y
H-7b2	2997.56	2997.54	-0.02	2997.45	2994.1-2996.1	Y
H-9b	2990.20	2991.31	1.11	2991.56	2973.4-2977.7	Y
H-10b	2994.49	2994.70	0.21	3026.81	3015.4-3029.9	N
H-11b4	2983.61	2984.65	1.04	3004.75	2990.2-3003.3	Y
H-12	2968.94	2969.63	0.69	3006.88	2993.1-3001.0	Y
H-14	3008.98	Recompleted to Magenta well (April 2001)			3007.9-3021.0	N/A
H-15	2961.86	Recompleted to Magenta well (April 2001)			3005.2-3019.4	N/A
H-17	2960.56	2961.97	1.41	3011.20	2985.9-2991.8	Y
H-18	3059.60	Recompleted to Magenta well (April 2001)			3055.4-3067.3	N/A
H-19b0	2988.52	2989.73	1.21	3011.50	N/A	N/A
P-15	3015.89	3015.60	-0.29	3016.38	3008.5-3013.8	Y
P-17	2983.47	2983.35	-0.12	2997.53	2981.0-2985.6	Y
P-18	3162.44	3164.05	1.61	3235.74	N/A	N/A
WIPP-12	3031.51	3032.15	0.64	3068.95	3062.7-3070.2	N
WIPP-13	3057.57	3057.08	-0.49	3067.64	3059.1-3068.2	N
WIPP-18	3033.55	Recompleted to Magenta well (April 2001)			3048.9-3062.7	N/A
WIPP-19	3038.93	3039.83	0.90	3077.62	N/A	N/A
WIPP-21	3015.17	3016.10	0.93	3040.25	N/A	N/A
WIPP-22	3029.15	3030.12	0.97	3061.19	N/A	N/A
WIPP-25	3057.46	3060.43	2.97	3057.36	3043.6-3050.2	Y
WIPP-26	3021.71	3021.40	-0.31	3021.53	3013.1-3014.8	Y
WIPP-27	3081.22	3082.10	0.88	3088.19	3075.5-3080.1	Y
WIPP-29	2967.37	2967.06	-0.31	2970.23	N/A	N/A
WIPP-30	3061.22	3067.85	6.63	3074.91	3060.4-3067.6	Y
WQSP-1	3053.00	3053.61	0.61	3070.29	N/A	N/A
WQSP-2	3059.11	3059.45	0.34	3079.19	N/A	N/A
WQSP-3	3011.21	3011.42	0.21	3068.49	N/A	N/A

Table 2. Summary of 2001 Culebra Water-Level Changes and Freshwater Heads cont.

Well I.D.	12/00 W.L. (ft AMSL)	12/01 W.L. (ft AMSL)	2001 Change (ft)	12/01 FWH (ft AMSL)	CCA Range (ft AMSL)	Outside CCA Range?
WQSP-4	2986.23	2987.17	0.94	3012.10	N/A	N/A
WQSP-5	3001.69	3002.59	0.90	3009.64	N/A	N/A
WQSP-6	3014.19	3015.51	1.32	3019.23	N/A	N/A

Bold **Y** signifies determination is independent if density uncertainty.

NA = not applicable; data from well not used in CCA–field calibration.

Table 3. Rounds 12 and 13 Ion Concentration and Baseline 95% Confidence Intervals

Well I.D.	Sample	Cl Conc. (mg/L)	SO_4 Conc. (mg/L)	HCO_3 Conc. (mg/L)	Na Conc. (mg/L)	Ca Conc. (mg/L)	Mg Conc. (mg/L)	K Conc. (mg/L)	Charge Balance Error (%)
WQSP-1	Round 12	37000/36000	4900/4800	51/52	19170/17460	1854/1794	**1255/1180**	**767/745**	**-5.8**
	Round 13	35900/36100	4730/4720	50/52	18450/17430	1828/1795	**1262/1270**	**896/871**	**-5.5**
	95% C.I.	31100-39600	4060-5600	45-54	15850-21130	1380-2030	940-1210	322-730	
WQSP-2	Round 12	35000/36000	5200/5600	48/50	19790/21340	1651/1715	**1199/1188**	**706/768**	-0.9
	Round 13	34900/34800	5160/5060	46/48	20910/21060	1689/1676	**1175/1193**	**841/856**	1.1
	95% C.I.	31800-39000	4550-6380	43-53	14060-22350	1230-1730	852-1120	318-649	
WQSP-3	Round 12	130000/130000	7200/7200	34/32	68300/71100	1310/1300	2120/2040	2180/2190	**-6.9**
	Round 13	131000/129000	7460/7190	32/34	81600/74400	1537/1430	2455/2312	3035/2862	-1.1
	95% C.I.	113900-145200	6420-7870	23-51	62600-82700*	1090-1620	1730-2500	2060-3150*	
WQSP-4	Round 12	54900/**52100**	6470/6380	40/38	35000/34200	1520/1650	1050/1060	1020/1090	1.6
	Round 13	55300/55000	6300/6130	36/34	34100/33170	1470/1505	1093/1134	1221/1245	-0.8
	95% C.I.	53400-63000	5620-7720	31-46	28100-37800	1420-1790	973-1410	784-1600*	
WQSP-5	Round 12	16100/15700	4890/4800	46/46	9756/9712	1011/1029	425/437	474/505	-2.6
	Round 13	15600/14800	4690/4470	46/44	**10600**/10200	1090/1080	**545/545**	452/454	3.5
	95% C.I.	13400-17600	4060-5940	42-54	7980-10420*	902-1180	389-535	171-523	
WQSP-6	Round 12	**5140/5170**	4600/4720	42/42	4320/4330	663/687	212/231	208/204	0.5
	Round 13	**4970/4820**	4500/4510	46/44	4090/4230	672/688	**234/236**	**278/282**	1.9
	95% C.I.	5470-6380*	4240-5120*	41-54	3610-5380*	586-777	189-233*	113-245	

Bolded entries indicate value exceeds 95% C.I.

for Mg and K concentrations had been exceeded for this well. SNL is currently evaluating the WQSP-2 results to determine if additional investigation needs to be conducted. Although the Round 12 and Round 13 WQSP-6 Cl concentrations fall outside the 95% CI, the Round 11 Cl concentrations (as well as Cl concentrations in previous rounds) were within the 95% CI so the trigger value for this well/concentration combination has yet not been reached; however, the WQSP-6 Cl concentrations determined from the next two sampling rounds will be closely scrutinized because of the emerging trend in the data.

Development of Well Test Data Interpretation Software – nSIGHTS

A new well-test analysis code nSIGHTS has been developed by Sandia. This code will be used by Sandia to re-analyze existing well test data and to analyze new well test data acquired during the Culebra investigations in support of the performance assessment calculations for the WIPP, as well as other well testing activities that may occur in the Magenta, Dewey Lake, and other WIPP units.

nSIGHTS is a numerical well-test analysis code developed as part of an advanced hydrological characterization methodology. nSIGHTS statistical methodology provides a mechanism to investigate and quantify uncertainties in well-test parameter estimates. The nSIGHTS methodology will be used to re-analyze existing Culebra and Magenta hydraulic test data to reduce uncertainty in previous transmissivity estimates and to analyze data from new well tests conducted as part of the WIPP integrated hydrology program (including Culebra, Magenta, Dewey Lake, and other WIPP units). The transmissivities will then be used to generate improved T fields for the performance assessment for recertification. The nSIGHTS methodology will also be applied to quantify the uncertainty in well-test parameter estimates, providing feedback on the type and amount of data needed to satisfy monitoring performance objectives. This feedback can be used to optimize test designs before starting any field tests, thereby improving the efficiency of the testing process.

All QA documentation that fulfills NP 19-1 (Chavez, 2002) has been completed, and has been placed in Sandia National Laboratories WIPP Records Center using the numbering system shown in Table 4. The nSIGHTS documentation, software, and tests are also stored in Sandia's Configuration Management System under the pathname - IBNSGHT::PACMS2:[CMS.NSGHT].

Culebra Water-Level-Change Investigations

Water-level changes observed in wells around the WIPP site have led to an integrated set of investigations aimed at identifying the potential cause(s) of the changes, defining and collecting data needed to verify that the identified causes are the correct ones, and developing new models of site hydrology capable of simulating the changes.

Table 4. nSIGHTS QA Documentation

Document	ERMS #
nSIGHTS Version 1.0 Software QA Plan	522293
nSIGHTS Version 1.0 Design Document	522059
nSIGHTS Version 1.0 Requirements Document	522058
nSIGHTS Version 1.0 Verification/Validation Plan	522060
nSIGHTS Version 1.0 Validation Document	522063
nSIGHTS User Manual Version 1.0	522061
Software Installation Checkout	522064
Implementation Document for nSIGHTS Version 1.0	522062

OBSERVED WATER-LEVEL CHANGES AND POTENTIAL CAUSES

Water-level records (hydrographs) from the WIPP wells reveal a variety of changes since monitoring began in the earliest wells in 1977. Hydrographs from the wells within the 16 square miles of the WIPP site typically show myriad effects because of the extensive well testing and shaft activities that occurred in the 1980's. Hydrographs from wells in Nash Draw and P-14 typically do not show responses to tests conducted on the WIPP site, but nevertheless show broad rising and falling trends over periods of several years (Figure 13). Since 1989, a general long-term rise has been observed in both Culebra and Magenta water levels (e.g., Figure 14) over a broad area including Nash Draw. At the time of the CCA, this long-term rise was recognized, but was thought (outside of Nash Draw) to represent the recovery from the accumulation of tests and shaft leakage that had occurred at the WIPP site since the late 1970's. Water levels in Nash Draw were thought to respond to changes in the amounts of potash mill effluent discharged into the draw (e.g., Silva (1996)). As the rise in water levels has continued over recent years, however, observed heads have exceeded the ranges of uncertainty established for the steady-state heads in most of the 32 wells used in calibration of the T fields for the CCA, throwing into question the earlier explanation for the rise. In addition, short-term fluctuations of unknown origin in Culebra water levels have occurred in specific areas (e.g., Figure 15).

In addition to the water-level changes discussed above, significant water-level fluctuations have also been observed in the Culebra at H-9 south of the WIPP site (Figure 16). Similar changes are also observed to the north in wells near the southern WIPP site boundary such as P-17 and H-12. Because of the presence of salt-water-injection wells several miles northeast of H-9 and extensive oil and gas drilling around H-9 (see Figure 17), speculation as to the cause of the water-level changes has centered on leaking boreholes (Silva, 1996). The target horizon for salt-water-injection wells (indicated by single diagonal lines in Figure 17) lies in the Bell Canyon or deeper formations. For water being injected at those depths to be influencing Rustler aquifers, it would have to be leaking either around the casing in the injection wells themselves or through other wells, perhaps improperly plugged and abandoned (P&A), (P&A wells are marked by horizontal bars in Figure 17), that penetrate the injection horizon.

Other possible explanations for observed water-level changes center on potash exploration holes. The potash exploration holes shown on Figure 17 are used to evaluate potash resources in the upper Salado, and are typically plugged and abandoned shortly after drilling. Some of these holes date back to the first half of the twentieth century, when plugging and abandonment practices were not as rigorous as they are today. From a search of Bureau of Land Management (BLM) records, plugging and abandonment records were found for 576 exploration holes in the vicinity of the WIPP site (T 20-24 S, R 30-32 E). Figure 18 shows the locations of 84 of these holes that were not filled with cement to the ground surface, but were instead filled with mud, sand, cuttings, salt cuttings, and/or brine, or were simply left open. These holes provide potential avenues for vertical hydraulic communication among the formations above the Salado.

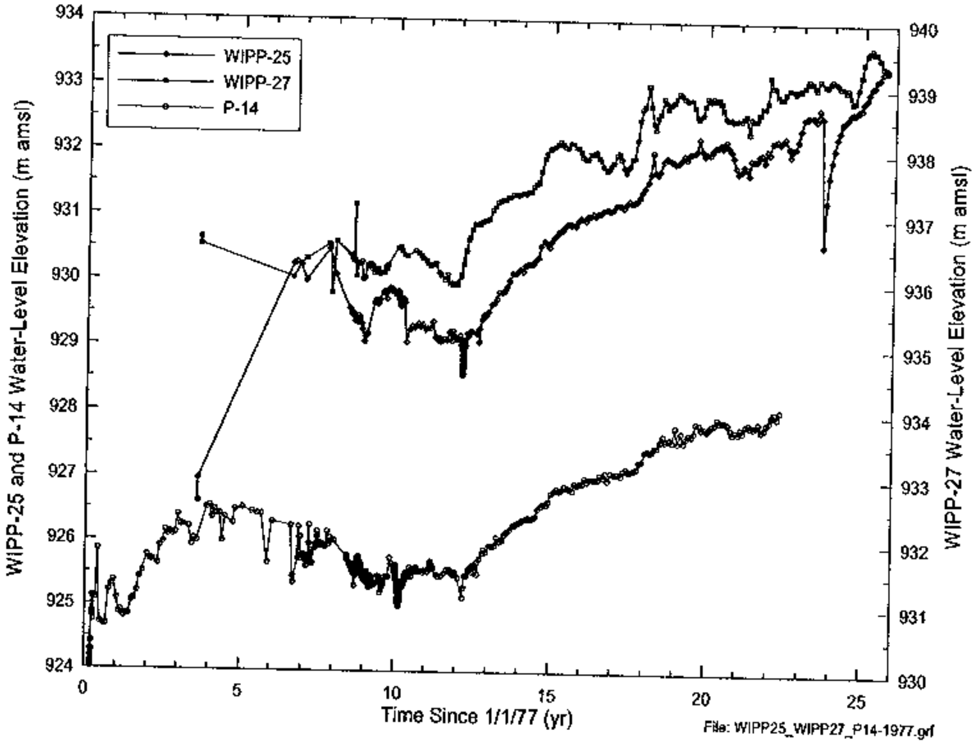


Figure 13. Water-level trends in Nash Draw wells and P-14.

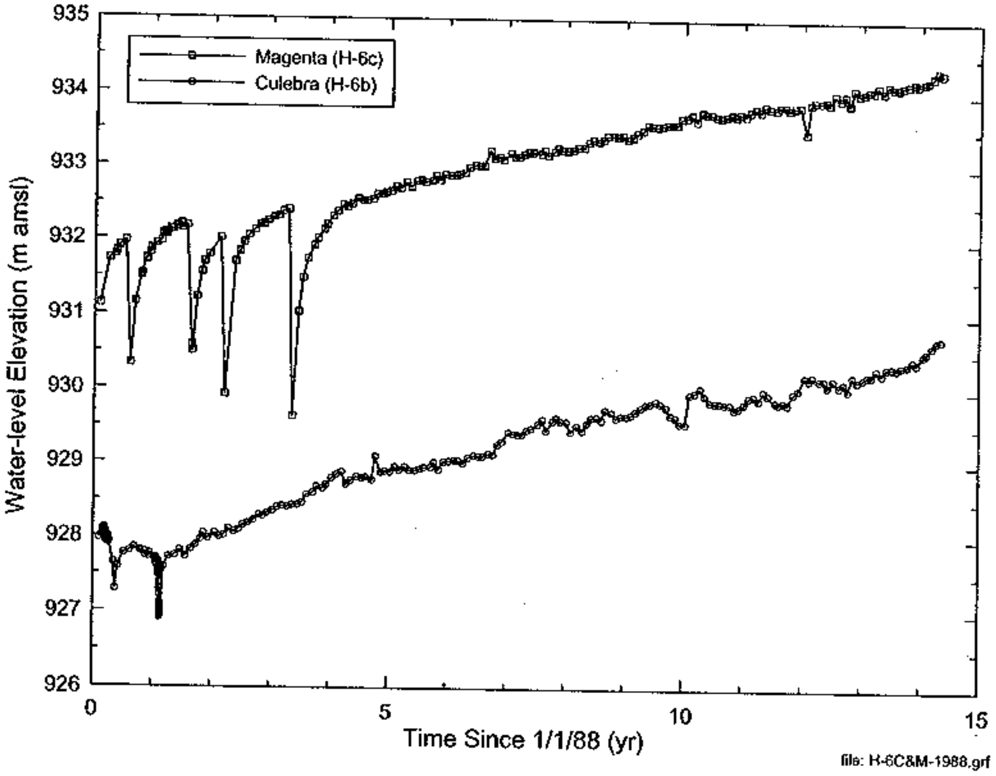


Figure 14. Rising Culebra and Magenta water levels at H-6.

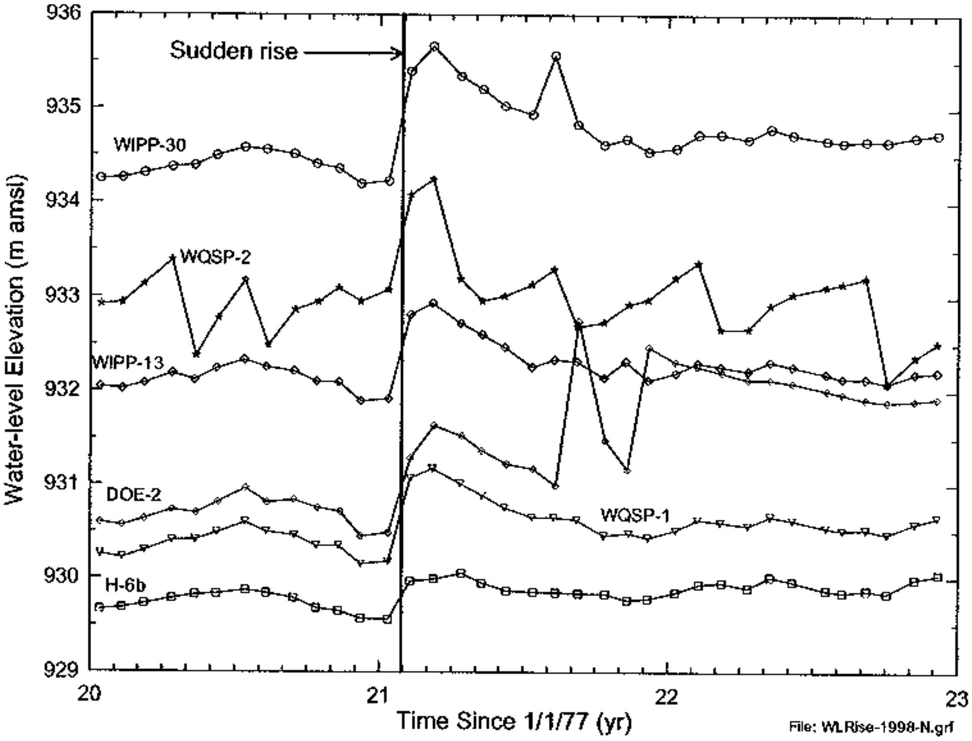


Figure 15. Example of short-term water-level fluctuation north of WIPP.

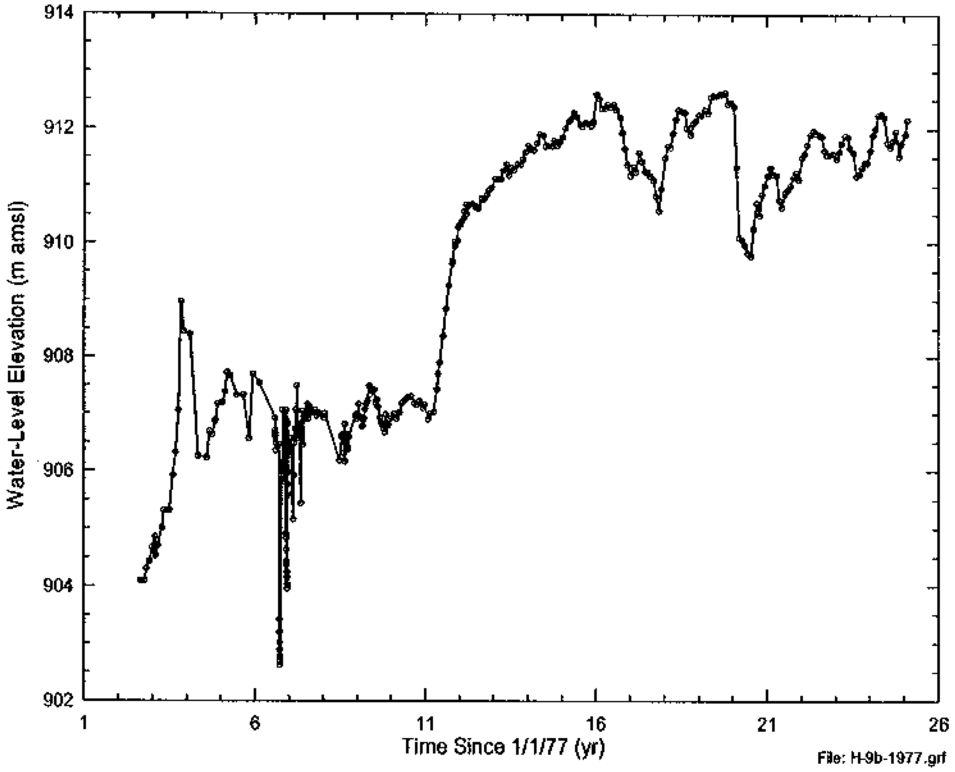


Figure 16. Culebra water levels at H-9.

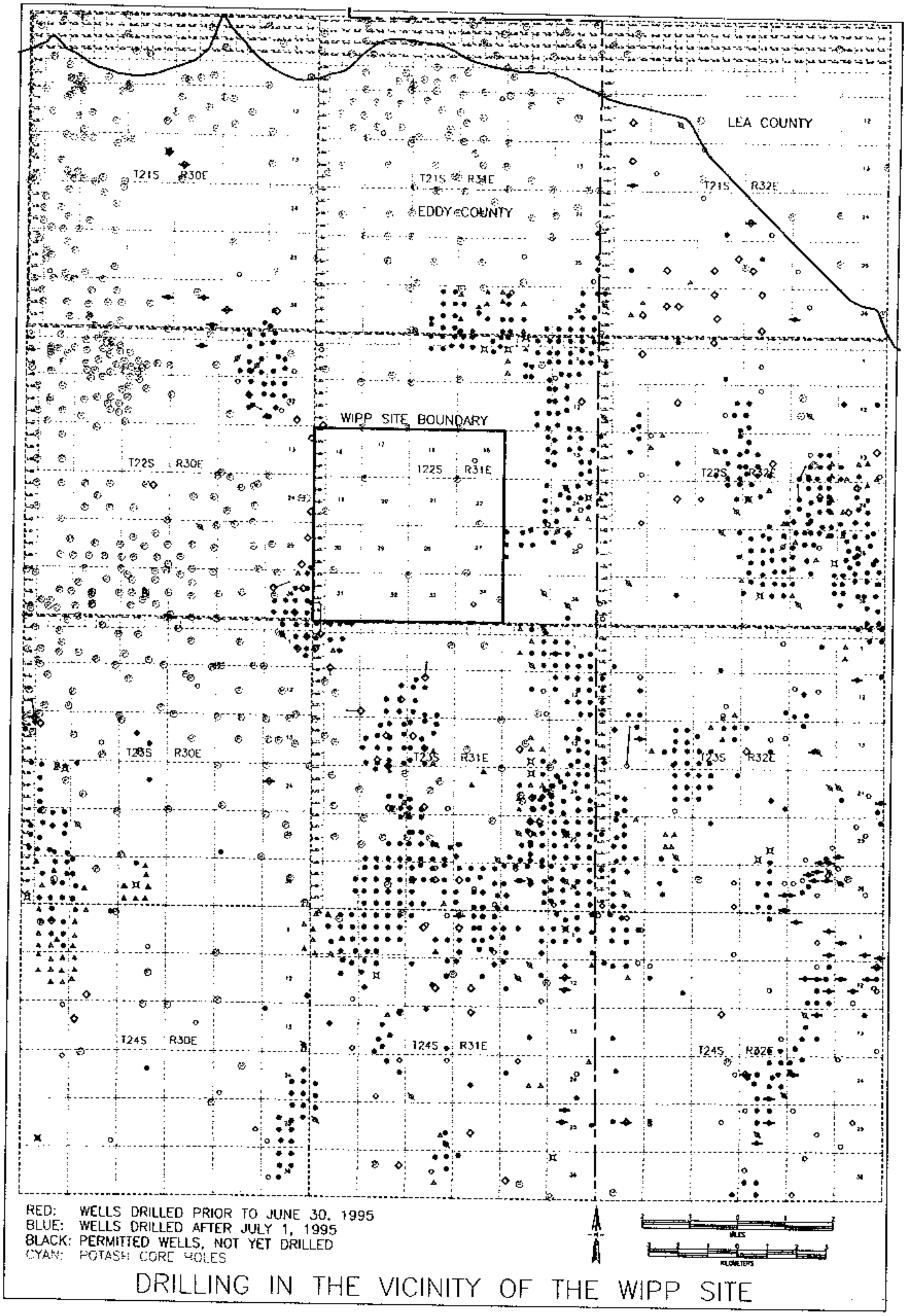


Figure 17. Petroleum and potash industry boreholes and coreholes around the WIPP site.

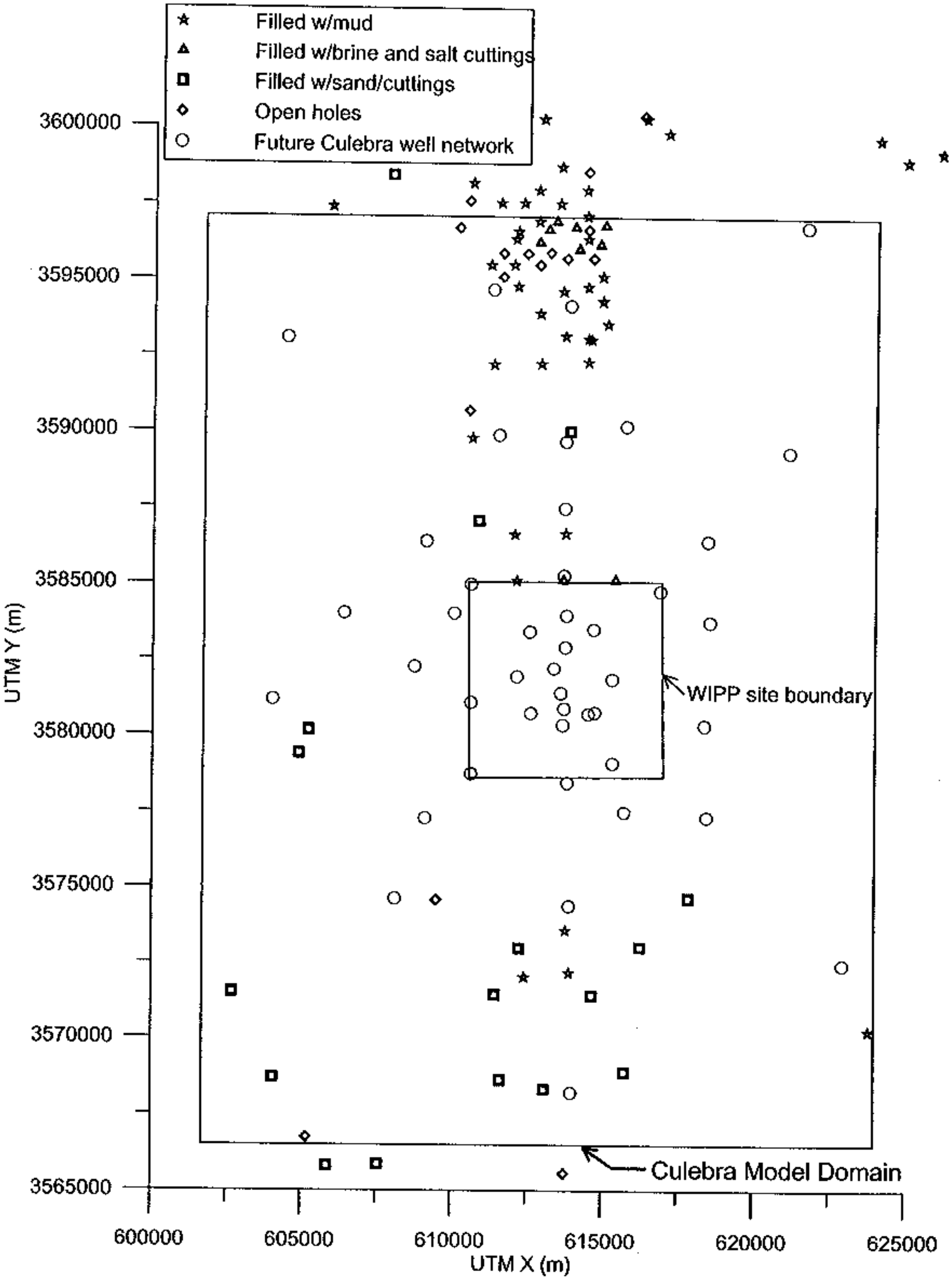


Figure 18. Location map denoting future Culebra wells and potentially leaky potash holes. Note, the data plotted in this figure represent a subset of the data shown previously in Figure 17. This subset includes potash holes that were abandoned using questionable methods (e.g., open holes or holes filled with mud, brine, and/or salt and sand cuttings) as indicated in the legend.

Many of the poorly plugged potash holes are located near, and in some cases beneath, the Mississippi East tailings pile located 7 to 8 miles due north of the WIPP site (Figure 19). Disposal of mine tailings and refining-process effluent at that location began in 1965. Records obtained from the New Mexico State Engineer show how much water has been used each year since 1973 in the potash-refining process (Figure 20). Since 1973, an average of 2400 acre-ft of water per year have been used. Based on knowledge of the potash refining process, approximately 90% of this water is estimated to be discharged onto the tailings pile. Geohydrology Associates (1978) estimated that approximately half of the brine discharged seeps into the ground annually, while the remainder evaporates. Therefore, on average, approximately 1100 acre-ft of brine may be infiltrating each year. Brine from this tailings pile may enter the Rustler through leaky boreholes and/or by first moving laterally into Nash Draw and then downward through subsidence fractures that have opened over potash mine workings (Figure 21).

Since the time of the CCA and the modeling reported by Corbet and Knupp (1996), many new petroleum exploration holes have been drilled around the WIPP site, as shown by the blue wells on Figure 17. A review of new and additional well logs from the potash and petroleum industries has identified two potential "re-entrants" of Salado dissolution extending from Nash Draw under the surface of Livingston Ridge to the southeast (see blue line on Figure 19). If these dissolution re-entrants are present and have increased the permeability of the Rustler and shallower units, they may provide local short-circuits of the flow system that were not captured by the CCA modeling.

Based on the information discussed above, three scenarios have been defined that are thought to have the potential to affect water levels and are considered worth investigating further:

- Leakage from the Mississippi East tailings pile/ponds causing locally elevated Culebra and Magenta heads, which then migrate to the south;
- Leakage through boreholes that are poorly cased or improperly plugged and abandoned, including both leakage among units above the Salado and leakage from units (or injection) below the Salado;
- High-T conduits caused by dissolution extending from Nash Draw to the southeast allowing heads in Nash Draw to affect heads under Livingston Ridge (including the WIPP site) more than previously thought.

Note that these scenarios are not mutually exclusive, and may all be contributing to the observed water-level fluctuations.

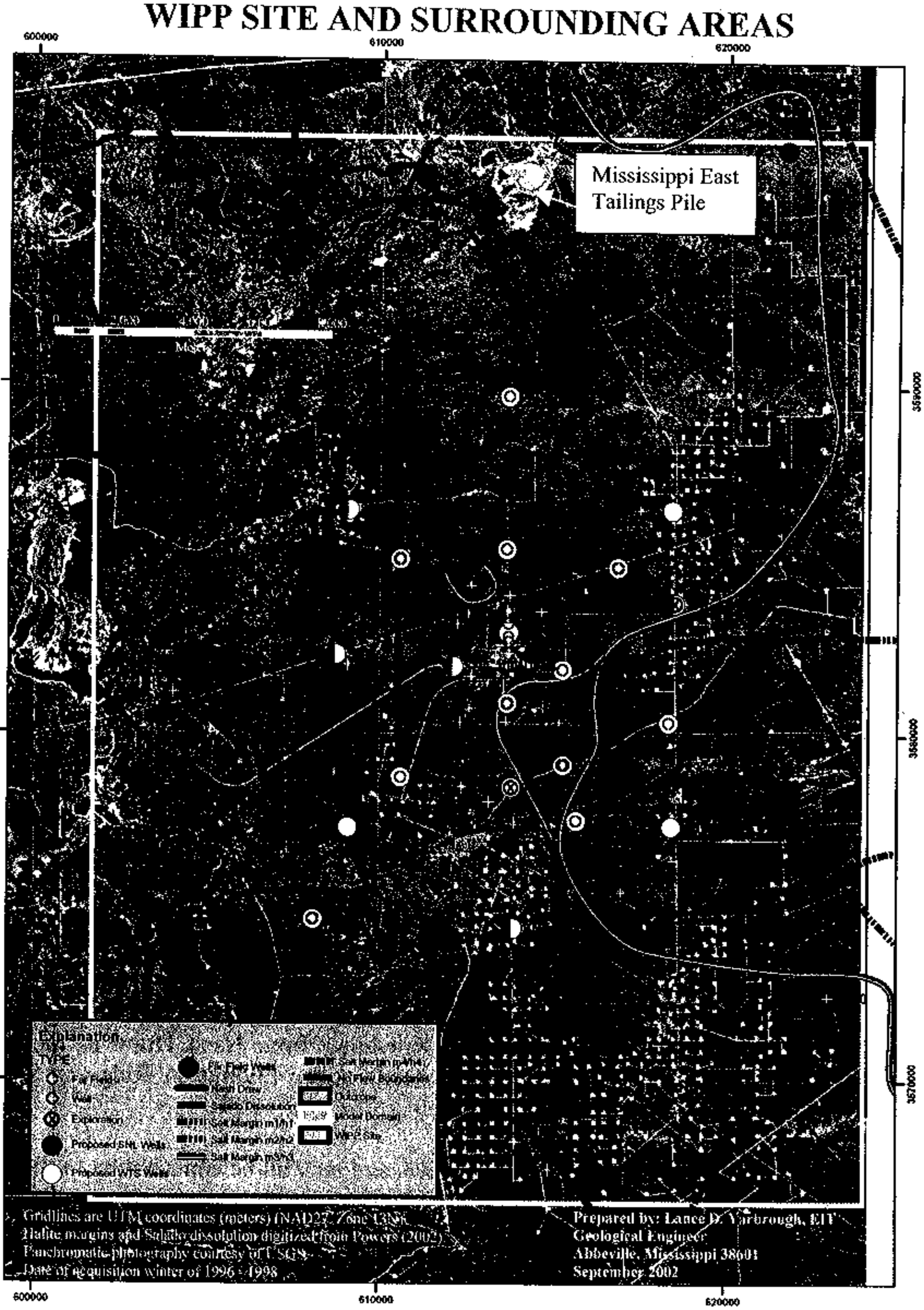


Figure 19. Air-photo map of WIPP area showing halite margins, locations of proposed new wells, and Culebra model domain.

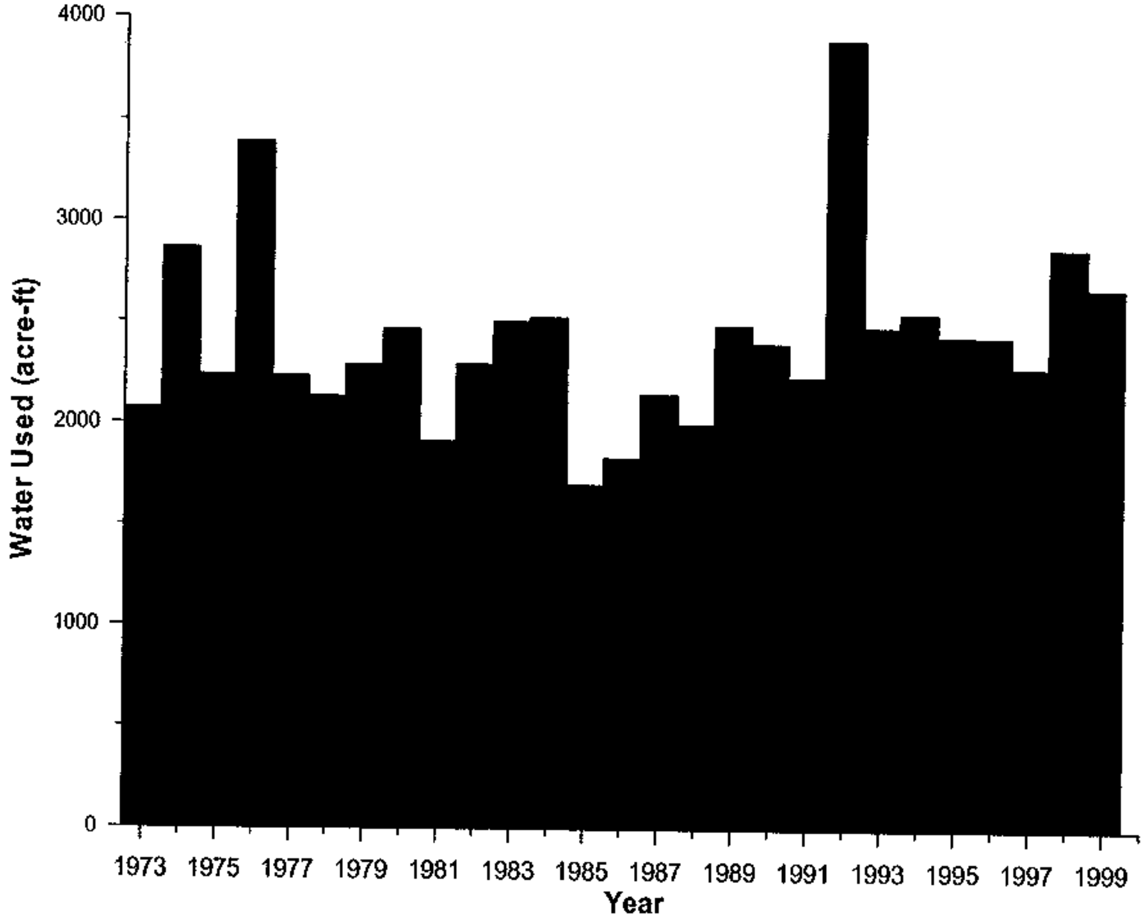


Figure 20. Annual water usage at Mississippi East potash mill location.

WIPP INTEGRATED HYDROLOGY PROGRAM PLAN

At the request of DOE, a Program Plan for a WIPP Integrated Hydrology Program has been developed to describe the hydrology-related activities to be performed between FY03 and FY 2009 to maintain compliance with applicable regulations. The overall objectives of these activities are to resolve questions related to observed water-level changes around the WIPP site, provide data needed for comprehensive modeling of WIPP hydrology, construct a groundwater monitoring network that can be maintained throughout the operational period of WIPP, and plug and abandon deteriorating steel-cased wells. This Program Plan (from which sections of this chapter have been abstracted) details the compliance drivers for the activities, discusses the water-level changes and potential causes, describes modeling activities underway and planned for the future, describes field activities (including drilling of new wells) planned to collect additional data, lays out a tentative schedule for these activities, describes well-construction activities, and delineates roles, responsibilities, milestones, and deliverables. The description of the activities to be performed in FY04 and beyond represents the best current estimate of the work that will be needed, but these activities are necessarily contingent on the results of previous years' activities.

The Program Plan has undergone two cycles of review by an independent review team appointed by DOE. The plan is currently being revised in response to the second set of comments.

CULEBRA T-FIELD REASSESSMENT

For the CCA, a basin-scale conceptual model of WIPP hydrology was developed and evaluated using a three-dimensional numerical model (Corbet and Knupp, 1996). In this conceptual model, groundwater flow in the Culebra in the vicinity of the WIPP site is considered a portion of a larger hydrologic system that includes all of the strata overlying the Salado Formation. This system extends laterally well beyond the WIPP site to the boundaries of the groundwater basin. A continuous water table extends across this basin, generally in the Dewey Lake Redbeds, although in some locations it may be present in rock of such low permeability that it is not easily observed. The shape and elevation of the water table largely determine rates and directions of groundwater flow in the Culebra and other units. The water table and modern-day pattern of groundwater flow have not fully equilibrated to the drier climate that has prevailed since the end of the Pleistocene, with the result that water levels might be expected to be slowly declining. Water levels might rise or fall by a few meters over a period of centuries, however, in response to cycles of wetter and drier climate that have occurred over the past 8,000 years. The lag time between a climate change and the resulting water-level change is probably several centuries.

Dissolution of the upper Salado, and associated subsidence, collapse, and fracturing, have resulted in a zoned distribution of permeability in the overlying units. Permeabilities are orders of magnitude higher in areas where dissolution has disrupted stratigraphic layering than in areas where the strata are intact. The WIPP site lies in the transition region between these two areas. None of the water in the Culebra at the WIPP site is thought to originate where the Culebra crops out or where overlying units have been removed or fractured (i.e., west and northwest of WIPP), but instead is thought to come from the east and northeast. The time required for water to travel from the water table upgradient of WIPP to the Culebra at the WIPP site is probably on the order of thousands to tens of thousands of years. Within the WIPP site boundary, groundwater inflow to the Culebra is predominantly from lateral flow, with a minor component coming from very slow leakage from the overlying Tamarisk—none of it comes from precipitation on the WIPP site land surface. Nearly all of the groundwater within the Culebra exits the WIPP site by lateral flow, so treating the Culebra as a fully confined aquifer was considered a reasonable approach to simulating off-site transport of radionuclides.

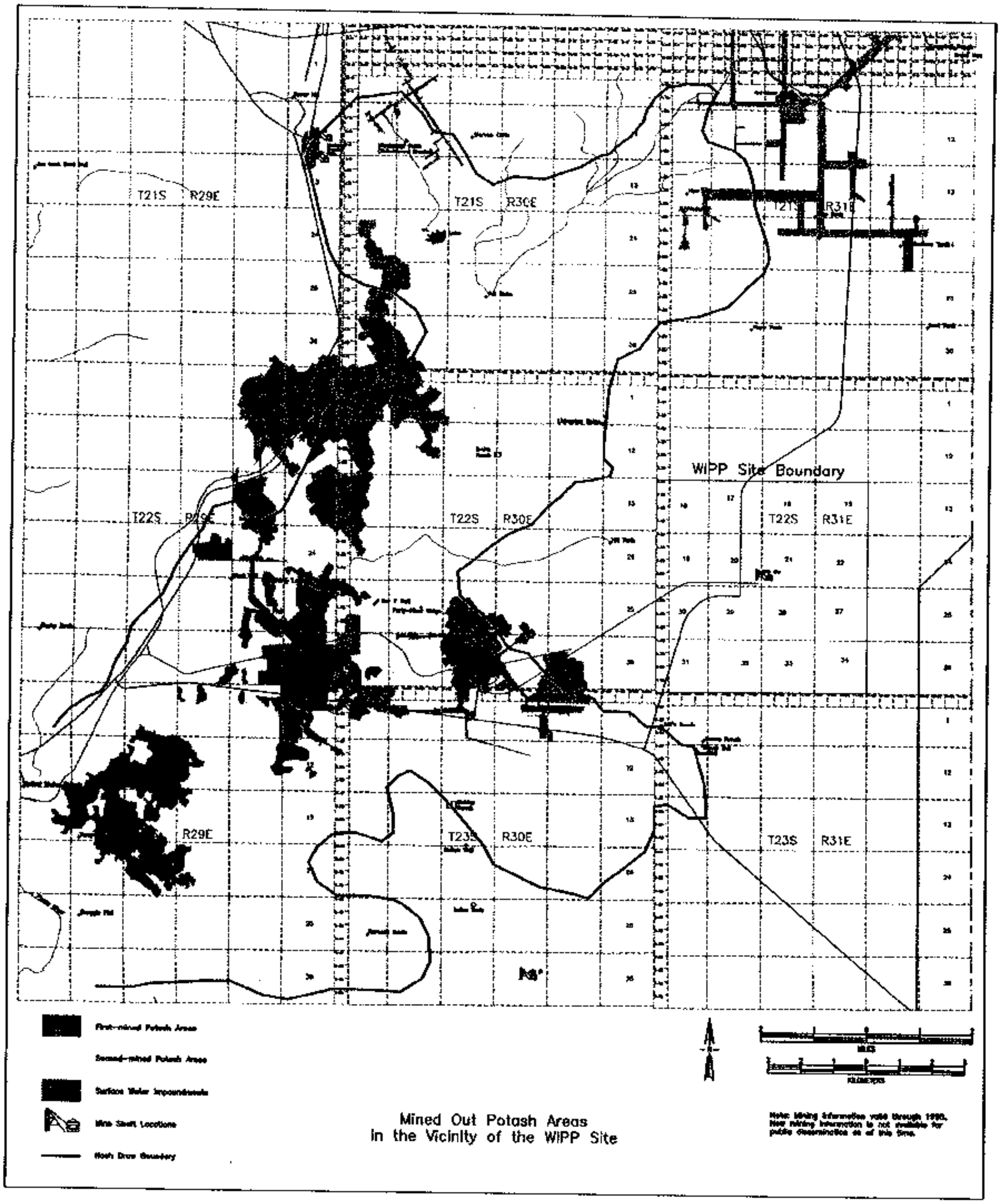


Figure 21. Mined areas in Nash Draw.

Because of the distance of the WIPP site from the natural hydrologic boundaries of the groundwater basin and the long times required for changes in the boundary conditions to be manifested at WIPP, it was assumed for the CCA that, except for the residual hydrologic effects of WIPP's own activities, the Culebra at WIPP could be considered to be under steady-state conditions. Culebra T fields were generated by, first, kriging the values of T inferred from hydraulic tests at individual wells to generate continuous distributions of T over the model domain. This was done using indicator categorical simulation to preserve the observed difference between low-T (log $T < -5.9\ m^2/s$) and high-T regions of the Culebra (see Appendix TFIELD in DOE, 1996). These T fields were then calibrated using a pilot-point method to inferred steady-state freshwater head values at 32 wells and to transient responses observed in connection with large-scale pumping tests, shaft construction, and leakage into shafts.

Three sets of 100 equally probable realizations of the Culebra T field were created (CCA replicates 1, 2, and 3). Groundwater flow and radionuclide transport through these T fields were simulated to assess the radionuclide releases that might occur from the WIPP repository to the accessible environment under undisturbed conditions, conditions of increased potash mining near WIPP in the future, and potential human intrusion of the repository.

While the conceptual basin-scale model described above is still considered essentially correct, some refinement of it is now thought to be necessary to account for localized conditions as described in the models of Holt and Powers (1988) and Holt (1997). The basin-scale conceptual model was the product, in part, of a 3D regional modeling study using 2-km by 2-km cells. The existence and effects of smaller scale features could not be assessed during that study. Such features might create local conditions different than those predicted by the regional model. In addition, the earlier conceptual model did not include anthropogenic influences that might currently be affecting the system, but instead assumed that, apart from hydrologic disturbances caused by WIPP's own activities, the hydrologic system was essentially at steady state.

Holt and Powers (1988) developed a more detailed conceptual model for the Rustler Formation based on examination of drillhole logs, core, outcrops, and shaft exposures. Holt (1997) later refined this model with respect to the Culebra. Holt and Powers observed four horizons within the Rustler Formation where mudstone is present. In some locations, halite is found with the mudstone at these horizons whereas in other locations it is not. They identified these horizons, shown in Figure 22, as follows:

- m1/h1—below the anhydrite layer in the middle of the Los Medaños Member,
- m2/h2—immediately below the Culebra at the top of the Los Medaños Member,
- m3/h3—between anhydrite layers in the lower Tamarisk Member, and
- m4/h4—between anhydrite layers in the middle of the Forty-niner Member.

Based on drillhole logs, they mapped the margins of the halite-bearing zones as shown (updated with more recent information) in Figure 19. The Rustler dips to the east from Nash Draw, and halite is found east of the margins, where the Rustler is buried more deeply.

Whereas early researchers (e.g., Snyder, 1985) interpreted the absence of halite west of these margins as evidence of dissolution, Holt and Powers (1988) interpreted it as reflecting changes in the depositional environment, not dissolution. In their model, the only place where dissolution of Rustler halite may have occurred is along the present-day margins.

The occurrence (or not) of dissolution is important because of its possible effects on the hydraulic properties of overlying units. Nash Draw, to the west of the WIPP site, is an area where dissolution of the upper Salado has occurred, resulting in subsidence and collapse of the overlying Rustler. Figure 19 shows how the eastward limit of dissolution of the upper Salado interpreted from drillhole logs coincides with the surface expression of Nash Draw. The Culebra is fractured and orders of magnitude more transmissive in Nash Draw than it is east of the WIPP site. Presumably, dissolution of halite from Rustler units would also result in increased transmissivity in the overlying dolomites.

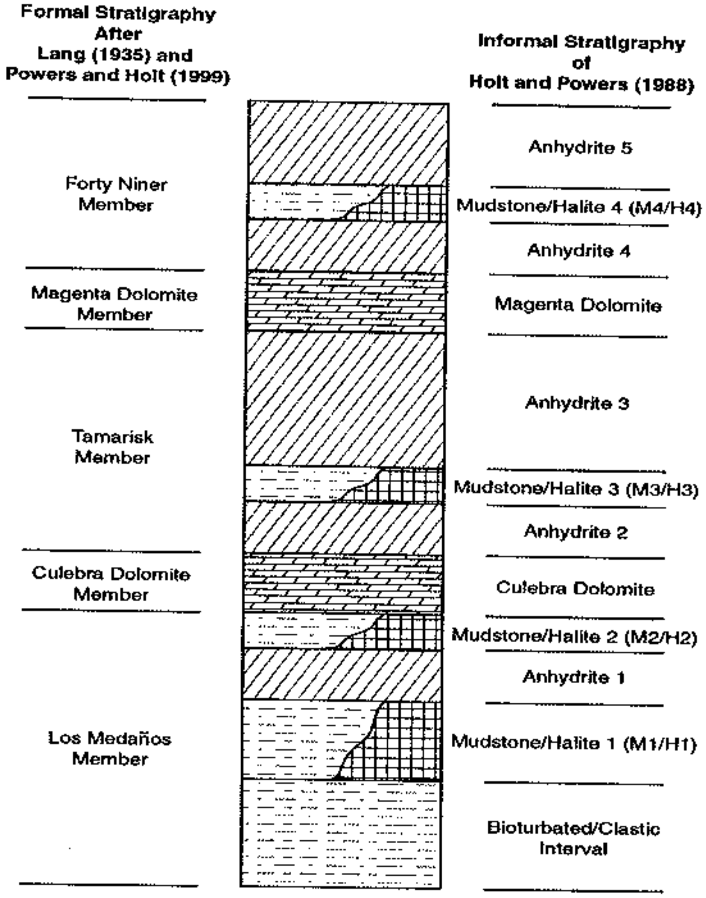


Figure 22. Stratigraphic subdivisions of the Rustler Formation.

Culebra transmissivity varies over three orders of magnitude on the WIPP site. If this variation is not caused by dissolution of Rustler halite, what is its source? According to Holt (1997), the spatial distribution of Culebra transmissivity is largely a function of a series of deterministic geologic controls, including Culebra overburden thickness, dissolution of the upper Salado Formation (already discussed), and the occurrence of halite in units above or below the Culebra. Overburden thickness is a metric for two different controls on Culebra transmissivity. First, fracture apertures tend to decrease with increasing overburden thickness, which should lead to lower transmissivity where Culebra depths are great. Second, erosion of overburden leads to stress-relief fractures, and the amount of Culebra fracturing increases as the overburden thickness decreases. Thus, generally speaking, Culebra transmissivities should increase from east to west as overburden thickness decreases.

All wells (e.g., H-12) located where halite occurs in the m2/h2 or m3/h3 intervals show low Culebra transmissivity. Transmissivity data are limited in this region, but it is unlikely that halite would survive in regions of high transmissivity because halite units are very close (several m) to the Culebra and would likely be dissolved by under-saturated Culebra waters. Therefore, it is assumed that high-transmissivity zones do not occur in regions where halite is present in the m2/h2 or m3/h3 intervals. In regions where halite is present in both the m2/h2 and m3/h3 intervals, no reliable estimates of Culebra transmissivity are available. Based upon geologic observations of halite-bound units elsewhere within the WIPP area, Holt (1997) suggests that porosity within the Culebra may contain abundant halite cements in these areas and transmissivity is correspondingly low. High-transmissivity zones within the Culebra occur between areas affected by Salado dissolution and areas where halite is present in the m2/h2 and m3/h3 intervals. In these zones, fractures are well interconnected, and fracture interconnectivity is controlled by a complicated history of fracturing with several episodes of cement precipitation and dissolution (Beauheim and Holt, 1990; Holt, 1997). No clear deterministic controls on high transmissivity have been identified in the region east of the Salado dissolution limit but west of the m2/h2 and m3/h3 halite margins, so the distribution of high T in this region is treated as the product of a stochastic process.

Development of a new generation of T fields based on the conceptual model presented above was begun in FY02 (Beauheim, 2002). The approach taken in development of the new Culebra T fields involved, first, defining a statistical correlation between Culebra transmissivities inferred from tests at individual wells and the thickness of overburden, taking into account geologic factors including the occurrence of dissolution of the upper Salado Formation, the presence of halite above or below the Culebra, and position between the m2/h2 and m3/h3 halite margins and the limit of Salado dissolution (Figure 23; Holt (2002)). This correlation was then used in combination with maps of the geologic factors (which are based on data from many more boreholes than those from which Culebra T information is available) to create 100 equally likely realizations of the Culebra transmissivity distribution ("base" T fields) over the domain of interest (e.g., Figure 24).

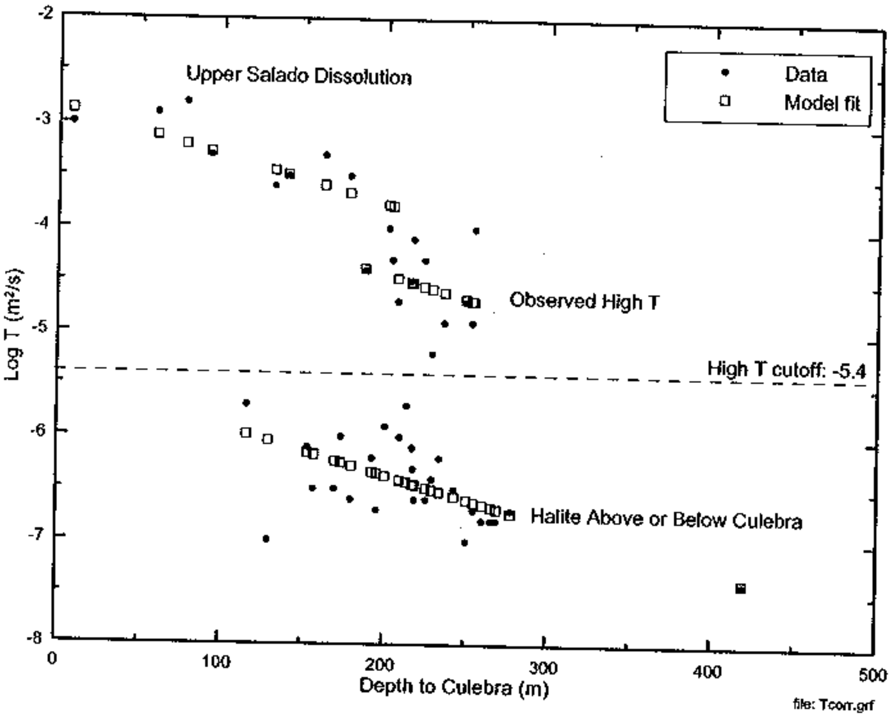


Figure 23. Correlation between Culebra T and overburden thickness for different geologic environments.

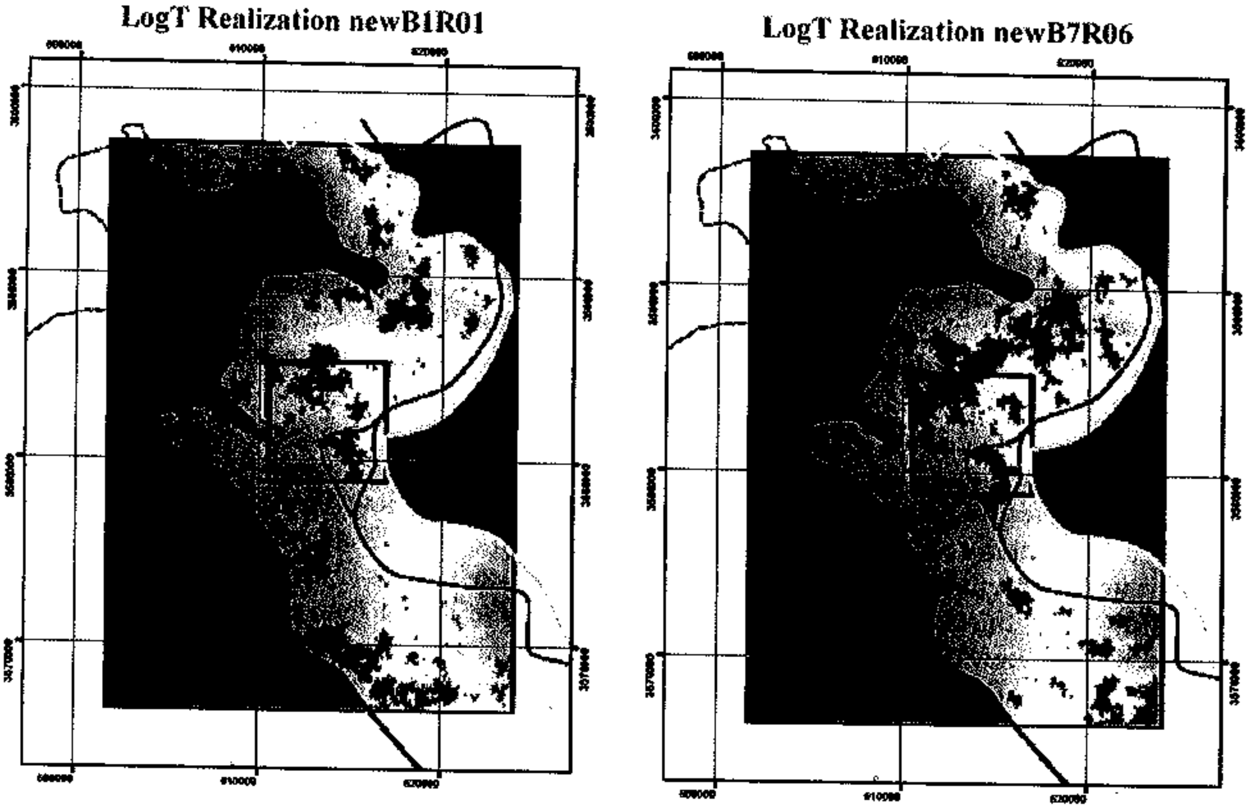


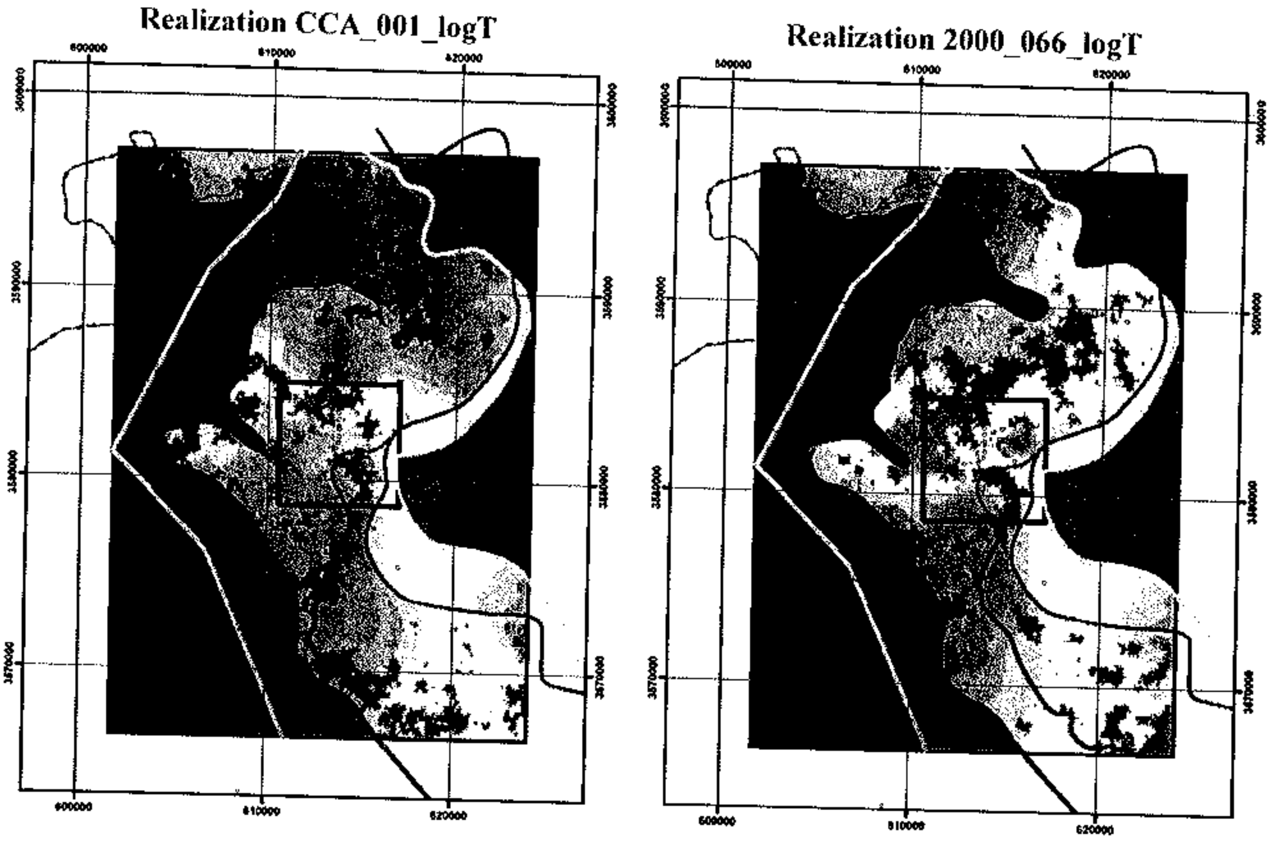
Figure 24. Example base T fields.

The modeling domain consists of a rectangle 22.3 km by 30.6 km in extent. It covers an area similar to that modeled in the CCA, but is oriented with its long axis extending from north to south, parallel to the principal flow direction in the Culebra, like the model domain of LaVenue et al. (1990). The modeling is being performed using MODFLOW 2000 with a uniform grid of 50-m by 50-m elements. Heads are specified for all boundaries except on the west. The northern model boundary is slightly beyond the limit of existing data, and coincides with an inferred groundwater divide. The eastern boundary lies in a region of inferred low transmissivity, where the 3D model of Corbet and Knupp (1996) indicates flow is due west. The southern boundary is slightly beyond the limit of existing data, in an area where flow is believed to be to the south. The western boundary of the model domain passes through Nash Draw. Groundwater is believed to flow both down the main axis of Nash Draw from northeast to southwest, and down the axis of the southern arm from northwest to southeast. Thus, flow lines along these axes are used as no-flow boundaries within the model domain (see green diagonal lines on Figure 19).

The base T fields described above are being used to evaluate the effect, if any, of simple increases in head on the inferred distribution of Culebra transmissivity. It is hypothesized that while the CCA assumption of Culebra heads being in steady state may have been incorrect, this would have no effect on the calibration of the T fields. As long as the heads used for calibration were in equilibrium with the boundary conditions on the system and both were reasonably defined in the model, an appropriate representation of the Culebra T fields should have been obtained. Thus, the major objective of this activity was to develop T fields using heads from three different time periods to show whether or not the calibration is significantly affected if the equilibrium state of the overall system changes. The groundwater travel time from above the center of the WIPP disposal panels to the WIPP site boundary (accessible environment) is being used as the metric by which a "significant" change to the T-field calibration is judged.

Calibration is performed using the parameter-estimation code PEST (a code currently being qualified by Sandia) and pilot points to modify the base T fields as little as possible while bringing simulated heads into agreement with measured heads. The base T fields have been conditioned to Culebra hydraulic heads representing equilibrium conditions at 10-year intervals (i.e., 1980, 1990, and 2000) and also to the "steady-state" heads used in the CCA (Table 5), producing four sets of 100 realizations of the Culebra T field (e.g., Figure 25).

To determine how much effect the differences in head have on the resulting T fields, cumulative distribution functions (CDF's) of the groundwater travel times from a point above the center of the waste-disposal panels to the WIPP site boundary have been generated for each set of 100 realizations. These CDF's have been compared to a CDF generated of the travel times determined for replicate 1 of the CCA transient-calibrated T fields (Figure 26). Figure 26 shows that the travel times in the four new sets of T fields are longer than those given in the CCA. However, the new T fields have not yet been calibrated to transient heads, and the process of transient calibration has been found in the past to decrease travel times.


Realization CCA_001_logT

Realization 2000_066_logT

Figure 25. Example equilibrium-state-calibrated T fields.

The next step in T-field generation is to calibrate a set of T fields to both equilibrium and transient conditions. The equilibrium conditions that will be used for this step are the 2000 heads, because those heads are closer to current conditions than either the 1980 or 1990 heads, and also produced the fastest travel times. The transient heads that will be used in the calibration represent the responses observed in various wells to the following events:

- construction of, and leakage into, the exploratory (now salt) and ventilation (now waste-handling) shafts,
- the H-3 multipad pumping test,
- the WIPP-13 multipad pumping test,
- the P-14 pumping test,
- the 1995-96 H-19 and H-11 tracer tests,
- the WQSP-1 pumping test, and
- the WQSP-2 pumping test.

Table 3. "Equilibrium-State" Heads Used in T-field Calibration.

Well	CCA Freshwater Head Range (m amsl)	1980 Freshwater Head Range (m amsl)	1990 Freshwater Head Range (m amsl)	2000 Freshwater Head Range (m amsl)
AEC-7	931.2-932.8		930.7-933.4	931.8-934.6
CB-1	910.4-911.8		911.6-913.8	
D-268	915.1-915.6		914.7-916.2	P&A
DOE-1	912.1-918.6		913.1-918.4	914.9-918.2
DOE-2	933.2-936.2		933.1-937.1	**938.0-942.0**
H-1	919.6-923.6	920.5-925.4		**925.6-928.7**
H-2b2	924.7-926.6			925.6-927.6
H-3	912.9-916.7	914.2-918.9		915.7-918.6
H-4b	910.8-912.0	911.1-914.2	**914.1-916.3**	**914.5-916.6**
H-5b	932.8-935.6	932.1-935.8	932.1-935.8	934.4-938.2
H-6b	931.0-933.0	931.4-934.4	930.4-933.5	932.7-935.7
H-7b1	912.6-913.2	911.8-913.2	912.6-914.0	**913.3-914.7**
H-9b	906.3-907.6	**908.0-909.8**	**911.1-913.0**	**910.6-912.5**
H-10b	919.1-923.5	918.3-923.6	918.2-923.4	P&A
H-11	911.4-915.4		912.9-916.0	914.0-917.0
H-12	912.3-914.7		914.0-917.5	912.4-917.0
H-14	916.8-920.8		915.2-916.9	919.0-921.5
H-15	916.0-920.3		914.7-918.0	918.2-921.5
H-17	910.1-911.9		**912.7-915.7**	**914.3-916.4**
H-18	931.3-934.9		932.1-935.3	**935.6-938.8**
P-14	926.0-927.8	926.1-928.8	926.2-928.9	P&A
P-15	917.0-918.6	915.7-920.5	917.2-918.7	P&A
P-17	908.6-910.0		**912.7-915.1**	**914.0-916.4**
WIPP-12	933.5-935.8		930.0-933.4	932.4-935.9
WIPP-13	932.4-935.2		932.3-935.7	933.5-936.8
WIPP-18	929.3-933.5			**934.4-937.8**
WIPP-25	927.7-929.7	925.9-930.5	928.7-931.7	**931.2-934.2**
WIPP-26	918.4-918.9	**915.4-917.1**	**919.2-920.5**	**920.5-921.8**

P&A: plugged and abandoned. **Bold red** signifies heads completely outside the CCA range.

Table 4. "Equilibrium-State" Heads Used in T-field Calibration cont.

Well	CCA Freshwater Head Range (m amsl)	1980 Freshwater Head Range (m amsl)	1990 Freshwater Head Range (m amsl)	2000 Freshwater Head Range (m amsl)
WIPP-27	937.4-938.8	**940.6-944.2**	938.0-940.3	**939.8-942.2**
WIPP-28	936.3-938.4	934.1-937.1		P&A
WIPP-30	932.8-935.0		934.0-936.8	**935.5-938.3**
USGS-1	909.7-910.2			

P&A: plugged and abandoned. **Bold red** signifies heads completely outside the CCA range.

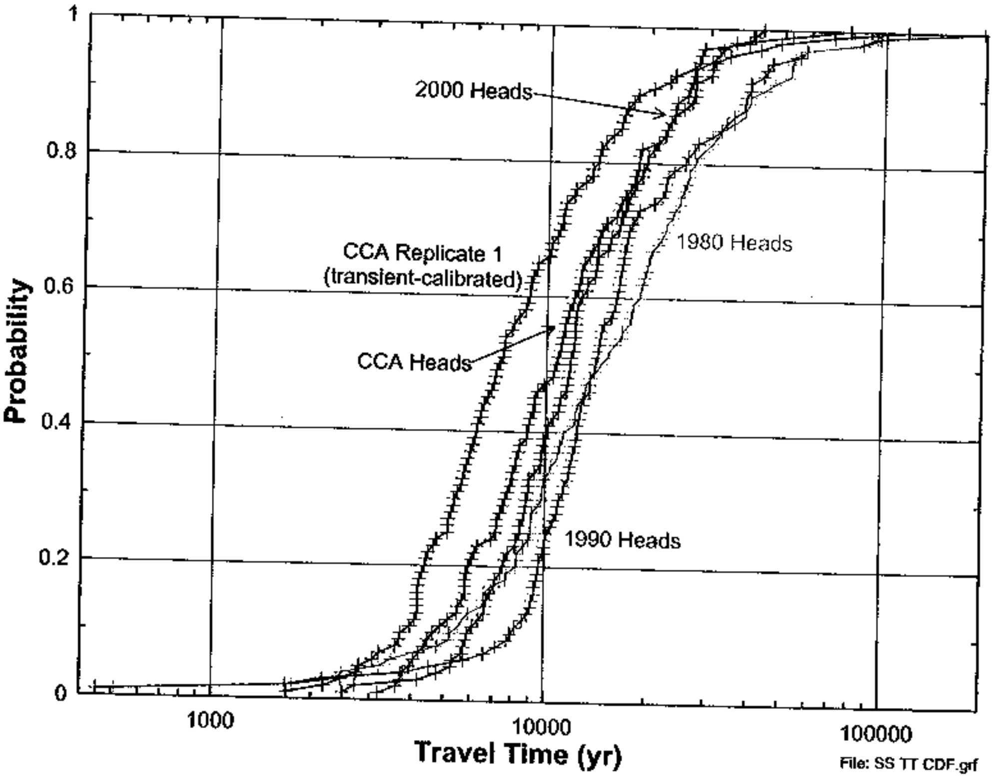


Figure 26. Comparison of travel time CDF's.

Additional geophysical logs have recently been obtained, primarily from oil wells drilled in the past few years, to allow better definition of the Salado dissolution line shown in Figure 19 and also better definition of the depth to Culebra. As a result, the base T fields used for the transient calibration will be slightly different (improved) from those used for the equilibrium-state calibration.

Once the calibration is completed, a CDF of the travel times will be generated for comparison to the CCA replicate 1 CDF shown in Figure 26. The new T fields will be used in the Compliance Recertification Application (CRA) to calculate flow paths and velocities through the Culebra under undisturbed and human-intrusion scenarios. The transient-calibrated T fields will also be altered to represent the potential effects of future potash mining as was done for the CCA. Transport through the new T fields under all of these scenarios will be calculated using SECO-TP.

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