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Exhaust Shaft Hydraulic Assessment Data Report

Prepared for:

Westinghouse
Waste Isolation Division
P.O. Box 2078
Carlsbad, New Mexico 88221

Prepared by:

INTERA
A Duke Engineering & Services Company
1012A West Pierce St.
Carlsbad, New Mexico 88220

6850 Austin Center Blvd., Suite 300
Austin, Texas 78731

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ABSTRACT

Surface geophysical investigations mapped conductive zones related to water leaking into the Exhaust Shaft. These surveys were used to locate five boreholes drilled to depths of up to 100 feet below ground surface (bgs) as part of a hydraulic assessment program to evaluate source(s) of fluid seeping into the Exhaust Shaft at the Waste Isolation Pilot Plant (WIPP) site located in southeastern New Mexico. Four boreholes (C-2505, C-2506, C-2507 and ES-001) penetrated water-bearing horizons between 48 and 63 feet bgs located in sandstones of the lower Santa Rosa Formation, and mudstones of the upper Dewey Lake Formation. Three boreholes (C-2505, C-2506, and C-2507) were drilled and selectively cored and completed as wells to determine the stratigraphic horizons producing fluid, to evaluate hydrologic parameters of saturated horizons, and possibly to de-water the shaft area. Slug and pump test data indicate hydraulic conductivity values range from 5.48×10^{-5} to 1.56×10^{-6} m/sec, with storativity values from 1.11×10^{-2} to 9.38×10^{-3}. Well C-2506 has an estimated 24-hour maximum sustainable pumping rate of about 0.5 gallons/minute (gpm). Water-level measurements from the three wells indicate a hydraulic gradient of about 28 ft/100 ft at S 20° W. Two other boreholes, ES-001 and ES-002, were drilled to depths of 54 feet and 19 feet, respectively, to investigate the nature of the Mescalero caliche. In four boreholes (C-2505, C-2506, C-2507, and ES-001), fluid samples were collected and the water-quality analyzed to identify trends and possible fluid sources into the Exhaust Shaft. Water-quality analysis of fluid samples indicates total dissolved solids ranging from a high of 11,500 milligrams/liter (mg/l) in C-2506 and 8,550 mg/l in C-2505 near the Exhaust Shaft to 4,510 mg/l in ES-001 and 4,000 mg/l in C-2507 moving to the south. In addition, reported trace-metal concentrations, including lead, are well below New Mexico Water-Quality Control Commission Standards, except for several selenium results.

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3.2.3 Borehole C-2507

Borehole C-2507 was drilled on October 1, 1996 and completed to a total depth of 72 feet bgs using a hollow-stem auger and a rotary-cone reaming bit on October 2. Core samples were collected during drilling from 39 to 63 feet bgs and these samples were used to describe the geologic materials in the formations encountered (Appendix D). Core-sample recovery averaged 95%. C-2507 was reamed to a diameter of approximately 8 inches from ground surface to 72 feet bgs in order to set a 4-inch PVC casing and well screen.

A saturated formation was encountered in interbedded grey sandstone, siltstone, and mudstone to claystone of the upper Dewey Lake Formation during the recovery of the core samples from 49.0 to 54.0 feet bgs on October 1. On the morning of October 2, a water-sample was collected from C-2507 using a disposable bailer. The sample was sent to the laboratory for analysis (Appendix C). Field analysis indicated that the specific conductivity of the water recovered from C-2507 was 5,050 µmhos/cm @25°C (Table 3.1). Before reaming C-2507, the water level was 42.55 feet bgs on the morning of October 2.

3.2.4 Borehole ES-001

Borehole ES-001 was drilled on October 2, 1996 to a total depth of 54 feet bgs using a hollow-stem auger. ES-001 is located approximately 100 feet south of the Exhaust Shaft and was drilled to confirm the stratigraphic information from C-2505, C-2506, and C-2507 and, if possible, to obtain a water sample. Core samples were not collected during drilling. Observations of the drill cuttings indicated that the thickness of the Mescalero caliche was approximately one foot.

A saturated formation was encountered during drilling from 49.0 to 54.0 feet bgs on October 2. On the morning of October 3, a water-sample from ES-001 was collected using a disposable bailer. The sample was sent to the laboratory for analysis (Appendix C). Field analysis indicated that the specific conductivity of the water recovered from ES-001 was 5,890 µmhos/cm @25°C (Table 3.1). Before water sampling ES-001, the water level was 43.14 feet bgs. After water-level measurements and sampling, ES-001 was backfilled to land surface with drill cuttings and bentonite gel.

3.2.5 Borehole ES-002

Borehole ES-002 was drilled on October 3, 1996 to a total depth of 19 feet bgs using a hollow-stem auger and split-spoon sampler. ES-002 is located approximately 75 feet southeast of the Exhaust Shaft and was drilled to investigate the Mescalero caliche. Soil samples were collected with a split-spoon sampler at selected intervals during drilling. These samples indicated that the Mescalero caliche in ES-002 was encountered between 11 and 14 feet bgs. After sampling, ES-002 was backfilled to land surface with drill cuttings and bentonite gel.

3.3 Well Completions

Boreholes C-2505, C-2506, and C-2507 were completed as wells to monitor water levels and to allow hydraulic testing of the water-saturated zones. The wells were cased with a 4-inch I.D. PVC casing with a 0.010-inch slotted screen placed across the water-saturated horizons. The screened intervals were from 45.0 to 65.0 feet bgs in C-2505 and C-2506, and from 44.0 to 68.73 feet bgs in C-2507.

The annulus of each screened interval was filled with 16-30 silica sand. Three linear feet of bentonite pellets were placed above this sand pack to serve as a seal. The remainder of the annular space between the casing and the borehole wall was filled with Portland cement. All wells have a surface completion consisting of a 3-foot by 3-foot concrete pad and a locking, rectangular, steel wellhead to protect the PVC casing Figures 3.1, 3.2, and 3.3 are diagrams of the well completions.

4.0 HYDRAULIC TESTING

Wells C-2505, C-2506, and C-2507 were developed by repeated bailing after completion. All wells appeared to recover quickly following the bailing-induced drawdown. The wells produced muddy sediment during bailing, indicating the need to remove the drilling-related fine material in the wellbore. Following development, the wells were hydraulically tested to develop estimates of the hydraulic properties of the water-saturated horizons. All three wells were tested using slug-injection techniques and a step-drawdown pumping test was conducted in C-2506.

4.1 Water-Level Observations

Water levels have been measured in wells C-2505, C-2506, and C-2507 and borehole ES-001. All boreholes appear to have encountered water at the same elevations in beds ranging over a short interval from the lower Gatuña through the Santa Rosa and the upper Dewey Lake. Figure 4.1 summarizes the water levels observed in these wells. Preliminary analysis of the data indicate that the piezometric surface represented by these data has a gradient of approximately 28 ft/100 ft at S 20° W. Further monitoring of these water levels will be performed to determine if this preliminary estimate is indicative of actual conditions.

4.2 Slug Testing

Slug-injection tests were performed in wells C-2505, C-2506, and C-2507. The tests were conducted by installing a test tool consisting of an inflatable packer with an access port valve (APV), supported by standard 1-1/4-inch black pipe. For testing, the packer was inflated so as to isolate the screened interval and the APV was closed to f the tubing above the packer with the injection fluid. Pressure transducers were installed to monitor the fluid pressures in the test interval and the annulus above the packer.

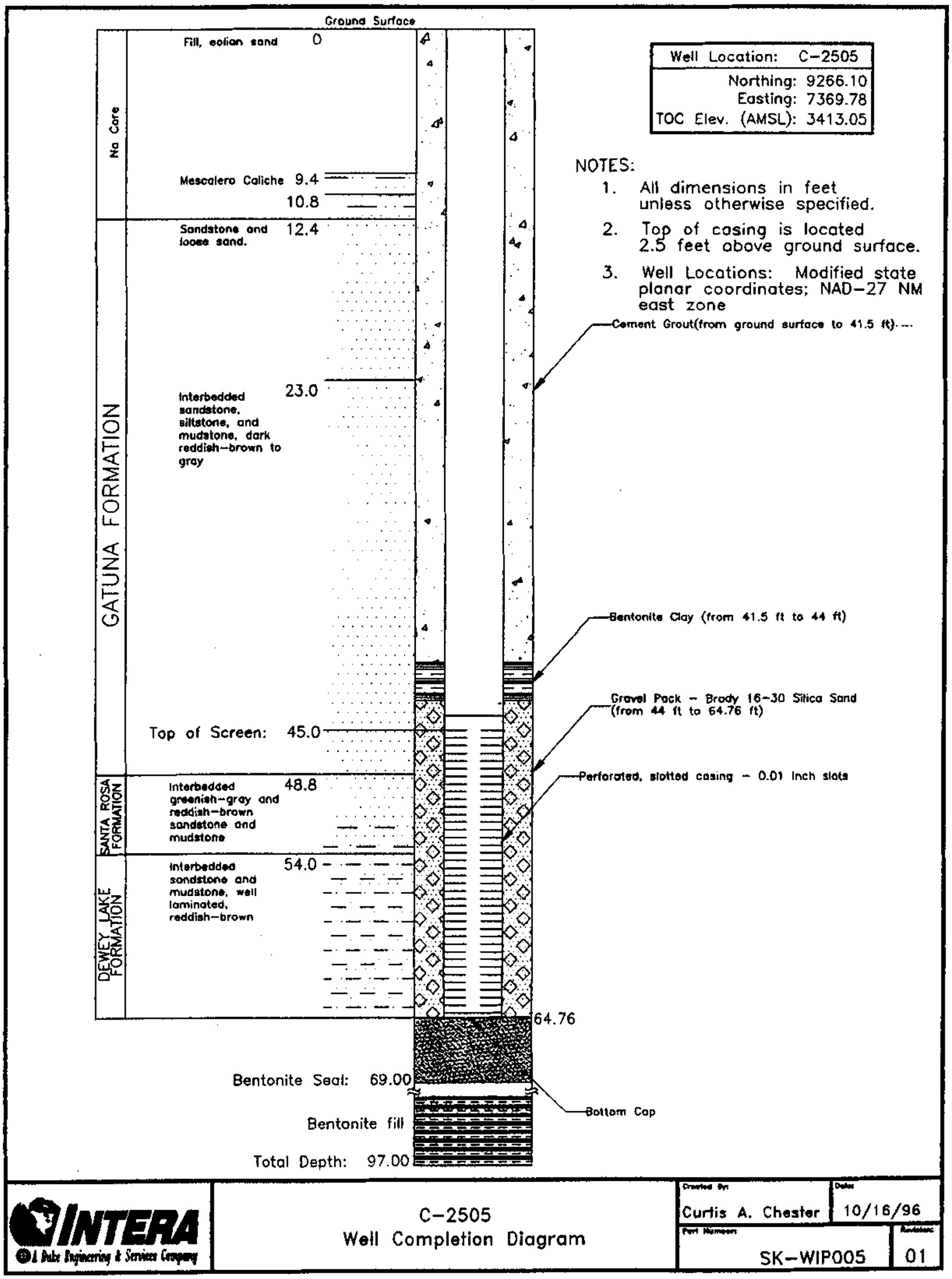


Figure 3.1 Well completion diagram - C-2505

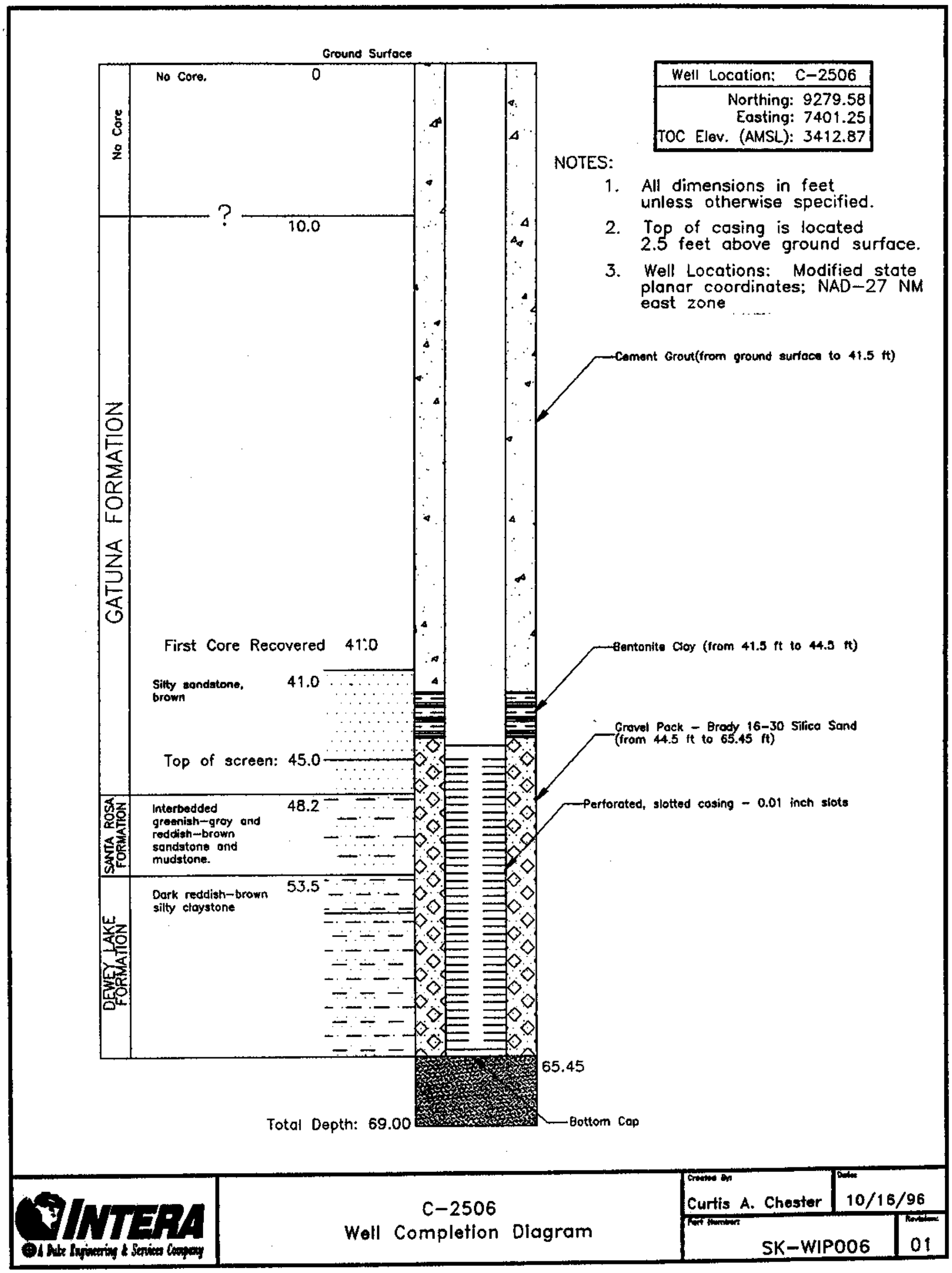


Figure 3.2 Well completion diagram - C-2506

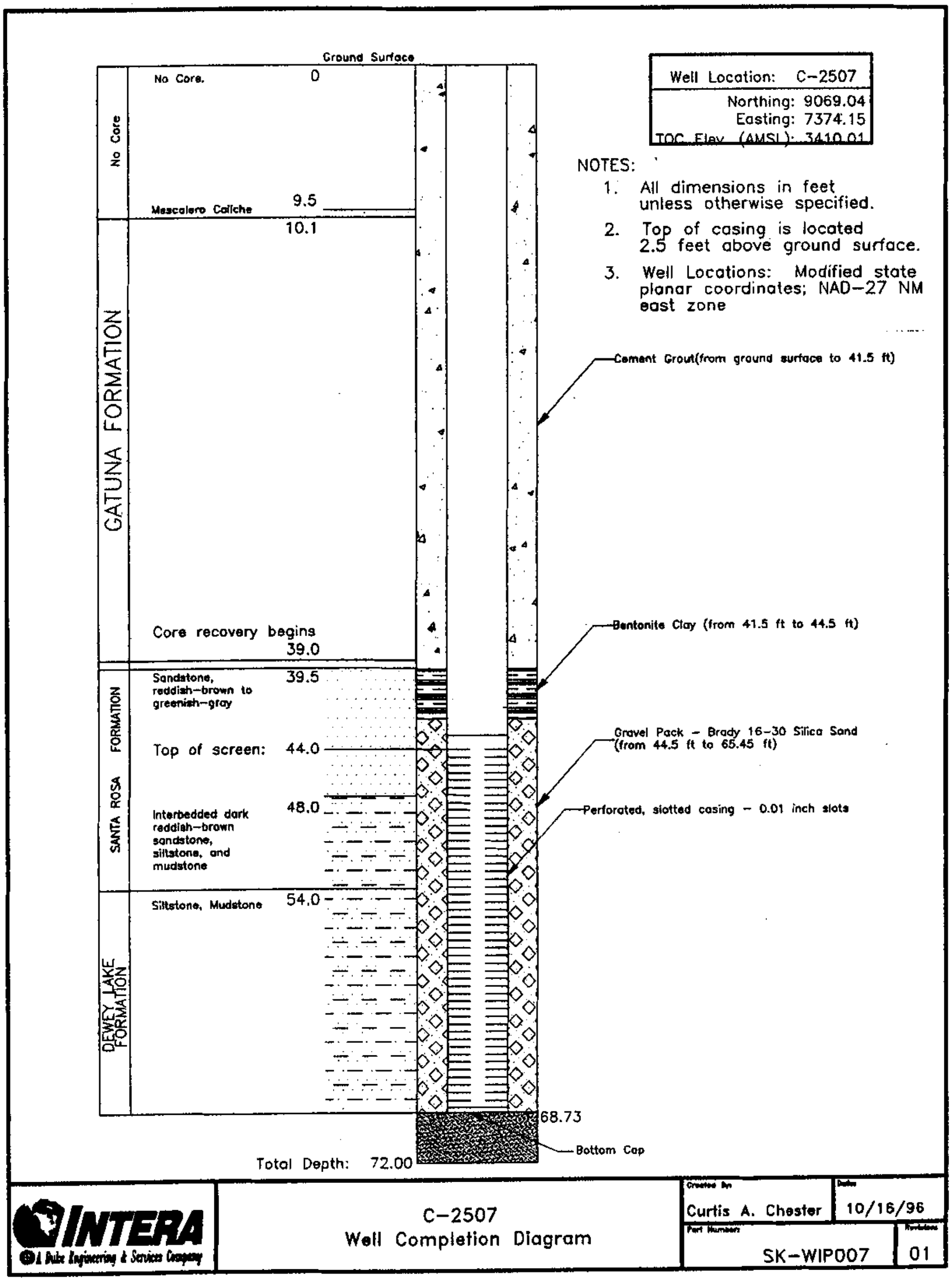
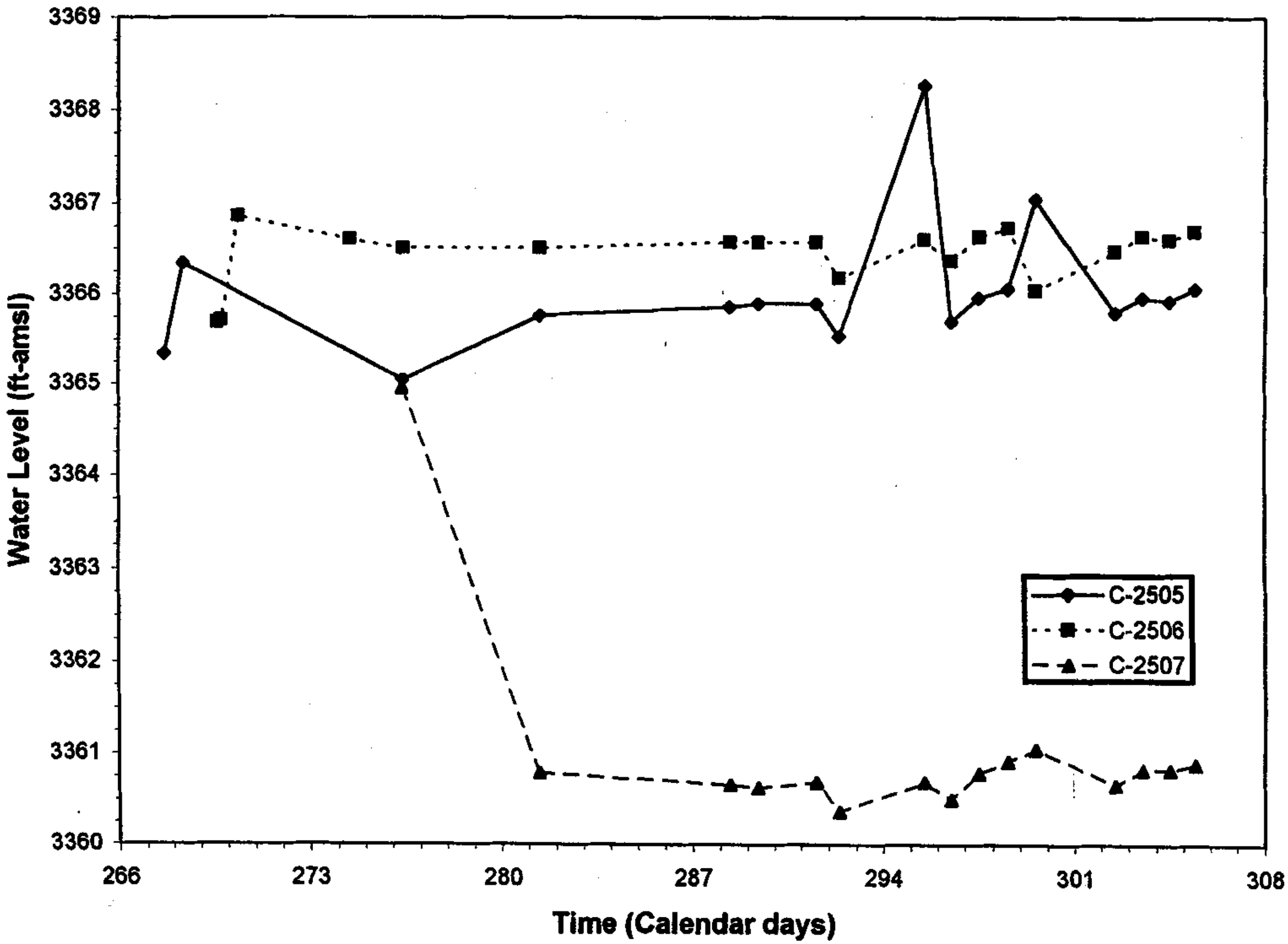


Figure 3.3 Well completion diagram - C-2507


3369
3368
3367
3366
3365
3364
3363
3362
3361
3360
Water Level (ft-amsl)
266
273
280
287
294
301
308
Time (Calendar days)
C-2505
C-2506
C-2507

Testing consisted of installing the test tool and inflating the packer. Once the packer inflation stabilized, the APV was closed and the tubing above the packer was filled with fresh water. Before starting a test, the fluid pressures in the isolated test interval and in the annulus were monitored until they were stable. A test was started by opening the APV allowing the formation to instantaneously be put under a pressure increase and then allow the water in the tubing to flow into the formation. The fluid pressures were monitored through each testing sequence.

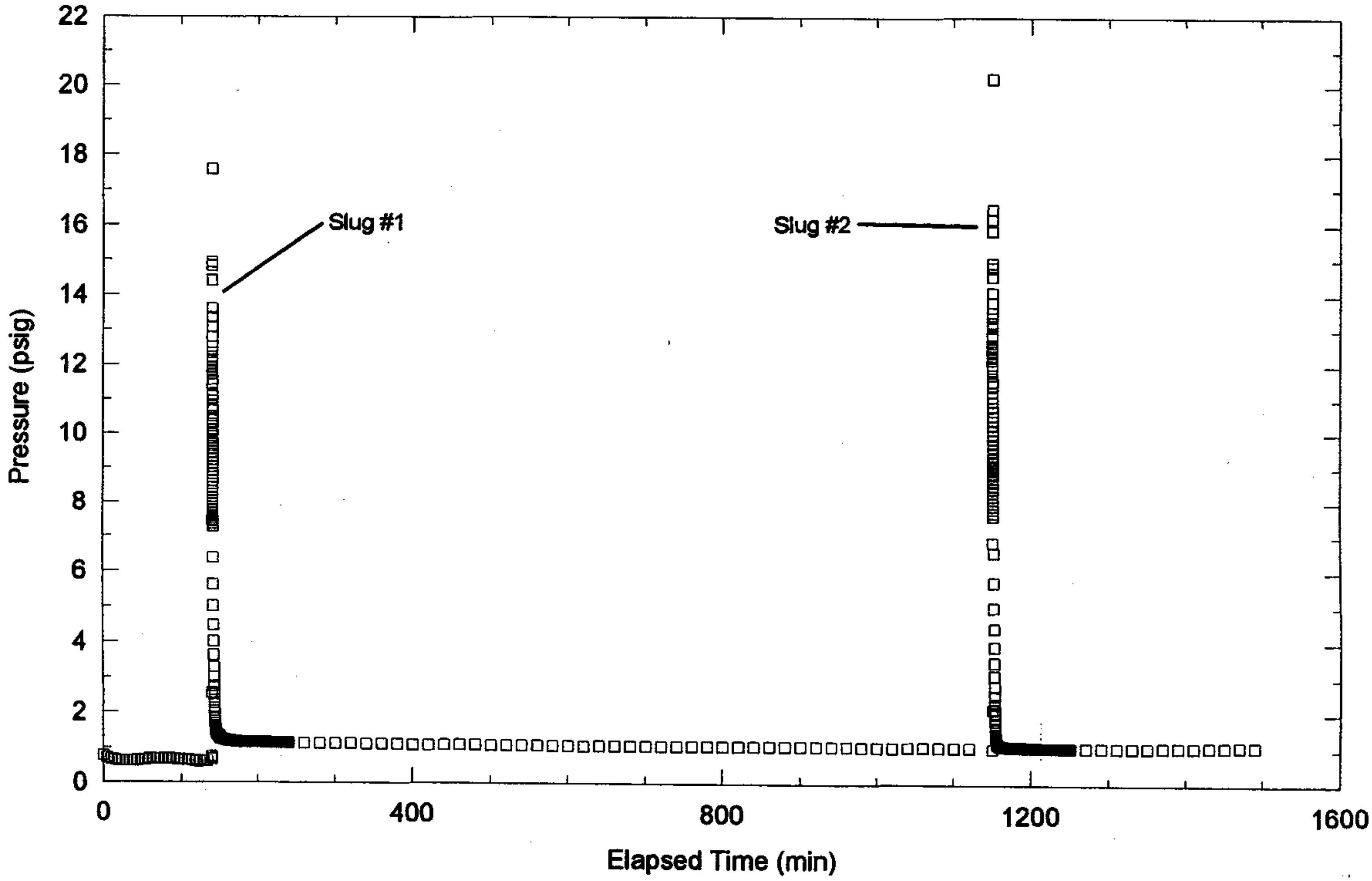
Two slug-injection tests, approximately 4.5 gallons in volume each, were conducted in each of the observation wells, i.e. C-2505, C-2506, and C-2507 between October 1-3, 1996. Figures 4.2, 4.3, and 4.4 are Cartesian plots of the testing sequences. All slug injections were absorbed within approximately 10 minutes. Evaluation of the data indicates that these tests were dominated by wellbore storage, indicating that the applied slug-injection pressures were not great enough to fully stimulate the formations. Because of the limited available head above the water level and the apparently limited thickness (~15 feet) of the water-saturated zones, the relevance of slug testing is limited in these wells.

Interpretations of the slug-injection tests in wells C-2505, C-2506, and C-2507 are probably not reflective of the true formation hydraulic characteristics because the tests did not have sufficient head difference and were not long enough to adequately stress the formations. These tests do indicate, however, that the wells do respond to applied pressures in a relatively rapid manner and may have sufficient transmissivity to sustain some level of pumping, at least as long as necessary to conduct a test to estimate the order of magnitude of the formation's transmissivity.

4.3 Step Drawdown Test

A step-drawdown test was conducted in well C-2506 on October 17, 1996. To conduct this test a ½-horsepower, electric-submersible pump was installed in C-2506 along with pressure transducers to observe the fluid pressure in C-2506. Pressure transducers were also installed in wells C-2505 and C-2507 before and during the pumping and recovery periods. After observing the quantities removed during the bailing of C-2506 and the recovery both to the bailing and the slug-injection tests, pumping rates from 0.25 to 1.0 gallons per minute (gpm) appeared to be appropriate for the step-drawdown testing.

The step-drawdown test in C-2506 consisted of three two-hour, consecutive pumping periods followed by a single recovery period after all pumping was complete. The pumping rates used were approximately 0.28 gpm, 0.60 gpm, and 0.78 gpm. The pumping rate was somewhat unstable during the first pumping period and, for the first two thirds of the two-hour step, the discharge water was turbid and contained enough sediment to impair the operation of the in-line totalizing flow meter. After the water became clear, the pumping rate stabilized for the remainder of the first step, and the pumping rates were very stable during steps 2 and 3. These observations indicate that during the early part of the test, well C-2506 was undergoing additional development. Figure 4.5 is a linear-linear plot of the pressure response versus time in pumping well



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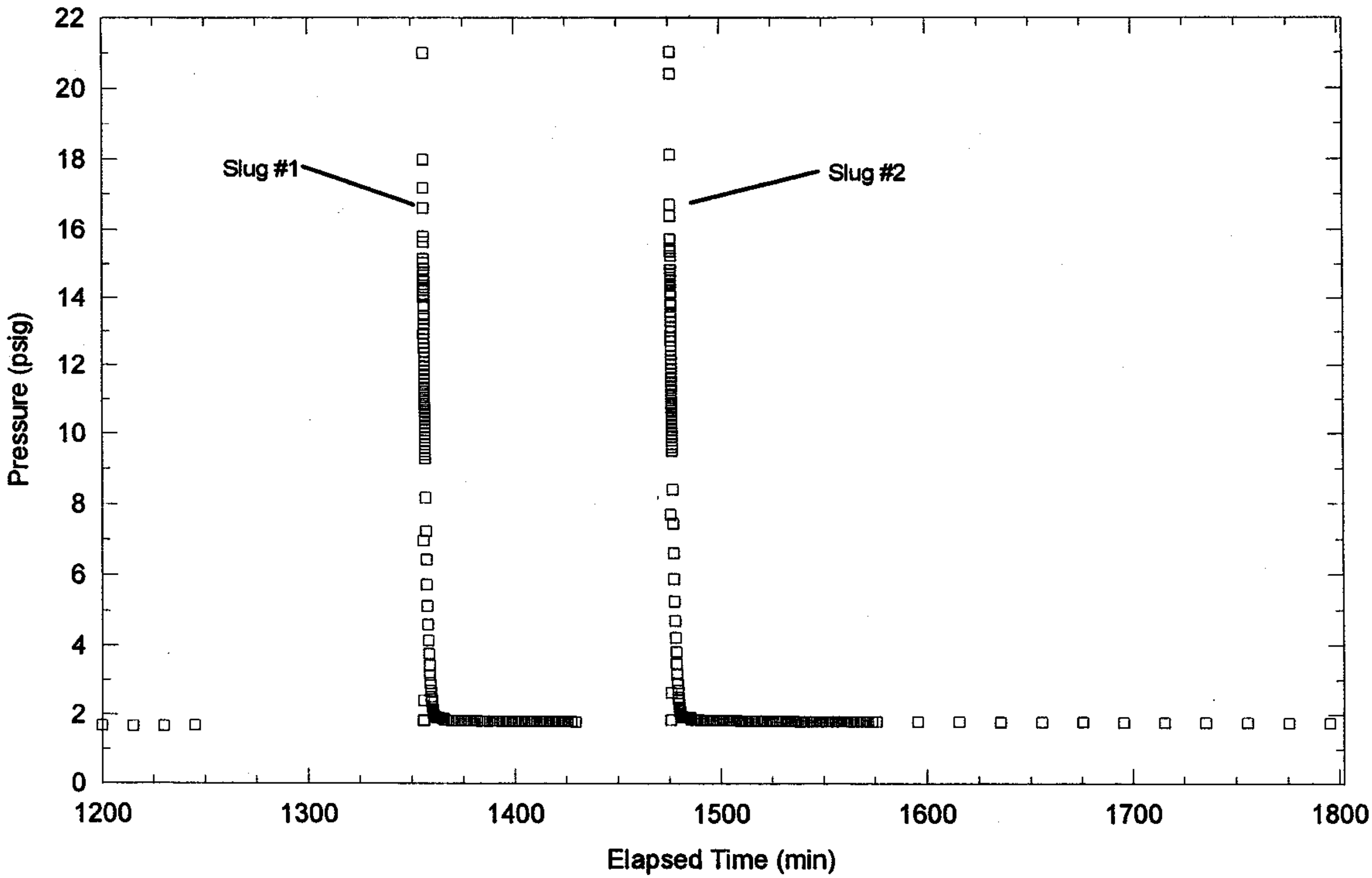
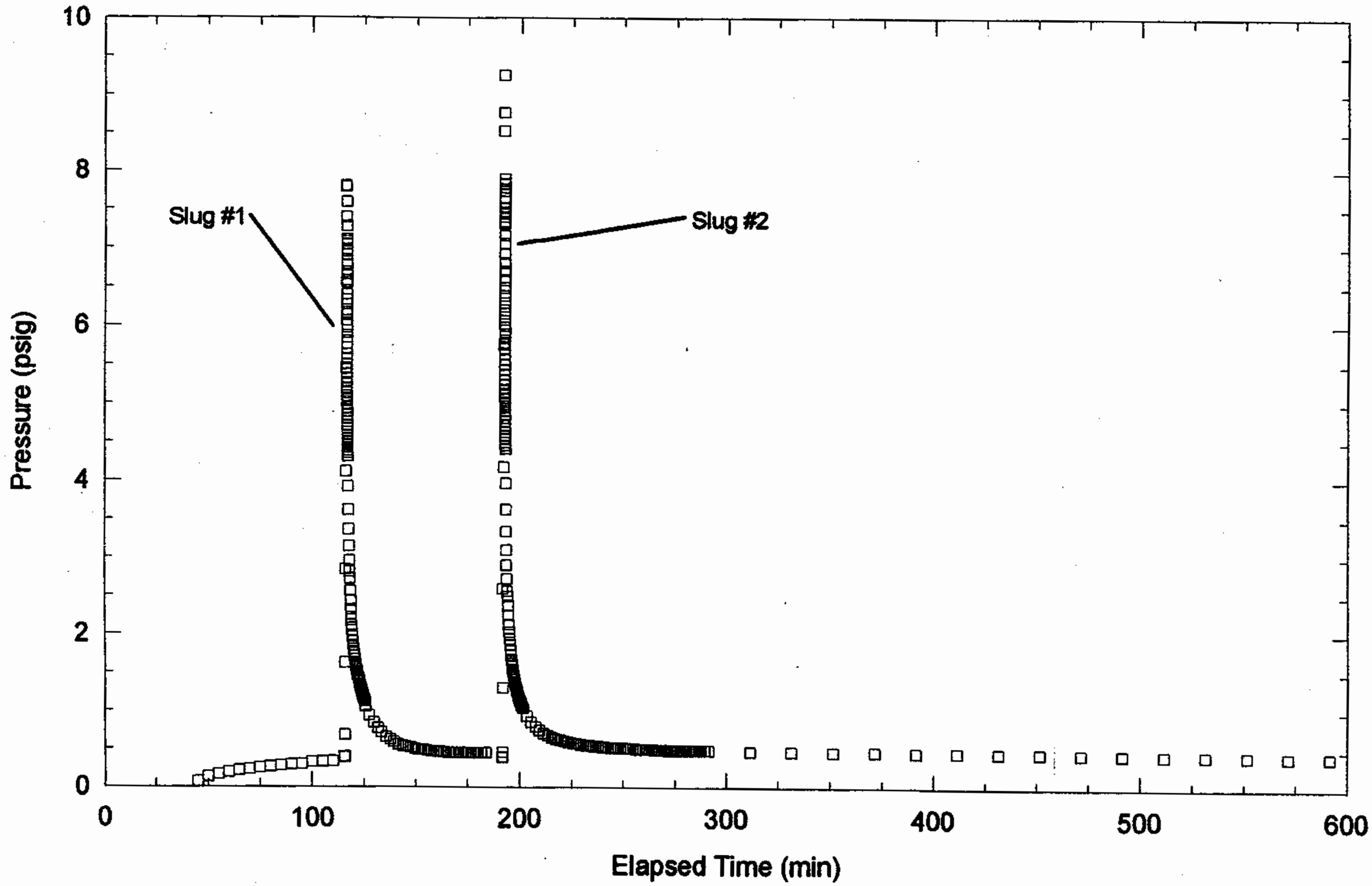


Figure 4.3. Well C-2506 pressure response to slug-injection tests.



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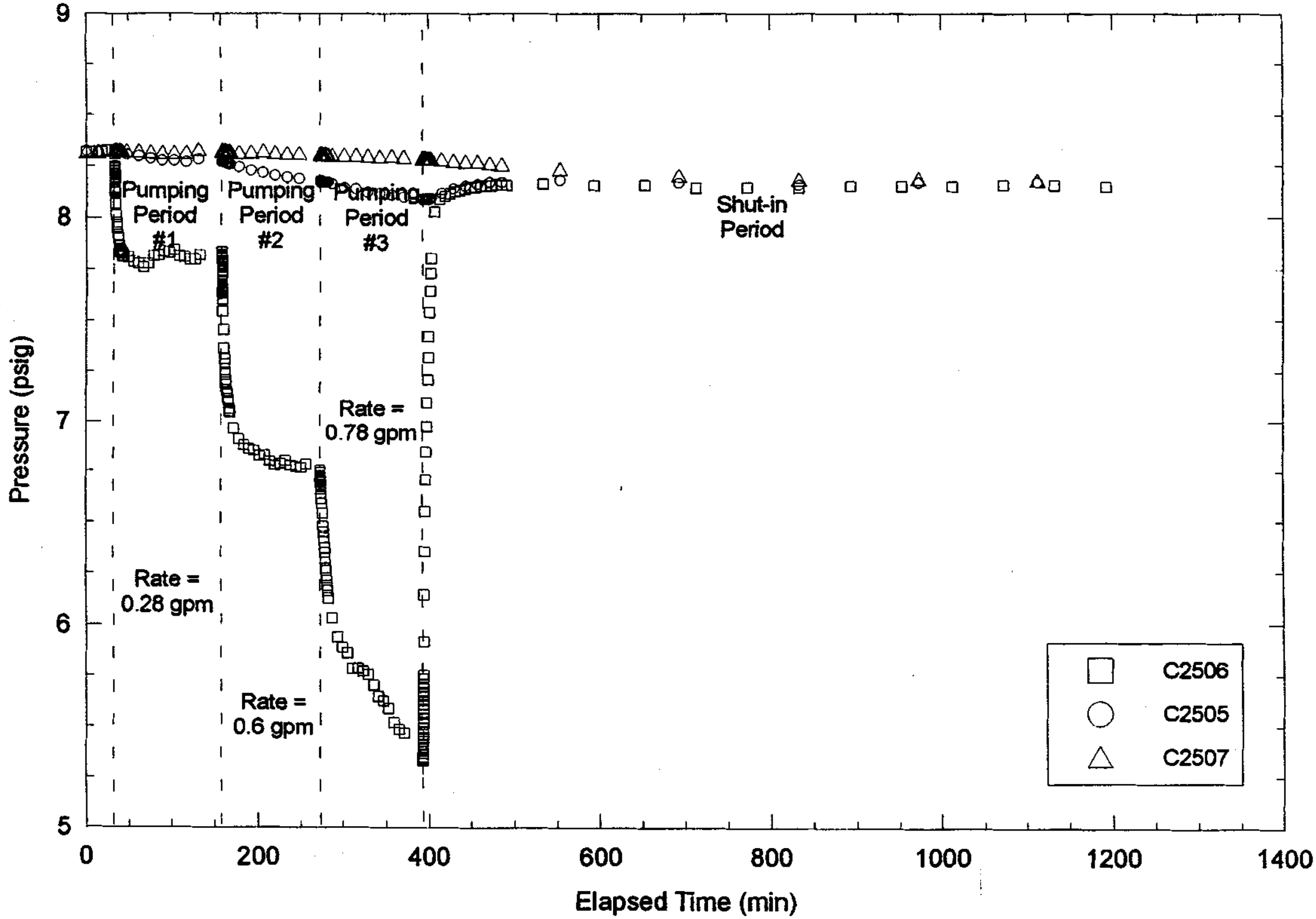


Figure 4.5. Linear plot of pressure response in C-2505, C-2506, and C-2507 to step-drawdown pump test in C-2506.

C-2506 and observation wells C-2505 and C-2507, while Figure 4.6 is a plot of the pumping rate data versus time during the step-drawdown pumping test. Figures 4.7 through 4.9 are simulations of test data representing the best-fit values of transmissi[illegible] and storativity for the pumping well C-2506 and observation wells C-2505 and C-2507 for the step-drawdown pumping test.

Evaluation of the step-drawdown test indicate:

- Approximately 200 gallons of water were removed from C-2506 during the tes[illegible]
- All three observation wells, C-2505, C-2506, and C-2507, responded to the test
- The C-2506 fluid-pressure responses for each pumping period indicate that th test influence moved beyond wellbore storage and affected the formation;
- The drawdown cone encountered a no-flow boundary toward the end of the thir[illegible] step-pumping period;
- Test data indicate a hydraulic conductivity range of 5.48×10^{-5} to 1.56×10^{-6} m/sec and a storativity range of 1.11×10^{-2} to 9.38×10^{-3}
- The water-bearing horizons behave as an unconfined system

5.0 WATER-QUALITY SAMPLING AND ANALYSIS

Water samples were collected with a disposable bailer for laboratory analysis from wells C-2505, C-2506, and C-2507 and borehole ES-001. The muddy water was fiel[illegible] filtered while other samples were decanted after allowing the sediment to settle befo[illegible] sending them to the laboratory. The water samples were sent for geochemical analysis to the Grand Junction Projects Office Analytical Laboratory in Grand Junction, Colorado. Total dissolved solids (TDS) ranged from 11,500 mg/L (C-2506) east of th[illegible] Exhaust Shaft, decreasing to 4000 mg/L (C-2507) to the south. Higher TDS values are linked to an increase in chloride and sodium concentrations. Decreases in the TDS values to the south appear related to mixing with a secondary source, possible recharge zone(s) (i.e. ponds located near ERDA-9) as identified in the geophysical survey report found in Appendix B. A report on the sampling and the results of the analysis are contained in Appendix C.

6.0 GEOLOGIC DESCRIPTIONS OF CORE-SAMPLES

Core samples were collected from wells C-2505, C-2506, and C-2507. The samples were collected with a hollow-stem auger or an air-rotary string. The samples were recovered with a triple-tube sampling apparatus. Core recovery was, in general, very good with recovery percentages greater than 90% for most cored intervals. Relativel[illegible] thin Pleistocene Mescalero caliche (up to about 3 feet) was encountered below seve[illegible] feet of surface fill and dune sand. Underlying the Mescalero is about 36 feet of partly calcified Miocene-Pleistocene Gatuña Formation. Below the Gatuña is approximatel[illegible] to 8 feet of Triassic Santa Rosa Formation Each of the drillholes encountered the Dewey Lake Formation between 48 and 54 feet below the surface and reached total depth in the upper part of the unit. Core inspection indicates a very moist zone in the lower Santa Rosa and upper Dewey Lake Formations. A detailed report is included a[illegible] Appendix D.

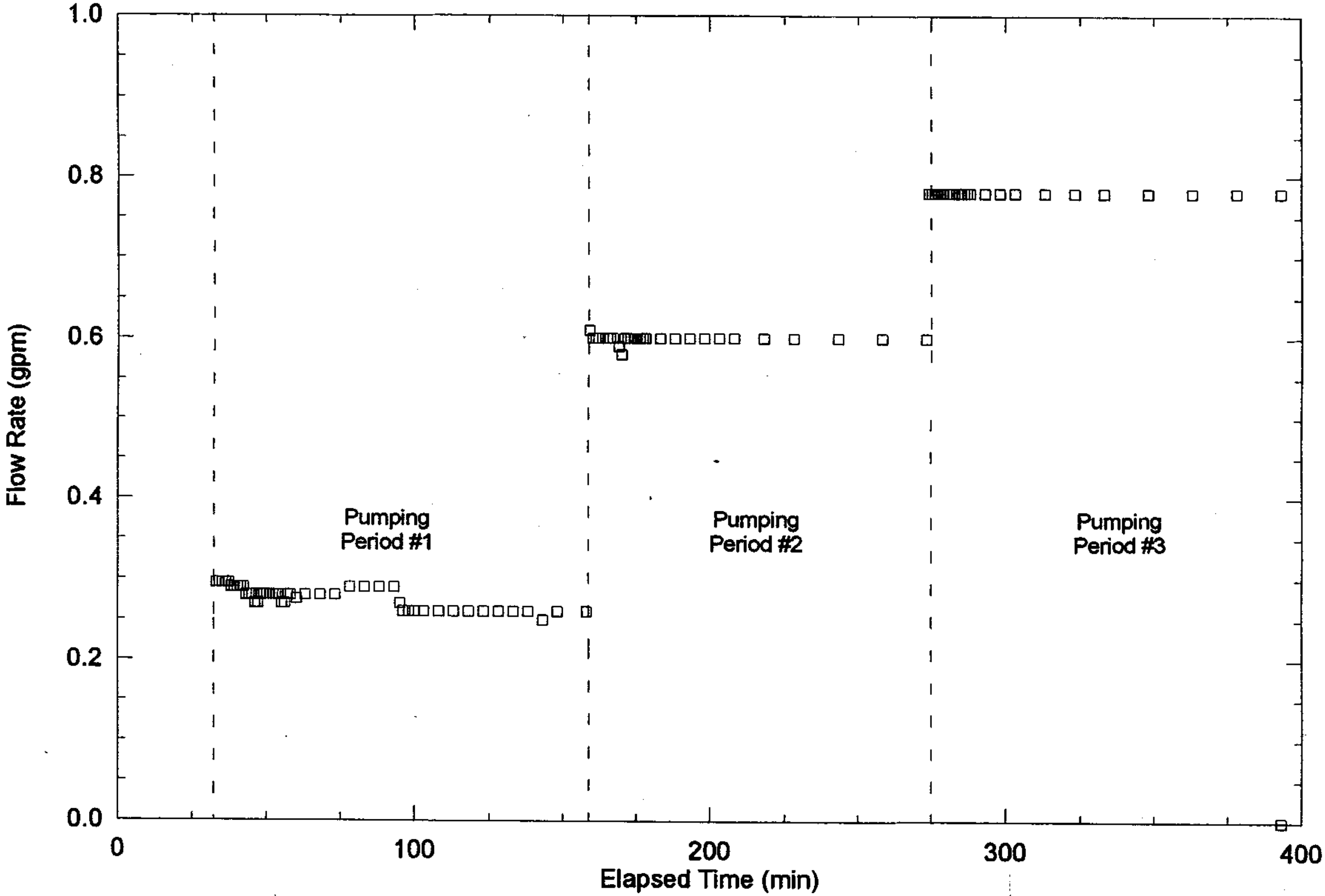
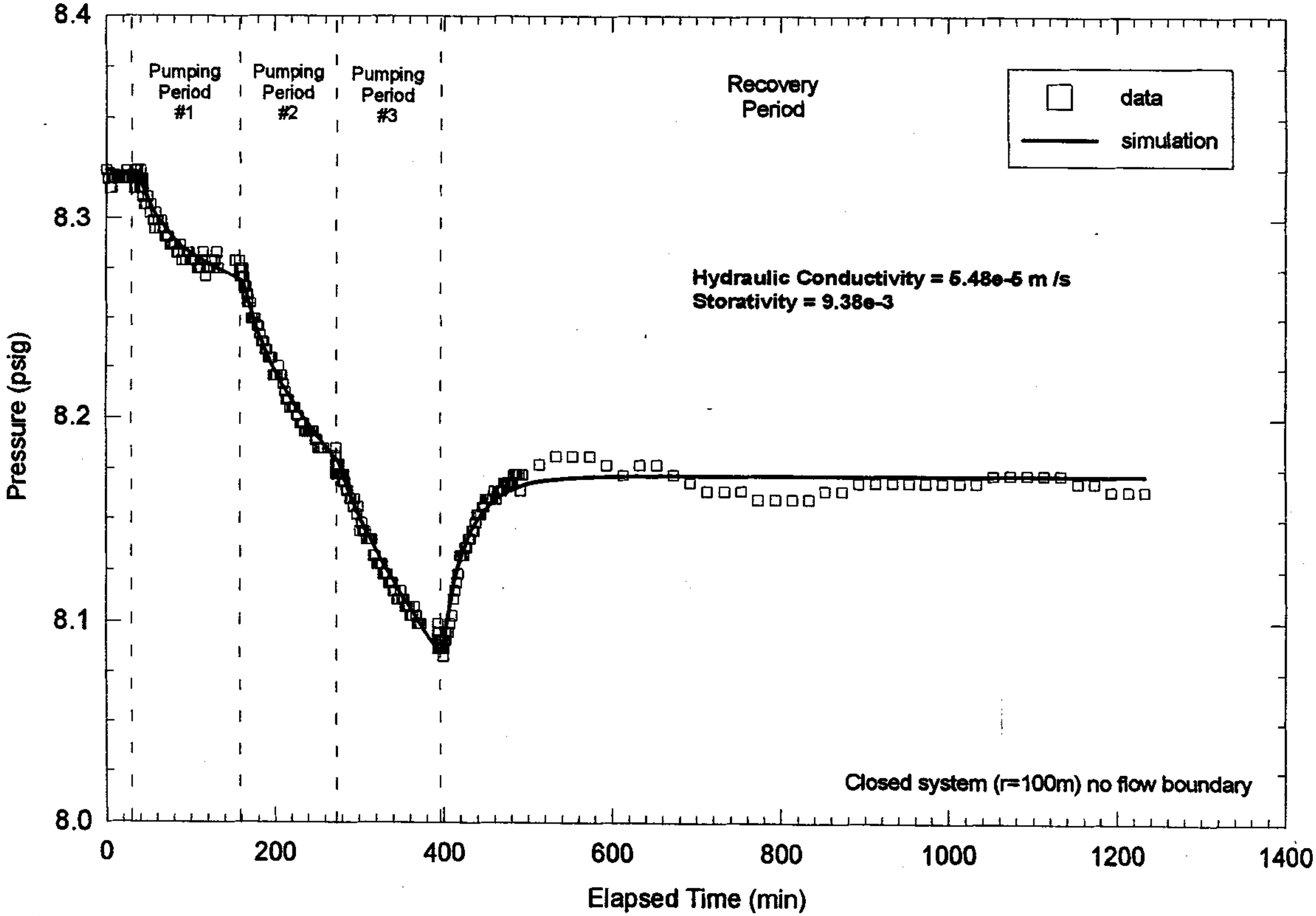


Figure 4.6. Pump rate data for the C-2506 step-drawdown test.



Pumping Period #1
Pumping Period #2
Pumping Period #3
Recovery Period
data
simulation
Hydraulic Conductivity = 5.48e-5 m /s
Storativity = 9.38e-3
Closed system (r=100m) no flow boundary
Pressure (psig)
8.4
8.3
8.2
8.1
8.0
0
200
400
600
800
1000
1200
1400
Elapsed Time (min)

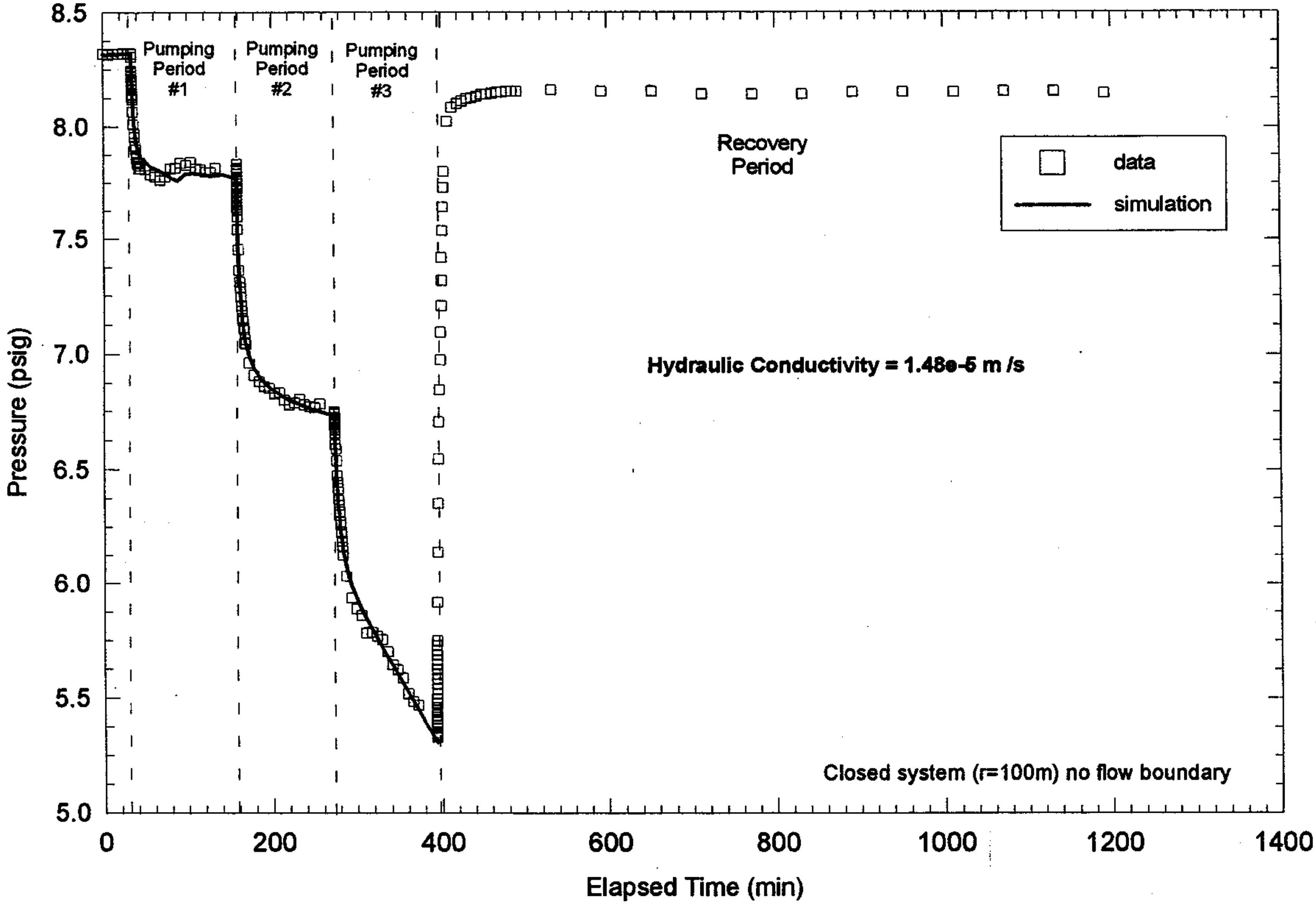
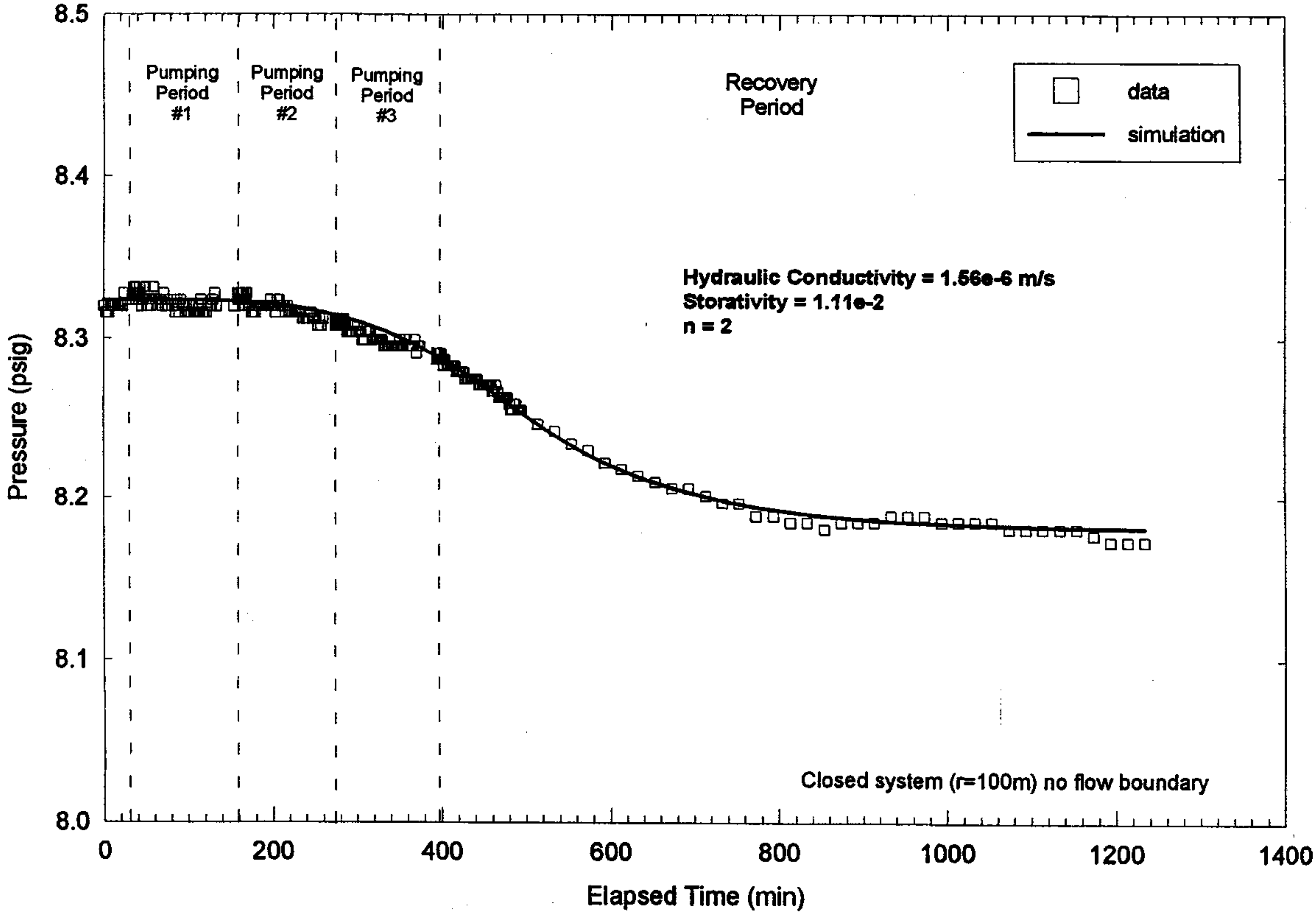


Figure 4.8. Well C-2506 pressure response to step-drawdown pumping test.


Pumping Period #1
Pumping Period #2
Pumping Period #3
Recovery Period
data
simulation
Hydraulic Conductivity = 1.56e-6 m/s
Storativity = 1.11e-2
n = 2
Closed system (r=100m) no flow boundary
Pressure (psig)
Elapsed Time (min)
8.5
8.4
8.3
8.2
8.1
8.0
0
200
400
600
800
1000
1200
1400

7.0 DISCUSSION

The data obtained from the installation, sampling, and testing associated with wells C-2505, C-2506, and C-2507 indicate that a water-saturated horizon is present in the lower Santa Rosa/upper Dewey Lake Formations in the depth range where water is leaking into the Exhaust Shaft (50 to 80 feet bgs). These data indicate that the wells nearest the Exhaust Shaft are capable of sustaining water production in the range of 0.3 to 0.6 gpm for a 24-hour period or longer.

Initial hydraulic gradient indicates that water flows from north to south, but data are limited to three wells that are located south and east of the Exhaust Shaft. In order to have a more complete understanding of the hydraulic gradient, data are needed west and north of the Exhaust Shaft to establish whether or not the gradient is a site-wide trend or a local condition. The water level in C-2507 (Figure 4.1), associated with the finer-grained rocks of the Dewey Lake may show a slower response time as compared to the other wells. It is also possible that C-2507 could have intercepted a discontinuous permeable zone which is serving as a drain for the water-saturated zone corresponding to similar stratigraphic horizons in wells C-2505 and C-2506.

The geochemical water-quality data indicate that the water in the lower Santa Rosa and the upper Dewey Lake Formations has a higher concentration of dissolved-solids near the south and east side of the Exhaust Shaft than that found in the same stratigraphic horizon 200 feet to the south. Coupled with the hydraulic gradient information, this may indicate that water near the shaft is being diluted by fresher water to the south (a secondary source). This would be consistent with the geophysical survey report which identified several high conductivity areas south of the Exhaust Shaft near ERDA-9. At the same time, because of a lack of information from the north, west and far east, these data are inconclusive regarding the source(s) of the groundwater in the lower Santa Rosa/upper Dewey Lake Formations. In addition, analysis of the samples indicates that the concentrations of lead in the samples collected from boreholes C-2505, C-2506, C-2507, and ES-001 are below NMGWCC standards and are not an apparent source of the lead found in previous samples collected near the base of the Exhaust Shaft.

The geophysical survey report identifies five high conductivity anomalies. Three anomalies are located south of the Exhaust Shaft lying on a line trending in an east-west direction near ERDA-9. These anomalies may be associated with surface water retention ponds, a drilling mud pit, and topographic low areas where recharge may occur during significant rainfall events. The two other anomalies which extend in a north-south direction between surface-water diversion berms are located in the Off-Site East (OSE) area as described in Appendix B. EM-34 surveys were conducted in the OSE area to establish background data free of any influence from metallic surface structures and are not considered conclusive data in defining changes in conductivity in the near surface. Further investigation could determine whether or not recharge is occurring from the east as a result of the salt pile and/or topographic low relief as determined from maps of the area prior to site construction associated with the OSE area.

A long-term pumping test, 1-to-7 days in length, or longer, would help to determine if wells C-2505 and C-2506 are sufficient as a dewatering mechanism, or if additional wells may be required to stop seepage through the shaft liner. A long-term pumping test would also indicate if dewatering would be an effective long-term solution. If significant dewatering occurs during testing, noted by head values not returning to pre pumping test conditions, then the water-bearing unit may be limited in areal extent. O.. the other hand, if head values do return to near pre-pumping test conditions, then the areal extent of the water-bearing horizon may be large enough to warrant further hydrologic investigations.

8.0 REFERENCES

Chester, C., G. Saulnier, W. Stensrud. 1996. Test Plan: Exhaust Shaft Hydraulic Assessment Program. Waste Isolation Pilot Plant, Carlsbad, New Mexico.

ATTACHMENT A
FREQUENCY-DOMAIN EM FIGURES

Appendix B

Surface Geophysical Surveys for the Hydrologic Assessment of the Exhaust Shaft

Prepared for:

Westinghouse
Waste Isolation Division
P. O. Box 2078
Carlsbad, NM 88221

Prepared by:

IT Corporation
5301 Central Avenue, NE
Suite 700
Albuquerque, New Mexico 87108

IT Corporation
312 Directors Drive
Knoxville, Tennessee 37923

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APPENDIX B

GEOPHYSICAL SURVEYS

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List of Acronyms

1-D	one-dimensional
bgs	below ground surface
E-W	east-west
EM	electromagnetic
EM-31	Geonics EM-31 Terrain Conductivity Meter
EM-34-3XL	Geonics EM-34 Terrain Conductivity Meter
EM-47	Geonics EM-47 Time-Domain System
EMIX-34	Interpex Frequency-Domain Electromagnetic Processing Software
FDEM	Frequency-Domain Electromagnetic
ft	foot
GEOSOFT	Geosoft Mapping and Processing System
GPR	Ground Penetrating Radar
GSSI	Geophysical Survey Systems Inc.
Hz	hertz
IT	IT Corporation
m	meter
Hz	hertz
MHz	megahertz
N-S	north-south
ns	nanosecond
NE-SW	northeast-southwest
ohm-m	ohm-meters
OSE	Off Site East Geophysical Survey Area
OSS	Off Site South Geophysical Survey Area
QA	quality assurance
SNL	Sandia National Laboratories
TDEM	Time-Domain Electromagnetic
TEMIX-XL	Interpex Time-Domain Electromagnetic Processing Software
WIPP	Waste Isolation Pilot Plant

B.1.0 Introduction

IT Corporation (IT) conducted a surface geophysical investigation at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico as part of a hydrological assessment of the exhaust shaft from August 21, through September 5, 1996. The investigation included three geophysical survey areas covering a total surface area of approximately 41,100 square meters (approximately 442,872 square feet; 10.2 acres). A detailed survey was conducted near the WIPP exhaust shaft, and two reconnaissance surveys were conducted at nearby off site locations. A site map showing the geophysical survey areas is presented as Figure 1.

The objectives of the WIPP geophysical surveys were to:

- Identify and map conductive zones related to water leaks in the exhaust shaft that occur at approximately 50 and 75 feet (ft) [approximately 15.3 and 22.9 meters (m)] below ground surface (bgs)

- Identify and map conductive zones around pipeline trenches in the vicinity of the exhaust shaft possibly related to leaking pipes and/or an accumulation of water

- Conduct a utility clearance survey in an approximate 50-ft (approximate 15.3-m) radius of the exhaust shaft in support of planned drilling activities.

To accomplish the objectives, integrated surface geophysical surveys were conducted using frequency- and time-domain electromagnetic (EM) methods for mapping subsurface conductive zones, and ground penetrating radar (GPR) and utility locator methods to map subsurface utilities in the WIPP exhaust shaft area. The frequency-domain EM (FDEM) data were mapped and color-enhanced to facilitate recognition of subtle anomalies and are presented as plan-view contour maps. Time-domain EM (TDEM) data were processed and modeled using geophysical inversion techniques and are presented as individual soundings. Site conditions including the geologic setting and surface conditions at each survey area are discussed in Section 2.0. Field procedures used during the investigation are described in Section 3.0. The data processing methods used and interpretation of the geophysical data are presented in Section 4.0. Conclusions and recommendations derived from the geophysical survey are presented in Section 5.0. Attachment A contains color-enhanced contour maps of FDEM data; Attachment B contains

TDEM sounding data from the exhaust shaft survey area; Attachment C contains TDEM sounding data from the off site south survey area; Attachment D contains a theoretical background discussion of the geophysical techniques used in this investigation.

B.2.0 Site Conditions

The following sections describe geologic information that was used to determine the appropriate geophysical techniques and survey design parameters for the investigation, and surface conditions encountered near the exhaust shaft.

B.2.1 Geologic Setting

The shallow (surface to 100 ft [30.5 m] bgs) geology in the area of the WIPP exhaust shaft consists of Quaternary, Triassic, and Permian units, as summarized in ERDA-9 (Sandia National Laboratories [SNL], 1983) south of the exhaust shaft, and the air intake (Holt and Powers, 1990). Both reports indicate a geologic section that consists primarily of calcareous quartz sands, silts, and muds. The ERDA-9 report indicates Holocene deposits of eolian sands with some artificial fill comprise the upper 22 ft (6.7 m) of the subsurface. This sequence is underlain by the 5-ft (1.5-m) thick Pleistocene Mescalero Caliche which is a white chalky limestone with quartz grains. Underlying the Mescalero, from 27 to 54 ft (8.2 to 16.5 m) bgs, is the Pleistocene Gatuna Formation which consists of very fine- to fine-grained calcareous sandstone. From 54 to 63 ft (16.5 to 19.2 m) bgs is the medium- to coarse-grained Triassic Santa Rosa Sandstone. The Permian Dewey Lake Red Beds occur from 63 to 550 ft (19.2 to 167.7 m) bgs and consist of dolomitic siltstone and mudstone (SNL, 1983).

B.2.2 Surface Conditions

The approximately 5,100-square-meter (approximately 54,930-square-foot; 1.3-acre) exhaust shaft (ES) site contains abundant subsurface utilities (from review of available utility and geophysical utility clearance work) and surface cultural features (e.g., metallic structures and ventilation ducts, railroad tracks, chain-link fences, and a TRU-PAC container). The surface of the ES site is generally flat consisting of fine- to coarse-grained sand and silt with little vegetation. The geophysical survey location map for the ES site (Figure 2) shows the detailed survey grid where FDEM surveys were conducted, and the locations of the ES area TDEM soundings.

A geophysical survey location map for the approximately 25,200-square-meter (approximately 271,466-square-foot; 6.2-acre) off site south (OSS) geophysical survey area is presented as Figure 3. This map also shows the locations where reconnaissance FDEM surveys and several TDEM soundings were conducted. The surface of the OSS area ranges from generally flat terrain with little or no vegetation from the east (Figure 3) to thick scrub with abundant mounds and holes in the western portion of the site. With the exception of the WIPP boundary fence and several steel culverts leading to the surface-water retention ponds, the OSS area was free from surface cultural interference.

The approximately 10,800-square-meter (approximately 116,476-square-foot; 2.7-acre) off site east (OSE) geophysical survey area, which includes the location where a reconnaissance FDEM survey was conducted, is shown on the Figure 1. The surface of the OSE area ranged from generally flat terrain with thick scrub in the north and south portions of the site to steep topography with some vegetation in the central portion of the site representative of a large stockpile of drill cuttings. With the exception of a north trending subsurface utility located just west of the OSE area, an east trending subsurface utility thought to cross through the south portion of the site, and east trending overhead electric lines that cross the northern portion of the site, the OSE area was free from surface cultural interference.

B.3.0 Field Procedures

This section describes the field procedures and instruments used to conduct the geophysical investgaion, including survey control, data acquisition and field instrument quality assurance (QA) procdures, and utility clearance procedures.

B.3.1 Survey Control

Survey control at the ES site was accomplished by using metric tapes and marking a detailed 5- by 5-m geophysical survey grid with paint. The locations of the survey grid points are shown in the ES site geophysical survey location map (Figure 2). Several large metallic boxcars were temporarily moved to another location. A chain-link fence between the exhaust shaft and the railroad tracks was removed for the survey. Obvious surface cultural features that could potentially affect the geophysical data (e.g., surface metallic objects, fences, etc.) were identified in the field and accurately plotted on a site map. Following the investigation, the X,Y coordinates (easting, northing) of each grid point were surveyed by the Garwin Group Ltd., and referenced to permanent site features and the Modified State Plane NAD-27, New Mexico East Zone Coordinate System, using the CONUS Datum.

Survey control at the reconnaissance OSS and OSE areas was accomplished by marking 15-m spaced survey lines and 60-m downline stations with wooden stakes. Following the investigation, corner stakes at the OSS area and all corner/downline station stakes at the OSE area were surveyed by the Garwin Group Ltd. The surveyed points were referenced to permanent site features and the Modified State Plane NAD-27, New Mexico East Zone Coordinate System, using the CONUS Datum. Interior geophysical survey grid points shown on site maps for the OSS and OSE reconnaissance areas were interpolated from civil survey coordinate data.

B.3.2 Geophysical Survey

The following sections describe the field procedures and instruments used to conduct the investigation.

B.3.2.1 Electromagnetic (EM) Investigations

FDEM surveys and TDEM soundings were conducted to map subsurface conductivity variations, either directly, by attempting to distinguish conductive anomalies caused by an accumulation of water at depth, or indirectly, by mapping variations in stratigraphy which may influence or determine migration pathways or cause perching or ponding of water. Additionally, the FDEM surveys were conducted to provide site screening for buried cultural features (e.g., subsurface utilities, buried metallic debris) that would likely interfere with accurate interpretation of TDEM data. The TDEM survey was designed to collect data representing the upper 30 m (98.4 ft) of subsurface.

B.3.2.1.1 Frequency-Domain Electromagnetic (FDEM) Surveys

EM equipment used to conduct the FDEM surveys consisted of Geonics EM-31 and EM-34-3XL terrain conductivity meters, each coupled to an Omnidata DL-720 digital data logger. A detailed description of the equipment and a theoretical discussion of the FDEM method, including depth of exploration for the various system configurations, are presented in Section D.1.0 of Attachment D in Appendix B.

Prior to conducting the FDEM surveys, field instrument base stations were established at fixed locations free of cultural interference (e.g., surface or subsurface metallic debris, fences, power lines). The EM-31 and EM-34 were calibrated at the base station in accordance with the manufacturer's specifications for each instrument. After calibration, 20 instrument readings of conductivity (and in-phase component for the EM-31) were recorded in the digital data logger at the base station prior to each data collection session and periodically throughout the day. These data were collected to provide a quantitative record of instrument drift during the survey period. Analysis of EM-31 and EM-34 base station data indicate the instruments were operating properly for the duration of the investigation.

Following base station calibration, EM-31 quadrature-phase (conductivity) and in-phase component EM-31 data were collected at 2-m (6.6-ft) intervals along N-S survey lines spaced 5 m (16.4 ft) apart across at the ES site to obtain adequate data density for mapping lateral variation in near-surface conductivity and for providing site-screening information. The data were stored in the digital data logger programmed with appropriate line and station numbers. The ES site EM-31 survey was repeated in the E-W direction north of the 50N local geophysical survey coordinate line to aid in interpreting subsurface utilities at the site.

EM-34 surveys were conducted across the ES, OSS, and OSE area grids. EM-34 data (conductivity only) were collected in both the horizontal and vertical dipole configurations. The data were collected using the 10- and 20-m (32.8- and 65.6-ft) transmitter to receiver coil separations at the ES and the OSS (20-m only at OSE) to determine how subsurface conductivity varied with depth. The EM-34, 10-m (32.8-ft) coil separation data were collected at 5-m (16.4 ft) intervals along N-S survey lines spaced 5 m (16.4 ft) apart at the ES site, and at 20-m (65.6-ft) intervals along E-W survey lines spaced 15 m (49.2 ft) apart at the OSS area .

The EM-34, 20-m (65.6-ft) coil separation data were collected at 10-m (32.8 ft) intervals along N-S survey lines spaced 10 m (32.8 ft) apart at the ES site, at 20-m (65.6-ft) intervals along E-W survey lines spaced 15 m (49.2 ft) apart at the OSS area, and at 20-m (65.6-ft) intervals along N-S survey lines spaced 15 m (49.2 ft) apart at the OSE area.

The EM-34 40-m (131.2-ft) coil configuration was not used at the ES site because the site was small and evaluation of the 20-m (65.6-ft) data contained no valuable information on subsurface conditions due to the abundant surface metal. The compressed schedule precluded conducting EM-34 surveys at OSS using the 40-m (131.2-ft) intercoil separation or at OSE using the 10- or 40-m (32.8- or 131.2-ft) intercoil separation configurations. It should also be noted that the OSS and OSE surveys were conducted to gather reconnaissance data to aid in interpretation of ES site data. Due to time constraints, the OSS and OSE survey areas were designed to be much smaller than usual reconnaissance survey grids.

Following each survey session, TDEM field data were downloaded to a personal computer and backed up daily on 3.5-inch floppy disks. All field data are archived in project files.

B.3.2.1.2 Time-Domain Electromagnetic (TDEM) Soundings

TDEM soundings were conducted using a Geonics EM-47 time-domain EM system. Data were collected at 285, 75, and 30 hertz (Hz), each containing 20 time gates in which transient voltages were measured and stored in the internal memory of the unit. A detailed description of the equipment and a theretical discussion of the TDEM method, including depth of exploration for the various system configurations, are presented in Section D.2.0 of Attachment D in Appendix B.

Prior to collecting TDEM sounding data, the field instrument base station established for the ES site (local geophysical survey coordinates 50E, 20N [Figure 2]) was occupied to calibrate the system and establish data collection parameters. Since the field instrument base station used for FDEM system checks at the OSS area (local geophysical survey coordinates 35E, 0N [Figure 3]) proved to difficult in consistently laying out the TDEM transmitter loop due to vegetation, an OSS area TDEM base station was established at local geophysical survey coordinates 35E, 30N

EM-47 system checks and calibration testing was conducted at each base station in accordance with the manufacturer's specifications for the instrument. System frequency tests, ambient noise tests, and system stacking tests were conducted to determine optimum data collection parameter for site conditions in each area. These tests were recorded and evaluated prior to choosing data acquisition parameters. An offset-receiver loop sounding geometry consisting of a 5- by 5-m (16.4- by 16.4-ft) transmitter loop separated from the receiver loop by 10 m (32.8 ft), and an input current of 3.0 Amps was used for the investigation. Analysis of daily TDEM base station data indicate the instrument was operating properly (i.e., base station data were repeatable) for the duration of the investigation.

As shown in Figure 2, TDEM sounding data were collected at 36 locations across the established ES survey area and 7 locations off site and east of the ES survey area, just west of the OSE area Eighteen TDEM soundings were conducted within the OSS area (Figure 3). TDEM sounding locations at the ES site were chosen in the field to provide the most information for evaluating subsurface conductivity near the exhaust shaft. The sounding locations were chosen, where possible, to avoid subsurface utilities and nearby surface metal. As shown on the ES site location map, several TDEM soundings were acquired away from the exhaust shaft. These were acquired to gain an understanding of background conductivity response to aid in interpreting anomalies seen in site-wide and individual sounding data, and to provide a possible tie between the water leaks in the exhaust shaft and recharge areas east of a large surface-water diversion berm. Likewise, TDEM soundings were collected at the OSS area (Figure 3) to provide background conductivity data and to determine the possibility of a hydraulic link between the water leaks in the exhaust shaft and two large surface-water retention ponds to the south and southwest of the ES site.

Following each survey session, TDEM field data were downloaded to a personal computer and backed up daily on 3.5-inch floppy disks. All field data are archived in project files.

B.3.2.2 Utility Clearance Survey

The geophysical utility clearance survey was conducted within an approximately 50-ft (approximately 15.3-m) radius of the exhaust shaft in support of planned drilling activities. The survey was conducted using a Metrotech 9860 EM utility locator and a Geophysical Survey Systems Inc. (GSSI) SIR-2P system coupled to 200- and 400-megahertz (MHz) antennas. The 400-Mhz GPR antenna allows for a greater depth of penetration at the expense of resolution. The GSSI antennas are shielded which allows for data collection near structures and metallic objects without significant signal degradation. GPR survey data was collected with each antenna along perpendicular lines spaced 5 m (16.4 ft) apart across the area shown in the utility clearance map (Figure 4). GPR data were recorded semicontinuously at 24 scans per second as the antenna was hand towed across the survey lines. Data were viewed in real-time on the GPR system color monitor and printed in real time with a DPU-5400 high-resolution thermal gray-scale printer. Utility lines shown on the utility clearance map (Figure 4) were derived from combining the results of the EM utility locator and GPR surveys and/or from available WIPP utility maps provided.

B.4.0 Data Processing and Interpretation

This section describes the data processing techniques used and the interpreted results of the investigation.

B.4.1 Frequency-Domain EM Data Processing

Contour maps of FDEM data (both EM-31 and EM-34) were generated using the GEOSOFT7® geophysical mapping system. The maps were color-enhanced to aid in interpretation of subtle anomalies. The color-contour maps are included as Figures A-1 through A-14 in Attachment A.

Prior to map generation, EM-31 and EM-34 data processing included screening the ASCII-format data files so that line and station ranges and overall data quality could be assessed. The data file names, including corresponding base station data files, were recorded on the data file tracking form. The base station data were reviewed and the quantitative instrument response for each file was recorded on the base station summary form. Following data quality assessment, geometry corrections to field data files were made, if necessary, using a text editor.

After final corrections were made to the FDEM data, files containing station coordinates (X,Y) and the geophysical measurement (Z) were converted to GEOSOFT7 format. The data files wer then gridded, optionally filtered, or otherwise processed and color-contoured. The names of the files generated and processing parameters used were recorded on data processing forms. All completed forms and computer printouts of EM-31 and EM-34 data collected during the investigation are retained in project files.

B.4.2 Time-Domain EM Data Processing

TDEM sounding data were reviewed and screened immediately following data collection to verify field data quality. Data were edited and modeled using Interpex TEMIX-XL® forward and inverse one dimensional (1-D) modeling software. The 1-D processing allowed for an estimate of conductivity variations with depth based on measured voltages at the various time gates. The voltages were then converted to apparent resistivity (inverse of apparent conductivity) values an unconstrained-depth, smooth model ridge-regression inversions were conducted on each sounding data set to evaluate the mathematical solution to the data. Sounding data were then constrained by a reasonable depth and the smooth model inversion was run again to more accurately define the geoelectric section representing the data. The smooth model inversion results for all soundings were then evaluated and compared with reasonable values for known geology in the area to obtain a depth versus resistivity model (forward model). The forward model parameters were then used to calculate a synthetic 1-D response which was compared with actual collected data. The error in fit of the forward model was evaluated and adjusted in an iterative process until an acceptable model was obtained. The forward model was then inverted to generate a layered model ridge-regression solution.

The results of the forward modeling were generated showing both the input resistivity model and the resultant forward model synthetic response. The layered inversion models were evaluated for uniqueness to determine the range of solutions that would generate the same inversion response as that seen in the inverted 1-D soundings. The final processed TDEM data (layered model inversion and/or smooth model inversion) were generated as individual soundings. The names of the files generated and processing parameters used were recorded on data processing forms. All completed forms and computer printouts of EM-47 data collected during the investigation are retained in project files.

B.4.3 Interpretation

Color-enhanced contour maps of EM-31 and EM-34 survey data representing the ES site investigation are presented in Attachment A as Figures A-1 through A-8; EM-34 survey data representing the OSS area investigation are presented as Figures A-9 through A-12; EM-34 survey data representing the OSE area investigation are presented as Figures A-13 and A-14 in Attachment A. TDEM sounding data representing the ES site are presented as Figures B-1 through B-32; TDEM sounding data representing the OSS area are presented as Figures C-1 through C-12 in Attachment C. The interpreted results of ES site TDEM sounding data combined with FDEM data is shown on the ES site geophysical interpretation map (Figure 5).

In general, FDEM survey data representing the three sites was most useful in determining lateral variations of subsurface conductivity (profiling), although limited interpretations of conductivity variations with depth (sounding) were also made. The TDEM sounding data provided for an interpretation of estimated depth to a conductive layer at the ES site (Figure 5) and at the OSS area. The EM-31 survey conducted near the exhaust shaft to identify and map conductive zones in pipeline trenches (potentially representing an/ accumulation of water) were unsuccessful due to

abundant noise introduced by surface metallic features and buried utilities in the area. The utility clearance portion of the investigation was successful (Figure 4).

B.4.3.1 Exhaust Shaft (ES) Site

As shown in FDEM contour maps for the ES site (Figures A-1 through A-8 in Attachment A), significant degradation in FDEM data quality resulted from the presence of abundant surface metallic objects and subsurface utilities in the immediate area of the surveys. Metallic structure: included within or along the perimeter of this very small site included several exhaust shaft struc tures, aboveground ventilation ducts, electrical substations, railroad tracks, and chain-link fences The results of geophysical utility clearance work (Figure 4) best indicate the abundant subsurfac utilities encountered in the ES survey area.

The FDEM data were most useful in determining the ambient noise level introduced by surface culture which helped in choosing TDEM sounding locations. The FDEM data contained little valuable information regarding interpretation of vertical variations of conductivity.

Anomaly A-1, located in the southeast portion of the site, occurs in the EM-31 conductivity data collected along N-S lines (Figure A-1) and EM-34, 10-m (32.8-ft) horizontal and vertical dipole data (Figures A-5 and A-6) as a small area of increased conductivity. Anomaly A-1 corresponds with an elevated mound of sand and gravel at the surface and the anomaly is thought to be caused either by highly-conductive materials comprising the surface mound or by the northward extension of anomaly A-3 (OSS area) discussed below. Other than anomaly A-1, no ES site conductivity anomalies due to subsurface features are evident in the ES site FDEM data.

TDEM data collected at the ES site (Figures B-1 though B-32 in Attachment B) were most usef in determining the depth to conductive features in the 50 to 75 ft (15.3 to 22.9 m) bgs range, which was the primary objective of this investigation. Of the 36 TDEM soundings collected at the ES site, 16 are presented as both smooth model and layer model inversions. Emphasis was placed on the layer model inversion results in estimating the depth to a conductive layer at the E site (Figure 5) since the model results incorporate reasonable geologic information for the site.

Initially, each TDEM sounding was evaluated following a smooth model ridge-regression inver sion with no depth constraint. Most of the sounding data showed little useful information beyond 25 to 30 m (82.0 to 98.4 ft). Starting and ending depth constraints were then chosen, based on the specific sounding. In general, 3 m (9.8 ft) was used as the near-surface depth constraint and 30 m (98.4 ft) was used for the ending depth. Due to the highly conductive nature of the subsurface in the area of the exhaust shaft, 25 to 30 m (82.0 to 98.4 ft) was approximately the maximum depth of exploration. TDEM soundings conducted at a distance greater than approximately 50 m (164.0 ft) from the exhaust shaft generally had a greater depth of exploration as indicated by the smooth model and layer model inversion results. Indeed, soundings conducted at the OSS area showed exploration depths generally exceeding 50 m (164.0 ft). The observed increase in exploration depth is thought to be due to more resistive near-surface geology. Since this type of change in data character is unusual over a small distance (approximately 150 m [492.0 ft] separates the ES and OSS sites), the near-surface (10 to 25 m) conductivity in the ES site data appears quite anomalous relative to the OSS area data which represents background conditions.

The TDEM data indicate a conductive layer occurs an approximate depth of 15 to 20 m (49.2 to 65.6 ft) in the area south and east of the exhaust shaft. The conductive feature may trend east-southeast in the immediate vicinity of the shaft and off site toward the OSE area, though a more detailed investigation beyond the reconnaissance survey conducted at the OSE area would be required to confirm this. In general, TDEM data collected within 10 m of the exhaust shaft (and other large surface metallic features) were noisy and difficult to interpret. Most of the soundings conducted in the immediate vicinity of the shaft showed significant noise in the early time gate data similar to that seen in soundings 45E,80N through 55E,80N (Figures B-4 through B-9). Near-surface resistivity (inverse of conductivity) values seen in the TDEM sounding data near the shaft had an average of approximately 1.0 ohm-m as compared with average background values of 10 ohm-m at distances greater than approximately 10 m (32.8 ft) or more away from the shaft. This elevated conductivity response generally corresponds with noisy early gate data caused by surface metal in the area.

Three of the seven TDEM soundings conducted east of the ES site along the N-S trending gravel road west of the OSE area (Figure 2) also contained noisy data. Review of a site utility map provided to IT following the investigation indicates a subsurface utility(s) is located under the gravel road, which turns toward the east at approximate local geophysical survey coordinates 90E,90N. Two high-quality TDEM soundings collected south of the utility (Figures B-28 through B-32) were used in estimating depth to the conductive layer shown in the geophysical interpretation map (Figure 5).

B.4.3.2 Off Site South (OSS) Area

As shown in FDEM contour maps for the OSS area (Figures A-9 through A-12 in Attachment A), steel culverts and associated reinforced concrete pads in the area of the surface-water retention ponds and a chain-link fence were the only surface features that degraded FDEM data quality.

Anomaly A-2, located in the western portion of the site, occurs in the EM-34 (10- and 20-m [32.8- and 65.6-ft]) horizontal and vertical dipole data (Figures A-9 through and A-12) as a broad area of increased conductivity. The anomaly is located south and west of the westernmost surface-water retention pond and may be caused by migration of fluids from the pond. However the anomaly may also be caused by natural variations in geology. To further define anomaly A-2, more FDEM surface coverage and TDEM soundings would be required. In the data collected, anomaly A-2 does not appear to be hydraulically connected to the ES site.

Anomaly A-3, located in the northeast portion of the site, occurs in the EM-34 10- and 20-m (coil separation [32.8- and 65.6-ft]) horizontal and vertical dipole data (Figures A-9 through and A-12) as a broad area of increased conductivity. The anomaly is located near ERDA-9 and is characteristic of a drilling mud pit. Anomaly A-3 may extend north into the ES site and be associated with anomaly A-1. It is unlikely anomaly A-3 is associated with the exhaust shaft water leak, although a more comprehensive TDEM sounding investigation in this area would be required to confirm this.

TDEM data collected at the OSS area (Figures C-1 though C-12 in Attachment C) were most useful in determining background resistivity conditions to aid in interpreting ES site data. Smooth model inversion results from TDEM soundings conducted at the OSS area (and layered model results for sounding 35E,75N only) indicate depths to the top of the shallowest conductiv layer range from approximately 20 to 30 m (65.6 to 131.2 ft) in the northern portion of the site to over 50 m (164.0 ft) in the southern portion of the site. It should be noted that these depth value are rough estimates since the data were collected using a TDEM system configuration and setup parameters to emphasize near-surface conditions and smooth model inversion results represent a mathematical solution to the data.

B.4.3.3 Off-Site East (OSE) Area

As shown in FDEM contour maps for the OSE area (Figures A-13 and A-14 in Attachment A), a possible surface metallic object(s) located northwest of the site and a possible E-W trending subsurface pipeline located in the southern portion of the site were the only cultural features that degraded FDEM data quality.

Anomaly A-4, located in the central portion of the site, occurs in the EM-34 horizontal dipole data (Figure A-13) as a broad area of increased conductivity thought to be caused by a large stockpile of geologic materials.

Anomaly A-5, located along the eastern boundary of the OSS area is a very strong conductivity feature seen primarily in the horizontal dipole EM-34 data, though also present in the vertical dipole data (Figure 14). Since A-5 is not completely delineated, its cause is unknown. Overhead utility lines located approximately 50 m (164.9 ft) east of the site were considered a possible cause, but are an unlikely the source of the anomaly due to the distance involved. The anomaly may be caused by highly-conductive materials that were placed at the surface or may be associated with a near-surface zone of moisture east of the site. Since the OSS survey was conducted in a topographically low area between surface-water diversion berms, adjacent to and east of the ES site, the area could be hydraulically connected to the ES site. To determine the cause of anomaly A-5 and the potential connection with the conductive layer mapped at the ES site, TDEM sounding data and a more comprehensive FDEM survey would be required east of the OSS area.

B.5.0 Conclusions and Recommendations

B.5.1 Conclusions

Surface geophysical surveys using frequency- and time-domain electromagnetic (EM), and ground penetrating radar (GPR) methods were conducted as part of the hydrologic assessment of the exhaust shaft. The objectives of the investigation were to (1) identify and map conductive zones related to water leaks in the exhaust shaft at 50 and 75 ft (15.3 and 22.9 m) bgs, (2) identify and map conductive zones around pipeline trenches possibly relating to a leaking pipe o an accumulation of water, and (3) provide utility clearance in an approximate 50-ft (15.3-m) radius of the exhaust shaft.

The investigation included three survey areas totaling approximately 442,872 square feet (10.2 acres). A detailed survey was conducted at the exhaust shaft (ES) site and reconnaissance surveys were conducted at two off site locations south and east (OSS and OSE, respectively) of the ES site to provide background geophysical data.

The frequency-domain EM (FDEM) data were most useful for mapping lateral variations in subsurface conductivity (profiling), although limited interpretations of conductivity with depth (sounding) were also made. The time-domain EM (TDEM) sounding data provided for an interpretation of estimated depth to a conductive layer at the ES site and at the reconnaissance OSS area located south of WIPP. The EM-31 terrain conductivity meter survey conducted near the exhaust shaft to map conductive zones in pipeline trenches (potentially representing an accumulation of water) was unsuccessful due to abundant noise introduced by surface metallic features and buried utilities in the area. The utility clearance portion of the investigation was successful (Figure 4).

The ES site FDEM data (Figures A-1, -5, and -6) indicated one anomaly not caused by surface metallic features or subsurface utilities. Anomaly A-1 is thought to be caused either by highly-conductive materials at the surface or the northward extension of an OSS area anomaly. TDEM sounding data representing the ES site indicate a conductive layer occurs at an approximate dep of 15 to 20 m (49.2 to 65.6 ft) in the area south and east of the exhaust shaft (Figure 5). The conductive feature may trend east-southeast in the immediate vicinity of the shaft and off site toward the OSE area, although a more detailed off site investigation would be required to confirm this.

Two FDEM (EM-34 terrain conductivity meter) anomalies were identified in data collected at the OSS area. Anomaly A-2 (Figures A-9 through A-12), located near the westernmost surface-water retention pond, may be caused by migration of fluids away from the pond, although the anomaly may also be caused by natural variations in geology.. A more detailed off site investigation would be required to delineate and interpret this feature and determine its possible connection with the ES site. Anomaly A-3 (Figures A-9 through A-12) is characteristic of a drilling mud pit. The anomaly is unlikely associated with the exhaust shaft water leak, although a more comprehensive TDEM sounding investigation in this area would be required to confirm this. TDEM sounding data representing the OSS area indicate a conductive layer occurs at an approximate depth ranging from 20 to 30 m (65.6 to 131.2 ft) in the northern portion of the site to over 50 m (164.ft) in the southern portion of the site.

Two FDEM (EM-34 terrain conductivity meter) anomalies were identified in data collected at the OSE area. Anomaly A-4 (Figure A-13) is thought to be caused by a large stockpile of geologic materials occupying the central portion of the site. Anomaly A-5 (Figures A-13 and A-14) occurs along the eastern boundary of the survey area and is unresolved. The anomaly may be caused by highly-conductive materials placed at the surface or it may be associated with a near-surface zone of moisture east of the site. Since the OSS survey was conducted in a topographically low area between surface-water diversion berms adjacent to and east of the ES site, the area could be hydraulically connected to the ES site. To determine the cause of anomaly A-5 and the potential connection with the conductive layer mapped at the ES site, a more detailed investigation would be required.

B.5.2 Recommendations

IT recommends surface geophysical surveys using FDEM and TDEM methods be extended south of the OSS area and east of anomaly A-5 at the OSE area to accurately map anomalies seen in the reconnaissance data and determine whether these potential recharge areas represent a connection with the exhaust shaft leak. Additional TDEM soundings are also recommended in the area of anomaly A-3 at the OSS area to further investigate whether the anomaly is caused by a drilling mud pit. No additional surface geophysical work is recommended at the ES site.

B.6.0 References

Holt, R. M., and D. W. Powers, 1990, ***Geologic Mapping of the Air Intake Shaft at the Waste Isolation Pilot Plant***, DOE-WIPP 90-051, U.S. Department of Energy, Carlsbad, New Mexico

Sandia National Laboratories and U.S. Geological Survey, 1983, ***Basic Data Report for Drillhole ERDA 9 (Waste Isolation Pilot Plant)***, SAND79-0270, Sandia National Laboratorie: Albuquerque, New Mexico.

ATTACHMENT A
FREQUENCY-DOMAIN EM FIGURES

Halliburton NUS CORPORATION

NUS LABORATORY
5350 Campbells Run Road
Pittsburgh, Pennsylvania 15205

TEL: (412) 747-2500
FAX: (412) 747-2559
September 10, 1995
Report No.: 00027423

LABORATORY ANALYSIS REPORT

CLIENT NAME: WESTINGHOUSE ELECTRIC CORPORATION, WID/WIPP
ADDRESS: P.O. BOX 2078
CARLSBAD, NM 88221-2078
ATTENTION: MR. RICK CHAVEZ

NUS CLIENT NO: 1783 0001
WORK ORDER NO: 55830
VENDOR NO: 01830727

Carbon Copy:

SAMPLE ID: WST-95-229
NUS SAMPLE NO: P0320159
P.O. NO.: 67763

DATE SAMPLED: 24-AUG-95
DATE RECEIVED: 28-AUG-95
APPROVED BY: Kieda, Chuck

LN	TEST CODE	DETERMINATION	RESULT	UNITS
1	1130	Chloride (as Cl)	14000	mg/L
2	1590	Solids, Dissolved at 180C	25000	mg/L
3	1730	Sulfate, Turbidimetric (as SO4)	1200	mg/L
4	1391	Nitrate/Nitrite as N	4.1	mg/L

COMMENTS:

Halliburton NUS
CORPORATION

NUS LABOR
5350 Campbells
Pittsburgh, Pennsylva

TEL: (412) 7·
FAX: (412)
September 10,
Report No.: 00
Section A Page

LABORATORY ANALYSIS REPORT

CLIENT NAME: WESTINGHOUSE ELECTRIC CORPORATION, WIO/WIPP
ADDRESS: P.O. BOX 2078
CARLSBAD, NM 88221-2078
ATTENTION: MR. RICK CHAVEZ

NUS CLIENT NO: 178
WORK ORDER NO: 558
VENDOR NO: 0

Carbon Copy:

SAMPLE ID: WST-95-230
NUS SAMPLE NO: P0320160
P.O. NO.: 67763

DATE SAMPLED: 2.
DATE RECEIVED: 28-
APPROVED BY: K

LN	TEST CODE	DETERMINATION	RESULT	
1	AHGW	Mercury, Total (Hg)	0.0010	mg
2	AASW	Arsenic, Total (As)	0.4	
3	ABAW	Barium, Total (Ba)	0.20	
4	ACDW	Cadmium, Total (Cd)	< 0.005	mg
5	ACRW	Chromium, Total (Cr)	< 0.02	m
6	APBW	Lead, Total (Pb)	0.14	
7	ASEW	Selenium, Total (Se)	< 0.1	m
8	AAGW	Silver, Total (Ag)	< 0.01	mg/

COMMENTS:

Halliburton NUS CORPORATION

NUS LABORATORY
5350 Campbells Run Road
Pittsburgh, Pennsylvania 15205

TEL: (412) 747-2500
FAX: (412) 747-2559

September 10, 1995
Report No.: 00027423

LABORATORY ANALYSIS REPORT

CLIENT NAME: WESTINGHOUSE ELECTRIC CORPORATION, WID/WIPP
ADDRESS: P.O. BOX 2078
CARLSBAD, NM 88221-2078
ATTENTION: MR. RICK CHAVEZ

NUS CLIENT NO: 1783 0001
WORK ORDER NO: 55830
VENDOR NO: 01830727

Carbon Copy:

SAMPLE ID: WST-95-227
NUS SAMPLE NO: P0320157
P.O. NO.: 67763

DATE SAMPLED: 24-AUG-95
DATE RECEIVED: 28-AUG-95
APPROVED BY: Kieda, Chuck

LN	TEST CODE	DETERMINATION	RESULT	UNITS
1	AHGW	Mercury, Total (Hg)	< 0.0002	mg/L
2	AASW	Arsenic, Total (As)	0.4	mg/L
3	ABAW	Barium, Total (Ba)	0.21	mg/L
4	ACDW	Cadmium, Total (Cd)	0.005	mg/L
5	ACRW	Chromium, Total (Cr)	< 0.02	mg/L
6	APBW	Lead, Total (Pb)	< 0.05	mg/L
7	ASEW	Selenium, Total (Se)	< 0.1	mg/L
8	AAGW	Silver, Total (Ag)	< 0.01	mg/L

COMMENTS:

Halliburton NUS
CORPORATION

NUS LABO
5350 Campbells
Pittsburgh, Pennsylv

TEL: (412)
FAX: (412)

September 10
Report No.:
Section A Pag

LABORATORY ANALYSIS REPORT

CLIENT NAME: WESTINGHOUSE ELECTRIC CORPORATION, WID/WIPP
ADDRESS: P.O. BOX 2078
CARLSBAD, NM 88221-2078
ATTENTION: MR. RICK CHAVEZ

NUS CLIENT NO:
WORK ORDER NO: 55
VENDOR NO:

Carbon Copy:

SAMPLE ID: WST-95-228
NUS SAMPLE NO: P0320158
P.O. NO.: 67763

DATE SAMPLED:
DATE RECEIVED: 28
APPROVED BY: Ki

LN	TEST CODE	DETERMINATION	RESULT	U
1	1050	BOD (O2) - 5 day	< 2	m

COMMENTS:
1 Sample was received and analyzed after expiration of holding time.

Halliburton NUS CORPORATION

NUS LABORATORY
5350 Campbells Run Road
Pittsburgh, Pennsylvania 15205

TEL: (412) 747-2500
FAX: (412) 747-2559

September 10, 1995
Report No.: 00027423

LABORATORY ANALYSIS REPORT

CLIENT NAME: WESTINGHOUSE ELECTRIC CORPORATION, WID/WIPP
ADDRESS: P.O. BOX 2078
CARLSBAD, NM 88221-2078
ATTENTION: MR. RICK CHAVEZ

NUS CLIENT NO: 1783 0001
WORK ORDER NO: 55830
VENDOR NO: 0183072

Carbon Copy:

SAMPLE ID: WST-95-231
NUS SAMPLE NO: P0320161
P.O. NO.: 67763

DATE SAMPLED: 24-AUG-95
DATE RECEIVED: 28-AUG-95
APPROVED BY: Kieda, Chuck

LN	TEST CODE	DETERMINATION	RESULT	UNITS
1	1050	BOD (O2) - 5 day	< 2	mg/L

COMMENTS:
1 Sample was received and analyzed after expiration of holding time.

Maps for DOE/WIPP 99-3119. 40 CFR Parts 191 and 194 Compliance Monitoring Implementation Plan. (17, 11x17 maps)

APPENDIX C

WATER-QUALITY ANALYSIS
BOREHOLES C-2505, C-2506, C-2507, AND ES-001

Appendix C

WATER-QUALITY ANALYSIS

C.1 Introduction

Five groundwater samples and their associated duplicates (ten total samples) were collected from sediments above the Dewey Lake Redbeds at the four locations, C-2505, C-2506, C-2507, ES-001, shown on Figure 1-1. Two samples and two duplicates were collected from Exhaust Shaft Boring (ESB) C-2505 at depths of 51.4 ft and 65 ft below ground surface. A single sample and duplicate were collected from each of the remaining borings. The samples and duplicates were analyzed for pH, specific gravity, total dissolved solids, and major, minor and trace ions. A list of the analytes and the analytical results can be found in Table C-1.

This geochemical analysis of the groundwater compositions will focus primarily on the major- and minor-ion chemistry to evaluate the origin of the groundwater. Trace ions will be discussed in a qualitative sense, as most trace-metal concentrations were near the analytical detection limit and results are considered estimates rather than validated quantitative numbers.

C.2 pH, Specific Gravity, and Total Dissolved Solids

The pH values recorded by the analytical laboratory range from 7.29 to 7.66 (Table C-1); there are no field pH measurements available. As discussed in Section C.3 (Major Ions), the laboratory pH measurements probably overestimate the pH values by approximately one-half of a pH unit, due to degassing of carbon dioxide (CO_2) during sample collection and shipping. The neutral to slightly basic pH values reflect groundwater reactions with calcite and dolomite (Section C.3).

Reported specific gravity values are 1.00 g/ml for all samples, except the sample value of 1.01 for ESB C-2506 (Table C-1). This range of values indicates most groundwaters are dilute solutions, with brackish conditions being reached by the sample and duplicate from ESB C-2506.

Total dissolved solids (TDS) range from 4,000 (ESB C-2507) to 11,500 mg/L (ESB C-2506) (Table C-1). TDS values are highest for samples obtained proximal to the exhaust shaft (ESB C-2505 and C-2506), and decrease at the sample locations south of the exhaust shaft (ES-001, 100 ft south; C-2507, 215 ft south). Higher TDS values in groundwater samples recovered from near the exhaust shaft are linked primarily to an increase in chloride and sodium concentrations, suggesting dissolution of halite (NaCl) (Section C.3).

C.3 Major Ions

The major ions (i.e., >100 mg/L) in recovered groundwater samples are chloride (Cl), sulf :e (SO_4), bicarbonate (HCO_3), sodium (Na), calcium (Ca), and magnesium (Mg). Bicarbona.. concentration is calculated from the reported value for total inorganic carbon (TIC) as follow

$$HCO_3\ (mg/L) = TIC\ (mg/L) * 5.08$$

Figure C-1 charts the increase of Cl, Na, Mg, and Ca concentrations as TDS increases from mg/L at ESB C-2507 to 11,500 mg/L at ESB C-2505. Sulfate and TIC concentrations decre slightly or remain unchanged as TDS increases. Chloride and Na ions account for about 6 percent of the solute mass in EBS C-2505 and C-2506, suggesting the source for the solute i halite and associated salts (e.g., anhydrite [CaSO4]). Although TDS levels generally incre s the direction of groundwater flow, preliminary hydrologic pump tests suggest groundwater f to the south, toward lower TDS values. TDS levels at all locations exceed the New Mexi o Water Quality Control Commission (NMWQCC) groundwater standard of 1,000 mg/L.

The variations of the Na/Cl molar ratio and Mg, Ca, and Na concentrations with Cl conce tr are shown on Figure C-2. All parameters increase as the Cl concentration increases from 1, mg/L (32.7 mmol/L) to 5,400-mg/L (152 mmol/L), and all groundwater samples are undersaturated with respect to halite, indicating halite will be dissolved where it is encounter the groundwater. Additionally, all groundwater samples have Cl concentrations that exce d established NMWQCC groundwater standard of 250 mg/L (7.05 mmol/L).

As noted above, if groundwater flow is to the south, than relatively higher solute concent t to the north indicate a potential point source for the dissolved ions near ESB C-2506. The s storage area north of ESB C-2506 and the exhaust shaft may serve as the source for the s lt Further evidence for the salt storage area serving as the source for solute in the groundwate the observed increase in the Na/Cl molar ratio as one moves from the south locations to the The Na/Cl ratio increases from an average of approximately 0.33 at locations ESB C-25 7 ES-001 south of the exhaust shaft to 0.48 at ESB C-2506. Rain water dissolving halite at th source produces surface water with a molar Na/Cl ratio of one. Therefore, if the salt sto g is a viable source for the Cl and Na observed in the groundwater sample, the Na/Cl ratio wil approach one as sample locations move toward the salt storage area. Na/Cl ratios less th n indicate Na ion is attenuated along the flow path as groundwater migrates to the south o h storage area. Alternatively, a secondary source of Cl may be present to elevate Cl concentr However, halite is the most probable source for the Cl ion.

Figure C-3 examines the origin of sulfate, calcium, and magnesium in the groundwater. Sulfate concentrations range from 852 mg/L (8.87 mmol/L) to 994 mg/L (10.3 mmol/L) and are similar in groundwater samples from ESB C-2505, C-2507 and ES-001, and about 10 percent lower in ESB C-2505. The Ca/SO_4 molar ratio is between 2.2 and 2.5 for samples obtained near the exhaust shaft and 1.1 to 1.2 for samples south of the exhaust shaft. Solubility calculations indicate all groundwater samples are undersaturated with gypsum ($CaSO_4$:$2H_2O$), anhydrite ($CaSO_4$), and hydrated $MgSO_4$ salts (e.g., kieserite, leonhardite, hexahydrite, epsomite), implying that additional sulfate minerals will be dissolved if encountered by the groundwater. Additionally, all samples have sulfate concentrations that exceed the NMWQCC groundwater standard of 600 mg/L (6.25 mmol/L).

A relative uniform distribution of SO_4 ion in the groundwaters suggests that sulfate sources are disseminated in the sediments containing the groundwater, rather than the point source indicated for Na and Cl concentrations. Gypsum and anhydrite are common minerals in the sediments of the Dockum Group, which underlie the WIPP surface facilities to a variable depth of 40 to 70 ft (Holt et al., 1990), but the very soluble $MgSO_4$ salts are not. Therefore, sulfate and calcium ions are likely to be derived from the dissolution of gypsum or anhydrite. In contrast, it is unlikely that significant Mg concentrations could be derived from sulfate minerals. The source for most Mg ions, and additional Ca ions, is probably dolomite ($MgCa(CO_3)_2$) grains in the calcareous sediments of the Dockum Group. Enhanced dissolution of dolomite at lower pH may be responsible for the relative increase in the Ca/SO_4 molar ratio of samples obtained from ESB C-2505 and C-2606 (2.2 to 2.5 relative to 1.1 to 1.2, Figure C-3). This hypothesis is discussed further below.

The carbonate system for the collected groundwater samples is summarized on Figure C-4. Values for TIC range from 39.9 mg/L (3.32 mmol/L) to 58.0 mg/L (4.83 mmol/L). Note that a millimole of TIC is equal to a millimole of CO_3 or HCO_3, and TIC has been plotted to coincide with TIC values listed in Table C-1. It is evident upon examination of Figure C-4 that the sample with the lowest TIC is isolated from its duplicate. TIC values for the sample and duplicate from the 51.4 ft depth of ESB C-2505 differ by 14 percent, compared to differences of less than 4 percent for remaining samples and their duplicates. Based on the similarity of Mg and Ca concentrations for the four samples from ESB C-2505, it appears that the low TIC value reflects a potential laboratory problem with the analysis of this sample.

In general, Figure C-4 shows that the concentrations of Ca and Mg ions decrease as TIC increases, which suggests carbonate mineral equilibria (i.e., calcite and dolomite) controls the concentrations of TIC, Ca, and Mg. This statement is supported by solubility calculations car out with the EQ3/6 geochemical code (Wolery, 1992; Wolery and Daveler, 1992), which p e all groundwaters to be supersaturated with calcite and dolomite at the reported pH values.

As noted in the pH discussion, laboratory pH measurements probably overestimate the pH f samples by approximately one-half pH unit. This is a common observed phenomenon in sam containing carbonate that undergo CO_2 degassing, and is suggested further by solubility calculations that indicate the calcite supersaturation state is reduced to saturation as the pH is dropped to 7. Plotted calcite solubility curves at a pH of 7 for brackish and dilute waters (Fi C-4) pass through or near all Ca concentrations except those from ESB C-2506. The brac is solubility curve fits samples obtained from ESB C-2505 (TDS≈ 8,600 mg/L), while the dilute curve fits samples obtained from ESB C-2507 and ES-001 (TDS < 4,500). Dolomite curv s not plotted because dolomite formation is a diagenetic process rather than precipitation, prob due to kinetic inhibition of nucleation sites (Berner, 1971). However, dissolution of dolor te hypothesized to play an important role in the observed Ca/Mg molar ratios.

Dissolution of dolomite in deionized water produces a Ca/Mg molar ratio of one. The Ca /I molar ratio of the samples on Figure C-4 varies between 0.72 and 0.82, which suggests Ca ic being removed by calcite precipitation to lower the Ca/Mg molar ratio. This is supported y position of the solubility curves on Figure C-4. The difference in reported pH is likely to acc for much of the difference in observed Mg and Ca concentrations, with lower pH values ir samples from near the exhaust shaft yielding higher Mg and Ca concentrations.

In summary, major ions in the groundwater samples suggest an increase in TDS and the N /C molar ratio to the north may reflect a point source for halite dissolution in the salt storage are Relatively uniform sulfate concentrations in all groundwater samples suggest a disseminat l source for sulfate in the Dockum Group sediments. Mg, Ca, and TIC values are tied to the dissolution of dolomite and precipitation of calcite, with highest observed Mg and Ca concentrations linked to lower pH and higher Na and Cl concentrations. Concentrations f r Cl, and SO_4 exceed the NMWQCC groundwater standards.

C.4 Minor Ions

Minor ions (i.e., 1 - 100 mg/L) in the samples include bromide (Br), nitrate (NO_3), total o ga carbon (TOC), and potassium (K). Samples from ESB C-2507 and ES-001 contain mino amounts of iron (Fe). All results for K are flagged with the B qualifier, indicating the reporte result is an estimate that lies between the practical quantitation limit (PQL) and the instru er detection limit (IDL). Results for Fe are flagged with E and N qualifiers, indicating problems with analyte interference (most likely Cl) and spike recovery. Therefore, Fe results are also considered estimates.

Bromide (Br) concentrations vary from 9.0 to 10.2 mg/L (Table C-1). The uniform distribution of Br relative to a distinct decrease in Cl ion from north to south is enigmatic. If the source of Na and Cl is halite dissolution, Br concentration should increase with Cl concentration, as some Br substitutes for Cl in the halite structure. If additional groundwater samples are obtained from near the salt storage area, further insight may be gained on this query.

Nitrate (NO_3) values are reported as NO_3, and indicate a range of 9.5 to 18.2 mg/L. These values may indicate some animal or human source for the nitrogen, but they are below the NMWQCC groundwater standard of 44 mg/L (as NO_3) and well below the NO_3 concentrations of 440 to 530 mg/L reported for groundwater from the Dewey Lake Redbeds at the Ranch Well (southern border of DOE withdrawn land) (DOE, 1992).

Values for TOC range from 5.6 to 10.5 mg/L (Table C-1). These values exceed TOC values reported for groundwater from the Dewey Lake Redbeds (<3 to 5 mg/L, DOE, 1992), and the slightly higher values may reflect infiltration of surface water runoff from the asphalt parking lots and roads at WIPP.

Estimates of K concentration range from 11.9 to 36.7 mg/L, with all reported values falling between the PQL and the IDL (Table C-1). Potassium exhibits limited substitution for Na in the halite structure, implying K concentrations should increase with Na as halite is dissolved. However, this is not observed in the data reported in Table C-1. Because of the qualitative nature of the K data, additional analysis at this time is not warranted.

Iron concentrations at ESB ES-001 and C-2507 are estimated to range from 1.12 to 4.95 mg/L, values which exceed the NMWQCC groundwater standard of 1 mg/L. Analytical problems with matrix interference and spike recovery limit the conclusions one can draw on these data. However, the large apparent increase of iron concentration at ESB ES-001 and C-2507, relative to borings near the exhaust shaft, suggests a lower oxidation potential for the groundwater as it moves south of the exhaust shaft.

C-5 Trace Metals

Analytical results for the metals boron (B) and zinc (Zn) and the RCRA metals arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), selenium (Se), and sil (Ag) are given inTable C-1. All reported trace-metal concentrations are below the NMW C groundwater standards, except for several Se results and a single B result. Individual trac r are discussed below, with the exception of results for Hg and Cd. All Hg and Cd results are below their respective IDLs of 0.0002 mg/L and 0.00056 mg/L.

All B results are between the PQL and IDL and are below the NMWQCC limit of 0.75 m L with the exception of a reported concentration of 1.2 mg/L for the groundwater sample obta at 51.4 ft at ESB C-2505. The duplicate for this sample has a B concentration of 0.2 mg/ other samples collected at the 65 ft depth at ESB C-2505 have B concentrations of 0.19 r Therefore, there is indication of analytical problems or a reporting error for the listed concentration of 1.2 mg/L.

Reported Zn results are approximately three to four orders of magnitude lower than the NMWQCC standard of 10 mg/L. Most results are near the IDL of 0.0033 mg/L, and are considered estimated quantities. Results from ESB ES-001 are above the PQL and are corr with the highest observable TIC results. Zinc is a common trace metal in calcite and dolo i and the correlation of Zn and TIC concentrations is probably tied to dissolution of dolomite.

Arsenic results (Table C-1) are approximately two orders of magnitude below the NMWQC groundwater standard of 0.1 mg/L. All results for As lie between the PQL and IDL and a e considered estimated values.

Results for Ba are approximately one order of magnitude below the NMWQCC groundw e standard of 1 mg/L. Most samples have Ba concentrations that lie between the PQL and ID exceptions being the sample and duplicate from ESB C-2506. The similar Ba concentrati n locations agrees with observations of similar SO_4 concentrations across the sampling sites ar suggests that Ba concentrations are controlled by barite ($BaSO_4$) solubility. This observa o agrees with solubility calculations that indicate all groundwater samples are saturated wit b

Chromium concentrations are 5 to 10 times lower than the NMWACC standard of 0.05 r y Most Cr results lie between the PQL and IDL, indicating the results are considered estimate Cr concentration. Additionally, the E qualifier associated with most Cr results indicates t e presence of element interference (probably Cl) during the analysis.

Analytical results for Pb (Table C-1) are approximately one order of magnitude below th

NMWQCC standard of 0.05 mg/L. All lead results lie between the PQL and IDL, which indicates they are estimated quantities.

Selenium results on samples from ESB C-2505 and C-2506 range from 0.0605 to 0.08221 mg/L, which exceed the NMWQCC groundwater standard of 0.05 mg/L. However, all Se results are flagged with the N qualifier, which indicates spike recoveries were not within acceptable ranges. Therefore, the accuracy of the results is questioned and reported concentrations are considered estimates.

Most results for Ag are below the IDL of 0.00022 mg/L. Reported results that lie between the PQL and IDL are approximately two orders of magnitude below the NMWQCC standard of 0.05 mg/L. Silver concentrations will remain very low in the presence of Cl ion due to precipitation of the relatively insoluble silver chloride (AgCl) compound.

C-6 Conclusions

Analytical results for 10 groundwater samples from 4 locations indicate laboratory pH measurements may overestimate the pH by approximately one-half pH unit and that there is significant variation in the concentrations of most major ions. Chloride, Na, Mg, and Ca concentrations increase as sample locations move from the south to the north, while SO_4 and TIC concentrations remain the same or decrease slightly. Na/Cl, Ca/SO_4, and Ca/Mg molar ratios suggest that the Na and Cl source is probably the salt storage area and Ca, Mg, SO_4 and TIC sources are gypsum, calcite, and dolomite minerals disseminated in the sediments. Reported concentrations for TDS, Cl, and SO_4 exceed the NMWQCC groundwater standards.

The principal minor ions in the groundwater samples are Br, NO_3, K and TOC, with Fe playing a role as a minor ion in samples from ESB ES-001 and C-2507. Bromide and K results do not mimic the trends of Cl and Na, as expected if halite is being dissolve. Nitrate concentrations are below the NMWQCC standard of 44 mg/L (as NO_3), and the reported levels of 10 to 18 mg/L may reflect past livestock grazing in the area. Local ranch wells within the Dewey Lake Redbeds have NO_3 concentrations of 20 to 530 mg/L. Results for TOC are slightly above concentrations reported for Dewey Lake Redbeds, which may indicate a component of surface runoff from asphalt parking lots and roads. Iron concentrations at ESB ES-001 and C-2507 exceed the NMWQCC standard of 1.0 mg/L. The increase in Fe values to the south suggests a lower oxidation potential in the groundwater south of the exhaust shaft.

All trace metals are below NMWQCC standards except for several Se results and a single B result. Six reported results for Se slightly exceed the NMWQCC standard, but the accuracy these results is questionable due to poor spike recovery of the analyzed QA/QC samples. Th single B result that exceeds the NMWQCC standard of 0.75 mg/L also appears to be rela d analytical problems or reporting errors, as the duplicate and two other samples from the sam location have B concentrations of 0.2 mg/L.

C-7 References

Berner, R.A., 1971, Principles of Chemical Sedimentology, McGraw-Hill Book Company, N York, New York.

DOE, 1992, Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1991, DOE/WIPP 92-007, Carlsbad, New Mexico.

Holt, R.M. and D.W. Powers, 1990, The Late Permian Dewey Lake Formation at the Wa te Isolation Pilot Plant, in Geological and Hydrological Studies of Evaporites in the Norther Delaware Basin, GSA Field Trip #14, Dallas, Texas.

Wolery, T.J., 1992, EQ3NR, A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations: Theoretical Manual, User's Guide, and Related Documentation (V r 7.0), Lawrence Livermore National Laboratory, UCRL-MA-110662 PT III, September 1 9

Wolery, T.J. and S.A. Daveler, 1992, EQ6, A Computer Program for Reaction Path Mo li Geochemical Systems: Theoretical Manual, User's Guide, and Related Documentation (Ver 7.0), Lawrence Livermore National Laboratory, UCRL-MA-110662 PT IV, October 19 .

Figure Captions

Figure C-1. Major-ion concentrations versus total dissolved solids. Chloride, sodium, magnesium, and calcium concentrations increase with TDS, while sulfate and total inorganic carbon decrease slightly or remain unchanged.

Figure C-2. Variation of Na/Cl molar ratio and magnesium, calcium, and sodium concentrations with chloride concentration. Increase of all parameters from south (C2507) to north (C2506) suggests a halite source at the salt storage area.

Figure C-3. Variation of Ca/SO4 molar ratio and magnesium and calcium concentrations with sulfate concentration. Similar sulfate concentrations suggests a gypsum source disseminated in the sediments, while differences in the Ca/SO_4 ratio and magnesium and calcium concentrations indicates additional sources for calcium and magnesium.

Figure C-4. Variation of Ca/Mg molar ratio and magnesium and calcium concentrations with total inorganic carbon (TIC). Similar TIC values indicates disseminated dolomite and calcite source in sediments. A Ca/Mg ratio below one suggests calcium is being removed by precipitation of calcite, which is supported by position of depicted solubility curves.

TABLE C-1:

WATER-QUALITY ANALYTICAL LABORATORY RESULTS FOR BOREHOLES C-2505, C-2506, C-2507, and ES-001

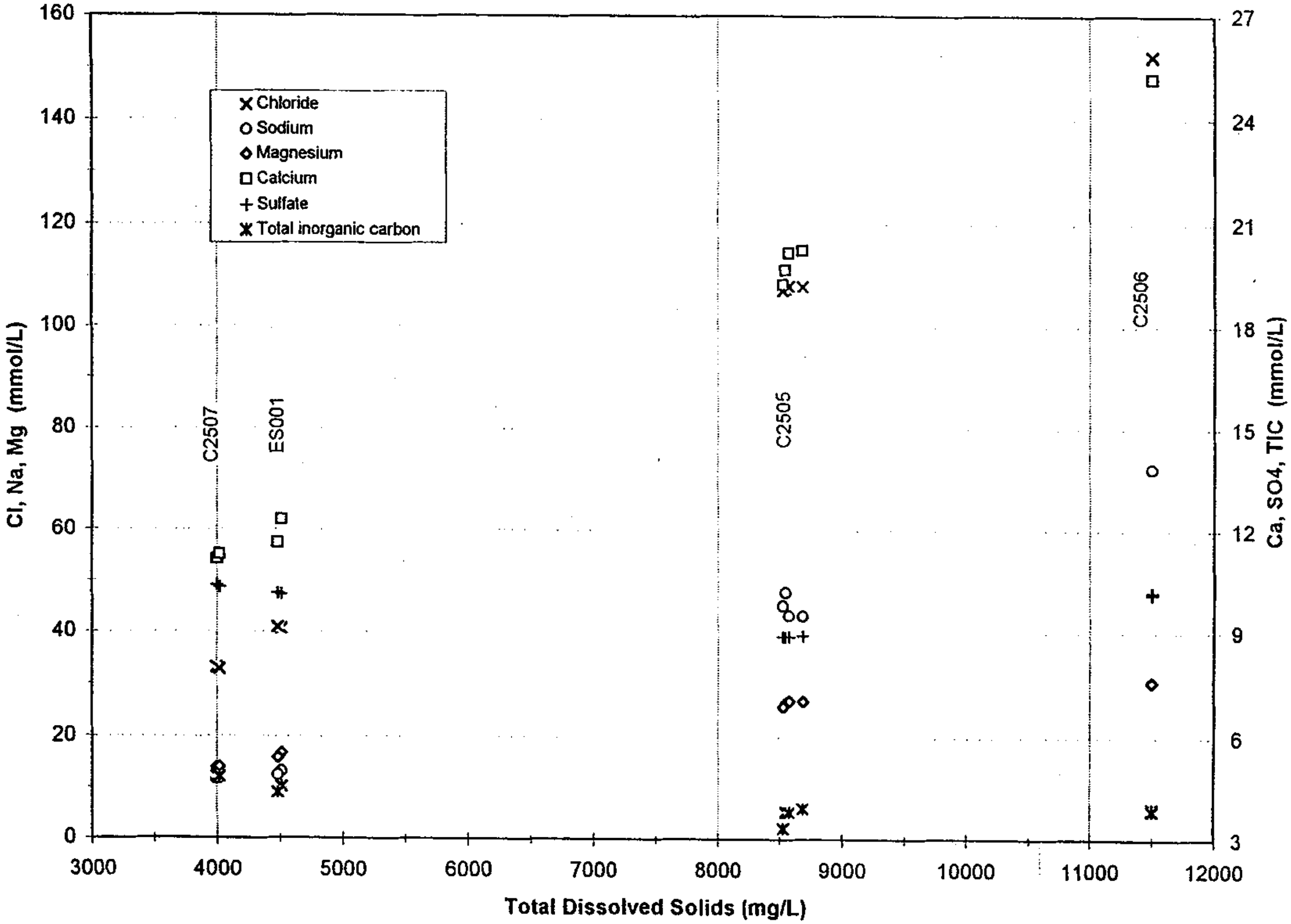
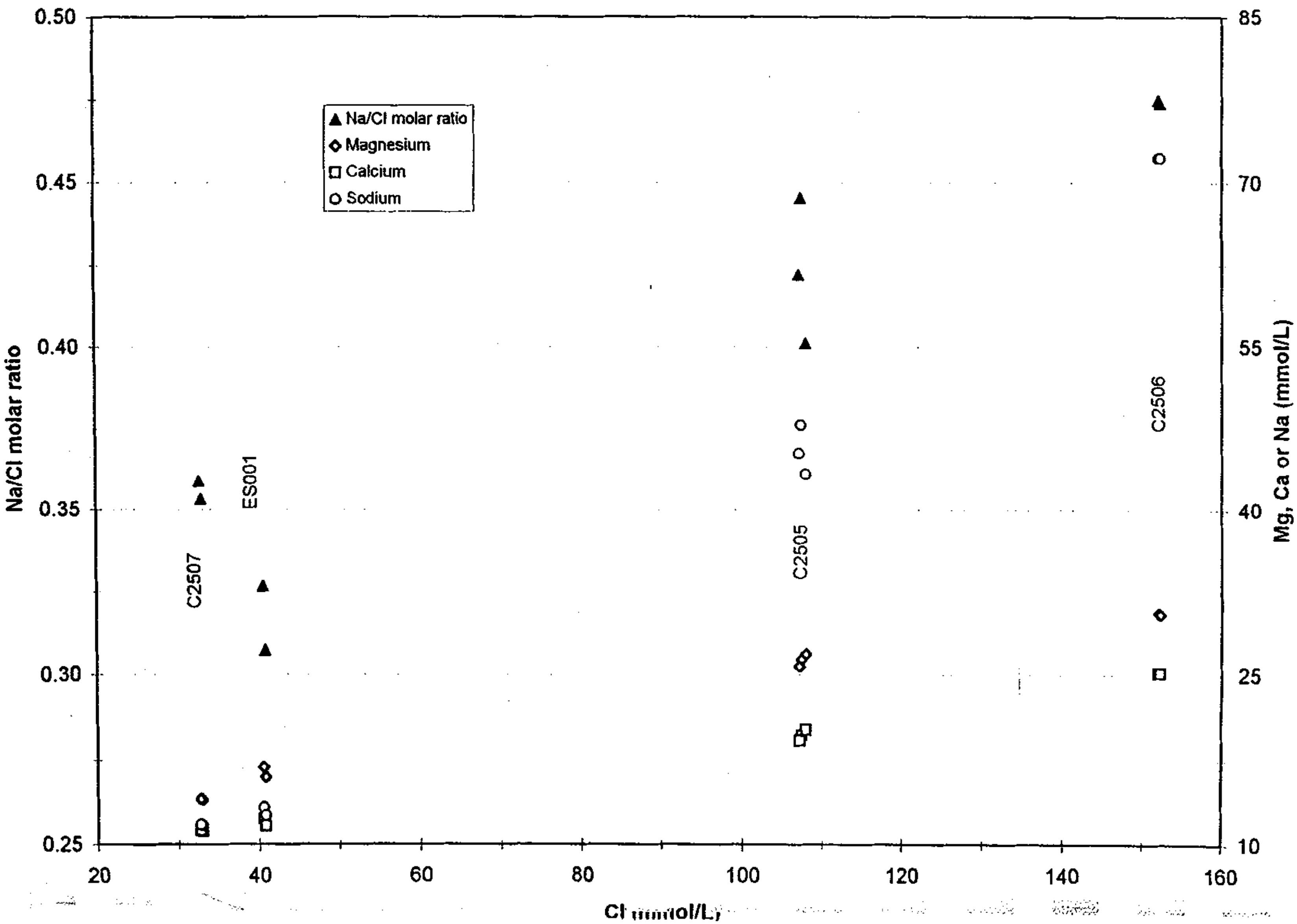


Figure C-1. Major-ion concentrations versus total dissolved solids.



Na/Cl molar ratio
Magnesium
Calcium
Sodium
Na/Cl molar ratio
Mg, Ca or Na (mmol/L)
Cl (mmol/L)
C2507
ES001
C2505
C2506
0.50
0.45
0.40
0.35
0.30
0.25
85
70
55
40
25
10
20
40
60
80
100
120
140
160

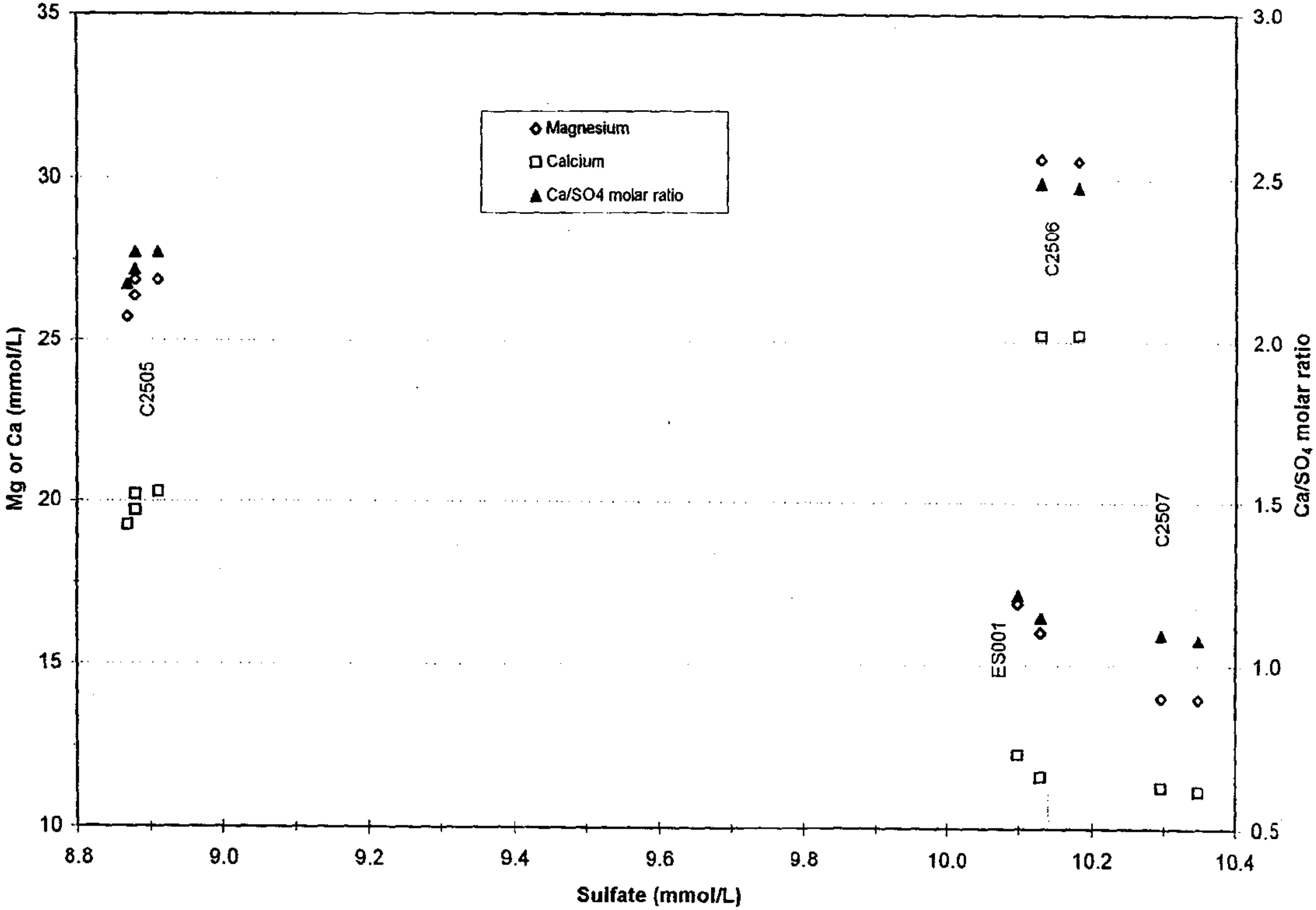
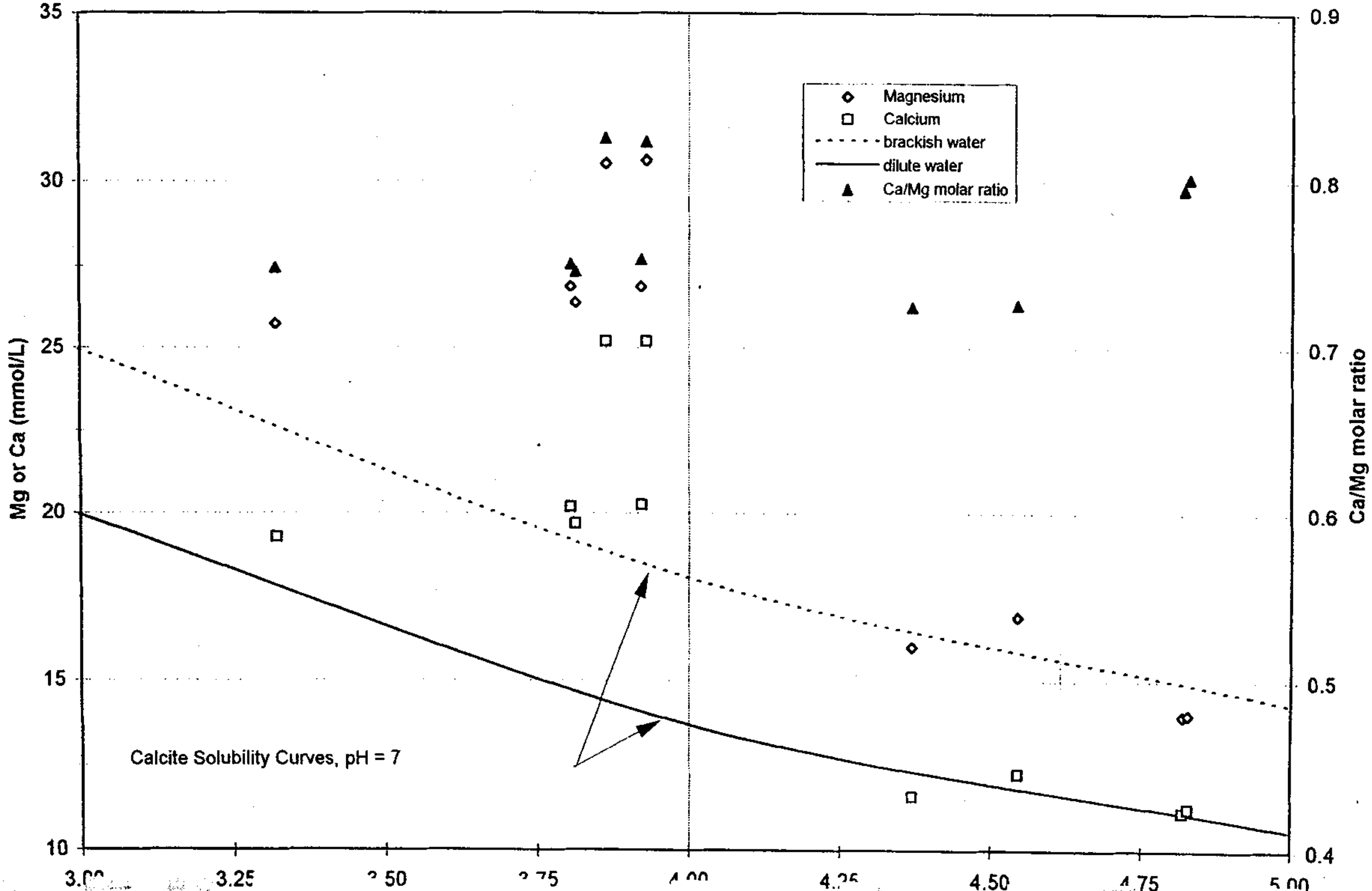


Figure C-3. Variation of Ca/SO_4 molar ratio and magnesium and calcium concentrations with sulfate concentration.



Magnesium
Calcium
brackish water
dilute water
Ca/Mg molar ratio
Mg or Ca (mmol/L)
Ca/Mg molar ratio
Calcite Solubility Curves, pH = 7
35
30
25
20
15
10
0.9
0.8
0.7
0.6
0.5
0.4
3.25
4.25
4.50
4.75

FIGURES

Grand Junction Projects Office Analytical Laboratory

V1.05

ANALYTICAL RESULTS

Customer ID: WST-96-380
Ticket ID:

Date: October 17, 1996
Lab ID: 240209

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep 26, 1996
Date Collected: Sep 24, 1996

ExShaft Borehole C-2505 @ 65'

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METHOD OF ANALYSIS
Silver	<0.22	UN	UG/L	10/08/96	AS-6 R06
Arsenic	~1.2	BN	UG/L	10/09/96	AS-4 R01
Boron	~0.19	B	MG/L	10/08/96	AS-5 R05
Barium	~94.1	B	UG/L	10/09/96	AS-6 R06
Bromide	9.1		MG/L	10/10/96	D-3 R13
Calcium	809		MG/L	10/08/96	AS-5 R05
Cadmium	<0.56	U	UG/L	10/08/96	AS-6 R06
Chloride	3830		MG/L	10/10/96	D-3 R13
Chromium	~8.9	BE	UG/L	10/08/96	AS-6 R06
Iron	~35.3	BEN	UG/L	10/09/96	AS-5 R05
Mercury	<0.20	UN	UG/L	10/07/96	AS-3 R04
Potassium	~30.9	B	MG/L	10/08/96	AS-1 R05
Magnesium	653		MG/L	10/08/96	AS-5 R05
Sodium	996		MG/L	10/08/96	AS-5 R05
Lead	~0.76	B	UG/L	10/08/96	AS-6 R06
pH	7.47			09/27/96	H-4 R04
Selenium	63.5	N	UG/L	10/10/96	AS-4 R01
Specific Gravity	1.00		G/ML	09/30/96	K-4 R01
Sulfate	853		MG/L	10/10/96	D-3 R13
Total Dissolved Solids	8580		MG/L	10/01/96	K-3 R06
Total Inorganic Carbon	45.7		MG/L	10/10/96	K-5 R05
Total Suspended Solids	22.0		MG/L	10/01/96	K-3 R06
Zinc	<3.3	U	UG/L	10/08/96	AS-5 R05

V1.05

ANALYTICAL RESULTS

Customer ID: WST-96-381
Ticket ID:

Date: October 17,
Lab ID: 240213

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep
Date Collected: Sep

ExShaft Borehole C-2505 @ 65'

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED
Ammonium	0.26		MG/L	10/07/96
Nitrite	~0.13	B	MG/L	10/08/96
Nitrate	16.0		MG/L	10/08/96
Total Organic Carbon	7.3		MG/L	10/11/96

Grand Junction Projects Office Analytical Laboratory

V1.05

ANALYTICAL RESULTS

Customer ID: WST-96-376
Ticket ID:

Date: October 17, 1996
Lab ID: 240207

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep 26, 1996
Date Collected: Sep 23, 1996

ExShaft C-2505@51.4'

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METHOD OF ANALYSIS
Silver	~0.36	BN	UG/L	10/08/96	AS-6 R06
Arsenic	~0.43	BN	UG/L	10/09/96	AS-4 R01
Boron	1.2		MG/L	10/08/96	AS-5 R05
Barium	~98.2	B	UG/L	10/09/96	AS-6 R06
Bromide	9.0		MG/L	10/10/96	D-3 R13
Calcium	789		MG/L	10/08/96	AS-5 R05
Cadmium	<0.56	U	UG/L	10/08/96	AS-6 R06
Chloride	3810		MG/L	10/10/96	D-3 R13
Chromium	~4.8	BE	UG/L	10/08/96	AS-6 R06
Iron	~14.6	BEN	UG/L	10/09/96	AS-5 R05
Mercury	<0.20	UN	UG/L	10/07/96	AS-3 R04
Potassium	~36.7	B	MG/L	10/08/96	AS-1 R05
Magnesium	641		MG/L	10/08/96	AS-5 R05
Sodium	1100		MG/L	10/08/96	AS-5 R05
Lead	~1.6	B	UG/L	10/08/96	AS-6 R06
pH	7.54			09/27/96	H-4 R04
Selenium	63.6	N	UG/L	10/10/96	AS-4 R01
Specific Gravity	1.00		G/ML	09/30/96	K-4 R01
Sulfate	853		MG/L	10/10/96	D-3 R13
Total Dissolved Solids	8550		MG/L	10/01/96	K-3 R06
Total Inorganic Carbon	45.8		MG/L	10/10/96	K-5 R05
Total Suspended Solids	~16.0	B	MG/L	10/01/96	K-3 R06
Zinc	<3.3	U	UG/L	10/08/96	AS-5 R05

ANALYTICAL RESULTS

Customer ID: WST-96-377
Ticket ID:

Date: October 17, 1[illegible]
Lab ID: 240211

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep [illegible]
Date Collected: Sep [illegible]

ExShaft Borehole C-2505 @ 51.4'

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED
Ammonium	0.30		MG/L	10/07/96
Nitrite	<0.10	U	MG/L	10/08/96
Nitrate	15.6		MG/L	10/08/96
Total Organic Carbon	9.2		MG/L	10/11/96

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ANALYTICAL RESULTS

Customer ID: WST-96-378
Ticket ID:

Date: October 17, 1996
Lab ID: 240208

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep 26, 1996
Date Collected: Sep 23, 1996

Dup. of WST-96-376

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METHOD OF ANALYSIS
Silver	~0.59	BN	UG/L	10/08/96	AS-6 R06
Arsenic	~0.42	BN	UG/L	10/09/96	AS-4 R01
Boron	~0.20	B	MG/L	10/08/96	AS-5 R05
Barium	~95.7	B	UG/L	10/09/96	AS-6 R06
Bromide	9.0		MG/L	10/10/96	D-3 R13
Calcium	772		MG/L	10/08/96	AS-5 R05
Cadmium	<0.56	U	UG/L	10/08/96	AS-6 R06
Chloride	3800		MG/L	10/10/96	D-3 R13
Chromium	18.0	E	UG/L	10/08/96	AS-6 R06
Iron	~93.7	BEN	UG/L	10/09/96	AS-5 R05
Mercury	<0.20	UN	UC/L	10/07/96	AS-3 R04
Potassium	~23.9	B	MG/L	10/08/96	AS-1 R05
Magnesium	625		MG/L	10/08/96	AS-5 R05
Sodium	1040		MG/L	10/08/96	AS-5 R05
Lead	~1.0	B	UG/L	10/08/96	AS-6 R06
pH	7.47			09/27/96	H-4 R04
Selenium	60.5	N	UG/L	10/10/96	AS-4 R01
Specific Gravity	1.00		G/ML	09/30/96	K-4 R01
Sulfate	852		MG/L	10/10/96	D-3 R13
Total Dissolved Solids	8530		MG/L	10/01/96	K-3 R06
Total Inorganic Carbon	39.9		MG/L	10/10/96	K-5 R05
Total Suspended Solids	~15.0	B	MG/L	10/01/96	K-3 R06
Zinc	~4.7	B	UG/L	10/08/96	AS-5 R05

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ANALYTICAL RESULTS

Customer ID: WST-96-379
Ticket ID:

Date: October 17, 19
Lab ID: 240212

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep
Date Collected: Sep

Dup. of WST-96-377

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED
Ammonium	0.38		MG/L	10/07/96
Nitrite	~0.15	B	MG/L	10/08/96
Nitrate	15.3		MG/L	10/08/96
Total Organic Carbon	6.4		MG/L	10/11/96

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ANALYTICAL RESULTS

Customer ID: WST-96-420
Ticket ID:

Date: October 17, 1996
Lab ID: 240293

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Oct 4, 1996
Date Collected: Oct 2, 1996

Ex Shaft Borehole C-2507

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METHOD OF ANALYSIS
Silver	<0.22	UN	UG/L	10/08/96	AS-6 R06
Arsenic	~0.67	BN	UG/L	10/09/96	AS-4 R01
Boron	~0.22	B	MG/L	10/08/96	AS-5 R05
Barium	~112	B	UG/L	10/08/96	AS-6 R06
Bromide	9.1		MG/L	10/09/96	D-3 R13
Calcium	492		MG/L	10/08/96	AS-5 R05
Cadmium	<0.56	U	UG/L	10/08/96	AS-6 R06
Chloride	1440		MG/L	10/09/96	D-3 R13
Chromium	12.8	E	UG/L	10/08/96	AS-6 R06
Iron	4950	EN	UG/L	10/09/96	AS-5 R05
Mercury	<0.20	UN	UG/L	10/07/96	AS-3 R04
Potassium	~35.0	B	MG/L	10/08/96	AS-1 R05
Magnesium	411		MG/L	10/08/96	AS-5 R05
Sodium	305		MG/L	10/08/96	AS-5 R05
Lead	~3.0	B	UG/L	10/08/96	AS-6 R06
pH	7.60			10/04/96	H-4 R04
Selenium	31.1	N	UG/L	10/10/96	AS-4 R01
Specific Gravity	1.00		G/ML	10/07/96	K-4 R01
Sulfate	970		MG/L	10/09/96	D-3 R13
Total Dissolved Solids	4510		MG/L	10/08/96	K-3 R06
Total Inorganic Carbon	54.6		MG/L	10/10/96	K-5 R05
Total Suspended Solids	122		MG/L	10/08/96	K-3 R06
Zinc	~16.2	B	UG/L	10/08/96	AS-5 R05

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Customer ID: WST-96-421
Ticket ID:

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000
Ex Shaft Borehole

ANALYSIS REQUESTED

Ammonium
Nitrite
Nitrate
Total Organic Carbon

APPENDIX C

WATER-QUALITY ANALYSIS
BOREHOLES C-2505, C-2506, C-2507, AND ES-001

... Junction Projects Office Analytical Laboratory

ANALYTICAL RESULTS

... WST-96-421

Date: October 17, 1
Lab ID: 240297

... IPP
...x: BRINE
...er: L30A90000
...ft Borehole C-2507

Case: 15099
Date Received: O...
Date Collected: Oc...

...QUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED
...	0.48		MG/L	10/07/96
	~0.30	B	MG/L	10/08/96
	18.1		MG/L	10/08/96
... Carbon	7.8		MG/L	10/11/96

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ANALYTICAL RESULTS

Customer ID: WST-96-423
Ticket ID:

Date: October 17, 1996
Lab ID: 240294

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Oct 4, 1996
Date Collected: Oct 3, 1996

Ex. Shaft Borehole C-2507

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METHOD OF ANALYSIS
Silver	<0.22	U	UG/L	10/08/96	AS-6 R06
Arsenic	~0.40	B	UG/L	10/09/96	AS-4 R01
Boron	~0.20	B	MG/L	10/08/96	AS-5 R05
Barium	~74.3	B	UG/L	10/08/96	AS-6 R06
Bromide	9.1		MG/L	10/09/96	D-3 R13
Calcium	465		MG/L	10/08/96	AS-5 R05
Cadmium	<0.56	U	UG/L	10/08/96	AS-6 R06
Chloride	1450		MG/L	10/09/96	D-3 R13
Chromium	~5.3	B	UG/L	10/08/96	AS-6 R06
Iron	1120	*	UG/L	10/09/96	AS-5 R05
Mercury	<0.20	U	UG/L	10/07/96	AS-3 R04
Potassium	~3360	B	MG/L	10/08/96	AS-1 R05
Magnesium	389		MG/L	10/08/96	AS-5 R05
Sodium	289		MG/L	10/08/96	AS-5 R05
Lead	~1.3	B	UG/L	10/08/96	AS-6 R06
pH	7.66			10/04/96	H-4 R04
Selenium	~80.8	N	UG/L	10/10/96	AS-4 R01
Specific Gravity	1.00		G/ML	10/07/96	K-4 R01
Sulfate	973		MG/L	10/09/96	D-3 R13
Total Dissolved Solids	4480		MG/L	10/08/96	K-3 R06
Total Inorganic Carbon	52.5		MG/L	10/10/96	K-5 R05
Total Suspended Solids	52.0		MG/L	10/08/96	K-3 R06
Zinc	~5.5	B	UG/L	10/08/96	AS-5 R05

ANALYTICAL RESULTS

Customer ID: WST-96-388
Ticket ID:

Date: October 17, 1996
Lab ID: 240221

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep 27, 1996
Date Collected: Sep 26, 1996

ExShaftBorehole C-2506 @ 43.5'

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METHOD OF ANALYSIS
Silver	<0.22	UN	UG/L	10/08/96	AS-6 R06
Arsenic	~1.5	BN	UG/L	10/09/96	AS-4 R01
Boron	~0.18	B	MG/L	10/08/96	AS-5 R05
Barium	234		UG/L	10/09/96	AS-6 R06
Bromide	10.2		MG/L	10/10/96	D-3 R13
Calcium	1010		MG/L	10/08/96	AS-5 R05
Cadmium	<0.56	U	UG/L	10/08/96	AS-6 R06
Chloride	5390		MG/L	10/10/96	D-3 R13
Chromium	12.8	E	UG/L	10/08/96	AS-6 R06
Iron	717	EN	UG/L	10/09/96	AS-5 R05
Mercury	<0.20	UN	UG/L	10/07/96	AS-3 R04
Potassium	~18.3	B	MG/L	10/08/96	AS-1 R05
Magnesium	744		MG/L	10/08/96	AS-5 R05
Sodium	1660		MG/L	10/08/96	AS-5 R05
Lead	~1.8	B	UG/L	10/08/96	AS-6 R06
pH	7.29			09/27/96	H-4 R04
Selenium	82.1	N	UG/L	10/10/96	AS-4 R01
Specific Gravity	1.01		G/ML	09/30/96	K-4 R01
Sulfate	973		MG/L	10/10/96	D-3 R13
Total Dissolved Solids	11500		MG/L	10/01/96	K-3 R06
Total Inorganic Carbon	47.2		MG/L	10/10/96	K-5 R05
Total Suspended Solids	32.0		MG/L	10/01/96	K-3 R06
Zinc	~13.8	B	UG/L	10/08/96	AS-5 R05

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ANALYTICAL RESULTS

Customer ID: WST-96-424
Ticket ID:

Date: October 17, 1996
Lab ID: 240298

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000
Ex Shaft Borehole C-2507

Case: 15099
Date Received: Oct 4, 1
Date Collected: Oct 3,

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METH ANAL
Ammonium	0.50		MG/L	10/07/96	F-6
Nitrite	~0.30	B	MG/L	10/08/96	D-[illegible]
Nitrate	18.0		MG/L	10/08/96	D-[illegible]
Total Organic Carbon	7.7		MG/L	10/11/96	K-5

ANALYTICAL RESULTS

Customer ID: WST-96-418
Ticket ID:

Date: October 17, 1996
Lab ID: 240296

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000
Ex Shaft Borehole ES001

Case: 15099
Date Received: Oct 4, 1996
Date Collected: Oct 2, 1996

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METHOD OF ANALYSIS
Ammonium	0.11		MG/L	10/07/96	F-6 R07
Nitrite	0.46	B	MG/L	10/08/96	D-3 R13
Nitrate	9.8		MG/L	10/08/96	D-3 R13
Total Organic Carbon	7.0		MG/L	10/11/96	K-5 R05

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ANALYTICAL RESULTS

Customer ID: WST-96-417
Ticket ID:

Date: October 17,
Lab ID: 240292

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: O
Date Collected: Oc

Ex Shaft Borehole ES001

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED
Silver	<0.22	UN	UG/L	10/08/96
Arsenic	~2.1	BN	UG/L	10/09/96
Boron	~0.22	B	MG/L	10/08/9
Barium	~159	B	UG/L	10/08/9
Bromide	10.0		MG/L	10/09/96
Calcium	451		MG/L	10/08/9
Cadmium	<0.56	U	UG/L	10/08/9
Chloride	1160		MG/L	10/09/96
Chromium	~10.1	BE	UG/L	10/08/96
Iron	4730	EN	UG/L	10/09/9
Mercury	<0.20	UN	UG/L	10/07/9
Potassium	~12.4	B	MG/L	10/08/96
Magnesium	341		MG/L	10/08/9
Sodium	270		MG/L	10/08/9
Lead	~2.4	B	UG/L	10/08/96
pH	7.59			10/04/96
Selenium	33.8	N	UG/L	10/10/9
Specific Gravity	1.00		G/ML	10/07/9
Sulfate	989		MG/L	10/09/96
Total Dissolved Solids	4020		MG/L	10/08/9
Total Inorganic Carbon	57.9		MG/L	10/10/9
Total Suspended Solids	144		MG/L	10/08/96
Zinc	30.9		UG/L	10/08/96

ANALYTICAL RESULTS

Customer ID: WST-96-382
Ticket ID:

Date: October 17, 1996
Lab ID: 240210

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep 26, 1996
Date Collected: Sep 24, 1996

Dup. of WST-96-380

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METHOD OF ANALYSIS
Silver	<0.22	UN	UG/L	10/08/96	AS-6 R06
Arsenic	~0.99	BN	UG/L	10/09/96	AS-4 R01
Boron	~0.19	B	MG/L	10/08/96	AS-5 R05
Barium	~94.5	B	UG/L	10/09/96	AS-6 R06
Bromide	9.2		MG/L	10/10/96	D-3 R13
Calcium	812		MG/L	10/08/96	AS-5 R05
Cadmium	<0.56	U	UG/L	10/08/96	AS-6 R06
Chloride	3840		MG/L	10/10/96	D-3 R13
Chromium	~3.4	BE	UG/L	10/08/96	AS-6 R06
Iron	~9.8	BEN	UG/L	10/09/96	AS-5 R05
Mercury	<0.20	UN	UG/L	10/07/96	AS-3 R04
Potassium	~31.4	B	MG/L	10/08/96	AS-1 R05
Magnesium	653		MG/L	10/08/96	AS-5 R05
Sodium	996		MG/L	10/08/96	AS-5 R05
Lead	~1.0	B	UG/L	10/08/96	AS-6 R06
pH	7.43			09/27/96	H-4 R04
Selenium	67.2	N	UG/L	10/10/96	AS-4 R01
Specific Gravity	1.00		G/ML	09/30/96	K-4 R01
Sulfate	856		MG/L	10/10/96	D-3 R13
Total Dissolved Solids	8690		MG/L	10/01/96	K-3 R06
Total Inorganic Carbon	47.1		MG/L	10/10/96	K-5 R05
Total Suspended Solids	24.0		MG/L	10/01/96	K-3 R06
Zinc	~5.6	B	UG/L	10/08/96	AS-5 R05

ANALYTICAL RESULTS

Customer ID: WST-96-383
Ticket ID:

Date: October 17, 1 9
Lab ID: 240214

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep 6
Date Collected: Sep 2

Dup. of WST-96-381

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	M A
Ammonium	0.21		MG/L	10/07/96	F
Nitrite	~0.12	B	MG/L	10/08/96	D
Nitrate	16.1		MG/L	10/08/96	D
Total Organic Carbon	10.5		MG/L	10/11/96	K

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ANALYTICAL RESULTS

Customer ID: WST-96-390
Ticket ID:

Date: October 17, 1996
Lab ID: 240222

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep 27, 1996
Date Collected: Sep 26, 1996

Dup of WST-96-388

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METHOD OF ANALYSIS
Silver	~0.24	BN	UG/L	10/08/96	AS-6 R06
Arsenic	~1.4	BN	UG/L	10/09/96	AS-4 R01
Boron	~0.18	B	MG/L	10/08/96	AS-5 R05
Barium	235		UG/L	10/09/96	AS-6 R06
Bromide	10.2		MG/L	10/10/96	D-3 R13
Calcium	1010		MG/L	10/08/96	AS-5 R05
Cadmium	<0.56	U	UG/L	10/08/96	AS-6 R06
Chloride	5400		MG/L	10/10/96	D-3 R13
Chromium	~6.1	BE	UG/L	10/08/96	AS-6 R06
Iron	860	EN	UG/L	10/09/96	AS-5 R05
Mercury	<0.20	UN	UG/L	10/07/96	AS-3 R04
Potassium	~19.1	B	MG/L	10/08/96	AS-1 R05
Magnesium	742		MG/L	10/08/96	AS-5 R05
Sodium	1660		MG/L	10/08/96	AS-5 R05
Lead	~1.7	B	UG/L	10/08/96	AS-6 R06
pH	7.29			09/27/96	H-4 R04
Selenium	~80.8	N	UG/L	10/10/96	AS-4 R01
Specific Gravity	1.00		G/ML	09/30/96	K-4 R01
Sulfate	978		MG/L	10/10/96	D-3 R13
Total Dissolved Solids	11500		MG/L	10/01/96	K-3 R06
Total Inorganic Carbon	46.4		MG/L	10/10/96	K-5 R05
Total Suspended Solids	113		MG/L	10/01/96	K-3 R06
Zinc	~7.3	B	UG/L	10/08/96	AS-5 R05

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ANALYTICAL RESULTS

Customer ID: WST-96-391
Ticket ID:

Date: October 17, [illegible]
Lab ID: 240226

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Se[illegible]
Date Collected: Sep[illegible]

Dup of WST-96-389

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED
Ammonium	0.08		MG/L	10/07/96
Nitrite	<0.10	U	MG/L	10/08/96
Nitrate	18.2		MG/L	10/08/9
Total Organic Carbon	8.5		MG/L	10/11/9[illegible]

ANALYTICAL RESULTS

Customer ID: WST-96-414
Ticket ID:

Date: October 17, 1996
Lab ID: 240291

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000
Ex. Shaft Borehole ES001

Case: 15099
Date Received: Oct 4, 1996
Date Collected: Oct 2, 1996

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METHOD OF ANALYSIS
Silver	<0.22	UN	UG/L	10/08/96	AS-6 R06
Arsenic	~1.8	BN	UG/L	10/09/96	AS-4 R01
Boron	~0.23	B	MG/L	10/08/96	AS-5 R05
Barium	~122	B	UG/L	10/08/96	AS-6 R06
Bromide	10.1		MG/L	10/09/96	D-3 R13
Calcium	446		MG/L	10/08/96	AS-5 R05
Cadmium	<0.56	U	UG/L	10/08/96	AS-6 R06
Chloride	1170		MG/L	10/09/96	D-3 R13
Chromium	~7.6	BE	UG/L	10/08/96	AS-6 R06
Iron	4160	EN	UG/L	10/09/96	AS-5 R05
Mercury	<0.20	UN	UG/L	10/07/96	AS-3 R04
Potassium	~11.9	B	MG/L	10/08/96	AS-1 R05
Magnesium	340		MG/L	10/08/96	AS-5 R05
Sodium	268		MG/L	10/08/96	AS-5 R05
Lead	~1.9	B	UG/L	10/08/96	AS-6 R06
pH	7.55			10/04/96	H-4 R04
Selenium	33.4	N	UG/L	10/10/96	AS-4 R01
Specific Gravity	1.00		G/ML	10/07/96	K-4 R01
Sulfate	994		MG/L	10/09/96	D-3 R13
Total Dissolved Solids	4000		MG/L	10/08/96	K-3 R06
Total Inorganic Carbon	57.9		MG/L	10/10/96	K-5 R05
Total Suspended Solids	125		MG/L	10/08/96	K-3 R06
Zinc	27.2		UG/L	10/08/96	AS-5 R05

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ANALYTICAL RESULTS

Customer ID: WST-96-415
Ticket ID:

Date: October 17,
Lab ID: 240295

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000
Ex Shaft Borehole E5001

Case: 15099
Date Received: Oct
Date Collected: Oc

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED
Ammonium	0.05		MG/L	10/07/96
Nitrite	7.7		MG/L	10/08/96
Nitrate	9.5		MG/L	10/08/96
Total Organic Carbon	5.6		MG/L	10/11/96

ANALYTICAL RESULTS

Customer ID: WST-96-390
Ticket ID:

Date: October 17, 1996
Lab ID: 240222

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep 27, 1996
Date Collected: Sep 26, 1996

Dup of WST-96-388

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METHOD OF ANALYSIS
Silver	~0.24	BN	UG/L	10/08/96	AS-6 R06
Arsenic	~1.4	BN	UG/L	10/09/96	AS-4 R01
Boron	~0.18	B	MG/L	10/08/96	AS-5 R05
Barium	235		UG/L	10/09/96	AS-6 R06
Bromide	10.2		MG/L	10/10/96	D-3 R13
Calcium	1010		MG/L	10/08/96	AS-5 R05
Cadmium	<0.56	U	UG/L	10/08/96	AS-6 R06
Chloride	5400		MG/L	10/10/96	D-3 R13
Chromium	~6.1	BE	UG/L	10/08/96	AS-6 R06
Iron	860	EN	UG/L	10/09/96	AS-5 R05
Mercury	<0.20	UN	UG/L	10/07/96	AS-3 R04
Potassium	~19.1	B	MG/L	10/08/96	AS-1 R05
Magnesium	742		MG/L	10/08/96	AS-5 R05
Sodium	1660		MG/L	10/08/96	AS-5 R05
Lead	~1.7	B	UG/L	10/08/96	AS-6 R06
pH	7.29			09/27/96	H-4 R04
Selenium	80.8	N	UG/L	10/10/96	AS-4 R01
Specific Gravity	1.00		G/ML	09/30/96	K-4 R01
Sulfate	978		MG/L	10/10/96	D-3 R13
Total Dissolved Solids	11500		MG/L	10/01/96	K-3 R06
Total Inorganic Carbon	46.4		MG/L	10/10/96	K-5 R05
Total Suspended Solids	113		MG/L	10/01/96	K-3 R06
Zinc	~7.3	B	UG/L	10/08/96	AS-5 R05

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ANALYTICAL RESULTS

Customer ID: WST-96-415
Ticket ID:

Date: October 17, [illegible]
Lab ID: 240295

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000
Ex Shaft Borehole E5001

Case: 15099
Date Received: Oct
Date Collected: Oc

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED
Ammonium	0.05		MG/L	10/07/96
Nitrite	7.7		MG/L	10/08/9
Nitrate	9.5		MG/L	10/08/9
Total Organic Carbon	5.6		MG/L	10/11/96

ANALYTICAL RESULTS

Customer ID: WST-96-388
Ticket ID:

Date: October 17, 1996
Lab ID: 240221

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep 27, 1996
Date Collected: Sep 26, 1996

Ex Shaft Borehole C-2506 @ 43.5'

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METHOD OF ANALYSIS
Silver	<0.22	UN	UG/L	10/08/96	AS-6 R06
Arsenic	~1.5	BN	UG/L	10/09/96	AS-4 R01
Boron	~0.18	B	MG/L	10/08/96	AS-5 R05
Barium	234		UG/L	10/09/96	AS-6 R06
Bromide	10.2		MG/L	10/10/96	D-3 R13
Calcium	1010		MG/L	10/08/96	AS-5 R05
Cadmium	<0.56	U	UG/L	10/08/96	AS-6 R06
Chloride	5390		MG/L	10/10/96	D-3 R13
Chromium	12.8	E	UG/L	10/08/96	AS-6 R06
Iron	717	EN	UG/L	10/09/96	AS-5 R05
Mercury	<0.20	UN	UG/L	10/07/96	AS-3 R04
Potassium	~18.3	B	MG/L	10/08/96	AS-1 R05
Magnesium	744		MG/L	10/08/96	AS-5 R05
Sodium	1660		MG/L	10/08/96	AS-5 R05
Lead	~1.8	B	UG/L	10/08/96	AS-6 R06
pH	7.29			09/27/96	H-4 R04
Selenium	82.1	N	UG/L	10/10/96	AS-4 R01
Specific Gravity	1.01		G/ML	09/30/96	K-4 R01
Sulfate	973		MG/L	10/10/96	D-3 R13
Total Dissolved Solids	11500		MG/L	10/01/96	K-3 R06
Total Inorganic Carbon	47.2		MG/L	10/10/96	K-5 R05
Total Suspended Solids	32.0		MG/L	10/01/96	K-3 R06
Zinc	~13.8	B	UG/L	10/08/96	AS-5 R05

ANALYTICAL RESULTS

A lytical Laboratory

: WST-96-391

Date: October 17, 1996
Lab ID: 240226

WIPP
ix: BRINE
per: L30A90000

Case: 15099
Date Received: Sep 27, 1996
Date Collected: Sep 26, 1996

Dup of WST-96-389

QUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METHOD OF ANALYSIS
	0.08		MG/L	10/07/96	F-6 R07
	<0.10	U	MG/L	10/08/96	D-3 R13
	18.2		MG/L	10/08/96	D-3 R13
ic Carbon	8.5		MG/L	10/11/96	K-5 R05

Date: October 17,
Lab ID: 240225

Case: 15099
Date Received: Se
Date Collected: Sep

'S	UNITS	DATE ANALYZED
	MG/L	10/07/96
	MG/L	10/08/96
	MG/L	10/08/9
	MG/L	10/11/9

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ANALYTICAL RESULTS

Customer ID: WST-96-382
Ticket ID:

Date: October 17, 1996
Lab ID: 240210

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep 26, 1996
Date Collected: Sep 24, 1996

Dup. of WST-96-380

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METHOD OF ANALYSIS
Silver	<0.22	UN	UG/L	10/08/96	AS-6 R06
Arsenic	~0.99	BN	UG/L	10/09/96	AS-4 R01
Boron	~0.19	B	MG/L	10/08/96	AS-5 R05
Barium	~94.5	B	UG/L	10/09/96	AS-6 R06
Bromide	9.2		MG/L	10/10/96	D-3 R13
Calcium	812		MG/L	10/08/96	AS-5 R05
Cadmium	<0.56	U	UG/L	10/08/96	AS-6 R06
Chloride	3840		MG/L	10/10/96	D-3 R13
Chromium	~3.4	BE	UG/L	10/08/96	AS-6 R06
Iron	~9.8	BEN	UG/L	10/09/96	AS-5 R05
Mercury	<0.20	UN	UG/L	10/07/96	AS-3 R04
Potassium	~31.4	B	MG/L	10/08/96	AS-1 R05
Magnesium	653		MG/L	10/08/96	AS-5 R05
Sodium	996		MG/L	10/08/96	AS-5 R05
Lead	~1.0	B	UG/L	10/08/96	AS-6 R06
pH	7.43			09/27/96	H-4 R04
Selenium	67.2	N	UG/L	10/10/96	AS-4 R01
Specific Gravity	1.00		G/ML	09/30/96	K-4 R01
Sulfate	856		MG/L	10/10/96	D-3 R13
Total Dissolved Solids	8690		MG/L	10/01/96	K-3 R06
Total Inorganic Carbon	47.1		MG/L	10/10/96	K-5 R05
Total Suspended Solids	24.0		MG/L	10/01/96	K-3 R06
Zinc	~5.6	B	UG/L	10/08/96	AS-5 R05

ANALYTICAL RESULTS

Customer ID: WST-96-383
Ticket ID:

Date: October 17, 1
Lab ID: 240214

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep
Date Collected: Sep

Dup. of WST-96-381

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED
Ammonium	0.21		MG/L	10/07/96
Nitrite	~0.12	B	MG/L	10/08/96
Nitrate	16.1		MG/L	10/08/96
Total Organic Carbon	10.5		MG/L	10/11/96

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ANALYTICAL RESULTS

Customer ID: WST-96-376
Ticket ID:

Date: October 17, 1996
Lab ID: 240207

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep 26, 1996
Date Collected: Sep 23, 1996

ExShaft C-2505@51.4'

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METHOD OF ANALYSIS
Silver	~0.36	BN	UG/L	10/08/96	AS-6 R06
Arsenic	~0.43	BN	UG/L	10/09/96	AS-4 R01
Boron	1.2		MG/L	10/08/96	AS-5 R05
Barium	~98.2	B	UG/L	10/09/96	AS-6 R06
Bromide	9.0		MG/L	10/10/96	D-3 R13
Calcium	789		MG/L	10/08/96	AS-5 R05
Cadmium	<0.56	U	UG/L	10/08/96	AS-6 R06
Chloride	3810		MG/L	10/10/96	D-3 R13
Chromium	~4.8	BE	UG/L	10/08/96	AS-6 R06
Iron	~14.6	BEN	UG/L	10/09/96	AS-5 R05
Mercury	<0.20	UN	UG/L	10/07/96	AS-3 R04
Potassium	~36.7	B	MG/L	10/08/96	AS-1 R05
Magnesium	641		MG/L	10/08/96	AS-5 R05
Sodium	1100		MG/L	10/08/96	AS-5 R05
Lead	~1.6	B	UG/L	10/08/96	AS-6 R06
pH	7.54			09/27/96	H-4 R04
Selenium	63.6	N	UG/L	10/10/96	AS-4 R01
Specific Gravity	1.00		G/ML	09/30/96	K-4 R01
Sulfate	853		MG/L	10/10/96	D-3 R13
Total Dissolved Solids	8550		MG/L	10/01/96	K-3 R06
Total Inorganic Carbon	45.8		MG/L	10/10/96	K-5 R05
Total Suspended Solids	~16.0	B	MG/L	10/01/96	K-3 R06
Zinc	<3.3	U	UG/L	10/08/96	AS-5 R05

ANALYTICAL RESULTS

Customer ID: WST-96-377
Ticket ID:

Date: October 17, 19
Lab ID: 240211

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep 2
Date Collected: Sep

ExShaft Borehole C-2505 @ 51.4'

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED
Ammonium	0.30		MG/L	10/07/96
Nitrite	<0.10	U	MG/L	10/08/96
Nitrate	15.6		MG/L	10/08/96
Total Organic Carbon	9.2		MG/L	10/11/96

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ANALYTICAL RESULTS

Customer ID: WST-96-378
Ticket ID:

Date: October 17, 1996
Lab ID: 240208

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep 26, 1996
Date Collected: Sep 23, 1996

Dup. of WST-96-376

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METHOD OF ANALYSIS
Silver	~0.59	BN	UG/L	10/08/96	AS-6 R06
Arsenic	~0.42	BN	UG/L	10/09/96	AS-4 R01
Boron	~0.20	B	MG/L	10/08/96	AS-5 R05
Barium	~95.7	B	UG/L	10/09/96	AS-6 R06
Bromide	9.0		MG/L	10/10/96	D-3 R13
Calcium	772		MG/L	10/08/96	AS-5 R05
Cadmium	<0.56	U	UG/L	10/08/96	AS-6 R06
Chloride	3800		MG/L	10/10/96	D-3 R13
Chromium	18.0	E	UG/L	10/08/96	AS-6 R06
Iron	~93.7	BEN	UG/L	10/09/96	AS-5 R05
Mercury	<0.20	UN	UG/L	10/07/96	AS-3 R04
Potassium	~23.9	B	MG/L	10/08/96	AS-1 R05
Magnesium	625		MG/L	10/08/96	AS-5 R05
Sodium	1040		MG/L	10/08/96	AS-5 R05
Lead	~1.0	B	UG/L	10/08/96	AS-6 R06
pH	7.47			09/27/96	H-4 R04
Selenium	~60.5	N	UG/L	10/10/96	AS-4 R01
Specific Gravity	1.00		G/ML	09/30/96	K-4 R01
Sulfate	852		MG/L	10/10/96	D-3 R13
Total Dissolved Solids	8530		MG/L	10/01/96	K-3 R06
Total Inorganic Carbon	39.9		MG/L	10/10/96	K-5 R05
Total Suspended Solids	~15.0	B	MG/L	10/01/96	K-3 R06
Zinc	~4.7	B	UG/L	10/08/96	AS-5 R05

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ANALYTICAL RESULTS

Customer ID: WST-96-379
Ticket ID:

Date: October 17, 1
Lab ID: 240212

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep
Date Collected: Sep

Dup. of WST-96-377

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED
Ammonium	0.38		MG/L	10/07/96
Nitrite	~0.15	B	MG/L	10/08/96
Nitrate	15.3		MG/L	10/08/96
Total Organic Carbon	6.4		MG/L	10/11/96

V1.05

ANALYTICAL RESULTS

Customer ID: WST-96-380
Ticket ID:

Date: October 17, 1996
Lab ID: 240209

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Sep 26, 1996
Date Collected: Sep 24, 1996

ExShaft Borehole C-2505@ 65'

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED	METHOD OF ANALYSIS
Silver	<0.22	UN	UG/L	10/08/96	AS-6 R06
Arsenic	~1.2	BN	UG/L	10/09/96	AS-4 R01
Boron	~0.19	B	MG/L	10/08/96	AS-5 R05
Barium	~94.1	B	UG/L	10/09/96	AS-6 R06
Bromide	9.1		MG/L	10/10/96	D-3 R13
Calcium	809		MG/L	10/08/96	AS-5 R05
Cadmium	<0.56	U	UG/L	10/08/96	AS-6 R06
Chloride	3830		MG/L	10/10/96	D-3 R13
Chromium	~8.9	BE	UG/L	10/08/96	AS-6 R06
Iron	~35.3	BEN	UG/L	10/09/96	AS-5 R05
Mercury	<0.20	UN	UG/L	10/07/96	AS-3 R04
Potassium	~30.9	B	MG/L	10/08/96	AS-1 R05
Magnesium	653		MG/L	10/08/96	AS-5 R05
Sodium	996		MG/L	10/08/96	AS-5 R05
Lead	~0.76	B	UG/L	10/08/96	AS-6 R06
pH	7.47			09/27/96	H-4 R04
Selenium	63.5	N	UG/L	10/10/96	AS-4 R01
Specific Gravity	1.00		G/ML	09/30/96	K-4 R01
Sulfate	853		MG/L	10/10/96	D-3 R13
Total Dissolved Solids	8580		MG/L	10/01/96	K-3 R06
Total Inorganic Carbon	45.7		MG/L	10/10/96	K-5 R05
Total Suspended Solids	22.0		MG/L	10/01/96	K-3 R06
Zinc	<3.3	U	UG/L	10/08/96	AS-5 R05

V1.05

ANALYTICAL RESULTS

Customer ID: WST-96-381
Ticket ID:

Date: October 17, 1[cut off]
Lab ID: 240213

Requestor: WIPP
Sample Matrix: BRINE
Project Number: L30A90000

Case: 15099
Date Received: Se[cut off]
Date Collected: Sep[cut off]

ExShaft Borehole C-2505 @ 65'

ANALYSIS REQUESTED	RESULTS	RESULT QUALI's	UNITS	DATE ANALYZED
Ammonium	0.26		MG/L	10/07/96
Nitrite	~0.13	B	MG/L	10/08/96
Nitrate	16.0		MG/L	10/08/96
Total Organic Carbon	7.3		MG/L	10/11/96

TABLE C-1:

WATER-QUALITY ANALYTICAL LABORATORY RESULTS FOR BOREHOLES C-2505, C-2506, C-2507, and ES-001

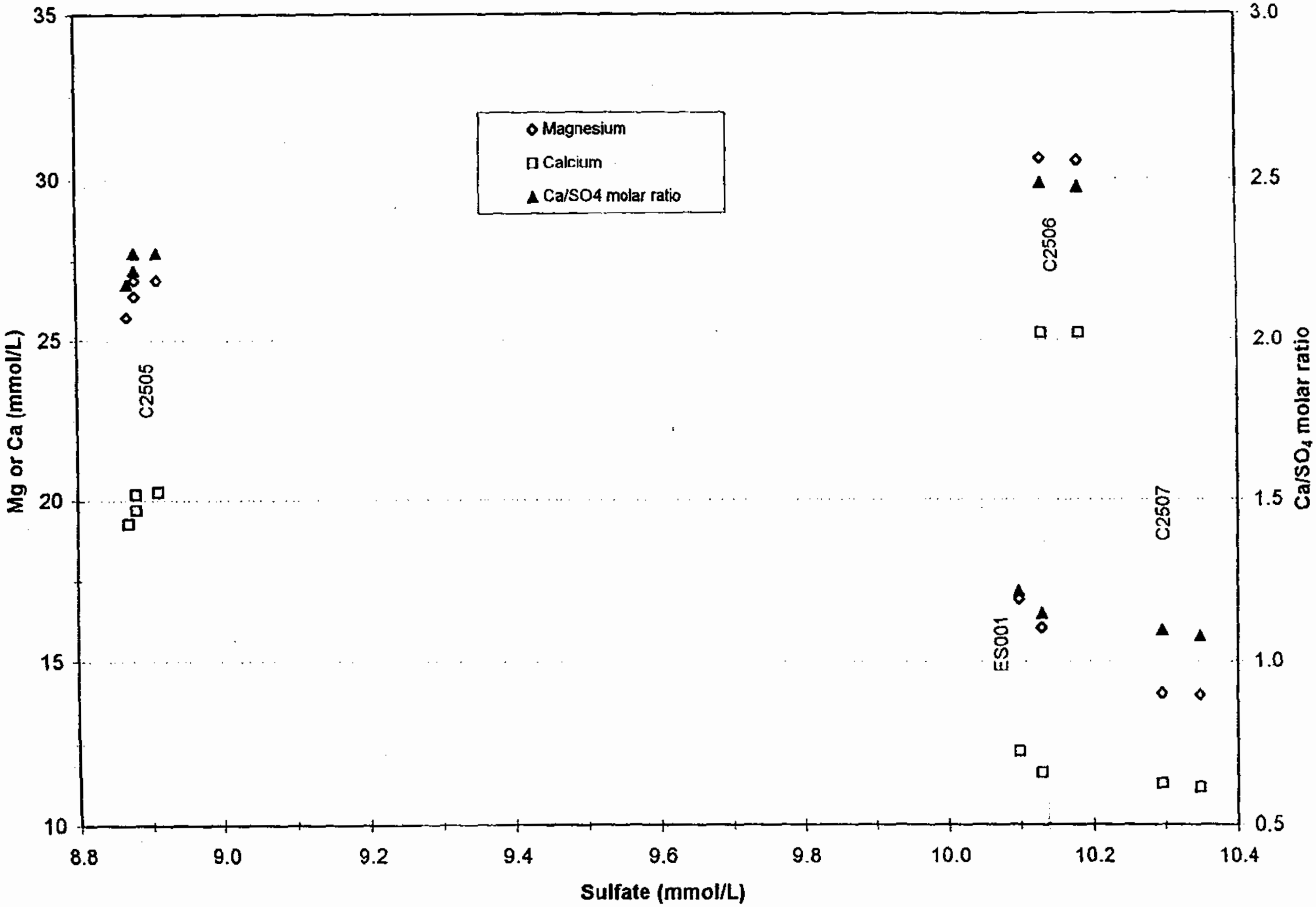
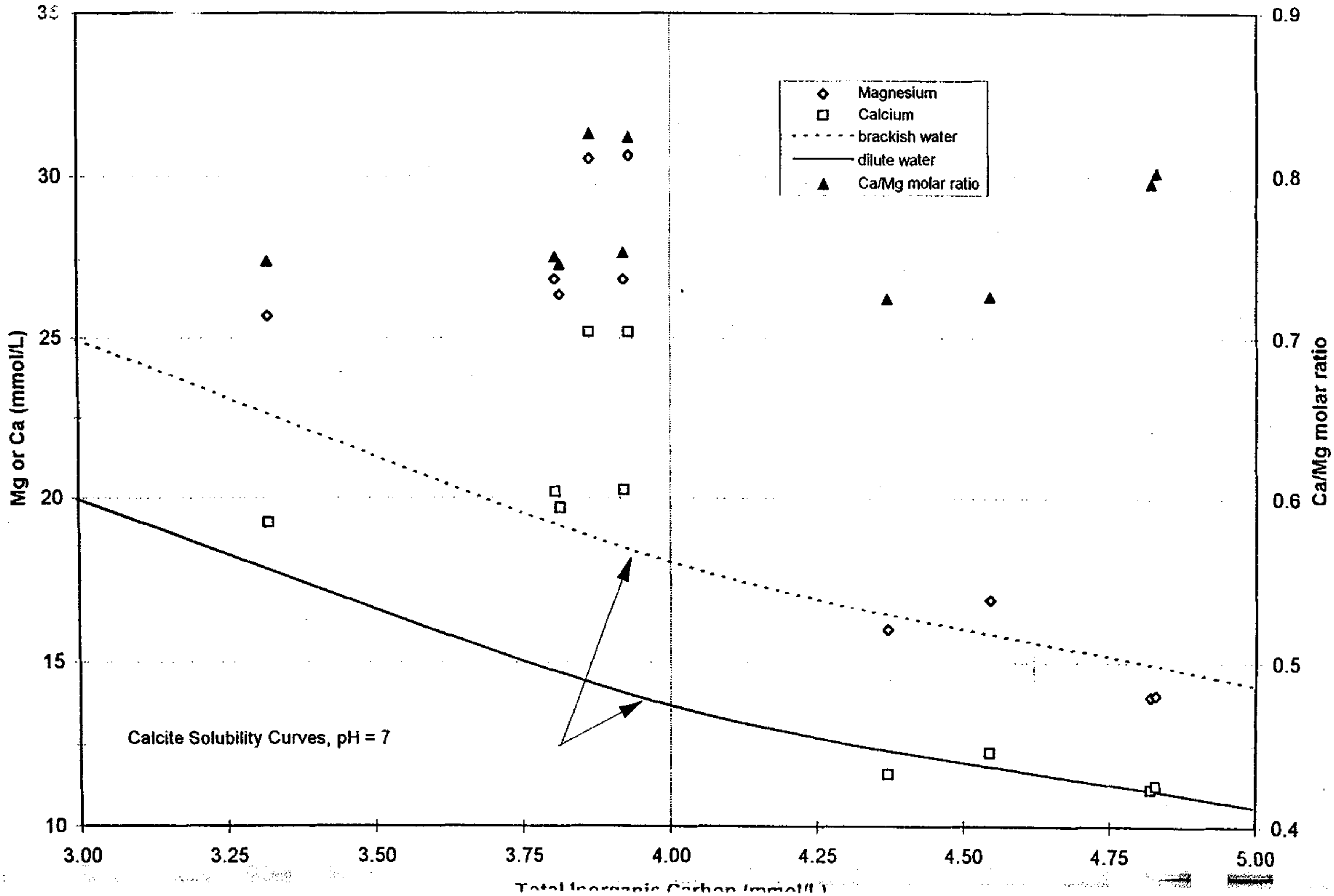


Figure C-3. Variation of Ca/SO_4 molar ratio and magnesium and calcium concentrations with sulfate concentration.



Magnesium
Calcium
brackish water
dilute water
Ca/Mg molar ratio
Calcite Solubility Curves, pH = 7
Mg or Ca (mmol/L)
Ca/Mg molar ratio
35
30
25
20
15
10
0.9
0.8
0.7
0.6
0.5
0.4
3.00
3.25
3.50
3.75
4.00
4.25
4.50
4.75
5.00

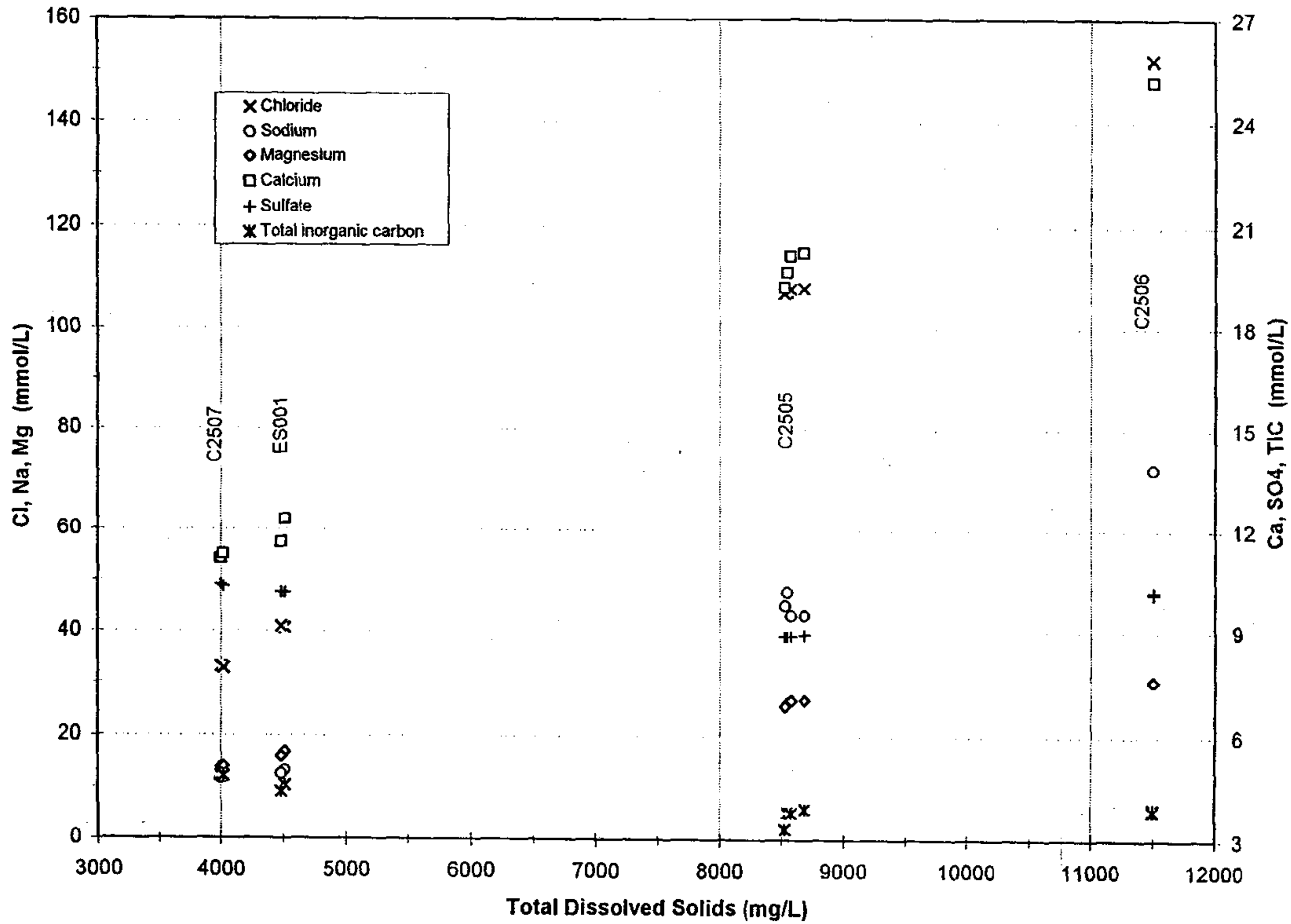
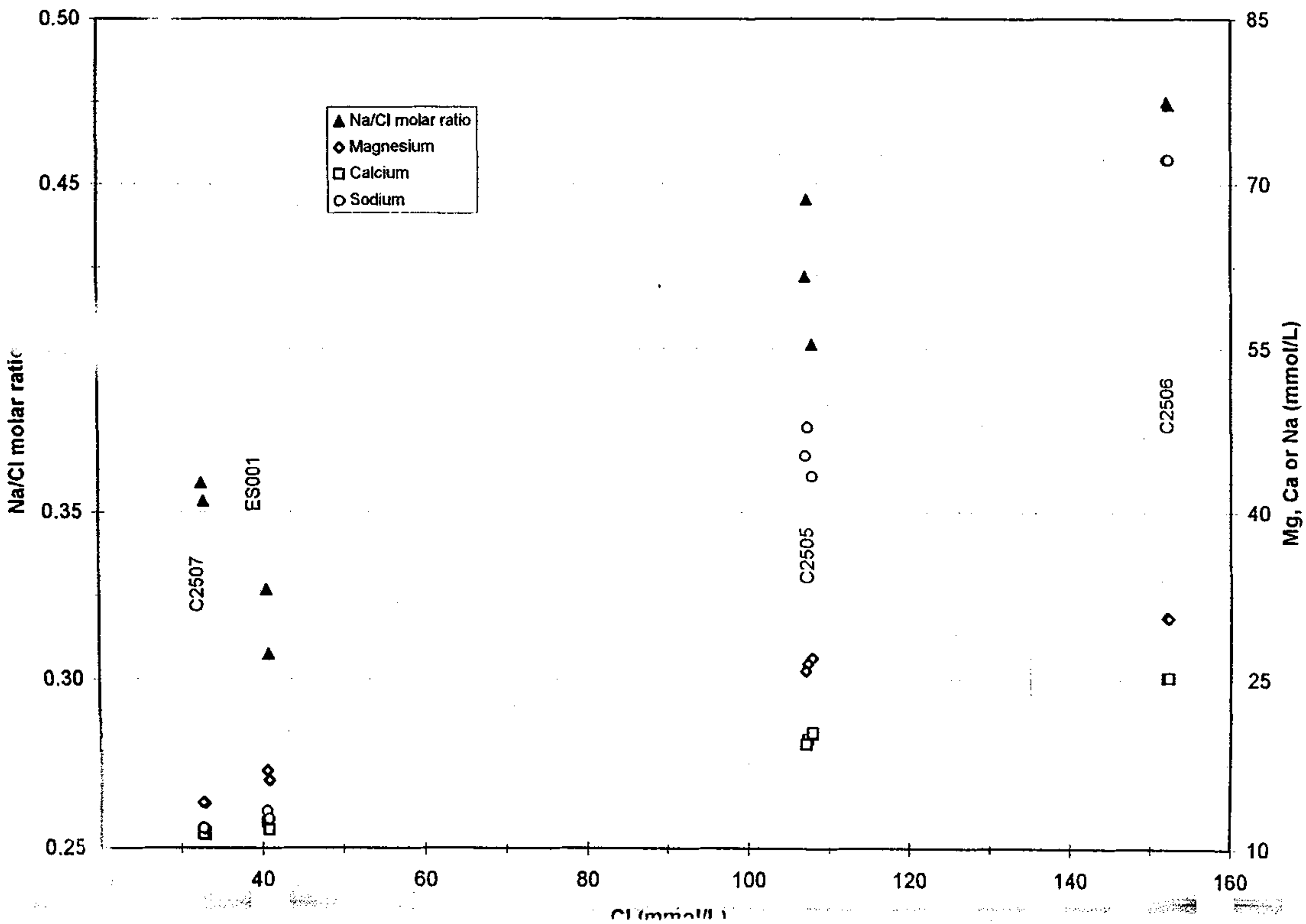


Figure C-1. Major-ion concentrations versus total dissolved solids.


Na/Cl molar ratio
Magnesium
Calcium
Sodium
C2507
ES001
C2505
C2506
0.50
0.45
0.35
0.30
0.25
85
70
55
40
25
10
40
60
80
100
120
140
160
Na/Cl molar ratio
Mg, Ca or Na (mmol/L)

FIGURES

Figure Captions

Figure C-1. Major-ion concentrations versus total dissolved solids. Chloride, sodium, magnesium, and calcium concentrations increase with TDS, while sulfate and total inorganic carbon decrease slightly or remain unchanged.

Figure C-2. Variation of Na/Cl molar ratio and magnesium, calcium, and sodium concentrations with chloride concentration. Increase of all parameters from south (C2507) to north (C2506) suggests a halite source at the salt storage area.

Figure C-3. Variation of Ca/SO4 molar ratio and magnesium and calcium concentrations with sulfate concentration. Similar sulfate concentrations suggests a gypsum source disseminated in the sediments, while differences in the Ca/SO_4 ratio and magnesium and calcium concentrations indicates additional sources for calcium and magnesium.

Figure C-4. Variation of Ca/Mg molar ratio and magnesium and calcium concentrations with total inorganic carbon (TIC). Similar TIC values indicates disseminated dolomite and calcite source in sediments. A Ca/Mg ratio below one suggests calcium is being removed by precipitation of calcite, which is supported by position of depicted solubility curves.

NMWQCC standard of 0.05 mg/L. All lead results lie between the PQL and IDL, which indicates they are estimated quantities.

Selenium results on samples from ESB C-2505 and C-2506 range from 0.0605 to 0.08221 mg/L, which exceed the NMWQCC groundwater standard of 0.05 mg/L. However, all Se results are flagged with the N qualifier, which indicates spike recoveries were not within acceptable ranges. Therefore, the accuracy of the results is questioned and reported concentrations are considered estimates.

Most results for Ag are below the IDL of 0.00022 mg/L. Reported results that lie between the PQL and IDL are approximately two orders of magnitude below the NMWQCC standard of 0.05 mg/L. Silver concentrations will remain very low in the presence of Cl ion due to precipitation of the relatively insoluble silver chloride (AgCl) compound.

C-6 Conclusions

Analytical results for 10 groundwater samples from 4 locations indicate laboratory pH measurements may overestimate the pH by approximately one-half pH unit and that there is significant variation in the concentrations of most major ions. Chloride, Na, Mg, and Ca concentrations increase as sample locations move from the south to the north, while SO_4 and TIC concentrations remain the same or decrease slightly. Na/Cl, Ca/SO_4, and Ca/Mg molar ratios suggest that the Na and Cl source is probably the salt storage area and Ca, Mg, SO_4 and TIC sources are gypsum, calcite, and dolomite minerals disseminated in the sediments. Reported concentrations for TDS, Cl, and SO_4 exceed the NMWQCC groundwater standards.

The principal minor ions in the groundwater samples are Br, NO_3, K and TOC, with Fe playing a role as a minor ion in samples from ESB ES-001 and C-2507. Bromide and K results do not mimic the trends of Cl and Na, as expected if halite is being dissolve. Nitrate concentrations are below the NMWQCC standard of 44 mg/L (as NO_3), and the reported levels of 10 to 18 mg/L may reflect past livestock grazing in the area. Local ranch wells within the Dewey Lake Redbeds have NO_3 concentrations of 20 to 530 mg/L. Results for TOC are slightly above concentrations reported for Dewey Lake Redbeds, which may indicate a component of surface runoff from asphalt parking lots and roads. Iron concentrations at ESB ES-001 and C-2507 exceed the NMWQCC standard of 1.0 mg/L. The increase in Fe values to the south suggests a lower oxidation potential in the groundwater south of the exhaust shaft.

All trace metals are below NMWQCC standards except for several Se results and a single B result. Six reported results for Se slightly exceed the NMWQCC standard, but the accuracy these results is questionable due to poor spike recovery of the analyzed QA/QC samples. Th single B result that exceeds the NMWQCC standard of 0.75 mg/L also appears to be relat d analytical problems or reporting errors, as the duplicate and two other samples from the sam location have B concentrations of 0.2 mg/L.

C-7 References

Berner, R.A., 1971, Principles of Chemical Sedimentology, McGraw-Hill Book Company, N York, New York.

DOE, 1992, Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1991, DOE/WIPP 92-007, Carlsbad, New Mexico.

Holt, R.M. and D.W. Powers, 1990, The Late Permian Dewey Lake Formation at the Wa e Isolation Pilot Plant, in Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin, GSA Field Trip #14, Dallas, Texas.

Wolery, T.J., 1992, EQ3NR, A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations: Theoretical Manual, User's Guide, and Related Documentation (V 7.0), Lawrence Livermore National Laboratory, UCRL-MA-110662 PT III, September 199.

Wolery, T.J. and S.A. Daveler, 1992, EQ6, A Computer Program for Reaction Path Mod i Geochemical Systems: Theoretical Manual, User's Guide, and Related Documentation (Vers 7.0), Lawrence Livermore National Laboratory, UCRL-MA-110662 PT IV, October 199

detection limit (IDL). Results for Fe are flagged with E and N qualifiers, indicating problems with analyte interference (most likely Cl) and spike recovery. Therefore, Fe results are also considered estimates.

Bromide (Br) concentrations vary from 9.0 to 10.2 mg/L (Table C-1). The uniform distribution of Br relative to a distinct decrease in Cl ion from north to south is enigmatic. If the source of Na and Cl is halite dissolution, Br concentration should increase with Cl concentration, as some Br substitutes for Cl in the halite structure. If additional groundwater samples are obtained from near the salt storage area, further insight may be gained on this query.

Nitrate (NO_3) values are reported as NO_3, and indicate a range of 9.5 to 18.2 mg/L. These values may indicate some animal or human source for the nitrogen, but they are below the NMWQCC groundwater standard of 44 mg/L (as NO_3) and well below the NO_3 concentrations of 440 to 530 mg/L reported for groundwater from the Dewey Lake Redbeds at the Ranch Well (southern border of DOE withdrawn land) (DOE, 1992).

Values for TOC range from 5.6 to 10.5 mg/L (Table C-1). These values exceed TOC values reported for groundwater from the Dewey Lake Redbeds (<3 to 5 mg/L; DOE, 1992), and the slightly higher values may reflect infiltration of surface water runoff from the asphalt parking lots and roads at WIPP.

Estimates of K concentration range from 11.9 to 36.7 mg/L, with all reported values falling between the PQL and the IDL (Table C-1). Potassium exhibits limited substitution for Na in the halite structure, implying K concentrations should increase with Na as halite is dissolved. However, this is not observed in the data reported in Table C-1. Because of the qualitative nature of the K data, additional analysis at this time is not warranted.

Iron concentrations at ESB ES-001 and C-2507 are estimated to range from 1.12 to 4.95 mg/L, values which exceed the NMWQCC groundwater standard of 1 mg/L. Analytical problems with matrix interference and spike recovery limit the conclusions one can draw on these data. However, the large apparent increase of iron concentration at ESB ES-001 and C-2507, relative to borings near the exhaust shaft, suggests a lower oxidation potential for the groundwater as it moves south of the exhaust shaft.

C-5 Trace Metals

Analytical results for the metals boron (B) and zinc (Zn) and the RCRA metals arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), selenium (Se), and silv (Ag) are given inTable C-1. All reported trace-metal concentrations are below the NMWQCC groundwater standards, except for several Se results and a single B result. Individual trace-r are discussed below, with the exception of results for Hg and Cd. All Hg and Cd results are below their respective IDLs of 0.0002 mg/L and 0.00056 mg/L.

All B results are between the PQL and IDL and are below the NMWQCC limit of 0.75 mg/L with the exception of a reported concentration of 1.2 mg/L for the groundwater sample obtai at 51.4 ft at ESB C-2505. The duplicate for this sample has a B concentration of 0.2 mg/L a other samples collected at the 65 ft depth at ESB C-2505 have B concentrations of 0.19 mg/L Therefore, there is indication of analytical problems or a reporting error for the listed concentration of 1.2 mg/L.

Reported Zn results are approximately three to four orders of magnitude lower than the NMWQCC standard of 10 mg/L. Most results are near the IDL of 0.0033 mg/L, and are considered estimated quantities. Results from ESB ES-001 are above the PQL and are corre with the highest observable TIC results. Zinc is a common trace metal in calcite and dolomit and the correlation of Zn and TIC concentrations is probably tied to dissolution of dolomite.

Arsenic results (Table C-1) are approximately two orders of magnitude below the NMWQCC groundwater standard of 0.1 mg/L. All results for As lie between the PQL and IDL and a considered estimated values.

Results for Ba are approximately one order of magnitude below the NMWQCC groundwa er standard of 1 mg/L. Most samples have Ba concentrations that lie between the PQL and IDI exceptions being the sample and duplicate from ESB C-2506. The similar Ba concentratic s locations agrees with observations of similar SO_4 concentrations across the sampling sites an suggests that Ba concentrations are controlled by barite ($BaSO_4$) solubility. This observat r agrees with solubility calculations that indicate all groundwater samples are saturated with ba

Chromium concentrations are 5 to 10 times lower than the NMWACC standard of 0.05 m /I Most Cr results lie between the PQL ...dicating the results are considered estimates Cr concentration. Additionally, the ...er associated with most Cr results indicates tl presence of element interfere... ...Cl) during the analysis.

Analytical results for Pb (Table C-... e approximately one order of magnitude below the

Figure C-3 examines the origin of sulfate, calcium, and magnesium in the groundwater. Sulfate concentrations range from 852 mg/L (8.87 mmol/L) to 994 mg/L (10.3 mmol/L) and are similar in groundwater samples from ESB C-2505, C-2507 and ES-001, and about 10 percent lower in ESB C-2505. The Ca/SO_4 molar ratio is between 2.2 and 2.5 for samples obtained near the exhaust shaft and 1.1 to 1.2 for samples south of the exhaust shaft. Solubility calculations indicate all groundwater samples are undersaturated with gypsum ($CaSO_4$:$2H_2O$), anhydrite ($CaSO_4$), and hydrated $MgSO_4$ salts (e.g., kieserite, leonhardite, hexahydrite, epsomite), implying that additional sulfate minerals will be dissolved if encountered by the groundwater. Additionally, all samples have sulfate concentrations that exceed the NMWQCC groundwater standard of 600 mg/L (6.25 mmol/L).

A relative uniform distribution of SO_4 ion in the groundwaters suggests that sulfate sources are disseminated in the sediments containing the groundwater, rather than the point source indicated for Na and Cl concentrations. Gypsum and anhydrite are common minerals in the sediments of the Dockum Group, which underlie the WIPP surface facilities to a variable depth of 40 to 70 ft (Holt et al., 1990), but the very soluble $MgSO_4$ salts are not. Therefore, sulfate and calcium ions are likely to be derived from the dissolution of gypsum or anhydrite. In contrast, it is unlikely that significant Mg concentrations could be derived from sulfate minerals. The source for most Mg ions, and additional Ca ions, is probably dolomite ($MgCa(CO_3)_2$) grains in the calcareous sediments of the Dockum Group. Enhanced dissolution of dolomite at lower pH may be responsible for the relative increase in the Ca/SO_4 molar ratio of samples obtained from ESB C-2505 and C-2606 (2.2 to 2.5 relative to 1.1 to 1.2, Figure C-3). This hypothesis is discussed further below.

The carbonate system for the collected groundwater samples is summarized on Figure C-4. Values for TIC range from 39.9 mg/L (3.32 mmol/L) to 58.0 mg/L (4.83 mmol/L). Note that a millimole of TIC is equal to a millimole of CO_3 or HCO_3, and TIC has been plotted to coincide with TIC values listed in Table C-1. It is evident upon examination of Figure C-4 that the sample with the lowest TIC is isolated from its duplicate. TIC values for the sample and duplicate from the 51.4 ft depth of ESB C-2505 differ by 14 percent, compared to differences of less than 4 percent for remaining samples and their duplicates. Based on the similarity of Mg and Ca concentrations for the four samples from ESB C-2505, it appears that the low TIC value reflects a potential laboratory problem with the analysis of this sample.

In general, Figure C-4 shows that the concentrations of Ca and Mg ions decrease as TIC increases, which suggests carbonate mineral equilibria (i.e., calcite and dolomite) controls the concentrations of TIC, Ca, and Mg. This statement is supported by solubility calculations car out with the EQ3/6 geochemical code (Wolery, 1992; Wolery and Daveler, 1992), which p e all groundwaters to be supersaturated with calcite and dolomite at the reported pH values.

As noted in the pH discussion, laboratory pH measurements probably overestimate the pH f samples by approximately one-half pH unit. This is a common observed phenomenon in sam containing carbonate that undergo CO_2 degassing, and is suggested further by solubility calculations that indicate the calcite supersaturation state is reduced to saturation as the pH is dropped to 7. Plotted calcite solubility curves at a pH of 7 for brackish and dilute waters Fi C-4) pass through or near all Ca concentrations except those from ESB C-2506. The brac..is solubility curve fits samples obtained from ESB C-2505 (TDS ≈ 8,600 mg/L), while the dilute curve fits samples obtained from ESB C-2507 and ES-001 (TDS < 4,500). Dolomite curv s not plotted because dolomite formation is a diagenetic process rather than precipitation, prob due to kinetic inhibition of nucleation sites (Berner, 1971). However, dissolution of dolon te hypothesized to play an important role in the observed Ca/Mg molar ratios.

Dissolution of dolomite in deionized water produces a Ca/Mg molar ratio of one. The Ca/ 1 molar ratio of the samples on Figure C-4 varies between 0.72 and 0.82, which suggests Ca ic being removed by calcite precipitation to lower the Ca/Mg molar ratio. This is supported / position of the solubility curves on Figure C-4. The difference in reported pH is likely to acc for much of the difference in observed Mg and Ca concentrations, with lower pH values ir samples from near the exhaust shaft yielding higher Mg and Ca concentrations.

In summary, major ions in the groundwater samples suggest an increase in TDS and the N C molar ratio to the north may reflect a point source for halite dissolution in the salt storage are Relatively uniform sulfate concentrations in all groundwater samples suggest a disseminate source for sulfate in the Dockum Group sediments. Mg, Ca, and TIC values are tied to the dissolution of dolomite and precipitation of calcite, with highest observed Mg and Ca concentrations linked to lower pH and higher Na and Cl concentrations. Concentrations f.. Cl, and SO_4 exceed the NMWQCC groundwater standards.

C.4 Minor Ions

Minor ions (i.e., 1 - 100 mg/L) in the samples include bromide (Br), nitrate (NO_3), total o: a carbon (TOC), and potassium (K). Samples from ESB C-2507 and ES-001 contain minor amounts of iron (Fe). All results for K are flagged with the B qualifier, indicating the repo te result is an estimate that lies between the practical quantitation limit (PQL) and the instrum..er

Appendix C

WATER-QUALITY ANALYSIS

C.1 Introduction

Five groundwater samples and their associated duplicates (ten total samples) were collected from sediments above the Dewey Lake Redbeds at the four locations, C-2505, C-2506, C-2507, ES-001, shown on Figure 1-1. Two samples and two duplicates were collected from Exhaust Shaft Boring (ESB) C-2505 at depths of 51.4 ft and 65 ft below ground surface. A single sample and duplicate were collected from each of the remaining borings. The samples and duplicates were analyzed for pH, specific gravity, total dissolved solids, and major, minor and trace ions. A list of the analytes and the analytical results can be found in Table C-1.

This geochemical analysis of the groundwater compositions will focus primarily on the major- and minor-ion chemistry to evaluate the origin of the groundwater. Trace ions will be discussed in a qualitative sense, as most trace-metal concentrations were near the analytical detection limit and results are considered estimates rather than validated quantitative numbers.

C.2 pH, Specific Gravity, and Total Dissolved Solids

The pH values recorded by the analytical laboratory range from 7.29 to 7.66 (Table C-1); there are no field pH measurements available. As discussed in Section C.3 (Major Ions), the laboratory pH measurements probably overestimate the pH values by approximately one-half of a pH unit, due to degassing of carbon dioxide (CO_2) during sample collection and shipping. The neutral to slightly basic pH values reflect groundwater reactions with calcite and dolomite (Section C.3).

Reported specific gravity values are 1.00 g/ml for all samples, except the sample value of 1.01 for ESB C-2506 (Table C-1). This range of values indicates most groundwaters are dilute solutions, with brackish conditions being reached by the sample and duplicate from ESB C-2506.

Total dissolved solids (TDS) range from 4,000 (ESB C-2507) to 11,500 mg/L (ESB C-2506) (Table C-1). TDS values are highest for samples obtained proximal to the exhaust shaft (ESB C-2505 and C-2506), and decrease at the sample locations south of the exhaust shaft (ES-001, 100 ft south; C-2507, 215 ft south). Higher TDS values in groundwater samples recovered from near the exhaust shaft are linked primarily to an increase in chloride and sodium concentrations, suggesting dissolution of halite (NaCl) (Section C.3).

C.3 Major Ions

The major ions (i.e., >100 mg/L) in recovered groundwater samples are chloride (Cl), sulf
(SO_4), bicarbonate (HCO_3), sodium (Na), calcium (Ca), and magnesium (Mg). Bicarbona
concentration is calculated from the reported value for total inorganic carbon (TIC) as follo

$$HCO_3\ (mg/L) = TIC\ (mg/L) * 5.08$$

Figure C-1 charts the increase of Cl, Na, Mg, and Ca concentrations as TDS increases from mg/L at ESB C-2507 to 11,500 mg/L at ESB C-2505. Sulfate and TIC concentrations de slightly or remain unchanged as TDS increases. Chloride and Na ions account for about 6 percent of the solute mass in EBS C-2505 and C-2506, suggesting the source for the solute halite and associated salts (e.g., anhydrite [CaSO4]). Although TDS levels generally incre the direction of groundwater flow, preliminary hydrologic pump tests suggest groundwater to the south, toward lower TDS values. TDS levels at all locations exceed the New Mexi Water Quality Control Commission (NMWQCC) groundwater standard of 1,000 mg/L.

The variations of the Na/Cl molar ratio and Mg, Ca, and Na concentrations with Cl conce are shown on Figure C-2. All parameters increase as the Cl concentration increases from 1, mg/L (32.7 mmol/L) to 5,400 mg/L (152 mmol/L), and all groundwater samples are undersaturated with respect to halite, indicating halite will be dissolved where it is encounte the groundwater. Additionally, all groundwater samples have Cl concentrations that exce established NMWQCC groundwater standard of 250 mg/L (7.05 mmol/L).

As noted above, if groundwater flow is to the south, than relatively higher solute concent to the north indicate a potential point source for the dissolved ions near ESB C-2506. The s storage area north of ESB C-2506 and the exhaust shaft may serve as the source for the s Further evidence for the salt storage area serving as the source for solute in the groundwate the observed increase in the Na/Cl molar ratio as one moves from the south locations to t The Na/Cl ratio increases from an average of approximately 0.33 at locations ESB C-25 ES-001 south of the exhaust shaft to 0.48 at ESB C-2506. Rain water dissolving halite at t source produces surface water with a molar Na/Cl ratio of one. Therefore, if the salt sto is a viable source for the Cl and Na observed in the groundwater sample, the Na/Cl ratio wi approach one as sample locations move toward the salt storage area. Na/Cl ratios less th indicate Na ion is attenuated along the flow path as groundwater migrates to the south of th storage area. Alternatively, a secondary source of Cl may be present to elevate Cl concentr However, halite is the most probable source for the Cl ion.

APPENDIX D

GEOL0GIC CORE DISCRIPTIONS

Preliminary Report on Geology of Drillholes C2505, C2506, and C2507

Dennis W. Powers, Ph.D
Consulting Geologist
HC 12 Box 87
Anthony, TX 79821

Merrie L. Martin
IT Corporation
5301 Central Ave NE
Albuquerque, NM 87108

ABSTRACT

Three drillholes to identify possible sources of small amounts of water flowing into the exhaust shaft were partially cored to recover rock samples representative of the near-surface geology. Through the cored intervals, recovery was good, averaging better than 90% overall.

The Pleistocene Mescalero caliche was encountered below several feet of surface fill and dune sand. It is not strongly indurated as in some other areas around the WIPP site, representing about stage 1 in development, and it is relatively thin (up to about 3 ft). The Mescalero did not appear to be laminar near the exhaust shaft, though it is hard and well-formed where exposed in constructed drainage ponds just outside the south WIPP fence.

The Miocene-Pleistocene Gatuña Formation immediately underlies the Mescalero, and the upper part has partly been calcified by pedogenic processes. It is about 36 ft thick where completely cored. The Gatuña lithology is typical in these drillholes. The interpreted thickness is about 20 ft more than in the exhaust shaft. The difference is due to local variations and a much more comprehensive knowledge of the Gatuña since the exhaust shaft was mapped.

The Triassic Santa Rosa Formation ranges from about 5 to 8 ft thick as assigned in these drillholes. In the exhaust shaft, the assigned thickness was about 20 ft. The difference is due to changed interpretation of the Gatuña-Santa Rosa contact in this study as well as some local variation. The Santa Rosa lithology is typical.

Each of the drillholes encountered the Dewey Lake Formation between 48 and 54 ft below the surface and reached total depth in the upper part of the unit. Dewey Lake lithology is typical for the formation. At about 65 ft depth, each drillhole encountered hard drilling, and samples from C2505 suggest this is a cementation change in the formation.

Wet samples were returned from each drillhole from about the same depth (about 50 ft), which ranged from Santa Rosa to upper Dewey Lake. Water depths measured after varying periods of observation correspond to the lower Gatuña in C2505 and C2506 and upper Santa Rosa in C2507.

A greenish-gray sandstone at the top of the Santa Rosa was wet when cored in C2505 and C2506. The core showed a short, near-vertical fracture in C2506. It is likely that the same greenish-gray sandstone, also with a short, near-vertical fracture, overlies the Dewey Lake in C2507 at the point where core became moist.

Local conditions of poorly developed Mescalero may locally improve percolation and the Dewey Lake cementation change may inhibit further infiltration. While these conditions may be important in localizing infiltration, they do not explain the original source of the water in the exhaust shaft.

INTRODUCTION

Project Background

For several years, water has persistently flowed into the exhaust shaft in small volumes at shallow depths. The source was clearly not ground water from deeper sources, but the nature and extent of the source was undetermined. A drilling progra was designed to try to determine the nature and extent of the source of the water. Locations were chosen partly on the basis of geophysical data collected to show possible shallow conductive zones.

Initial drillholes (C2505, C2506) were located close to the exhaust shaft to provide the best opportunity to find any saturated zone and determine its characteristics. A third drillhole (C2507) was located further away to try to determi e the extent of the saturated zone. Two additional drillholes (ES-001, ES-002) provide more limited information and were filled in on completion. ES-001 showed limited caliche development and was deepened for water samples. ES-002 was shallow and also demonstrated limited caliche development.

Drilling and completion methods are covered in the main report on the project.

The core descriptions were the responsibility of Dennis Powers and Merrie Martin (IT Corporation). Liane Terrill (Westinghouse) provided an initial description of C2507, and Dennis Powers prepared a supplemental description. ES-001 and ES-00 were examined in less detail. Copies of the original logs are attached to this report.

Geology Background

The general geology for these drillholes could be forecast on the basis of the mapping of the exhaust shaft (Holt and Powers, 1986). From the surface, these drillholes were expected to encounter construction fill, dune sand, Pleistocene Mescalero caliche, Miocene-Pleistocene Gatuña Formation, Triassic Santa Rosa Formation, and Permian Dewey Lake Formation. All formations were encountered during the drilling generally as expected.

The Mescalero caliche in the area of WIPP is best known from the work of George Bachman (e.g., Bachman, 1974, 1976). Further away, Powers (1993) studied the Mescalero in pipeline trenches, finding a range of development from about stage 2 through stage 5 (Bachman and Machette, 1977) across topographic changes. In general, the Mescalero is continuous across the general site area and provides broad evidence of geomorphic stability.

The Gatuña Formation is relatively thin across the WIPP site (Bachman, 1985) and thickens considerably to the west, especially along Nash Draw and nearer the present day Pecos River (Powers and Holt, 1993, 1995a). It was deposited predominantly in a fluvial environment. The base of the formation is regionally unconformable, and it can be locally erosional, forming some channeling. This can cause considerable local variations in thickness. The formation has formed in response to dissolution in some areas along the general Pecos River trend (Powers and Holt, 1995a).

The Triassic Santa Rosa Formation is thin near the center of the WIPP site (e.g., Powers and Holt, 1995b). It thickens rapidly to the east. The formation was deposited in dominantly fluvial environments (e.g., McGowen et al., 1979). It lies unconformably on the Dewey Lake.

The Permian Dewey Lake Formation thickens from west to east across the site to a regional maximum of about 600 ft (Schiel, 1988). It was deposited as fluvial deposits during ephemeral flooding. The unit is characteristically fine-grained, ranging from interbedded fine sandstone to mudstone. It has a distinctive reddish-brown color with small zones and spots that are greenish-gray.

Drillhole C2505

Stratigraphic Summary

encountered in C2505 from surface:

Depth (ft)	Unit
-9.4	no core; fill and dune sand (hand augered)
.4-12.4	Mescalero caliche
2.4-48.8	Gatuña Formation
-8.8-54.0	Santa Rosa Formation
4.0-97.0	Dewey Lake Formation (TD @ 97 ft)

Moisture/Saturated Zones

st indication of moisture was in the rocks retrieved from the core run rillhole depth of 51.4 ft (Santa Rosa). Cores from 48.8 to 50.0 consist d ray fine to medium grained sandstone that appeared wet. Below 50.0 ft. nterbedded siltstone and mudstone appeared to have little moisture. n to return mud to the surface while drilling between 64 and 65 ft. Water easured at 44.8 ft (at the level of the lower Gatuña Fm), and water sam e ed.

est indication of moisture was damp core recovered from a minor vugg stone interval from about 92 to about 93 ft, but there appeared to be little ne.

C2505

res were available to 9.4 ft. Previous hand augering debris indicates t a s composed mainly of sand and caliche gravel that has been used as naterial. The sand source is the local dune sands present before and the upper part was disturbed during construction of the exhaust sha 0.8 ft., the eolian sand in core appears to be undisturbed by construction ero caliche is present from 10.8 to 12.4 ft. The caliche generally tage 1 development, with disseminated carbonate coating the grains and

APPENDIX D

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Dennis W. Powers, Ph.D
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HC 12 Box 87
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ABSTRACT

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The Pleistocene Mescalero caliche was encountered below several feet of surface fill and dune sand. It is not strongly indurated as in some other areas around the WIPP site, representing about stage 1 in development, and it is relatively thin (up to about 3 ft). The Mescalero did not appear to be laminar near the exhaust shaft, though it is hard and well-formed where exposed in constructed drainage ponds just outside the south WIPP fence.

The Miocene-Pleistocene Gatuña Formation immediately underlies the Mescalero, and the upper part has partly been calcified by pedogenic processes. It is about 36 ft thick where completely cored. The Gatuña lithology is typical in these drillholes. The interpreted thickness is about 20 ft more than in the exhaust shaft. The difference is due to local variations and a much more comprehensive knowledge of the Gatuña since the exhaust shaft was mapped.

The Triassic Santa Rosa Formation ranges from about 5 to 8 ft thick as assigned in these drillholes. In the exhaust shaft, the assigned thickness was about 20 ft. The difference is due to changed interpretation of the Gatuña-Santa Rosa contact in this study as well as some local variation. The Santa Rosa lithology is typical.

Each of the drillholes encountered the Dewey Lake Formation between 48 and 54 ft below the surface and reached total depth in the upper part of the unit. Dewey Lake lithology is typical for the formation. At about 65 ft depth, each drillhole encountered hard drilling, and samples from C2505 suggest this is a cementation change in the formation.

Wet samples were returned from each drillhole from about the same depth (about 50 ft), which ranged from Santa Rosa to upper Dewey Lake. Water depths measured after varying periods of observation correspond to the lower Gatuña in C2505 and C2506 and upper Santa Rosa in C2507.

A greenish-gray sandstone at the top of the Santa Rosa was wet when cored in C2505 and C2506. The core showed a short, near-vertical fracture in C2506. It is likely that the same greenish-gray sandstone, also with a short, near-vertical fracture, overlies the Dewey Lake in C2507 at the point where core became moist.

Local conditions of poorly developed Mescalero may locally improve percolation and the Dewey Lake cementation change may inhibit further infiltration. While these conditions may be important in localizing infiltration, they do not explain the original source of the water in the exhaust shaft.

during the drilling generally as expected.

The Mescalero caliche in the area of WIPP is best known from the work of George Bachman (e.g., Bachman, 1974, 1976). Further away, Powers (1993) studied the Mescalero in pipeline trenches, finding a range of development from about stage 2 through stage 5 (Bachman and Machette, 1977) across topographic changes. In general, the Mescalero is continuous across the general site area and provides broad evidence of geomorphic stability.

The Gatuña Formation is relatively thin across the WIPP site (Bachman, 1985) and thickens considerably to the west, especially along Nash Draw and nearer the present day Pecos River (Powers and Holt, 1993, 1995a). It was deposited predominantly in a fluvial environment. The base of the formation is regionally unconformable, and it can be locally erosional, forming some channeling. This can cause considerable local variations in thickness. The formation has formed in response to dissolution in some areas along the general Pecos River trend (Powers and Holt, 1995a).

The Triassic Santa Rosa Formation is thin near the center of the WIPP site (e.g., Powers and Holt, 1995b). It thickens rapidly to the east. The formation was deposited in dominantly fluvial environments (e.g., McGowen et al., 1979). It lies unconformably on the Dewey Lake.

The Permian Dewey Lake Formation thickens from west to east across the site to a regional maximum of about 600 ft (Schiel, 1988). It was deposited as fluvial deposits during ephemeral flooding. The unit is characteristically fine-grained, ranging from interbedded fine sandstone to mudstone. It has a distinctive reddish-brown color with small zones and spots that are greenish-gray.

Drillhole C2505

Stratigraphic Summary

providing a whitish color to the rock; it is poorly lithified. A few soil pisolites are present, indicating that the Mescalero is either in early stages of development or is a remnant of an earlier higher stage of develpment. For the moment, given the general knowledge of the Mescalero in the vicinity of the WIPP, we favor the latter interpretation. The Mescalero caliche most likely had been developed to stages 4 or 5 before devolving through infiltration. At this time, we do not believe the Mescalero has been disturbed or removed by construction.

We assigned rocks to the Gatuña Formation based on lithology, color, bioturbation, MnO_2 staining, and carbonate cementation. It is similar to the formation as found during field studies of the unit.

We assigned rocks to the Santa Rosa Formation based on lithology (including larger clasts, coarser grain sizes, and biotite as a principal accessory mineral), color (more intense hues than in either Gatuña or Dewey Lake), and induration.

We assigned rocks to the Permian Dewey Lake Formation based on lithology (fine sandstones interbedded with siltstones and mudstones), primary sedimentary structures (abundant thin laminae and slight cross-cutting relationships), and color (relatively uniform medium to dark reddish brown mottled with greenish gray reduction spots or zones). A hard zone was encountered at a depth of about 65 ft that required a switch from augers to rotary drilling. There appears to be a cementation change, with possible silica cements more important below this interval.

Comparison to Exhaust Shaft Lithology

The drillhole lithology is very comparable to the exhaust shaft. Principal differences are lesser caliche formation in the drillhole and thicker section assigned to the Gatuña. As a consequence, the Santa Rosa is thinner in the drillhole. The position of the Santa Rosa/Dewey Lake contact appears to be the same depth in borehole and shaft.

Drillhole C2506

Stratigraphic Summary

Units encountered in C2506 from surface:

Depth (ft)	Unit
0-41.0	no core; fill and dune sand; Mescalero caliche; Gatuña I .r
41.0-48.2	Gatuña Formation
48.2-53.5	Santa Rosa Formation
53.5-69.0	Dewey Lake Formation (TD @ 69 ft)

Summary of Moisture/Saturated Zones

The first indication of moisture in the rocks occurred when the core barrel surface was moist from the run between 48.2 to 50.0 ft (Santa Rosa). Cores were r c to 56.0 ft (upper Dewey Lake) and were dry below that. Rocks through the moist zon consisted of greenish gray to reddish brown fine to medium grained sandstone of tl e basal Santa Rosa to dark reddish brown silty claystone of the uppermost Dewey Lak that appeared wet.

Geology of C2506

No cores were available to 41.0 ft. Augering debris showed intervals of sand and caliche gravel that has been used as construction material, Mescalero caliche, a upper Gatuña.

We assigned rocks to the Gatuña Formation based on lithology, color, bioturbation, MnO_2 staining, and carbonate cementation. It is similar to the formatin as found during field studies of the unit.

We assigned rocks to the Santa Rosa Formation based on lithology (includi g larger clasts, coarser grain sizes, and biotite as a principal accessory mineral), colo (more intense hues than in either Gatuña or Dewey Lake), and induration. The basal sandstones of the Santa Rosa included short, near-vertical fractures from about 49.0-49.8 and 51.7 to 52.0 ft depth, in the zone containing moisture. The fractures did not appear to be induced by drilling; there was no fracture filling.

We assigned rocks to the Permian Dewey Lake Formation based on lithology (fine sandstones interbedded with siltstones and mudstones), primary sedimentary structures (abundant thin laminae and slight cross-cutting relationships), and color (relatively uniform medium to dark reddish brown mottled with greenish gray reduction spots or zones). A hard zone was encountered at about 64 ft depth, and no cores were obtained between 64.2 and TD at 69 ft. This may be a cementation change similar to C2505.

Comparison to Exhaust Shaft Lithology

The drillhole lithology is very comparable to the exhaust shaft. Principal differences are probable lesser caliche formation in the drillhole and thicker section assigned to the Gatuña. As a consequence, the Santa Rosa is thinner in the drillhole. The position of the Santa Rosa/Dewey Lake contact appears to be the same depth in borehole and shaft.

Drillhole C2507

Stratigraphic Summary

Units encountered in C2507 from surface:

Depth (ft)	Unit
0-39.0	no core; fill and dune sand; Mescalero caliche; Gatuña Fm
39.0-39.5	Gatuña Formation
39.5-48.0	Santa Rosa Formation

48.0-72.0 Dewey Lake Formation (TD @ 72 ft after reaming)

Summary of Moisture/Saturated Zones

Cores were moist from 49.0 to 50.5 ft (upper Dewey Lake). Mudstones fror 62.5-63.0 ft were also moist and formable. Rocks through the upper moist zone consisted mainly of interbedded reddish brown fine grained sandstone, siltstone, a nd mudstone of the uppermost Dewey Lake. Greenish-gray sandstones of the basal Santa Rosa immediately overlie this zone.

Geology of C2507

No cores were available to 39.0 ft. Augering debris showed intervals of sar d and caliche gravel that has been used as construction material, Mescalero caliche, a upper Gatuña.

We assigned only the first half foot of cored rocks to the Gatuña Formation based on lithology, color, bioturbation, MnO_2 staining, and carbonate cementatior similar to the formation as found during field studies of the unit.

We assigned rocks to the Santa Rosa Formation based on lithology (incluc ng larger clasts, coarser grain sizes, and biotite as a principal accessory mineral), color (more intense hues than in either Gatuña or Dewey Lake), and induration. The ba sa greenish-gray sandstones include a vertical fracture, about 0.3 ft long, at 47.6 ft dep This is similar to C2506.

We assigned rocks to the Permian Dewey Lake Formation based on lithology (fine sandstones interbedded with siltstones and mudstones), primary sedimentar structures (abundant thin laminae and slight cross-cutting relationships), and color (relatively uniform medium to dark reddish brown mottled with greenish gray redu ic spots or zones). A hard zone was encountered during drilling from about 63 ft to TD 69 ft. During reaming the hole was deepened to about 72 ft. No cores were takei

This hard zone corresponds to hard zones in the other drillholes, and probably reflects a general cementation change in the Dewey Lake.

Comparison to Exhaust Shaft Lithology

The drillhole lithology is very comparable to the exhaust shaft. Principal differences are probable lesser caliche formation in the drillhole and thicker section assigned to the Gatuña. As a consequence, the Santa Rosa is thinner in the drillhole. We assigned more rocks to the Santa Rosa in C2507, however, than in the other two drillholes. The position of the Santa Rosa/Dewey Lake contact appears to be nearly the same depth as at the shaft.

ES-001 and ES-002

The Mescalero caliche encountered in these drillholes is similar to that encountered in the other 3 drillholes. It is minimally developed, most likely as a consequence of destruction of a better developed pedogenic carbonate that is being or has been partially destroyed by local infiltration.

SIGNIFICANCE OF CEMENTATION

The hard drilling zone in the Dewey Lake at depths of about 65 ft in each drillhole likely signifies a cementation change. Within the exhaust shaft, the apparent cementation change is at about 121 ft, but the observations in the exhaust shaft were not keyed to cementation changes in this interval and may not be as precise.

It is suggested that a cementation change, as indicated by drilling and core samples, at a depth of about 65 ft below the surface in the drilling area may be an impediment to infiltration of surface water and causes perching.

In addition, the Mescalero caliche does not appear to be cemented as strongly in the drilling area as it is in other areas of the WIPP. There is a local topographic low in this area. Other local topographic lows show less developed caliche, probably as a result of some concentration of surface runoff and local removal of some of the carbonate as runoff percolates through this zone. This also permits increased loc infiltration.

The combination of low-grade caliche and Dewey Lake cementation probab assists in concentrating water locally in the area near the exhaust shaft. This does n provide an explanation of the actual sources of water, only of some conditions tha m assist in concentrating the water.

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GEOLOGIC ROCK CORE LOGS

GEOLOGIC ROCK CORING LOG

HOLE ID: C2505 DRILLING DATE: 9/23/96 HOLE DIAMETER: ____ (IN) HOLE DEPTH: ____ (F

LOCATION: Exhaust Shaft EXCAVATION DATE: 9/23/96 NORTHING: ____

DRILLING DIRECTION: vertical down DRILLING CREW: ____ EASTING: ____

DRILL MAKE/MODEL: ____ DRILL METHOD: Hollow Stem Auger COLLAR ELEVATION: ____

LOGGED BY: M. Martin/Dennis Powers DATE: ____ SCALE: 1" = 2 ft SHEET 1 OF 6

RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH ( )	LITHOLOGY	DESCRIPTION	REMARKS
			0		No core. Fill, calian sand.	
			2			
			4			
			6			
			8			
1			10		Sand, f. to med., reddish orange, friable; sl. calcareous. Grains round to well rounded, < 1% dark grains. Rare white calc. blebs 2-3 mm dia. Equivalent to dune sand. 1.4' thick	
	4.6'		12		Sand and ss, f. to med, light gray, friable; sl. to mod. calcareous. Grains subang to subround; silty, w/small prop (<5%) of clay size material. Small (~5 mm) blebs forming pisolite structures (incipient). Mescalero caliche (stage 1)	
					Gatuña Fm. Sandstone and sand, f. to coarse, friable to poorly indurated. Generally med. sand grains, poor to mod. sorting. Sub ang. to subrounded grains. 1-2% dark grains. Calcareous blebs and streaks from caliche penetration, nodule formation ~17' (?). Rare small MnO_2 stains	
1/2			14			
			16			

GEOLOGIC ROCK CORING LOG (continuation)

HOLE ID: C2505 DRILLING DATE: 9/23/96 HOLE DIAMETER: ______ (IN)

LOGGED BY: Dennis Powers DATE: 9/23/96 SCALE: 1" = 2 ft SHEET

RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH ( )	LITHOLOGY	DESCRIPTION
2	3ft		16, 18		
3	3ft		20, 22, 24		19'-21'. As above, loose sand. ~2'.
					23'-25' Ss, silty, argill, calc. Dark reddish brown w/ zones or nodules of gray. Poorly Indurated Sand is f to med, subrounded to rounded, mod. sorting. Rare pebble. Laminar bedding < 1 mm. 2' thick
3 / 4 (DWP)					
4	3'		26		25-28.8 Ss, slightly silty and argill, dark reddish brown with whitish zones or gray reducing areas. Grains are f-med sand, subround to round, mod sorted. Calcareous. Poor to mod. induration. Bedding < 1 cm, core also discing. Black MnO_2 stains. Small pores due to bioturbation. 3.8' thick
					Y represents bioturbation (plant root zones)
5	2'		28		28.8-29.0 Ss, as above, v. calc., well indurated. Med. reddish brown
6	3'		30		29.0-31.2 (DWP) Ss, similar to 25-28.8. Strong MnO_2 in lower 6". Bedding not well defined in friable areas. 2.2' thick
					31.2-32.8 Ss, argill, slightly calc. Dark reddish brown w/ MnO_2 stains. Incipient nodules 2-3 cm across, calcareous, mod reddish brown. Bioturb. common. Mod to poor induration. 1.6' thick
7	2'		32, 34		32.8-34.6 Sim. to above, less indurated, less MnO_2 and bioturbation. Rare grains of gypsum?
7					Sandy silty claystone. V. sl. calc. (DWP?) Dark reddish brown with MnO_2,

GEOLOGIC ROCK CORING LOG (continuation)

HOLE ID: C2505 DRILLING DATE: 9/23/96 HOLE DIAMETER: ______ (IN)

LOGGED BY: Dennis W. Powers DATE: 9/23/96 SCALE: 1" = 2 ft SHEET 3 OF 6

RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH ( )	LITHOLOGY	DESCRIPTION	REMARKS
8	5'		34	MnO2	cont. and bioturbation. Lam bedding 34-35'. Calc. zone 35-36'.	
			36			
					37-39.6 SS., argill. Slightly to v. calc. Mod DUSP reddish brown. Grains gen med, mod sorted, subround to round. Poorly indurated. No observable bedding. Sand inc. 1-2% opaques. Loose in lower 1'	
8 / 9	5'		38			
			40		39.6–40.6 SstoSand w/ pebbles (Santa Rosa) and granules. V. poorly sorted. V. calc., not indurated to mod ind.	
					40.6-41.4 Ss, v.f grained, silty, argill, calc. Dk reddish brown w/ gray zone. Mottled w/ slight MnO_2, some bioturbation.	
				Oxidized zone	greenish gray 41.4-43.7 SS, greenish gray at top, gen dk reddish brown w/ slight mottling gray, minor MnO_2. Sand gen f. to med, subrounded, well sorted, 1-2% opaques, esp. biotite. Lam. bedding gen ~1 mm. Sl. silty, argill. 2.3' thick	
9			42			
10	5		44		Ss., sim. to above, lam bedding pronounced, well indurated but separates along laminae. 0.3 ft.	
					44-48.8 Ss., f-med, generally dk reddish brown with thin zones of greenish gray. Gen poor to mod. induration. Grains sub ang to subround, mod sorted. Biotite content increases downward. Limited MnO_2, bioturbation. Some silt and clay, varies in fining upward units 6-12" thick. 4.8' thick	
			46			
			48	MnO2		
10 / 11	2.4				48.8-50.0 —— Santa Rosa Fm. SS, greenish gray, sl. silty, sl. calcareous. Grains f.-med, subrounded, <1% opaques, mod sorting. Laminated @ ~1-2 mm, possibly cross-laminated. 1.2' thick	
			50		Interbedded gray sltst + dk reddish brown mudstone. Slt, v.f. grained sand with silt. Interbeds 1-4" thick. Small intraclasts of mudst in mudstone @ 51.4 ~ 2' thick	51.4 moisture
11 / 12			52		bottom @ 52	

GEOLOGIC ROCK CORING LOG (continuation)

HOLE ID: C2505 DRILLING DATE: 9/23/96/9/24/96 HOLE DIAMETER: ______ (IN)

LOGGED BY: Dennis W. Powers DATE: 9/23/96/9/24/96 SCALE: 1" = 2 ft SHEET

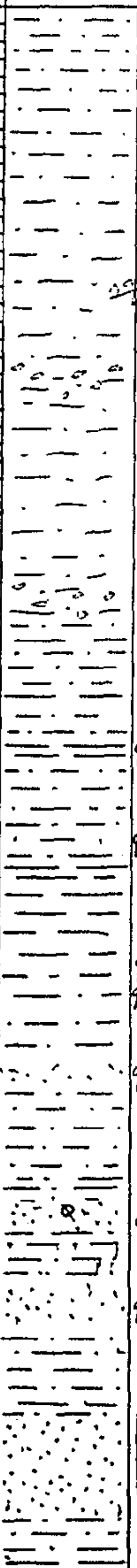
RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH ( )	LITHOLOGY	DESCRIPTION	
12	1		52–53		SS, dk reddish brown, v. well indurated. Sand is v.f.-f., rounded, well sorted. Calc, slow to effervesce. Lam. bedding 2-4 mm. Prob. partly quartz/silica cement. Includes some lam. w/ more silt + clay. 1 ft thick.	from 52-
NC			53–54			drill ... re...
13	3'		54–59		DEWEY Lake Fm. 54. Interbedded SS (greenish gray or reddish brown) and mudstone (dk reddish brown). Ss grains are f to vf, round, well sorted, cmtd w/ calc, maybe some silica cmt. Some greenish gray reduction spots in zones. Mudstones + ss. well laminated @ 1 mm + finer.	
14	4.5'		59–62		gg (greenish gray)	Run 14: may ... cor... gg
15	2'		62–64			
16	1		64–65		end 9/23/96 begin 9/24/96	return hard d... rota... silicified. Change to bit ... air.
NC			65–66.5		Cuttings from 66-66.5' - ss, f-med, rounded, silicified, sl. calcareous, dk reddish brown.	
17	2.3'		66.5–69.5		66.5-69.5 Ss, v.f.-f, dk reddish brown with zones mottled greenish-gray; subrounded grains, well-sorted, 1-2% opaques; well-indurated, little or no carb, possible silica cmt; thin laminae and slight cross bedding. Some zones have more silt. Interbedded thin laminae of mudstone, silty claystone gen 2-5 mm thick.	
~~17~~ 16			69.5–70			

DWP

GEOLOGIC ROCK CORING LOG (continuation)

HOLE ID: C2505 DRILLING DATE: 9/24/96 HOLE DIAMETER: ______ (IN)

LOGGED BY: DW Powers DATE: 9/24/96 SCALE: 1" = 2 ft SHEET 5 OF 6



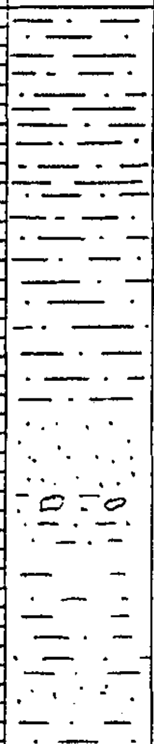
RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH ( )	DESCRIPTION	REMARKS
18	2'		70–72	gg 69.5-72 as above, more sltst, mudstone. 2 4" pieces in run	
19	5'	(35%)	72–77	72'-77' Interbedded siltstone/mudstone. vf to f, dk reddish-brown, sub-rounded grains, well sorted. Well indurated. Mild effervescence of cmt. Mottled green-gray zones in upper 6". Granular zone at 74'-74.5', clasts ~1/4" to 1/2" diam. Gyp? Gypsum - reduction spots around vertical fracture 74-75'. Similar structures at 76.5' & 77'. Ripple bedding and thin laminae (2-4mm) from 76-77'.	
20	4.9'	3.5/4.9 x 100 ≈ 78%	77–82	77-82 Dominated by silty clayst and mudstone with fewer interbeds of siltston. Bedding generally 1/2-1 cm, with laminae 1-2mm (parallel, generally horizontal). Gray green mottles rare and small (2-3mm) between marked gray green (gg) zones (1 cm thick). gg (78.5), gg (79.5), gg (81), gg (81.3)	
21	5.0	0.85/5.0 x 100 = 17%	82–87	gg 82-87 gen as above, more calcareous. Wavy laminae 82.5. Ripples 83.8, Ss at 86.2-87 is v.f., subrounded, few opaques, well sorted, calc. gray gypsum/anhyd nodule (84). gray (85)	
22			87–88	gg 87-92: sim to above. Calc to ~88'. Noncalc below. Color is more med reddish brown than dark r.b.	

GEOLOGIC ROCK CORING LOG (continuation)

HOLE ID: C2505 DRILLING DATE: 9/24/96 HOLE DIAMETER: ______ (IN)

LOGGED BY: Dennis Powers DATE: 9/24/96 SCALE: 1" = 2 ft. SHEET

RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH ( )	LITHOLOGY	DESCRIPTION
22	4.6'	1.9/4.6 x 100	88–92		gray
23	3.8'	0	92–97		92-97 gen sim. to above; positions of lithology approximate. ss. in upper part. Vuggy porosity (up to 2" across) about 93'; prob due to loss of gypsum prior to drilling.
			98, 100, 102	?	



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5:00

GEOLOGIC ROCK CORING LOG

HOLE ID: C2506　DRILLING DATE: 9/25/96　HOLE DIAMETER: ____ (IN)　HOLE DEPTH: ____ (FT)

LOCATION: Exhaust Shaft　EXCAVATION DATE: 9/25/96　NORTHING: ____

DRILLING DIRECTION: Vertical down　DRILLING CREW: ____　EASTING: ____

DRILL MAKE/MODEL: ____　DRILL METHOD: ____　COLLAR ELEVATION: ____

LOGGED BY: DW Powers　DATE: 9/25/96　SCALE: 1" = 2 ft　SHEET 1 OF 2

RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH ( )
1	3'	0	41–44
2	4'		44–48.5
3	2		49–50.2
4	0.5		50.2–50.5
5	0.8		50.5–51.3
6	1.0		51.3–52.3
7	1.4		52.3–54
8			54–56

Depth scale: 40, 42, 44, 46, 48, 50, 52, 54, 56

LITHOLOGY

DESCRIPTION

Gatuña Fm.
Ss, silty, brown, f-med, subround, poorly indurated to friable, non-calcareous. Faint laminae 2-5 mm apart distinguished by darker color.
Large (2 inch) piece of probable Mescalero caliche in upper part of recovered sample. Contains chert pebbles. May also be carb. cemented interval in Gatuña, but not likely.

Santa Rosa Fm.
Ss, greenish-gray. f-med grn, subrounded, <1% gypsum, some biotite. Mod well indurated. Biotite on bedding planes. Porous. Noncalc? Bedding parallel, horizontal (1-3 mm). Near vertical fracture ~49-49.8, uncemented, no alteration.
48.2-50.0': 1.8 ft thick

50.0-53.5
Ss, reddish brown + greenish gray, with interbeds of siltst and mudstone. Well cemented, sl. calc. Sand is f-med, subround to well rounded. Some bedding parallel, horiz.
Greenish gray zone about 51.7-52.0, sim. to ss at 49.5-50. Includes near vert fracture.

53.5-56　Dewey Lake Fm.
Dark reddish brown silty claystone, poorly indurated, soft. Parallel horiz bedding 2-4 mm. Small greenish gray reduction spots; small gray zone 55.8. Moist. Some slightly sandy layers.

REMARKS

Auger, no core to 39'.
Auger, core not recovered 39-41'.

Augers removed from drillhole + re-entered. May be clast dislodged from upper part of drillhole.

Moisture on barrel, ss

Core moist to 56', dry below.

GEOLOGIC ROCK CORING LOG (continuation)

HOLE ID: C2506 DRILLING DATE: 9/25/96 HOLE DIAMETER: ______ (IN)

LOGGED BY: DW Powers DATE: 9/25/96 SCALE: 1" = 2ft SHEET _

RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH ( )	LITHOLOGY	DESCRIPTION	
8	5'		56–58	99	56-59 sim to above in lithology + features. Dry.	
					59-64 v. sim to above in lithology + features. Wet.	
9	5'		60–62	99		
10	0.2		64			drilled No ... Hard d...
11	0		66–68			
			70			

Geologic Rock Coring Log

HOLE ID: C2507 LOCATION: ~175' south of Exhaust Shaft

DRILLING DATE: 10-01-96 EXCAVATION DATE: ______ NORTHING: ______

DRILLING DIRECTION: V-down DRILL METHOD: ______ EASTING: ______

DRILL MAKE/MODEL: CME COLLAR ELEVATION: ______

HOLE DIAMETER: — (IN) HOLE DEPTH: ______ (FT) DRILLING CREW: GE Projects, Int'l.

LOGGED BY: T. Terrill DATE: 10-01-96 SCALE: 1" = 2' SHEET 1 OF 1

RUN NUMBER	RECOVERED LENGTH (ft)	RQD	DEPTH (feet)	LITHOLOGY	DESCRIPTION	REMARKS
1		0	39 – 41		39'-41' SS, reddish-brown, f-m, sub-rounded, well sorted, poorly indurated to friable. Calcareous zones, esp. at 41.6' and 42', where light-gray zones of poorly-consolidated caliche, ea. zone ~2" thick. Some opaques, biotite.	Auger begun 1525. Caliche at ~9.5', thickness ~6"-7". Core begun at 39'. 39'-41' removed 17:15
2			41 – 44		41'-44' Same as above but becomeing more well-indurated downward, actually "disking" after ~~43.6~~ 43.5'. Light pink zone 41'-41.3'. Less calcic overall.	
3			44 – 49		44'-49' SS, light pinkish becoming greenish-gray after 45.3'. f-m grns. Well sorted. Poorly consolidated in pink area becoming more consoldt in greenish area to ~46', then unconsolidated to 48'. Sharp contact w/ lower, reddish siltstone at 48', top of Dewey Lake.	Vertical fracture at ~47.6, ~0.3'.
4			49 – 53		49'-59' Reddish-brown siltstone, thinly bedded. Some mudstone layers ~~up~~ to ~1' thick. Greenish-gray	49'-50.5', mudstone, moist, formable. Altered zone ~~53.5'-~~ 51.5'-52'

Geologic Rock Coring Log (continuation)

HOLE ID: C2507 DRILLING DATE: 100196

LOGGED BY: WTerrill DATE: 100196 SCALE: 1" = 2' SHEET

RUN NUMBER	RECOVERED LENGTH (ft)	RQD	DEPTH (feet)	LITHOLOGY	DESCRIPTION
4			53		spots. Friable, some calcic zones. f-vf gnd. MgO_2 (?) stains on mudstone @ 49'-50'.
5			55 57		55.5': 5" zone of somewhat competent rock; mod. calc. 58.75 - 59' Greenish-gray, vf-f, well consolidated, mod. calc., altered zone. 59'-63' Same as above. Siltstn-Mudstone 61.5'-63'.
6			59 61 63		
					Hard material encountered 63'-69' - no core taken. Auger brought up to 43' (base) for overnight. ~19:00

Geologic Rock Coring Log

HOLE ID: C2507 (Supplemental Description) LOCATION: ~175' S. of Exhaust Shaft

DRILLING DATE: 10/01/96 EXCAVATION DATE: ______ NORTHING: ______

DRILLING DIRECTION: Vertical-down DRILL METHOD: ______ EASTING: ______

DRILL MAKE/MODEL: ______ COLLAR ELEVATION: ______

HOLE DIAMETER: ______ (IN) HOLE DEPTH: ______ (FT) DRILLING CREW: Geo Projects

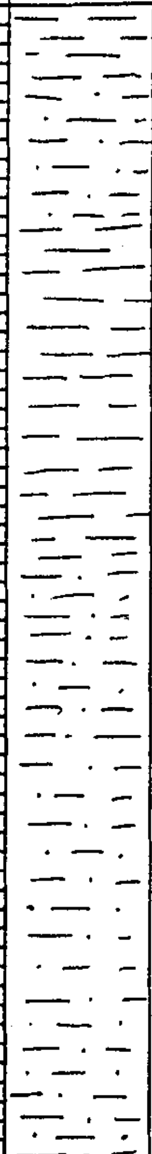
LOGGED BY: Dennis Powers DATE: 10/11/96 SCALE: 1"=2ft SHEET 1 OF 2

RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH ( )	LITHOLOGY	DESCRIPTION	REMARKS
			39		39-39.5 Ss, med reddish brown. F. to med sand, subrounded, mod. sorting. Friable to poorly indurated. 39.5-41 Prob. local top of Santa Rosa. Ss, dk reddish brown to med. reddish brown. F. to med sand, subrounded, mod sorting. Friable to poorly indurated with grains showing some calc coating. ~1% opaque grns. Poorly developed bedding in upper part.	Only lithologic description in supplement.
			41		41-41.3 Ss, light purplish brown, Very similar lithology to above, but is better cemented, has thin parallel bedding. Color is distinctive	
			43		41.3-~~Ss~~ 44 Ss, med to dk reddish brown, slightly argill V. similar to 41-41.3 except color, slight argill. Bedding is common, thin.	
			45		44-48 Ss, light greenish gray. V. similar to above except color, lacks clay. Thin bedding is common.	
			47			
			49		48'-63' Top Dewey Lake Fm. @ 48' to claystone Interbedded ss, siltstone, and mudstone, dark reddish brown w/green mottles or spots and thin greenish gray zones (gg). Poor to mod ind. ss: fine grained, subround, some v.f. grained. Most include silt and some clay. Bedding is poor. Some gg zones of v.f. sand. sltst: generally sandy + argill. Bedding is thin, parallel. Mudstone: may also show bedding, be a mix of laminae of differing grain size. Mica-rich laminae may bound claystone laminae.	
			51			
			51			

Geologic Rock Coring Log (continuation)

HOLE ID: C2507 (Supplemental Description) **DRILLING DATE:** 10/01/96

LOGGED BY: Dennis Powers **DATE:** 10/11/96 **SCALE:** 1" = 2' **SH E**



RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH ( )	LITHOLOGY	DESCRIPTION
			51		
			53		
			55		
			57		gy
					gy
			59		gy
					gy
			61		
			63		end of core

Geologic Rock Coring Log

HOLE ID: ES-002 LOCATION: ~50' SSE of Exhaust Shaft

DRILLING DATE: 10-03-96 EXCAVATION DATE: – NORTHING:

DRILLING DIRECTION: V-dn DRILL METHOD: EASTING:

DRILL MAKE/MODEL: CME COLLAR ELEVATION:

HOLE DIAMETER: – (IN) HOLE DEPTH: – (FT) DRILLING CREW: GE Projects, Int'l.

LOGGED BY: LJTerrill DATE: 10-03-96 SCALE: 1"=2' SHEET 1 OF

RUN NUMBER	RECOVERED LENGTH (ft)	RQD	DEPTH (feet)	LITHOLOGY	DESCRIPTION	REMARKS
1			9–14 (11, 13)		9'-14' Sand, med-f gnd, undergoing very early stage of caliche formation. Some cem'n at 9.5', zone ~ 1" thick. Sand red to 9.5', then buff to light-pink. Cementation increases downward, becoming moderately compacted below ~11', to moderately cemented below ~13.5'. Red sand appears again below 13.5'	Top sand mod-well sorted, sub-rounded.
2			14–19 (15, 17, 19)		14'-19' Gatuña Fm. 14'-15.3', caliche development along top of Gatuña is poor; early stage, mottled appearance w/ clasts of Gatuña ave. ~ 1/2" thick. Gatuña is poorly to mod sorted, f-vf gnd W/ larger random grains & pebbles ~1/8" thick (diam). Poorly consolidated.	

Geologic Rock Coring Log

HOLE ID: ES-002 LOCATION: ~50' SSE of Exhau[...]

DRILLING DATE: 10-03-96 EXCAVATION DATE: — NORTHING: -

DRILLING DIRECTION: V-dn DRILL METHOD: EASTING:

DRILL MAKE/MODEL: CME COLLAR ELEVATION:

HOLE DIAMETER: - (IN) HOLE DEPTH: - (FT) DRILLING CREW: GE Projects

LOGGED BY: LJMerrill DATE: 10-03-96 SCALE: 1"=2' SHE[ET]

RUN NUMBER	RECOVERED LENGTH (ft)	RQD	DEPTH (feet)	LITHOLOGY	DESCRIPTION	
1			9–14		9'-14' Sand, med-f gnd, undergoing very early stage of caliche formation. Some cem'n at 9.5', zone ~1" thick. Sand red to 9.5', then buff to light-pink. Cementation increases downward, becoming moderately compacted below ~11', to moderately cemented below ~13.5'. Red sand appears again below 13.5'	Top mc sort[...] ro[...]
2			14–19		14'-19' Gatuña Fm. 14'-15.3', caliche development along top of Gatuña is poor; early stage, mottled appearance w/ clasts of Gatuña ave. ~1/2" thick. Gatuña is poorly to mod sorted, f-vf gnd W/larger random grains & pebbles ~1/8" thick (diam). Poorly consolidated.	

Depth scale marks: 11, 13, 15, 17, 19