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EXHAUST SHAFT: PHASE 2 HYDRAULIC ASSESSMENT DATA REPORT INVOLVING DRILLING, INSTALLATION, WATER-QUALITY SAMPLING, AND TESTING OF PIEZOMETERS 1-12

Prepared for:

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

Prepared by:

DE&S
Duke Engineering & Services

1012-A Pierce St.
Carlsbad, New Mexico 88220
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1.0 INTRODUCTION

This report presents data collected during near surface borehole soil investigations, drilling, fluid sampling for water-quality analysis, water-level monitoring, and hydrologic-testing activities for the Exhaust Shaft: Hydraulic Assessment Program Phase II, at the WIPP site located near Carlsbad in southeastern New Mexico. Twenty-seven shallow boreholes were hand augered to determine soil conditions to a depth of about 14 feet. Twelve 2-inch diameter piezometers were installed to depths of up to 82 feet below ground surface (bgs) to characterize the areal extent, water-quality, potentiometric surface, and potential source(s) of fluid at shallow depths in the Santa Rosa Formation. Drilling, sampling, water-level monitoring and testing activities included in this report were performed between June 9 and September 24, 1997.

1.1 Background

Surface geophysical investigations mapped possible conductive zones in the shallow soil and bedrock in the vicinity of the Exhaust Shaft and were reported in Exhaust Shaft: Hydraulic Assessment Program at WIPP (DOE, Jan 1997). Based on these geophysical investigations, five boreholes were drilled in September and October 1996 to depths of up to 100 feet bgs to evaluate the near surface formations as potential ground water sources of the fluid seeping into the Exhaust Shaft (Figure 1.1). Four boreholes (C-2505, C-2506, C-2507, and ES-001) penetrated water-bearing horizons between 48 and 63 feet bgs, located in sandstone's 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 to determine the stratigraphic horizons producing fluid and were then completed as monitoring wells (Figures 1.2, 1.3, 1.4).

Slug tests were conducted on wells C-2505, C-2506, and C-2507 from October 1 to October 4, 1996, to characterize the water bearing zones. In addition, a six-hour drawdown pumping test was performed on C-2506 to provide data with which to estimate the hydraulic conductivity (a measure of formation permeability), and specific yield of the formation.

Slug-test and pumping-test data indicated a hydraulic conductivity ranging from 5.48 x e-5 to 1.56 x e-6 m/sec, with storativity values ranging from 1.10x e-2 to 9.38x e-3. Water-level data were used to calculate a hydraulic gradient of 0.0245 ft/ft in a south/southeasterly directions. Test data indicated that the wells nearest the Exhaust Shaft were capable of sustaining water production in the range of 0.3 to 0.6 gallons per minute (gpm) for a period of 24 hours or longer. In addition, the step-drawdown pumping test in C-2506 indicated that the

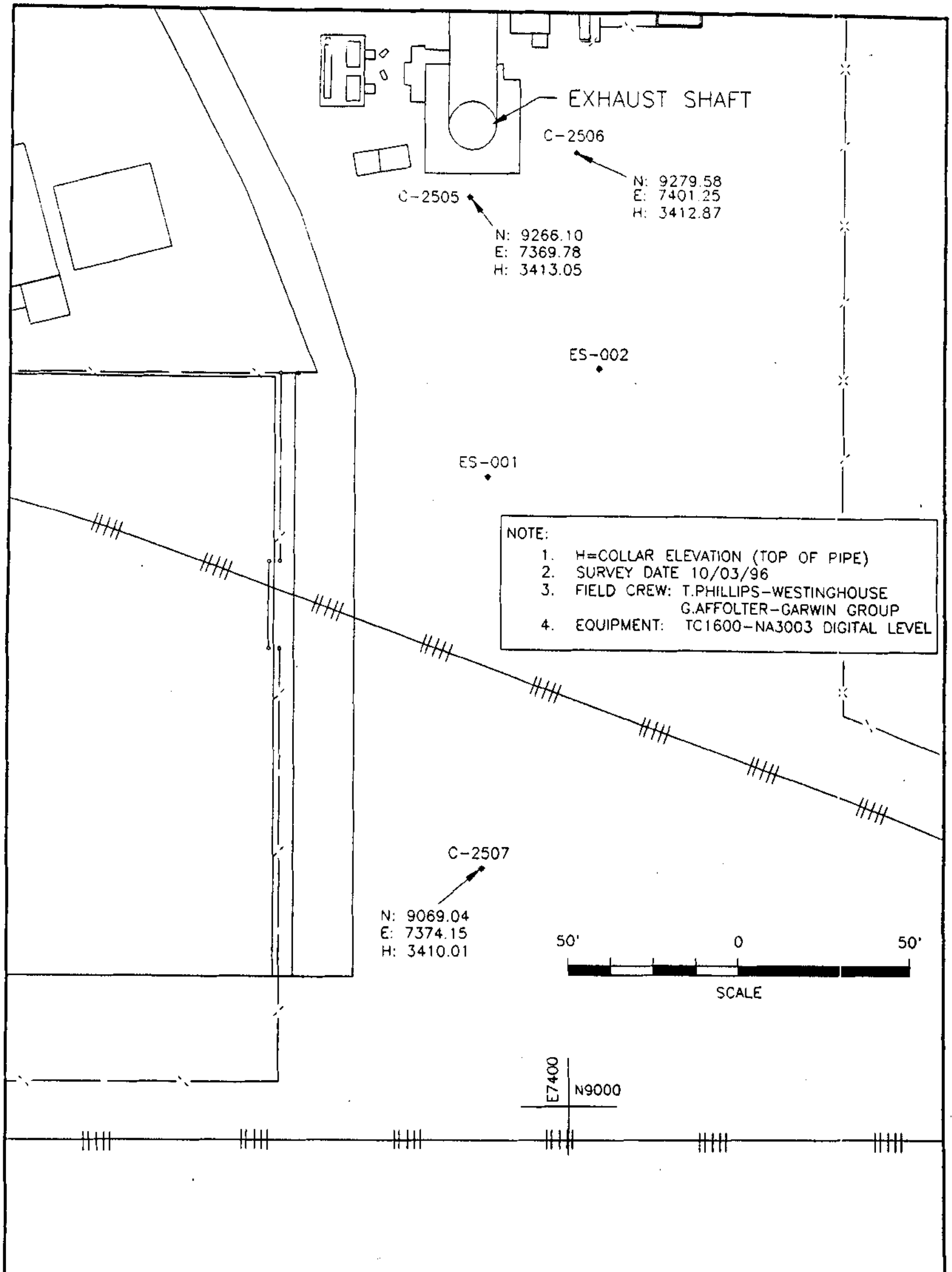
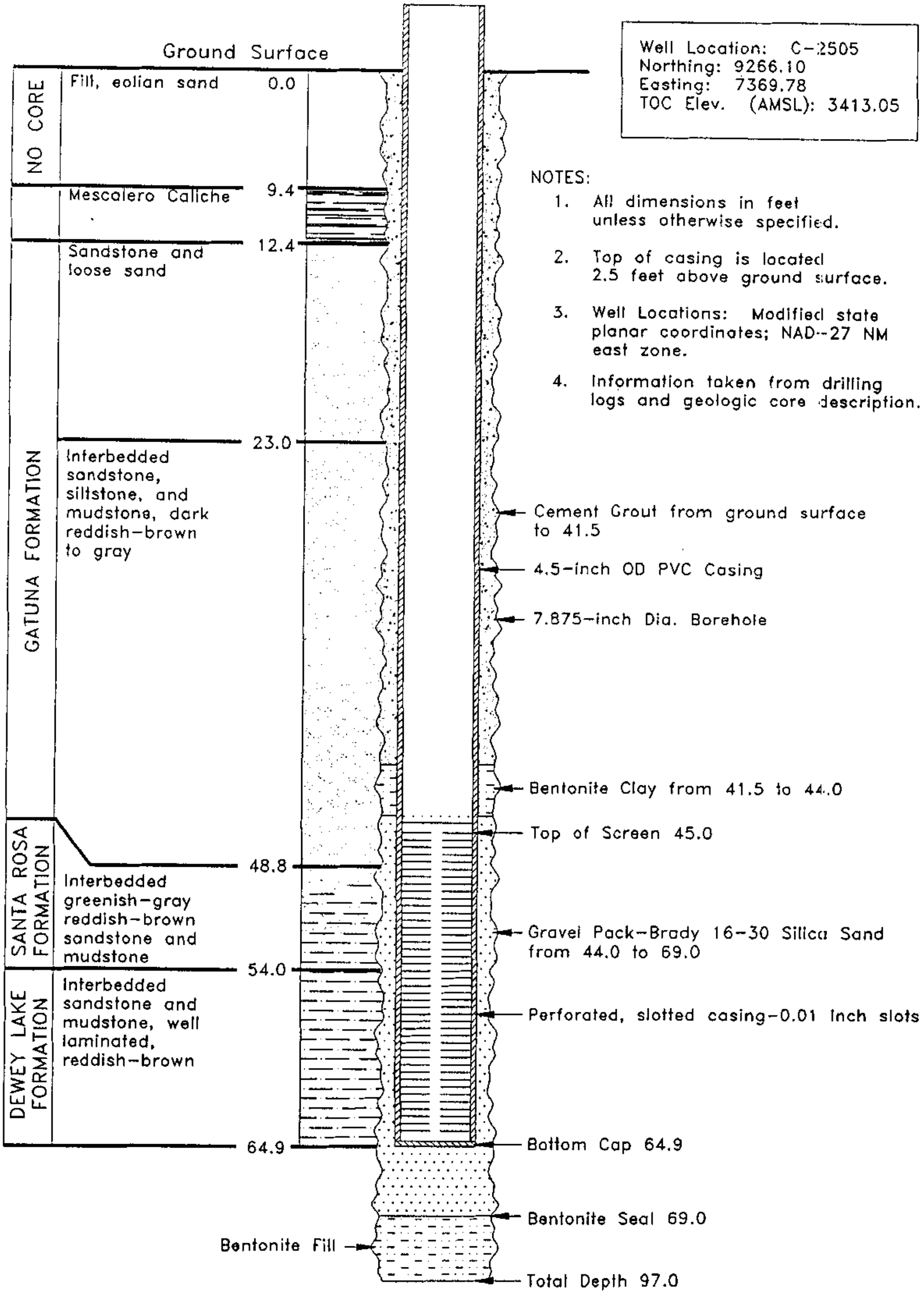
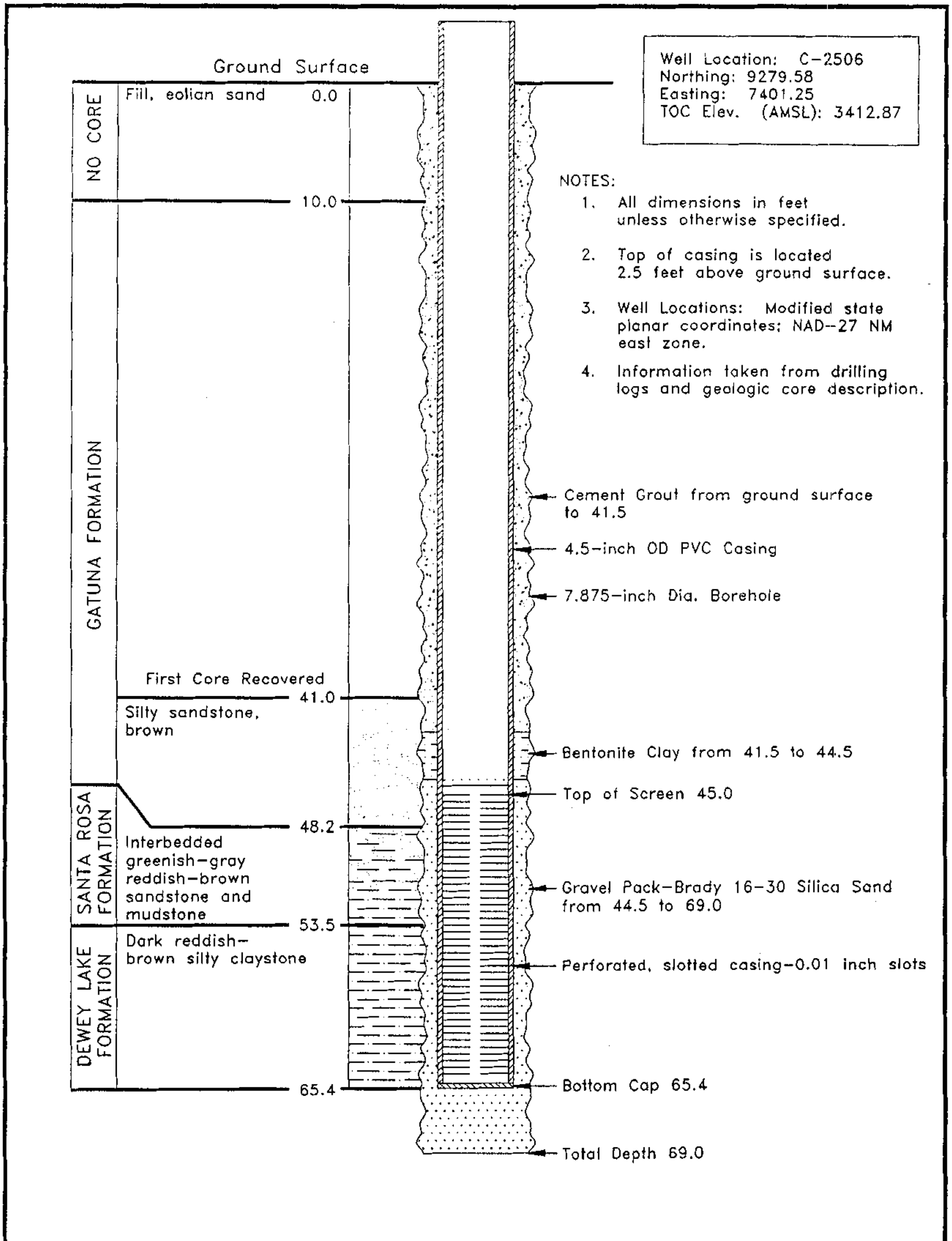


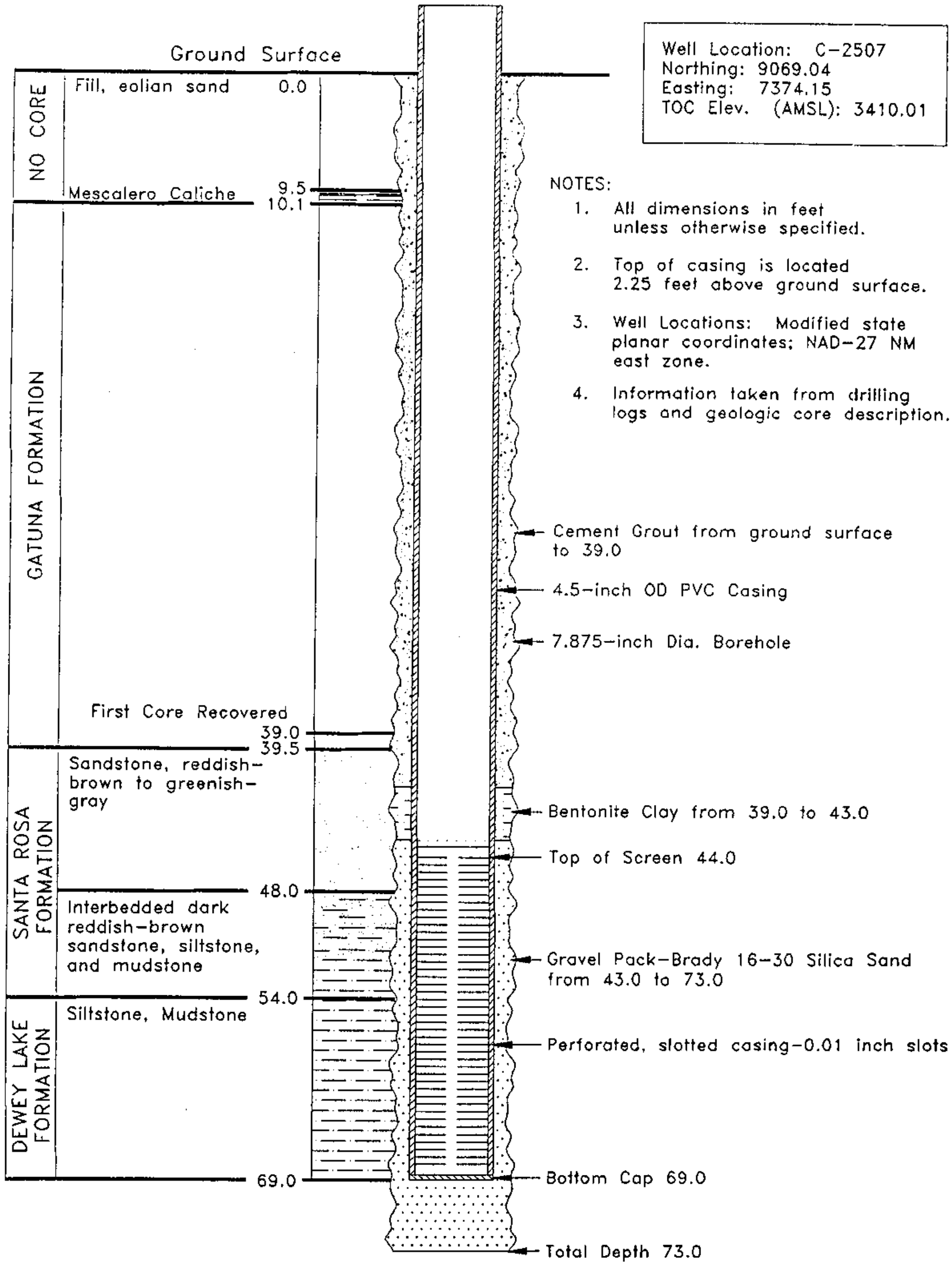
Figure 1.1 Location of Boreholes C-2505, C-2506, and C-2507



Duke Engineering & Services	Figure 1.2 C-2505 Well Completion Diagram	DATE: 04/97-12/97 REF: JBP/WIPP05 REV: C



Duke Engineering & Services	Figure 1.3 C-2506 Well Completion Diagram	DATE: 05/97-12/97 REF: JBP/WIPP06 REV: C



Duke Engineering & Services	Figure 1.4 C-2507 Well Completion Diagram	DATE: 05/97-12/97 REF: JBP/WIPP07 REV: C

drawdown cone of depression encountered a no-flow boundary at the end of the third pumping period (DOE, Jan 1997).

Water samples were collected from wells C-2505, C2506, and C-2507 a few days after drilling. The water-quality data from these wells indicated that total dissolved solids (TDS) were greatest near the Exhaust Shaft, ranging from 11,500 mg/L in C-2506 located east of the Exhaust Shaft to 8500 mg/L to the south of the shaft in C-2505, and to 4000 mg/L in C-2507 located 200 feet directly south of the shaft.

In February and March 1997, additional water-level monitoring, testing and water-quality sampling were conducted. Testing consisted of a 72-hour pumping test in C-2506 and a 24-hour pumping test in C-2505. In addition, water-quality samples were collected from each well at the completion of testing. The purposes for conducting longer term hydraulic tests were to:

- determine if the water bearing horizon within the lower Santa Rosa Formation is limited in areal extent or is part of a sub-regional groundwater system;
- define local boundary conditions;
- determine if existing wells C-2505 and C-2506 are sufficient to dewater the area around the Exhaust Shaft;
- determine if additional wells are required to characterize the shallow groundwater; and
- collect additional water-quality samples to characterize potential source(s) of groundwater.

Water-level data collected between October 1996 and March 1997 revealed that water levels had risen linearly in wells C-2505, C-2506, and C-2507 with a range from 1.6 to 2.6 feet. Water levels in C-2505 and C-2506, located nearest the shaft had risen at a rate of about 0.012 ft/day, while the water level in C-2507 had risen at a rate of 0.009 ft/day. Fresh-water-head values indicated a 6-foot difference between well C-2506 located near the Exhaust shaft and well C-2507 located approximately 200 feet to the south. (DOE, May 1997)

Water-level measurements collected on October 14, 1996, prior to the 6-hour step-drawdown pumping test indicated a flow direction toward the south/southeast and a hydraulic gradient of 2.45x e-2 ft/ft. Water-level measurements collected on March 24,1997 also indicated a direction of south/southeast but a steeper gradient of 3.19x e-2 ft/ft.

Comparison of the October 1996 and February 1997 step-drawdown pumping tests performed in well C-2506 indicated that the hydrologic characteristics of the system changed during this 5-month period. Both pumping and observation well fluid-pressure-data responses indicated:

- a quick pressure recovery response in C-2506; and
- no measurable fluid-pressure response in observation well C-2507 during the February 1997 pumping test in C-2506.

In the October 1996 test, water levels in both observation and pumping wells decreased as a function of time during constant-rate withdrawal periods. This was not the case in the February 1997 test. Also, during the October 1996 test, there were measurable responses in both of the observation wells in a relatively short period of time. Again, this was not the case in the 72-hour pumping test February 1997 test. In the February test, only a minimal response was observed in well C-2505, and there was no observed response in well C-2507.

During the February 1997, 24-hour C-2505 step-drawdown pumping test, measurable fluid-pressure responses were observed in both observation wells, C-2506 and C-2507. However the magnitude of the response in C-2507, 197 feet away from C-2505 was almost twice the magnitude of the response in the observation well C-2506, 34 feet away from C-2505, suggesting some type of connection.

Water-quality samples were collected upon the completion of the 72-hour pumping test in well C-2506 and upon completion of the 24-hour pumping test in well C-2505. In both wells the total dissolved solids (TDS) concentration were less than observed in October 1996. In C-2506 the TDS decreased from about 11500 to 6000 MG/L, while in C-2505 the TDS decreased from about 8500 to 4500 MG/L.

1.2 Objectives of the 1997 Field Investigations

Following the geophysical site investigations, drilling, hydrologic testing, and water-quality sampling and water-level monitoring described in Section 1.1 a second phase of investigation was initiated. The principle objectives of this second phase were to:

- determine the quantity and areal extent of the fluid present in the lower Santa Rosa Formation/upper Dewey Lake Formation;
- provide data with which to characterize this fluid in the vicinity of the Exhaust Shaft; and

- to obtain data for use in a flow model that could be used to assist in the location further wells if required.

1.3 Scope of Work

Twenty-seven shallow boreholes were hand augered to depths of up to 14 feet bgs to determine if any water was present in the near surface soil above the Mescalero caliche. Twelve boreholes were drilled to depths of up to 82 feet to provide potentiometric surface data for determining the hydraulic gradient of the shallow groundwater in the vicinity of the Exhaust Shaft. These boreholes were completed as piezometers, and they were also used to collect fluid samples and to provide water-quality data that will be useful in establishing trends to aid in characterizing the shallow groundwater. Finally, boreholes were bailed and hydraulic tests were performed to improve conditions for water-quality sampling and to provide hydraulic information on the piezometers.

2.0 CONSTRUCTION HISTORY

2.1 Shallow Hand Augured Boreholes

Twenty-seven shallow boreholes (Figure 2.1) were hand augered through the utility horizon at the WIPP site down to the top of the Mescalero caliche or to a depth of up to 14 feet below ground surface (bgs). Boreholes were augered by hand to comply with site safety regulations related to drilling through the utility horizon. The objective of the hand-augured boreholes were to:

- determine if any water was present above the Mescalero caliche;
- evaluate general soil-moisture conditions and the quality of the near-surface caliche; and to
- provide potential locations for the drilling and installation of piezometers.

Table 2.1 provides a list of the shallow hand-augered boreholes and their depths. No water was encountered in any of the twenty-seven boreholes indicating there are probably no leaks from water or wastewater lines in the vicinity of those boreholes.

2.2 Piezometer Construction

Twelve 6-5/8-inch diameter boreholes were hollow-stem augered/cored and/or air-rotary drilled to depths of up to 82 feet bgs through the Santa Rosa Formation into the Dewey Lake Formation (Figure 2.2) between June 23 and July 10, 1997. As the boreholes were completed, 2-inch I.D. piezometers were installed, packed with sand above the screened intervals, sealed with bentonite, and grouted to ground surface. The locations and elevations of each piezometer were surveyed immediately upon completion of each installation. Elevation data were then used with water-level measurement data to determine the location of succeeding piezometers in order to define the hydraulic gradient, and to determine the areal extent and vertical extent of fluid within the Santa Rosa Formation. Upon completion of the work, protective well-head covers were placed on each piezometer in order to maintain security of each location. Figures 2.3 to 2.14 are completion diagrams for piezometers 1 to 12. Table 2.2 lists the piezometer-completion information for of each piezometer for comparison.

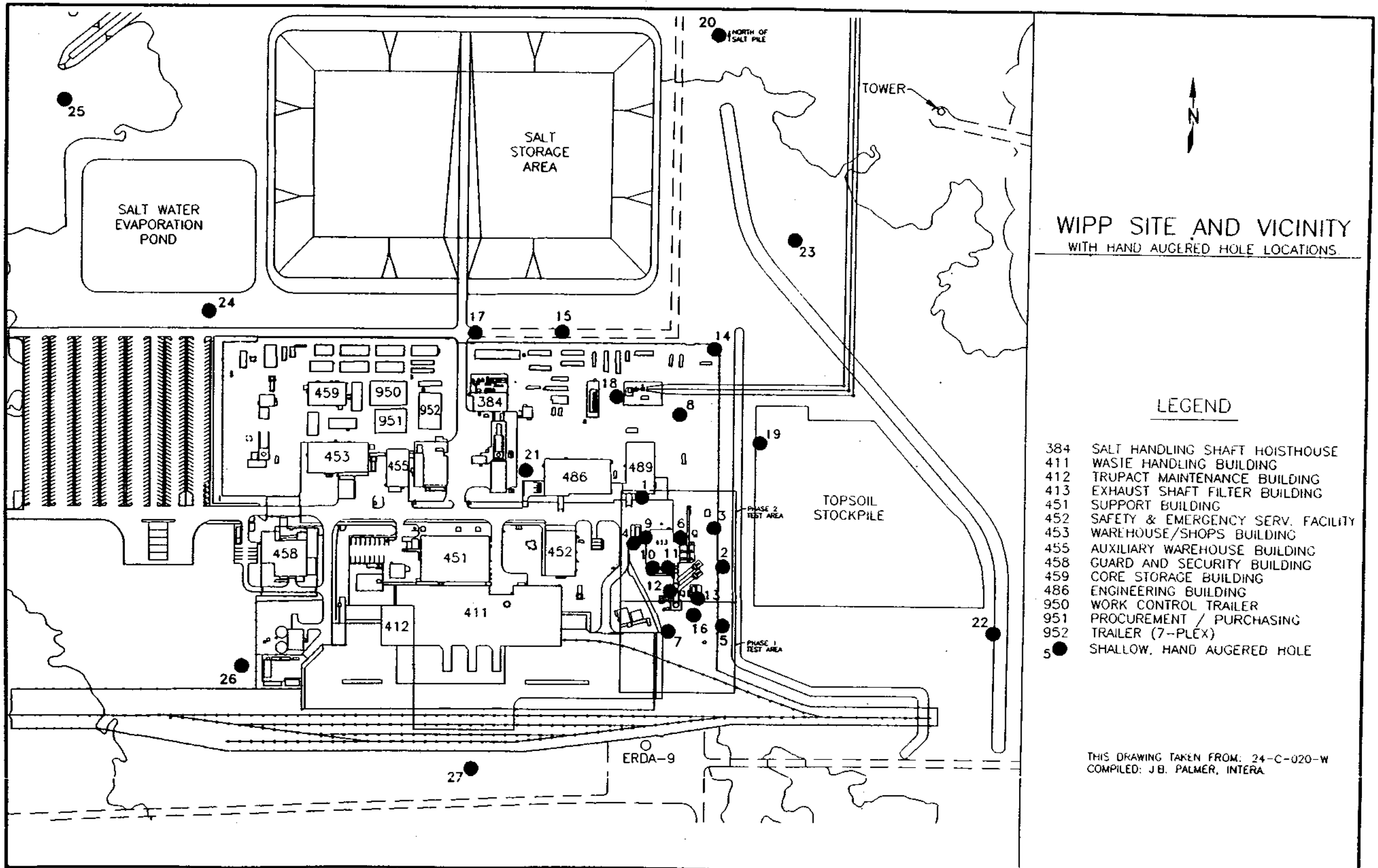


Figure 2.1 Location of Shallow Hand Augered Boreholes

Table 2.1 History of Hand Augured Boreholes

Borehole Number	Date	Mescalero Caliche Top (ft-bgs)	Comments
Borehole-1	6-10-97	6.0	no water present
Borehole-2	6-10-97	9.0	no water present
Borehole-3	6-10-97	9.0	no water present
Borehole-4	6-9-97	7.0	no water present
Borehole-5	6-10-97	11.5	no water present
Borehole-6	6-10-97	?	no water present
Borehole-7	6-9-97	6.5	no water present
Borehole-8	6-10-97	6.5	no water present
Borehole-9	6-9-97	8.0	no water present
Borehole-10	6-9-97	8.5	no water present
Borehole-11	6-9-97	9.0	no water present
Borehole-12	6-9-97	8.0	no water present
Borehole-13	6-9-97	8.5	no water present
Borehole-14	6-10-97	5.0	no water present
Borehole-15	6-10-97	5.5	no water present
Borehole-16	6-9-97	9.0	no water present
Borehole-17	6-10-97	6.0	no water present
Borehole-18	6-10-97	6.0	no water present
Borehole-19	6-10-97	6.0	no water present
Borehole-20	6-10-97	12.0	no water present
Borehole-21	7-2-97	?	Augered to 5 .0 ft
Borehole-22	7-8-97	?	Augured to 5 .0 ft
Borehole-23	7-7-97	?	Augered to 5 .0 ft
Borehole-24	7-1-97	?	Augured to 5 .0 ft
Borehole-25	7-9-97	?	Augered to 5 .0 ft
Borehole-26	7-10-97	?	Augured to 5 .0 ft
Borehole-27	7-10-97	?	Augered to 5 .0 ft

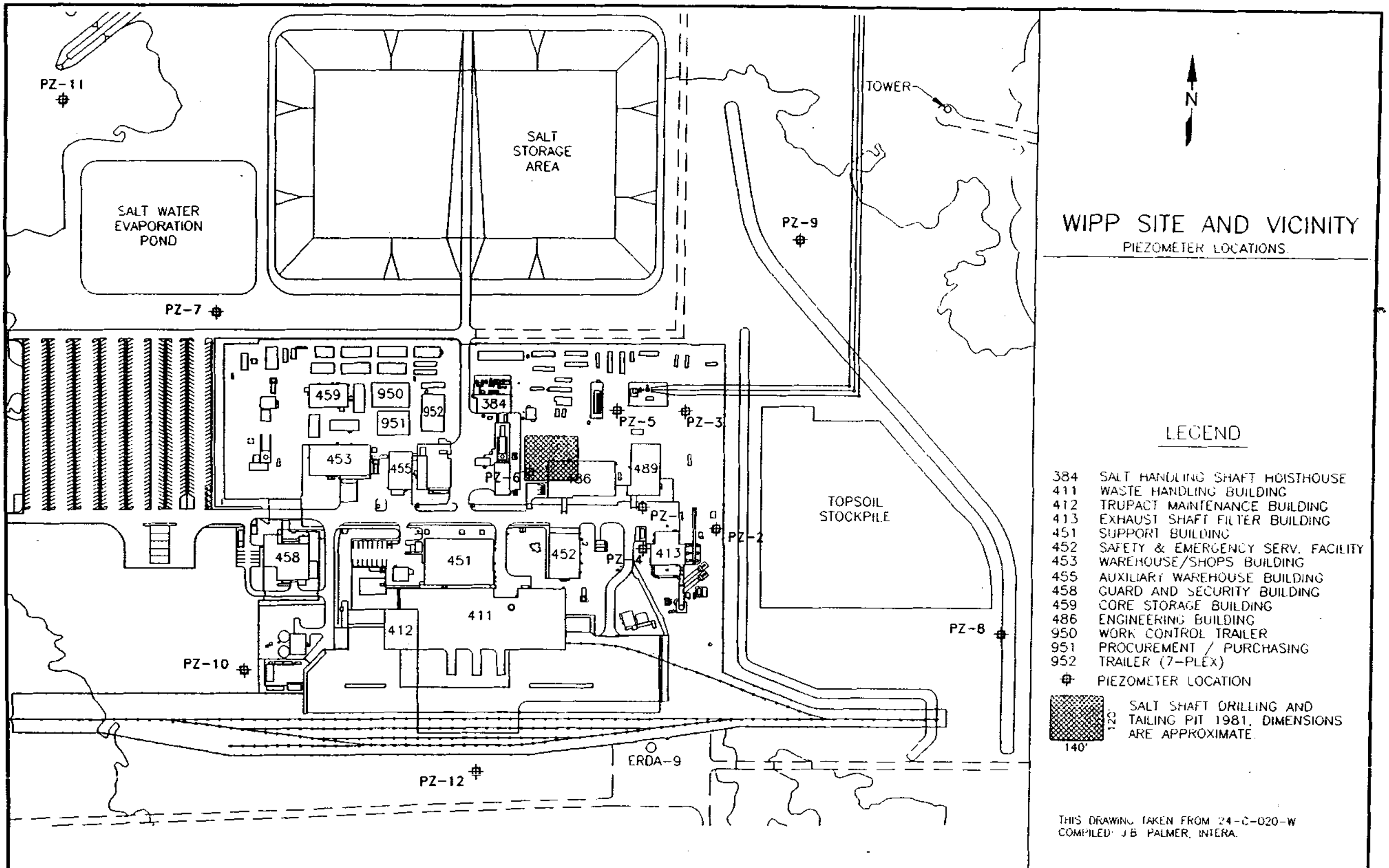
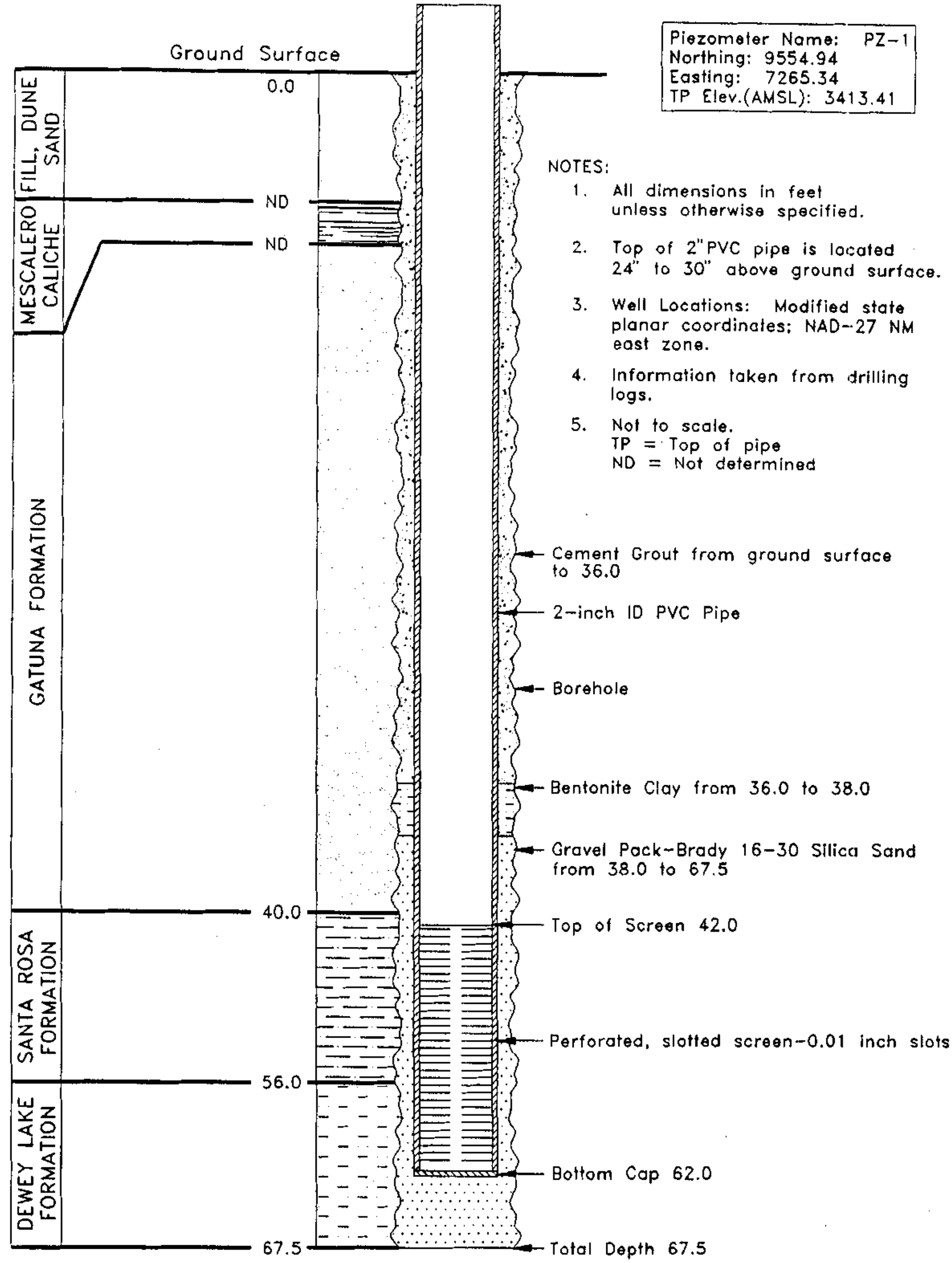
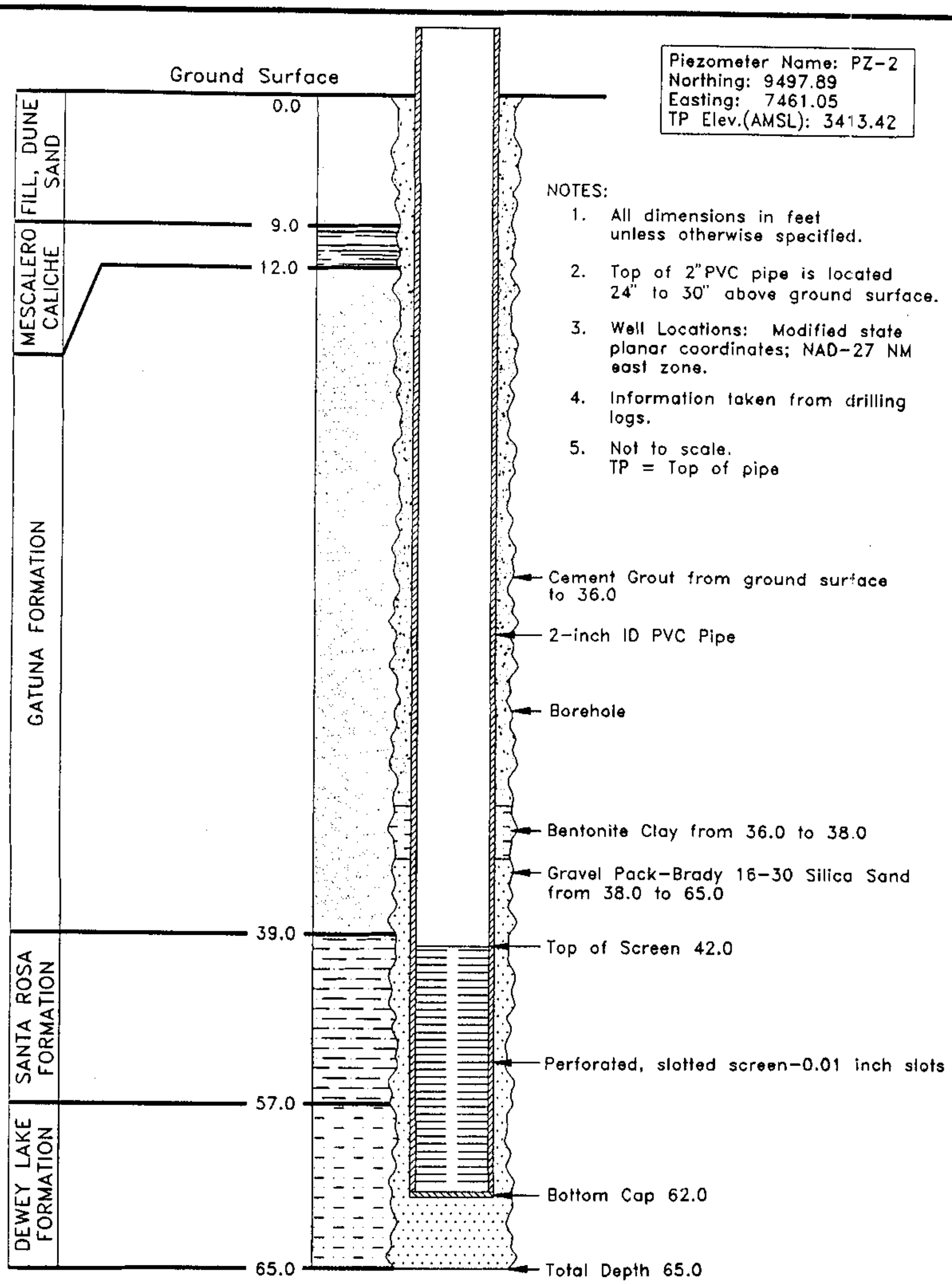


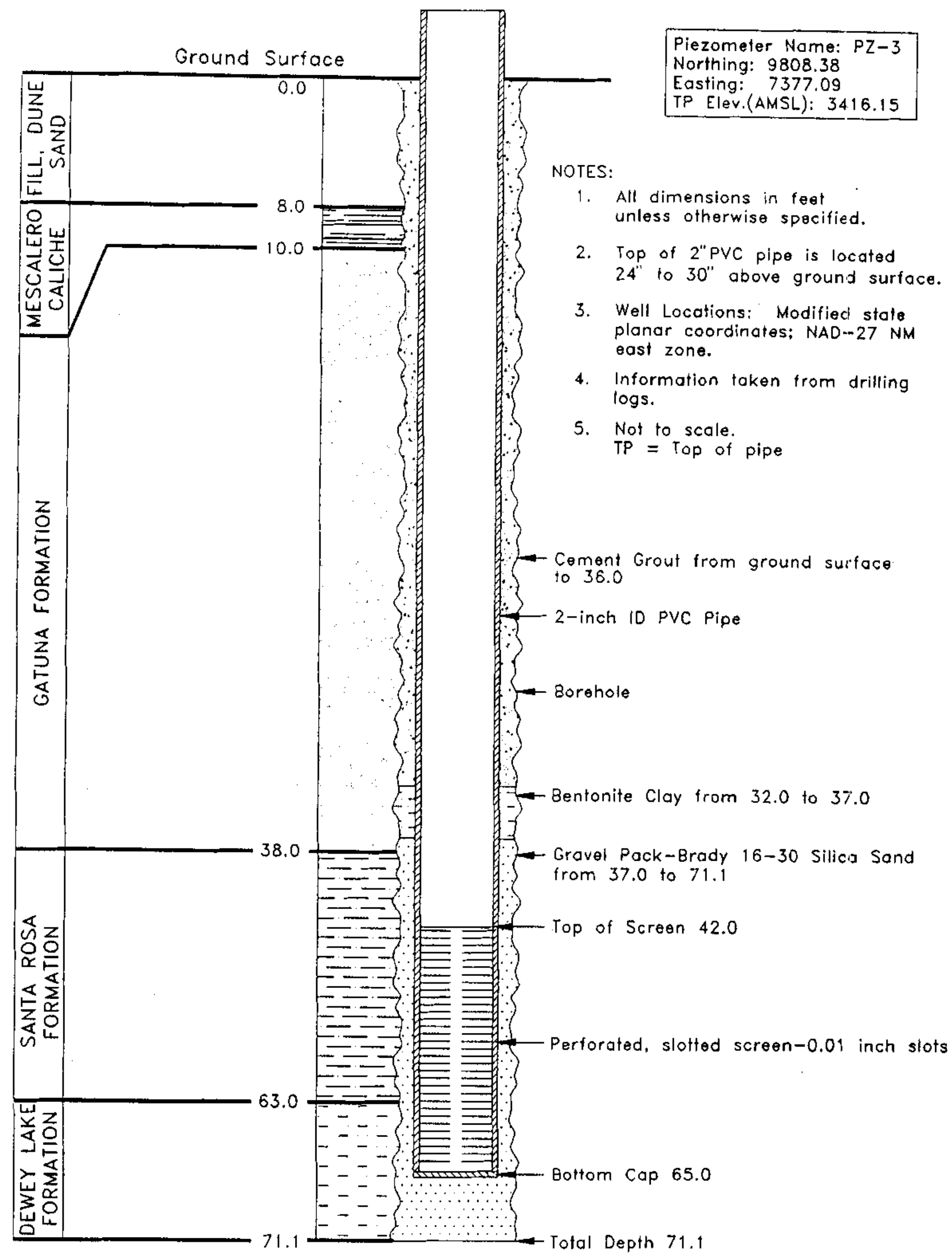
Figure 2.2 Location of Piezometers PZ-1 through PZ-12



Duke Engineering & Services	Figure 2.3 PZ-1 piezometer completion diagram	DATE: 07/97-11/97 REF: JBP/PZ-1 REV: B



Duke Engineering & Services	Figure 2.4 PZ-2 piezometer completion diagram	DATE: 07/97--11/97	
		REF: JBP/PZ--2	REV: 8



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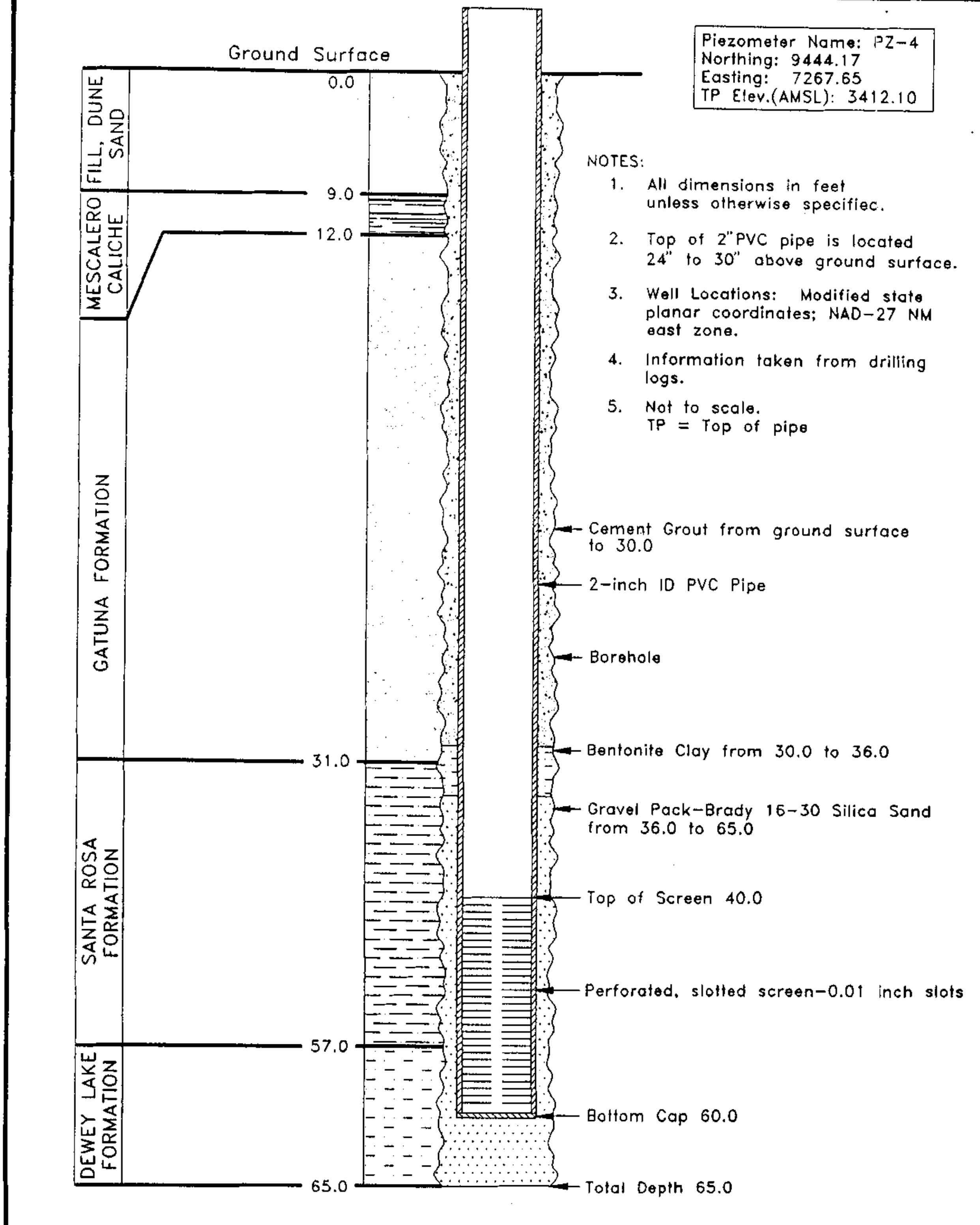
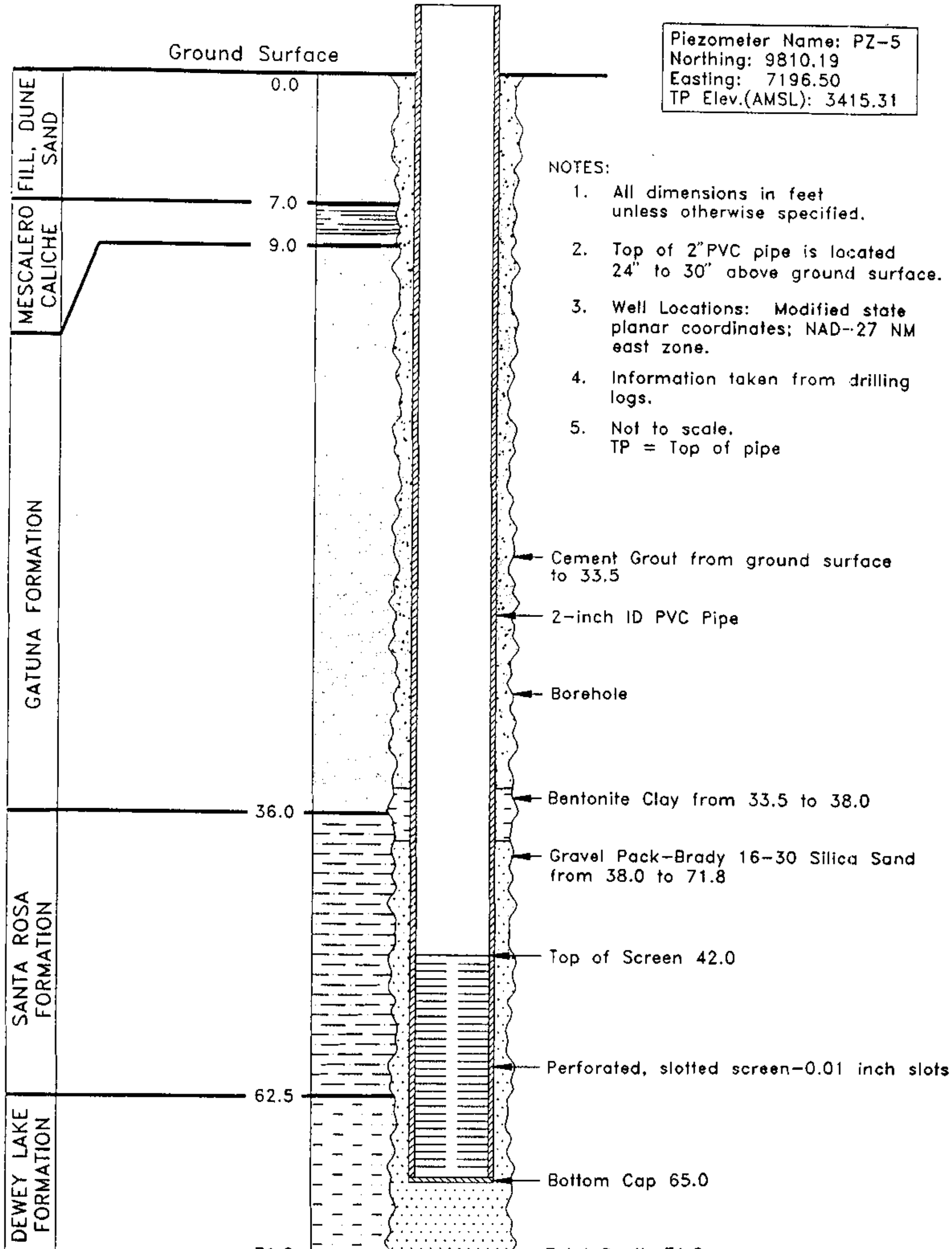
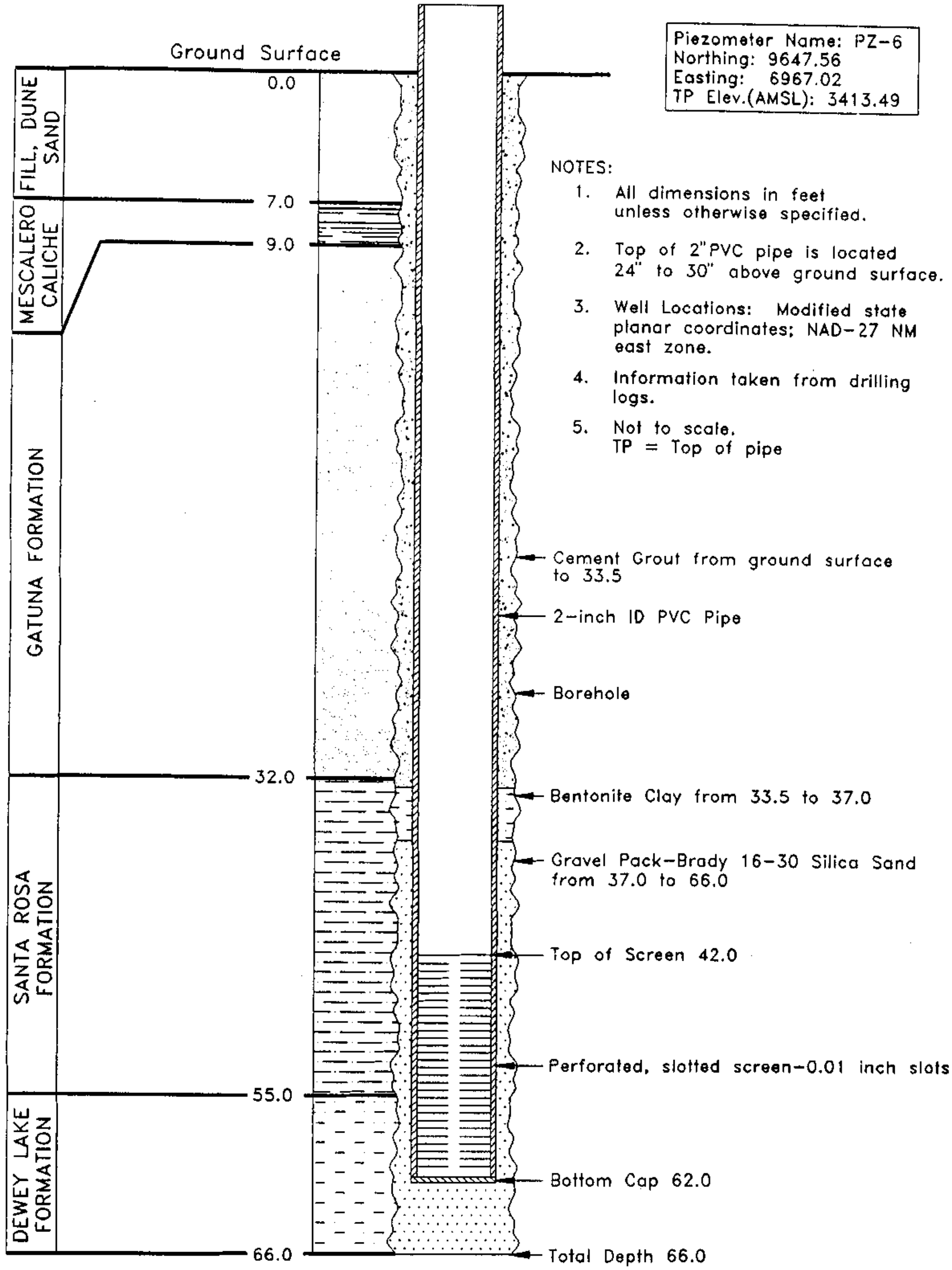


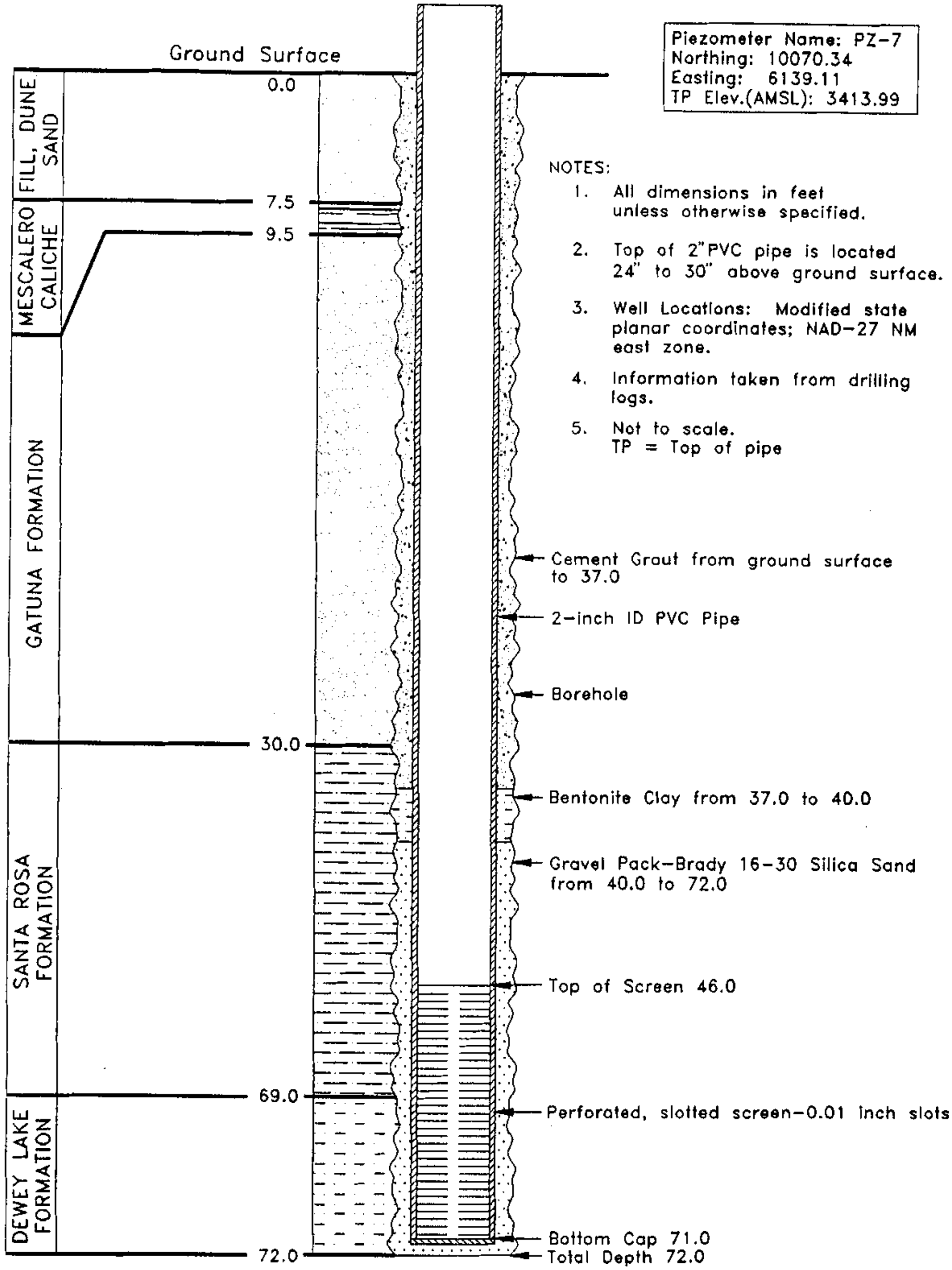
Duke Engineering & Services	Figure 2.6 PZ-4 piezometer completion diagram	DATE: 07/97-11/97 REF: JBP/PZ-4 REV: B



Duke Engineering & Services	Figure 2.7 PZ-5 piezometer completion diagram	DATE: 07/97-11/97
		REF: JBP/PZ-5 · REV: B



Duke Engineering & Services	Figure 2.8 PZ-6 piezometer completion diagram	DATE: 07/97-11/97 REF: JBP/PZ-6 REV: B



Duke Engineering & Services	Figure 2.9 PZ-7 piezometer completion diagram	DATE: 07/97-11/97
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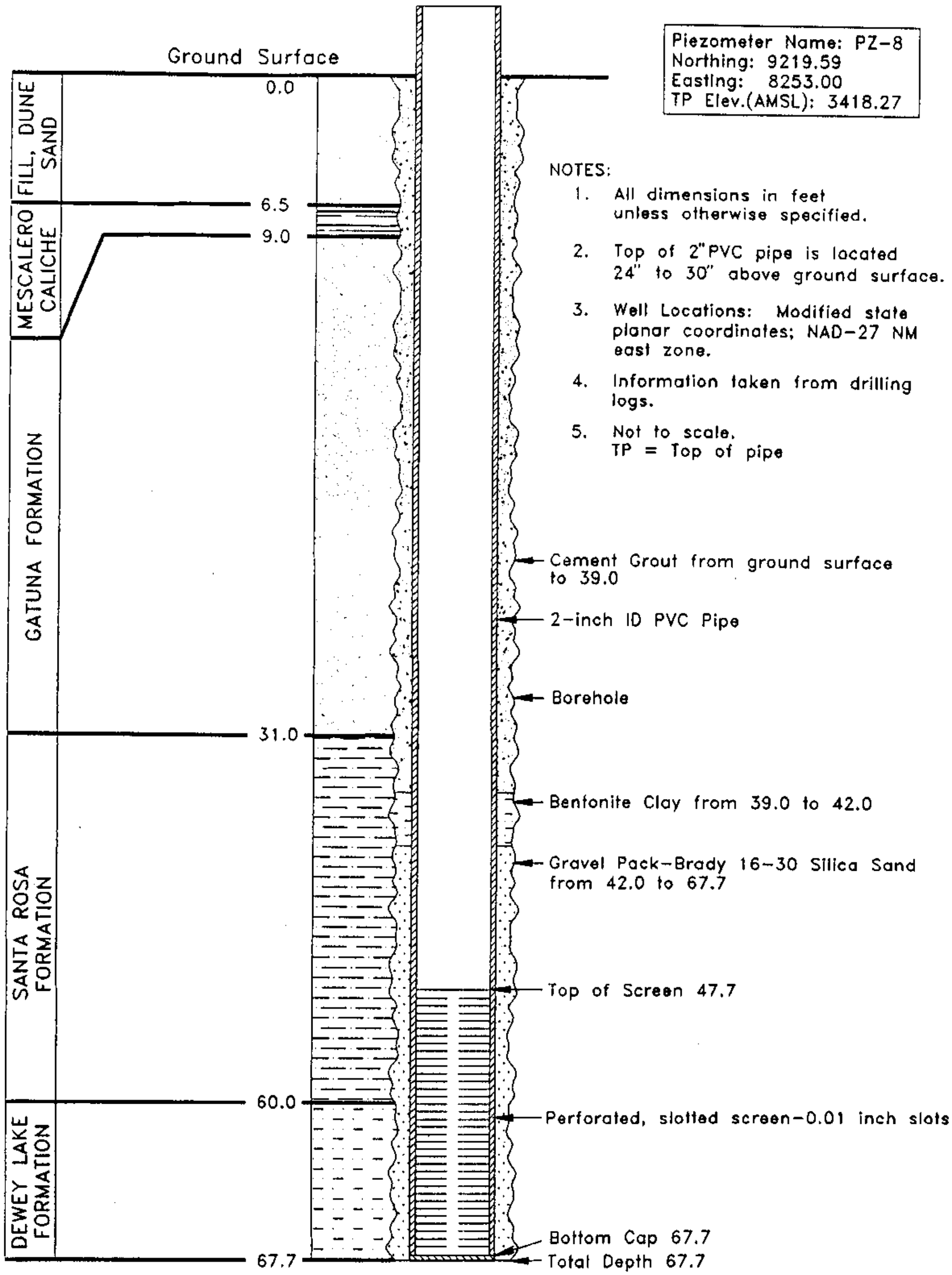

Duke Engineering & Services	Figure 2.10 PZ-8 piezometer completion diagram	DATE: 07/97-11/97	
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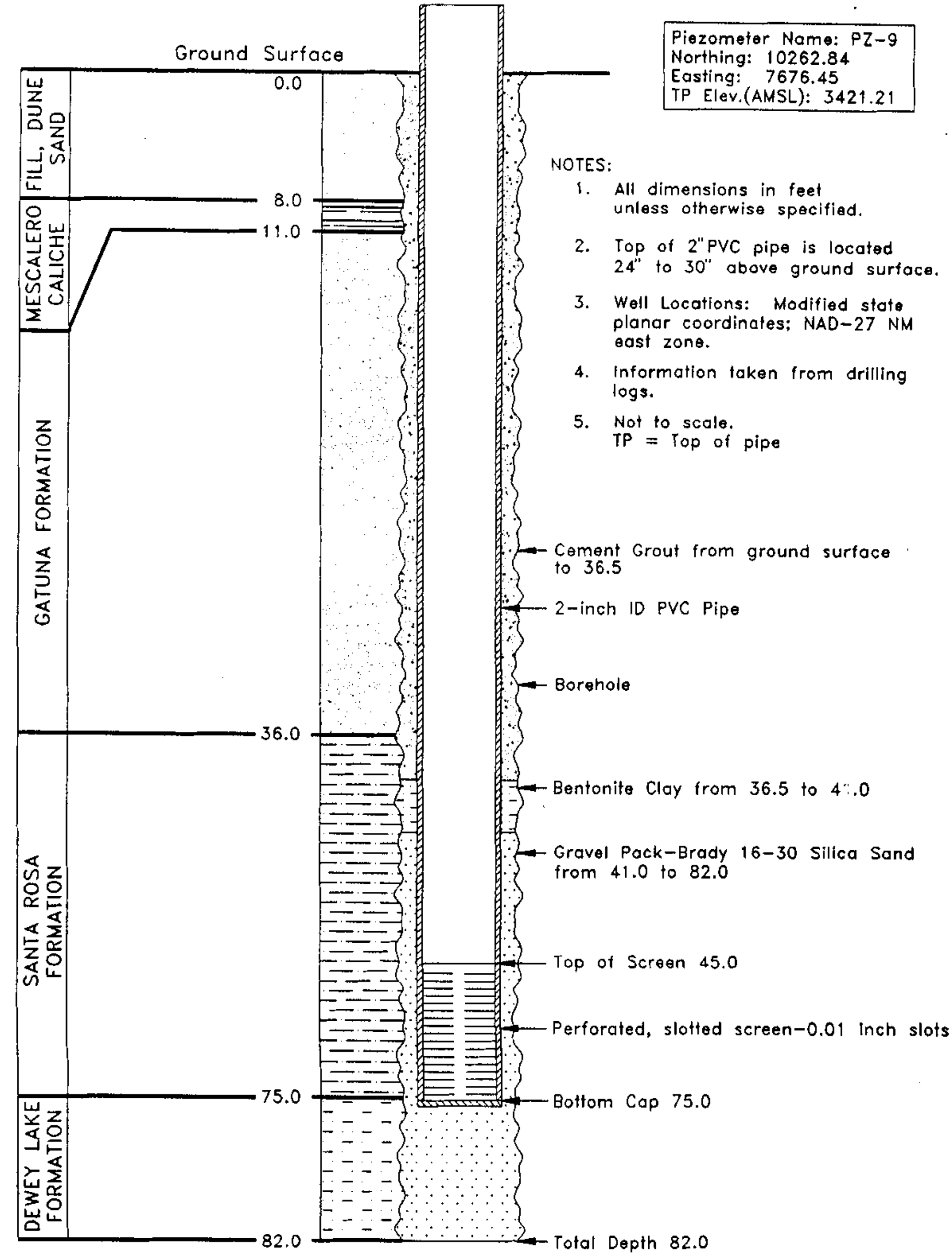

Duke Engineering & Services	Figure 2.11 PZ-9 piezometer completion diagram	DATE: 07/97-11/97
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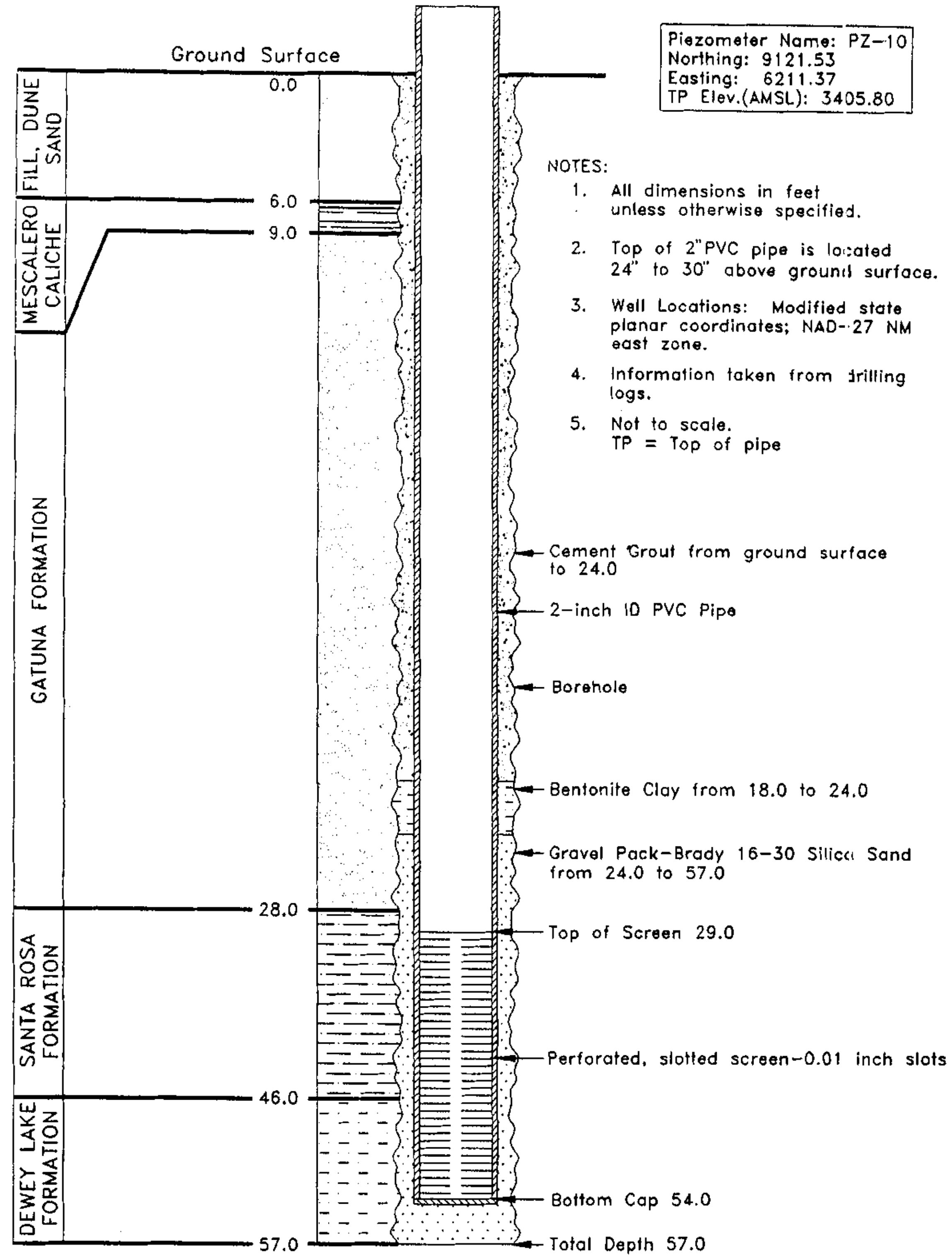

Duke Engineering & Services	Figure 2.12 PZ-10 piezometer completion diagram	DATE: 07/97-11/97
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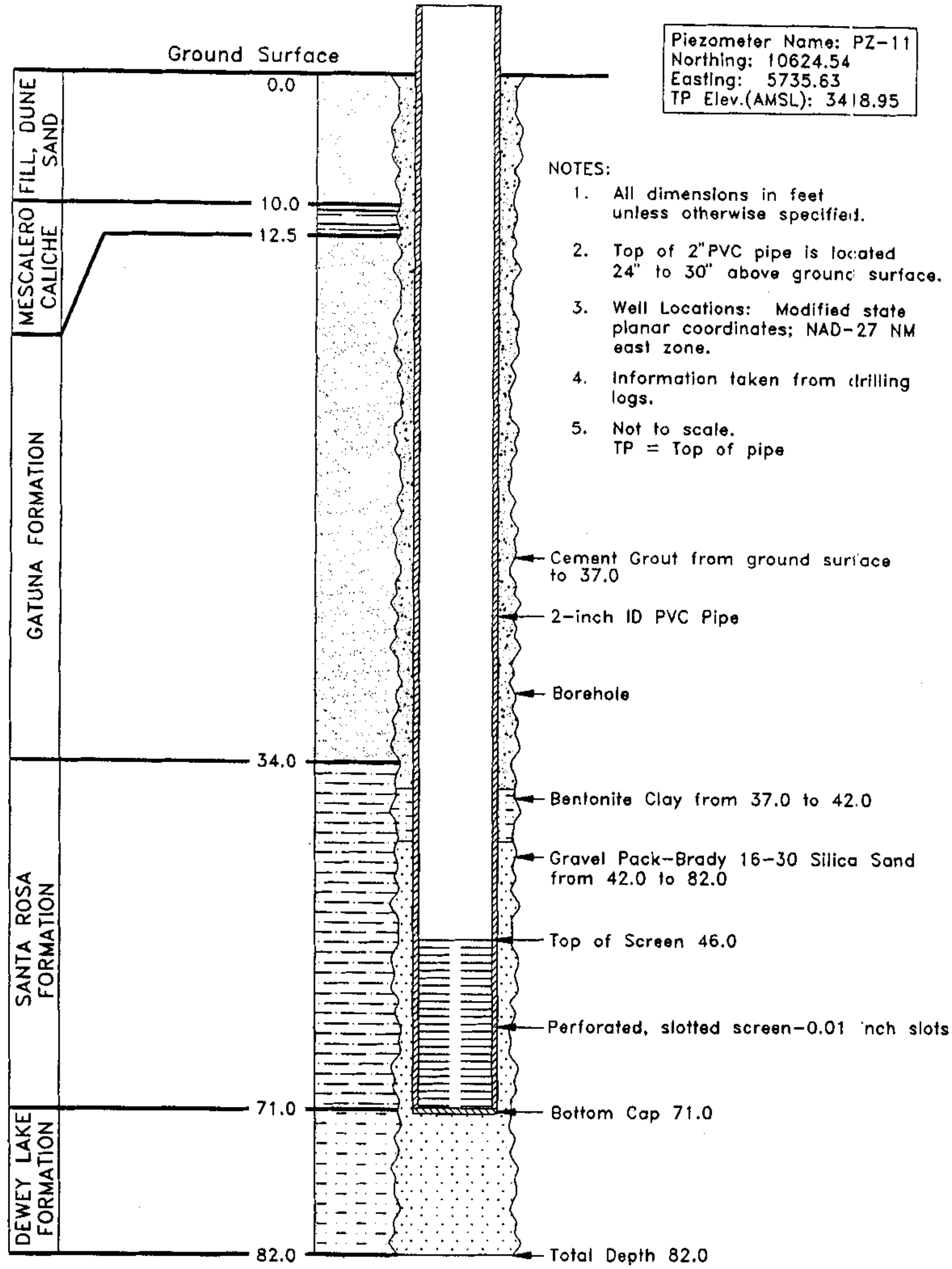

Duke Engineering & Services	Figure 2.13 PZ-11 piezometer completion diagram	DATE: 07/97-11/97	
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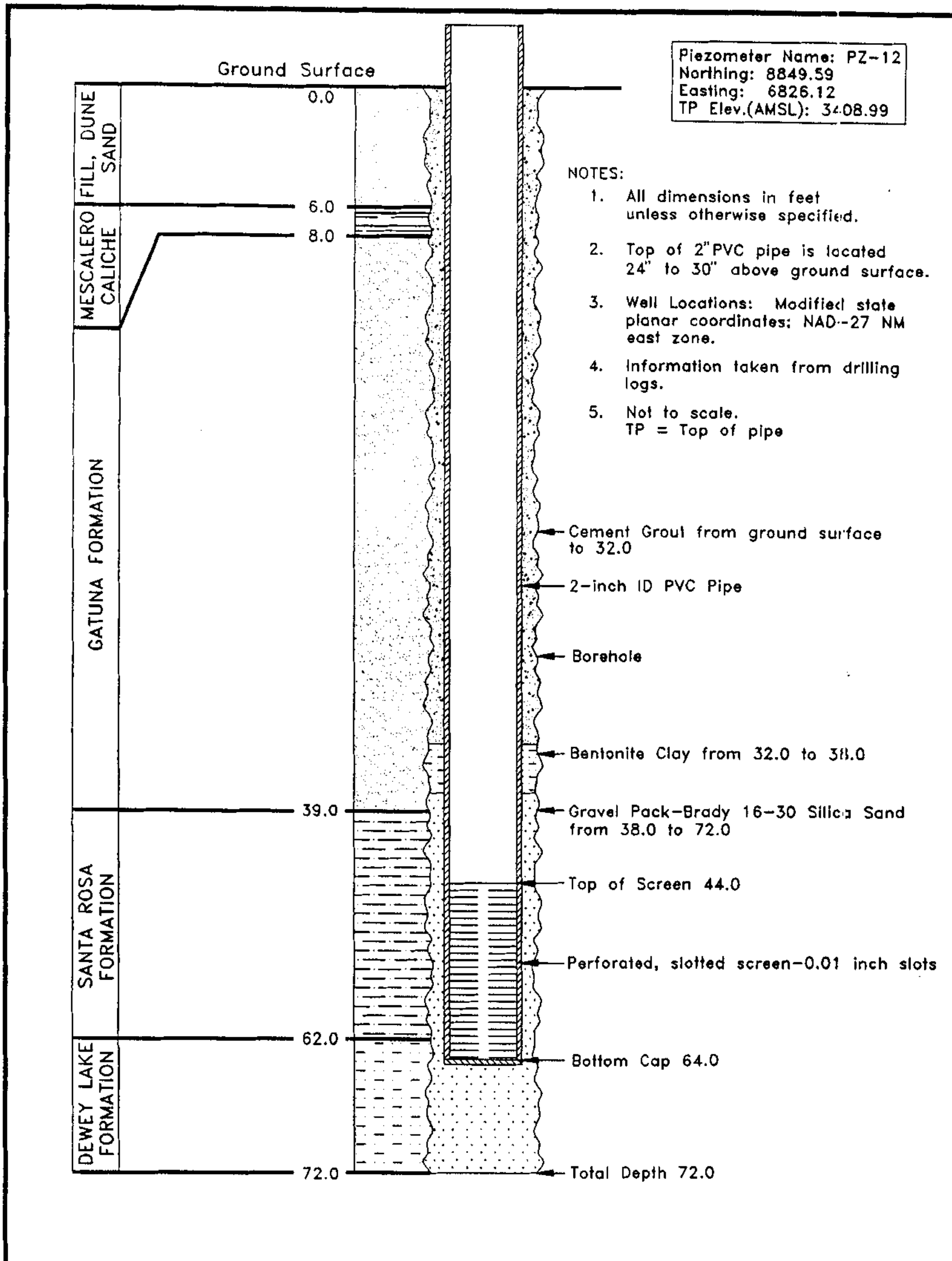


Duke Engineering & Services	Figure 2.14 PZ-12 piezometer completion diagram	DATE: 07/97-11/97 REF: JBP/PZ-12 REV: B

Table 2.2 Piezometer completion information: piezometers 1-12

PIEZOMETERS	TOTAL DEPTH (feet bgs*)	SCREENED INTERVAL (feet bgs)	SAND PACKED (feet bgs)	BENTONITE SEAL (feet bgs)
PZ-1	67.5	42-62	38-67.5	36-38
PZ-2	65.0	42-62	38-65	36-38
PZ-3	71.1	42-65	37-71.1	32-37
PZ-4	65	40-60	36-65	30-36
PZ-5	71.8	42-65	38.8-71.8	33.5-38
PZ-6	66	42-62	37-66	33.5-37
PZ-7	72	46-71	37-72	37-40
PZ-8	67.7	47.7-67.7	42-67.7	39-42
PZ-9	82	45-75	51-82	36.5-41
PZ-10	57	29-54	24-57	18-24
PZ-11	82	42-82	42-82	37-42
PZ-12	72	38-72	38-72	32-38

*bgs = below ground surface

3.0 DATA PRESENTATION

3.1 Stratigraphy

Boreholes for piezometers 1-12 were installed using hollow-stem auger and/or air-rotary drilling methods through the Santa Rosa Formation into the top of the Dewey Lake Formation. Where core samples were not collected, air-rotary cuttings were collected, sampled and described to determine the stratigraphic horizon exposed in the borehole. Table 3.1 is the stratigraphic description for piezometers 1-12. These descriptions indicate the stratigraphic depth intervals for the Mescalero caliche, and the Gatuña, Santa Rosa and the Dewey Lake Formations. For a complete lithologic description of the core samples and the stratigraphic nomenclature refer to Appendix 1.

3.2 Water-Level Data

Water-level measurements have been collected from wells C-2505, C-2506, and C-2507 since October 1996. In addition, water-level measurements have also collected from piezometers 1 through 12 beginning upon completion of installation and continuing through September 24, 1997. Water-level measurements have been collected to provide data with which to evaluate hydrologic behavior of the Santa Rosa:

3.2.1 Water-Level Measurements From Wells C-2505, C-2506, and C-2507

Water-level monitoring of wells C-2505, C-2506, and C-2507 began in October 1996 and extended through September of 1997. Figures 3.1, 3.2 and 3.3 are linear plots of the water level recorded in feet above mean sea level (amsl) verses time in calendar days in wells C-2505, C-2506, and C-2507, respectively. From October 1996 until mid March 1997 water levels in C-2505 and C-2506 rose approximately 3.0 feet with a 1.6-foot increase in the water level in C-2507 (Figure 3.1-3.3). Since March, water levels in C-2505 and C-2506 have declined by about 0.5 feet while the fluid level in C-2507 has continued to increase.

Table 3.1 Summary stratigraphic data from PZ drilling.

Depth (ft) Interval for Stratigraphic Units					
Drillhole	Fill, Dune Sand	Mescalero caliche	Gatuña Formation	Santa Rosa Formation	Dewey Lake Fm
PZ-1	nd§	nd	nd-40	40-~56	~56-67.5 (TD)
PZ-2	0-9	9-12	12-39	39-~57	~57-65 (TD)
PZ-3	0-8	8-10	10-38	38-63	63-70 (TD)
PZ-4	0-9	9-12	12-31	31-57	57-65 (TD)
PZ-5	0-7	7-9	9-36	36-62.5	62.5-71.5 (TD)
PZ-6	0-7	7-9	9-32	32-55	55-66 (TD)
PZ-7	0-7.5	7.5-9.5	9.5-30	30-69	69-71.5 (TD)
PZ-8	0-6.5	6.5-9	9-31	31-60	60-67 (TD)
PZ-9	0-8	8-11	11-36	36-75	75-82.5 (TD)
PZ-10	0-6	6-9	9-28	28-46	46-57 (TD)
PZ-11	0-10	10-12.5	12.5-34	34-71	71-82 (TD)
PZ-12	0-6	6-8	8-39	39-62	62-77 (TD)

§ND = not determined. Depths are approximate (about ± 1 ft). Some contacts to nearest 0.5 ft due to marked contrast. Gatuña-Santa Rosa contact is difficult; the Gatuña incorporated Santa Rosa sediment.

Exhaust Shaft Hydraulic Assessment

C-2505

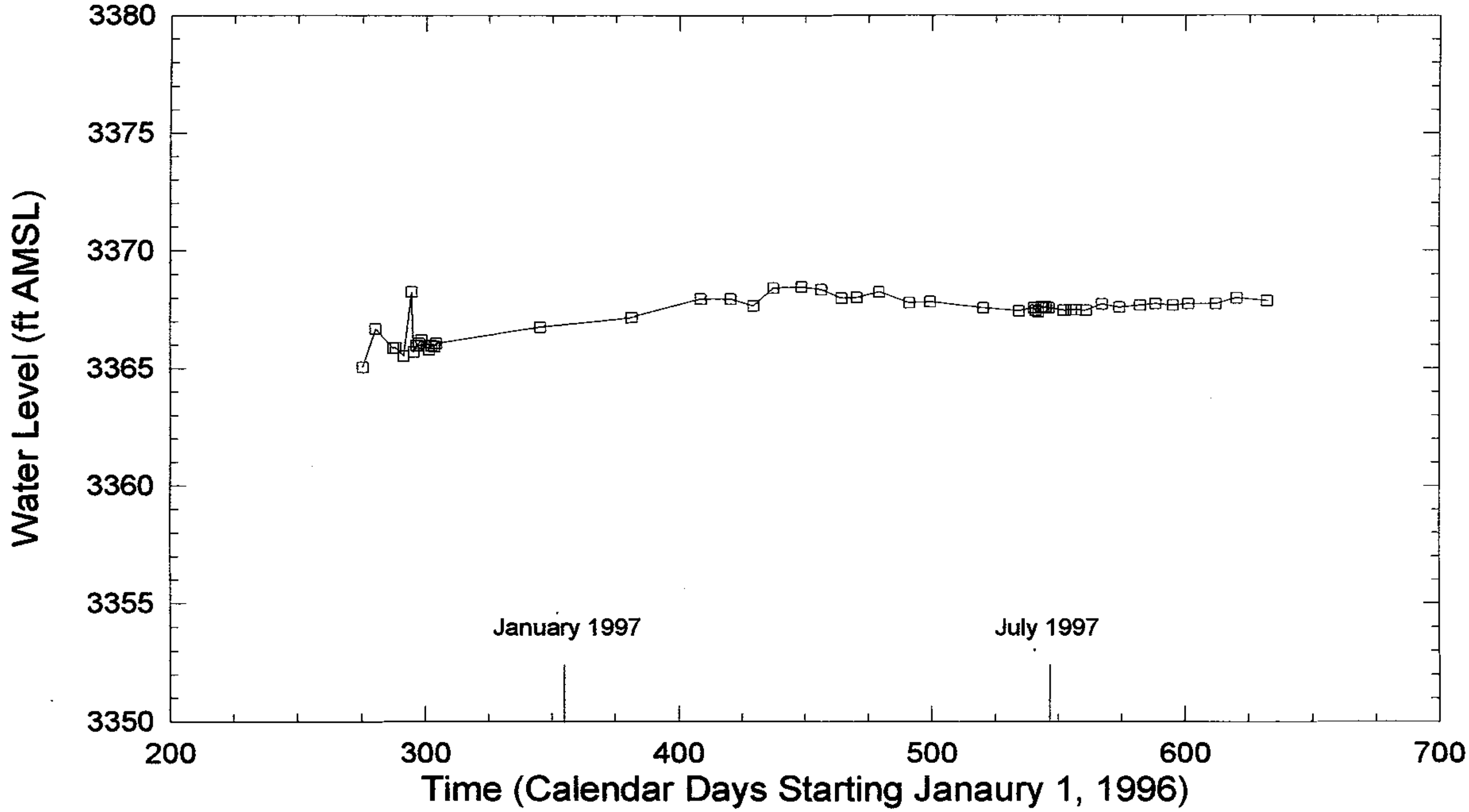


Figure 3.1. Water level versus time for monitor well C-2505

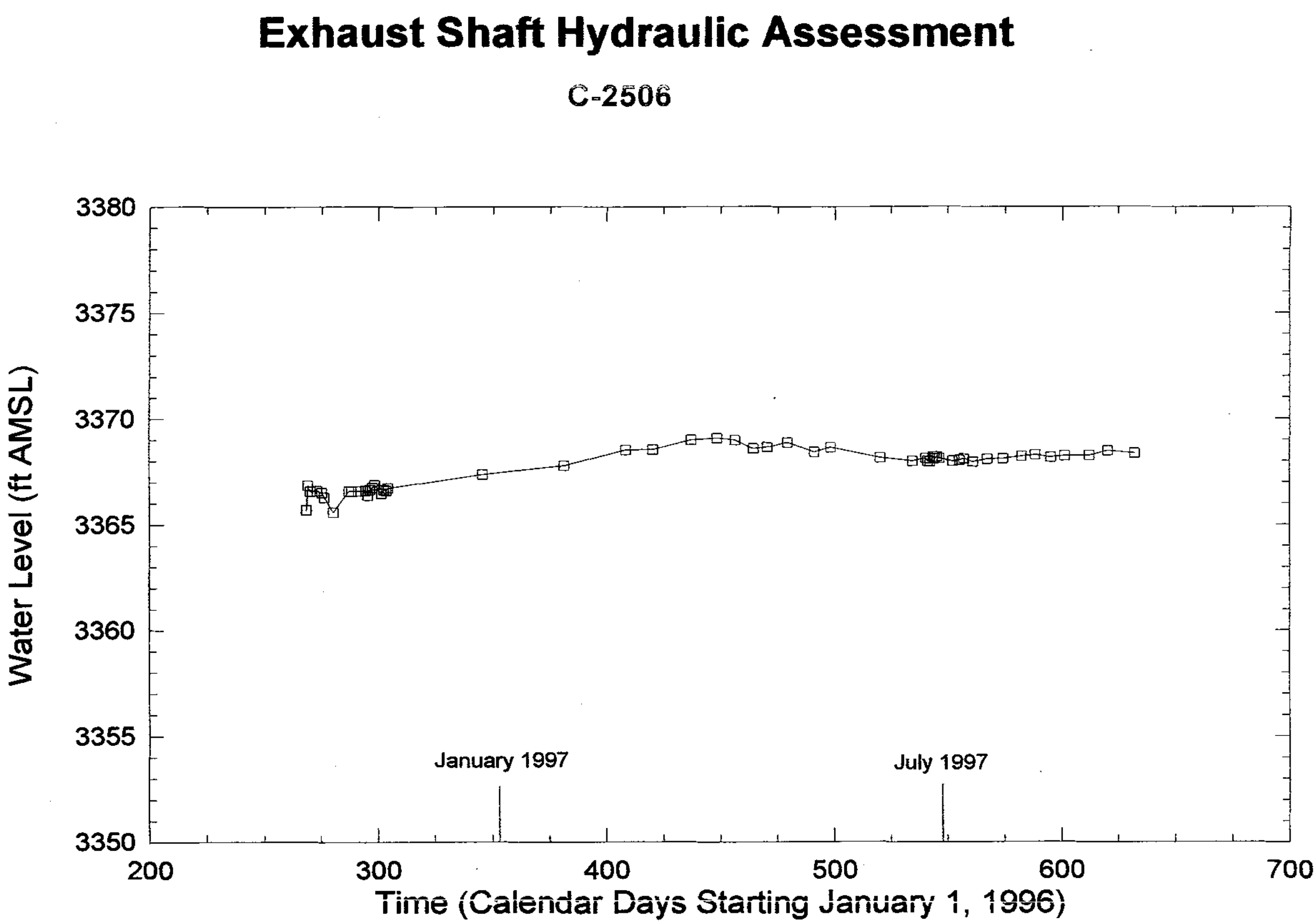


Figure 3.2. Water-level versus time for monitor well C-2506

Exhaust Shaft Hydraulic Assessment

C-2507

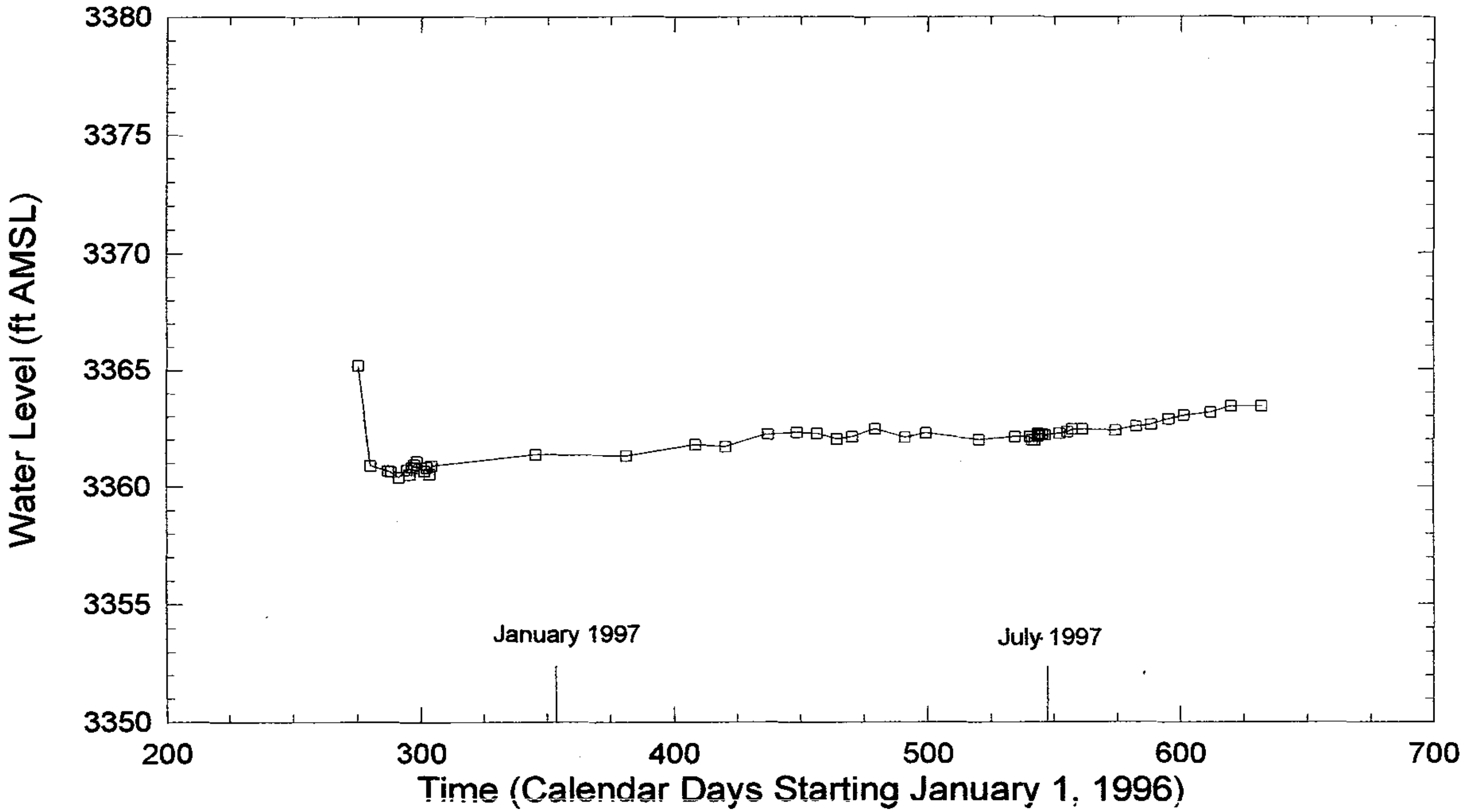


Figure 3.3. Water-level versus time for monitor well C-2507

3.2.2 Water-Level Measurements From Piezometers 1 to 12

Water-level measurements have been collected through September 1997 from piezometers 1-12 since their completion in June and July. As each piezometer was completed, water-level measurements were used along with geophysical and other related data to determine the drilling location of subsequent piezometer boreholes. Depths to water in these piezometers were combined with their top of casing elevations to provide the water-level elevations in each piezometer. Figures 3.4-3.15 are linear plots of the water levels recorded as feet above mean sea level (amsl) versus time in calendar days.

3.3 Water-Quality Data

Above drilling and installing the piezometers, Westinghouse implemented a water-quality sampling and analysis program with oversight by Dr. Rich Abitz, Geochemical Consultant, to collect periodic series of samples from each piezometer. This program, coupled with the existing water-quality monitoring program for wells C-2505, C-2506, and C-2507, provided additional information to improve understanding of the hydrogeology and geochemistry associated with the groundwater in the Santa Rosa. Suites of samples were collected between July 16-22, 1997 and August 25 - September 11, 1997. Samples were collected using a Grundfous Redi-Flow II 1-7/8-inch diameter submersible pump. Piezometers were pumped for periods ranging from 70 minutes to over 150 minutes depending on the production rate, wellbore volume pumped, and problems associated with silting and clogging of the pump. Several piezometers experienced either very low production rates or excessive silting problems which effected sampling and pumping. These boreholes included PZ-1, PZ-2, PZ-4 and PZ-9.

Table 3.2 is a list of field conductance measurements collected during water-quality sampling between July 16-22, 1997. Groundwater samples were collected and sent to a certified analytical laboratory for geochemical analysis of groundwater compositions focusing on major and minor-ion chemistry. For a complete evaluation and description of the water-quality sampling activities performed between July 16-22 and August 25 - September 11, 1997 please refer to Appendix 1.

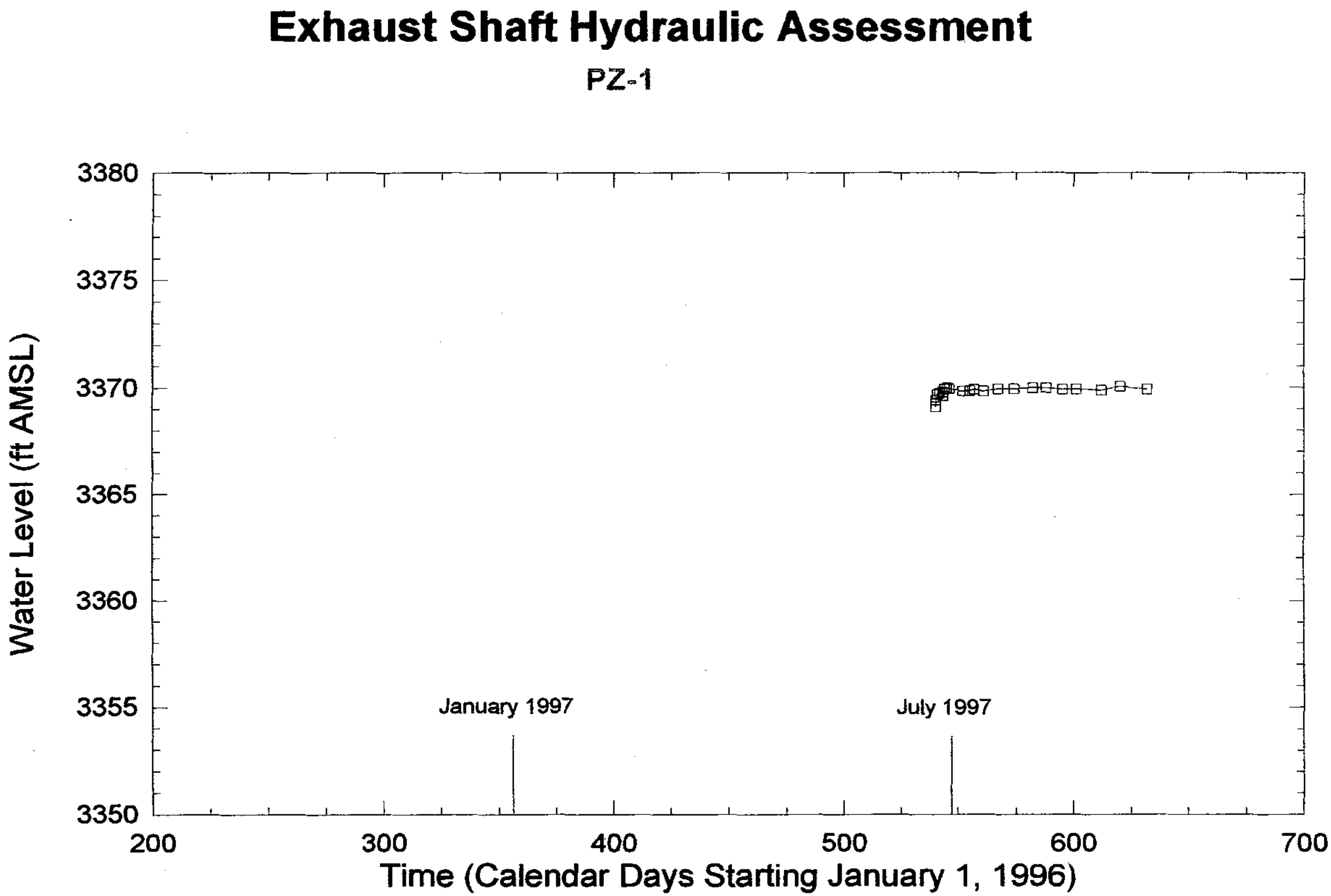


Figure 3.4. Water-level versus time for piezometer PZ-1

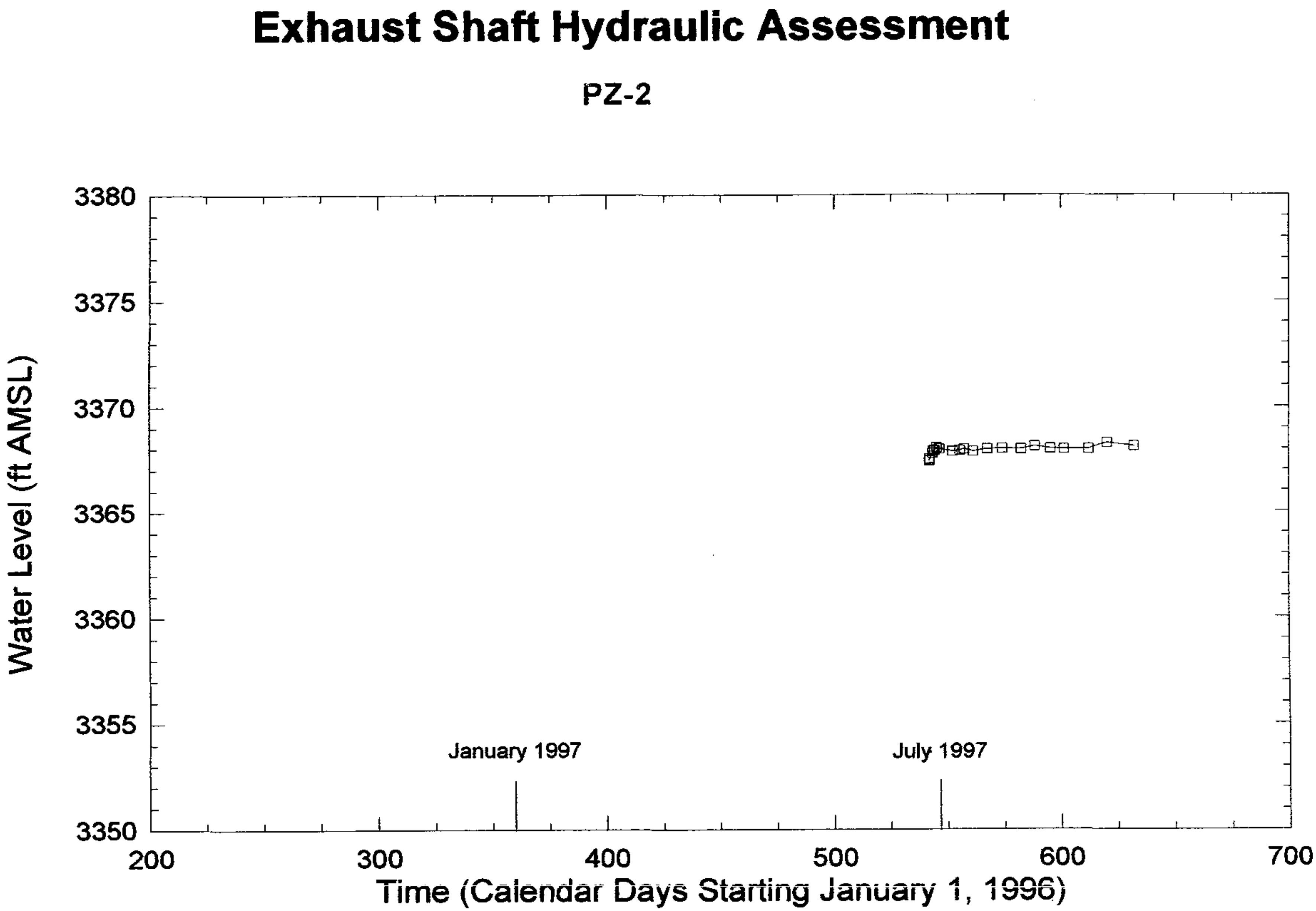


Figure 3.5. Water-level versus time for piezometer PZ-2

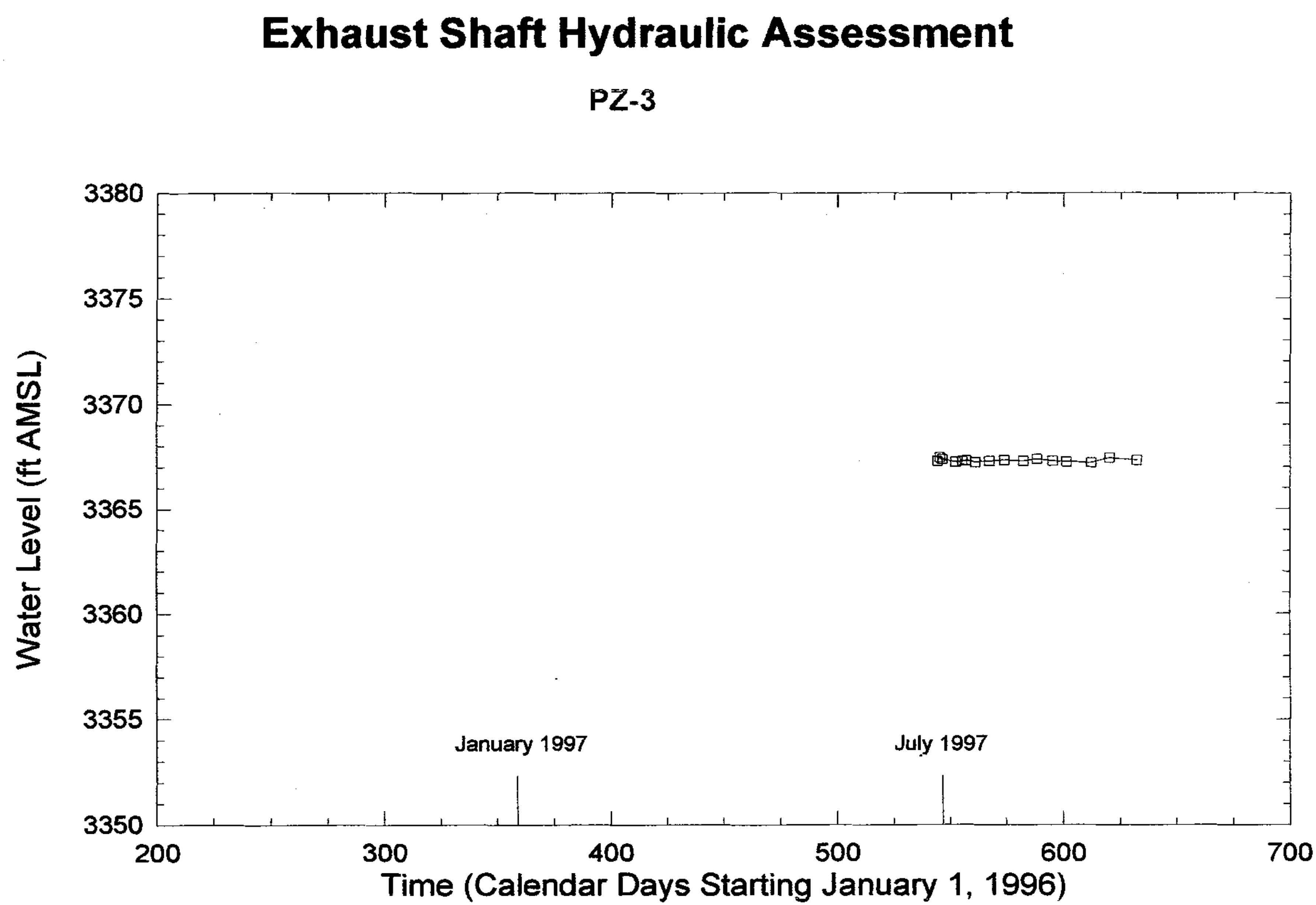


Figure 3.6. Water-level versus time for piezometer PZ-3

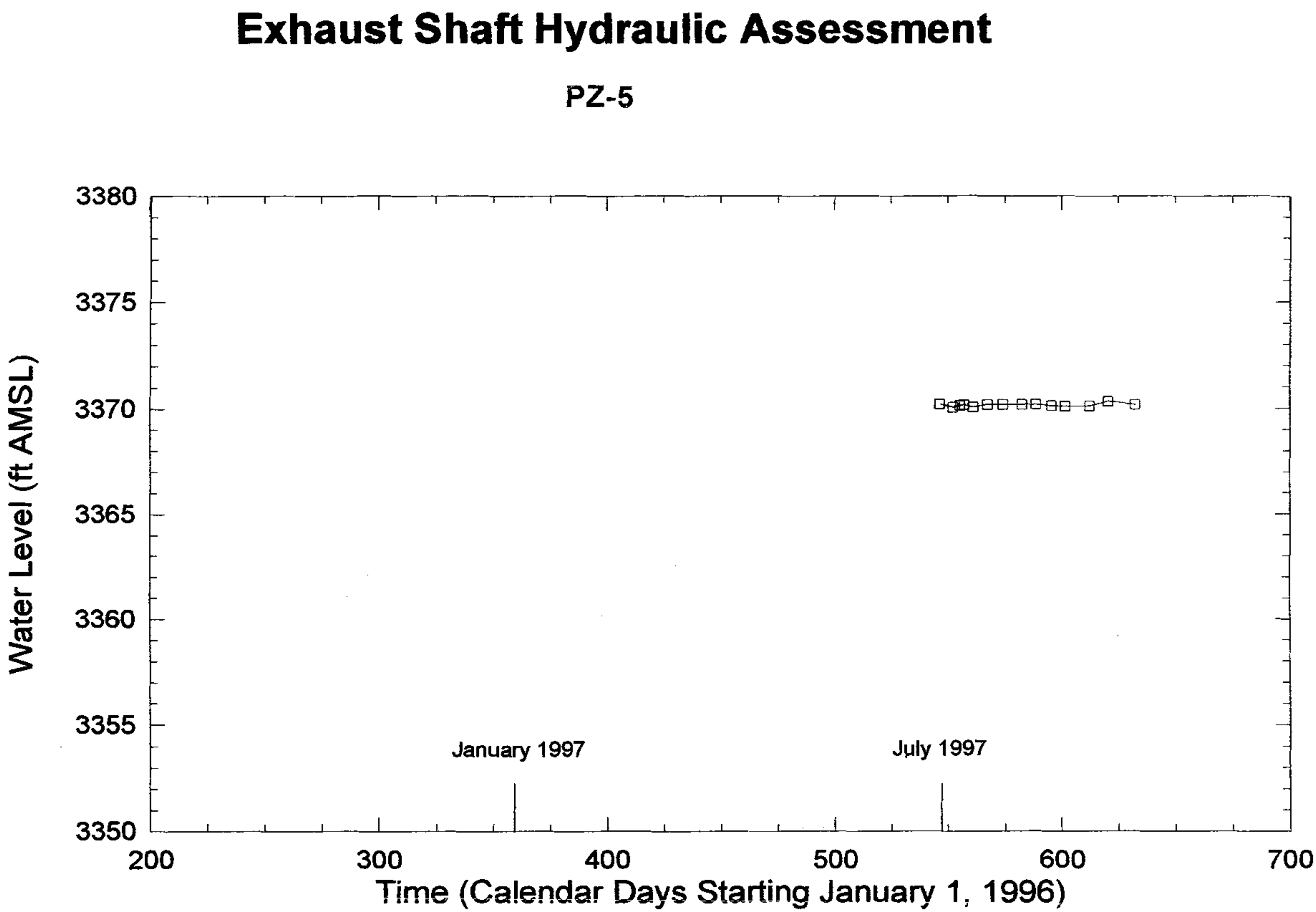


Figure 3.8. Water-level versus time for piezometer PZ-5

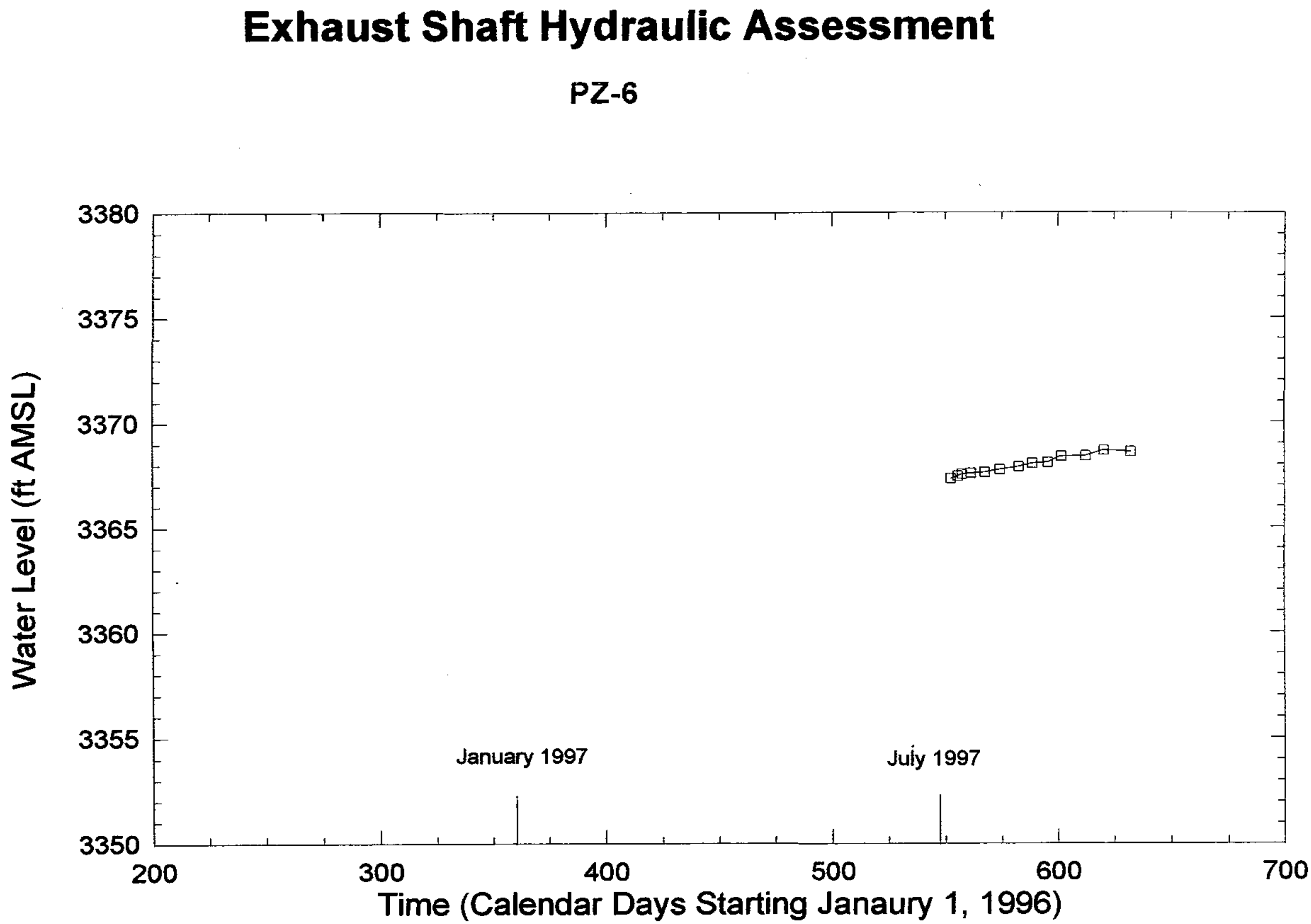


Figure 3.9. Water-level versus time for piezometer PZ-6

Exhaust Shaft Hydraulic Assessment

PZ-7

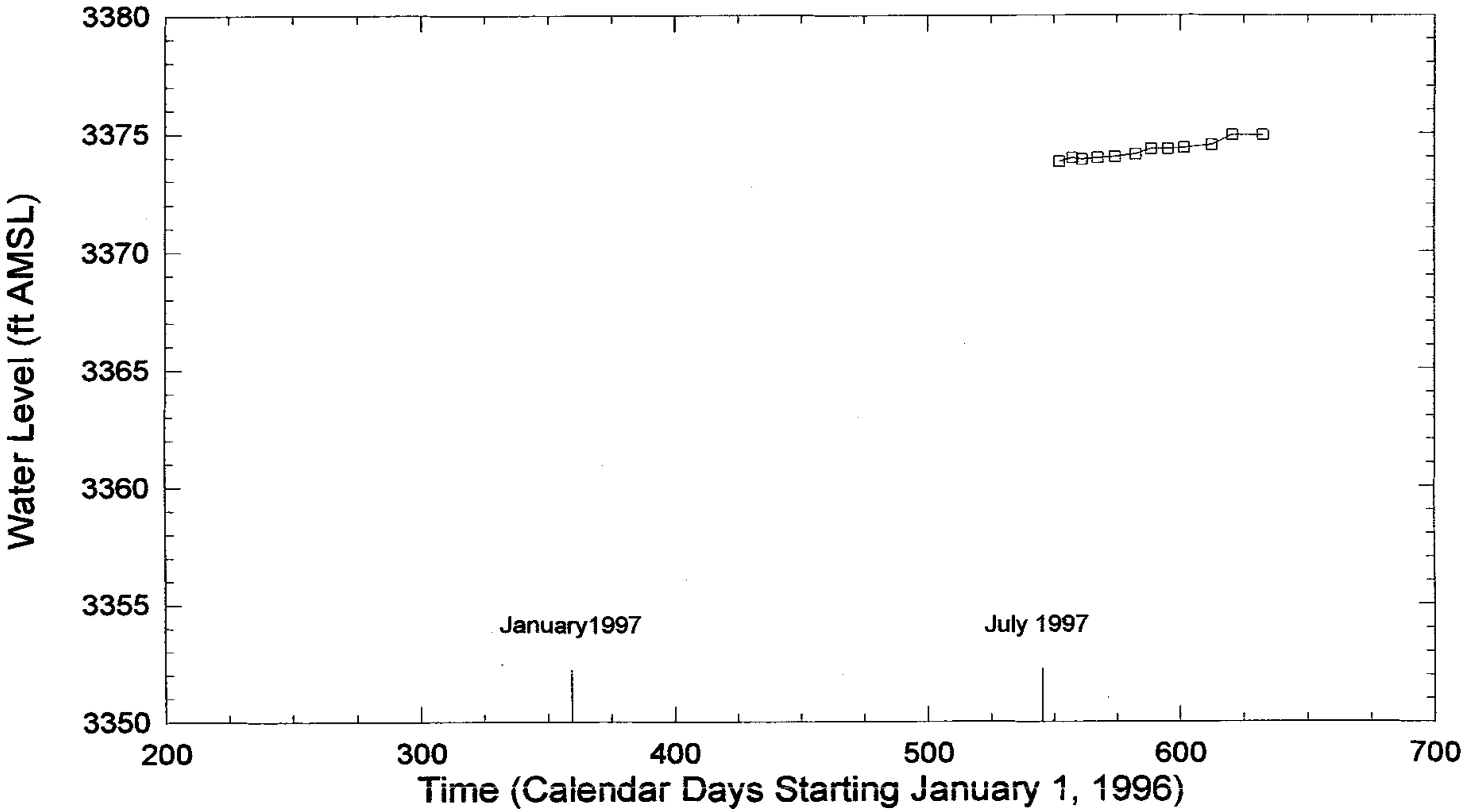


Figure 3.10. Water-level versus time for piezometer PZ-7

Exhaust Shaft Hydraulic Assessment

PZ-8

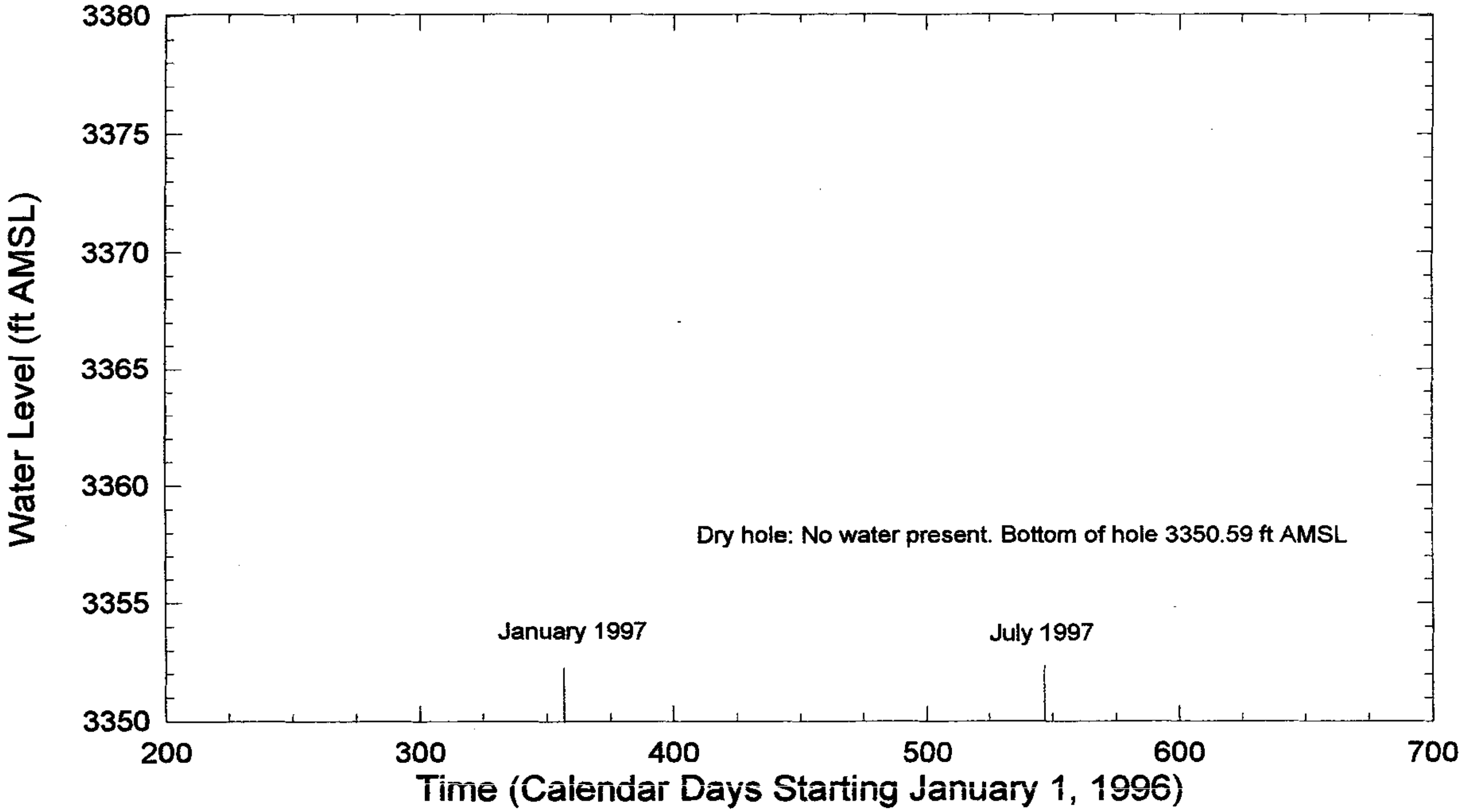


Figure 3.11. Water-level versus time for piezometer PZ-8

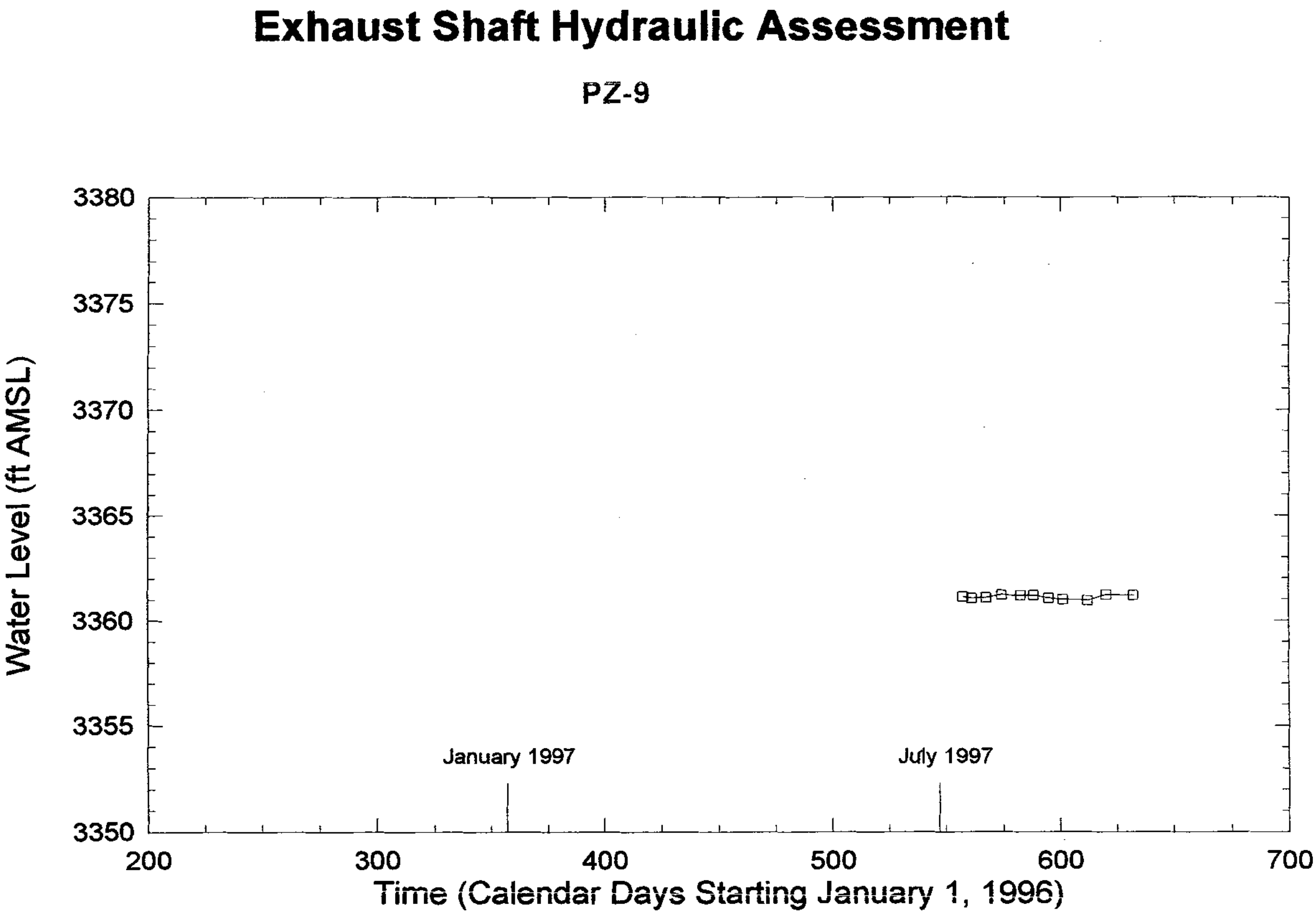
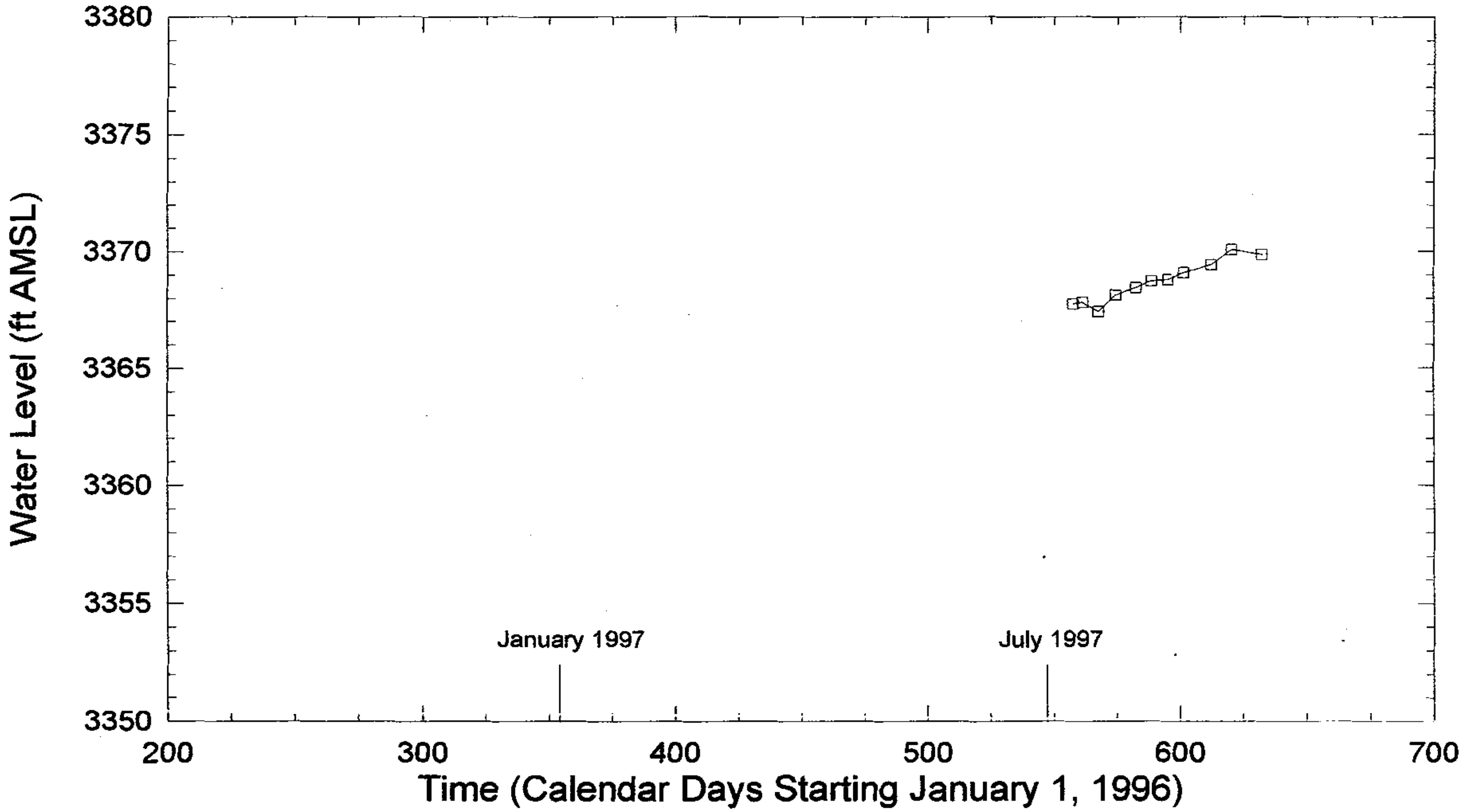


Figure 3.12. Water-level versus time for piezometer PZ-9

Exhaust Shaft Hydraulic Assessment

PZ-10



Fgiure 3.13. Water-level versus time for piezometer PZ-10

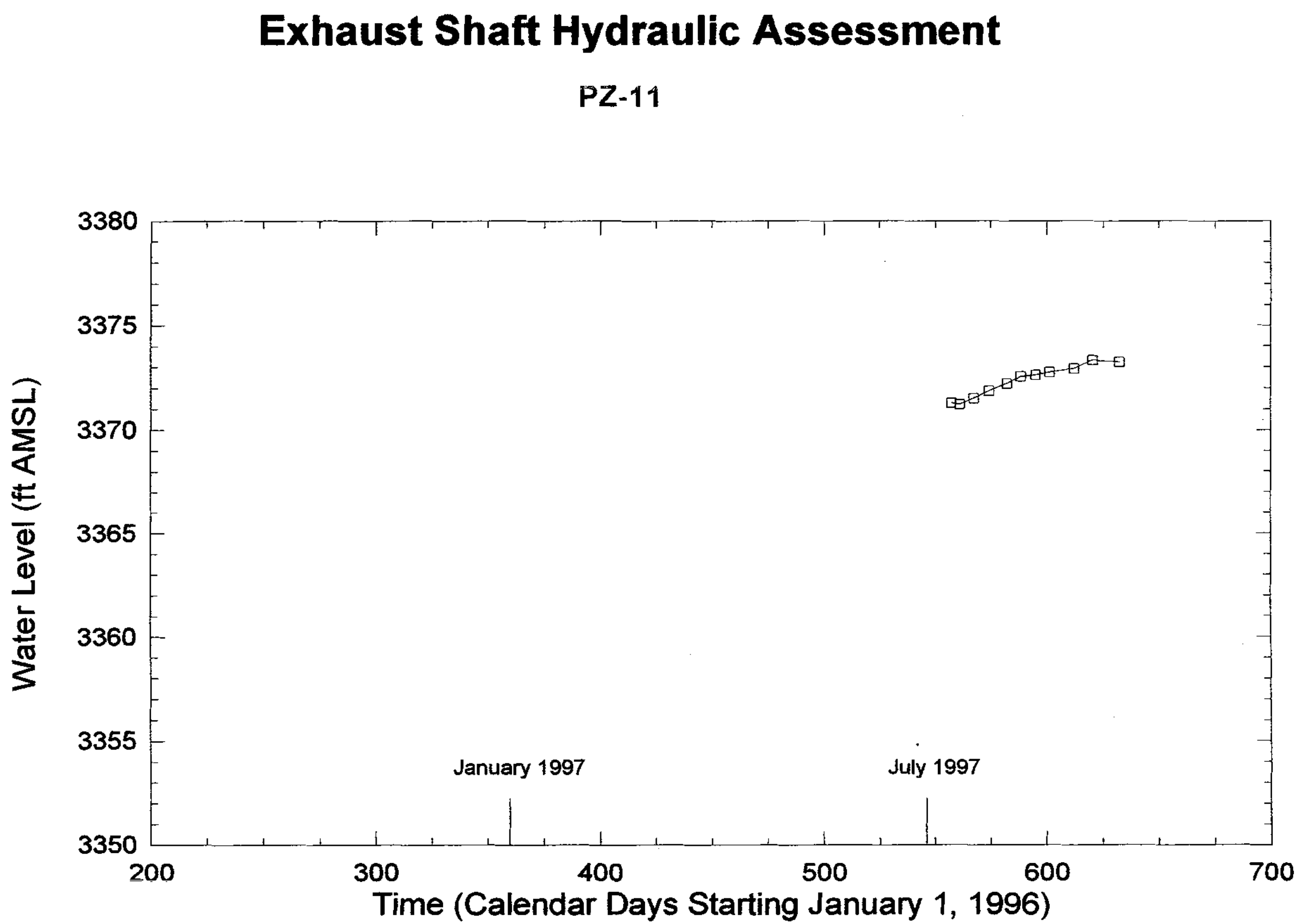


Figure 3.14. Water-level versus time for piezometer PZ-11

Exhaust Shaft Hydraulic Assessment

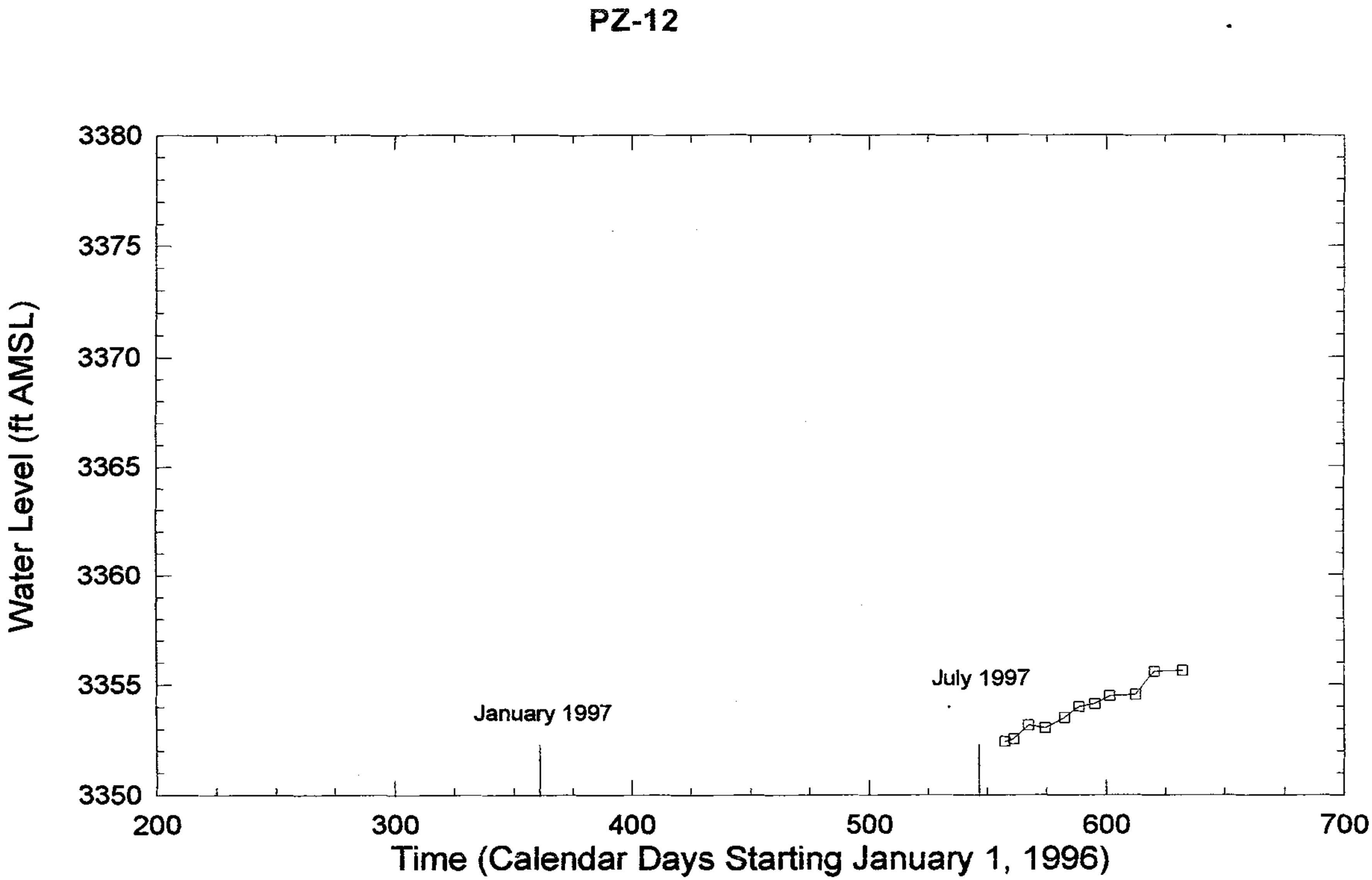


Figure 3.15. Water-level versus time for piezometer PZ-12.

Table 3.2 Specific conductance measurements for wells C-2505, C-2506, C-2507, and piezometers 1-12

DATE	PIEZOMETERS	CONDUCTANCE µSmhos/cm
7-22-97	PZ-1	122,600
7-17-97	PZ-2	34,132
7-18-97	PZ-3	154,951
7-18-97	PZ-4	50,209
7-18-97	PZ-5	112,916
7-17-97	PZ-6	46,484
7-18-97	PZ-7	25,720
7/22/97	PZ-8	dry hole
7-22/97	PZ-9	78,500
7-21-97	PZ-10	3,700
7-21-97	PZ-11	43,093
7-21-97	PZ-12	5,260
7/16/97	C-2505	6,065
7-16-97	C-2506	11,265
7/16/97	C-2507	5,105

3.4 Well Development: Piezometers PZ-1, PZ-2, PZ-4, and PZ-9

Water-quality sampling in July 1997 for piezometers PZ-1, PZ-2, PZ-4 and PZ-9 yielded groundwater samples with an unacceptably high sediment load. The amount of sediment appeared to be such that water-quality analysis may have been biased by the dissolution of the sediment during sample-preservation procedures. In addition, the sediment indicates that the piezometers had limited productivity at that time due to fine material in the filter pack. Therefore, on August 11 the four piezometers were bailed to remove sediment and to develop the piezometers in order to improve production.

3.5 Hydraulic Testing

The addition of piezometers PA-1 to PZ-12 provided an opportunity to expand the formation hydraulic conductivity data base to an area larger than the immediate vicinity of the Exhaust Shaft. More widely distributed permeability data will allow the development of a more representative numerical model to predict system responses to a variety of stresses. Formation parameter estimates for PZ-1, PZ-2, PZ-4, PZ-5, PZ-6, PZ-7, PZ-10, PZ-11, and PZ-12 were obtained by conducting pumping tests or slug test between August 21 and September 12, 1997. In addition, a pumping test was performed on well C-2507 on September 5, 1997 to complete characterization of the hydrology in the southeastern portion

of the WIPP site. Estimates of hydraulic conductivity (K) were developed from drawdown and recovery data from all of these locations. Because estimates of storage/specific yield are uncertain when derived from single well tests, this parameter was not reported for any of these tests.

Figures 3.16 through 3.25 present the pressure versus time data from each of the respective tests conducted during this most recent testing campaign. Figures representing the testing conducted on monitor wells C-2505 and C-2506 have been presented in *Exhaust Shaft Data Report: 72-Hour Pumping Test on C-2506 and 24-Hour Pumping Test on C-2505* (May 1997). The methodology used to estimate the hydraulic conductivity for each of the locations has been previously described in DOE (January 1997) and *Exhaust Shaft Data Report: 72-Hour Pumping Test on C-2506 and 24-Hour Pumping Test on C-2505* (May 1997).

Table 3.3 presents hydraulic conductivity estimates for each of the monitor wells/piezometers that have been tested to date.

Table 3.3 Hydraulic Conductivity Estimates

Well/Piezometer	Hydraulic Conductivity (m/s)
C-2505	7.80e-6
C-2506	1.99e-5
C-2507	5.88e-6
PZ-1	5.70e-8
PZ-2	2.64e-8
PZ-3	no value *
PZ-4	2.42e-6
PZ-5	1.39e-7
PZ-6	3.75e-6
PZ-7	1.73e-6
PZ-8	dry hole
PZ-9	no value *
PZ-10	5.17e-6
PZ-11	3.28e-6
PZ-12	2.11e-5

* Hydraulic conductivity too low to perform pumping test

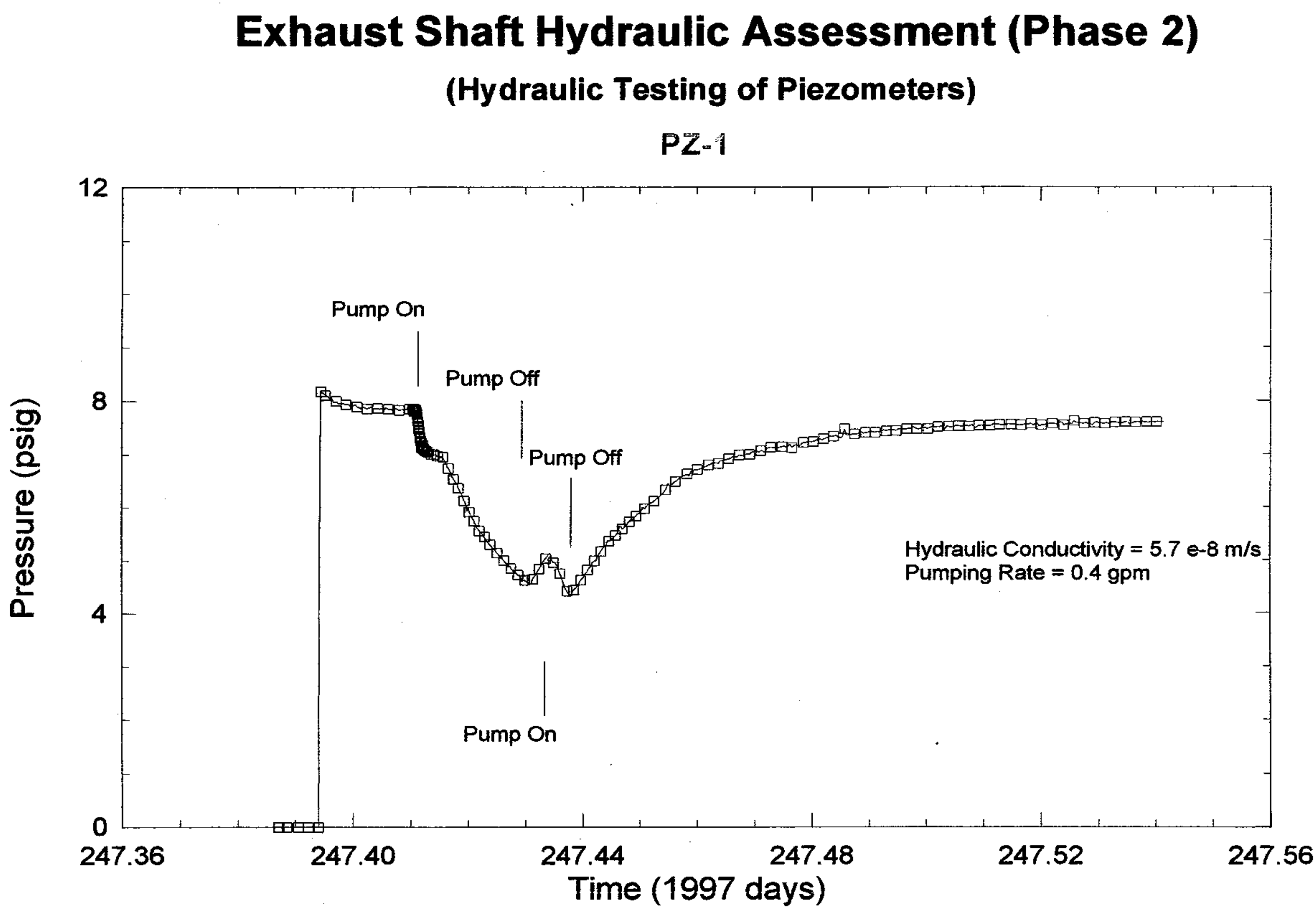


Figure 3.16. Piezometer PZ-1 pressure response to pumping

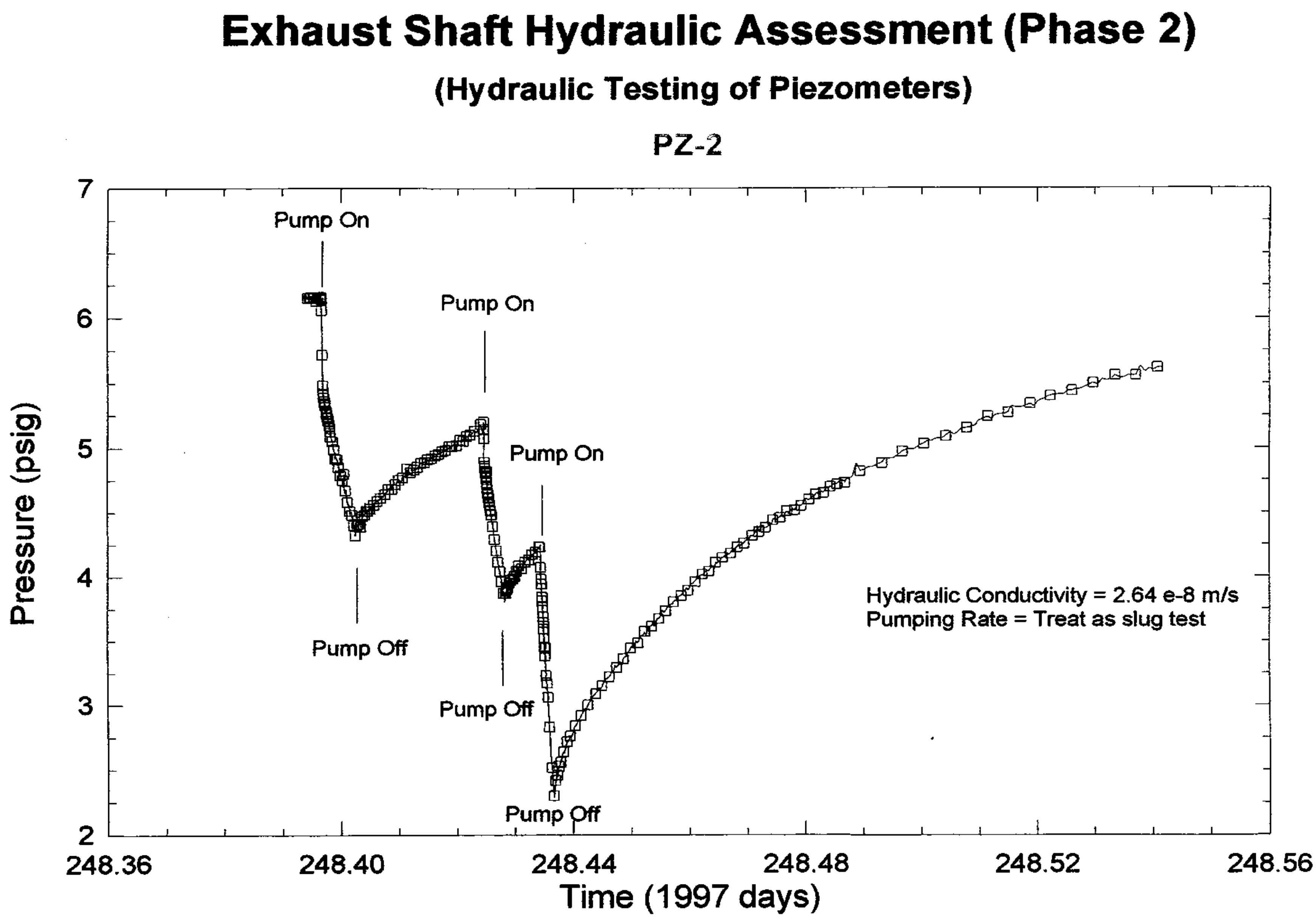


Figure 3.17. Piezometer PZ-2 pressure response to pumping

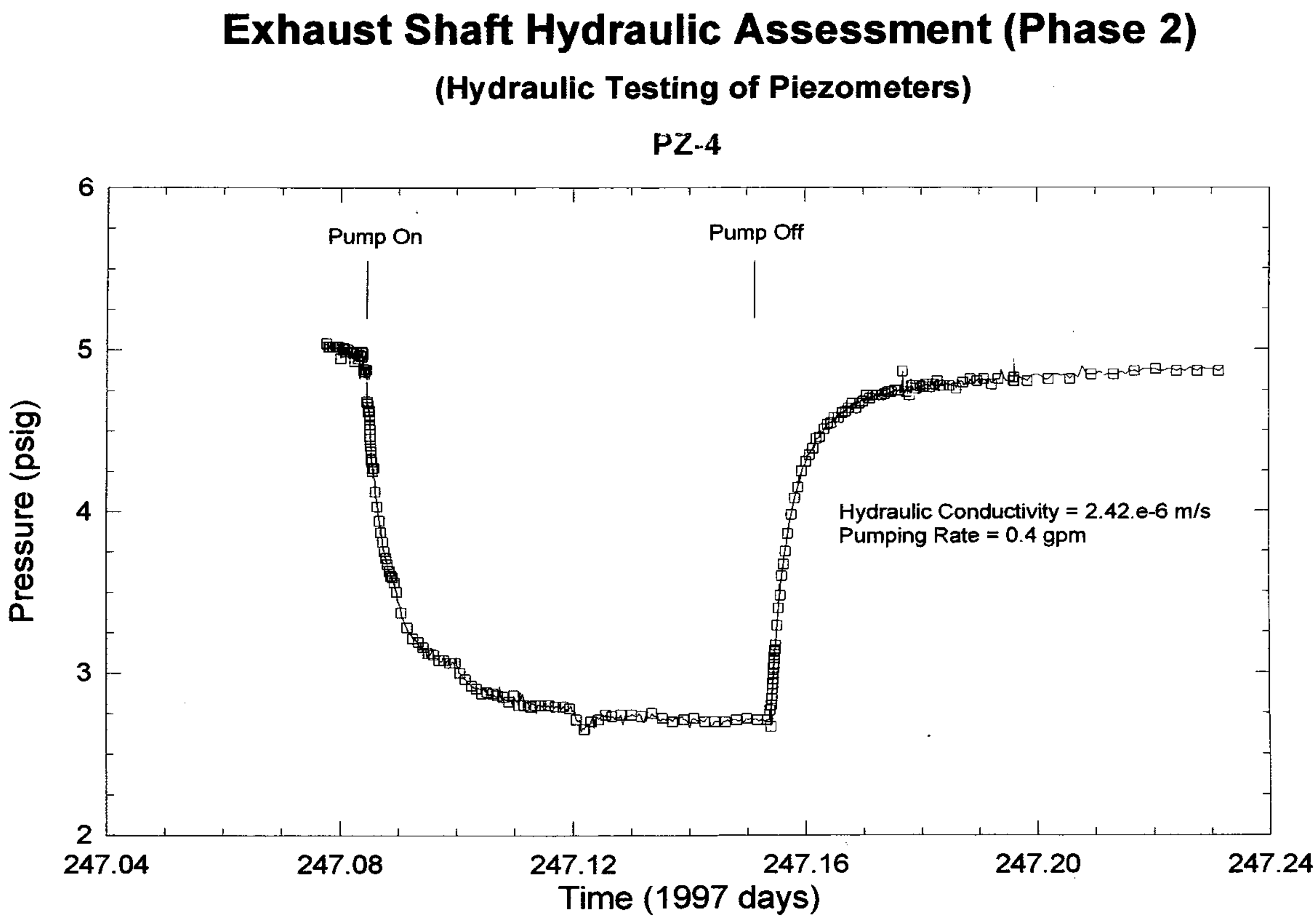


Figure 3.18. Piezometer PZ-4 pressure response to pumping

Exhaust Shaft Hydraulic Assessment (Phase 2)

(Hydraulic Testing of Piezometers)

PZ-5

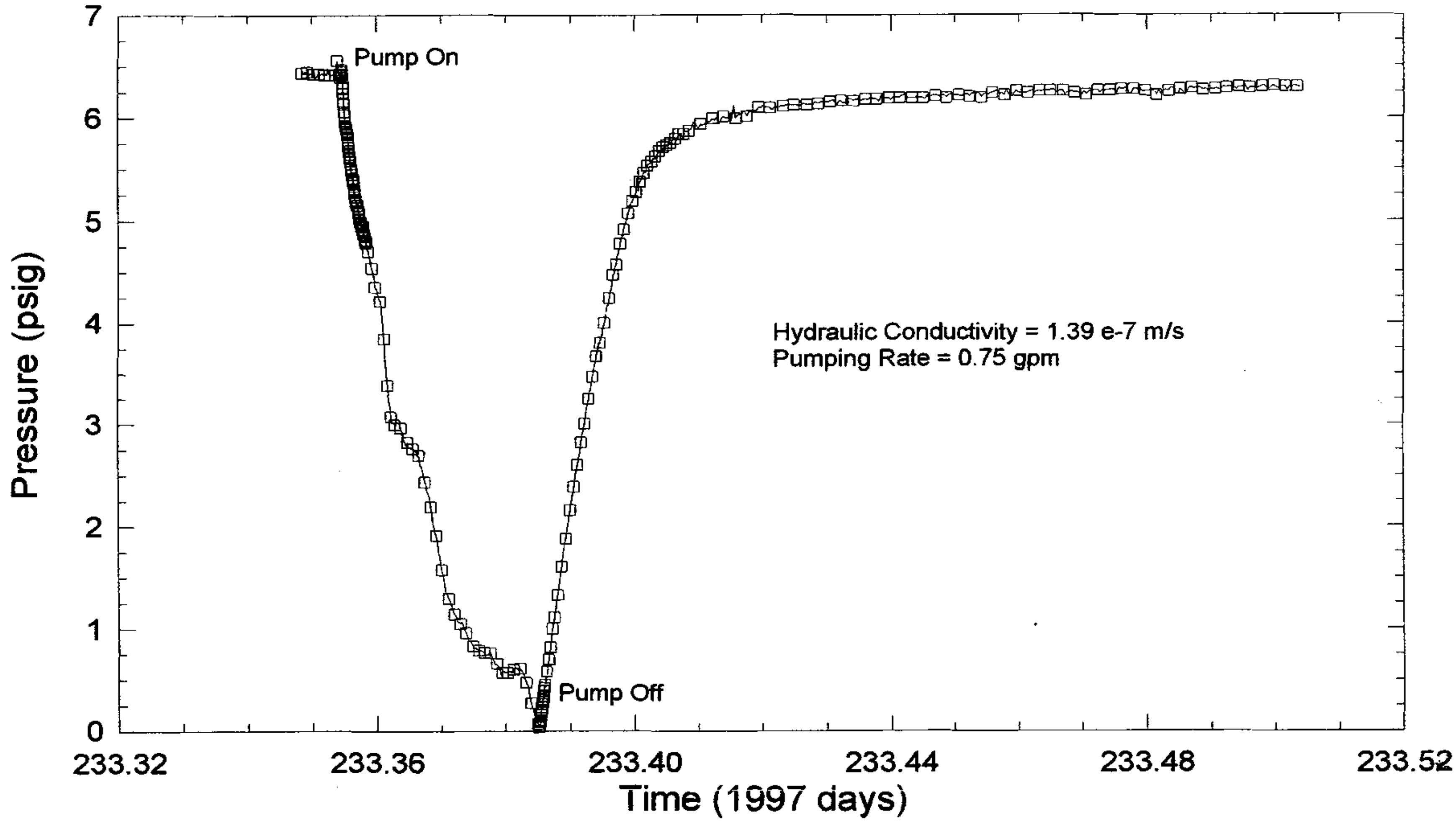


Figure 3.19. Piezometer PZ-5 pressure response to pumping

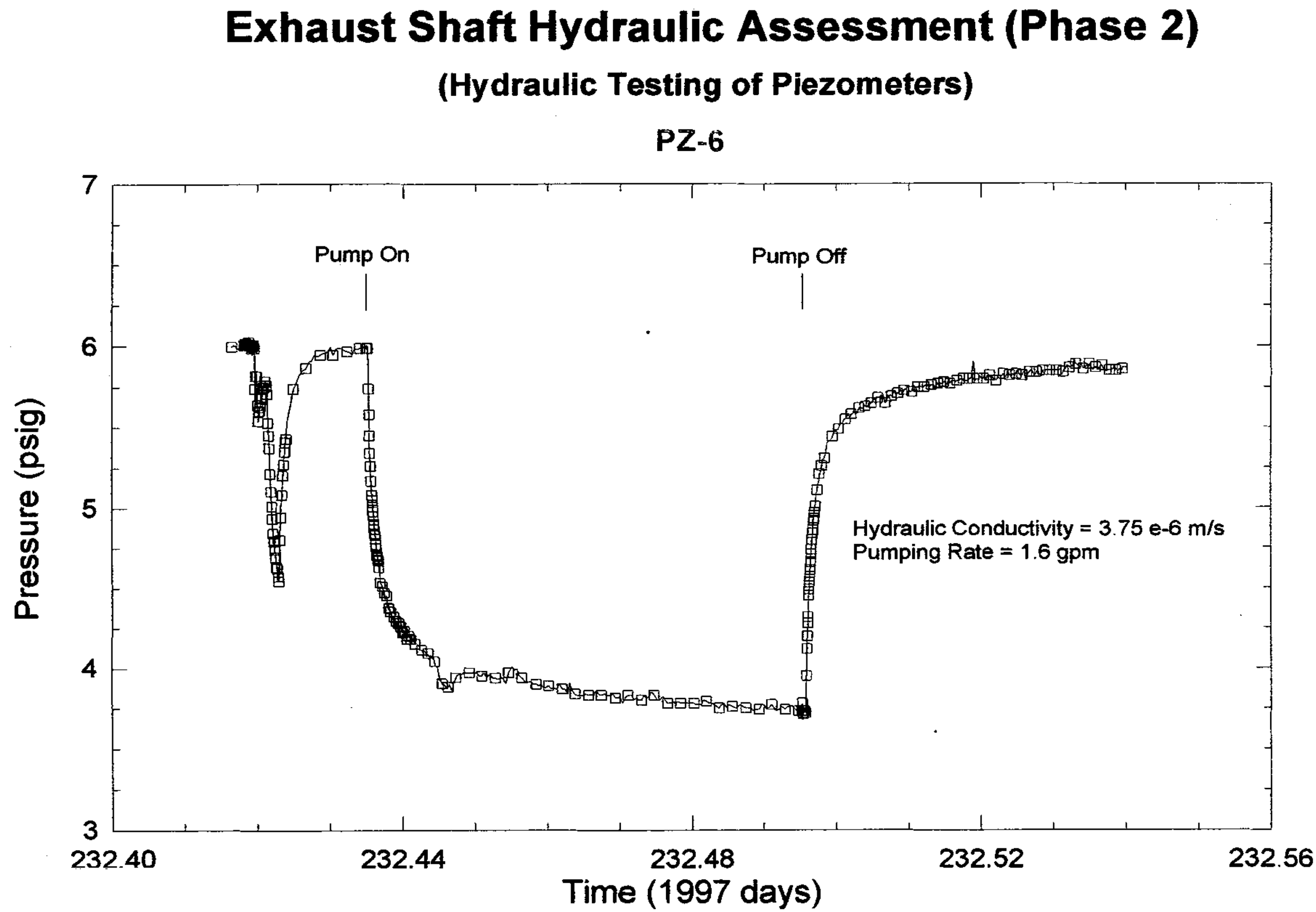


Figure 3.20. Piezometer PZ-6 pressure response to pumping

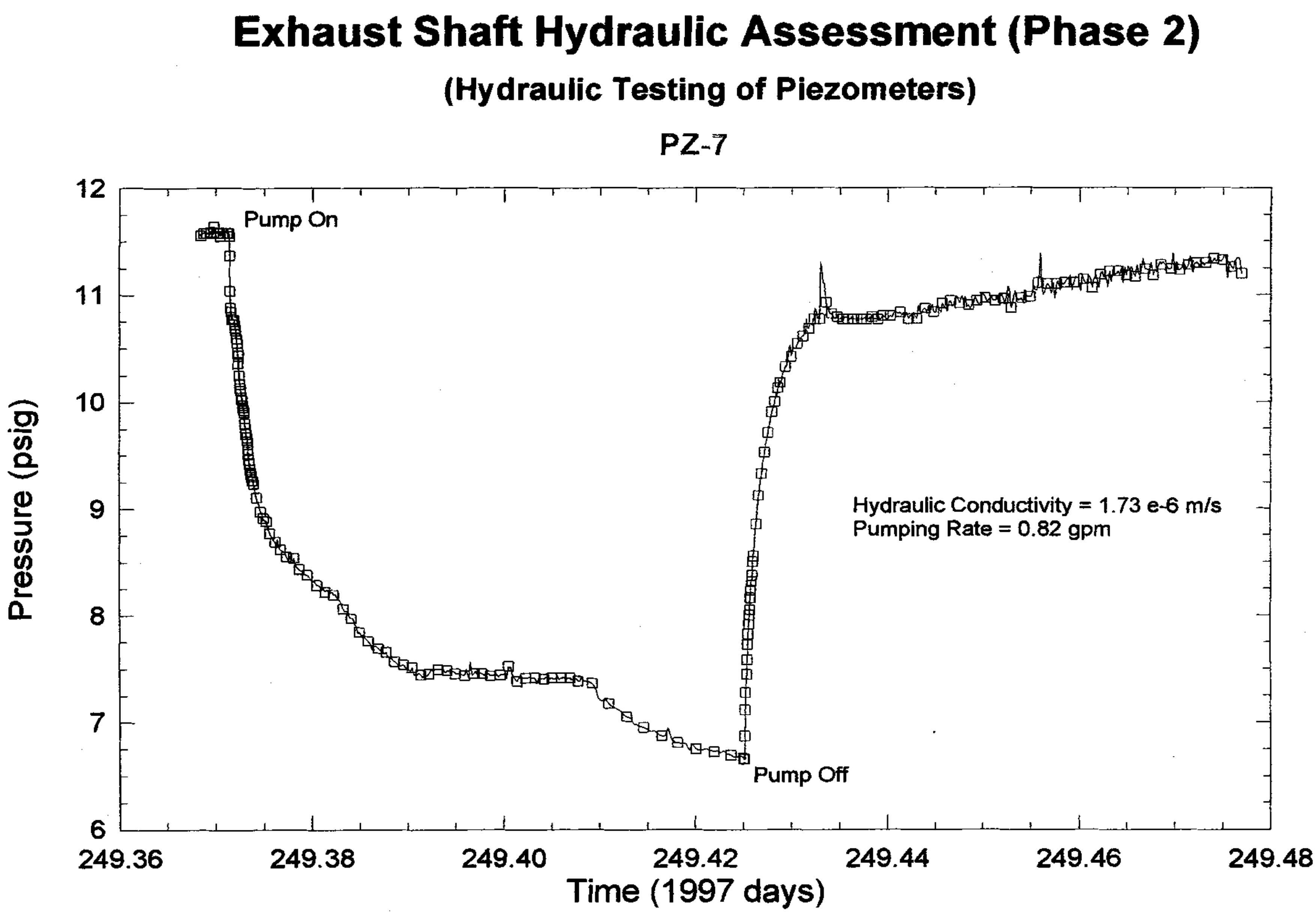


Figure 3.21. Piezometer PZ-7 pressure response to pumping

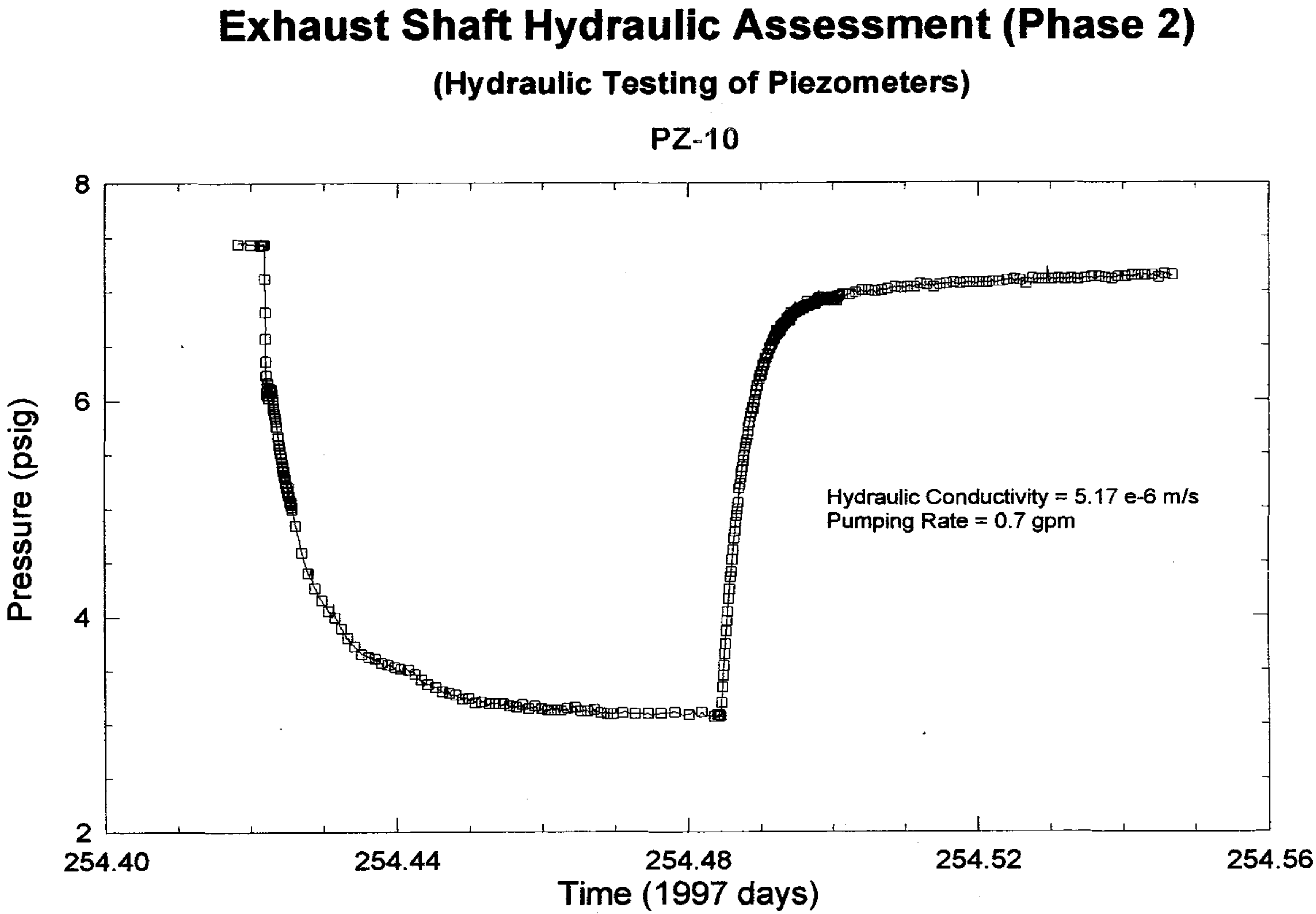


Figure 3.22. Piezometer PZ-10 pressure response to pumping

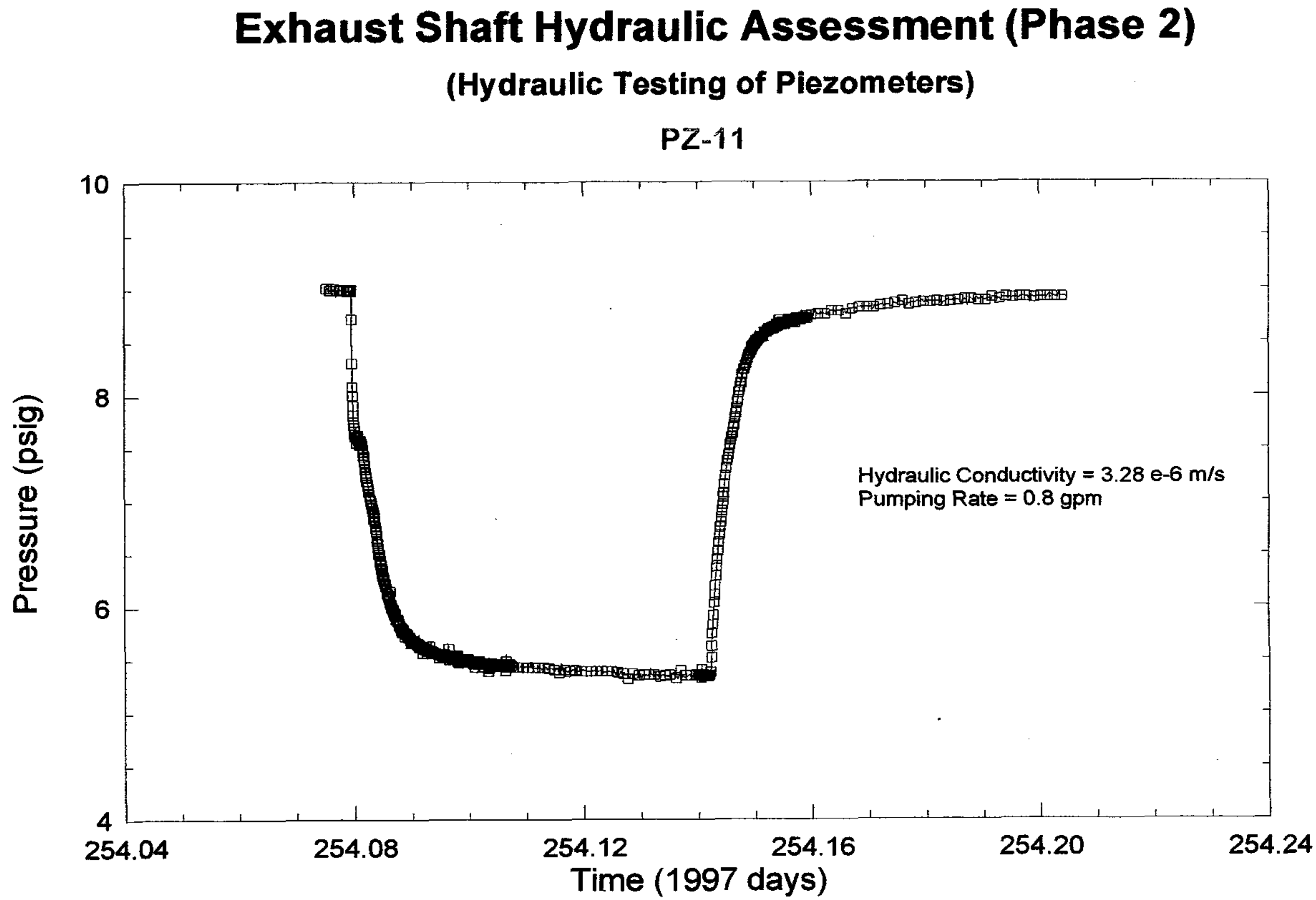


Figure 3.23. Piezometer PZ-11 pressure response to pumping

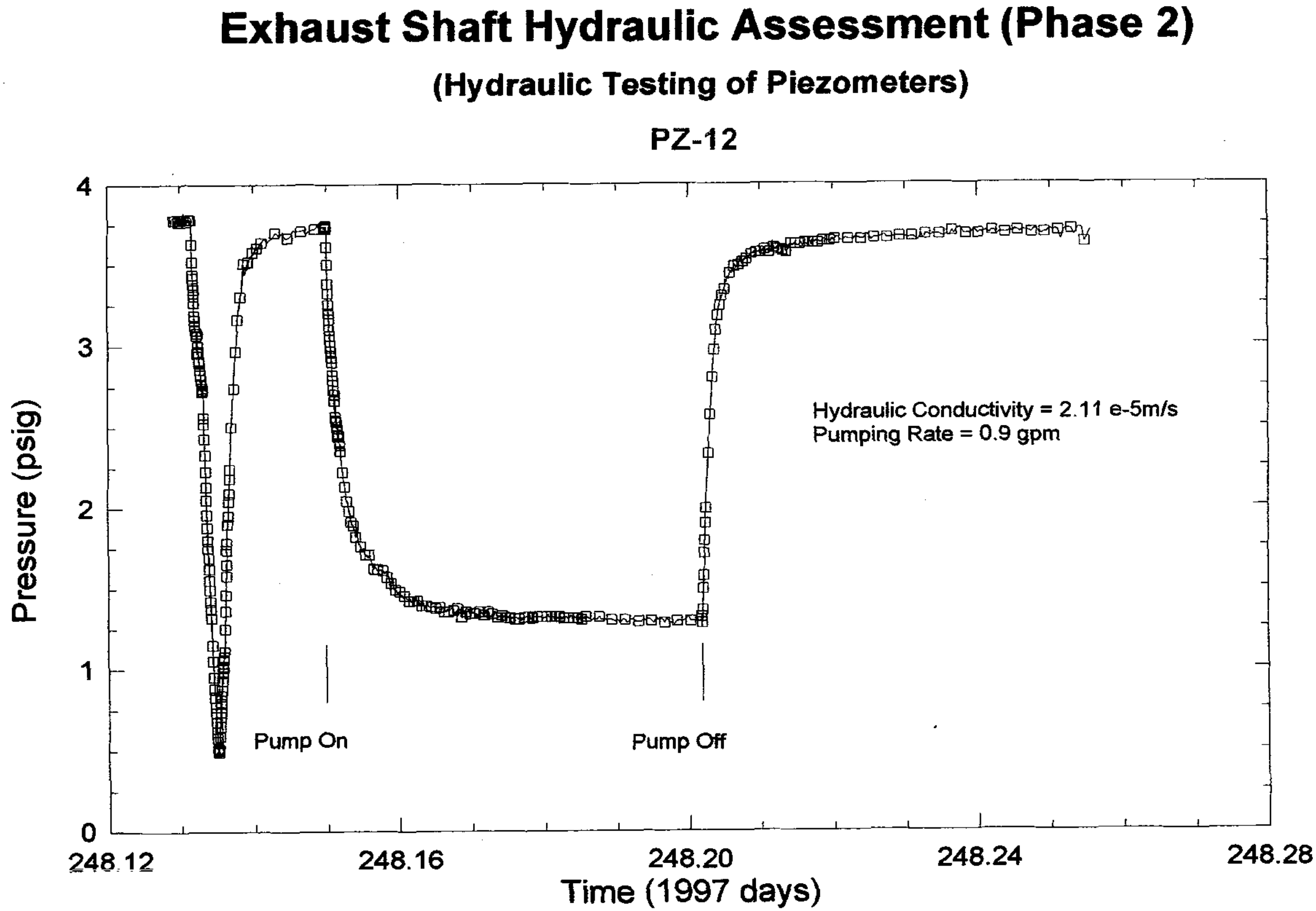


Figure 3.24. Piezometer PZ-12 pressure response to pumping

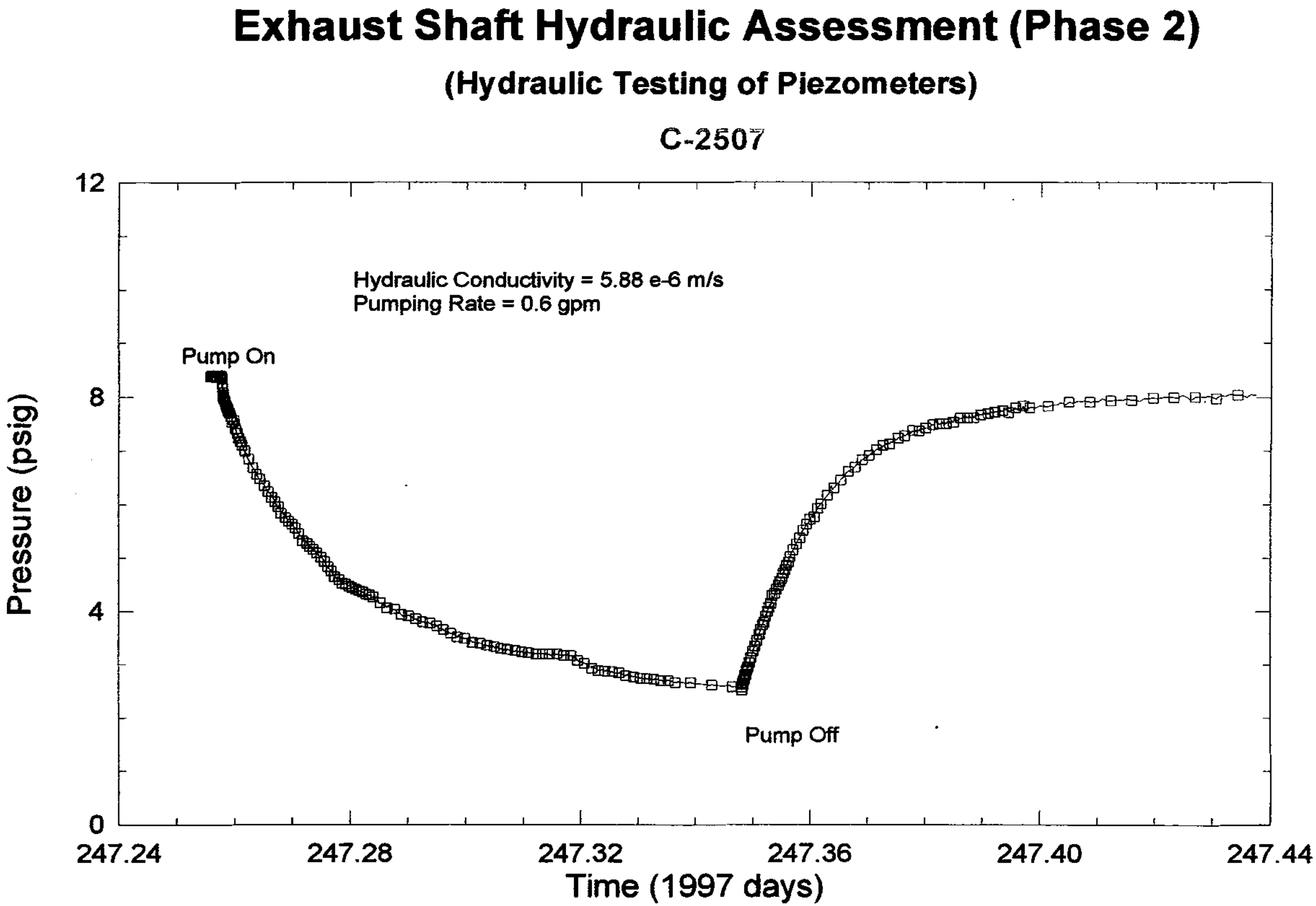


Figure 3.25. Monitor well C-2507 pressure response to pumping

3.6 Dewey Lake, Rustler, and Salado Formation Behavior in the Exhaust Shaft

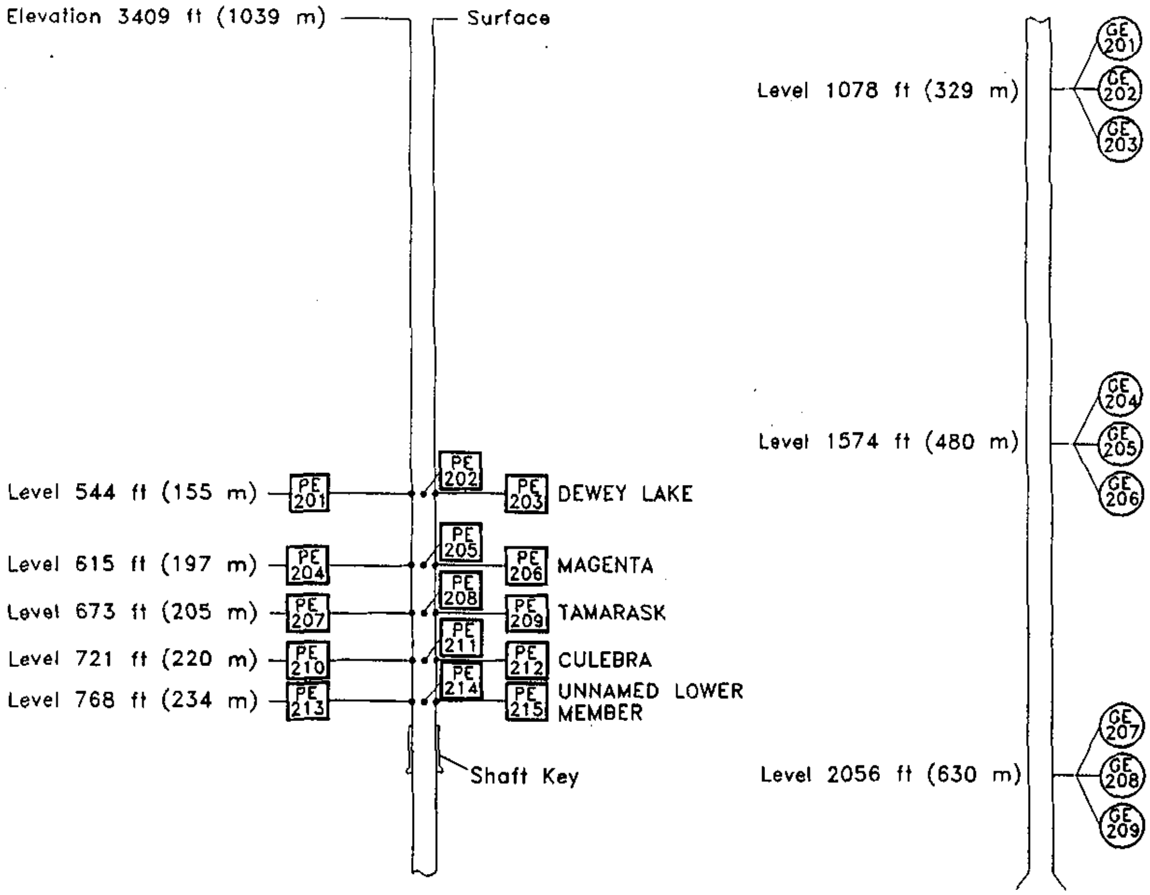
The Exhaust Shaft was drilled and lined between 1983 and 1985. During that time, site investigations did not report the presence of groundwater within 195 feet of the surface. During sinking and mapping of the Exhaust Shaft the shallowest fluid production noted was from the Magenta and the Culebra dolomites. Both aquifers were instrumented with piezometers to monitor hydraulic heads. In addition, the Dewey Lake, the Forty-niner, the Tamarisk and the unnamed member of the Rustler Formation were also instrumented with piezometers as well as the contact between the Rustler/Salado Formations to monitor the hydraulic heads in those stratigraphic units. Figure 3.26 provides the location and depth of the gauges located in the Exhaust Shaft in feet and meters below the top of the collar.

Figures 3.27 - 3.33 are linear plots of the fluid pressure expressed in pounds-per-square inch (psi) versus time in calendar years (years) for the gauges monitoring the Dewey Lake Formation, the Forty-niner member, the Magenta member, the Tamarisk member, the Culebra member, and the unnamed member of the Rustler Formation and the contact between the Rustler/Salado Formations.

3.7 WIPP Site Precipitation

Figure 3.34 is a plot of precipitation versus time from a climatological monitoring station located at the WIPP Site for the period extending from August 1 1996 - August 31, 1997. Long-term precipitation data may be useful in evaluating infiltration. Figure 3.34 shows that there was significant rainfall between June-July 1996 and June-August 1997.

EXHAUST SHAFT



NOTES

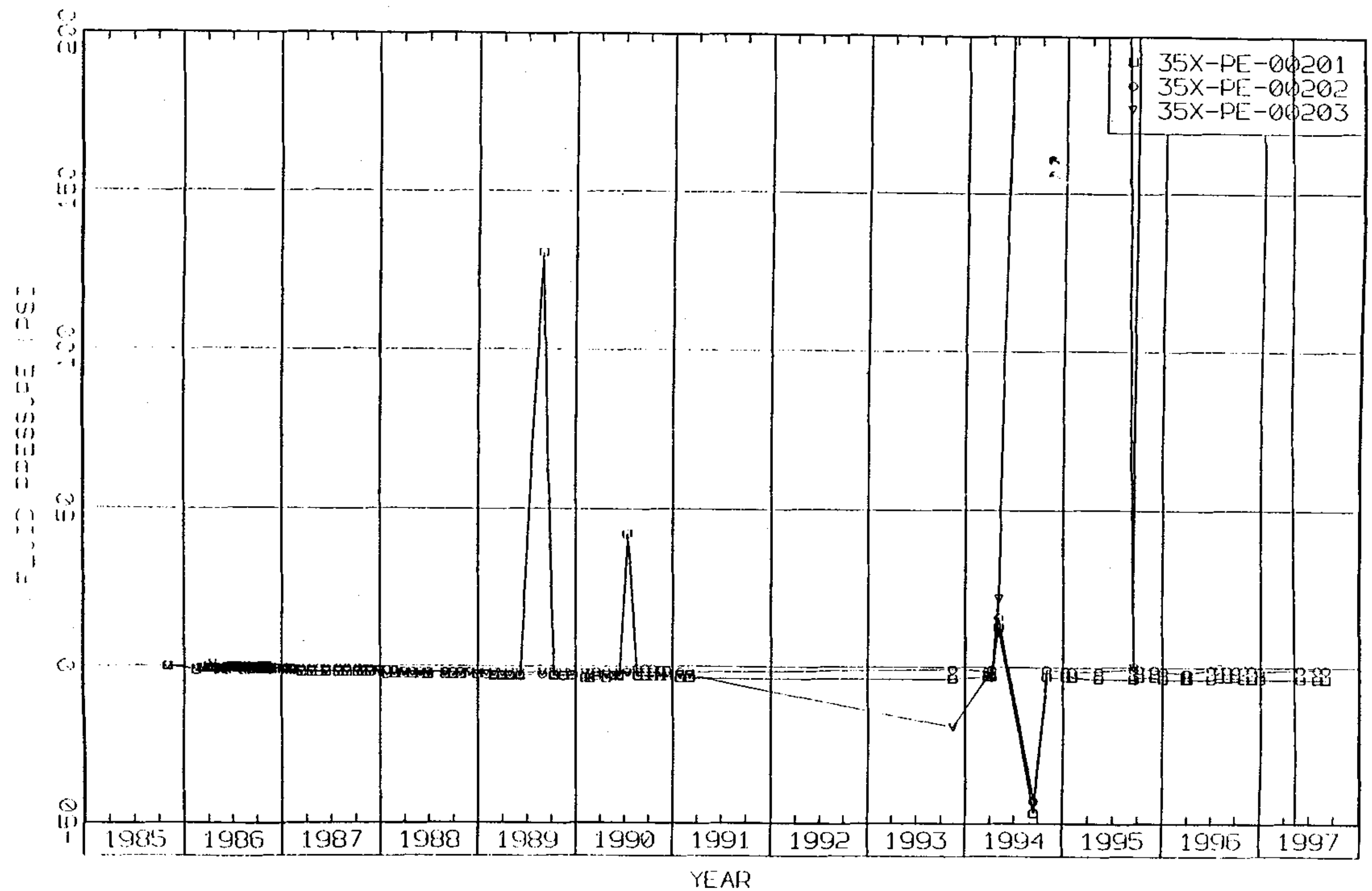
1. The term "level" is an approximate depth from the shaft collar at elevation 3409 ft (1039 m) above MSL.
2. Piezometers and extensometers are orientated at N75°E, N45°w and S15°W.
3. Not to scale.

LEGEND

PE Piezometer

GE Extensometer

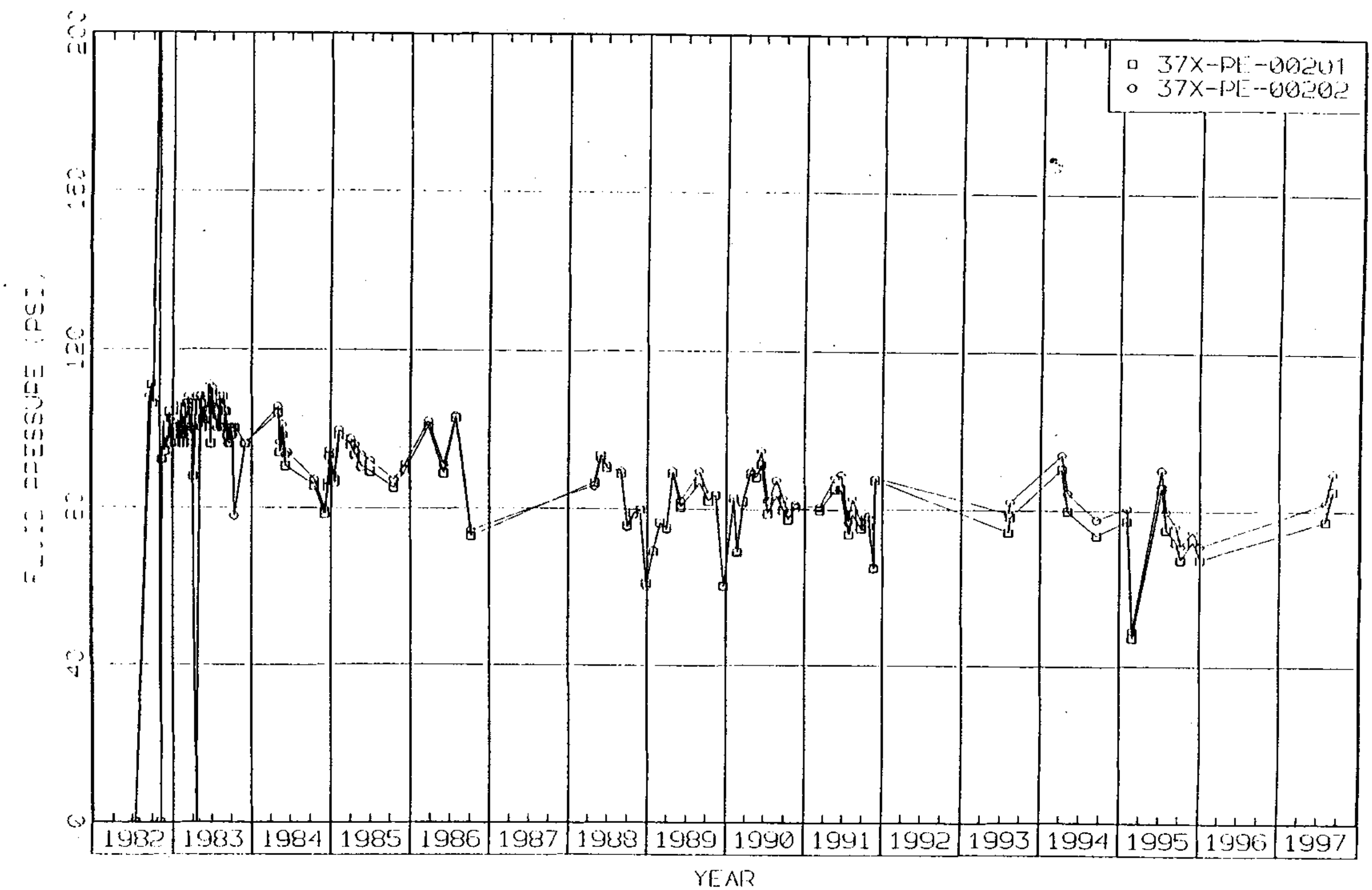
Duke Engineering & Services	Figure 3.26 Exhaust Shaft Instrumentation	DATE: 12/11/97 REF: JBP/EXSHAFT REV: A



NOTES:
1. EXCAVATION DATE: OCTOBER 1984.

FIGURE 2-39
PIEZOMETERS
EXHAUST SHAFT-LEVEL 544'
BASE OF DEWEY LAKE REDBEDS

Figure 3.27 Piezometer Pressures In Dewey Lake Formation Located in the Exhaust Shaft



NOTES:
1. STEEL LINER WAS INSTALLED IN NOVEMBER AND DECEMBER 1981.

FIGURE 2-9
PIEZOMETERS
SALT HANDLING SHAFT-LEVEL 580'
FORTY-NINER MEMBER

Figure 3.28 Piezometer Pressures in the Forty-Niner Member of the Rustler Formation Located in the Exhaust Shaft

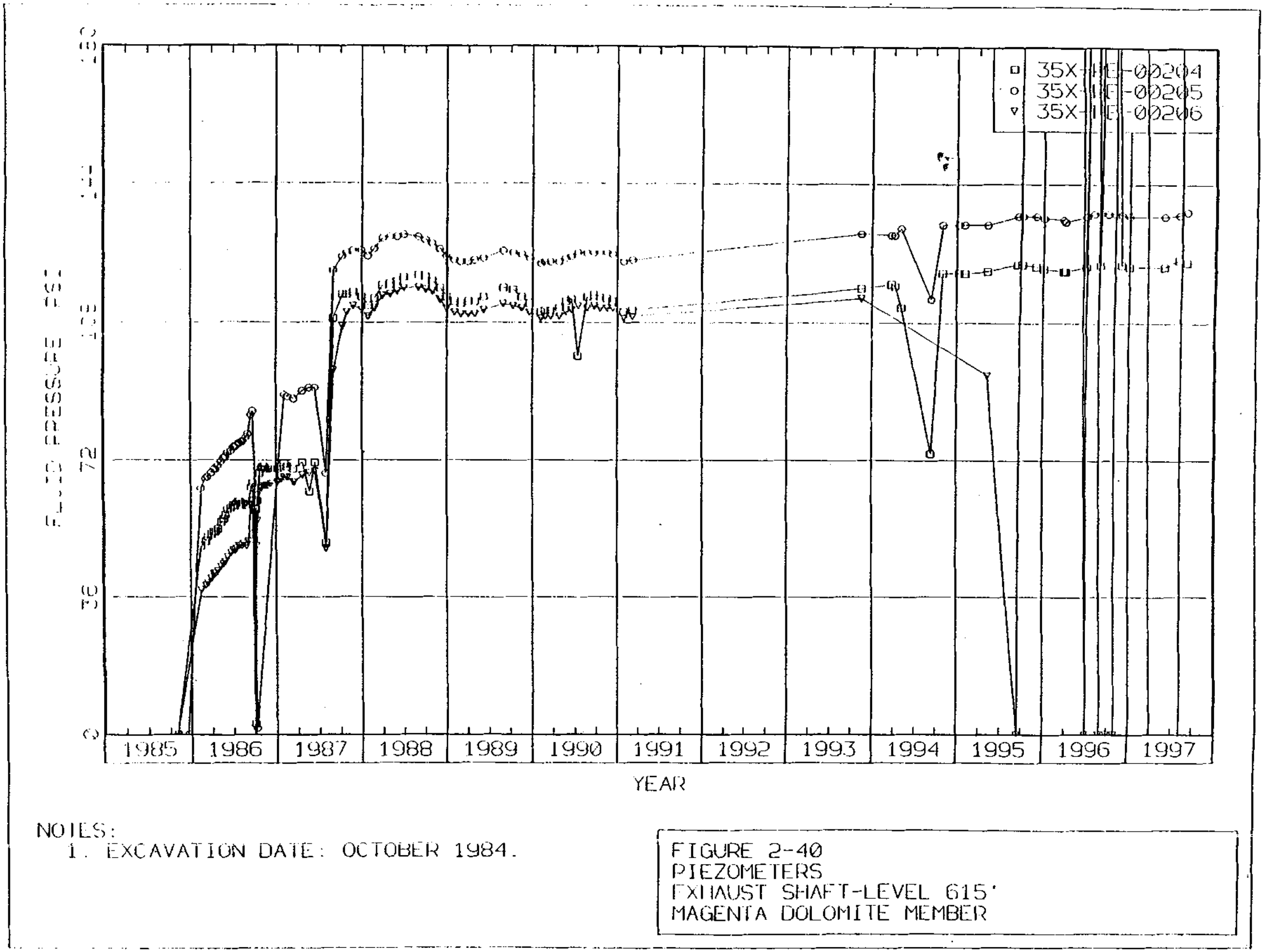


Figure 3.29 Piezometer Pressures in Magenta Dolomite Member of the Rustler Formation Located in the Exhaust Shaft

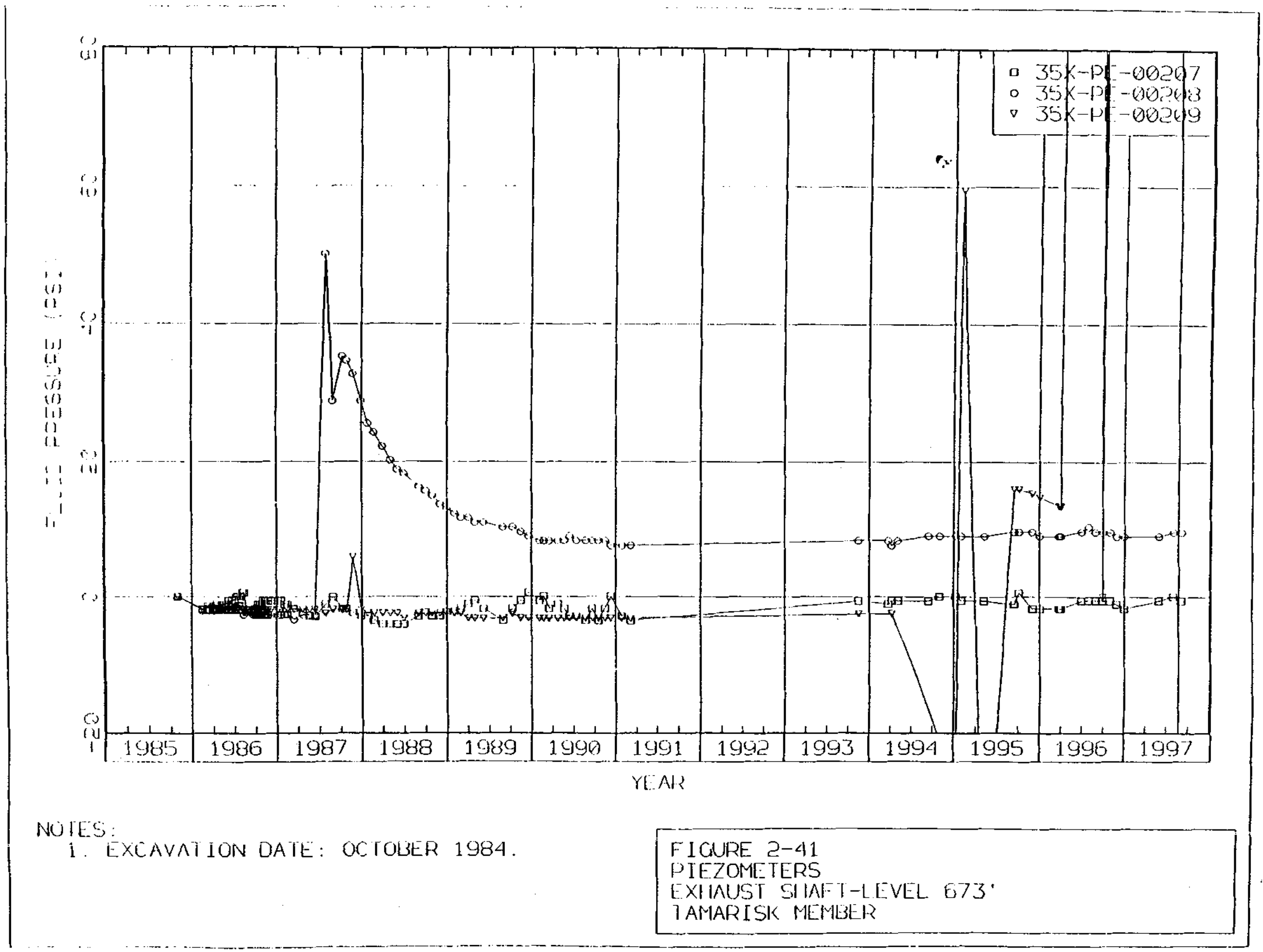
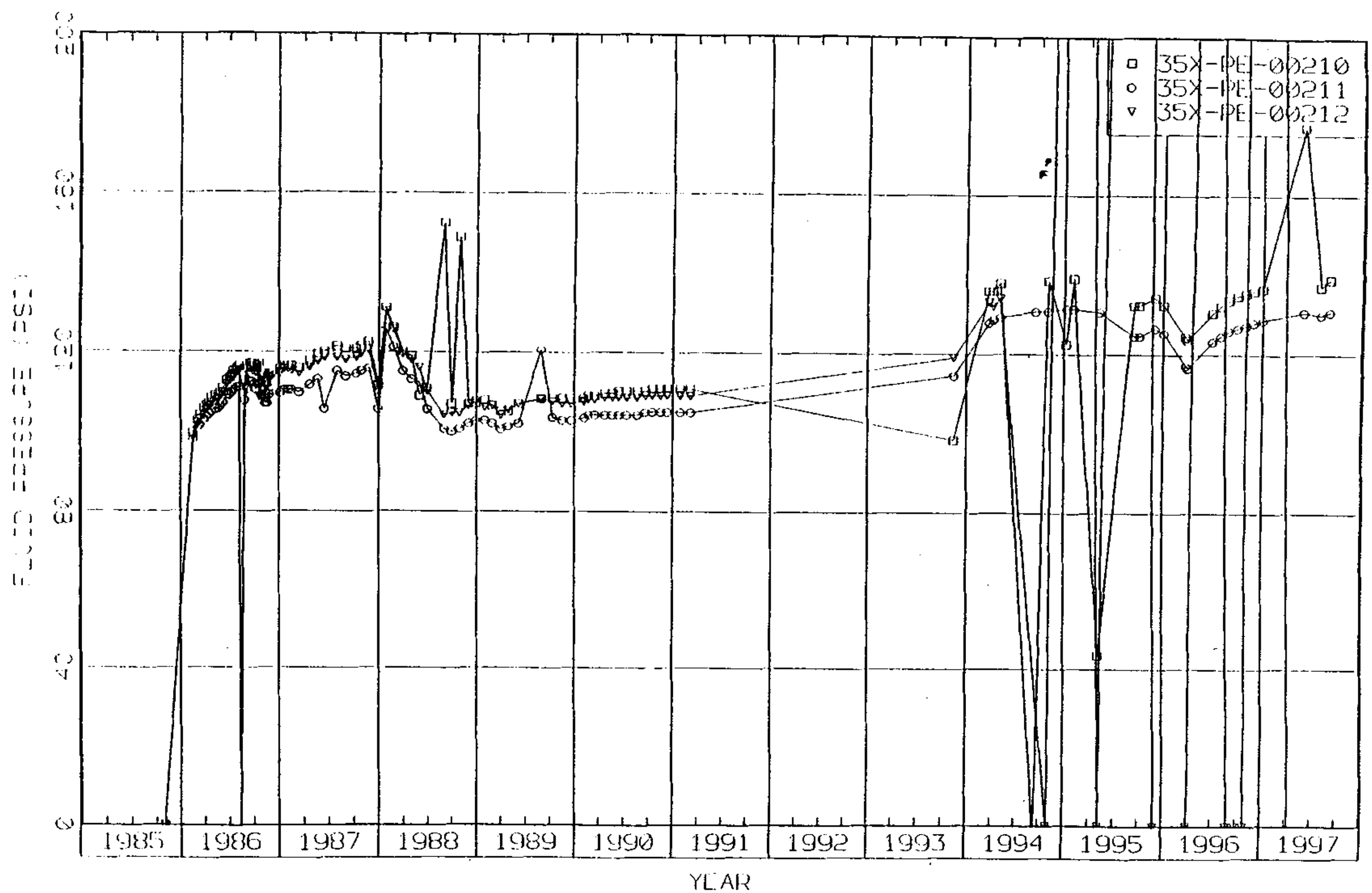


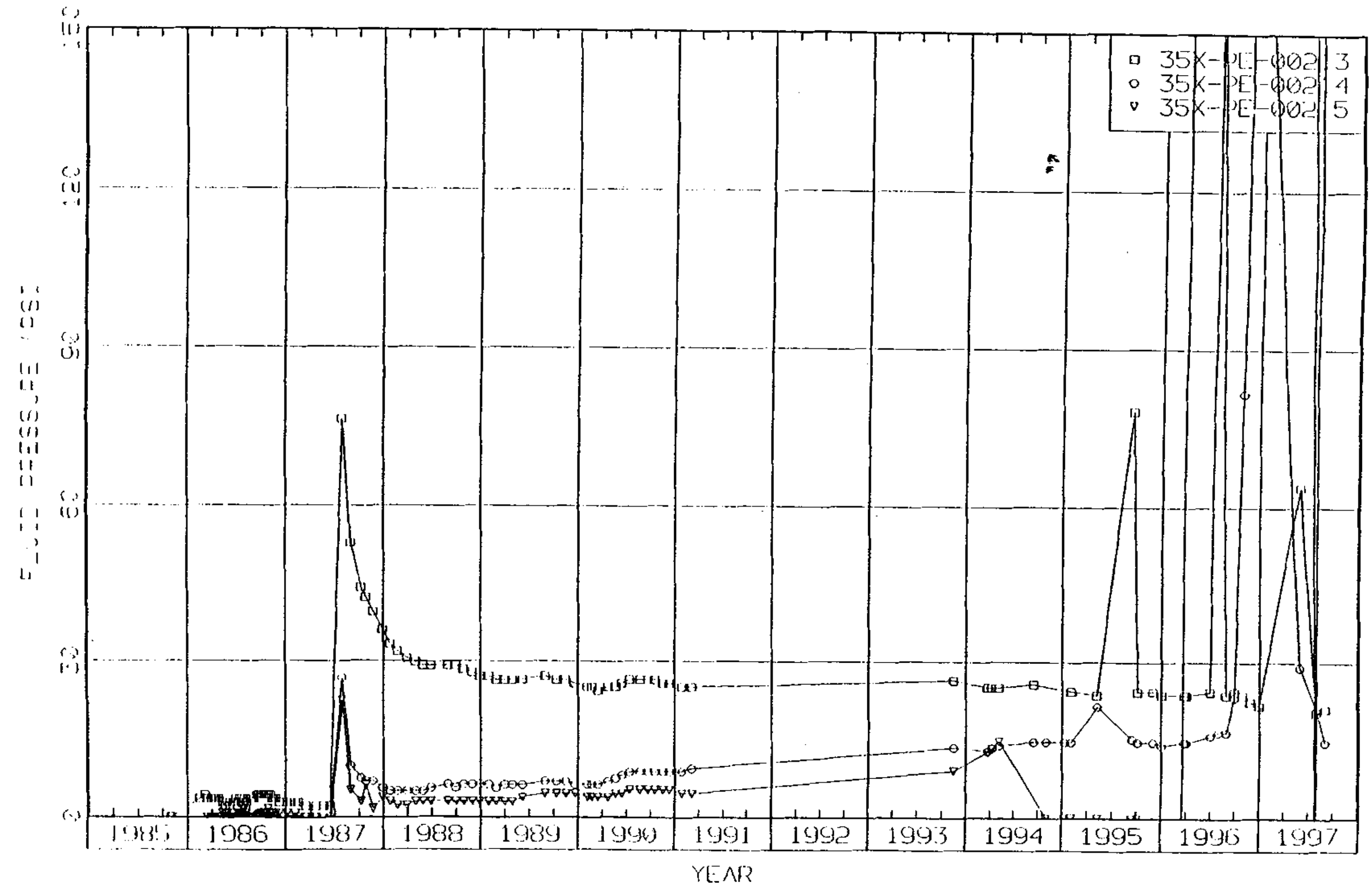
Figure 3.30 **Piezometer Pressures in Tamarisk Member of the Rusiter Formation Located in the Exhaust Shaft**



NOTES:
1. EXCAVATION DATE: OCTOBER 1984.

FIGURE 2-42
PIEZOMETERS
EXHAUST SHAFT-LEVEL 721'
CULEBRA DOLOMITE MEMBER

Figure 3.31 **Piezometer Pressures in Culebra Dolomite Member of the Rustler Formation Located in the Exhaust Shaft**



NOTES:
1. EXCAVATION DATE: NOVEMBER 1984.

FIGURE 2-43
PIEZOMETERS
EXHAUST SHAFT-LEVEL 768'
UNNAMED LOWER MEMBER

Figure 3.32 Piezometer Pressures in Unnamed Member of the Rustler Formation Located in the Exhaust Shaft

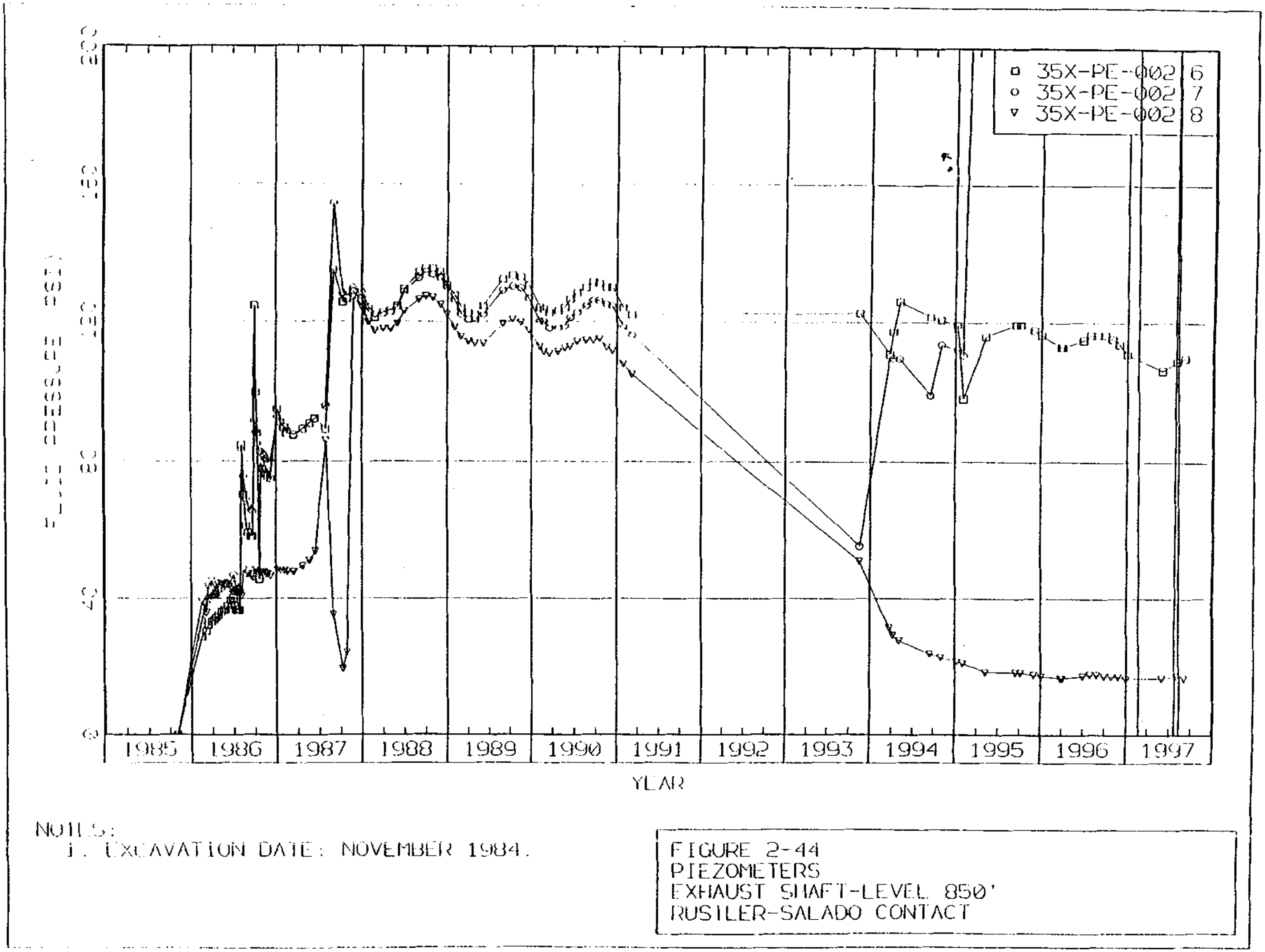


Figure 3.33 Piezometer Pressures at the Contact of the Rustler/ Salado Formations

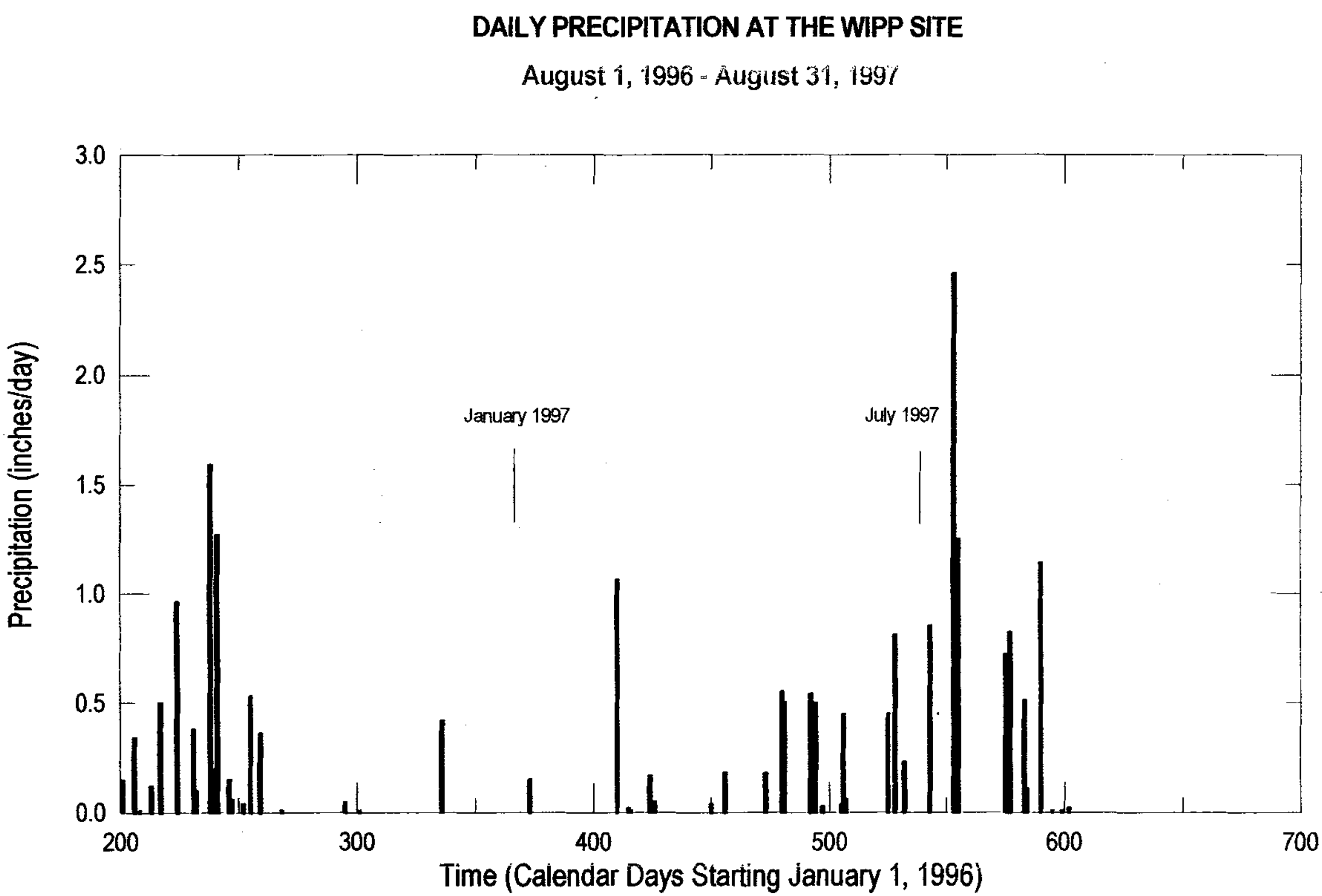


Figure 3.34 Daily Precipitation at WIPP Site

4.0 DISCUSSION

4.1 Hydrostratigraphy

Examination of core and drill cuttings from the 12 piezometer boreholes indicate that there is a water-bearing horizon in the Santa Rosa Formation perched on top of the less permeable Dewey Lake Formation. Water was found present in 11 of the 12 piezometer boreholes. In addition, the presence of water in the Santa Rosa is limited in areal extent as indicated by the absence of water in PZ-8 located 1/4 mile east of the WIPP Site Secured Area. Figure 4.1 is 3-dimensional contour plot showing the top of the Dewey Lake Formation. Though the data is limited, there is clearly an identified structural feature within the Dewey Lake Formation, which includes a trough dipping to the southwest, and a semicircular ridge in the southern portion of the site separating a second trough to the north.

4.2 Hydrology

4.2.1 Hydraulic Gradient

In addition to the 3-dimensional contour plot in Figure 4.1, Figure 4.2 is a 2-dimensional water-level elevation map based on water-level data collected from wells C-2505, C-2506, C-2507 and piezometers 1-12. The map indicates that there is a water-level high located northwest of the WIPP site near PZ-7. There is also another slight water-level high near PZ-5. The water-level map indicates that the hydraulic gradient or direction of flow varies across the site. In the northern portion of the WIPP Site the gradient is west to east. In the southern portion of the site the gradient is northwest to south and southeast. The absence of water in PZ-8 maybe due to an apparent saturation front located somewhere west of PZ-8. The perched water zone indicated that the occurrence of groundwater in other piezometers may be lensatic in nature (see 4.2.6)

4.2.2 Hydraulic Conductivity

Based on pumping tests and slug tests performed on wells C-2505, C-2506, and C-2507 and piezometers 1-12, hydraulic conductivity values across the site range from 2.11 e-5 to 5.7 e-8 m/s. Tests indicate that the maximum sustainable pumping rate is approximately 2.0 gpm at PZ-12. The minimum sustainable pumping rate is approximately 0.2 gpm at PZ-2. The average sustainable pumping rate for the wells and piezometers is about 0.6 gpm.

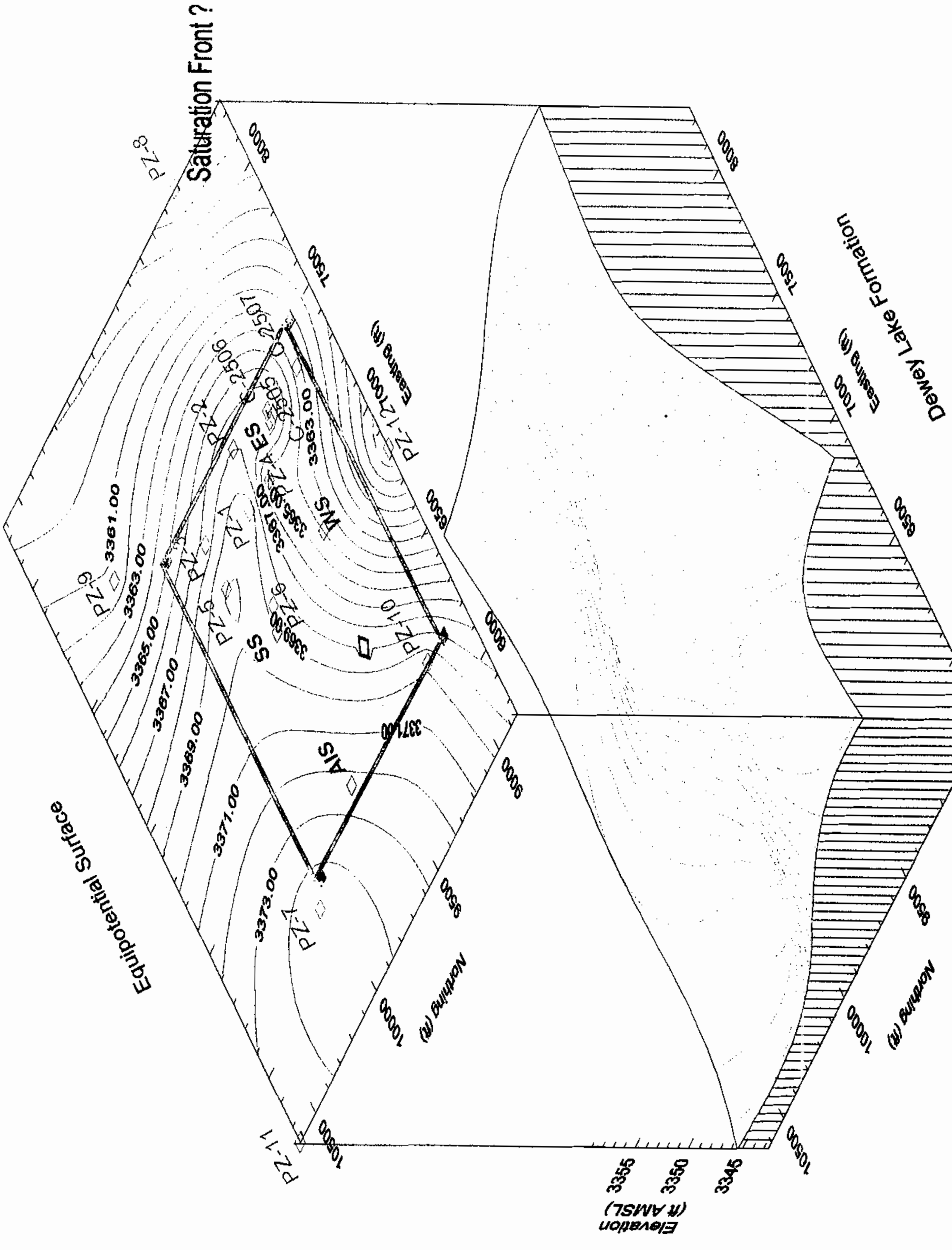


Figure 4.1 3-Dimensional representation of the water-bearing system

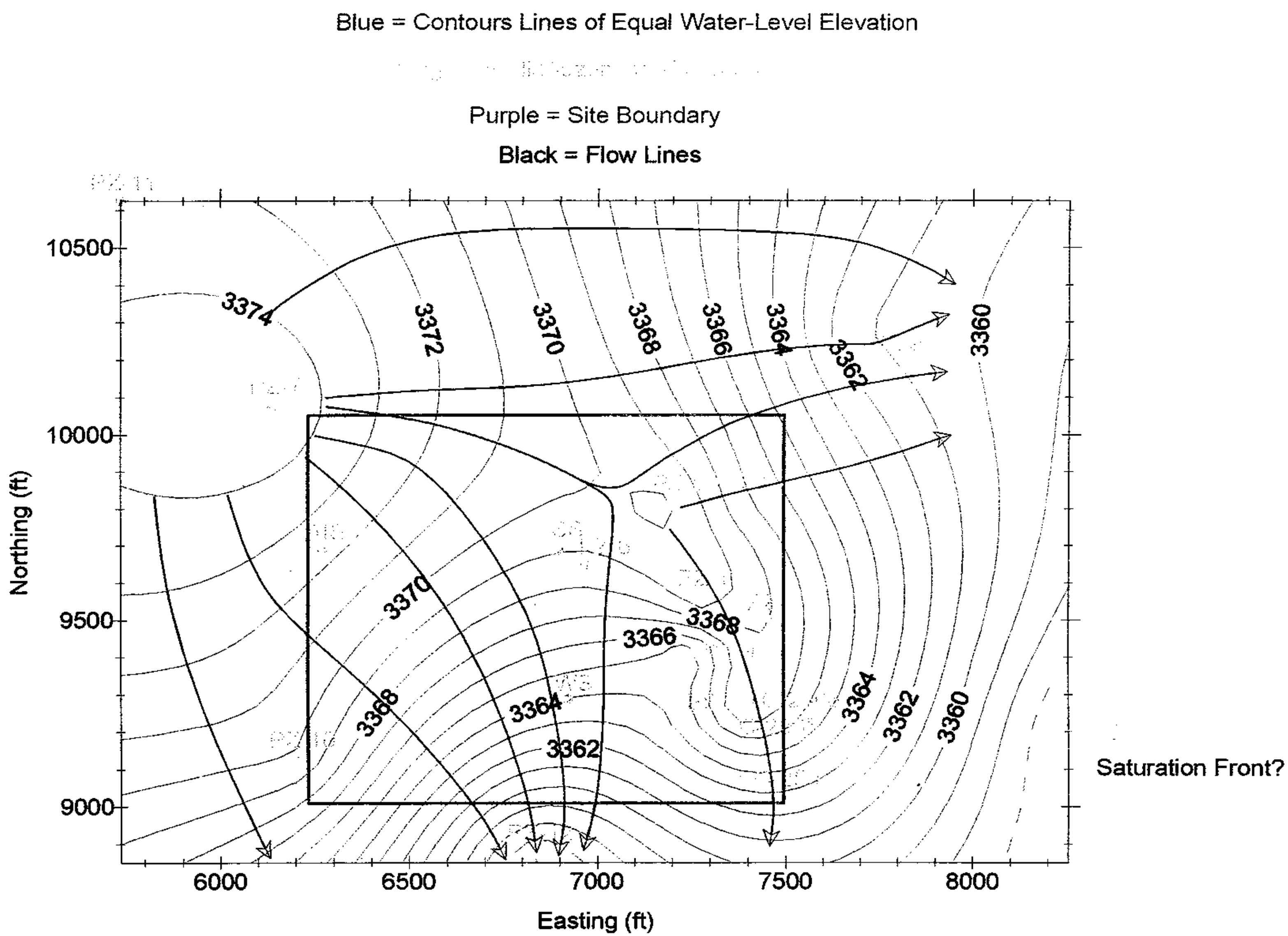


Figure 4.2 Equipotential surface in the vicinity of the WIPP Site

4.2.3 Santa Rosa Formation Hydrologic Parameters

In order to evaluate the hydrology of the Santa Rosa three parameters must be determined: the saturated area, the saturated thickness, and the porosity of the Santa Rosa Formation.

4.2.3.1 The Saturated Area of Investigation

Of the twelve piezometers and three wells installed at WIPP between September 1996 and August 1997, only PZ-8 is dry. In every other monitoring well water is present, indicating that the investigative area bounded by PZ-11 to the north and west, PZ-12 to the south, and PZ-9 to the east appears saturated with water (Figure 4.1). The area defined by those boundaries is approximately 80 acres in size. It is also likely that the saturated area is significantly larger than the present 80-acre investigative area, but in order to clearly define the areal extent of water within the Santa Rosa Formation additional boreholes would have to be drilled.

Another important factor is that because piezometer PZ-8 is dry, that there maybe a wetting front or saturation front moving away from some source point(s). Typically fluid will move down and through the higher permeable zones (sandstones) and saturating those horizons, followed by saturating the less permeable zones (siltstones and mudstones). These siltstones and mudstones may be discontinuous and/or fractured creating lenses upon which water will move around rather than through (lensatic nature). Slight changes in permeability, fracturing, and other properties will likely create lenses through which fluid will move preferentially.

4.2.3.2 The Saturated Thickness of the Santa Rosa Formation

During the drilling/coring of the twelve piezometers PZ 1-12 and three wells C-2505, C-2506 and C-2507 at WIPP, careful attention was paid in identifying the water bearing horizons within each borehole. In the drilling of C-2505, C-2506, and C-2507 water-bearing horizons appeared associated with unconsolidated greenish-gray sandstones. These alterated sandstones varied in thickness ranging from 0.3 to 1.8 feet or more. These sandstones were sandwiched between relatively dry or less than saturated siltstones and mudstones indicating that fractures and/or bedding planes may play a role in transporting fluid from the surface through the Santa Rosa Formation.

In drilling of the piezometer boreholes, delineating the fluid producing horizons was more difficult as most of the boreholes were drilled with air and no core was collected. The stratigraphy was based on description of drill cuttings, therefore once a fluid-producing horizon was intercepted the remaining drill cuttings were always mixed with fluid making it more difficult to delineate which stratagraphic units within the Santa Rosa were contributing fluid and which ones were not. In addition, these stratigraphic units are somewhat variable within the Santa Rosa Formation across the WIPP site. In other words, fluid may migrate downward from the surface by the force of gravity around discontinuous lenses of lower permeability siltstones and mudstones through higher permeability sandstones. Therefore estimates of the saturated thickness of the Santa Rosa made without a clearer understanding of the heterogeneity within the Santa Rosa may be unrealistic and subjective.

4.2.3.3 Porosity

Porosity is the ration of the volume of the void spaces in the soil or rock to the total volume of the soil or rock, In addition, there are two different types of porosity. There is primary porosity, which is due to the soil or rock matrix, and secondary porosity, which may be due to such phenomena as secondary solution or structurally controlled regional fracturing. The Santa Rosa Formation appears to have both primary and secondary porosity. There are clearly porous unconsolidated sandstones within the Santa Rosa that transmit significant quantities of water. On the other hand, there are also well consolidated low-permeability siltstones and mudstones in the Santa Rosa that do not transmit significant quantities of water. Some core samples contained fractures indicating that fracturing may be a secondary source for fluid flow within and between more porous units. Because there are no laboratory analysis of the core samples, there are no estimates of porosity of the perched horizons beneath the WIPP site.

4.2.3.4 Fluid Volume Calculations

Estimates of the volume of fluid present in the Santa Rosa can be made to provide information on what it would take to pump, control or remove the water from the perching horizons beneath the WIPP site. However, sections indicate 4.2.3.1-4.2.3.3 that there is a great degree of variability in the estimated area and saturated thickness, the porosity, and the heterogeneity of the Santa Rosa Formation. Estimated fluid-volume calculations could vary by one-to-two orders of magnitude. A period of observation monitoring and reevaluation may help resolve these and provide insight into the best courses of action in the future.

4.2.4 Water-Level Data

The water-level plots for each of the piezometers reveals that water levels have risen in piezometers PZ-6 (0.75 ft), PZ-7 (0.5 ft), PZ-10 (1.5 ft), PZ-11 (1.25 ft), and in PZ-12 (2.5 ft) since July 1997. In addition, water levels in C-2505, and C-2506 rose by about 2.5 feet between October 1996 and March 1997. And water levels decreased by as much as a foot between March and June but have risen by 0.5 feet in July, August and September. The observed fluid-level responses do not appear to be explainable by local barometric-pressure variations, a phenomenon indicative of confined aquifers. The pattern of the fluid-level changes is similar to responses observed to occur as a result of local recharge. Potential sources of recharge could include features such as local precipitation captured by the north salt-disposal mound, the retention ponds located along the south border of the site, the salt-evaporation pond west of the north-disposal mound, or releases from on-site water or sewage systems.

4.2.5 Preliminary Water-Quality Conductance Measurements

Figure 4.3 is a contour plot of lines of equal fluid specific conductance for water samples collected in June, 1997. On figure 4.3 the water-quality areal data are superimposed on a plot of equal water-level elevation measured in the observation wells and piezometers on September 24, 1997. The pattern of specific-conductance show that there is an area with high specific conductance located in the vicinity of PZ-3, and in the north central WIPP-site area in general.

Conductance values from the samples collected in the northern portion of the site range from 40,000 to over 150,000 φS/cm. For comparison the specific conductance of sea water is 50,000 φS/cm. The high conductance area is also roughly coincident with the water-level ridge in the central portion of the WIPP site as shown by the water-level contours on the figure. In contrast, groundwater downgradient from this saline water has a specific conductance of around 10,000 φS/cm or less. Plots of Cl/Br ratio versus location and potassium concentration versus location (Figures 4.4 and 4.5) indicate that there are roughly three types of groundwater in the shallow aquifer beneath the WIPP site; one type in the area around the Exhaust Shaft; one type in the central and north-central part of the WIPP site; and a third type in the west and southwest part of the WIPP site. The data also indicate that potassium-rich groundwater occurs in the central and north-central WIPP site and was also observed in some early samples from near the Exhaust Shaft.

In general, groundwater accumulates salinity as it flows downgradient and freshening occurs only under extra-ordinary circumstances where large quantities of fresh water enter the flow system. Formation fluids with dissolved-solids concentrations greater than sea water are generally found in sediments

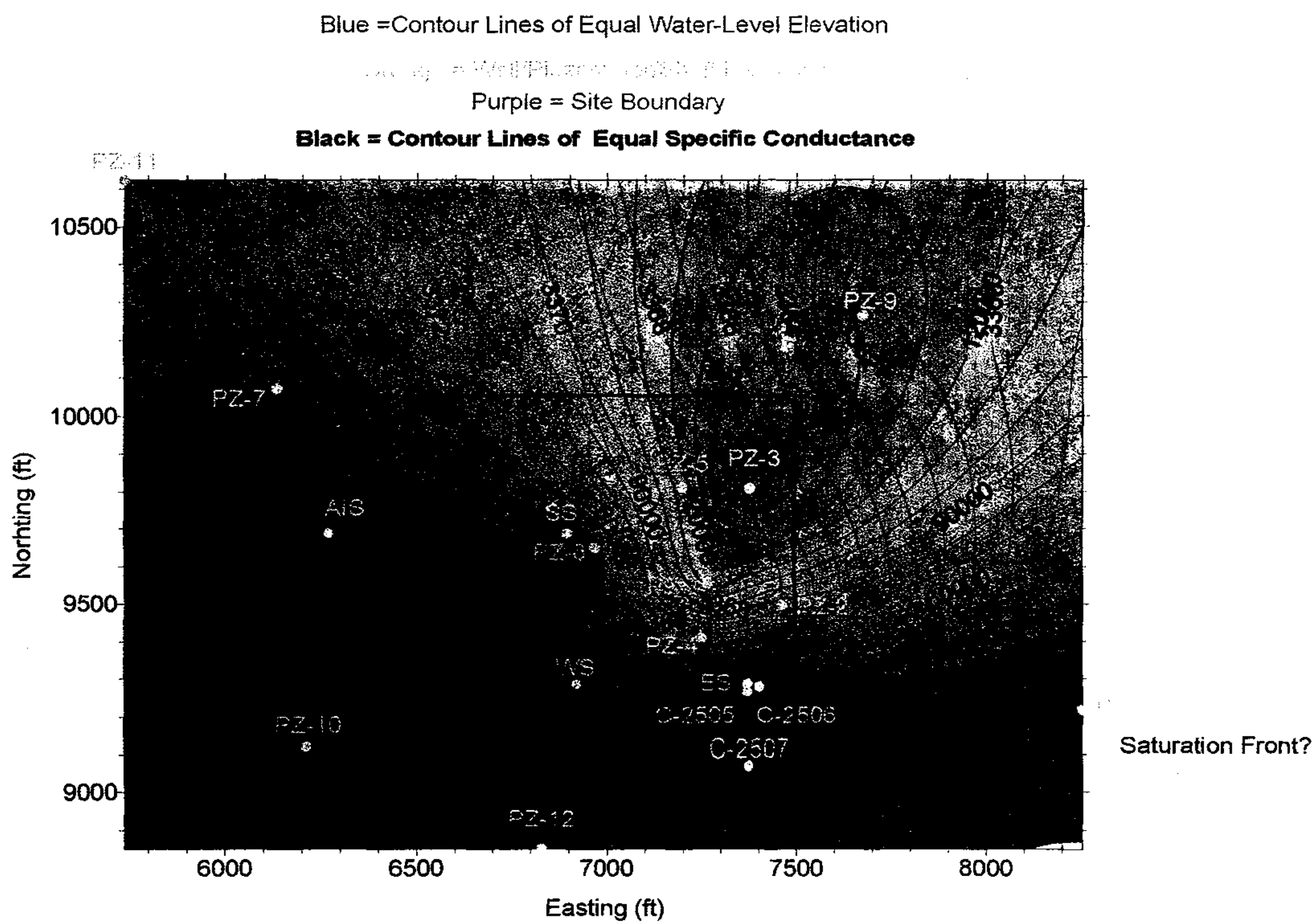


Figure 4.3 Conductance with respect to equipotential surface in the vicinity of the WIPP site

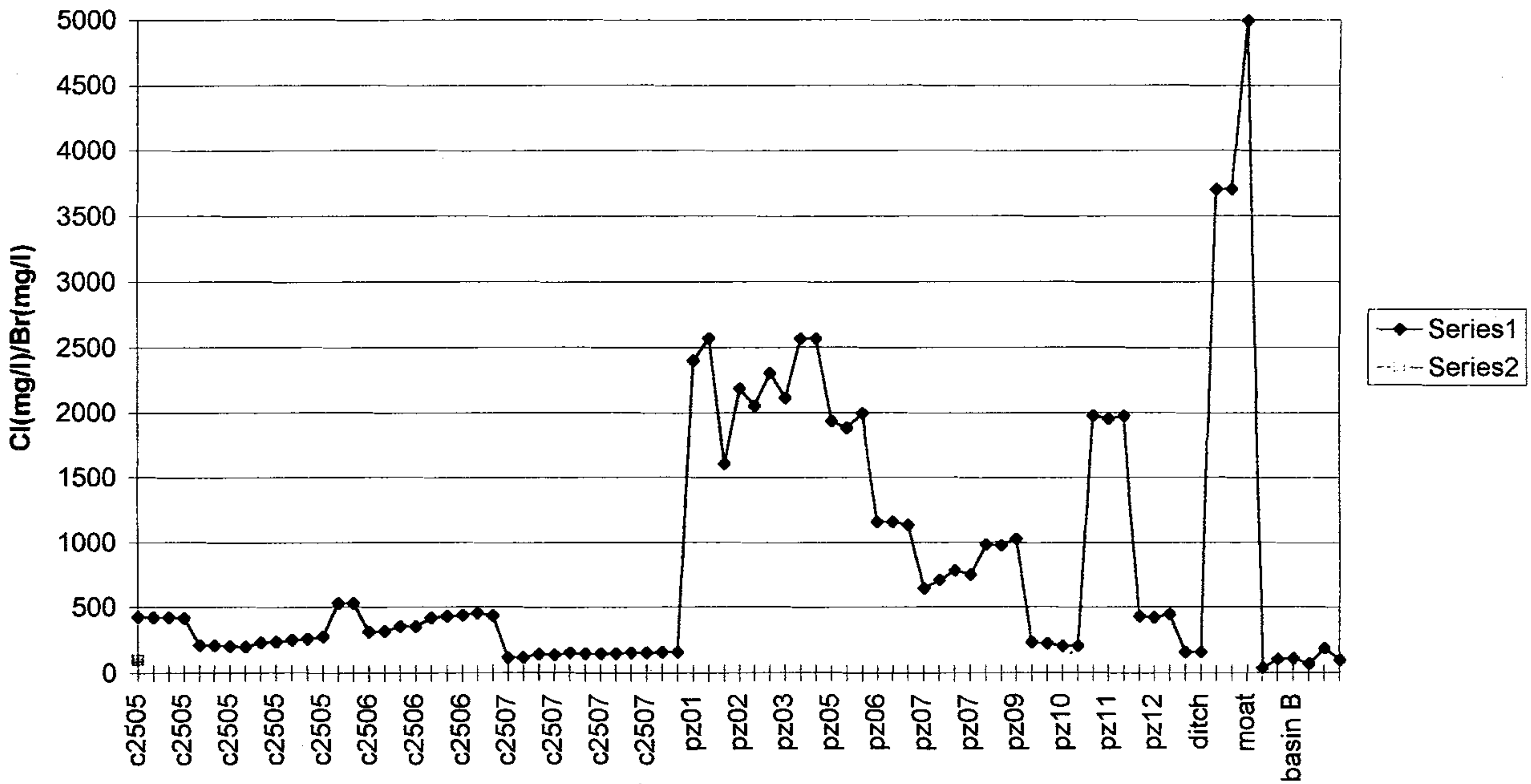


Figure 4.4 Cl/Br by sample location

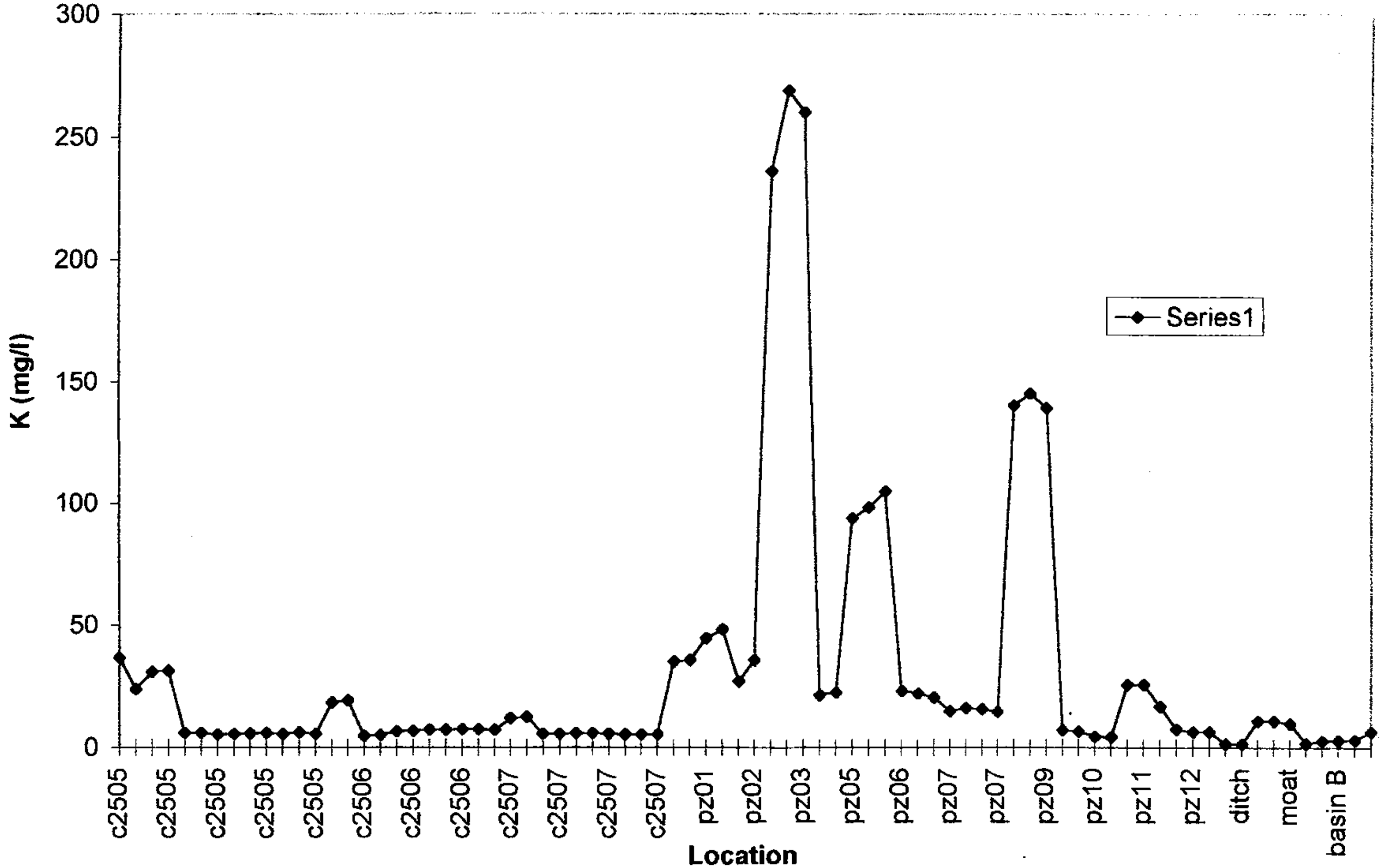


Figure 4.5 Potassium (mg/l) vs location

beneath evaporating basins such as playa lakes, in groundwater from halite deposits such as the Salado Formation, in deep sedimentary deposits such as the Permian Basin, and in water which flows over saline sedimentary deposits such as exposed salt domes or other salt deposits which either outcrop or are found near land surface. The downgradient groundwater in the southeastern part of the WIPP site not only has a lower salinity than that of the upgradient water, but also has a different ionic composition and displays characteristics typical of sedimentary rocks in desert regions with access to calcium sulfate and nitrogenous soil. Alternatively, water following the groundwater gradient from the west part of the WIPP site becomes much more saline along flow lines. The groundwater with high specific conductance is, in general dominated by dissolved sodium and chloride. However, Figure 4.6 shows that the concentration data, plotted as moles of sodium and chloride per sample, fall below a line with a 1:1 ratio of sodium to chloride. The data probably fall below the line because other chloride salts are present in the material from which the salt is derived.

Examination of the chloride to bromide (Cl/BR) ratios from the results of the analyses of the water samples from the wells and piezometers also provides additional insight into the possible origin of these waters. In general, sea water has a Cl/Br ratio between 100 and 300. As halite is precipitated from evaporating brine, the CL/BR ratio decreases as the remaining fluid becomes relatively enriched in bromide. Alternatively, when the evaporated halite is subsequently redissolved, the CL/BR ratio is greater than 500 because the precipitation of the halite has selectively removed chloride from the formative brine. Figure 4.4 shows the WIPP groundwater with the high dissolved-solids concentration, as indicated also by the high specific conductance, displays a CL/Br ratio greater than 500, a characteristic of water derived from the redissolution of halite. The water samples from the central-WIPP-site area also display relatively high concentration of dissolved potassium as compared to more dilute groundwater in other parts of the site.

The water-quality data collected at the WIPP site also indicates conductance has a combination of a Chloride/Bromide ratio characteristic of redissolved halite and high amounts of potassium.

Given the terrigenous sedimentary composition of the Gatuna, Santa Rosa, and Dewey lake deposits (See Appendix 1 for a complete lithologic description of the core samples), it is unlikely that the highly saline water is representative of the original groundwater in the sedimentary sequence. Given that the shallow aquifer is unconfined, saline-water recharge is potentially the source of the saline water in the shallow aquifer. At present, there are two likely sources of this saline water. The first source is the North Salt Storage Area which contains material mined from the WIPP repository horizon in the predominantly halite

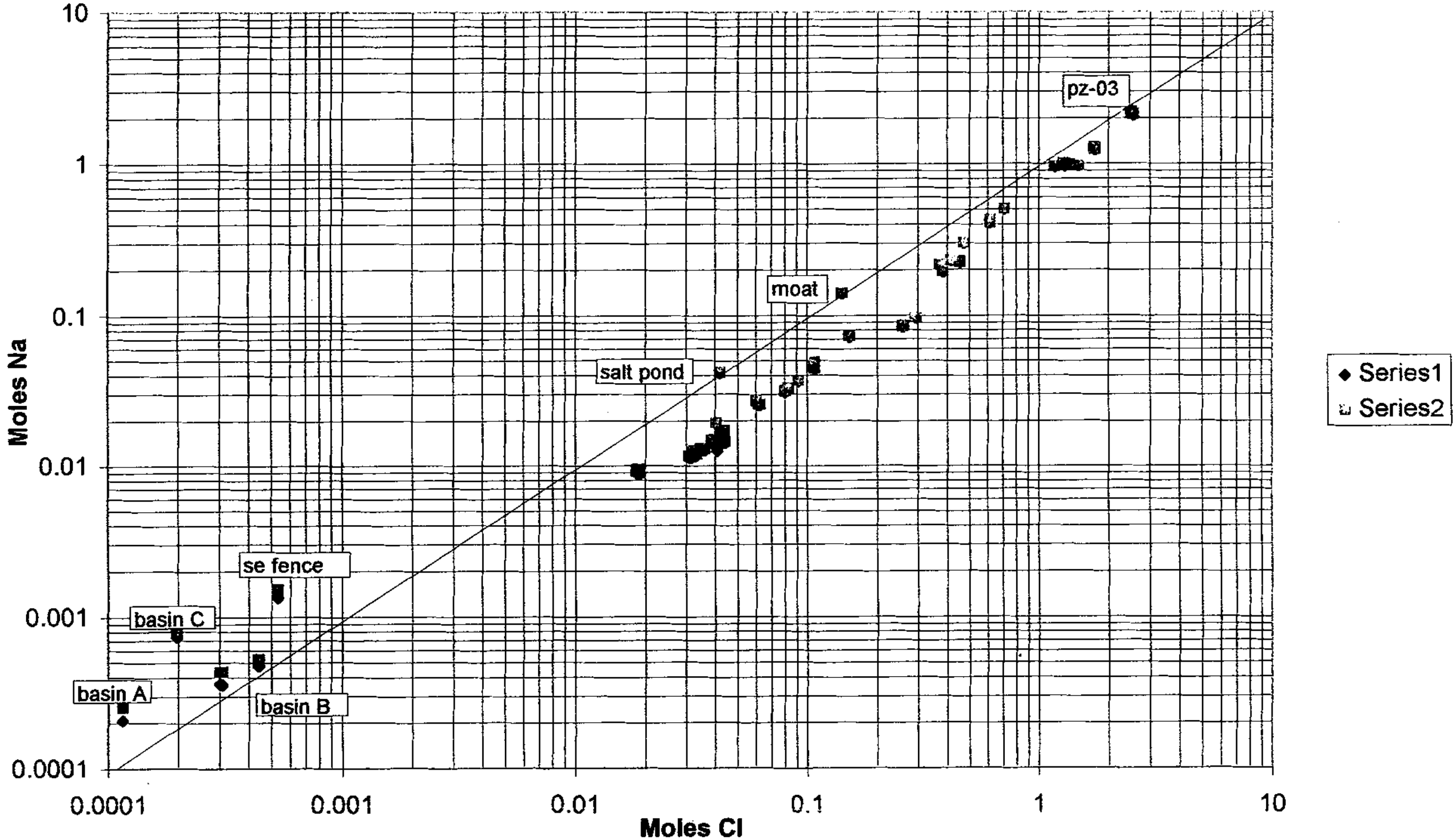


Figure 4.6 Moles Cl vs. Moles Na

Salado Formation. In addition to being highly soluble desegregate salt, the moat along the south side of the North Salt Storage Area was also the area where saline construction and sump-collection water was removed from the WIPP repository horizon was discharged for several years. The North Salt Storage Area could have and could still serve as a source of recharge to the shallow perched aquifer beneath the WIPP site.

A second potential source of saline fluid could be attributable to residuum in the drilling and cuttings pit used during the drilling and excavation of the C&SH (now Salt) Shaft in 1981. This 150-ft by 120-foot pit was used to settle drill cuttings from the initial 6-ft-diameter pilot shaft for the Salt Shaft and later served as a depository for material excavated from the finished shaft. This waste material could serve as the source of the potassium reported in chemical analysis from water samples collected from the central WIPP-site area. Because shaft pilot-hole drilling and excavation would have encountered the entire Salado formation including the soluble potassium salts of the McNutt member of the Salado Formation, and because drilling practice in the 1980's often included the use of saturated brine from potash operations as drilling fluid in order to mitigate Salado dissolution, the waste material in the old mud pit could be a source of both the sodium and potassium chloride content of the shallow saline groundwater. From personal communication reports (Bob Roland, 1997), upon completion of drilling of the Salt Shaft in 1982, fluid was pumped from the pit liner leaving residuum (drill cuttings and non-pumpable fluids) in the pit to dry for several months before the liner was covered with fill. Approximately a year later, a series of holes were drilled through the liner to allow any remaining fluid to drain from the cuttings. The liner and the drill cuttings were later removed and the pit backfilled with caliche and compacted just prior to the construction of the engineering building in 1990. Any remnant fluid or cuttings from the Salt Shaft pit could be a contributing factor to the conductance values observed in the north-central portion of the site near PZ-3 and PZ-5.

4.2.6 Nature of the Aquifer

The combination of the hydraulic-testing, water-level, geologic, and water-quality data collected during the present investigation appear to indicate that the shallow groundwater at the WIPP is a variably saturated, perched unconfined aquifer. Recharge to the system appears to have occurred within the time that operations have been active at the WIPP site, that is since the early 1980s.

An unconfined aquifer by definition is saturated from a low permeability unit at the base of the water bearing unit to the water level in the well and the pressure at the water-table is atmospheric. Perched aquifers are lensatic and may occur as a series of interconnected lenses depending on local stratigraphic variations above the water table. Water may directly recharge the water table by moving downward from land surface under the influence of gravity. In order for recharge to occur, fluid must saturate the soil by overcoming the soil-moisture deficit and achieving sufficient head to overcome soil-moisture tension. Local fractures, boreholes, and other anthropogenic features may short circuit the normal recharge routes and thus provide focused recharge to a perched aquifer. The water levels in wells completed to water-table aquifers generally rise and fall with seasonally and/or focused recharge. Focused recharge may be due to a specific event, a soil-moisture condition, or the presence of fractures in rock/soil overlying the water table, the presence of a continuous water source such as a body of surface water, or some combination of these (and other) features.

A confined aquifer is bounded above and below by units with lower permeability that confine flow in the aquifer and allow only limited fluid and pressure communication with these units. The water level in a confined aquifer generally is above the level of the upper surface of the aquifer. Recharge areas for confined aquifers are generally where the units are exposed at land surface or have access to surface-water recharge. Water levels in wells completed to confined aquifers are generally very stable unless there is a point of pressure disturbance such as a production or injection well. Long-term responses may occur due to major climatic changes or when some portion of the aquifer is subject of long-term injection or withdrawal.

The water-level changes observed in the shallow wells and piezometers completed to the Santa Rosa/Dewey Lake aquifer exhibit the short-term fluid-level responses typical of unconfined aquifers and the storativities estimated from pumping tests performed in these boreholes confirm this observation. The apparent lack of a definite saturation indication in the recovered core samples collected during well and piezometer installation is probably due in part to the method of drilling and the thick capillary fringe in the heterogeneous sandy material encountered during drilling. In addition, some of the short-term variation in the responses may be due to the effects of a combination of the net effect of variations in piezometer completion and the periodic water-quality sampling activities.

4.3 Dewey Lake and Rustler Formation Pressure Responses

Table 4.2 presents pressure head or depth to water measurements for the units underlying the Santa Rosa Formation. The depth to water in well C-2505, located approximately 13 feet south of the Exhaust Shaft, is approximately 45.6 feet bgs. As seen in the Table 4.2, the recorded highest water-level measurement is found in the Magenta dolomite with a depth-to-water measurement of 296.5 feet bgs, approximately 250 below the fluid level in the Santa Rosa. The data indicates that there is no communication between the

Santa Rosa Formation and Dewey Lake Formation or the underlying members of the Rustler Formation.

Table 4.1 Pressure measurements from piezometers located in the Exhaust Shaft monitoring the Dewey Lake Formation and members of the Rustler Formation converted to depth to water below ground surface.

UNIT MONITORED	EXHAUST SHAFT LOCATION (feet-bgs)	PRESSURE (psi)	DEPTH TO WATER (feet-bgs)*
Dewey Lake Formation	544	0	none present
Forty-Niner	580	85	383.8
Magenta Dolomite	615	138	296.5
Tamarisk	673	10	649.9
Culebra Dolomite	721	180	305.6
Unnamed Member	768	153.3	615.7

5.0 REFERENCES

DOE/WIPP 97-2219, January 1997. Exhaust Shaft Hydraulic Assessment Data Report. Waste Isolation Pilot Plant, Carlsbad, New Mexico.

DOE/WIPP 97-2219, May, 1997. Exhaust Shaft Data Report: 72-Hour Pumping Test on C-2506 and 24-Hour Pumping Test on C-2505. Waste Isolation Pilot Plant, Carlsbad, New Mexico.

Freeze, Alan, and Cherry, John, 1979. Groundwater. Prentice-Hall. New Jersey.

APPENDIX 1:

GEOLOGY OF PIEZOMETER HOLES TO INVESTIGATE SHALLOW WATER UNDER THE WASTE ISOLATION PILOT PLANT

APPENDIX 2:

PRELIMINARY DRAFT REPORT ON THE ORIGIN OF PERCHED WATER AT THE SANTA ROSA/DEWEY LAKE CONTACT

APPENDIX 1:

Geology of Piezometer Holes to Investigate Shallow Water Sources Under the Waste Isolation Pilot Plant

Geology of Piezometer Holes to Investigate Shallow Water Sources Under the Waste Isolation Pilot Plant

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

ABSTRACT

Twelve holes (PZ 1-12) were drilled around the area of the WIPP surface facilities to determine the lateral and stratigraphic extent of shallow water known to exist in the lower Santa Rosa Formation around the exhaust shaft. All of the drillholes encountered surficial eolian sand (and fill), the Mescalero caliche, the Gatuña Formation, the Santa Rosa Formation, and the upper Dewey Lake Formation. Eleven drillholes produced water from the lower Santa Rosa.

All units were geologically consistent with previous studies. Across the facility area, units from Mescalero to Dewey Lake are continuous, exhibit gentle slopes (structure contours), and reflect broader trends in thickness and structure. Except for drillhole PZ-8, which was dry, moist zones and water were encountered in the Santa Rosa. The uppermost Dewey Lake in several of these holes was proven dry; dry dust was blown from this interval while drilling.

Drilling for design work (1978-79) and mapping in the exhaust shaft (1984) show that this shallow water did not exist through at least 1984. The air intake shaft (AIS) in 1988 flowed enough water (with dissolved salt) from the Santa Rosa and upper Dewey Lake to be moist and develop salt efflorescences. Solutes in waters from PZ drillholes and AIS indicate infiltrating waters contacted WIPP surface salt piles or another near-surface source of salt from WIPP activities.

The lower Santa Rosa revealed zones that were much harder drilling due to silicification. These indurated zones combined with reduced permeability of fine grained rocks of the uppermost Dewey Lake to perch the water.

Several lines of evidence have been synthesized as possible indicators of site-wide trends to probable changes in vertical permeability of the Dewey Lake and Santa Rosa. Data on fluid levels during logging, uppermost reported gypsum, lost circulation zones, reports of water or moist zones, and site-wide resistivity surveys were gathered from WIPP sources. These data are less precise than is information from PZ drillholes. Trends in these data are interpreted as indicators of permeability and are related to different perching zones.

As hypothesized, these perching zones are effective at different depths across the site because of the more recent geological history of the area. There is a strong

relationship between encounters of water in the Dewey Lake and indicators of perching zones. At the WIPP site facilities location, the uppermost two effective perching zones are the lower Santa Rosa (investigated here) and the upper Dewey Lake (as indicated in the air intake shaft). Southwest across the site, the Santa Rosa is absent because of erosion, and the uppermost effective perching zone is created by cementation changes (sulfate) in the Dewey Lake.

If the shallow water found in this study under the WIPP facilities has migrated laterally to the south and west well beyond the present area of investigation, it will involve Dewey Lake perching zones, as the Santa Rosa pinches out in that direction.

INTRODUCTION

Project Background

For several years, water has flowed in small volumes into the WIPP exhaust shaft at shallow depths. The water is clearly not from deeper ground water sources such as the Rustler Formation, but the extent of the water, its chemistry, and likely sources were undetermined. Three drillholes very close to the exhaust shaft were drilled during 1996 and prepared for water sampling and water level measurements (Intera, 1996). These drillholes demonstrated that the water was not restricted to the immediate shaft area and that the water occurred in the Santa Rosa Formation (or possibly the uppermost Dewey Lake Formation). Nevertheless, the areal extent of the water was undetermined, and the origin(s) poorly bounded.

During June and July, 1997, 12 additional holes were drilled and prepared for water sampling and water level measurements. The main objectives during this preliminary phase were to determine the extent of shallow water, obtain head and chemical data to indicate possible sources of the water, to determine the stratigraphic units in which water is present, and to provide the basis for any further programs to explore the extent of water or place dewatering drillholes, if desired. Overall program objectives, drilling and completion methods, and hydrological data and analysis are included in the main report by Intera.

Geological descriptions of cores and cuttings, and the interpretation of the geological data, were the responsibility of Dennis Powers. Field log descriptions are attached to this report (Appendix A).

Geological Units and Background for PZ Drillholes

Seven identifiable formal and informal artificial and natural units (Figure 1) have been encountered during drilling for this program, though not all are identifiable or present in each drillhole. From the surface down, these are: 1) fill - local units disturbed by construction or material brought in for construction, 2) Holocene(?) dune sand, 3) Pleistocene Berino soil, 4) Pleistocene Mescalero caliche, 5) Miocene - Pleistocene Gatuña Formation, 6) Triassic Santa Rosa Formation, and 7) Permian Dewey Lake Formation. All formations were encountered during the drilling generally as expected.

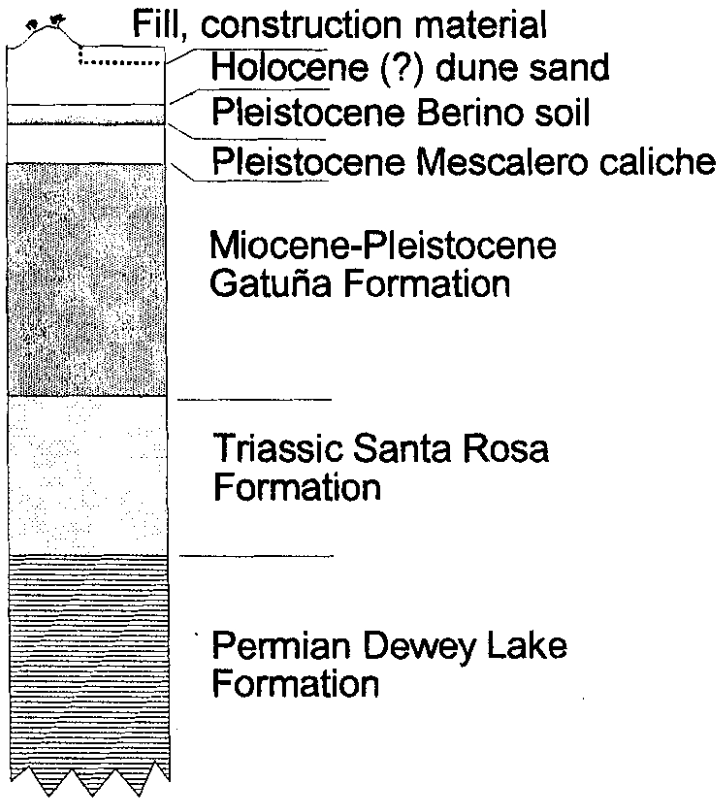


Figure 1
Units Commonly Encountered During Shallow Drilling at WIPP

The geology of these drillholes could be forecast on the basis of the mapping of the exhaust and air intake shafts (Holt and Powers, 1986, 1990) as well as nearby drillholes such as B-25 (Bechtel National, Inc., 1979) and WIPP 21 (Sandia [National] Laboratories and US Geological Survey, 1980). Drilling to investigate potash resources revealed the broader stratigraphic relationships and presence of the Santa Rosa over the site (Jones, 1978). Numerous shallow holes (B series) were drilled in 1979 for design of surface facilities, and these drillholes demonstrated the lack of very shallow groundwater as well as the distribution of near surface rock units (Sergent, Hauskins & Beckwith, 1979).

Fill, Construction Materials. Around the facilities, significant areas have been modified by construction activities. Much of the dune sand has simply been levelled in place, though some of the upper part has been removed as "soil" for later rehabilitation following decommissioning of the WIPP facility. Gravel from nearby caliche pits has been imported to stabilize the surface, and one hole (PZ-1) was drilled through asphalt surfacing. Another drillhole (PZ-7) was located on top of a small berm, constructed of dune sand with caliche surfacing, around an evaporation pond.

Holocene(?) Sand Dunes. The Holocene sand dunes in this area have been little studied as geological units. While most are stabilized, small areas remain active around the site. These dunes may be older than Holocene and may represent more than one episode of dune formation, based on limited examination of aerial photographs.

Berino Soil. The Berino soil, originally designated by Chugg and others (1971) during the soil survey of Eddy County, is a dark reddish brown siltstone to argillaceous sandstone that is partially lithified, mainly by accumulation of clay minerals. It is a fossil soil or paleosol. It was examined by Bachman (1980) briefly, who noted its occurrence overlying the Mescalero caliche and under dune sand. Bachman interpreted the Berino as probably a remnant B horizon relative to the underlying Mescalero caliche, and Powers (1993) agreed with that assessment. Powers and others (1997) reassessed the relationship based on trenches west of WIPP and concluded that the Berino was distinct from the Mescalero in origin.

In a study of the ages of near-surface units, Rosholt and McKinney (1980) interpreted the age of formation of the Berino as 330,000 ± 75,000 years.

Mescalero Caliche. The Mescalero caliche in the area of WIPP is best known from the work of George Bachman (e.g., Bachman, 1974, 1976; Bachman and Machette, 1977). The Mescalero is an informal stratigraphic unit originally designated by Bachman (1976) for the pedogenic carbonate deposits across the Mescalero plains. The drillhole data for design studies for WIPP was used to prepare a map of the elevation of the top of the caliche in the area where surface facilities now exist (Sergent, Hauskins & Beckwith, 1979, figure 3). 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. Powers and others (1997) examined outcrops of the Mescalero exposed in the El Paso Energy pipeline trench just west of the WIPP boundaries and found that the caliche is stratigraphically continuous across the area. The unit is locally variable and was disrupted by erosion/solution prior to formation of the Berino soil (about 330,000 years ago). In general, the Mescalero caliche is continuous across the general site area and provides broad evidence of geomorphic stability.

Rosholt and McKinney (1980) dated carbonate from the Mescalero using uranium-trend methods. The lower part yielded an age of about 570,000 ± 110,000 years, and the upper part was 420,000 ± 60,000 years.

Miocene-Pleistocene Gatuña Formation. The Gatuña Formation is relatively thin across most of the WIPP site (Bachman, 1985). In the eastern half of the WIPP withdrawal area, no Gatuña is reported; caliche is developed on the Santa Rosa. Several caliche quarries at topographic highs east of the WIPP withdrawal area expose well-lithified Santa Rosa under caliche. The Gatuña 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 fill localized channels caused by erosion. The thickness of the unit can vary considerably over short distances. The formation has filled in some areas along the general Pecos River trend where dissolution caused subsidence (Powers and Holt, 1995a).

Triassic Santa Rosa Formation. The Santa Rosa is thin near the center of the WIPP site (e.g., Powers and Holt, 1995b). It thickens rapidly to the east (Jones, 1978) as a consequence of eastward dip and eastward rise in the surface topography. The formation was deposited in dominantly fluvial environments (McGowen et al., 1979). It lies unconformably on the Dewey Lake.

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

Unit Distinctions

During this study, some cores were taken using flight augers and retrievable core barrels. Most holes were drilled using a tricone bit and compressed air to remove cuttings. The stratigraphy of these drillholes was determined by monitoring the cuttings for composition and color. Because the return time (to the surface) for cuttings at these shallow depths is very short, distinct changes in composition can commonly be determined quickly and accurately. Depths to most units are considered accurate to the nearest foot; a few unit distinctions are taken to the nearest half foot. Over intervals where cores were not retrieved or cuttings did not return to the surface, boundaries may be placed on the basis of changes in drilling rates. Most of the following discussion is based on distinctions made on the basis of cuttings.

The fill material/graded material is mainly orange to brownish, unconsolidated sand from the stabilized dunes that covered the site prior to construction. Some caliche gravel or other coarse material is mixed with the upper surface in some locations. There is little to distinguish the base of graded material at most locations from the undisturbed dune sand. In some drillholes, the basal dune sand included additional silt and clay, is more lithified, and is a darker reddish brown. This corresponds to the Berino soil (e.g., Chugg et al., 1971; Bachman, 1980; Powers and others, 1997) that overlies the Mescalero across most of the site.

The top of the Mescalero is reliably determined because of the abrupt change in cuttings to white carbonate and reduced drilling rates. Sergent, Hauskins & Beckwith (1979) prepared a contour map of the elevations of the top of Mescalero from the B series holes, and the data correspond closely to our findings.

The top of Gatuña for this study is placed where brownish to reddish-brown Gatuña sandstone is observable as part of the cuttings. This corresponds to the contact as it is observed in outcrops and other cores (Powers and Holt, 1993, 1995; Powers, 1993). Mescalero caliche infiltrated the upper Gatuña, forming nodules and carbonate crusts. The alteration decreases with depth. In outcrops, the Mescalero dominates over an interval that is generally about 3 ft thick (see Powers, 1993; Powers and others, 1997; Kennedy, 1997). Gatuña character is distinguishable below that and increases with depth. Cuttings begin to change color from white to slightly brownish white and are accompanied by increasing proportions of Gatuña sandstone. The sand grains are generally fine to coarse, poorly sorted, and chips show small pores from bioturbation as well as bluish-black MnO_2 stains.

The Sergent, Hauskins & Beckwith (1979) study consistently places the Mescalero-Gatuña boundary much deeper, implying that the Mescalero is 10-15 ft thick across the WIPP site center. The upper Mescalero, as described in the Sergent, Hauskins & Beckwith report, corresponds to the differentiation of the Mescalero in this report; they included much more of the carbonate-cemented sandstone in Mescalero, while I attribute it to Gatuña that has been altered by Mescalero pedogenic processes.

The Santa Rosa is a common source of the sediment that forms the Gatuña, making this boundary the most difficult to place in either core or cuttings. The Santa Rosa includes fine to coarse, highly micaceous sandstones interbedded variably with claystones or siltstones. Santa Rosa sandstones are generally dark brown, while claystones and siltstones can include green. Some beds display whitish reduction spots. Outcrops of the Santa Rosa commonly strike the eye as having a purplish cast. The distinction at the base of Gatuña was commonly made on the basis of higher mica concentrations, more intense hues (browns, greens), and induration (slower drilling rates). Some beds near the base of the Santa Rosa are highly indurated. Cuttings from these beds are limited, but tests with acid show little carbonate cement. The beds are probably partially cemented by silica.

The Dewey Lake is most commonly differentiated from the Santa Rosa on the basis of color (more of a brick red color and chips with greenish-gray reduction spots) and composition (no coarser sands, decreased mica content). Drilling rates for the Dewey Lake also increased over the basal Santa Rosa and became more constant.

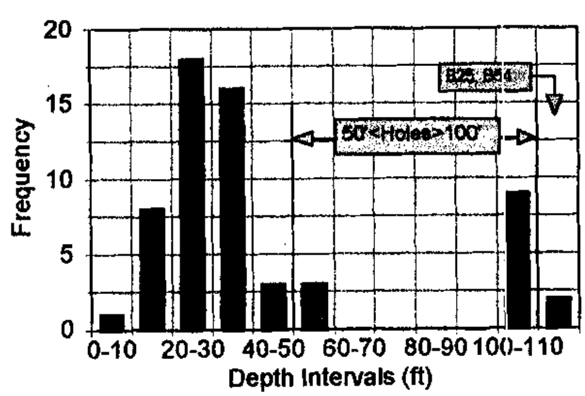
Origin of Water

To understand the origin of this water, we consider both the likely sources as well as how long the water has been in place. While the current study is designed to understand the sources of the water in some detail, previous geological studies greatly constrain the possibilities of how long this zone has been saturated.

Design studies included drilling holes at 54 locations from late 1978 through part of 1979 at the location of proposed WIPP facilities. There were 54 principal drillholes and 6 supplemental or offset drillholes. The drillholes ranged in depth from about 6 to about 902 ft in depth. At 52 locations, the drillholes had total depths of 100 ft or less and were drilled with air (Bechtel, 1979, p. 10). Two drillholes (B25 and B54) were 901.8 and 210 ft deep, respectively. Drilling mud was used for B25 (Bechtel, 1979b); I assume drilling fluid was used for B54, but I found no specific information in the original reports. Twelve of the drillholes were drilled with air and were between 50 and 100 ft deep (Figure 2) and should have been deep

Figure 2

Depth of B Series Holes



enough to intercept the water at its current depth. These drillholes cross the area where water has currently been found as well as some areas beyond the area of the PZ wells; they demonstrate that the water was not present below the site in 1979.

In 1984, the exhaust shaft was constructed and mapped (Holt and Powers, 1986). No water was found through this shallow interval during the mapping. The water was not present at the exhaust shaft in 1984.

During the mapping of the air intake shaft (AIS) late in 1988, Holt and Powers (1990) noted that the shaft walls were wet in the basal sandy siltstones of the Santa Rosa Formation at a depth of 51.5 ft (33 ft below plenum + 18.5 ft of plenum) (elevation of 3358.5 ft msl). Holt and Powers suggested that water was accumulating in Santa Rosa sandstones overlying the siltstones. Salt efflorescence accumulated on the surface of the shaft to a depth of about 63 ft as air flowing into the shaft evaporated the water. Holt and Powers also found moist zones and salt efflorescence above a cementation change in the Dewey Lake at a depth of about 182.5 ft (164 + 18.5 ft). They concluded that the source was infiltration of meteoric water that had come in contact with the halite muck pile immediately north of the facilities. By 1988, water had infiltrated in the vicinity of the AIS and charged units at 51.5 ft and 183 ft depth.

These geological investigations show that the shallow water found during this study (PZ drillholes) did not exist generally across the site in 1979, and was not observable at the exhaust shaft in 1984. It is reasonable to conclude that it did not exist at all at least as late as 1984. By 1988, the AIS mapping showed that water with dissolved halite had infiltrated to the Santa Rosa and Dewey Lake at this location. The solutes in the water in the AIS and also indicated in preliminary testing of water from PZ holes show that the water flow path has to involve a surface source of halite such as tailings piles from WIPP or brine pits for drilling and is not due, for example, to leaks from pipes carrying water of drinking quality. Further solute analyses will be significant in determining what were the sources and flow path of the water.

SUMMARY STRATIGRAPHIC DATA FROM PZ DRILLING

Basic stratigraphic data for each drillhole in the PZ series is included in a table for convenience (Table 1).

TABLE 1

Depth (ft) Interval for Stratigraphic Units					
Drillhole	**Fill, Dune Sand**	**Mescalero caliche**	**Gatuña Formation**	**Santa Rosa Formation**	**Dewey Lake Fm**
PZ-1	nd§	nd	nd-40	40-~56	~56-67.5 (TD)
PZ-2	0-9	9-12	12-39	39-~57	~57-65 (TD)
PZ-3	0-8	8-10	10-38	38-63	63-70 (TD)
PZ-4	0-9	9-12	12-31	31-57	57-65 (TD)
PZ-5	0-7	7-9	9-36	36-62.5	62.5-71.5 (TD)
PZ-6	0-7	7-9	9-32	32-55	55-66 (TD)
PZ-7	0-7.5	7.5-9.5	9.5-30	30-69	69-71.5 (TD)
PZ-8	0-6.5	6.5-9	9-31	31-60	60-67 (TD)
PZ-9	0-8	8-11	11-36	36-75	75-82.5 (TD)
PZ-10	0-6	6-9	9-28	28-46	46-57 (TD)
PZ-11	0-10	10-12.5	12.5-34	34-71	71-82 (TD)
PZ-12	0-6	6-8	8-39	39-62	62-77 (TD)

§ND = not determined. Depths are approximate (about ± 1 ft). Some contacts to nearest 0.5 ft due to marked contrast. Gatuña-Santa Rosa contact is difficult; the Gatuña incorporated Santa Rosa sediment.

In part because of grading, the fill and dune sand over caliche shows a relatively uniform depth across the area of investigation. This is also consistent with the findings of the pre-construction surveys.

The Mescalero is consistently 2 to 3 ft thick in this investigation. This is consistent with outcrop and trench data in the area, though it contrasts with pre-construction surveys because of different concepts of the Mescalero-Gatuña contact.

The Gatuña averages 24 ft thick in the 11 drillholes in which both top and base were picked. Most of the cores and cuttings of the Gatuña display evidence of bioturbation, Mn staining, and possible mineral precipitation along likely ped [a soil structure] surfaces that are consistent with pedogenic alteration of the upper part of the formation as it was accumulating in this area prior to development of the Mescalero. Most of the formation would be similar to the part called informally the "McDonald Ranch member" by Powers and Holt (1993, 1995a).

The Santa Rosa averages about 39 ft thick in the PZ series holes. This is consistent with the broader site relationships, where the site center is near the western limit of Santa Rosa following erosion prior to Gatuña deposition. The Santa Rosa thins rapidly to the south and west of this area.

COMPARISON WITH STRATIGRAPHIC DATA FROM PREVIOUS STUDIES

The main sources of comparable data within the WIPP fenced area and out to a radius of about 3 miles are drillholes for the design studies (Figure 3) (Sergent, Hauskins, Beckwith, 1979; Bechtel, 1979), potash exploration for WIPP (Jones, 1978), and various exploratory and hydrologic drillholes for WIPP (Figure 4) (see, for example, data summaries of relevant units in Powers and Holt, 1995b). Units down to the upper Dewey Lake can be compared for the area of the facilities; the thickness of the Dewey Lake for a broader area is based on deeper drillholes that were not a part of this study.

Figure 3

Basemap of Drillhole Locations Near WIPP Site

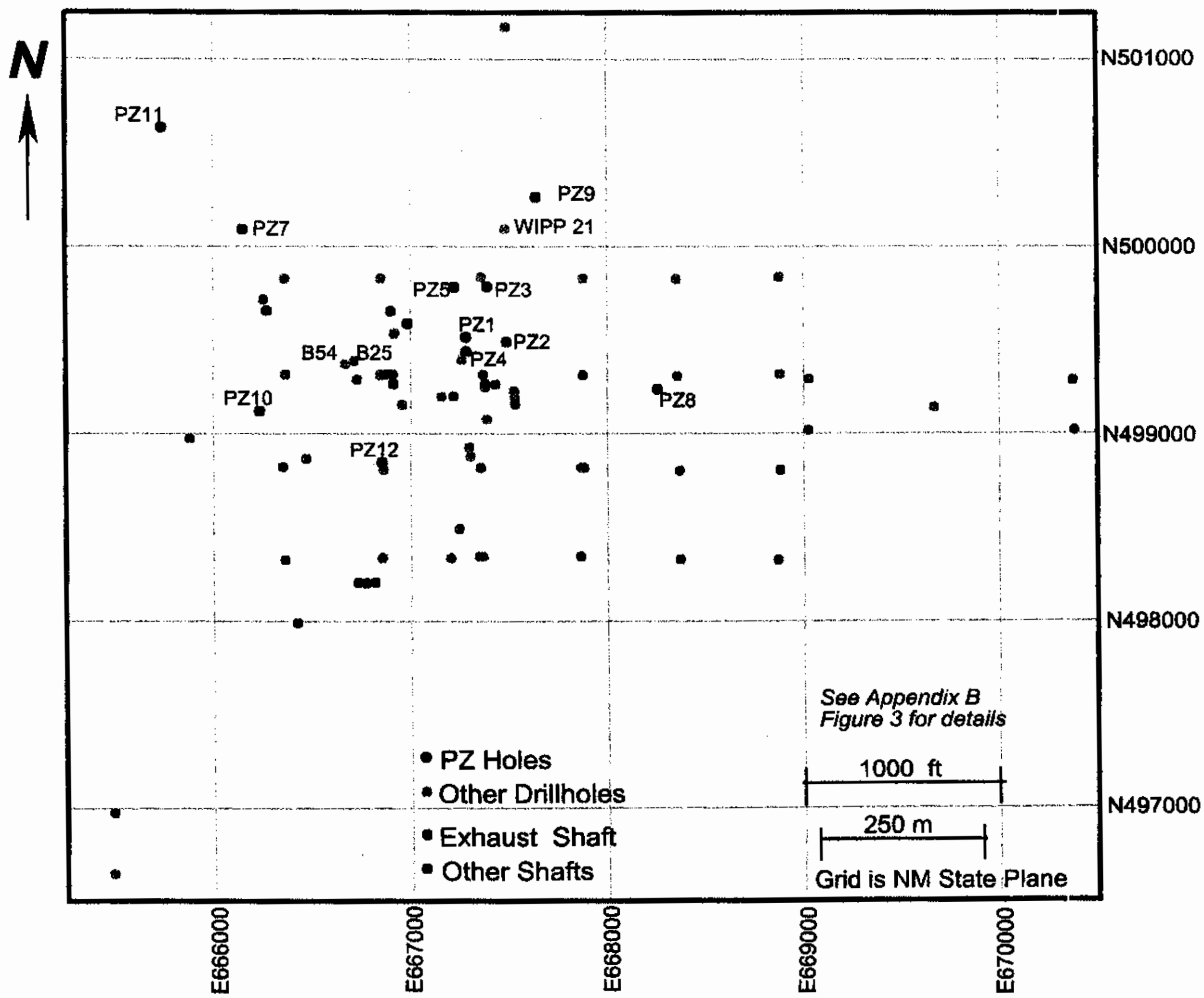
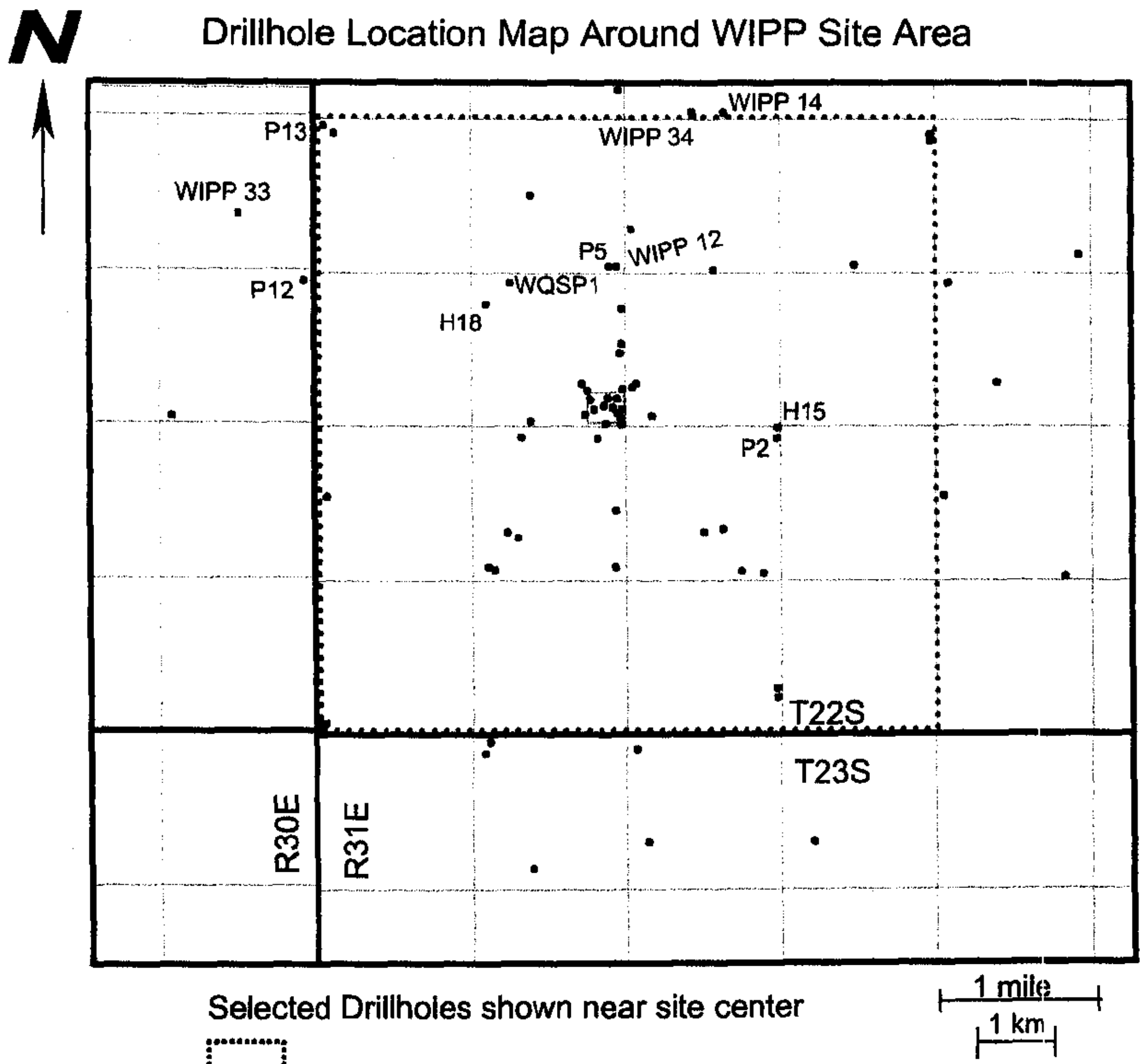


Figure 4

Drillhole Location Map Around WIPP Site Area



Selected Drillholes shown near site center

WIPP Withdrawal Area

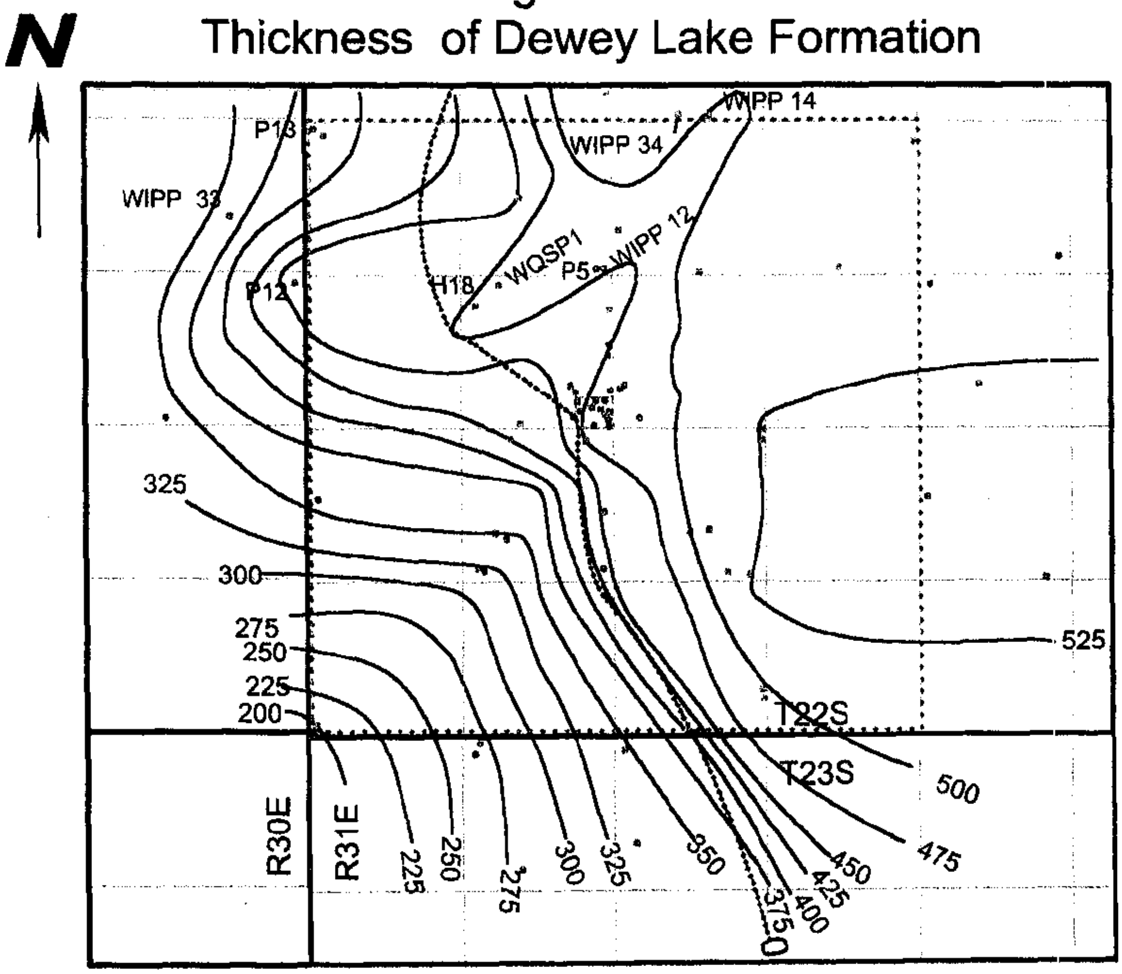
Hole Location, selected holes identified

See Appendix B Figure 4 for details

Dewey Lake Data

From the larger area (Figure 5), Dewey Lake thicknesses reveal three main features. In the eastern part of the map area, the Dewey Lake is more than 525 ft thick; this is similar to much of the Dewey Lake to the east, where it thickens to about 600 ft

Figure 5
Thickness of Dewey Lake Formation



contour interval is 25 ft

1 mile
1 km

WIPP Withdrawal Area

See Appendix B Figure 5 for details

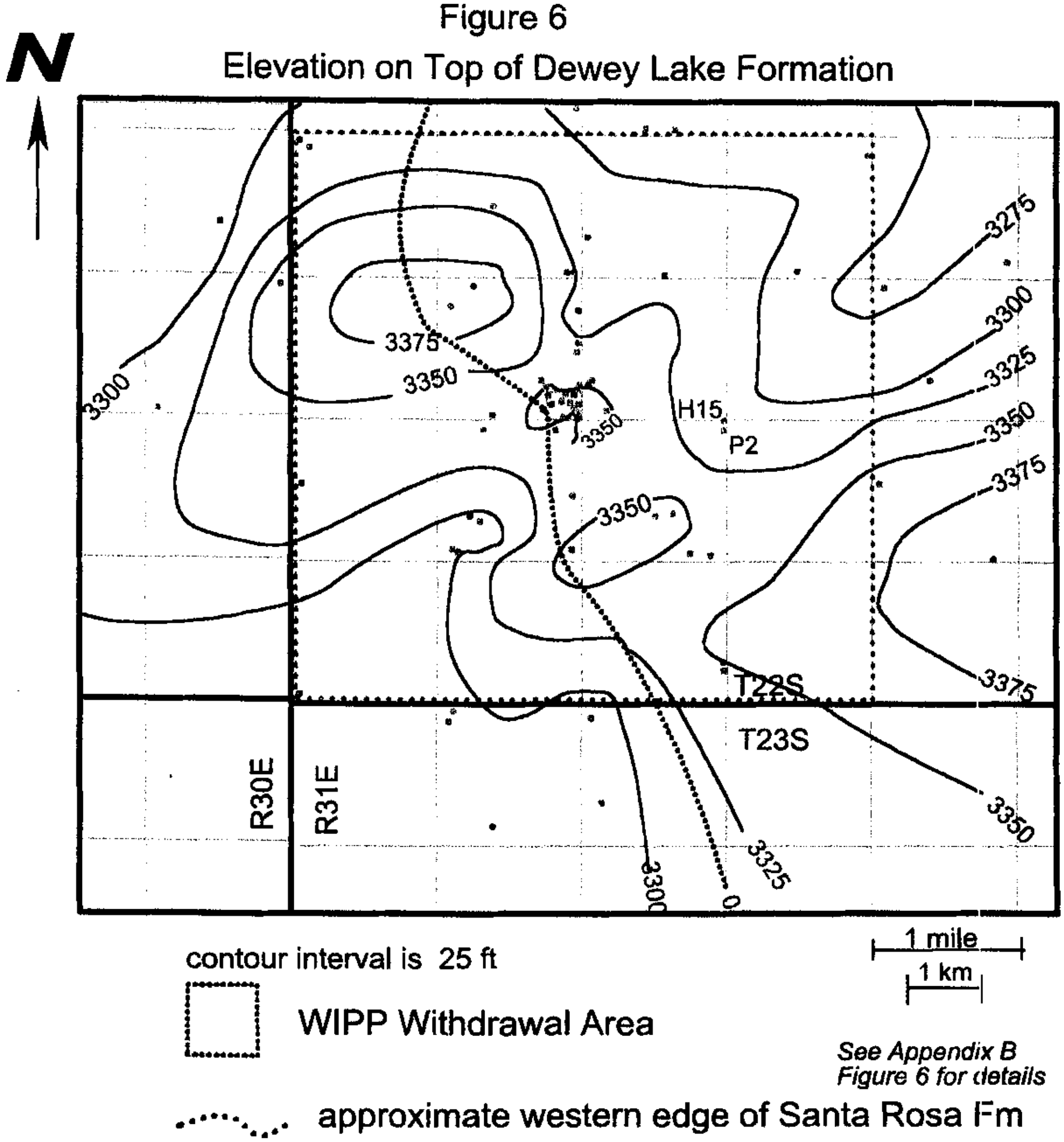
approximate western edge of Santa Rosa Fm (e.g., Schiel, 1988). The southwestern half of the map shows thinning with a persistent gradient to the southwest. The isopach contours generally parallel the estimated edge of the Santa Rosa. The northeastern quarter of the map has somewhat thinner Dewey Lake, about 500 ft thick.

The thickness map also shows two minor features. In the center of the northwest quadrant, the Dewey Lake appears to be thicker toward the west along a "nose" defined by drillholes P12, H18, and WQSP1 (Figure 4). This nose does not differ in thickness greatly from the northwest-southeast trend defined through the site center. The nose is accentuated by drillholes P13 and WIPP 33, where the Dewey Lake is significantly thinner. The second minor feature is a narrow thinner zone near the north center area of the map defined by WIPP12, P5, and WIPP14. This zone trends north-northeast. It is not a significant feature, as it is defined by differences as little as 5 ft between drillholes WIPP34 and WIPP14, which is generally about the normal interpretive limits for precision on geophysical logs (e.g., Holt and Powers, 1988).

A map of the elevation of the top of the Dewey Lake (Figure 6) does not reflect regional structure for these units. The structure of units of the underlying Rustler Formation show that the regional dip is eastward and is of the order of 100 ft/mile. The general trend of elevation on top of the Dewey Lake is for a relative high or ridge along a zone from southeast to northwest with a saddle near the WIPP surface facilities. The Dewey Lake tends to be slightly higher under the WIPP site. The top of the Dewey Lake slopes off both to the southwest and northeast from this ridge.

The slope to the southwest corresponds mainly to broader erosional thinning of the Dewey Lake prior to deposition of the Gatuña. The Santa Rosa is missing over most of this area, having also been eroded prior to Gatuña deposition.

Figure 6
Elevation on Top of Dewey Lake Formation

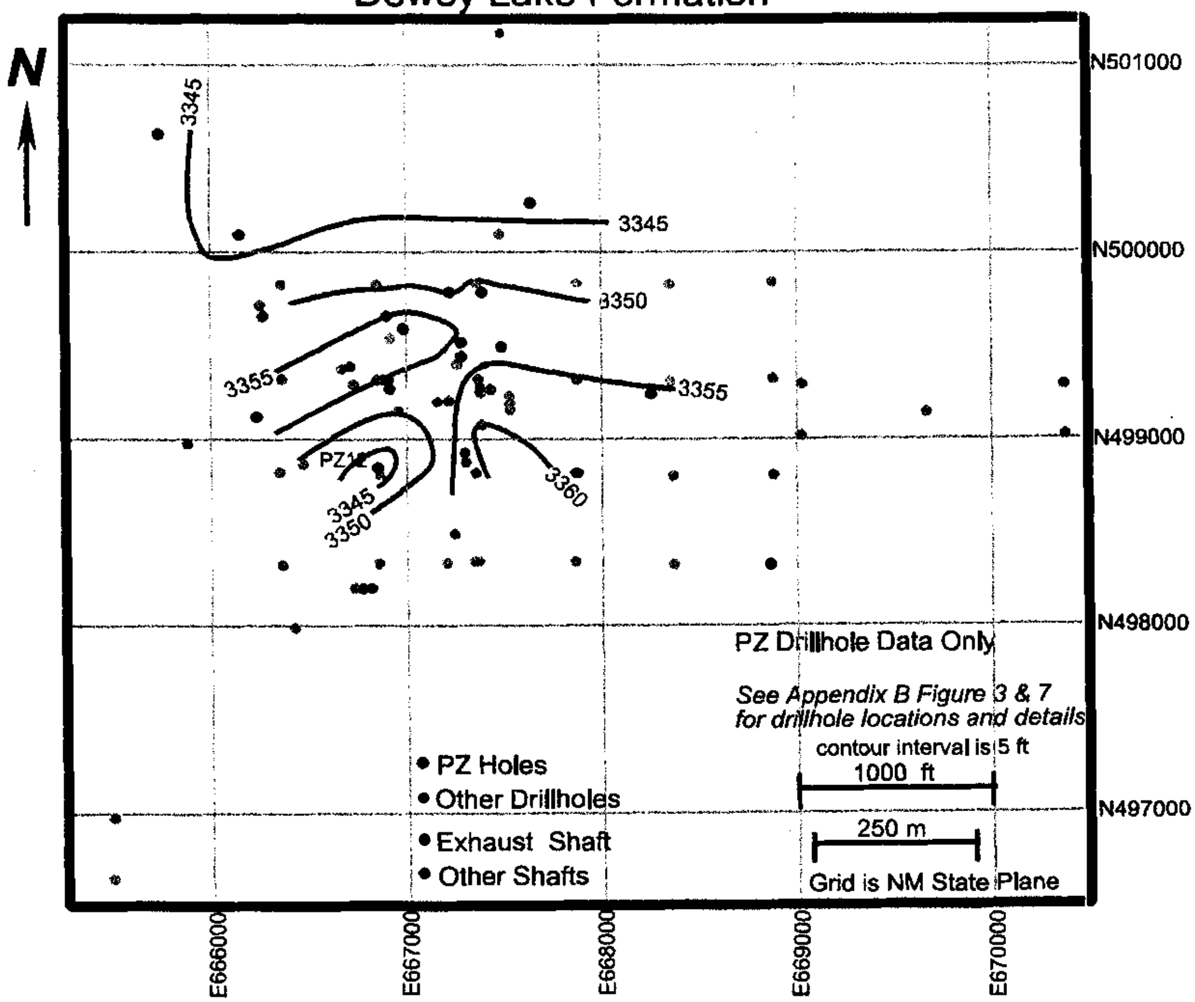


The slope to the northeast corresponds to thicker Santa Rosa and slightly thinner Dewey Lake. I interpret this as due mainly to more localized erosion of the Dewey Lake prior to Santa Rosa deposition.

At the facilities location, concentrated data from the PZ drillholes and B series permits more detailed reconstruction of the surface of the Dewey Lake that can be compared to the broader site area information.

The PZ data alone (Figure 7) indicates a northward slope across this limited area. The exception is the point at drillhole PZ 12 at the south central part of the map with an elevation of 3344. While a re-examination of the drillhole log data indicates the original

Figure 7
Elevation of Top of
Dewey Lake Formation

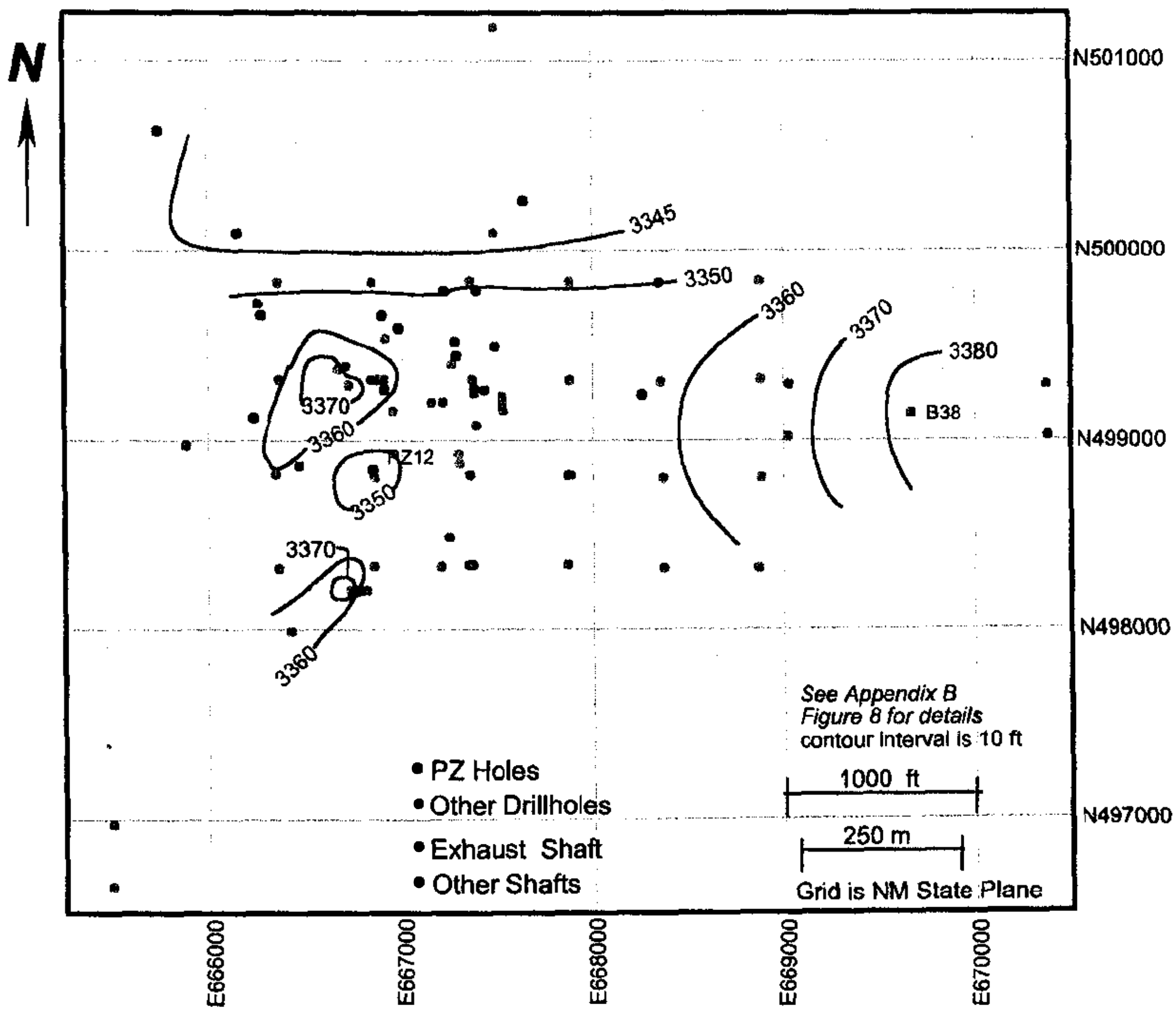


"pick" is consistent with the data, it is also very possible that the contact could be as high as 3359 ft (depth of 47 ft). Cuttings and core from the claystones and siltstones of this zone are not always clearly diagnostic (see, for example, AIS mapping; Holt and Powers, 1990). This datum is not being modified here; no conclusions of this report have been based on this single point.

Combining the PZ and B series data (Figure 8) reveals the same pattern across the facilities areas. In addition to the apparent anomalously low value at PZ 12, B 38

Figure 8

Elevation of Top of Dewey Lake Formation



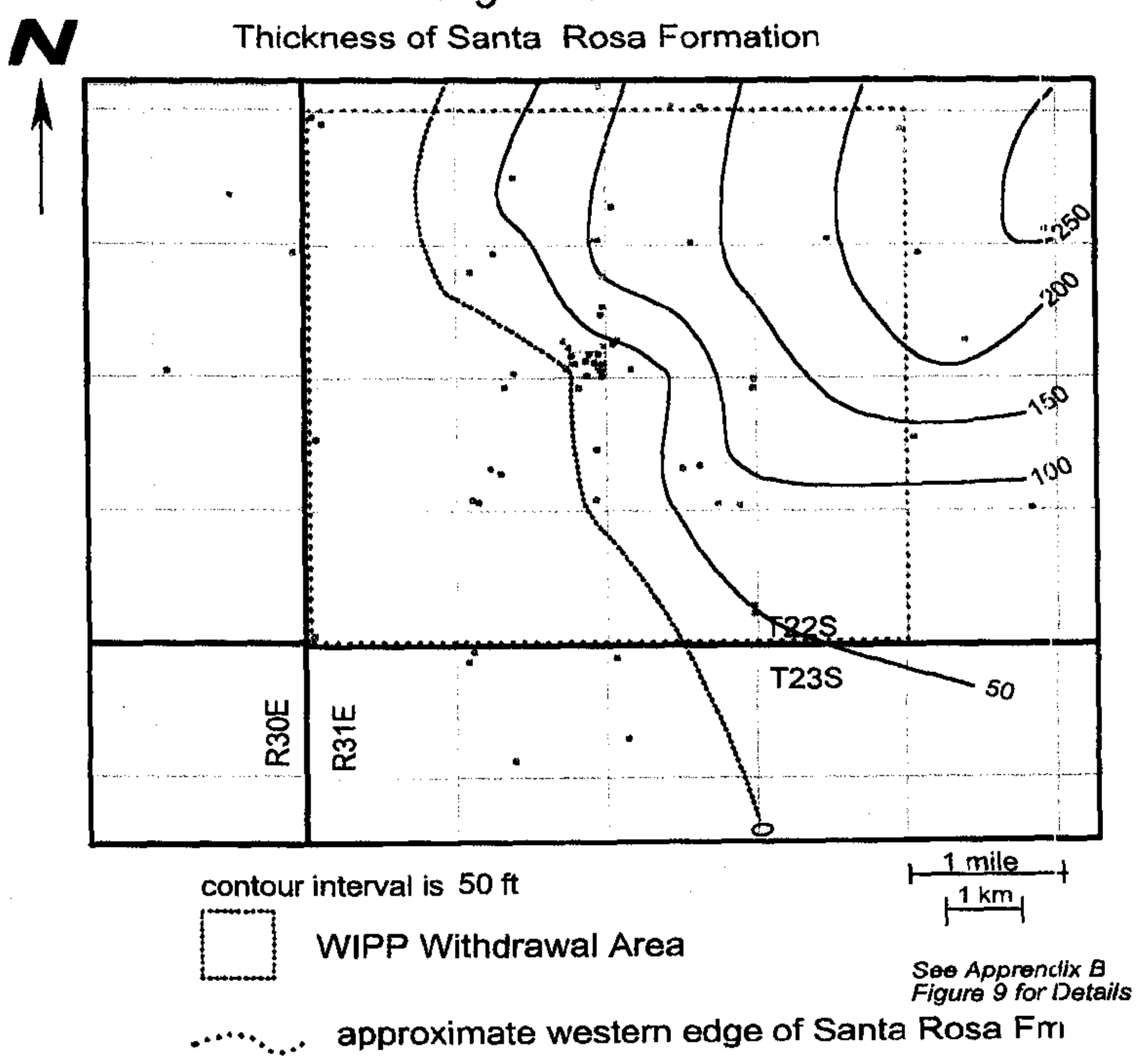
appears to have an anomalously high value of 3386 ft. The broader pattern (Figure 6) is that the surface of the Dewey Lake is becoming deeper to the east, toward P 2 and H15. The drill log of B 38 doesn't permit another interpretation of the data.

Santa Rosa Data

A map of the thickness of the Santa Rosa (Figure 9) displays a single trend of thickening to the northeast. The west-southwest half of the map is not known to have

Figure 9

Thickness of Santa Rosa Formation

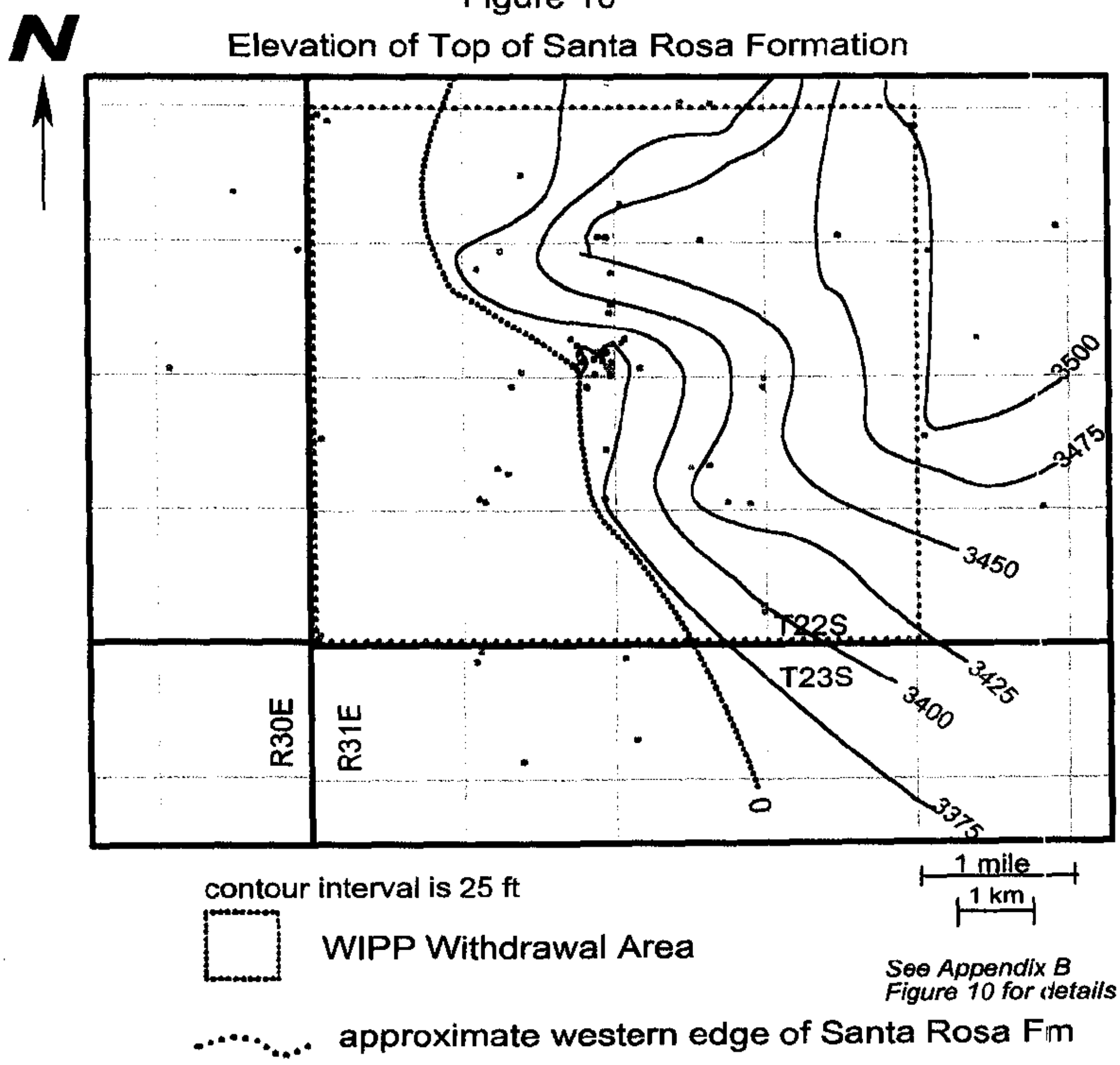


Santa Rosa, and an erosional edge of the Santa Rosa has been inferred based on drillhole locations and approximate gradient of thickness changes in the Santa Rosa.

Combined with the elevation map on top of the Dewey Lake, the Santa Rosa thickness indicates modest localized erosion and fill of the deepened area.

Elevations on top of the Santa Rosa (Figure 10) do not reflect regional structure trends. The elevations slope downward to the southwest toward the erosional edge of

Figure 10
Elevation of Top of Santa Rosa Formation



the formation from a high area near the northeast corner of the map. Across the northern edge of the map, the top of the Santa Rosa drops off more sharply.

Across much of the map area, Gatuña erosion of the Santa Rosa was fairly uniform across a planar surface. At the facilities location in the center of the map, a concentration of data causes some more abrupt contour changes. A modest valley trends approximately east from the facility areas, mirroring modern surface topography.

Within the facility area, the top of the Santa Rosa can be interpreted in more detail by considering the PZ and B series data. Two maps have been constructed, and they show very similar patterns. One map (Figure 11) uses the PZ and B data that are explicit; for the second map (Figure 12), I have inferred some Santa Rosa values where the original report (Sergent, Hauskins & Beckwith, 1979) did not include an interpretation of the top of Santa Rosa.

These two maps generally show that the top of the Santa Rosa declines to the southwest. Several drillholes from the area of the exhaust shaft to the southwest outline a narrow, deeper area of the contact between the Santa Rosa and overlying Gatuña. This is interpreted as an erosional channel on top of the Santa Rosa.

The Santa Rosa showed some characteristics that were common to most of the PZ drillholes. Medium to coarse grained greenish gray sandstones were observed in most drillholes in the lower part of the Santa Rosa. In addition, a zone of hard drilling was encountered near the base of the Santa Rosa. Chips from this zone effervesced very little and retained integrity even when treated with strong (muriatic) acid for at least 24 hours. This zone is likely partially silicified.

Gatuña Formation Data

The Gatuña in general thickens to the south and southwest of the site facility area (Figure 13). North and northeast of the facility area, the Gatuña is not present, and the Santa Rosa forms the subcrop under surficial sand and the Mescalero caliche.

Figure 11

Elevation of Top of Santa Rosa Formation (PZ & B Series Data)

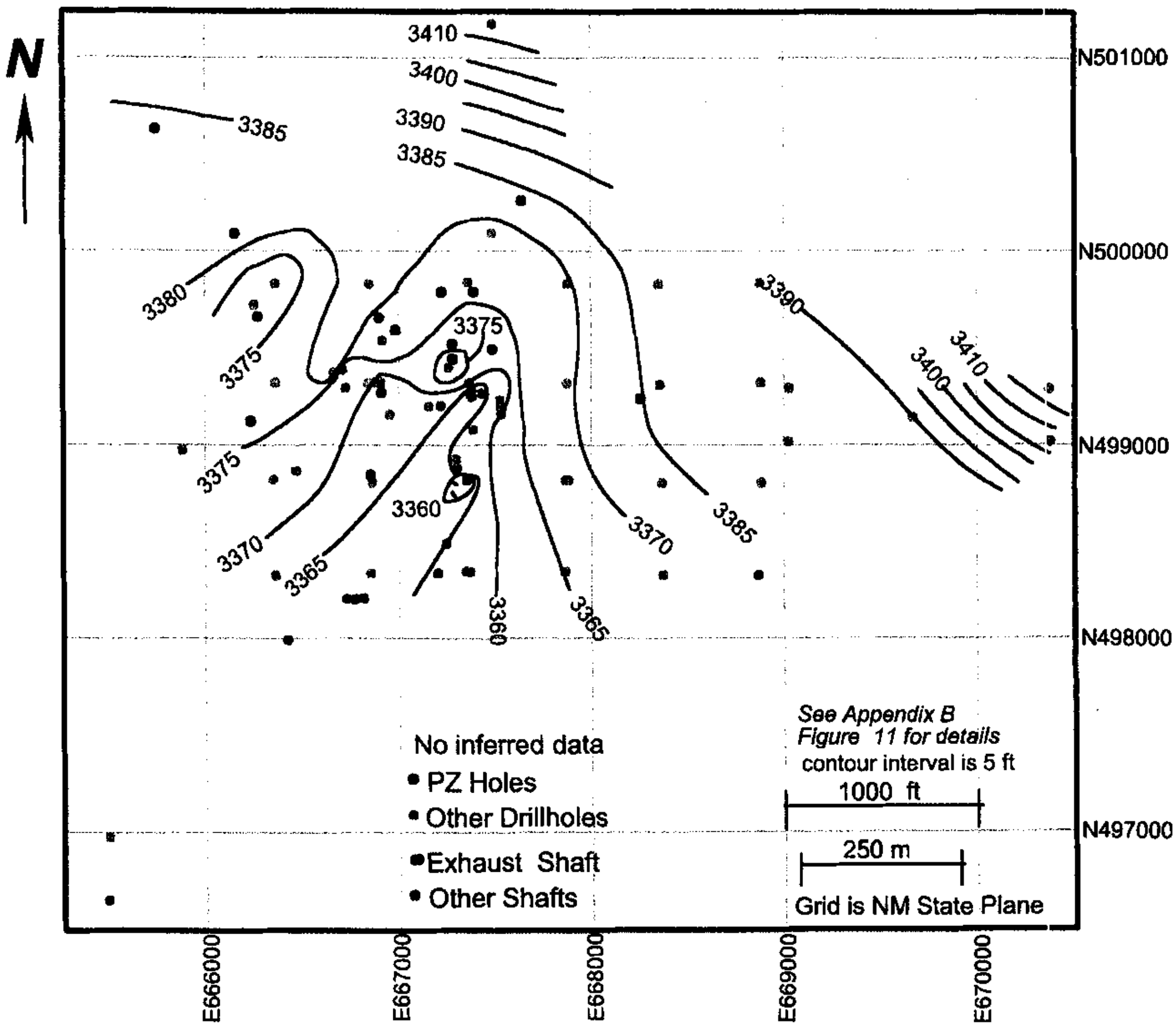


Figure 12

Elevation of Top of Santa Rosa Formation (PZ and Inferred B Series Data)

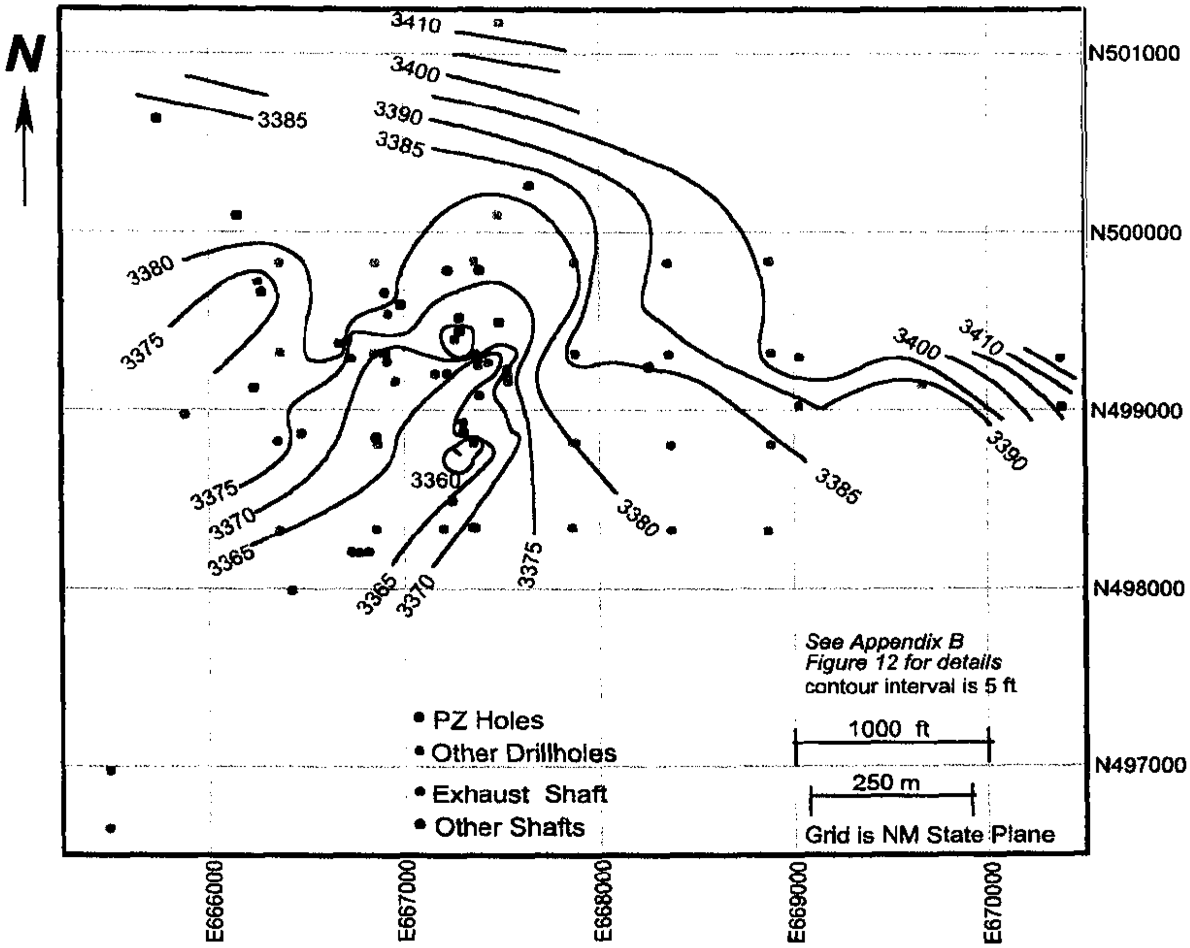
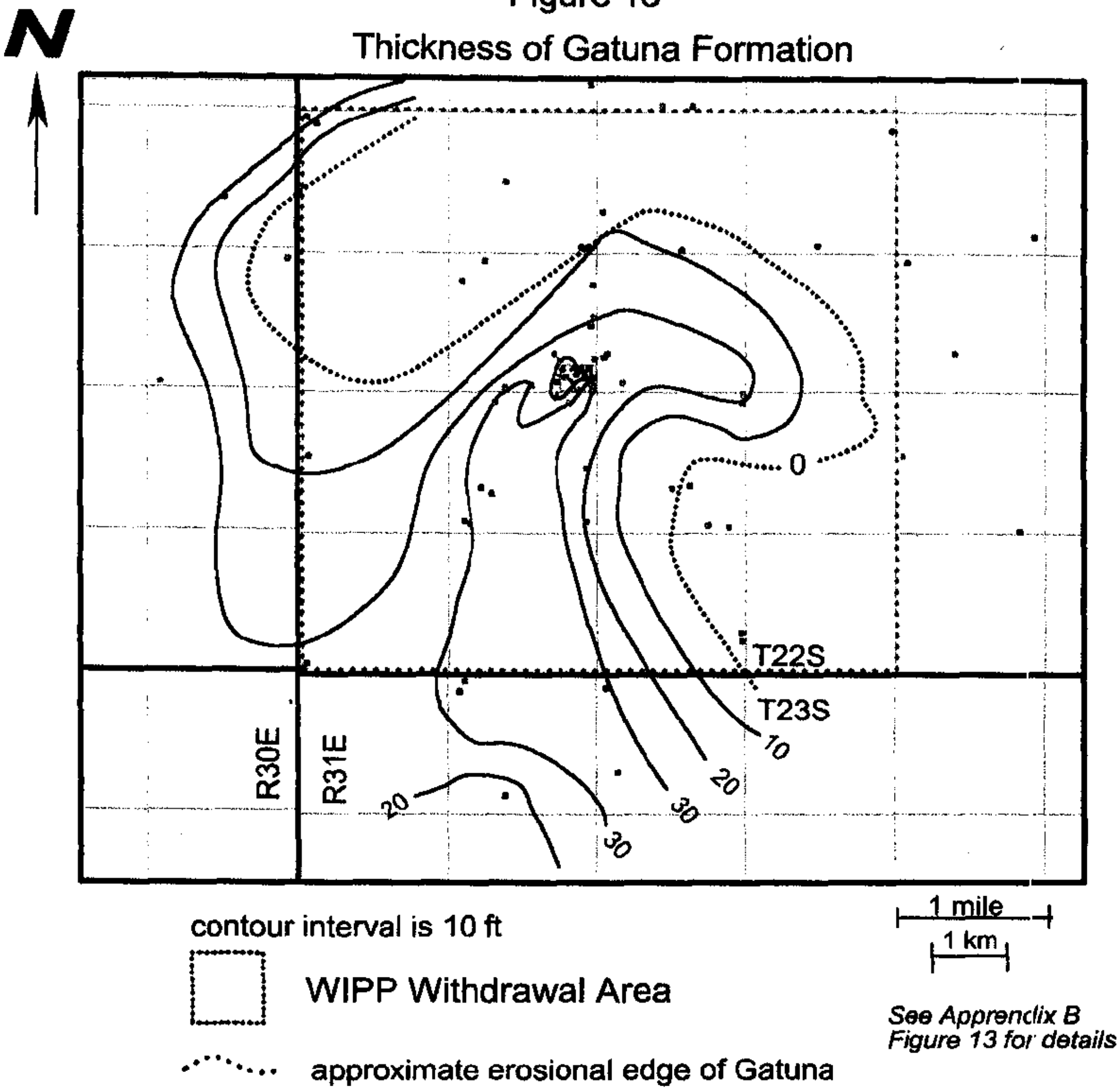


Figure 13

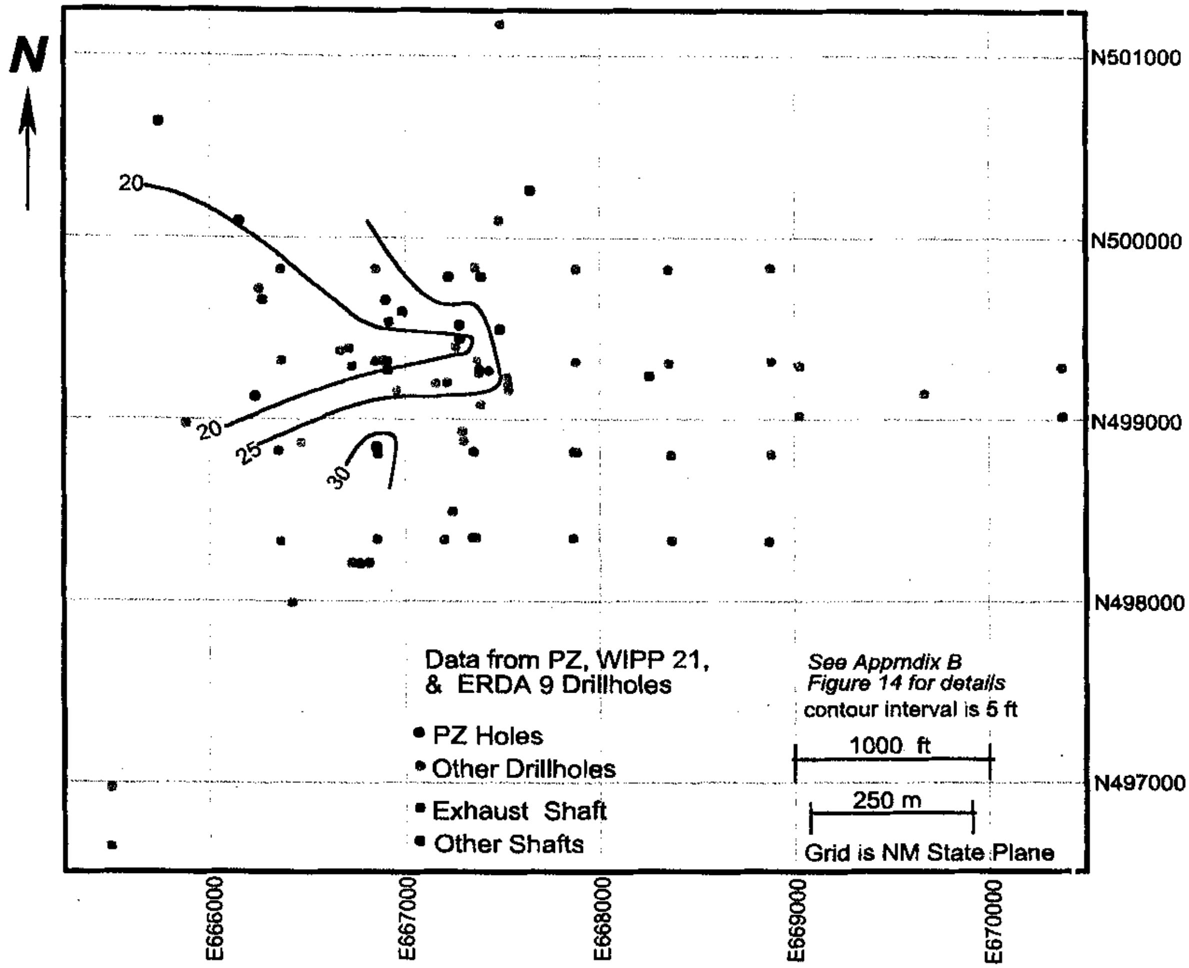
Thickness of Gatuna Formation



The Gatuña ranges from 19 to 31 ft thick in drillholes at the location of the surface facilities (Figure 14). The surface of the Santa Rosa was eroded by drainage to the south and southwest before the Gatuña began to accumulate in this area. Thinner Gatuña under the western area of the surface facilities is likely due to more recent erosion and erosion before the Mescalero began to form.

Figure 14

Thickness of Gatuna Formation



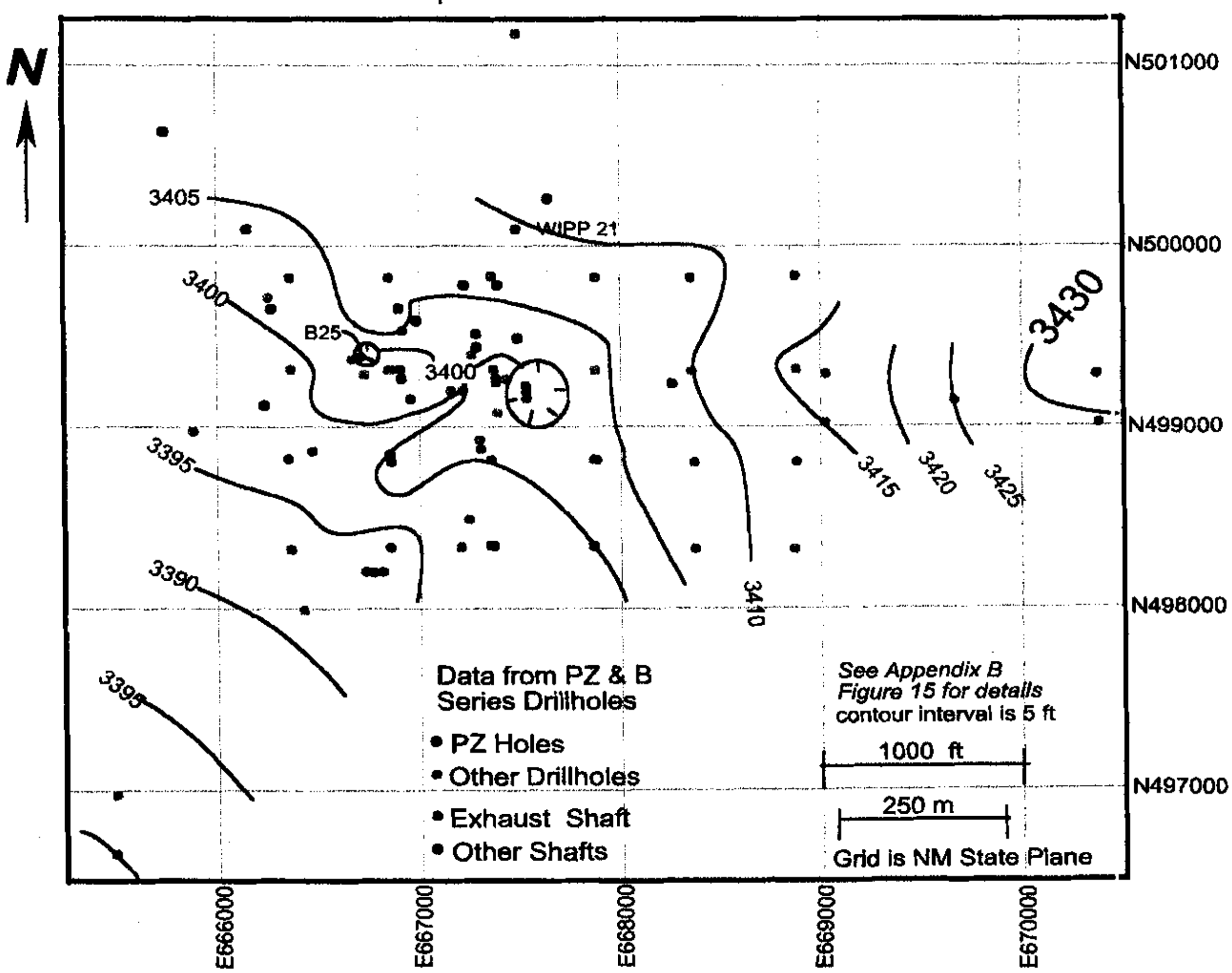
It is clear from drilling logs of the B series holes that the contact between Gatuña and Mescalero caliche for that work was distinguished differently from the current study and from most of the other site drillhole logs. In the B series drillholes, the Mescalero was continued downward through the zone where carbonate dominated or was at least quite significant. The Mescalero is commonly between 10 and 20 ft thick, as differentiated by this criterion in the B holes. The Mescalero is about 3 ft thick in other studies as well as for the PZ holes because the Gatuña is "picked" at about the first identifiable Gatuña sandstone. The B hole data are not equivalent to PZ data, they were not used to construct the map.

Mescalero Caliche Data

The Mescalero is generally present across the site and is noted in basic data reports for various drillholes. Only the elevation map of the top of Mescalero for the vicinity of the site facilities was constructed (Figure 15). Data from the B holes as well as current drilling are comparable.

Figure 15

Elevation of Top of Mescalero Caliche



As expected, Mescalero data generally conform to the topography of the area at the site, rising to the east and north. The most dramatic feature is an elevation low around 3 drillholes of the B series about 200 ft southeast of the exhaust shaft. This corresponds to a topographic low with more dense vegetation observable on aerial photos (Figure 16) taken before development of the surface facilities at WIPP.

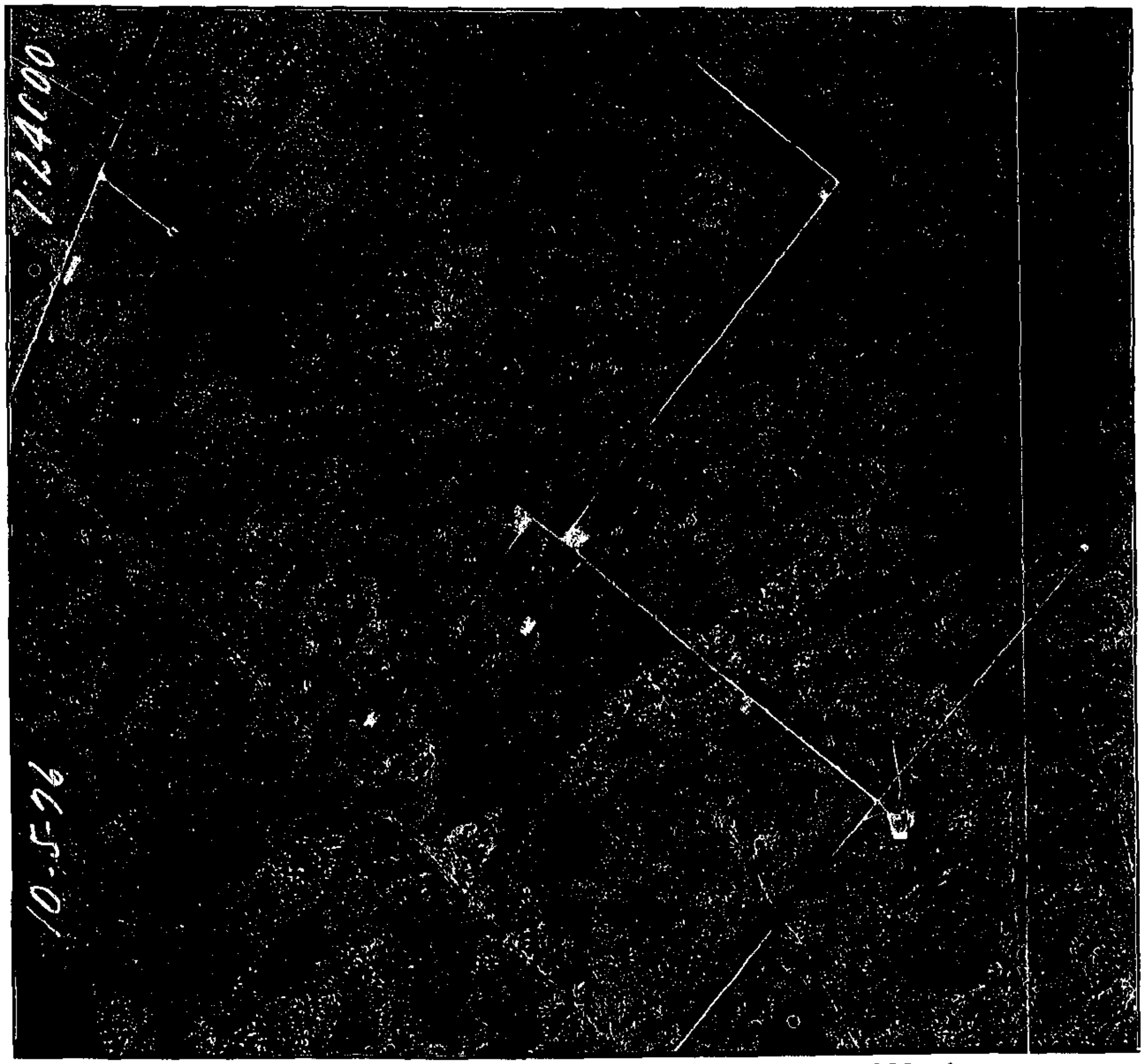


Figure 16. Aerial photo (10/5/76) of central WIPP site. Scale 1:24000. Arrow near center points to dense vegetation at location of topographic low and low on Mescalero caliche (see Figure 16). ERDA 9 drilling pad to left of central arrow.

Surface Sand and Berino Soil

The surficial sediments above the Mescalero were mapped for the design studies prior to construction. The main features of a map of thickness of this sand (Bechtel, 1979, figure 2) is a thick area that corresponds to the low on the Mescalero caliche and thinner sands to the west and southwest. Because there are very local differences associated with dune and interdune areas, no conclusions are based on these sand distributions.

OTHER DATA RELATED TO PERCHED WATER

In order to better understand the various geological factors that may affect location and distribution of the water at shallow depths under the facility, I examined records for other information that may bear on this problem. While these data are neither as precise nor as directly relevant as some of the recent drilling data, they are helpful in understanding broader patterns. The drilling for the potash tests (Jones, 1978) is used as the data base because it provides a reasonably consistent data set with respect to drillhole logging techniques, drilling methods, and descriptions. Some of the other WIPP drillholes near the WIPP site supplement the data from the potash drilling.

Long study of the WIPP site consistently demonstrates that the rocks above the Rustler are not saturated, though apparentlyirregular zones of perched water have been encountered. As porosity is a necessary factor for perched water, I examined phenomena that may signify porosity zones in the shallow subsurface. Examples are reports of cementing minerals, levels of drilling fluids during geophysical logging, loss of circulation, and resistivity changes.

Presence of Sulfate in Dewey Lake

Sulfate occurs in the Dewey Lake most visibly as fillings of fractures (e.g., Holt and Powers, 1990). In addition, Holt and Powers (1990) reported a cementation change in the AIS at a map depth of 164.5 ft (183 ft below surface) that coincided with the uppermost detectable gypsum fracture fillings. Though not analyzed further, Holt and Powers (1990) suggested that the cement was probably anhydrite. The Dewey Lake just above this cementation change was moist in the AIS, suggesting that the cementation change can perch available water if it infiltrates to that depth. For this analysis, I used reported gypsum, which is almost certainly from fracture fillings, as a proxy for this cementation change because of the relationship in the AIS.

I plotted the elevation of the uppermost reported sulfate (Figure 17) as an estimate of trend of the cementation/fracture filling across the WIPP site. The map includes an area along the eastern part of the map where the top of first reported sulfate is high, above 3200 ft. There are also high areas in the north and western parts. A low area trends from near the site center to the south-southwest, and there is a low based on one drillhole at the south central edge of the map.

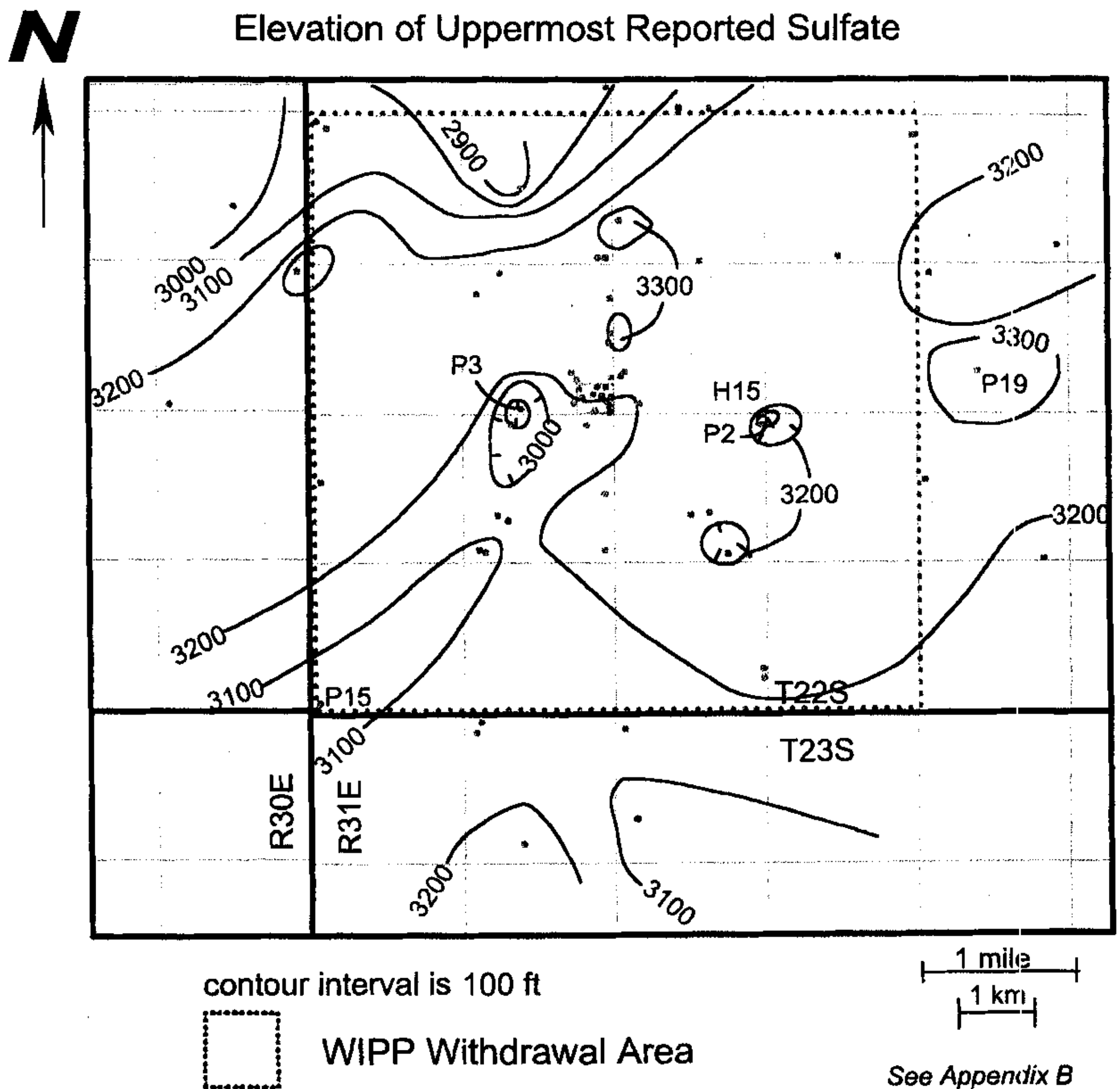
This map should not be overinterpreted. There is a difference of about 140 ft in the first reports of gypsum in two adjacent drillholes (P2, H15; Figure 4) in the east-central part of the map. This is most likely a consequence of a factor such as how the drilling was returning cuttings to the surface at any particular time. The main features are the broad high areas and the lows along the northwest corner and south of the facilities, and they are indicated by several drillholes rather than a single data point.

The top of the Dewey Lake is somewhat irregular compared to the general eastward dip on underlying units. To the east and northeast, gypsum is stratigraphically higher in the Dewey Lake. At P19, gypsum was reported in the lower Santa Rosa. West of the site center, there are also some drillholes in which the gypsum is stratigraphically high. To the northwest and in the south central part of the map, gypsum is progressively lower in the Dewey Lake; at P15, in the southwestern corner of T22S, R31E, the Dewey Lake does not appear to have gypsum at all.

As a first approximation, gypsum in the Dewey Lake is believed to signal a vertical change in porosity due to cementation that can retard further infiltration and result in perched water. This change corresponds generally to a position close to but below reports of water in the Dewey Lake in the southern part of the site area.

Figure 17

Elevation of Uppermost Reported Sulfate



See Appendix B Figure 17 for details

Fluid Level During Logging

The fluid level during logging is a function of factors such as rock permeability, drilling techniques (including adding material to reduce loss of drilling fluids), and adding fluid to the drillhole before logging. While there is no information about the potash drilling that allows reconstruction of all of these factors, the methods of drilling were the same, and the logging target was the Salado. It is less likely that, for example, additional fluid was added to the hole during logging to maintain the level to near the surface. As in the review of data about gypsum, trends are more likely to be real, while a single drillhole might be atypical because of a variety of events preceding and during geophysical logging.

The fluid level was reported explicitly for a few of the potash drillholes (Jones, 1978). The neutron and density log responses for the drillholes indicate depth of water during logging; the only ambiguous drillhole was P19.

The map pattern of fluid levels during logging (Figure 18) shows high areas to the east and along the west, with a low trough trending northwest-southeast across the southern part of the site.

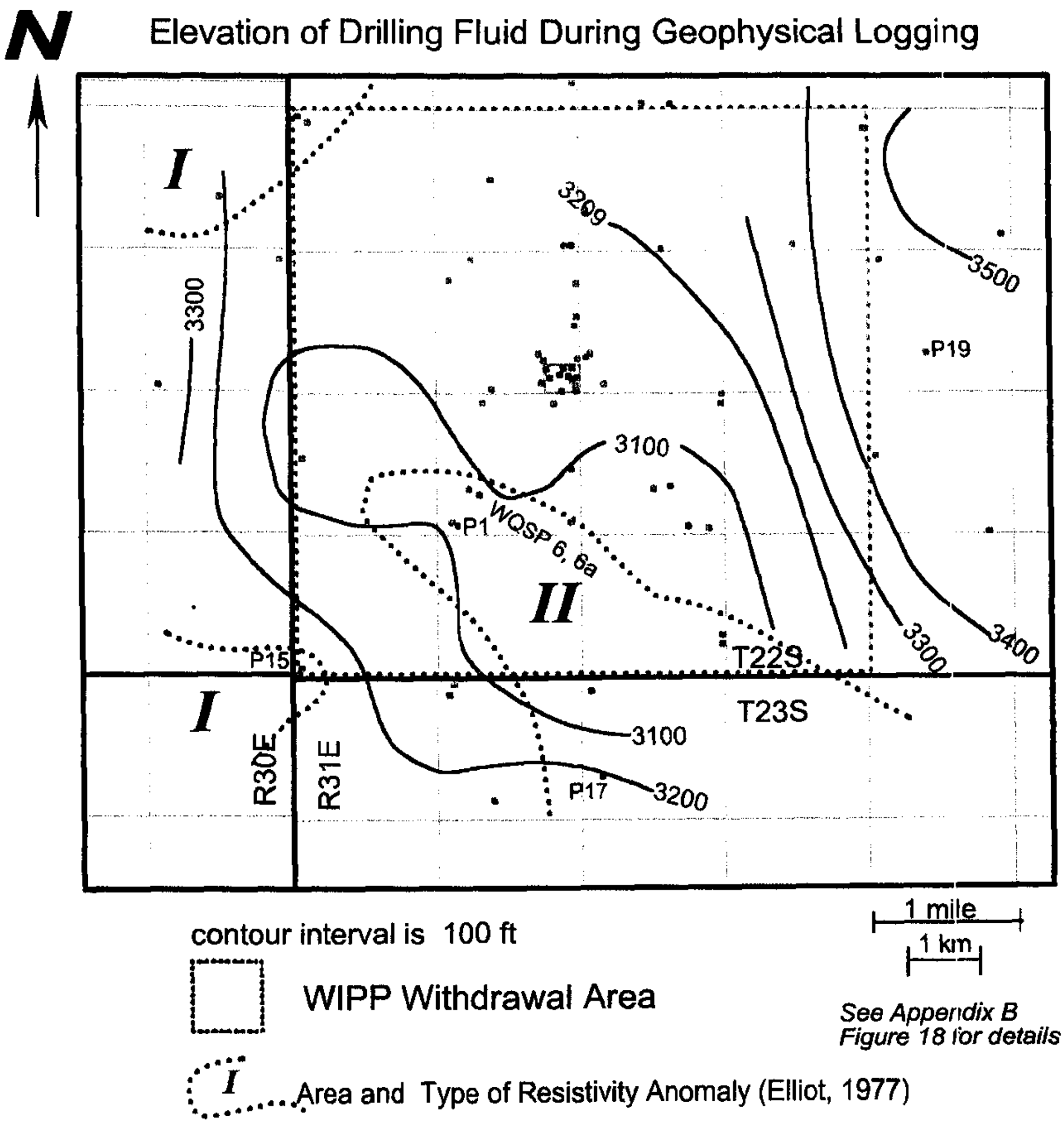
Along the eastern side of the map, the logging water remained close to the surface in a position stratigraphically equivalent to the upper Santa Rosa. The high elevation of logging water along the western side and southwestern corner of the map is the top of the Dewey Lake, also near the ground surface. Along the low trough, the top of the logging water was commonly 200 to 300 ft below the top of the Dewey Lake.

Loss of Circulation/Reported Water/Resistivity Data

Along with information from the potash drilling, basic data reports for most other drillholes in the map area were examined, and loss of circulation was indicated at relatively shallow depths in several drillholes (Table 2). While loss of circulation indicates zones of relatively greater permeability, it is again only useful as an indicator of trends. Drilling techniques varied for many holes, and air drilling doesn't respond in the same manner as drilling with water or brine.

Figure 18

Elevation of Drilling Fluid During Geophysical Logging



As a number of the potash holes were drilled with air through the upper section, encounters of water were more likely to be observed and reported. Water was reported in the Dewey Lake from three drillholes (P1, P15, P17, noted on Figure 17) during potash exploration, but none of the drillholes was completed as an observation or test hole for this water. These drillholes are all in the southwestern part of the map. More recently, WQSP6 (noted on Figure 18) encountered water in the lower part of the Dewey Lake as well at a location less than a mile from P1.

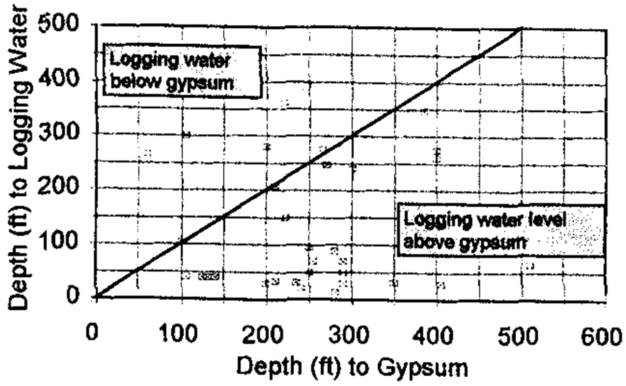
A major resistivity survey of the WIPP site was conducted in 1976 and 1977 (Elliot, 1977) as part of site characterization. Three larger areas with anomalously low resistivity were identified; they were classified as type I and II anomalies (Figure 18). Elliot (1977) inferred that the type I anomalies, located in the northwest and southwest corners of the studied area, were associated with a dissolution front and water. The lobate type II anomaly is oriented northwest to southeast and was believed to reflect an area of greater porosity. Elliot suggested that this anomaly reflects "an increase in porosity or water-bearing properties of perhaps the upper Salado, definitely the Rustler Formation and maybe even the lower part of the Dewey Lake Formation." All four of the drillholes (P1, P15, P17, WQSP6) that encountered water in the Dewey Lake are in the type I and II resistivity anomalies. [Note that the main differences between "type I and II" anomalies is in the interpretation, not in the geophysical response.]

Discussion of "Other Data"

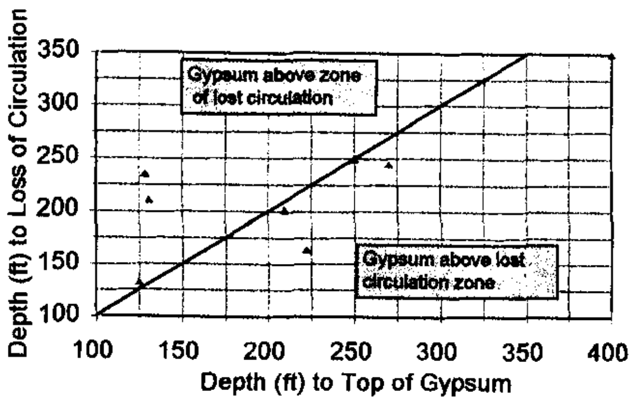
In principle, the change in cementation of the Dewey Lake, fluid levels during logging, loss of circulation, and occurrences of water in the shallow subsurface should show some relationship. The three features of cementation, fluid levels, and loss of circulation (Figure 19a,b,c) (Table 2) show little relationship among these variables. The maps (Figures 17, 18) are a better indicator of some trends.

Figure 19

A. Logging Water vs Gypsum



B. Gypsum vs Circulation Loss



C. Log Water vs Loss of Circulation

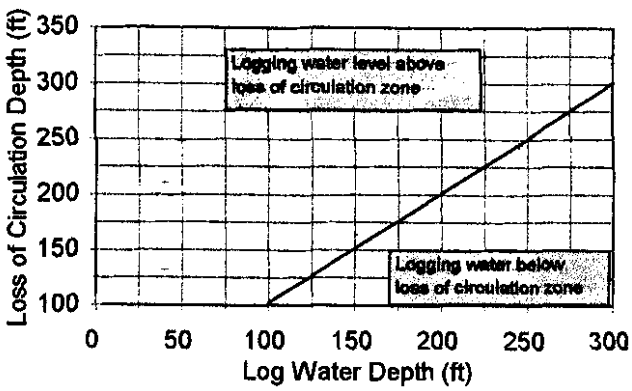


Table 2

Data for Figure 19A,B,C

Drillhole Name	Top of Gypsum	Top of Log Water	Lost Circulation Zone
P1	270	245	245
P2	385	345	
P3	400	260	
P4	245	382	
P5	265	276	
P6	105	306	
P7	210	208	
P8	200	280	
P9	250	395	
P10	255	70	
P11	350	32	
P12	60	266	
P13	300	240	
P14	105	40	
P15	235	32	
P16	100	104	
P17	280	88	
P18	290	30	
P20	405	30	
P21	280	14	
e9	222	150	164
w12	199	30	
w13	510	65	
w18	250	50	249
w19	131	40	211
w21	210	35	
w22	210	35	202
w33	400	274	350
w34	290	70	
h11b3	122	458	
h11b4	240	20	
h12	129		235
h14	220	360	
h15	250	95	
h16	140	40	
h17	290	50	
h18	125	40	132

Note: All data in feet below ground.

Logging fluid levels indicate that in the east and northeast of the map area, there are few porous zones for the fluid to leak into in the shallow subsurface.

The most striking relationship (Figure 18) is between the 3 factors of logging fluid elevations, areas with anomalously low resistivities for the area (Elliot, 1977), and occurrences of water within the Dewey Lake. All of the WIPP holes that encountered Dewey Lake water in the southern area are clearly associated with the resistivity anomaly. And the outline of anomaly II is very similar to the low area on drilling fluids. The resistivity anomalies also correspond well with low elevations of uppermost sulfate in a southeasterly trend as well as at the southwestern corner of the WIPP site. The very low elevation of sulfate in P3 near the center of the site doesn't correspond to resistivity anomalies. That point is anomalous with respect to other sulfate data, and the uppermost sulfate may have been missed.

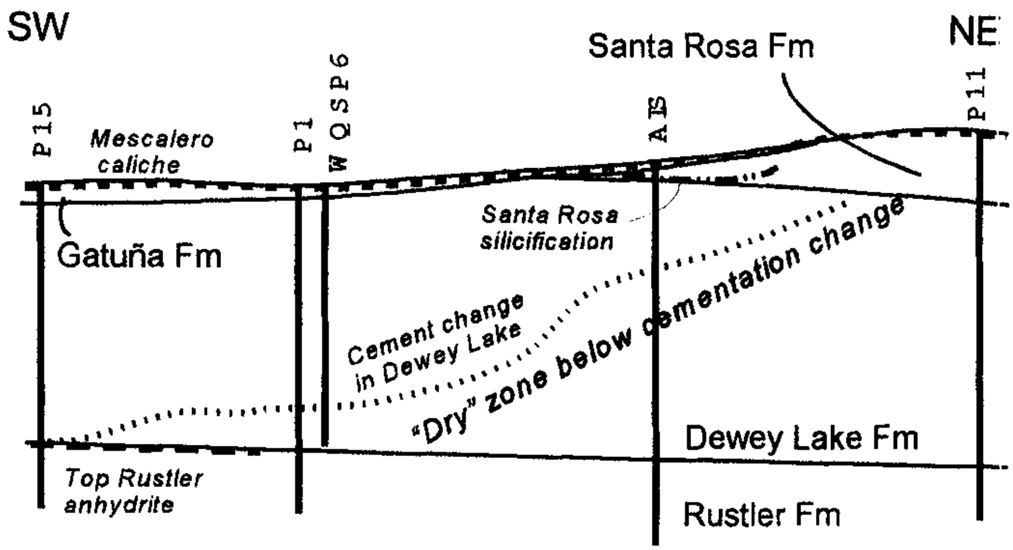
HYPOTHESIZED PERCHING ZONES ACROSS WIPP

The combination of rock types and observed moisture suggests that there are four zones (Figure 20) from the top of Rustler that may serve as perching horizons if water infiltrates to the zones.

The lowermost perching zone (Figure 20) exists across the site because of the relative impermeability of the uppermost anhydrite of the Rustler. It is likely only effective around the southern and western margins of the WIPP site (e.g., P15) where stratigraphically higher horizons are not impeding infiltration.

The next higher perching zone is hypothesized to be a cementation change within the Dewey Lake, such as Holt and Powers (1990b) observed at the AIS. I took the uppermost sulfate as an approximation for this cementation change based on the AIS data. Sulfate is observed progressively higher stratigraphically across the site from southwest to northeast, with an area corresponding generally to the resistivity anomaly and water occurrences that roughly parallels dip. From the

Figure 20
Diagrammatic Representation of Perching Zones Hypothesized Across the WIPP Site



middle of the site to the east, this perching zone may be less involved as overlying zones reduce infiltration. At the site center, this perching zone appears also to have affected water infiltrating from surface halite tailings piles, considering the report of a second wet zone in the AIS.

Around the WIPP surface facilities, we encountered a hard drilling zone or zones in the lower Santa Rosa in association with the shallow water. As the uppermost Dewey Lake was clearly dry in several PZ drillholes, the finer grained siltstones and claystones of the Dewey Lake likely combined with indurated lower Santa Rosa to create a perched zone.

The surface sands above the Mescalero caliche are very commonly damp, as was noted both during our drilling program for the PZ holes and for the design studies (B series drillholes). This moisture from surface precipitation ordinarily only infiltrates to about the level of the Mescalero; this is the source of this particular unit. Well formed Mescalero will impede infiltration locally, but it is unlikely to form a strong perching zone. If water ponds frequently in a area, the eventual result will be to dissolve the carbonate and move it deeper through infiltration. Though I list the Mescalero as a potential perching zone, it would only be a short term barrier from a geological perspective.

CONCLUSIONS

Water encountered during drilling of the PZ holes appears to be restricted to the lower Santa Rosa. Sandstones in this zone are commonly fine to coarse grained and quite porous. While some drillholes show thicker greenish-gray sandstone at about this level, the saturated sandstone in other drillholes is generally brown. One characteristic of the lower Santa Rosa is hard drilling zones, and chips from these units have little carbonate. There is likely some silicification. The greenish-gray reduction and silicification are undoubtedly ancient features and are unrelated to the water currently at this level. The water is perched on the upper Dewey Lake, which was clearly dry in several of the drillholes.

The Santa Rosa also includes interbedded siltstones and claystones that appear variable in thickness and distribution, though rotary drilling through the Santa Rosa in most drillholes limits estimates of the thickness and extent of these less permeable intervals of the Santa Rosa. Cores from some of the drillholes show relationships and variation consistent with fluvial depositional environments interpreted for the Santa Rosa. These zones will affect estimates of the saturated thickness and fluid volume in the saturated zone.

Review of shaft data and facility design drillholes demonstrates that the Santa Rosa under the site facilities area was not saturated through 1984. The water encountered here postdates 1984, and the sodium chloride content shows that at least some infiltrating water contacted surface salt piles or other sources of salt at

WIPP. By 1988, the AIS had wet zones with salt efflorescence in the Santa Rosa and also the Dewey Lake.

Less precise data about sulfate cements, fluid levels during logging, loss of circulation zones, and resistivity anomalies were reviewed as guides to broader site characteristics to explain the shallow water at the site facilities. There are likely several perching zones (uppermost Rustler anhydrite, cement change in Dewey Lake, silicification/induration of lower Santa Rosa, and, temporarily, the Mescalero caliche) that are involved at different locations and to differing degrees across the site, depending on the geologic history of erosion and exposure.

To the south and west of the area investigated during this study, the Santa Rosa pinches out due to erosion prior to Gatuña deposition. If the shallow water in the Santa Rosa moves in that direction, the Santa Rosa will cease to be a perching horizon, and the water will seek the next perching horizon, which is most likely the cementation change in the Dewey Lake.

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APPENDIX A

Field Geological Logs
for PZ Series Drillholes

GEOLOGIC ROCK CORING LOG

HOLE ID: PZ-1	LOCATION: North of Exhaust Shaft - WIPP	
DRILLING DATE: 6/23/97	EXCAVATION DATE:	NORTHING:
DRILLING DIRECTION: Down	DRILL METHOD:	EASTING:
DRILL MAKE/MODEL:		COLLAR ELEVATION:
HOLE DIAMETER: 3¼ ID 6 OD (IN)	HOLE DEPTH: 67.5 (FT)	DRILLING CREW: Geoprojects
LOGGED BY: DW Powers	DATE: 6/23/97	SCALE: 1 inch = 2 ft SHEET 1 OF 4

RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH (ft)	LITHOLOGY	DESCRIPTION	REMARKS
augered			13–29 (15, 17, 19, 21, 23, 25, 27, 29)		Probable fill of eolian sand, some pebbles, pieces of caliche to 11 ft depth. All moist, some calcareous clay @ about 9 ft. Top of undisturbed Gatuña Fm @ 11 ft. Siltst, argillaceous, sandy zones. Very calc. at top, mod calc. downward with some non-calc. zones. Gen. 2.5YR 6/6 light red. 11-34.	Begin about 3pm. Augered to 15 ft (down location augered by hand). Augering to estimat. 34' before coring.

GEOLOGIC ROCK CORING LOG

HOLE ID: PZ-1	LOCATION: Nof exhaust shaft		
DRILLING DATE: 6/23-24/97	EXCAVATION DATE:	NORTHING:	
DRILLING DIRECTION: down	DRILL METHOD:	EASTING:	
DRILL MAKE/MODEL:		COLLAR ELEVATION:	
HOLE DIAMETER: 6" OD 3¼" ID (IN)	HOLE DEPTH: 67.5 (FT)	DRILLING CREW: Geoprojects	
LOGGED BY: DW Powers	DATE: 6/23/97 & 6/24/97	SCALE: 1" = 2ft	SHEET 2 OF 4

RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH (ft)	LITHOLOGY	DESCRIPTION	REMARKS
augered			29		Gatuña Fm., cont	
			31			
			33			begin coring 4:10 p
1	~1'	34.5			included plug from augers. root casts, <<1 mm dia, MnO_2 staining.	
2	~4'	NA	35		Ss, silty, argill, and siltstone, sandy, argill. 2.5YR3/6 dark red. Gen poor to mod induration, core doesn't hold together well. Porous, some scattered bioturbation and MnO_2. Sand is fine to very fine, generally subround, mod. sorting.	
			37	MnO_2	Calc. zone, hard, pebbles from Santa Rosa - black chert. Small pores, root casts.	
					Hard, calc. ss. @ ~38.7, w/crystalline cement and 1 mm. clayst. clasts	
		39.0	39	no recovery	Gatuña Fm (possible that Santa Rosa begins @ 37.5 ft; matrix appears ≈ Gatuña to ~40').	
3	~2.0				Santa Rosa Fm	
			41			
					gg moist 42.1-42.4 5YR8/1 white	
			43		Arg. sltst., slightly sandy, calc 10R4/6 red.	
		44.0				end drilling at 44.0 @ 5pm. water @ 41.82 ft bgs @ ~8 am 6/24/97
			45			

GEOLOGIC ROCK CORING LOG

HOLE ID: Pz-1	LOCATION: N. of Exhaust Shaft		
DRILLING DATE: 6/24/97	EXCAVATION DATE: 6/24/97	NORTHING:	
DRILLING DIRECTION: Down	DRILL METHOD:	EASTING:	
DRILL MAKE/MODEL:		COLLAR ELEVATION:	
HOLE DIAMETER: (IN)	HOLE DEPTH: 67.5 (FT)	DRILLING CREW: Geoprojects	
LOGGED BY: DW Powers	DATE: 6/24/97	SCALE: 1" = 2 ft.	SHEET 3 OF 4

RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH ( )	LITHOLOGY	DESCRIPTION	REMARKS
4	52"	NA	45–49		Ss. w/thin zones siltstone. Sand is v.f.-med, subround, mod. sorting, ~1% mica (mainly biotite). Poor to mod induration, mild effervescence. Thin bedding (2-4 mm) with variable cementation. (44'-49.5)	Core 4 moist.
5	~4	49.0–49.5	49			
no core			49.5–52		Ss, silty, dark brown, poor recovery - strat position probable	recovered soupy mud on top of core
6	3'	52.0	53	7.5YR 6/4 light brown; brownish gray to gg zone; 5YR 7/2	Ss, generally light brown to greenish-gray from about 51.5-54.3 Sand gen. fine to fine, some med, subround to round, mod. sorting, slight fining upward. Bed effervesces slowly. Well cemented. Breaks horiz. into 1/4 to 10" pieces	slow drilling
7	6"	54.0–54.5			SS, dk brown w/ white cemented pores, gen. med sand, subround. Calcareous, brittle - discs ~1/8"?	
cement			55			slow drilling - clean hole out - did not log material recovered.
8	2'	NA	57	Dewey Lake Fm 2.5YR 4/4	Interbedded dark brown siltstone and silty claystone w/ greenish gray reduction spots. Calcareous - slow eff. Core recovered in pieces. Some thin layering observed, v.f. ss. layers	
9	5'	NA	59–61	-gg		

GEOLOGIC ROCK CORING LOG

HOLE ID: PZ-1	LOCATION: N. of Exhaust Shaft	
DRILLING DATE: 6/24/97	EXCAVATION DATE:	NORTHING:
DRILLING DIRECTION: Down	DRILL METHOD:	EASTING:
DRILL MAKE/MODEL:		COLLAR ELEVATION:
HOLE DIAMETER: 6" OD 3¾" ID (IN)	HOLE DEPTH: 67.5 (FT)	DRILLING CREW: Geoprojects
LOGGED BY: DW Powers	DATE: 6/24/97	SCALE: 1" = 2ft SHEET 4 OF 4

RUN NUMBER	RECOVERED LENGTH (ft)	RQD	DEPTH ( )	LITHOLOGY	DESCRIPTION	REMARKS
9	5'		61–63		V. thin laminae (fissile) silty claystone 61-63.5; fissile; 88. D.L. shows some slight fining upwards cycles from sandy siltst. or siltstone to silty claystone.	dry
10	4'	67.5	65–67		88; 87; ← diagrammatic rep. of fining upward cycle thicknesses.	TD 67.5 @ 12:08 pm

GEOLOGIC ROCK CORING LOG

HOLE ID: PZ-2	LOCATION: East of Exhaust Shaft Bldg.		
DRILLING DATE: 6/24/97	EXCAVATION DATE:	NORTHING:	
DRILLING DIRECTION: Down	DRILL METHOD:	EASTING:	
DRILL MAKE/MODEL:		COLLAR ELEVATION:	
HOLE DIAMETER: 6" OD 3¾" ID (IN)	HOLE DEPTH: 65 (FT)	DRILLING CREW: Geoprojects	
LOGGED BY: D.W. Powers	DATE: 6/24/97	SCALE: 1" = 4ft	SHEET 1 OF 3

RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH (ft)	LITHOLOGY	DESCRIPTION	REMARKS
auger only			0		light brown eolian sand/fill to 6', slightly reddish brown from ~6' - ~9'	spud 4:55 pm
			4			
			8		Berino?	
					Mescalero caliche	
			12		Gatuña - highly calcareous sand, ss, f to coarse, poorly sorted	
			16			
					light reddish brown	
			20			5:25 pm.
					med reddish brown	
			24			
			28			
			32			

GEOLOGIC ROCK CORING LOG

HOLE ID: PZ-2	LOCATION: East of Exhaust shaft		
DRILLING DATE: 6/24/97-6/25/97	EXCAVATION DATE:	NORTHING:	
DRILLING DIRECTION: Down	DRILL METHOD: Auger/Auger with split spoon	EASTING:	
DRILL MAKE/MODEL:		COLLAR ELEVATION:	
HOLE DIAMETER: 6" OD 3¼" ID (IN)	HOLE DEPTH: 65 (FT)	DRILLING CREW: Geoprojects	
LOGGED BY: DW Powers	DATE: 6/24/97-6/25/97	SCALE: 1" = 2ft	SHEET 2 OF 3

RUN NUMBER	RECOVERED LENGTH ( )	RQD	DEPTH (ft)	LITHOLOGY	DESCRIPTION	REMARKS
end augering			32–34			end augering @ 5:45p. lightning
1	6"		34		Ss, pebbly (to 1"). Sand mainly f-c, poorly sorted, subang to subround, <1% opaques, little biotite. Pebbles of ss (intraclasts, some prob Santa Rosa), and chert granules. Friable to poor induration, porous, gen non-calc. to ~37.5'. Calcareous, MnO_2 staining 37.5 to 39.0	begin 8:20am 6/25/97
2	3½ ft	NA	36–39.0		~2.5YR 4/6 non calc. calc. Slight MnO_2 ~2.5YR 5/6-4/6 Gatuña	
3	3'	1 piece 1' long	39.0–42		Santa Rosa — Sandstone, dark reddish brown, well indurated, slightly calc, grains show prob. silica overgrowth for slight add. cementation. Sand gen f, mod well sorted, well rounded to subround, ~1% opaques, includes biotite. Laminae ~2-3mm thick, parallel bedding 39-42; 2-4mm from 46.5-48; 3-5mm from 48.5-52. 2.5YR 3/4 Dark reddish Brown Zone from ~42-44 shows intra clasts of SR ss in reddish brown sandy siltstone.	possible moistening of core
4	2'	friable to pieces 2"	42–44.0		2.5YR 4/6 mottled 6/6	
5	4'	gen. friable	44.0–48		2.5YR 3/6 dark red - non-calc 2.5YR 4/4 slightly calc. thin lam. 2-4mm - 48	core moist top core ~45-46.5 harder drilling