Hydrologic Assessment of Shallow Subsurface Water

Waste Isolation Pilot Plant

Carlsbad, New Mexico

Prepared for **Washington TRU Solutions LLC**

December 18, 2008

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List of Acronyms

ac-ft	acre-feet
bgs	below ground surface
Cl	chloride
cm/s	centimeters per second
DBS&A	Daniel B. Stephens & Associates, Inc.
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
ft^2	square feet
ft/d	feet per day
ft/ft	foot per foot
ft/yr	feet per year
GCL	geosynthetic clay liner
GWQB	Ground Water Quality Bureau (NMED)
HDPE	high-density polyethylene
in/yr	inches per year
K_{sat}	saturated hydraulic conductivity
K_{θ}	unsaturated hydraulic conductivity
m/s	meters per second
mg/L	milligrams per liter
Na	sodium
NaCl	halite
NMED	New Mexico Environment Department
SPDV	Site and Preliminary Design Validation
SSE	Salt Storage Extension
SSW	shallow subsurface water
TDS	total dissolved solids
USGS	U.S. Geological Survey
WIPP	Waste Isolation Pilot Plant
WTS	Washington TRU Solutions LLC

Executive Summary

The hydrologic assessment presented in this report examines the shallow subsurface water (SSW) conditions at the Waste Isolation Pilot Plant (WIPP) site near Carlsbad, New Mexico. The hydrologic assessment was conducted on behalf of the U.S. Department of Energy (DOE) by Daniel B. Stephens & Associates, Inc. (DBS&A), under contract to Washington TRU Solutions LLC (WTS). The assessment provides an update to previous SSW investigations and examines the effects of infiltration controls that have been implemented to halt recharge to the SSW.

The goal of the SSW hydrologic assessment was to evaluate data collected since the installation of the infiltration controls for the purpose of updating the conceptual model of the important hydrologic processes controlling the SSW hydrologic system. The hydrologic assessment uses the complete monitoring record from 1996 to 2008 to examine the effects of infiltration controls installed in 2004 and 2005. The assessment considers the observed hydrologic responses that are evident from the monitoring to determine whether the infiltration controls are producing positive results. A comprehensive database was assembled to bring together all of the relevant monitoring data to analyze trends in SSW flow and water quality before and after infiltration control systems were put in place. The liners and covers that have been put in place will halt the primary SSW recharge; however, the infiltration controls will not eliminate the existing SSW lens, which will persist in the Santa Rosa sandstone and potentially migrate laterally or downward into the Dewey Lake redbeds.

The infiltration control systems require continued operation and maintenance in order to effectively manage on-site stormwater. The lined stormwater ponds that receive stormwater with elevated salinity (Salt Storage Extension and Salt Pile Evaporation Ponds) are designed for full retention through an inflow/evaporation water balance. The lined stormwater ponds that receive relatively fresh stormwater runoff (Detention Basin A, Pond 1, and Pond 2) are designed with evaporation capacities that are supplemented by using stormwater for irrigation of vegetation on the Salt Storage Area final cover.

A time-series analysis completed to examine SSW water level trends shows that the water table has risen since the first monitor wells were installed in 1996. Recharge causing a rising water table is correlated with precipitation rates. Water level rises occur 3 to 9 months after periods of heavy precipitation. The June 2008 measurements indicated a decline in water levels in most wells, potentially the first sign of a response to the infiltration controls; however, it is too early to reach a conclusion regarding a possible trend toward water level declines without a longer monitoring record. Monitor wells that appear to be at the fringes of the SSW saturated lens show rising water levels and increasing saturated thickness. In March 2007, saturation was detected for the first time in monitor well PZ-08, which had previously been dry. Water levels at the three new monitor wells installed in 2007 around the Site and Preliminary Design Validation (SPDV) pile suggest that the saturation found in this area is not directly hydrologically connected to the main SSW saturated lens.

The SSW water quality is dominated by highly saline brine that is representative of halite (NaCl) dissolution. Total dissolved solids (TDS) concentrations range from less than 10,000 milligrams per liter (mg/L) to as high as 245,000 mg/L. The highest TDS concentration is in monitor well PZ-13, installed in 2007 near the SPDV pile. Within the 15 monitor wells in the main SSW lens underlying the WIPP facilities area, higher TDS concentrations are found in the northern half of the site near the Salt Storage Area and Salt Pile Evaporation Pond. TDS concentrations are much lower in the southern half of the site, where low-TDS water recharged the SSW from stormwater retention ponds prior to installation of liners to prevent recharge. Sufficient time has not yet elapsed since installation of the liners to observe water quality changes that can be attributed to reduced SSW recharge.

Due to the implementation of the infiltration controls, the initially high moisture content of the vadose zone materials will gradually drain to lower moisture content. Calculations of moisture redistribution in the vadose zone beneath former recharge sources estimate the duration and magnitude of transient drainage providing continued moisture input to the SSW. Moisture redistribution calculations were completed for a 5-year duration for a range of vadose zone hydrologic properties. Based on likely hydrologic parameters that are representative of field conditions, a total of approximately 120 acre-feet of transient drainage is estimated to occur.

During the 3 years since the infiltration controls were completed in 2005, most of the rapid transient drainage should have occurred. Under all cases tested for variable hydrologic properties, transient drainage reaches slow (but continuing) rates beyond 3 years. The transient drainage volume is estimated to add approximately 12 to 33 percent additional water to the SSW and cause an estimated water table rise of between 8 feet over the immediate area around the former recharge sources and 2 feet over the entire SSW lens.

The primary benefit of implementing the infiltration controls is prevention of continued recharge that was predicted to continue increasing the SSW saturated volume. Due to the effect of transient drainage, water level field data do not yet show the expected positive effect of the infiltration controls to gradually reduce water levels.

1. Introduction

The hydrologic assessment presented in this report examines the shallow subsurface water (SSW) conditions at the Waste Isolation Pilot Plant (WIPP) site near Carlsbad, New Mexico. The assessment provides an update to previous SSW investigations and examines the effects of infiltration controls that have been implemented to halt recharge to the SSW. The hydrologic assessment was conducted on behalf of the U.S. Department of Energy (DOE) by Daniel B. Stephens & Associates, Inc. (DBS&A), under contract to Washington TRU Solutions LLC (WTS).

The hydrologic assessment focuses on updating the SSW conceptual model that was developed during previous investigations. Much of the investigation field work was completed in 1996 and 1997. In 2003, DBS&A completed a water budget analysis to quantify the recharge sources and characteristics of the SSW. Infiltration control systems were constructed in 2004 and 2005. The hydrologic assessment considers new monitoring data collected since the 2003 water budget analysis to determine the effects of infiltration controls on the SSW hydrology and water quality. The hydrologic assessment provides a comprehensive review of all SSW monitoring data from before and after implementation of infiltration controls to improve understanding of the effectiveness of the surface infiltration controls that have been implemented at WIPP.

The goal of the SSW hydrologic assessment is to update the conceptual model of the important hydrologic processes controlling the SSW hydrologic system. The assessment evaluates how the infiltration controls may be affecting SSW water levels, water chemistry, and the rate and direction of flow.

The overall purpose of the SSW hydrologic assessment is to support DOE efforts to ensure regulatory compliance at the WIPP and to provide information that will assist DOE decision makers in determining the efficacy of actions to control and monitor the SSW.

2. Hydrologic Assessment Methodology

The hydrologic assessment uses the complete monitoring record from 1996 to 2008 to examine the SSW conditions and the effects of the infiltration control systems since 2005. The hydrologic assessment considers the highly variable SSW water quality measured at monitor wells to evaluate the sources of recharge water quality and mixing of various waters that could lead to the SSW geochemistry observed. To examine the effects of infiltration controls, the assessment considers the observed hydrologic responses that are evident in the monitor well network to determine whether the infiltration controls are producing positive results.

The SSW hydrologic assessment includes the following components:

- A comprehensive database was assembled to bring together all of the relevant SSW monitoring data, including water level measurements, water quality monitoring, well construction details, geologic information, and climate data.

- A time-series analysis was completed using hydrographs that show the water level, total dissolved solids (TDS) concentration, and precipitation at each monitor well for the complete monitoring record.

- Maps showing water level elevation contours for the SSW monitor wells were prepared to show water level and flow direction changes at approximately annual time steps over the complete monitoring record.

- Maps showing TDS contours for the SSW monitor wells were prepared to show water quality changes at approximately annual time steps over the complete monitoring record.

- SSW geochemistry was evaluated based on water quality within the SSW monitor wells:
  - Charge balance was calculated to determine water chemistry data quality.
  - Saturation indices were calculated for the water quality at each monitor well to classify the water quality and mineral dissolution from recharge sources.

  – Durov plots were prepared to display water quality characteristics of major cations and anions, TDS, and pH.

- Moisture redistribution calculations were completed to estimate the rate of draindown of residual moisture beneath the infiltration controls in order to understand the rate and impact of moisture movement below the former recharge sources.

Each component of the hydrologic assessment is described in this report, followed by a discussion of the results.

3. Hydrologic Setting

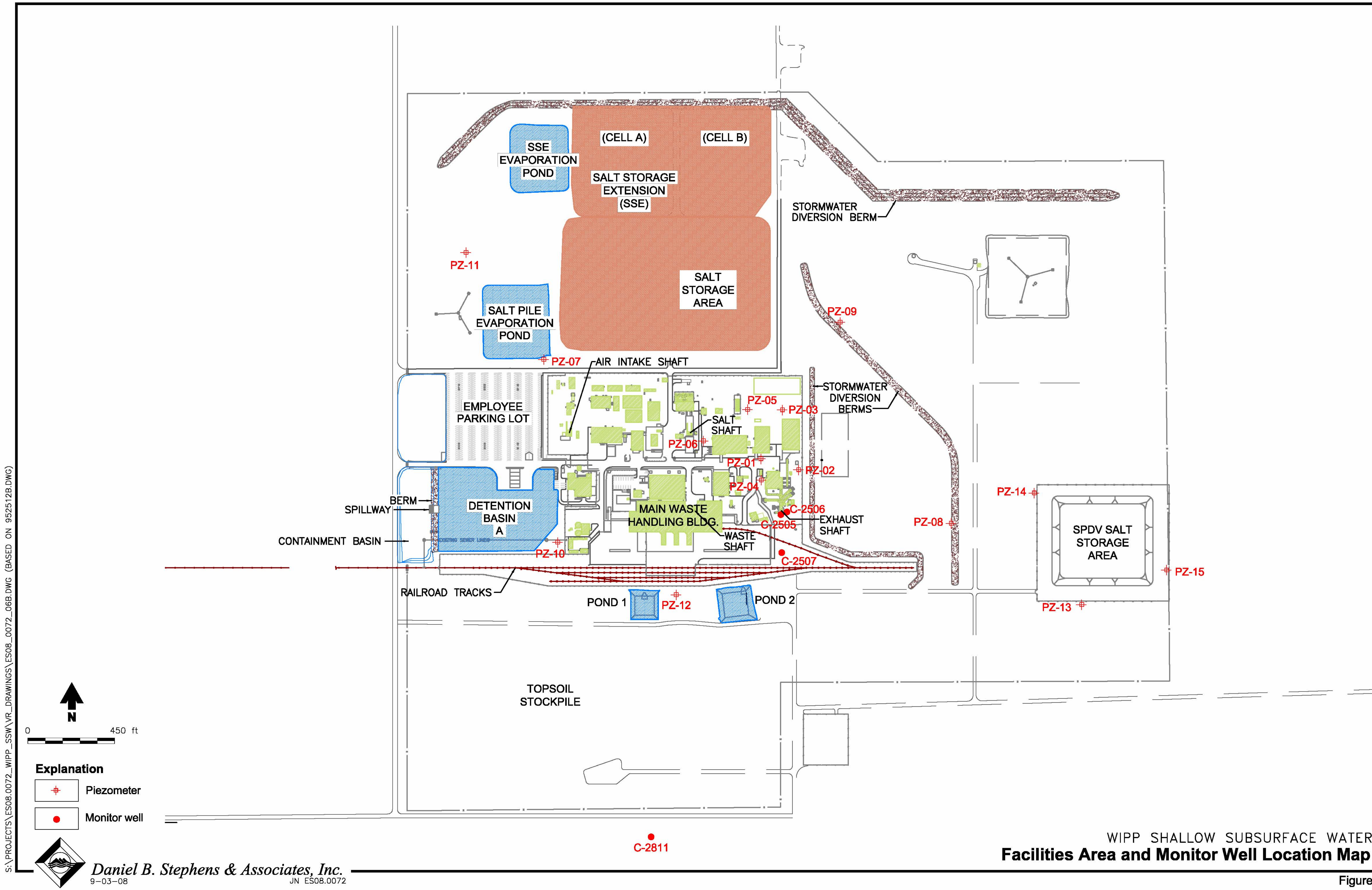
The WIPP site is located in eastern Eddy County, New Mexico, in a remote area 26 miles east of Carlsbad, New Mexico. The entire land withdrawal area for the WIPP site is 16 square miles, and the surface facilities area covers roughly 150 acres. A detailed site plan of the WIPP surface facilities is provided in Figure 1. An aerial photograph of the WIPP surface facilities area from 2005 is provided in Figure 2.

3.1 Climate and Physiography

The WIPP site is located in a semiarid region of the U.S. desert southwest. The average annual precipitation for Carlsbad, New Mexico is 12.22 inches per year (in/yr) based on records beginning in 1949 for the Carlsbad Federal Aviation Administration (FAA) Airport. Records of precipitation from the on-site WIPP weather station for 1986 to 2007 show an average annual precipitation of 13.48 in/yr. Annual evaporation from surface water for the Carlsbad area exceeds 98 in/yr (Mercer, 1983). Native vegetation consists of mesquite, scrub oak, and other plants typical of the northern Chihuahuan Desert (Mercer, 1983). Surficial soils at the WIPP site are characterized by sand and dune sand deposits (Campbell et al., 1996).

Climate data used in the hydrologic evaluation were obtained from the Carlsbad FAA Airport weather station and an on-site weather station (Table 1). The detailed climate data required for some analyses are available only for more recent years; therefore, data from various time frames were used in the water budget analysis (Table 1). The primary precipitation data used for the hydrologic evaluation are monthly precipitation totals from the WIPP weather station from 1995 to 2008.

The long-term record of precipitation data from the Carlsbad FAA Airport and the WIPP weather station is illustrated in Figure 3. As shown in this figure, precipitation was below normal until around 1970 and above normal from 1984 (the year that construction of the main WIPP facilities began) to 1992. Above-average precipitation has also been experienced at WIPP each year from 2004 to 2007.



WIPP SHALLOW SUBSURFACE WATER

Facilities Area and Monitor Well Location Map

Figure 1

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NOT TO SCALE

Source: June 25, 2005 aerial photograph provided by Google Earth.

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WIPP SHALLOW SUBSURFACE WATER

Aerial Photograph of WIPP Facilities Area, 2005

Figure 2

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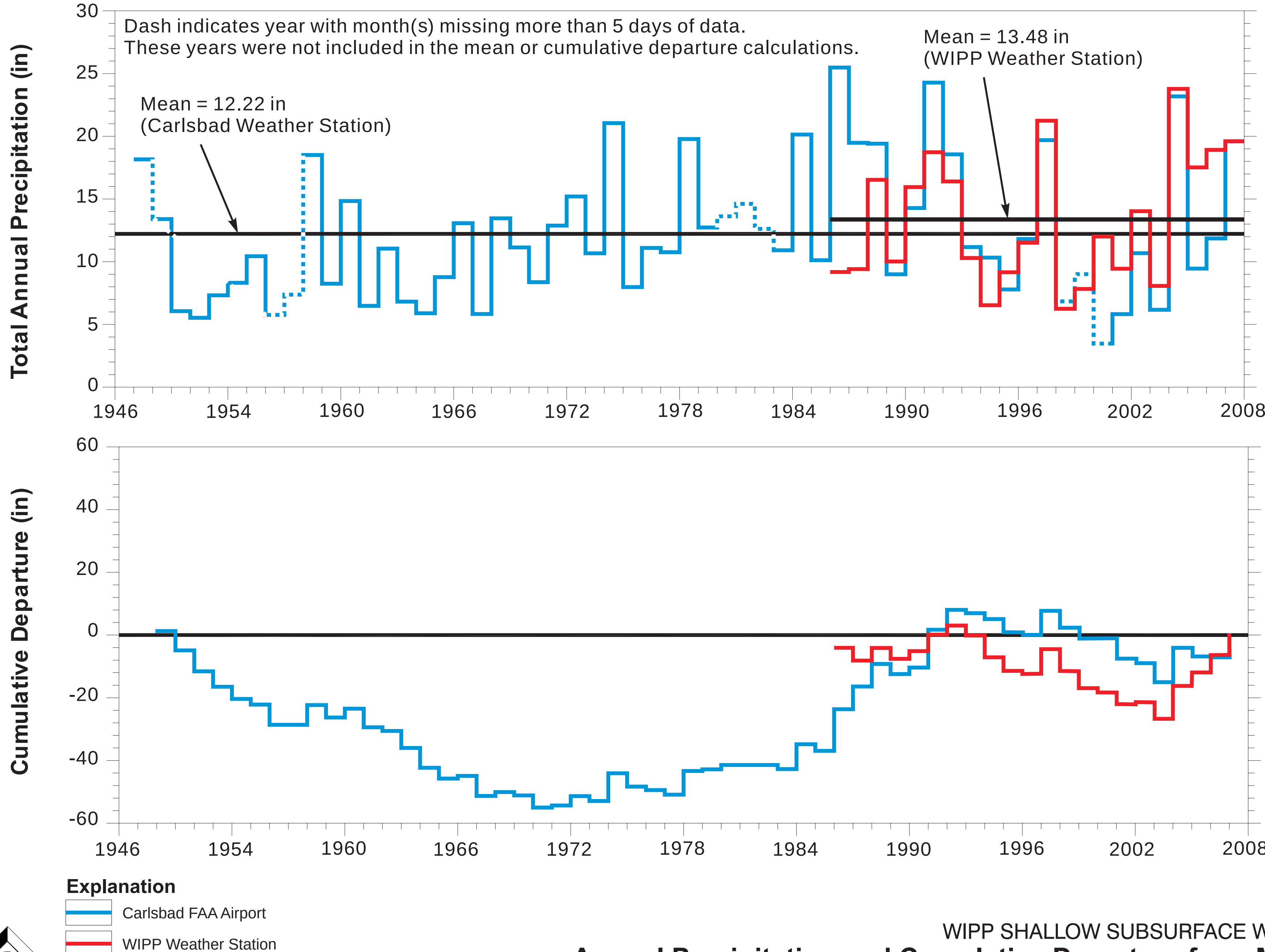

Figure 3

WIPP SHALLOW SUBSURFACE WATER

Annual Precipitation and Cumulative Departure from Mean

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Based on the long-term precipitation records available from the Carlsbad FAA Airport, the average annual precipitation has been 13.65 in/yr over the years from the initial development of the WIPP facilities in 1984 through 2007. This precipitation rate is approximately 12 percent above the long-term average (Table 1).

Table 1. Precipitation Summary Statistics

Station	Start Date	End Date	Duration (years)	Annual Precipitation (inches)		
				Mean	Maximum	Minimum
Carlsbad FAA [a]	Jan-49	Dec-07	59	12.22	25.48	5.76
Carlsbad FAA [a]	Jan-84	Dec-07	24	13.65	25.48	5.82
WIPP station	Jan-86	Dec-07	22	13.48	23.78	6.25
WIPP station	Jan-95	Dec-07	13	13.79	23.78	6.25

[a] Excludes years with more than five days missing in any month.
FAA = Federal Aviation Administration WIPP = Waste Isolation Pilot Plant

3.2 Hydrogeologic Regime

The regional hydrogeologic regime in the area of the WIPP has been described by several investigators. Comprehensive reports by Hendrickson and Jones (1952) and Bachman (1984) describe the regional geologic setting. A more detailed description of the local hydrogeologic regime at the WIPP site is provided by Mercer (1983).

At the WIPP site, Powers (1995) reports the following stratigraphic column from geologic mapping of the WIPP Exhaust Shaft:

0 to 7.5 feet below ground surface (bgs)	Quaternary dune sand
7.5 to 17 feet bgs	Mescalero caliche
17 to 34 feet bgs	Gatuña Formation
34 to 54 feet bgs	Santa Rosa Sandstone Formation
54 to 546 feet bgs	Dewey Lake Redbeds Formation
546 to 851 feet bgs	Rustler Formation
851 to 2,150(+) feet bgs	Salado Formation

The SSW hydrologic assessment focuses on unsaturated flow processes in the vadose zone and saturated flow in the SSW perched lens in the upper formations within 100 feet of the ground surface. This section describes the geologic units in these shallower formations, including the Dewey Lake Redbeds Formation (hereafter referred to as Dewey Lake) and the overlying geologic units.

3.2.1 Dewey Lake Redbeds Formation

The Dewey Lake, which consists of alternating thin beds of siltstone and fine-grained sandstone, is the deepest formation examined in the hydrologic assessment. This formation is absent in some areas due to erosion since Triassic time, but is as thick as 560 feet in eastern Eddy County and western Lea County (Bachman, 1984) near the WIPP site. Drilling within the WIPP facilities area shows that the Dewey Lake is approximately 500 feet thick (Powers, 1995). The Dewey Lake dips gently eastward and also increases in thickness to the east (Mercer, 1983).

The Dewey Lake is at the base of the SSW, with saturated conditions found in an overlying perched zone. A siliceous layer in the upper Dewey Lake at the Santa Rosa/Dewey Lake contact (Intera, 1997a; Powers, 2003b) and a sulfate (gypsum) cementation zone in the lower Dewey Lake (Powers, 2003a) form zones of reduced permeability in the otherwise more permeable sandstone. During hydrogeologic investigations undertaken during the development of the WIPP, minor thin, discontinuous saturated zones were identified in the Dewey Lake (Mercer, 1983).

In this report, the terms upper, middle, and lower Dewey Lake are used to describe the stratigraphic position in the formation along with certain characteristics of the formation that relate to the occurrence of saturated conditions. Although these horizons are not strictly defined and their thicknesses vary, the terms upper, middle, and lower are useful to describe the hydrologic conditions.

- The upper Dewey Lake consists of a thick, generally unsaturated section.

- The middle Dewey Lake is the interval immediately above the sulfate cementation change, where saturated conditions and a natural water table have been identified in limited areas.

- The lower Dewey Lake is below the sulfate cementation change, with predominantly low permeability.

Within the WIPP site, monitor well WQSP-6A, located approximately 1.25 miles southwest of the surface facilities area, intersects water in the Dewey Lake. Well WQSP-6A is screened across an interval from 189 to 214 feet bgs and has a water level measured at approximately 165 feet bgs (Stensrud, 1995). At this location, the Dewey Lake occurs from a depth of 35 to 410 feet bgs (U.S. DOE, 1996), which places the saturated horizon within the middle portion of the formation.

The Dewey Lake generally does not yield a water supply to wells; however, in a localized area at the Mills Ranch (formerly James Ranch, located about 1 mile south of the WIPP site boundary in T23S, R31E, Sections 6 and 7), domestic and stock supply wells produce water from the middle Dewey Lake at depths of 94 to 212 feet bgs (Mercer, 1983).

3.2.2 Santa Rosa Sandstone Formation

The Santa Rosa Sandstone Formation (hereafter referred to as Santa Rosa), of Triassic age, unconformably overlies the Dewey Lake. The Santa Rosa consists of gray and red sandstone with lenses of shale and conglomerate (Hendrickson and Jones, 1952). The Santa Rosa encountered in potash exploration holes immediately east of the WIPP site boundary is 200 to 300 feet thick; however, due to erosion, its thickness is much reduced in the central part of the WIPP site and is zero west and southwest of the site (U.S. DOE, 2004). Drilling within the WIPP facilities area (Intera, 1997a) shows that the Santa Rosa ranges in thickness from 16 to 39 feet in the area of the SSW.

Shallow water in the Santa Rosa is the focus of the water budget. Earlier hydrogeologic investigations show that the Santa Rosa was generally not water-bearing at the WIPP site.

Saturation was detected in the lower part of the Santa Rosa in two test holes drilled approximately 3 miles northeast of the WIPP surface facilities (Mercer, 1983).

At the WIPP facilities area, water in the Santa Rosa is perched on the relatively impermeable underlying Dewey Lake. Small amounts of water may discharge downward into the Dewey Lake through fractures and along bedding planes, although drilling performed to investigate the Santa Rosa perched water found the Dewey Lake to be dry below the Santa Rosa (U.S. DOE, 2000).

3.2.3 Gatuña Formation

The Gatuña Formation (hereafter referred to as the Gatuña), of Pleistocene age, unconformably overlies the Santa Rosa at the WIPP site. This formation consists of silt, sand, and clay, and is discontinuous, with deposits in localized depressions (Hendrickson and Jones, 1952). Boring logs from on-site drilling by Sergent, Hauskins & Beckwith (1979) describe the Gatuña as predominantly sandstone with interbedded siltstone that is highly weathered, fractured, and moderately hard. Drilling within the WIPP facilities area shows that the Gatuña ranges in thickness from 19 to 31 feet (Intera, 1997a).

The Gatuña is water-bearing in some areas, with saturation occurring in discontinuous perched zones. However, because of its erratic distribution, the Gatuña has no known continuous saturated zone (Mercer, 1983). Drilling at the WIPP site, including 30 exploration borings drilled between 1978 and 1979 in the surface facilities area, did not identify any saturated zones in the Gatuña.

3.2.4 Mescalero Caliche

The Mescalero Caliche is an informal stratigraphic unit consisting of well-lithified deposits of finely crystalline limestone (caliche) that developed below the surficial soils and in the upper portion of the Gatuña (Mercer, 1983). Powers (2002) indicates that the caliche is generally well developed in the vicinity of the WIPP. The Mescalero Caliche is described in detail by Phillips (1987), who indicates that although the caliche is continuous and well-lithified in some areas, it is often dissected by holes, fractures, and other discontinuities. The Mescalero Caliche is typically between 2 and 10 feet thick, with the upper contact of the caliche between 5 and 10 feet bgs (Sergent, Hauskins & Beckwith, 1979).

3.2.5 Soils

Berino series soils make up the sandy, surficial soils at the WIPP site (Bachman, 1980). These soils are developed in reddish, noncalcareous, wind-worked deposits, generally about 3 feet in thickness. The Berino soils are classified as loamy fine sands with a sandy clay loam subsoil and are very susceptible to wind and water erosion, often forming hummocks or dunes.

3.2.6 Recharge in Native Soils

Under natural conditions, recharge rates through the native soils are extremely low, and little recharge to the Santa Rosa SSW zone is likely to occur in the vicinity of the WIPP site. Most precipitation falls on rangeland and is returned to the atmosphere through evapotranspiration. Hunter (1985) estimated an evapotranspiration rate of 96 percent for a broad water balance study area encompassing 2,000 square miles in Eddy and Lea Counties. A preliminary water balance estimate for a 400-square-mile area surrounding the WIPP site determined recharge rates of 0.5 to 2 percent of precipitation, or less than 0.25 in/yr (Hunter, 1985). A study by Campbell et al. (1996) determined recharge rates for the WIPP site based on stable isotopes in soil waters and chloride mass balance analysis. These investigators estimated recharge rates in surficial soils of only 0.06 to 0.6 percent of precipitation, or less than 0.08 in/yr.

The extremely low recharge rates that occur in native soils covered with desert vegetation indicate that natural recharge around the WIPP facilities area is likely an insignificant component of recharge to the SSW. However, site development at the WIPP has altered the recharge conditions by focusing stormwater in retention ponds and removing vegetation over large areas, thereby decreasing evapotranspiration and increasing recharge in comparison to natural conditions.

3.3 Previous SSW Investigation

Early exploratory drilling at the WIPP site (Sergent, Hauskins & Beckwith, 1979; Mercer, 1983) and geologic mapping of the Exhaust Shaft in 1984 and 1985 (Powers, 1995) did not detect saturated conditions in the Santa Rosa at the WIPP site prior to site development. Seepage into the Exhaust Shaft was first detected in 1995 (U.S. DOE, 2002), and subsurface investigations of the source of this seepage determined that a saturated zone had developed in the Santa Rosa underlying the WIPP surface facilities.

3.3.1 Site Investigation Activities

While many hydrogeologic investigations have been conducted at the WIPP site, this section describes only the investigations that focus on the SSW. SSW investigations were initiated following the May 1995 detection of fluid seeping through cracks in the Exhaust Shaft concrete liner at depths of 50 to 80 feet bgs (Intera, 1996). This section describes a series of investigations and ongoing monitoring to characterize the SSW and meet regulatory requirements.

3.3.1.1 1996 to 1997 Initial Investigation

A series of SSW investigation activities was conducted by Intera in 1996 and 1997 (Intera, 1996, 1997a, and 1997b), including the following:

- Geophysical survey to identify saturated zones in the subsurface
- Drilling of 3 monitor wells (C-2505, C-2506, and C-2507 [4-inch-diameter])
- Drilling of 12 piezometers (PZ-01 through PZ-12 [2-inch-diameter])
- Pumping and slug tests to determine hydrologic properties of the saturated zone
- Sampling of the SSW for water quality analysis

Hereafter, this report refers to the 3 C-series monitor wells and the 12 PZ-series piezometers collectively as monitor wells. The locations of monitor wells installed to investigate the SSW and shaft seepage are shown in Figure 1. Copies of well logs (Intera, 1996 and 1997a) are provided in Appendix A.

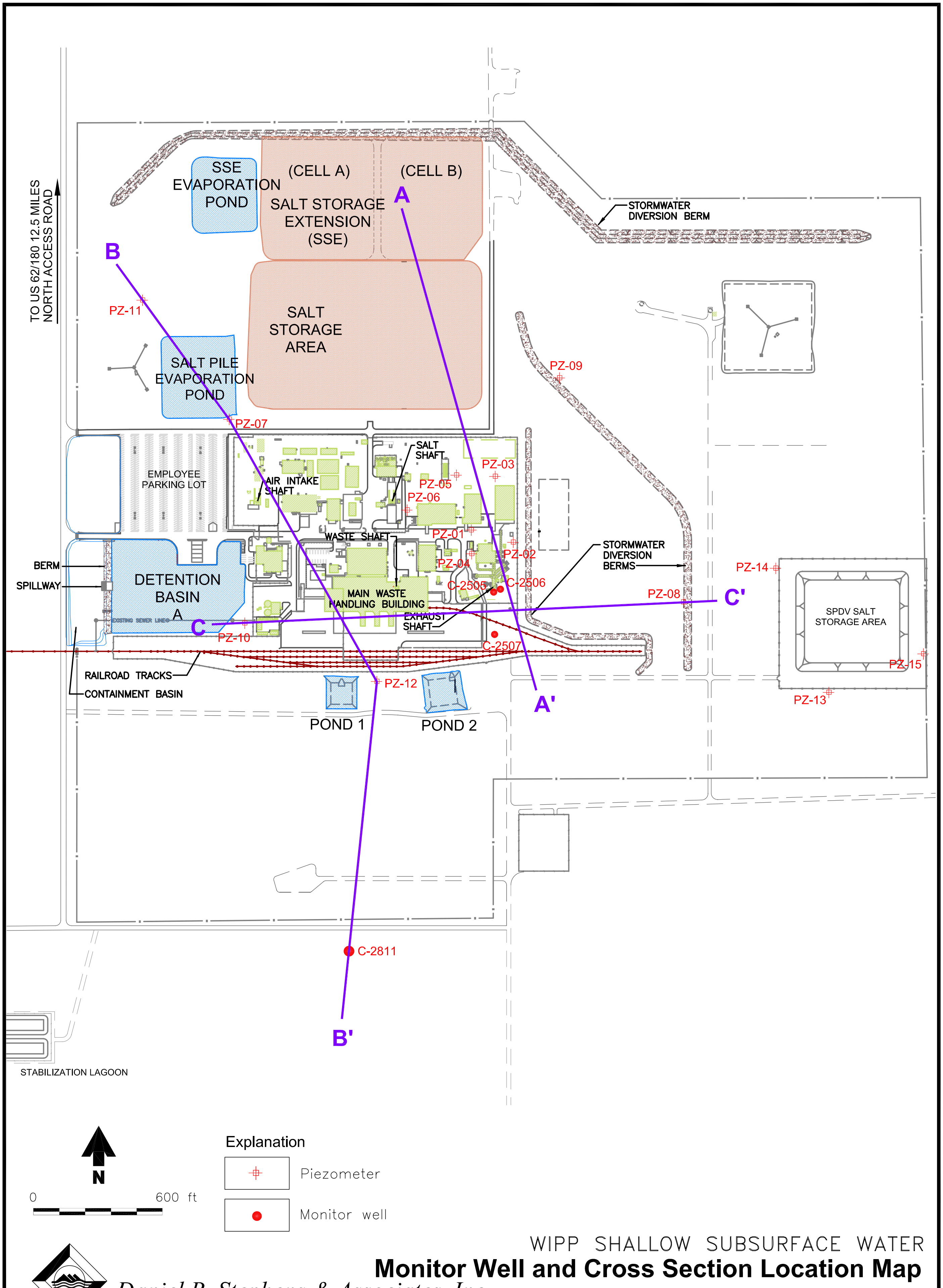
During the initial investigation, a saturated zone ranging in thickness from 12 to 32 feet was encountered in the Santa Rosa in wells completed at depths ranging from 54 to 75 feet bgs. The well screens are predominantly in the saturated interval in the lower portion of the Santa Rosa, and the wells typically penetrate approximately 5 to 10 feet into the Dewey Lake. The Dewey Lake was found to be dry in the interval penetrated, although one borehole (C-2507) was reported to have saturation within the upper 5 feet of the Dewey Lake (Intera, 1996). The dry Dewey Lake horizon below the saturated Santa Rosa indicates that the saturated lens in the Santa Rosa is perched and downward infiltration into the Dewey Lake occurs very slowly in the low-permeability redbeds. Piezometer PZ-08, the easternmost piezometer at the time of the initial investigation, located approximately 0.25 mile east of the facilities area, did not intersect the SSW, indicating a limit on the saturated zone in this area.

Water quality analysis of samples from the monitor wells and piezometers indicated TDS concentrations ranging from 3,700 to 155,000 milligrams per liter (mg/L) (Intera, 1997a). Pumping and slug tests showed saturated hydraulic conductivity (K_{sat}) values for the Santa Rosa of 2.64 x 10^{-8} to 5.48 x 10^{-5} meters per second (m/s) (Intera, 1996 and 1997a).

The monitor well and piezometer installations showed that the lower portion of the Santa Rosa contains a substantial saturated zone, the areal extent of which includes the entire WIPP surface facilities area. Based on a typical porosity range of 5 to 30 percent for sandstone, Intera (1997a) estimated a total volume of SSW between 20 to 120 million gallons. Intera (1997b) concluded that the increase in water level and gradient observed between October 1996 and March 1997 indicated a significant recharge source north of the Exhaust Shaft.

3.3.1.2 2001 Investigation

Water encountered in the upper Dewey Lake at monitor well C-2811 may be interconnected with the SSW in the Santa Rosa, although the interconnection is uncertain (Powers, 2002). Shallow monitor well C-2811, drilled in March 2001 approximately 1,300 feet south of the nearest SSW monitoring location, PZ-12 (Figure 4), was completed in the upper Dewey Lake and intersected water at a depth of approximately 60 feet bgs (Powers, 2002). According to Powers (2002), the Dewey Lake encountered at C-2811 was not saturated during drilling of earlier wells nearby. The thin zone of Santa Rosa, encountered from 35 to 45 feet bgs at the



WIPP SHALLOW SUBSURFACE WATER

Monitor Well and Cross Section Location Map

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Figure 4

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C-2811 location, was not water-bearing. The water quality from C-2811 is consistent with that of the SSW wells, with similar molar ratios (Powers, 2002). The TDS concentration in C-2811 was 2,630 mg/L, which is lower than TDS concentrations in the SSW wells but follows the trend of decreasing TDS concentration toward the south.

Figures 4 through 7 show geologic cross sections through the SSW perched zone that are based on drilling logs from previous investigations (Appendix A). Cross section B-B′ (Figure 6) shows the relationship of the Santa Rosa, where the SSW is known to occur, and the shallow saturated zone encountered at well C-2811 in the predominantly unsaturated upper Dewey Lake. The saturated zone in the Dewey Lake at C-2811 is stratigraphically lower than the SSW occurring in the Santa Rosa to the north.

The location of monitor well WQSP-6A in relation to the WIPP facilities area and SSW monitor wells is shown in Figure 8. Geologic cross section D-D’ (Figure 9) shows the SSW perched lens in the Santa Rosa in relation to the deeper water table encountered at WQSP-6A in the middle Dewey Lake. The saturated zone at C-2811 in the upper Dewey Lake is both vertically and laterally distinct from the water at monitor well WQSP-6A, located about 1 mile southwest, where saturation occurs in the middle Dewey Lake.

3.3.1.3 2007 Investigation

Recent investigations in 2007 included installation of 3 new SSW monitor wells near the Site and Preliminary Design Validation (SPDV) salt and mine rock pile (U.S. DOE, 2008). As shown in Figure 1, the SPDV pile is located east of the WIPP facilities area and the other SSW monitor wells. The SPDV pile covers approximately 10 acres and ranges in height from approximately 7 to 20 feet above ground surface. The approximate pile volume, including an estimate of 10 percent below grade, is 168,000 cubic yards (DBS&A, 1996). The pile is about 95 percent mined salt interspersed with various types of construction debris and fine-grained sediments generated during drilling of shafts and underground excavation. A final cover was constructed over the SPDV pile in 2000, consisting of a geosynthetic clay liner covered by 3 feet of soil cover with a revegetated surface (U.S. DOE, 2008).

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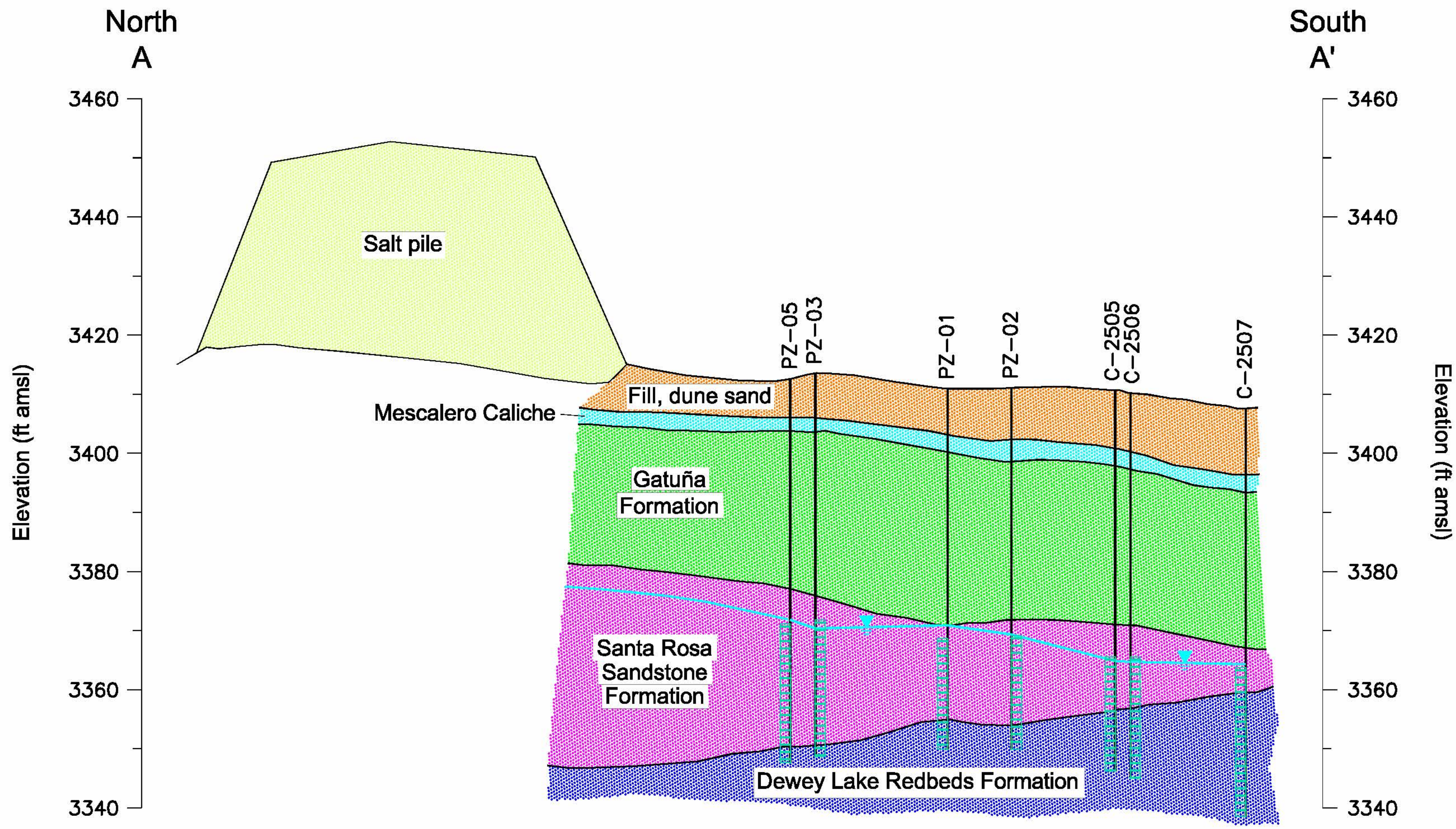

Vertical exaggeration = 10x

0 300 ft

Explanation

Water level (phreatic) surface

Note: Monitor well and water level elevations are projected to the cross section line in Figure 4.

WIPP SHALLOW SUBSURFACE WATER

Cross Section A-A'

Daniel B. Stephens & Associates, Inc.

11-13-08

JN ES08.0072

Figure 5

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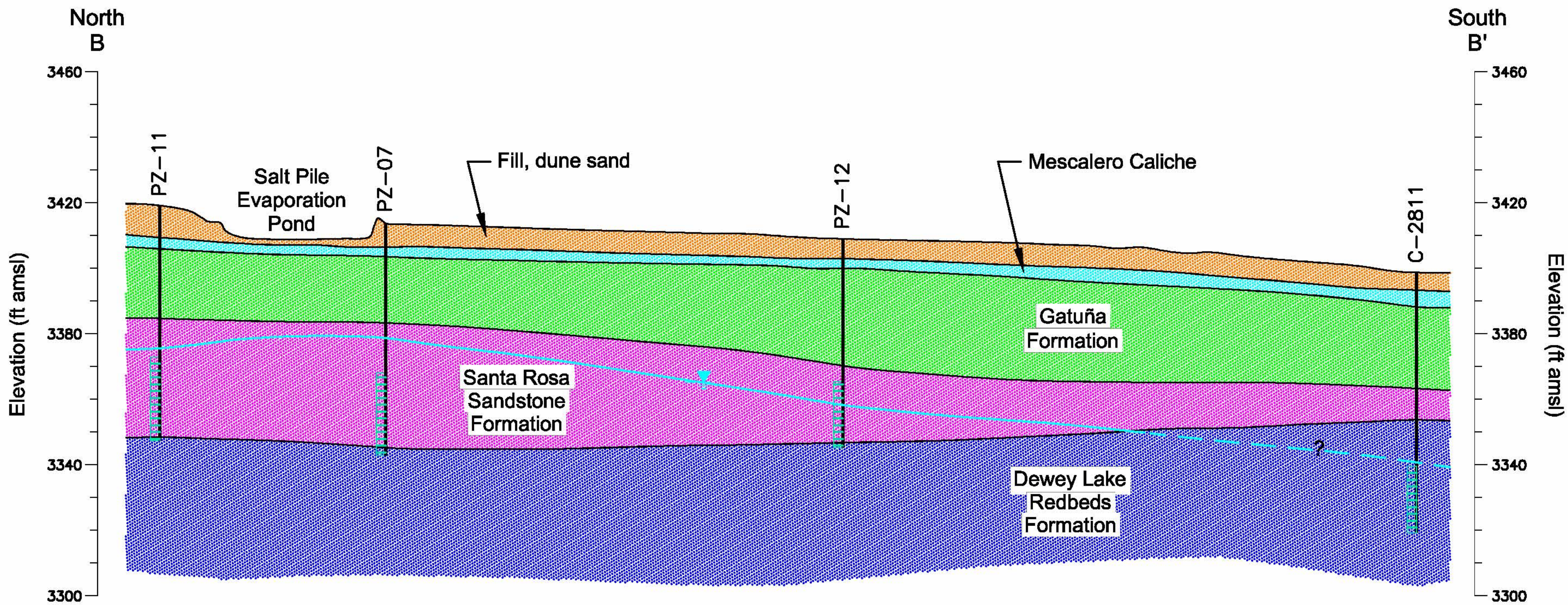

Vertical exaggeration = 10x

0 500 ft

Explanation

Water level (phreatic) surface

? Continuity of water table uncertain in Dewey Lake Redbeds Formation

Note: Monitor well and water level elevations are projected to the cross section line in Figure 4.

WIPP SHALLOW SUBSURFACE WATER

Cross Section B-B'

Figure 6

Daniel B. Stephens & Associates, Inc.
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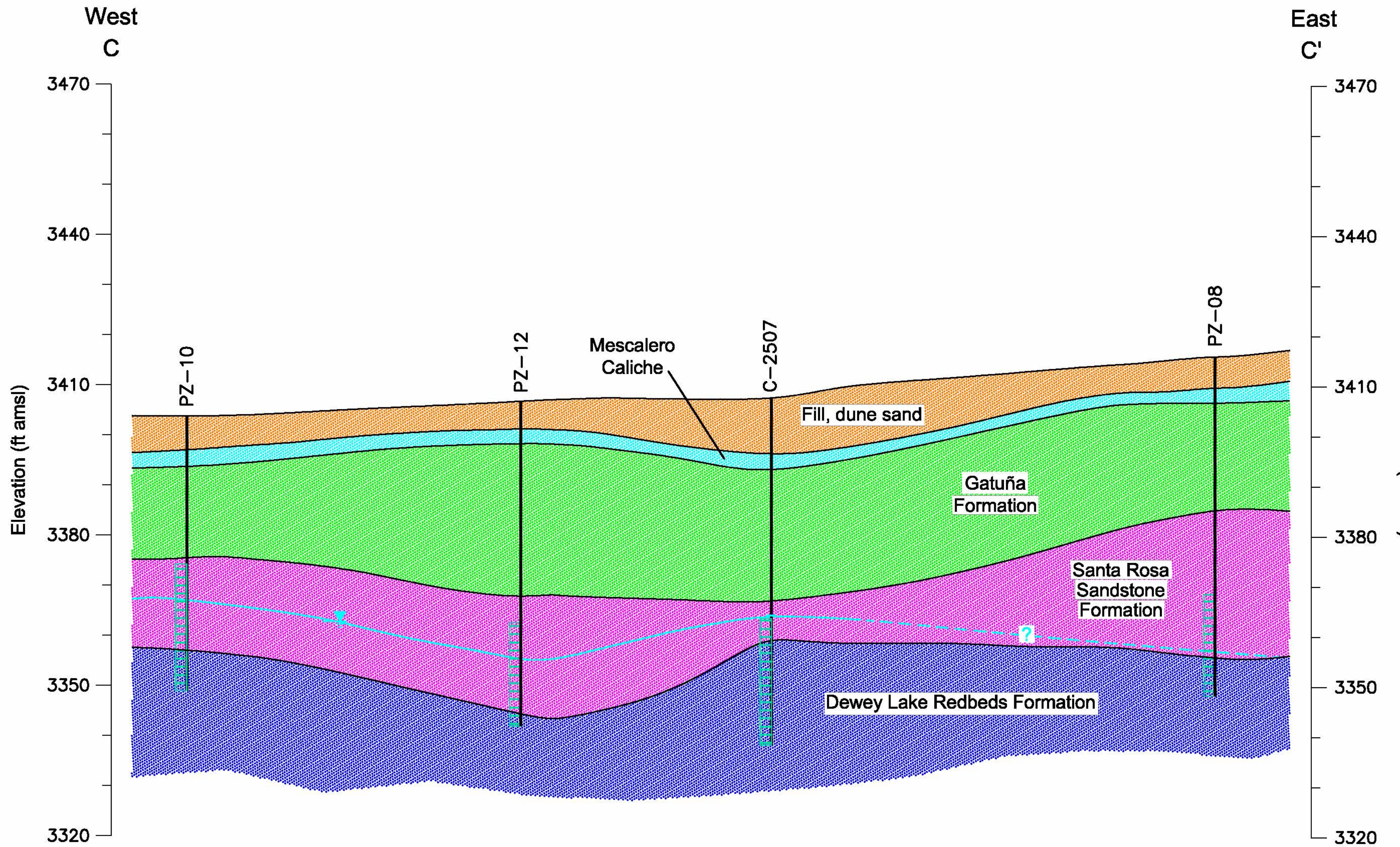

Vertical exaggeration = 10x

0 300 ft

Explanation

Water level (phreatic) surface

Note: Monitor well and water level elevations are projected to the cross section line in Figure 4.

WIPP SHALLOW SUBSURFACE WATER

Cross Section C-C'

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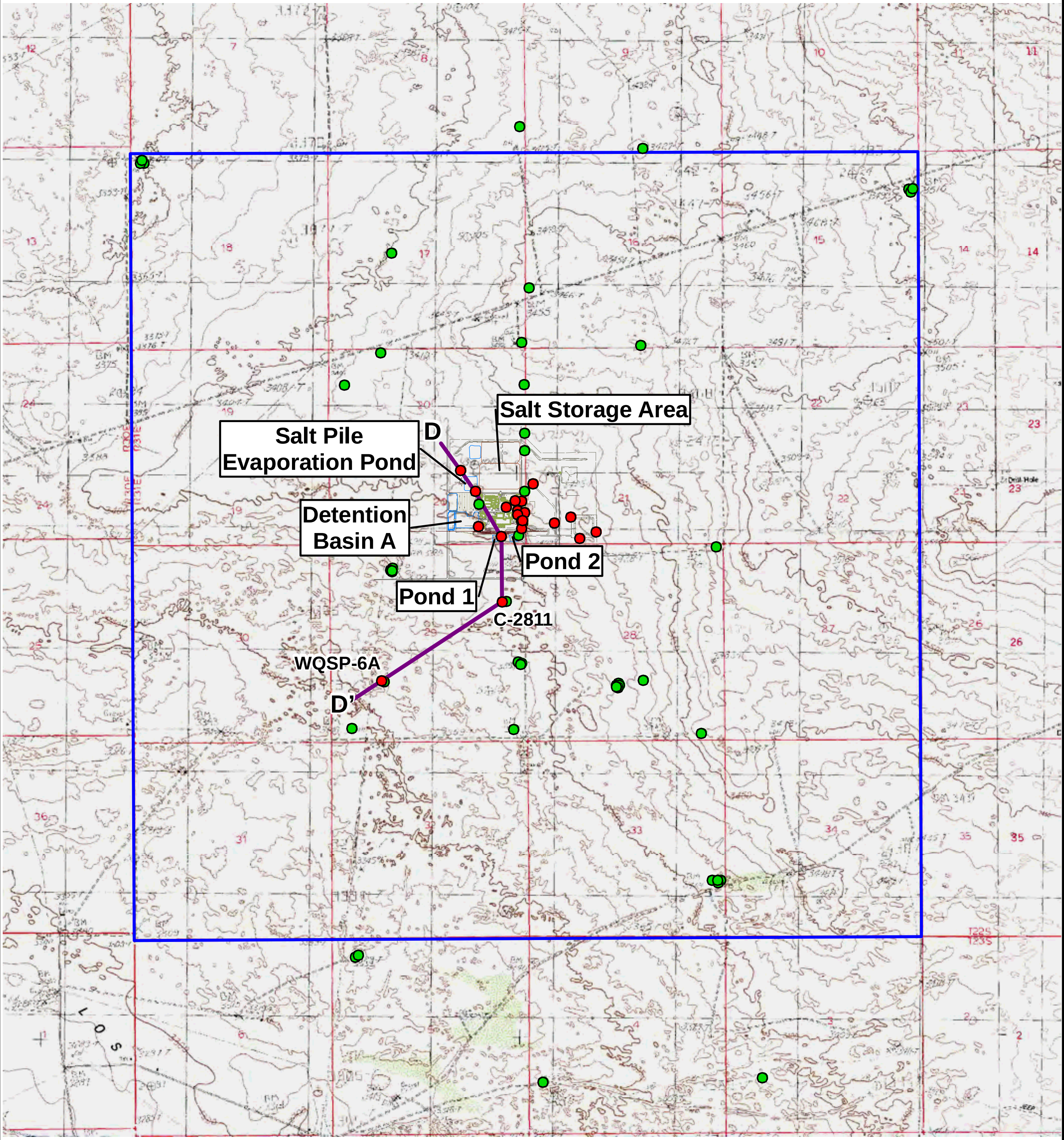
12-8-08

JN 9525

Figure 7



N

0 2000 4000
Feet

Explanation

- Santa Rosa or Dewey Lake monitor well
- Monitor well
- Cross section D-D'
- WIPP land withdrawal boundary

WIPP SHALLOW SUBSURFACE WATER
WIPP Base Map

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Figure 8

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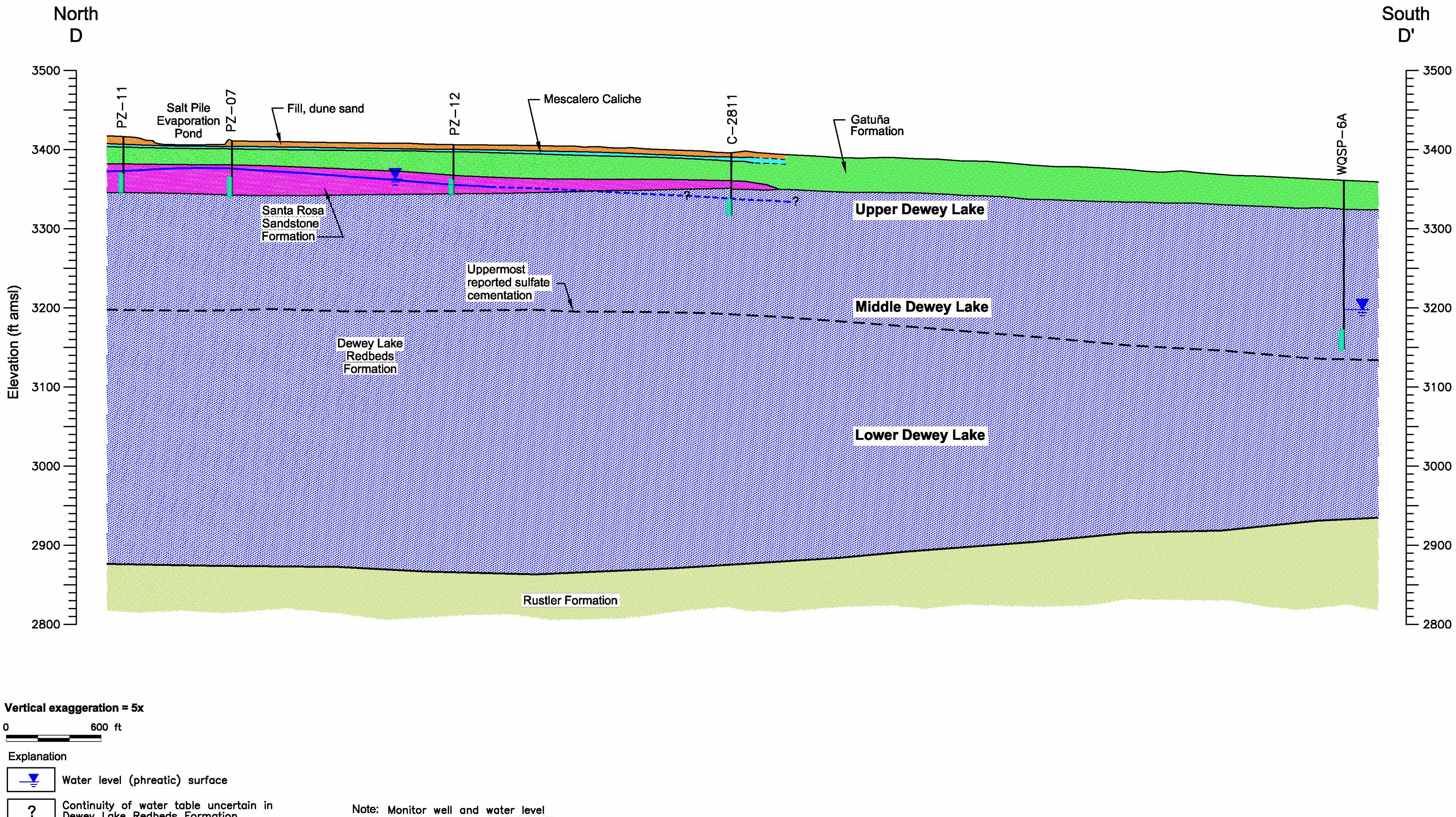

Note: Monitor well and water level elevations are projected to the cross section line in Figure 8.

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11-13-08
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WIPP SHALLOW SUBSURFACE WATER
Cross Section D-D'

Figure 9

Complete details of the 2007 well installations are provided in an October 2008 report by DOE (U.S. DOE, 2008). The SPDV monitor wells, PZ-13, -14, and -15, encountered water in thin saturated zones in formation horizons that differ from the other SSW monitor wells in the previously studied SSW saturated lens. Only PZ-14 encountered saturation in the lower Santa Rosa, perched on the Dewey Lake contact, consistent with other SSW monitor wells. A thin saturated layer 0.8 foot thick was identified in PZ-14, overlying dry Dewey Lake claystone/siltstone. At PZ-13, a saturated interval 2.5 feet thick was encountered in a sandy siltstone layer in the middle Santa Rosa. This saturated interval is perched above a hard sandstone layer in the lower Santa Rosa, approximately 10 feet higher than the Dewey Lake contact. At PZ-15, saturation was encountered in the lower Gatuña, above the Santa Rosa, where a dry and very hard sandstone was encountered. The water quality in the SPDV pile monitor wells is highly variable. The TDS is reported to be 2,060 mg/L in PZ-15, 106,000 mg/L in PZ-14, and 245,500 mg/L in PZ-13. Based on the variability in the formation intervals where saturation occurs and water quality, the water encountered in the SPDV pile wells is not clearly linked to the main SSW saturated lens and may be a result of infiltration through the SPDV pile prior to final cover construction or recharge from other sources.

3.3.1.4 Ongoing Monitoring

The current understanding of the SSW conditions is based on the culmination of the investigation activities from 1996 through 2008 and ongoing monitoring and interpretation of the SSW monitor wells (well logs in Appendix A). Monitoring activities have been carried out by DOE since 1996 to meet the regulatory requirements of groundwater discharge permit DP-831, administered by the New Mexico Environment Department (NMED) Ground Water Quality Bureau (GWQB). The groundwater discharge plan regulates the SSW, as well as WIPP wastewater facilities that are not addressed by this hydrologic assessment. Continued water quality monitoring and water level measurements have been carried out by WIPP personnel from 1996 to present. During some monitoring intervals, DOE has tested for water quality parameters that exceed the discharge plan requirements. The complete monitoring record has been used in this hydrologic assessment.

The current groundwater discharge permit was approved on September 9, 2008 (NMED, 2008). It includes sampling of PZ-01, PZ-05, PZ-06, PZ-07, PZ-09, PZ-10, PZ-11, PZ-12, PZ-13, C-2507, C-2811, and WQSP-6A. The required water quality parameters include the following:

- Field parameters: pH, temperature, specific conductance
- General chemistry: sulfate, chloride, TDS
- Nitrate-nitrogen and total Kjeldahl nitrogen in WQSP-6A only

Water level measurements are required in all 20 monitor wells, including the additional PZ-series and C-series wells that are not included in water quality sampling. Monitoring is performed on a semiannual basis.

The complete set of water quality data collected for the SSW monitor wells is provided in Appendix B. Over the complete monitoring record, water quality testing has included variable parameters during sampling intervals, with some monitoring events testing for a more extensive list of chemical parameters. The monitoring frequency has varied during the period of record, ranging from monthly to annually. The monitoring data used in this hydrologic assessment include the complete monitoring record for all 20 wells used for SSW monitoring.

3.3.2 Water Budget Analysis

A water budget analysis was completed in 2003 to quantify the SSW sources and consider the potential for migration and the effectiveness of planned infiltration controls (DBS&A, 2003). The water budget refined the conceptual model of the SSW by quantifying the important hydrologic processes controlling the SSW system, providing the following:

- An estimate of the volume of water contained within the perched zone
- Quantification of seepage inputs to the SSW from past and current practices
- A model of SSW accumulation, flow conditions, and potential long-term migration
- Determination of the effects of engineered seepage reduction measures that could be implemented at existing seepage sources

The water budget analysis focused on the sources of water introduced to the subsurface as a result of site development at the WIPP. Because site investigation found the Santa Rosa to be unsaturated prior to site development, the SSW is considered to be anthropogenic, the result of a variety of water discharges and changes in site drainage that have occurred since on-site development of the WIPP began. Increases in recharge from the site have contributed to the saturated, perched zone at depths of 40 to 60 feet bgs within the Santa Rosa.

The water budget analyses included seepage estimates from five principal SSW recharge sources within the WIPP surface facilities area: (1) the Salt Storage Area, (2) the Salt Pile Evaporation Pond, (3) Detention Basin A, (4) stormwater retention pond 1, and (5) stormwater retention pond 2. An aerial photograph from 2000 (Figure 10) shows the condition of these recharge sources before liners and covers were constructed to control infiltration. Since 1984, when the WIPP surface facilities were constructed, recharge of precipitation to the subsurface has increased because runoff from impervious surfaces is routed into retention ponds. Recharge from the Salt Storage Area occurs when precipitation falling on the salt pile infiltrates through the highly fractured surface.

The water budget included the following analyses:

- *Compilation of recorded discharges:* Records of past discharges were compiled to quantify the extent of discharges from activities such as drilling, shaft dewatering, water line purging, water line leakage, and sewage treatment.

- *Site drainage summary:* Stormwater runoff calculations were completed to determine the volume of on-site stormwater that drains to the four stormwater retention ponds, where seepage may contribute to the SSW.

- *Surface infiltration modeling:* Infiltration rates were modeled for the four stormwater retention ponds and the Salt Storage Area. The model calculated evaporation and plant transpiration losses and the amount of recharge to the SSW.

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WIPP SHALLOW SUBSURFACE WATER

Aerial Photograph of WIPP Facilities Area, 2000

Figure 10

- *Saturated flow modeling:* Saturated flow modeling was conducted to quantify recharge from the stormwater retention ponds and Salt Storage Area and to determine whether such recharge accounts for observed conditions in the SSW.

- *Long-term migration modeling:* The long-term SSW migration was modeled for a 100-year time frame to evaluate whether the SSW has the potential to migrate to known groundwater resources. The potential for migration was examined both with and without the engineered infiltration controls to prevent recharge and reduce SSW migration.

The water budget results indicated that seepage from the five primary sources provides sufficient recharge to account for the observed SSW saturated lens and that the lens is expected to spread. The water budget results quantified the following components of the SSW hydrologic system:

- The SSW saturated zone covers approximately 150 to 520 acres to a maximum saturated thickness exceeding 30 feet, and contains a total estimated volume of water in the range of 108 to 315 million gallons.

- Average annual precipitation on the 85-acre watershed surrounding the WIPP facilities area amounts to approximately 29.2 million gallons per year, and average annual stormwater flow to the retention ponds and precipitation falling on the Salt Storage Area amounts to approximately 25.0 million gallons per year.

- Modeling by three independent methods produces seepage estimates in the range of 5.4 to 16.9 million gallons per year from the five primary seepage sources, which is equivalent to 18 to 58 percent of on-site precipitation.

- Records of discrete discharges from drilling and construction activities during the 1980s indicate that these discharges total approximately 6 million gallons, with evaporative losses further reducing the volume that these discharges may have contributed to the SSW.

- The estimated leakage from water lines providing input to the SSW is 0.22 million gallons per year, totaling approximately 4 million gallons of water line leakage since the WIPP facilities opened in 1984.

- Seepage into the Exhaust Shaft, which is a loss from the SSW, amounts to approximately 4 million gallons since seepage was detected in 1995.

The quantified water budget components show that seepage from on-site precipitation is the most significant recharge source providing input to the SSW saturated lens. To develop a valid conceptual model of the SSW, considering the uncertainties of the models and calculations, multiple analysis methods were used to obtain a range of independent results, enhancing the reliability of the overall analysis.

The potential extent of long-term SSW migration was examined by expanding the saturated flow model domain to include the 16–square-mile WIPP land withdrawal area. A two-layer model was established. The upper model layer includes the SSW perched lens in the Santa Rosa and the Gatuña. The lower model layer includes the Dewey Lake, which is the shallowest groundwater depth interval used for water supply near the WIPP boundary. If SSW migration toward the regional groundwater were to occur, the potential migration of SSW would involve downward flow from the Santa Rosa moving vertically through the unsaturated upper Dewey Lake and laterally to areas where a natural water table exists in the middle Dewey Lake. The two-layer model is conservative in that it simulates all of the Dewey Lake recharge accumulating in a saturated lens, whereas a complex system of discontinuous saturated pathways in the predominantly unsaturated upper Dewey Lake may disperse the flow and lead to less migration. The rate of downward flow from the Santa Rosa to the Dewey Lake, controlled by the vertical hydraulic conductivity, was established by a model calibration phase that matched observed SSW water levels for the 1996 to 2002 record. The calibrated model was then run for 100-year predictive simulations of SSW migration with seepage ending in either 2035 when the facility closes or in 2006 after the implementation of engineered infiltration controls.

The long-term migration model simulations indicated that the engineered seepage controls that were subsequently implemented by DOE in 2004 and 2005 would substantially reduce the extent of migration. The simulations predicted that without seepage controls, the SSW has the potential to migrate as far as the northern WIPP boundary and to the Dewey Lake saturated zone in the southwestern corner of the WIPP site near monitor well WQSP-6A over a 100-year time frame. The predictive modeling results showed that engineered infiltration controls would prevent the existing SSW saturated volume from otherwise doubling over the next 20 years if recharge were allowed to continue. The long-term migration model predicted that the infiltration controls prevent SSW migration from reaching the facility boundary within 100 years.

4. Infiltration Controls

In order to reduce or eliminate recharge to the SSW, engineered infiltration control systems were constructed over the primary recharge sources in 2004 and 2005. The infiltration controls consist of liners installed in each of the stormwater retention ponds, an impermeable cover over the Salt Storage Area, and new lined areas for salt storage and stormwater containment.

4.1.1 Stormwater Retention Ponds

Prior to construction of the infiltration controls, surface water drainage at the WIPP site consisted of four watershed areas that drain to four on-site stormwater retention ponds. The four ponds include the following:

- Salt Pile Evaporation Pond
- Detention Basin A
- Stormwater retention pond 1
- Stormwater retention pond 2

The areas of the ponds and watersheds, including the pervious and impervious areas, are summarized in Table 2. The surface conditions of the watersheds range from relatively permeable bare ground to impermeable pavement and rooftops. Three of the ponds receive relatively clean stormwater from the surface facilities, while the Salt Pile Evaporation Pond received runoff containing dissolved salt from the outer slopes of the Salt Storage Area prior to cover construction. Stormwater runoff calculations by DBS&A (2003) found that the average annual stormwater runoff for a 5-year period of record from 1997 to 2001 was 19.8 million gallons. The total runoff is divided among the four ponds as follows:

- Detention Basin A: 55.5 percent
- Salt Pile Evaporation Pond: 26.5 percent
- Pond 1: 5.0 percent
- Pond 2: 13.0 percent

Table 2. Summary of Watershed and Pond Areas

Pond	Pervious [a] Watershed Area		Impervious [b] Watershed Area		Entire Pond Area		Total Watershed Area [c]	
	ft^2	acres	ft^2	acres	ft^2	acres	ft^2	acres
Salt Pile Evaporation Pond	724,393	16.6	0	0	158,024	3.63	882,417	20.3
Detention Basin A	502,172	11.5	890,778	20.4	249,956	5.74	1,642,906	37.7
Stormwater retention pond 1	119,793	2.75	16,615	0.38	21,818	0.50	158,226	3.63
Stormwater retention pond 2	98,643	2.26	222,328	5.10	32,416	0.74	353,387	8.11
Totals	1,445,001	33.1	1,129,721	25.9	462,214	10.61	3,036,936	69.7

[a] Pervious surfaces represent bare ground, gravel, and vegetated ground conditions.
[b] Impervious surfaces represent asphalt and concrete surfaces, and rooftops.
[c] Areas adjacent to the railroad tracks are excluded from the watersheds. Little runoff is expected from these gravel surfaces, which are level or in swales without an apparent discharge point.

Past observations of the stormwater retention ponds found that water collected to a significant depth (up to a depth of 8 feet) following storm events. Water levels in the basins decrease in response to combined losses of infiltration and evaporation, but ponded water may remain for days. Eventually, the ponded water completely infiltrates and/or evaporates.

Records regarding the design and construction of WIPP facilities indicate that the ponds were constructed between 1981 and 1984. The total capacity of the ponds is designed to handle the runoff from either a 100-year/24-hour storm event (U.S. DOE, 1993) or two consecutive 10-year/24-hour storms (Westinghouse, 1992). During 1993 to 1994, design improvements were completed on Detention Basin A and Ponds 1 and 2 to provide total stormwater retention (Westinghouse, 1992). Constructed berms to the north and east of the site prevent surface water from running onto the operations area at the WIPP site (hereafter referred to as on-site) (Figure 1). Therefore, all of the stormwater collected in the retention ponds is from on-site runoff.

4.1.2 Salt Storage Area

The Salt Storage Area used in the past to receive salt mined from the WIPP underground mine workings covers an area of 18.8 acres. When placement of salt in the Salt Storage Area ended in 2004, the average height of the salt pile was approximately 30 feet. The top deck of the Salt Storage Area was sloped to drain internally with perimeter berms to contain stormwater on top of the salt pile and prevent runoff of stormwater contacting the salt. The Salt Storage Area had steep side slopes to shed stormwater to a perimeter drainage channel that routed stormwater to the Salt Pile Evaporation Pond.

Precipitation that falls on the Salt Storage Area infiltrates below the salt pile surface through extensive fractures and dissolution channels (i.e., macropores) observed on the salt pile surface (DBS&A, 2003). The halite (NaCl) contained in the Salt Storage Area is susceptible to dissolution by precipitation leaching through the salt. Based on a halite solubility constant of 38.1944 (log K_{sp} = 1.528) (Parkhurst, 1995), water saturated with respect to halite contains 133,000 mg/L sodium and 205,000 mg/L chloride, and has an approximate TDS concentration of 338,000 mg/L, depending on the exact composition of the crushed rock salt. Seepage that is near saturation with respect to dissolved halite would have a TDS concentration approximately twice as high as the highest TDS concentration measured in the main SSW lens. Seepage through the Salt Storage Area may be near halite saturation, while stormwater runoff from the side slopes would be expected to be at a fraction of halite saturation concentration.

4.1.3 Infiltration Control Systems

Infiltration control systems have been constructed to prevent recharge to the SSW due to seepage beneath the stormwater retention ponds and Salt Storage Area. Details of the infiltration control systems engineering design are shown on design drawings prepared by WTS (2005). A new lined Salt Storage Extension (SSE) has been constructed for the placement of mined salt over a lined area to prevent seepage of halite-impacted water that leaches through the salt. A new lined SSE Evaporation Pond has also been constructed to contain and prevent infiltration of stormwater runoff from the SSE. These infiltration control systems were proposed by DOE and incorporated into the groundwater discharge permit DP-831 that was approved by the NMED GWQB. In addition to the infiltration controls constructed in 2004 and 2005, a final cover was constructed over the SPDV pile in 2000. The location of these infiltration control systems is shown on Figure 1.

Table 3 provides the capacity of the lined ponds and runoff quantities and areas draining to the ponds based on information provided in the WTS request for proposals for this project. Table 4 lists infiltration controls constructed in the study area. The infiltration controls listed in Table 4 are described in further detail below.

- *SPDV Pile.* A final cover has been constructed over the SPDV pile consisting of a geosynthetic clay liner (GCL) covered by a 3-foot-thick soil layer, which serves as a soil rooting medium to support vegetative growth on the cover. The final cover is designed with slopes to shed stormwater. Efforts to revegetate the final cover with shallow-rooted plants have been successful in establishing a well-vegetated surface.

- *Detention Basin A, Pond 1, and Pond 2.* These stormwater retention ponds receive relatively fresh stormwater from on-site. Each pond has had a 60-mil high-density polyethylene (HDPE) liner installed within nearly the same pond configuration as the previously unlined pond. Detention Basin A has a spillway on the west side of the pond to allow excess water to overflow to a secondary containment basin, which is unlined.

- *Salt Storage Area.* A final cover has been constructed over the Salt Storage Area consisting of 60-mil HDPE covered by a 3-foot-thick soil layer, which serves as a soil rooting medium to support vegetative growth on the cover. The final cover is designed to shed stormwater with a minimum 2 percent slope on the top deck and 3:1 (3 horizontal to 1 vertical) side slopes. Vegetation is nearly absent on the cover and rill erosion is evident on the side slopes. The runoff conveyance ditches around the perimeter of the Salt Storage Area have also had 60-mil HDPE liners installed, with runoff directed to the Salt Storage Evaporation Pond.

- *Salt Pile Evaporation Pond.* The Salt Pile Evaporation Pond previously received runoff from the uncovered Salt Storage Area, but now receives relatively fresh stormwater after

Table 3. Infiltration Control Ponds and Runoff Volumes

Evaporation Pond	Drainage Area (ft^2)	Runoff Volume for Design Storm [a] (gallons)	Pond Capacity [b] (gallons)
Salt Pile Evaporation Pond	690,100	1,677,633	5,506,989
Salt Storage Extension Evaporation Basin	1,047,800 [c]	2,547,202 [c]	4,170,732
Pond A	1,642,199	3,992,186	6,670,940
Pond 1	178,595	434,163	813,925
Pond 2	387,681	942,452	2,447,692

[a] Runoff volumes are calculated for a 25-year/24-hour design storm event of 3.90 inches assuming 100% runoff and including the volume that falls onto the surface area of the pond.

[b] Capacity is the maximum capacity without any freeboard.

[c] Current configuration with only Cell A has a drainage area of 538,000 square feet (ft^2), runoff volumes for the 3.90-inch rainfall event is 1,307,878 gallons.

Table 4. Infiltration Controls

Infiltration Control	Completion Date [a]	Liner/Cover
SPDV pile final cover	2000	GCL cover with 3-foot soil rooting medium
SSE evaporation pond liner	January 2004	HDPE geomembrane liner
SSE liner	February 2004	HDPE geomembrane liner
Salt Storage Evaporation Pond liner	July 2004	HDPE double geomembrane liner with leak detection system
Salt Storage Area cover	July 2004	HDPE geomembrane cover with 3-foot soil rooting medium
Salt Storage Area runoff ditches	January 2005	HDPE geomembrane liner
Pond 1 liner	January 2005	HDPE geomembrane liner
Pond 2 liner	January 2005	HDPE geomembrane liner
Detention Basin A liner	July 2005	HDPE geomembrane liner

[a] Completion dates from U.S. DOE (2008) and Roush (2008)
SPDV = Site and Preliminary Design Validation
GCL = Geosynthetic clay liner
SSE = Salt Storage Extension
HDPE = High-density polyethylene

the Salt Storage Area has been covered. The Salt Pile Evaporation pond has had a 60-mil HDPE liner installed within nearly the same pond configuration as the previously unlined pond.

- *Salt Storage Extension.* The SSE has been constructed with a 60-mil HDPE liner covered by a 200-mil geonet and a 2-foot protective soil layer. The liner is constructed on a 2 percent slope and the geonet conveys any fluid on the liner to a sump that discharges to the SSE Evaporation Pond. The SSE includes Cell A, which has been constructed, and Cell B, which will be added in the future. The SSE liner is seamed directly to the Salt Storage Area cover along the north side slope of the cover.

- *Salt Storage Extension Evaporation Pond.* The SSE Evaporation Pond receives stormwater runoff from the SSE and water that is conveyed to the SSE liner sump. The water managed in the pond is highly saline, and has contacted halite in the SSE. The SSE Evaporation Pond has a double liner consisting of two layers of 60-mil HDPE with a 200-mil geonet between the liners to convey any leakage through the primary liner to a sump on the secondary liner. The liner is constructed on a 2 percent slope to convey water to the sump. Primary liner leakage in the sump is pumped back to the pond when detected.

The infiltration controls that have been constructed have eliminated the major sources of recharge to the SSW. The infiltration controls have now been in place for three years, preventing continued input to the SSW saturated lens that would have occurred had the controls not been put in place.

4.1.4 Design, Operation, and Maintenance

The infiltration control systems were designed in a manner that requires ongoing operation to manage stormwater. Based on the groundwater discharge plan (DP-831), the stormwater ponds were designed to meet the following design capacity requirements (U.S. DOE, 2003):

- Salt Pile Evaporation Pond and SSE Evaporation Pond

  - Designed to contain a 25-year, 24-hour design storm event
  - Designed for full retention of stormwater by an inflow/evaporation water balance based on average annual precipitation

- Detention Basin A, Pond 1, and Pond 2
  - Original unlined ponds designed with capacity to store two 10-year, 24-hour storm events
  - Lined ponds appear to have been designed to contain 25-year, 24-hour storm
  - Calculations of an inflow/evaporation water balance not provided in the discharge plan

Detention Basin A, Pond 1, and Pond 2 each have liners that were constructed within nearly the same footprint area as the original unlined ponds. The capacity and surface area of these ponds do not provide for complete evaporation of the stormwater. Monthly pond inspection records indicate that the ponds have been near capacity during the recent years of above-average precipitation (U.S. DOE, 2004-2008).

Stormwater is managed in Detention Basin A, Pond 1, and Pond 2 by pumping between the ponds using temporary water lines and portable pumps. Water is removed from the ponds and pumped to irrigate the surface of the final cover on the Salt Storage Area. Irrigation is used both to manage stormwater and to aid efforts to revegetate the final cover.

Vegetation is nearly absent on the Salt Storage Area final cover. As a result, erosion repair on the cover has been an ongoing maintenance need. The absence of vegetation also reduces the amount of stormwater that can be applied to the cover through irrigation. Without vegetation, water applied to the soil surface is lost through evaporation only. Much more water is removed from the system with plant growth on the cover because the plants remove water from the cover soil and release it to the atmosphere through transpiration.

Due to the high precipitation rates since 2005 and limits on capacity to manage stormwater in Detention Basin A, Pond 1, and Pond 2, overflows have been experienced at the spillway from

Detention Basin A (Roush, 2008). These overflows discharge to the small secondary containment basin west of Detention Basin A; this secondary containment basin is unlined, allowing for a limited amount of stormwater infiltration and recharge to the SSW.

5. Hydrologic Assessment Methods and Results

This section describes the hydrologic assessment methods and results, providing details for each of the project components identified in Section 2, including the following:

- Database compilation
- Time-series analysis using hydrographs
- Water level contour maps
- Water quality contour maps
- Geochemical analysis
- Moisture redistribution calculations

5.1 Database Compilation

A comprehensive database was organized to evaluate and present data on the SSW. DBS&A obtained a series of Microsoft Excel spreadsheets from WTS containing data potentially relevant to evaluation of the SSW. The data were organized in a central Microsoft SQL database following standard procedures developed by DBS&A to enable efficient evaluation and presentation of environmental data. Site documents obtained from WTS and from DBS&A's files from prior work were used to supplement and spot check the data for any potential problems or omissions due to the fact that the spreadsheets may not have all been originally intended for construction of a database. The types of data provided included the following:

- Water chemistry
- Water level measurements
- Geology
- Precipitation
- Survey coordinates

The water chemistry data provided in WTS spreadsheets were supplemented with details provided in available reports, including measurements of field parameters, sampling techniques that could potentially affect laboratory results, and laboratory qualifiers. The spreadsheets provided list laboratory qualifiers for most analytes, but not for TDS, chloride, sulfate, total inorganic carbon, or silicon. Water quality reports from 1998 and 1999 indicate that some of these data had been previously rejected according to criteria established by Westinghouse. These data were retained in the database and flagged with an R qualifier. The set of qualifiers reported with data from Wastren laboratory are not uncommon, but also are not universally recognized; that is, the B, E, and N qualifiers are defined differently by many other laboratories. Therefore, each qualifier was translated to a corresponding qualifier used by the U.S. Environmental Protection Agency (EPA) or to a custom qualifier with a definition provided in a separate table.

Compiling the water level elevation data in a central database provided a continuous time-series of data from multiple files and reconciled vertical elevation data that had historically been referenced to more than one datum. The majority of water level measurements were reported as elevations referenced to an early survey using the NGVD 29 datum. Therefore, more recent water level and geology data referenced to an October 2007 survey using the NAVD 88 datum were adjusted according to WTS protocol to be consistent with older data on the NGVD 29 datum. Data for horizontal coordinates were not adjusted for smaller differences on the order of one-tenth of a foot between the different surveys.

Geologic data were included in the database primarily to assist in calculation of hydraulic head above perching horizons; the data were therefore limited to elevations of these horizons relevant to the SSW assessment. Depths in the geology table were checked against boring logs.

Precipitation data in the database included monthly totals for the WIPP meteorological station; higher-resolution site data and monthly data from the Carlsbad FAA Airport station were considered but not included in the database. Precipitation data were compared to records for the WIPP station posted online by the Desert Research Institute (WRCC, 2008). The online precipitation data included a longer historical record with additional details; specifically, it listed any days missing from the record in a given month. In cases where the online data differed from data provided by WTS (apparently due to WTS having a more complete record in recent years), the data provided by WTS were assumed to be more reliable.

Complete water quality data for the full period of record since 1996 are presented in Appendix B. Water level data are presented in the hydrographs provided in Appendix C. The geologic contact elevations, based on well logs for the SSW monitor wells, are also provided on the hydrographs in Appendix C. Precipitation summary results are presented in Figure 3, and a more complete data set of monthly and annual precipitation totals is provided on the hydrographs in Appendix C.

5.2 Time-Series Analysis

A time-series analysis was completed to examine water level trends for each of the SSW monitor wells. Water level hydrographs were plotted showing the record of water level fluctuations based on regular water level measurements that have been performed on all monitor wells since their installation. Also plotted on the hydrographs are additional data including the following:

- Monthly precipitation totals from the WIPP weather station
- TDS concentration
- Elevation of the Santa Rosa/Dewey Lake contact and top of Santa Rosa
- Monitor well screened interval

The data plotted on the hydrographs allow the water level elevation to be seen in relation to the saturated thickness above the Santa Rosa/Dewey Lake contact. In some cases, the water level elevation rises into the Gatuña. The hydrographs include data needed to evaluate changes in water levels in comparison to precipitation rates and fluctuations in TDS concentration.

Hydrographs for each of the SSW monitor wells are included in Appendix C. Select hydrographs are provided in Figures 11 through 16. The SSW water levels appear to correlate with precipitation rates over the 12-year period of record.

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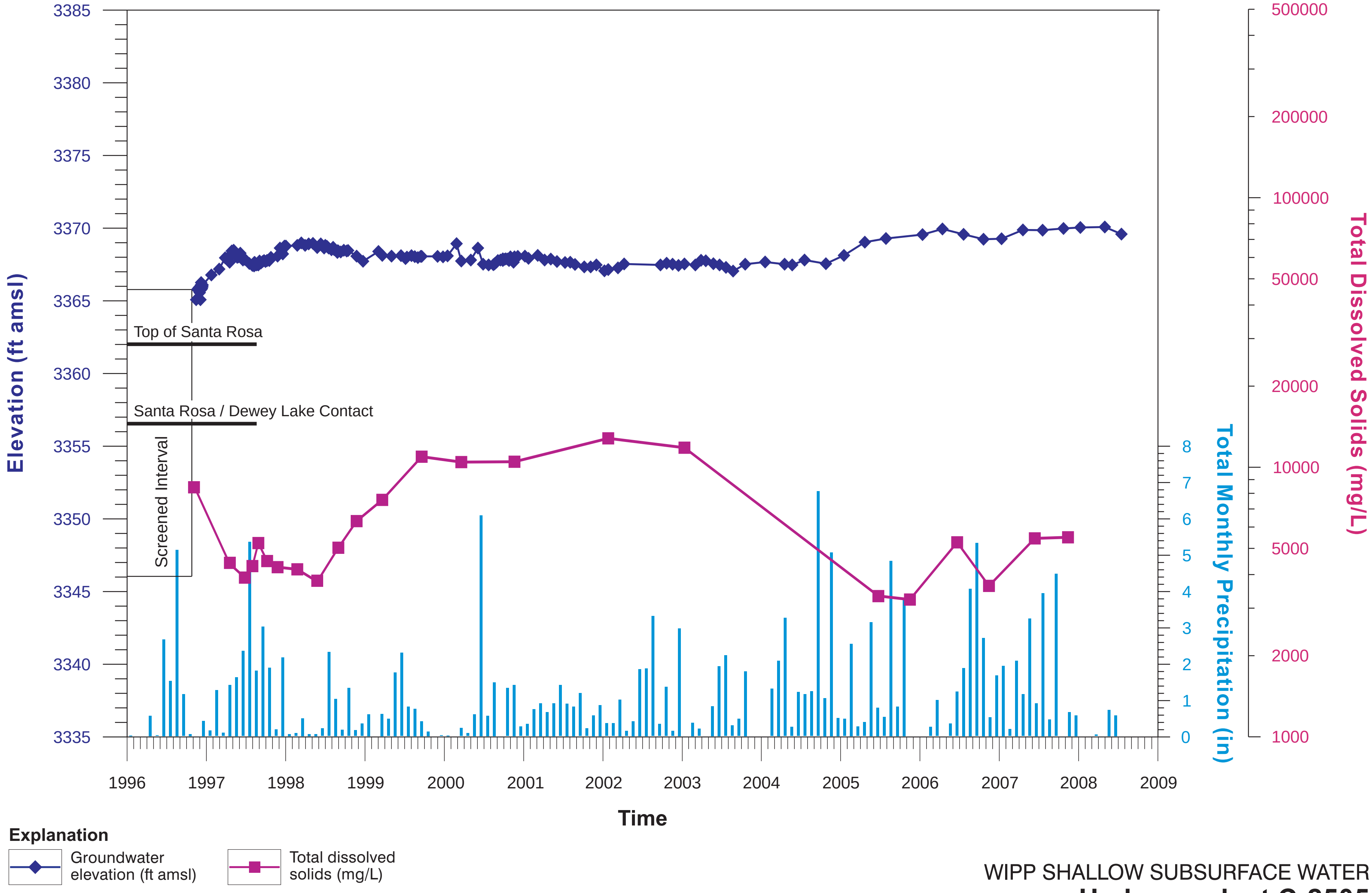

WIPP SHALLOW SUBSURFACE WATER

Hydrograph at C-2505

Monthly Precipitation and Total Dissolved Solids

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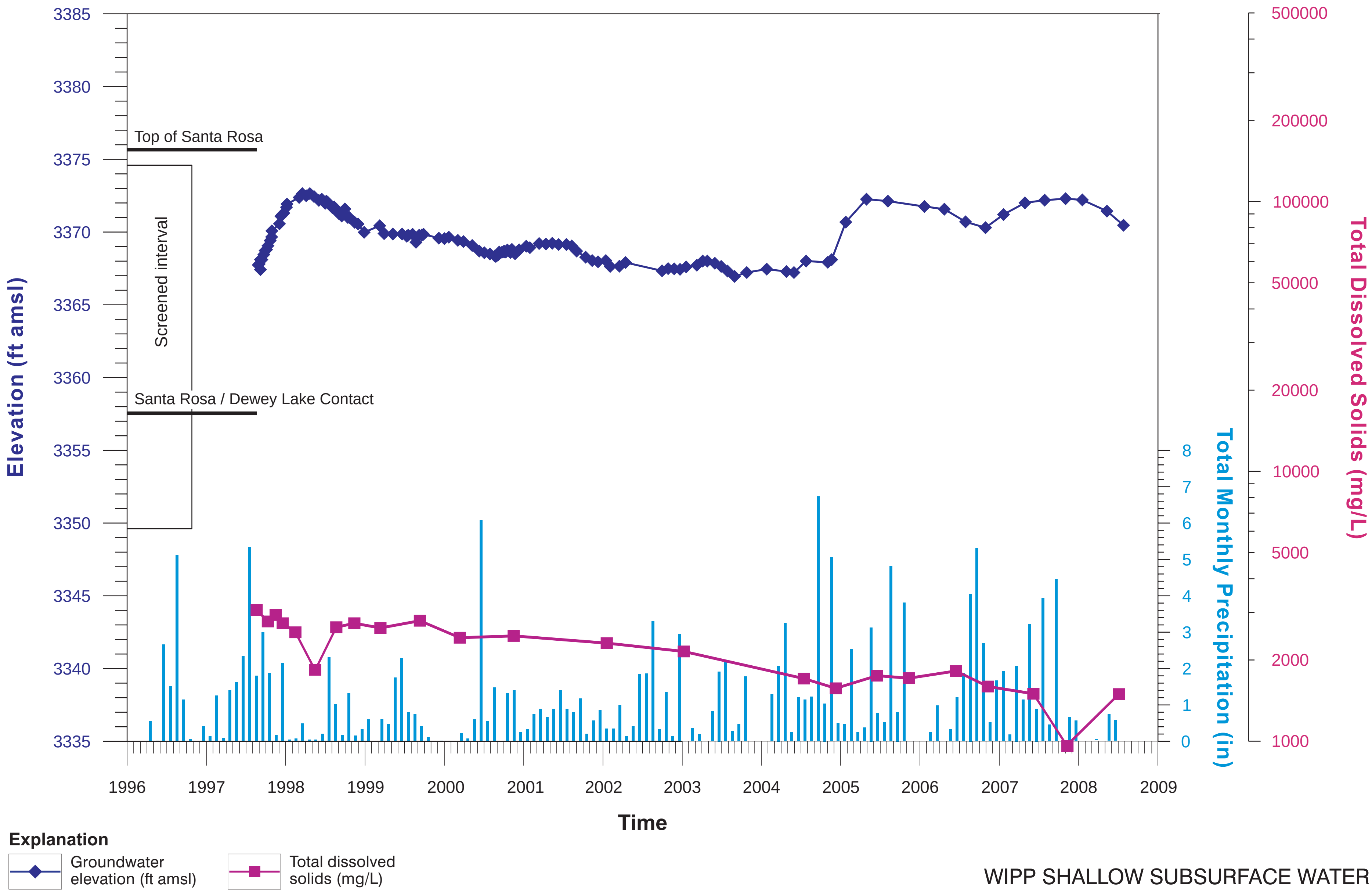
8-28-08

JN ES08.0072

Figure 11



WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-10

Monthly Precipitation and Total Dissolved Solids

Figure 12

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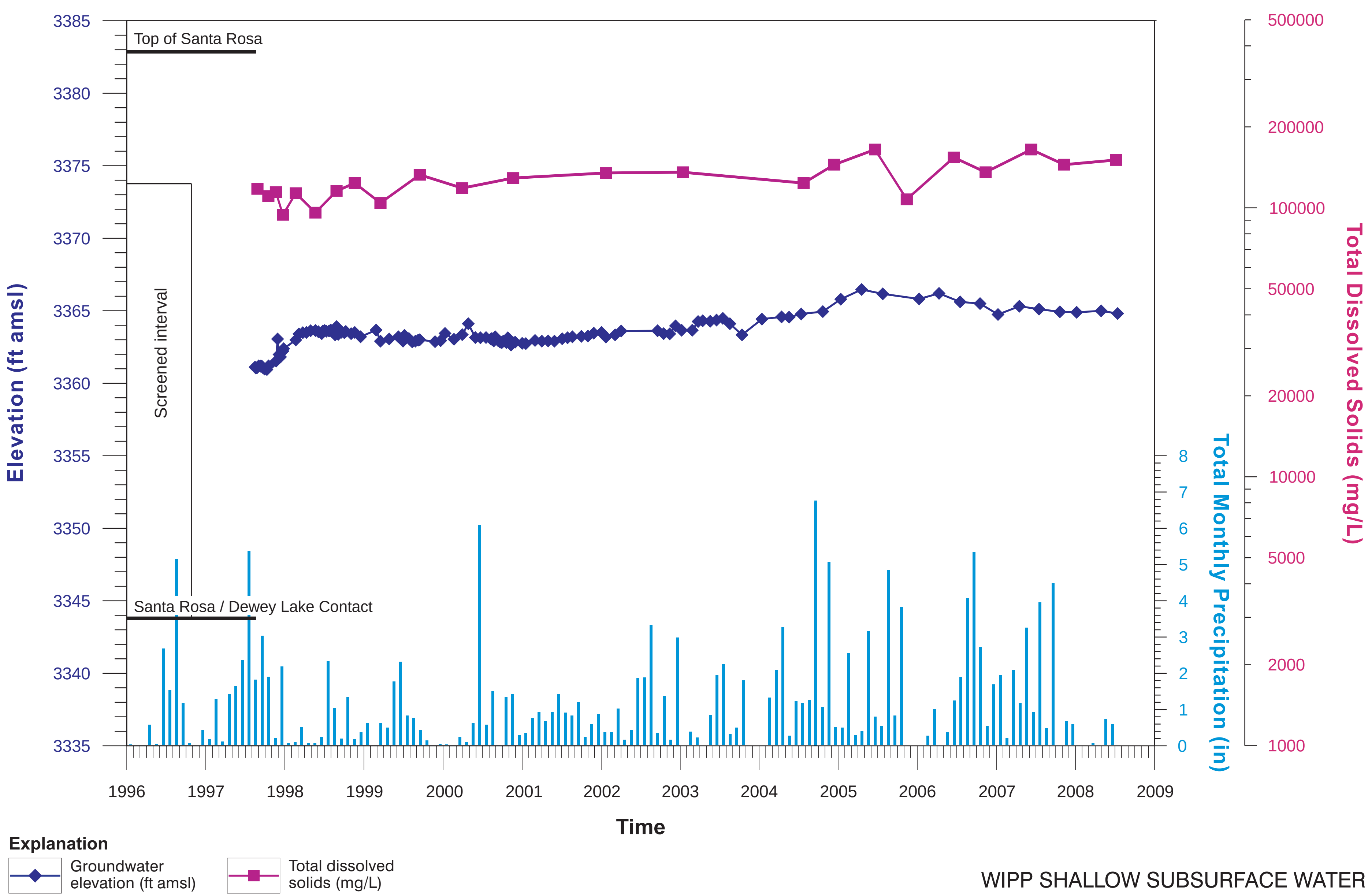

WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-09

Monthly Precipitation and Total Dissolved Solids

Figure 13

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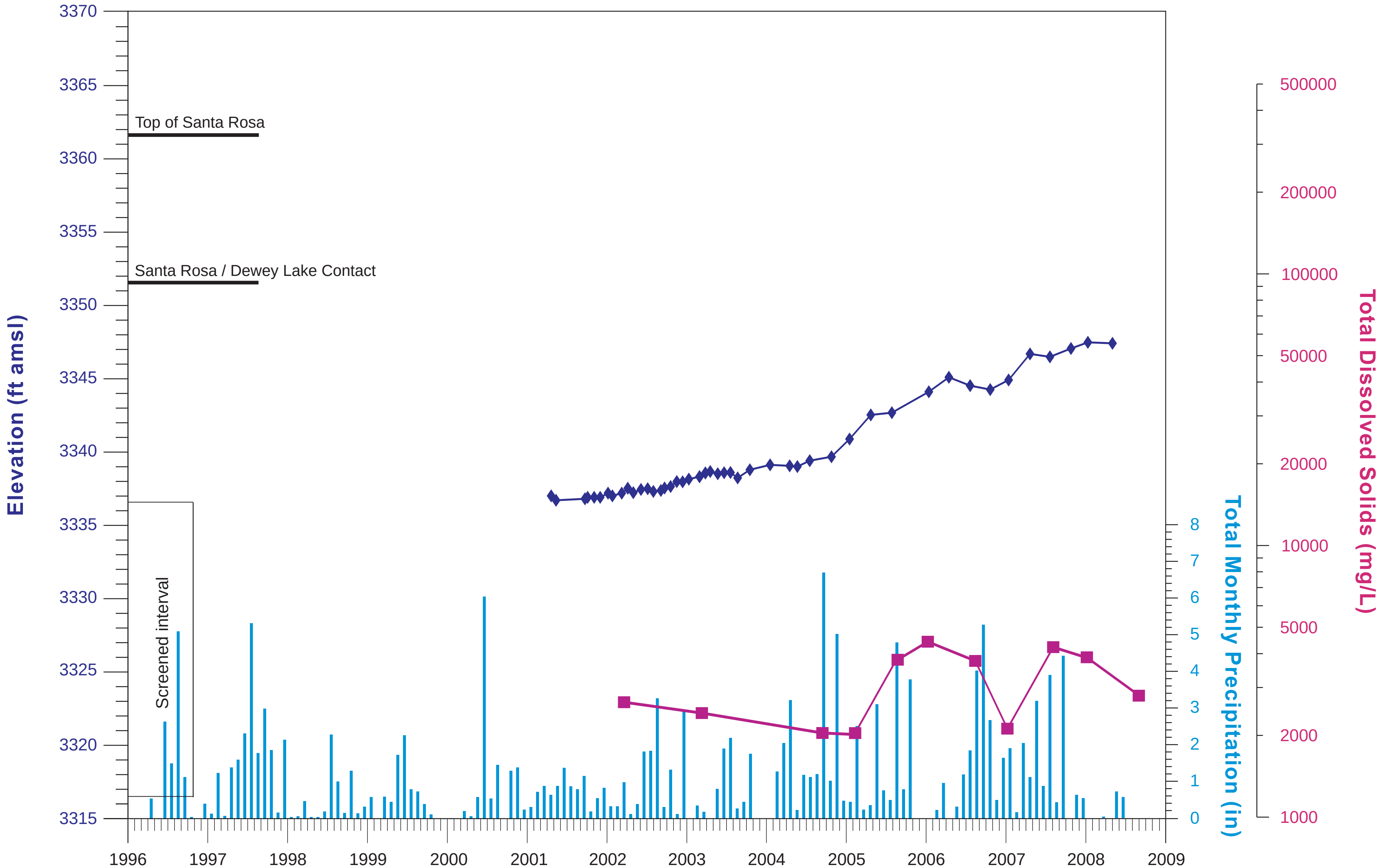

Explanation

Groundwater elevation (ft amsl)

Total dissolved solids (mg/L)

WIPP SHALLOW SUBSURFACE WATER

Hydrograph at C-2811

Monthly Precipitation and Total Dissolved Solids

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Figure 14

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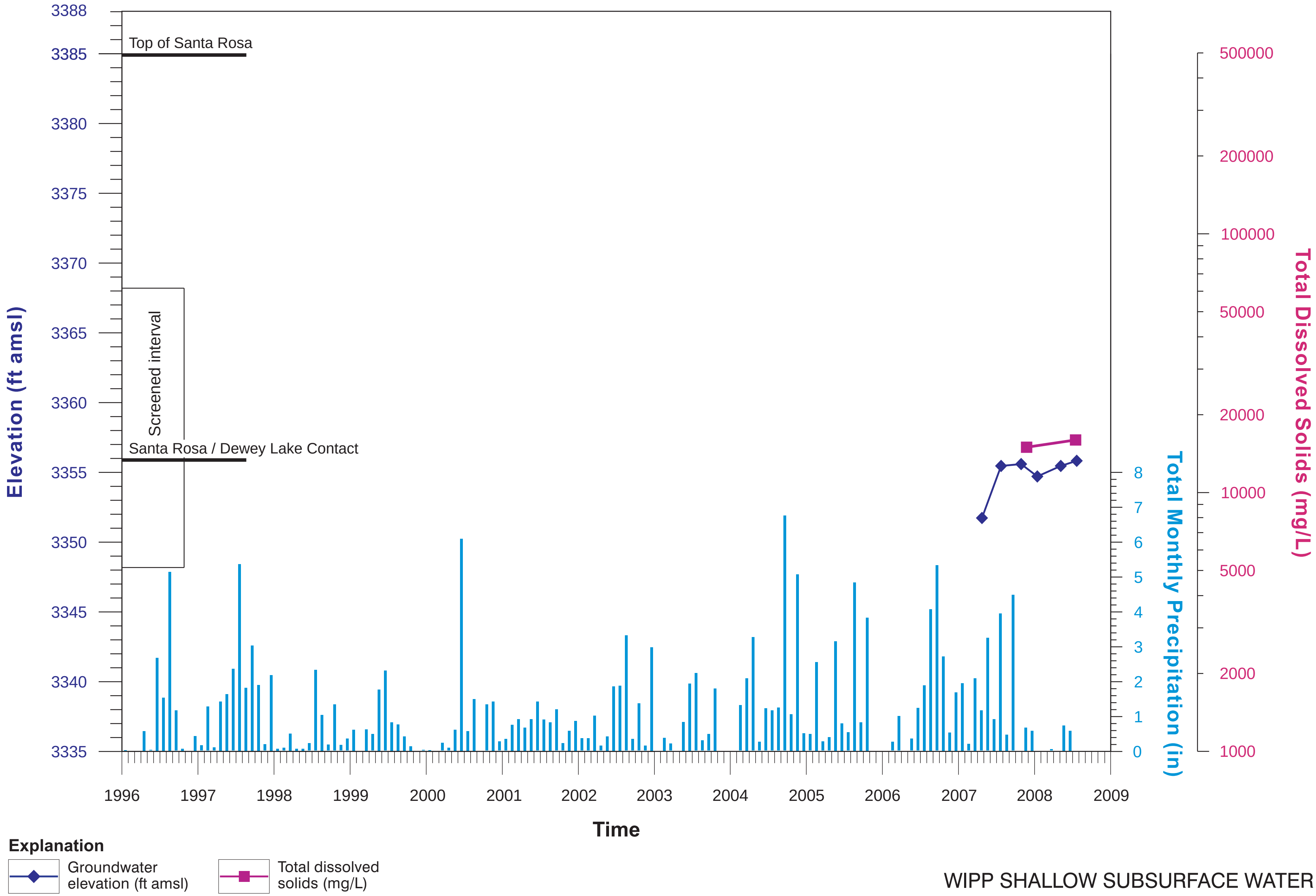

WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-08

Monthly Precipitation and Total Dissolved Solids

Figure 15

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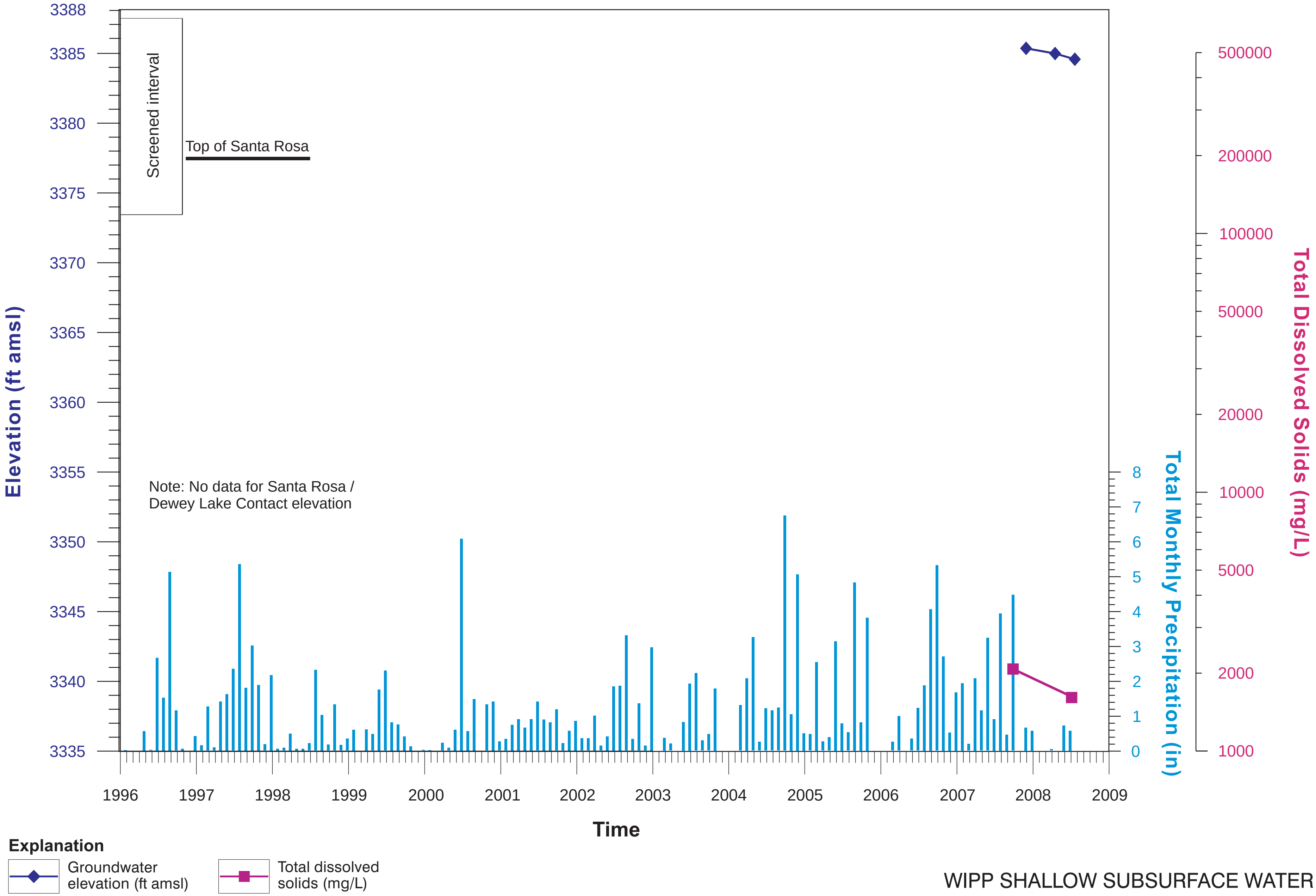

WIPP SHALLOW SUBSURFACE WATER
Hydrograph at PZ-15
Monthly Precipitation and Total Dissolved Solids

Figure 16

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Water levels were observed to rise significantly in the SSW monitor wells during the first years of record, from 1996 to 1998. The first 15 SSW monitor wells were installed in 1996 and 1997. In 1997, when the total annual precipitation (23.91 in/yr) was nearly twice the average annual precipitation (13.24 in/yr at the WIPP weather station), SSW water levels increased sharply. In contrast, during the ensuing years from 1999 to 2004, when the total annual precipitation was below the WIPP station average (Figure 3), water levels remained fairly constant in most monitor wells. From 1999 to 2004, some wells show gradual rising or falling trends. In 2005, a strong water level rise was observed in many of the wells, after which water levels again leveled out in 2006 and 2007. The water level rise in 2005 follows a year of heavy precipitation in 2004, when the annual precipitation was 23.78 inches. Early 2005 also had heavy precipitation (6.78 inches from January through May 2005) at the time of year when precipitation rates are typically low. The most recent monitoring event included in the database, the June 2008 event, indicated a decline in water levels in most wells.

The hydrograph for monitor well C-2505 (Figure 11) is a typical example that illustrates the general trends observed in most monitor wells. Water levels were rising quickly in 1996 and 1997, shortly after the first monitor wells were installed. The water level declines gradually from 1999 to 2004, followed by a sharp water level rise in 2005. The plot of TDS concentrations shows that the SSW salinity tends to be highly variable. The TDS concentration varies from approximately 3,000 to 13,000 mg/L, with an apparent correlation between low TDS concentrations during times of increasing water levels and higher TDS concentrations when water levels are constant.

The rise in water levels observed in 2005 occurs in the same time frame during which the infiltration control systems were being constructed to stop recharge from the four original stormwater ponds and the Salt Storage Area. The infiltration controls for these areas were completed from July 2004 to July 2005. The infiltration controls presumably prevented some recharge from occurring as a result of the heavy precipitation period in 2004 and early 2005. However, the largest recharge source, Detention Basin A, was the last area to be lined in July 2005. The response to recharge occurring in 2004 and 2005 is evident in the hydrograph trends. The strongest water level increase in 2005 is observed in monitor wells PZ-10 (Figure 12) and PZ-12, located near the stormwater retention ponds that remained unlined during 2004. The 2005 water level rise is moderate in most monitor wells in the main SSW lens and is least pronounced in the northernmost wells, PZ-09 (Figure 13) and PZ-11.

Other notable features of the hydrographs include the following:

- *C-2811* (Figure 14): A steady water level rise has been observed in monitor well C-2811 since its installation. This trend suggests that the saturation observed in this well may be connected to the SSW. The rising water level is consistent with the conceptual model of the SSW lens gradually spreading out, increasing the saturated thickness at C-2811 approximately 1,300 feet south of the nearest SSW monitoring location, PZ-12 (Figure 4). Monitor well C-2811 was drilled in March 2001. Saturation was encountered in the upper Dewey Lake at a depth of approximately 60 feet bgs (Powers, 2002). According to Powers (2002), the Dewey Lake encountered at C-2811 was not saturated during drilling of earlier wells nearby. The water level in C-2811 has risen 12 feet since its installation.

- *PZ-08* (Figure 15): In March 2007, saturation was detected at monitor well PZ-08 for the first time since monitoring began in 1996. By March 2008, the water level in this monitor well had risen 4 feet. Like at monitor well C-2811, the detection of saturation and rising water level in PZ-08 is consistent with the conceptual model of the SSW lens gradually spreading out, increasing the saturated thickness at PZ-08.

- *PZ-15* (Figure 16): The water level elevation at monitor well PZ-15 is higher than at any of the other SSW monitor wells. This saturated zone exists in the Gatuña, perched above the Santa Rosa. The water level at PZ-15 suggests that this saturated zone is not directly connected to the main SSW lens encountered by the first 12 PZ-series wells and the 3 C-series wells.

5.3 Water Level–Precipitation Cross Correlation Analysis

Cross correlation analysis was used to quantitatively examine the relationship between monitor well water levels and precipitation. Cross correlation is a statistical measure of the degree of correlation between two series. Given two time-series, each consisting of a sequence of observations of some variable measured at successive, uniform intervals, an intuitive measure of their correlation is given by multiplying the series point-by-point and summing the results. If the series are well correlated, the result will be large and positive. If they are well correlated but opposite in sign (i.e., negatively correlated), the result will be large and negative. If they are uncorrelated, the agreement and disagreement of the signs will be random and the resulting sum will be small in magnitude. The magnitude of the result can be scaled by the product of the standard deviation of the two series in order to facilitate interpretation of the result. Normalized this way, a resulting sum of 1 means that the series are perfectly correlated and a resulting sum of zero means that the series are completely uncorrelated. This operation can be performed for simultaneous observations from the two series, providing the "instantaneous" correlation between the observables. It can also be performed for measurements offset by one or more sampling intervals, providing the correlation between observables lagged in time. Each time the series are shifted, the number of overlapping data points is reduced by one, making it impracticable to evaluate the cross correlation at lags comparable to the total length of the series.

To perform the cross correlation operation, the time-series must have certain characteristics. The observations from each series must be simultaneous and separated by constant intervals of time. The series must be stationary—the descriptive statistics of the series (mean, variance and higher order moments) should not depend on when the measurement was made. In effect, this means that there should be no trend in the series; if there is, the trend should be removed. Series were tested for stationarity by examining their autocorrelation functions. Just as two series may be compared by their cross correlation, a series may be compared to itself using the autocorrelation. Operationally, autocorrelation is identical to cross correlation. The autocorrelation provides a means of assessing the similarity measurements of some observable to subsequent measurements. For a stationary series, the measurement of an observable at any given time should not correlate with previous measurements. This can be seen in the autocorrelation as a steep drop at lags greater than zero.

Four wells were included in this analysis, PZ-07 (adjacent to the Salt Pile Evaporation Pond), PZ-09 (immediately outside the east stormwater diversion berm), PZ-10 (adjacent to Detention

Basin A) and PZ-12 (between Pond 1 and Pond 2). Water levels measurements in these wells have been made on varying schedules since their installation. Quarterly measurements are available from September 1997 to March 2008, with the exception of December 1997, December 1998, September 1999, March 2002, June 2002, and September 2005. For these quarters, the water level was estimated by a linear interpolation of the previous and subsequent measurements. For quarters in which more than one measurement of water level was made, the average monthly water level was used. Quarterly cumulative precipitation was obtained from the WIPP meteorological station. Stationarity for both types of data was achieved by subtracting the fitted linear trend from each series. This approach was confirmed by analysis of the autocorrelation function, which showed the expected pattern (Appendix D).

Two scenarios were analyzed: (1) the unlined scenario (before construction of infiltration controls) and (2) the lined scenario (after construction of infiltration controls). The unlined scenario was defined to apply from September 1997 to June 2005. The lined scenario was defined to apply from October 2005 to March 2008. Cross correlation plots of the unlined scenario for PZ-07 and PZ-09 showed a similar pattern of the cross correlation of a negative correlation at zero lag rising to a positive sill at a lag of 3 (9 months). Cross correlation for PZ-10 was similar, though it rose to a sill value at a lag of 2 (6 months). The cross correlation of PZ-12 was positive at lag zero and rose to a sill at a lag of 1 (3 months) before falling off thereafter. The results for PZ-07, PZ-09 and PZ-10 are consistent with infiltration times of between 6 and 9 months. The cross correlation for PZ-12 shows a stronger correlation at lag zero and at 3 months, suggesting a shorter infiltration time. Analysis of the lined scenario did not provide useful results due to the short period of record and very limited dataset when evaluating cross correlation at lag times.

5.4 Water Level Contour Maps

Water level contour maps for the SSW were prepared to show water level and flow direction changes over the complete monitoring record. A series of water level maps is provided in Appendix E, illustrating approximately annual time steps. This section discusses the water level contour map preparation methods and results.

5.4.1 Water Level Density Correction

The high TDS concentrations in the SSW at many locations result in a measurable difference in the density of the SSW relative to freshwater. Given the differences in TDS across the site, the potential for a density gradient to contribute to the hydraulic gradient must be considered. Because of contrasting TDS concentrations observed in the SSW, corrections were made to the measured water levels to account for water density differences.

The concept of equivalent freshwater head was employed to account for density differences across the SSW. Equivalent freshwater head is the height of a column of freshwater with the same potential energy as the measured height of a column of brackish to briny water. The equivalent freshwater head represents the potentiometric surface that controls the flow rate and direction within a hydrologic regime with variable salinity.

To adjust the measured water level, a calculated specific gravity was multiplied by the height of the water column, yielding an equivalent freshwater head water elevation. The base of the column in each well was defined as the elevation of the surface on which the SSW is perched. In most of the wells, the surface used was the Dewey Lake/Santa Rosa contact. In the new wells PZ-13 and PZ-15, water is perched on hard layers within the Santa Rosa. Equivalent freshwater head was obtained in this case by multiplying the measured height of the column of SSW in a well by its specific gravity. The corresponding water level elevation was obtained by adding the resulting equivalent freshwater head to the elevation of the surface above which it was measured.

Specific gravity measurements were available over much of the period of record for most of the wells; however, the laboratory-measured specific gravity values were not reported for any wells after 2002, and they were not of high precision. Therefore, it was necessary to estimate specific gravity from the available data using a consistent procedure. It was assumed that specific gravity could be predicted from solute concentration alone, neglecting any variations in pressure and temperature across the site on a given date (Guo and Langevin, 2002).

Of the data available for the whole period of record, only TDS and chloride were considered predictive of specific gravity. Because most of the TDS in the SSW is attributable to halite dissolution, the concentrations of TDS, sodium, and chloride are typically dependent variables, although TDS is a more general measure of the total solute load. Sodium was generally not measured after 2002.

A site-specific relationship between specific gravity and TDS was preferred because relationships for saline water of differing quality do not reflect the exact composition and specific gravity of the SSW. High-precision measurements of specific gravity made with hydrometers are available for samples that were also analyzed for TDS and chloride in December 2001. Using the specific gravity data, plots were prepared of specific gravity versus TDS and specific gravity versus chloride. Despite temperature variation of a few degrees Celsius between the samples, the measured specific gravities were highly correlated to both TDS and chloride concentrations and produced simple linear relationships. One measured specific gravity value deviated significantly from the relationship and was rejected as anomalous and possibly a typographic error (an original data report could not be located, but rearrangement of the last two digits would have placed the value along the same line as the others). To avoid reliance on insignificant digits, and for easier comparison to literature values, the intercepts of the fitted lines were prescribed values of unity (Figure 17). The resulting equation relating specific gravity to TDS concentration was as follows:

$$SG = 1 + TDS \bullet 6.6 \times 10^{-7} \quad (1)$$

where SG = specific gravity
TDS = TDS concentration (mg/L)

The equation relating specific gravity to chloride concentration was as follows:

$$SG = 1 + Cl \bullet 1.2 \times 10^{-6} \quad (2)$$

where Cl = chloride concentration (mg/L)

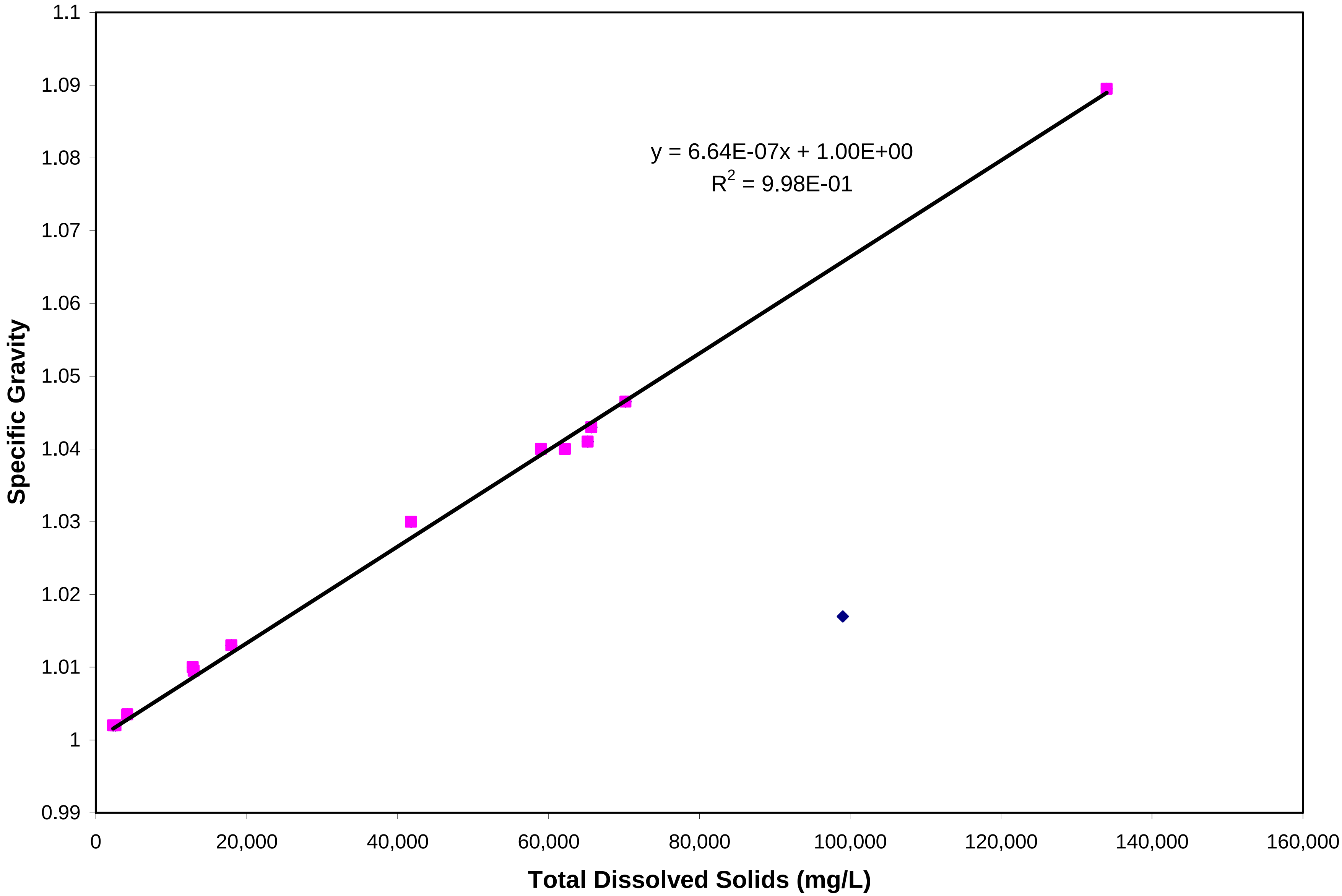

Figure 17

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Specific Gravity–TDS Relationship

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The relationship between specific gravity and TDS concentration was retained to predict specific gravities used in calculations of equivalent freshwater head. The relationship between specific gravity and chloride concentration was useful for validation purposes because a U.S. Geological Survey (USGS) study of halite brine near Syracuse, New York (Yager et al., 2007) reported a corresponding relationship intended for use with an updated version of the variable-density flow model, SEAWAT (Guo and Langevin, 2002), that was identical to the SSW relationship within the accuracy of the results. The report did not tabulate all the data used and did not state the equation of the line, but by digitizing a plot of the line, the equation was determined to be as follows:

$$SG = 1.000001 + Cl \bullet 1.19 \times 10^{-6} \tag{3}$$

The authors reported a coefficient of determination (R^2) of 0.988 for chloride concentrations between 0 and roughly 125,000 mg/L (Yager et al., 2007).

Upon verifying the relationship between chloride concentration and measured specific gravity for the WIPP halite-dominated water, the corollary relationship between TDS concentration and measured specific gravity was used to compute the equivalent freshwater head for each water level measurement used in preparing water level contour maps for the SSW.

5.4.2 Water Level Contour Maps

Water level contour maps were prepared using the equivalent freshwater head elevations as the basis for the potentiometric surface contours. The contour maps were generated using Surfer software to interpolate the data, without any additional interpretation or revisions. A series of 12 water level contour maps is provided in Appendix E. These maps show a time-series of water level changes at approximately 1-year time steps over the monitoring record. The frequency of water level measurements has varied over the monitoring record. Most of the contour maps reflect water level measurements collected in October or another fall month each year. Fall data were selected because this sampling time follows the period of heaviest precipitation during the summer monsoon season. During some years, data were not available for a consistent time horizon; therefore, data from other seasons are used in some of the water level contour maps. The series of maps also includes the most recent water level measurements included in the database (the June 2008 measurements).

Figures 18 and 19 show the water level contours for the first (October 1997) and last (June 2008) monitoring periods selected. The time-series of maps consistently uses the set of SSW monitor wells installed in 1996 and 1997, including C-2505, -2506, and -2507 and PZ-01 through -12, but excluding PZ-08, which was dry until 2007. The contour maps exclude monitor well PZ-08, which was dry until 2007, and monitor wells PZ-13, PZ-14, and C-2811, which are not conclusively linked by a direct hydrologic connection with the main SSW lens.

5.4.3 Direction and Rate of Flow

The series of water level contour maps shows that the potentiometric surface has remained relatively consistent from 1997 to 2008 with respect to SSW flow direction and gradient. Each of the contour maps shows a similar pattern of contours. However, water levels have consistently risen in the monitor wells by approximately 2 to 4 feet.

The water level contour maps indicate that a water table mound exists near the Salt Pile Evaporation Pond and Salt Storage Area. The SSW flow pattern suggests radial flow outward from the high point at PZ-07, with a predominantly eastward flow toward PZ-03, -05, and -09 and a predominantly southward flow toward PZ-10 and -12. In the WIPP facilities area, where most SSW monitor wells are located, the SSW flows south and east from the apex of the water table mound. Monitor well PZ-11, located approximately 200 feet northwest of the Salt Pile Evaporation Pond, suggests a gradient to the north; however, the existing monitor well locations do not provide sufficient data to clearly demonstrate the gradient and extent of the SSW to the north and west of the water table mound. The SPDV monitor wells PZ-13, -14, and -15 appear to monitor SSW that is distinct from the main SSW lens. The SPDV monitor wells do not show a radial flow pattern that is consistent with the other SSW monitor wells. Water level elevations in the SPDV monitor wells are higher than the water level at PZ-08, which is located between the SPDV wells and the main SSW lens.

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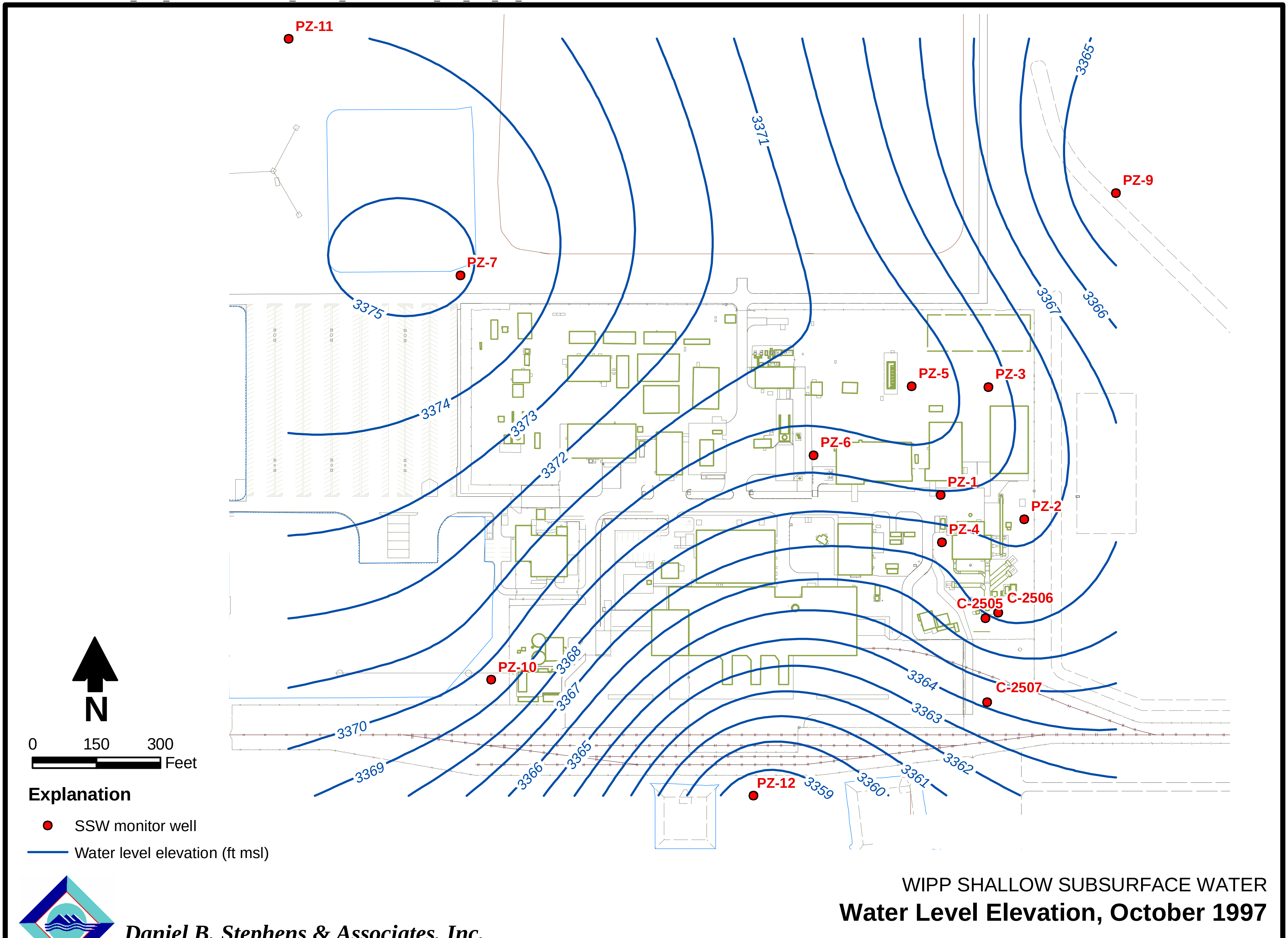

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Water Level Elevation, October 1997

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Figure 18

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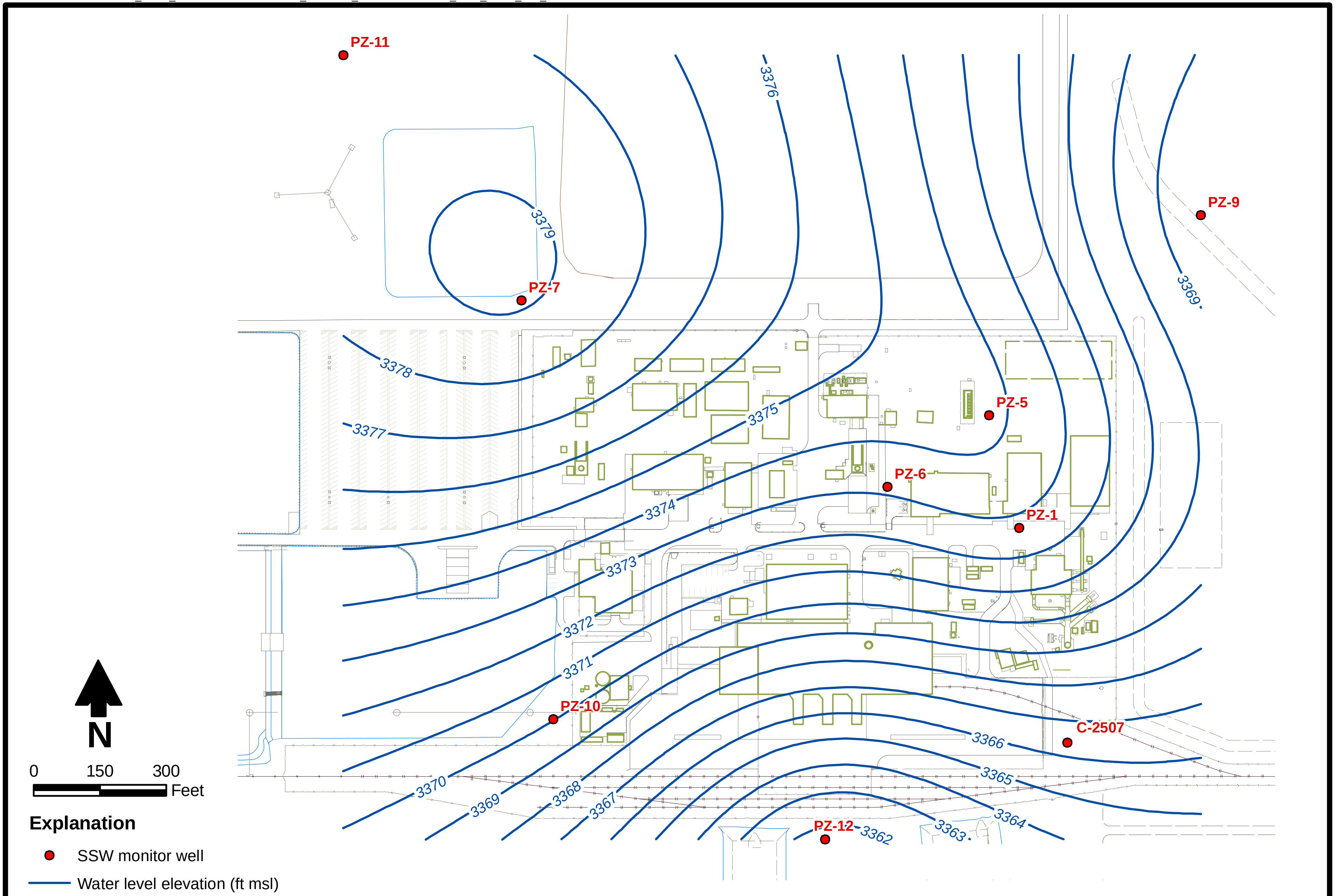

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Water Level Elevation, June 2008

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Figure 19

The potentiometric surface is influenced by the areas of recharge and geologic controls on flow. Previous recharge estimates found that the Salt Storage Area, Salt Pile Evaporation Pond, and Detention Basin A are the most significant recharge sources (DBS&A, 2003). SSW water table mounding would be expected in these high recharge areas. The potentiometric surface is also affected by geologic controls that include the following:

- Configuration of the irregular Santa Rosa/Dewey Lake contact that forms the perching horizon
- Other perching horizons, such as the Gatuña/Santa Rosa contact at PZ-15 and middle Santa Rosa at PZ-13
- Hydraulic conductivity of the formations where SSW occurs

The Santa Rosa/Dewey Lake contact is an erosional unconformity with an irregular surface. A contour map of the contact elevation based on contact elevations from the well logs is provided in Figure 20. The contact surface exhibits a higher ridge area between monitor wells C-2505 and PZ-10 and a lower trough area near PZ-07. The contact surface drops steeply to the south toward PZ-12. The SSW flow regime interacts with the contact surface at the top of the low-permeability Dewey Lake.

The hydraulic conductivity of the formations involved with SSW flow also influences the potentiometric surface. Pumping and slug tests performed in 1996 and 1997 indicated a lower Santa Rosa hydraulic conductivity zone in the area around PZ-01, -02, and -05 (Intera, 1996, 1997a, and 1997b). The low hydraulic conductivity in this area may play a role in the slow migration of SSW to eventually reach PZ-08 in 2007. This zone may also limit the rate of flow between the SSW and new monitor wells PZ-13 and -14 near the SPDV pile. The rate of flow to C-2811, if this well is in hydraulic connection with the SSW, is also affected by the contrasting hydraulic conductivity in the Dewey Lake potentially limiting downward flow to a saturated horizon in the upper Dewey Lake, approximately 10 feet below the Santa Rosa/Dewey Lake contact.

The water level contour map from June 2008 (Figure 19) shows that the hydraulic gradient and flow direction are variable. This variation leads to variable flow rates, with the flow rate

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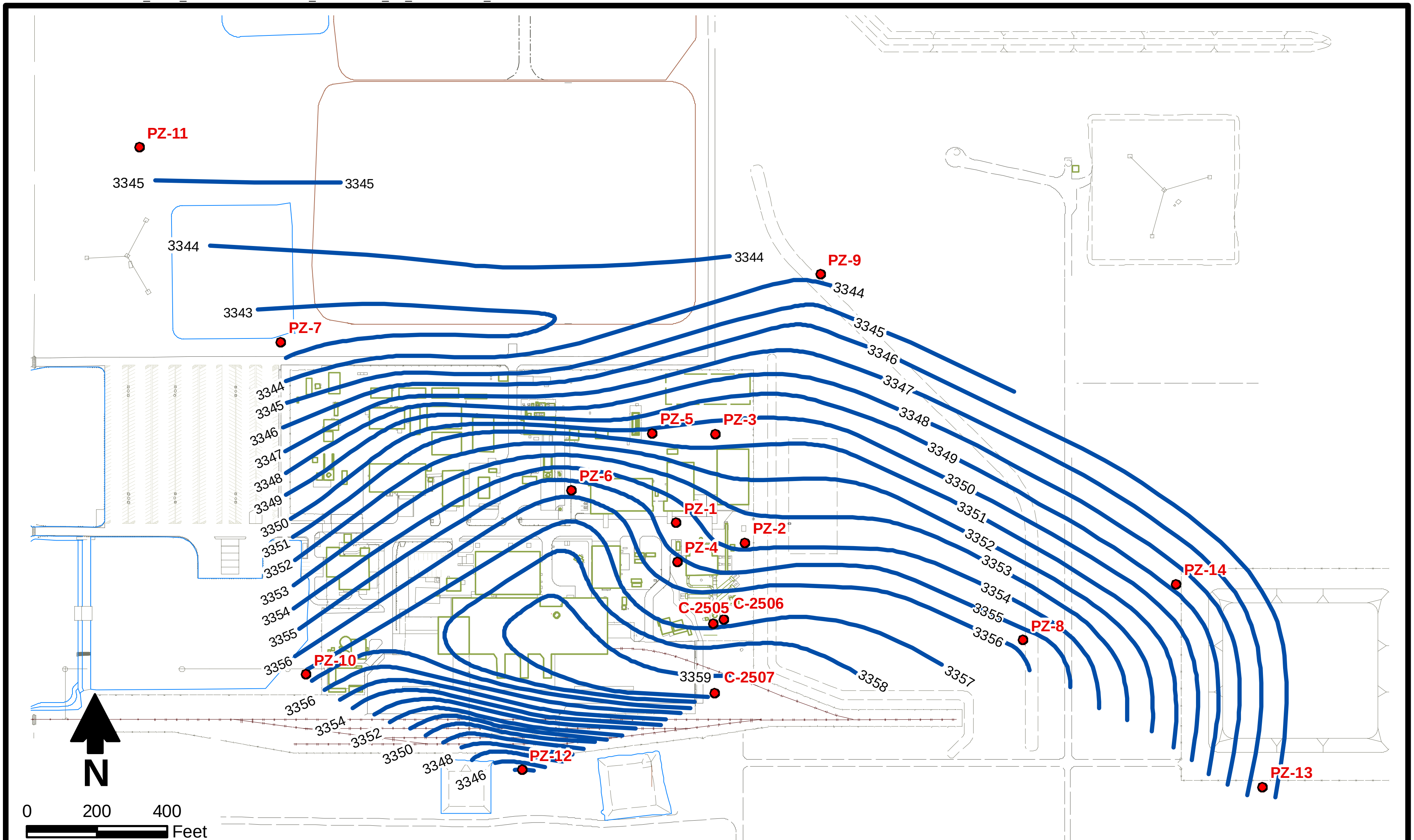

Explanation

SSW monitor well

Santa Rosa/Dewey Lake contact elevation contours (ft msl)

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Contours of Santa Rosa/Dewey Lake Contact

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Figure 20

dependent on hydraulic gradient and hydraulic conductivity of the formation. Using the June 2008 contours, the typical hydraulic gradient is approximately 0.012 foot per foot (ft/ft) toward the southeast. A typical SSW seepage velocity can then be calculated using an effective porosity of 10 percent (DBS&A, 2003) and the geometric mean hydraulic conductivity (Intera, 1997a) of 1.5 feet per day (ft/d) for wells PZ-06, -07, -10, and -12 (located in the central portion of the site where a relatively uniform southeasterly gradient is observed). The resulting seepage velocity is 0.18 ft/d, which represents a typical SSW flow velocity for current conditions.

5.5 Water Quality Contour Maps

Water quality contour maps for the SSW were prepared to evaluate trends in water quality over the complete monitoring record. The water quality maps use TDS concentration as the indicator of SSW salinity because elevated salinity is the most significant water quality indicator for the SSW. The contour maps were generated using Surfer software to interpolate the data, with no additional interpretation or revisions. A series of water quality contour maps is provided in Appendix F illustrating approximately annual time steps, the same time steps illustrated in water level contour maps. This section discusses the water quality contour map preparation methods and results.

Figures 21 through 23 show the water quality contours for October 1997, June 2004, and June 2008 monitoring periods. These monitoring periods represent the start and end of the monitoring record, as well as the time in June 2004 when salinity reached peak concentrations. The time-series of maps uses the set of SSW monitor wells installed in 1996 and 1997, including C-2505, C-2506, C-2507, and PZ-01 through -12, but excluding PZ-08, which was dry until 2007, and excluding monitor wells PZ-13, PZ-14, and C-2811, which are not conclusively linked by a direct hydrologic connection with the main SSW lens. During early years of monitoring, from 1997 to 2002, all 14 of the monitor wells were monitored for TDS. Beginning in 2003, the number of wells monitored on a regular basis was reduced to 9; these wells were used in water quality contour maps from 2004 to 2008.

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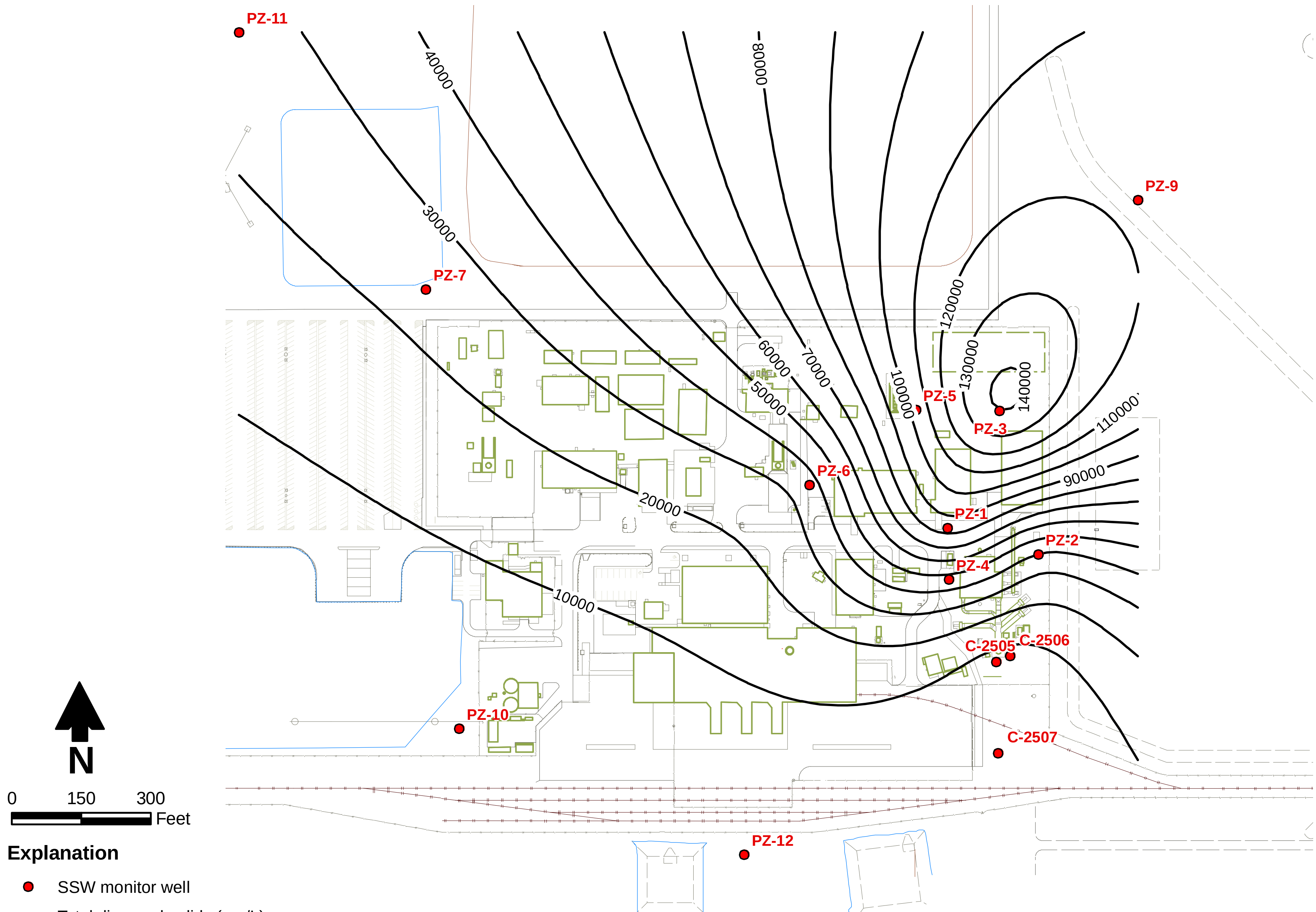

Explanation

SSW monitor well

Total dissoved solids (mg/L)

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Total Dissolved Solids, October 1997

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Figure 21

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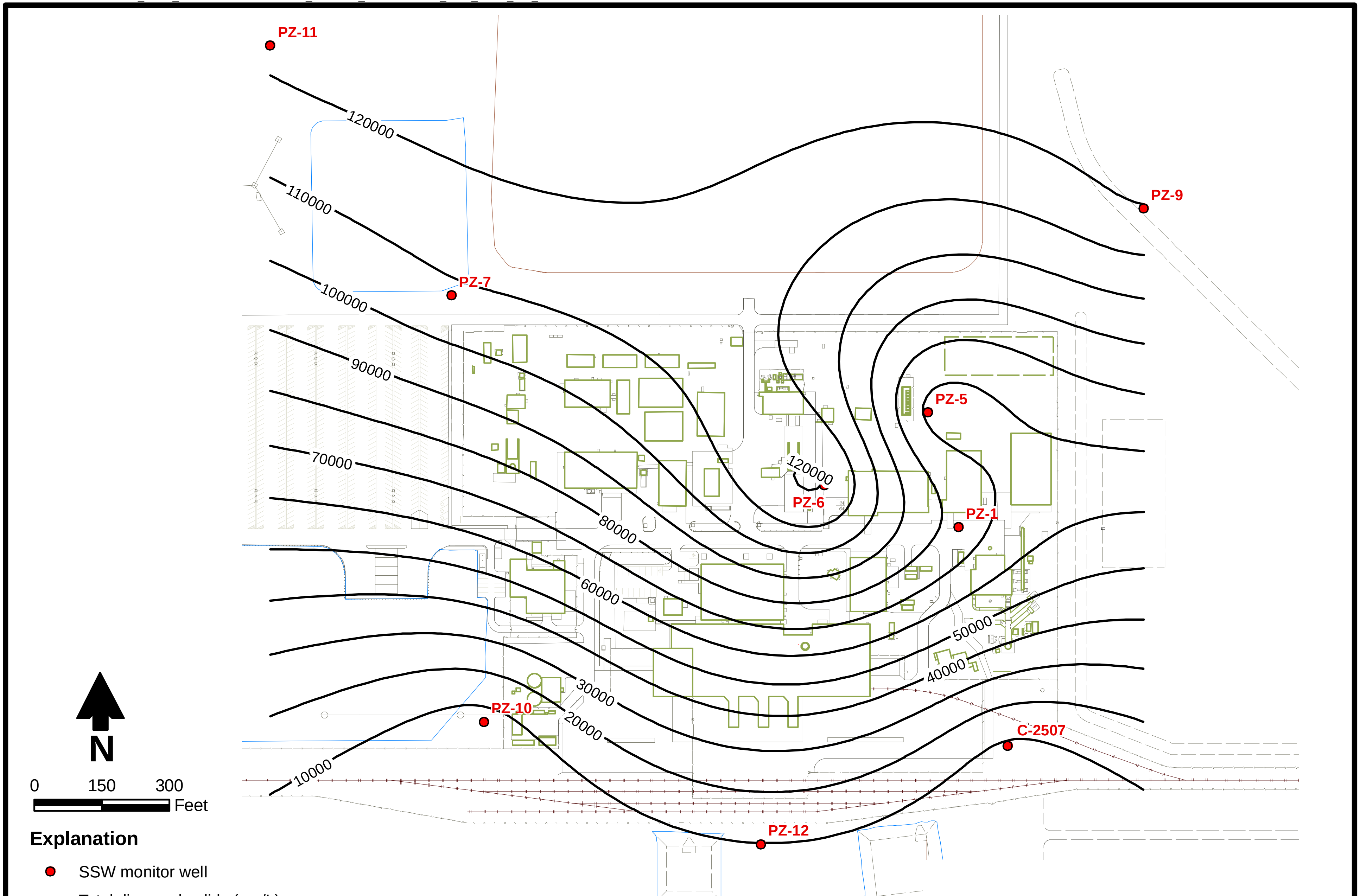

Explanation

SSW monitor well

Total dissoved solids (mg/L)

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Total Dissolved Solids, June 2004

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JN ES08.0072

Figure 22

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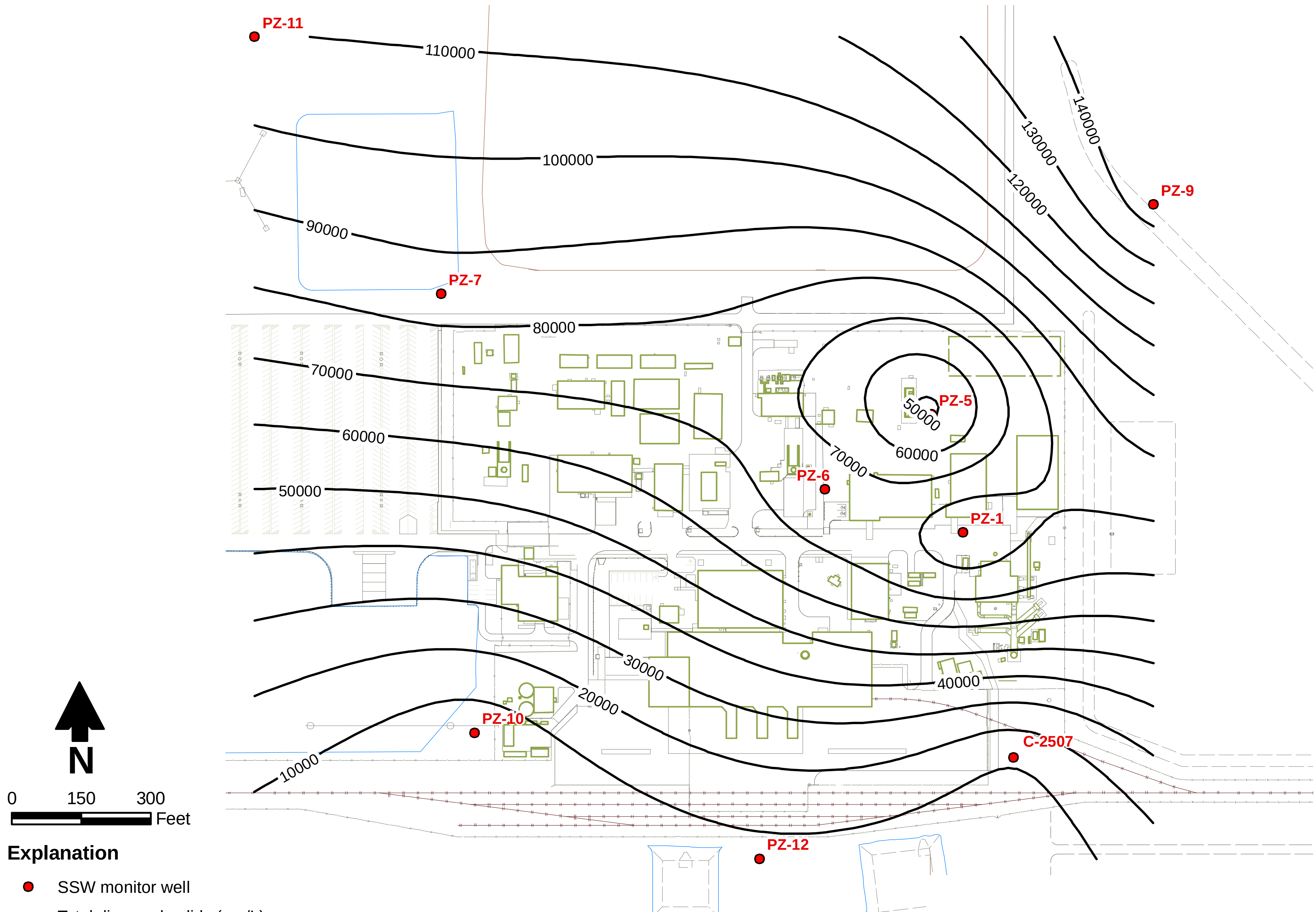

Explanation

SSW monitor well

Total dissoved solids (mg/L)

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Total Dissolved Solids, June 2008

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Figure 23

5.5.1 Salinity Distribution

The series of water quality contour maps shows that salinity levels are highly variable in the SSW monitor wells. TDS concentrations range from less than 10,000 mg/L to more than 200,000 mg/L. All of the SSW is characterized by high salinity, ranging from water considered brackish (TDS concentration of approximately 3,000 mg/L) to water classified as brine (TDS concentration greater than the salinity of seawater, or approximately 35,000 mg/L [National Academy of Sciences, 2008]). The highest TDS concentrations are found throughout the northern half of the WIPP facilities area and near the SPDV pile, where much of the water contains TDS concentrations exceeding 50,000 mg/L. Wells near the Salt Storage Area, Salt Pile Evaporation Pond, and SPDV pile have the highest salinity. TDS concentrations are much lower in the southern part of the WIPP facilities area, where low TDS water recharges the SSW from stormwater retention ponds. Wells near Detention Basin A, Pond 1, and Pond 2 have the lowest salinity (TDS concentrations less than 10,000 mg/L).

Salinity levels were lowest during the earliest years of monitoring from 1997 to 1998 (Figure 21). Salinity levels then increased to the highest concentrations by 2004 (Figure 22). By 2008, salinity levels declined slightly from the peak (Figure 23). Over the monitoring record, higher salinity levels in the northern part of the site gradually shift southward, in the general direction of SSW flow. The observed water table mound, centered near the Salt Pile Evaporation Pond and Salt Storage Area, causes an outward radial flow from the mound’s apex, with the high-salinity plume spreading radially and increasing the TDS concentrations in wells at the periphery.

Additional water quality details can be reviewed in the monitoring data tables included in Appendix B. The data include all monitoring events. The monitoring data show that high TDS concentrations exceeding 100,000 mg/L have been measured in monitor wells PZ-03, -07, -09, and -11. The highest TDS concentration within the main SSW lens was 185,000 mg/L, measured in PZ-03 in 1999. Currently, the highest TDS concentration within the main SSW lens is 150,000 mg/L in PZ-09. The highest TDS concentration in any monitor well was 245,500 mg/L, measured in PZ-13 in 2007, although this water near the SPDV pile appears to be hydrologically separated from the main SSW lens. The lowest TDS concentrations have been measured in monitor well PZ-10, in the range of 1,000 to 3,000 mg/L. The TDS concentration in monitor well PZ-08, which was sampled for the first time in October 2007, is 15,000 mg/L. As shown in the water quality data in Appendix B and hydrographs in Appendix C, the TDS concentration in individual wells fluctuates significantly over time in many of the monitor wells.

5.5.2 Salinity Sources

The SSW water quality has the signature of halite brine, containing high concentrations of sodium (Na) and chloride (Cl). U.S. DOE (2002) indicates that the composition of the Santa Rosa and overlying sediments does not provide a mechanism to produce naturally occurring water with the high salinities observed; therefore, the SSW is likely derived, at least in part, from anthropogenic saline sources. Two potential sources of SSW salinity are the Salt Storage Area and Salt Pile Evaporation Pond, which are close to the monitor wells with the highest TDS concentrations. Monitor wells PZ-13 and -14, near the SPDV pile, also exhibit high salinity. In contrast, monitor wells near the stormwater retention ponds, which are sources of freshwater recharge, exhibit the lowest TDS concentrations. Other salinity sources associated with WIPP drilling and construction activities in the 1980s could also contribute to the SSW salinity, although the quantity of water discharges at that time were a small fraction of the SSW volume (DBS&A, 2003).

The halite (NaCl) contained in the Salt Storage Area is susceptible to dissolution by precipitation leaching through the salt. Dissolution is dependent on the rate of infiltration and the area of exposed mineral surfaces. Based on a halite solubility constant from Parkhurst (1995), water saturated with halite contains 133,000 mg/L sodium and 205,000 mg/L chloride and has an approximate TDS concentration of 338,000 mg/L, depending on the exact composition of the crushed rock salt. Seepage that is near saturation with dissolved halite would have a TDS concentration approximately twice as high as the highest TDS concentration measured in the main SSW lens. Thus, seepage from the Salt Storage Area provides a potential mechanism to generate the TDS concentrations observed in the monitor wells.

The SPDV pile received mined tailings and construction debris from the drilling of two 2,150-foot shafts and the excavation of tunnels and rooms during the WIPP design validation phase (U.S.

DOE, 2008). Based on available information, the composition of the pile is expected to be predominantly halite, with small amounts of other minerals. Other minerals possibly present include dolomite, calcite, gypsum, anhydrite, sylvite, carnallite, soda niter, and other evaporites such as polyhalite that may be present as impurities in the primary materials. The mined salt extends to approximately 5 feet bgs, where the underlying caliche is undisturbed (DBS&A, 1996). Test borings in the SPDV pile encountered multiple layers of recrystallized salt (DBS&A, 1996), implying some amount of historical infiltration.

5.5.3 SPDV Monitor Wells

Water quality in new SPDV monitor wells (PZ-13, -14, and -15) is addressed in detail in the Basic Data Report for these wells (U.S. DOE, 2008). This report also provides water quality data for monitor well PZ-08, located between the main SSW lens and the SPDV pile, which was sampled for the first time in 2007.

The SPDV wells have highly variable water quality. Monitor well PZ-13 has a TDS concentration of 245,500 mg/L, higher than any previously tested monitor well. Monitor well PZ-14 also has a high TDS concentration of 106,000 mg/L. In contrast, monitor well PZ-15, which is screened in a saturated zone in the lower Gatuña, has a low TDS concentration of 2,060 mg/L.

U.S. DOE (2008) has evaluated the water quality in the SPDV monitor wells and concluded that the water encountered in PZ-13 and -14 has a geochemical association with minerals in the SPDV pile. It appears that this water is the result of infiltration through the SPDV pile and is not associated with the main SSW saturated lens. The water encountered in PZ-15 has a much lower TDS concentration and is associated with recharge that has not been significantly affected by mineral dissolution.

5.6 Water Chemistry and Monitoring

The SSW water chemistry was evaluated to determine the distinguishing characteristics of the water and to examine relationships between the monitor wells and potential salinity sources. Using Geochemist's Workbench software, the following analyses were completed:

- The cation/anion charge balance was calculated for individual samples.
- Saturation indices were calculated for major minerals.
- Durov plots were prepared to display water chemistry characteristics and variability.

5.6.1 Charge Balance

Water chemistry calculations of charge balance accounting, using the major cations and anions to examine the balance between positive and negative charges, produced results generally similar to calculations provided by WTS. The SSW monitor well water quality data produce charge balances reasonably near to neutrality; greater than 95 percent of the SSW data had deviations less than 5 percent, and all of the SSW data had deviations less than 10 percent, with the exception of a single sample from PZ-02, which was previously rejected. Monitor well WQSP-6A had multiple samples in which measured ion concentrations had large deviations from neutrality. WTS had previously employed criteria requiring charge balance within 5 percent of neutrality for screening the data; however, none of the data were rejected from consideration in the interpretations that follow.

The Geochemist's Workbench software was used to calculate a TDS concentration based on the concentrations of the individual dissolved constituents. The method adjusts the ion values to achieve charge balance before calculating the TDS concentration. Comparison of the calculated TDS values with measured TDS values showed that, on average, the measured TDS values were significantly higher, which could reflect suspended sediment in the samples. Samples collected prior to the initiation of low-flow sampling techniques around 2000 may be more susceptible to the effects of suspended sediment.

5.6.2 Saturation Indices

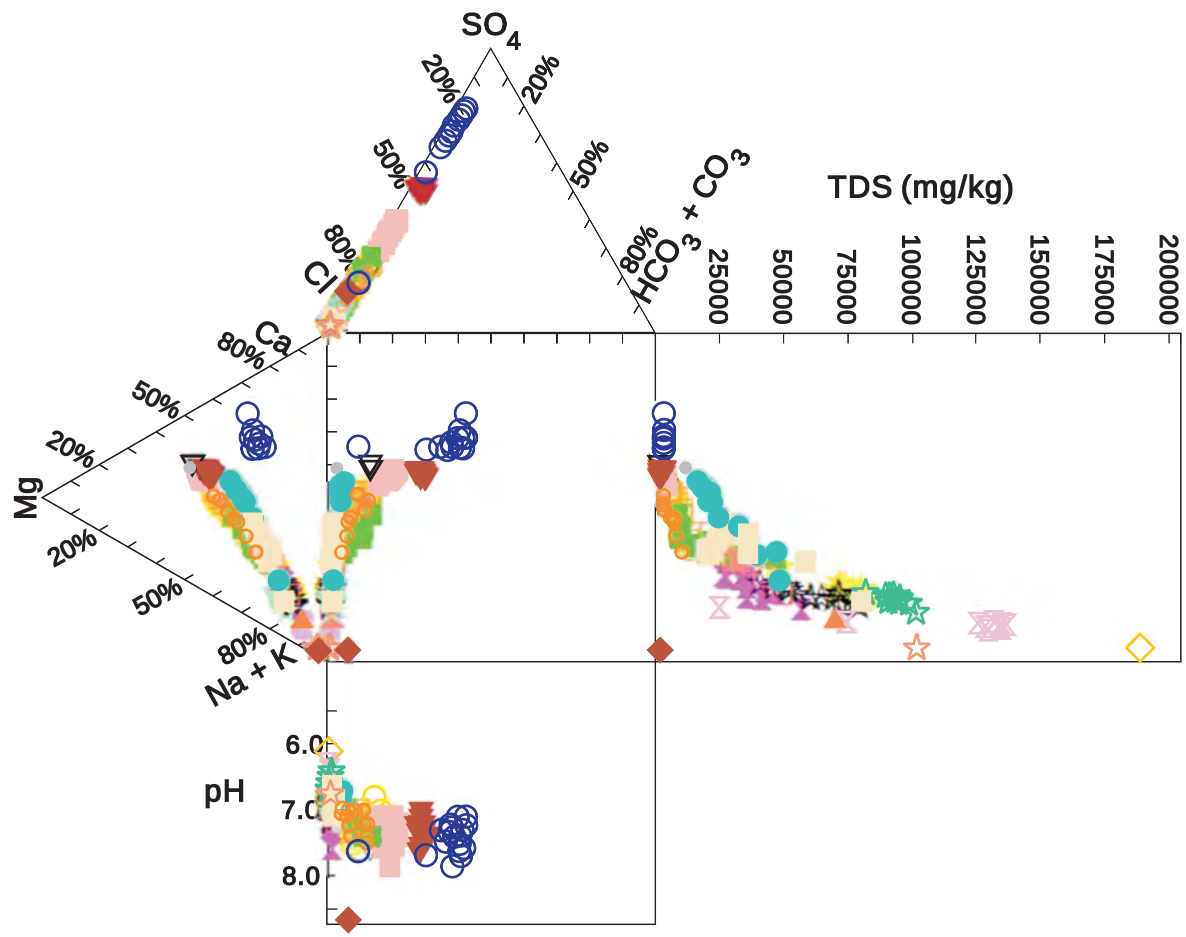
Saturation indices were calculated for the water quality at each monitor well to classify the water quality and mineral dissolution from recharge sources. Geochemist's Workbench was used to calculate saturation indices for major minerals by determining activity coefficients for each major ion in solution.

The highest TDS concentrations in the SSW are associated with high sodium and chloride concentrations indicative of halite dissolution. SSW is undersaturated with respect to halite in all of the wells. Typical halite saturation indices are 1 to 5 orders of magnitude below saturation (saturation indices –1 to –5), except in PZ-13, which is still below saturation (saturation index -0.6).

In parts of the SSW where TDS concentrations transition to lower values, the contribution of halite to the water quality becomes somewhat less dominant, and the concentrations of calcium, magnesium, and sulfate account for an increasing share of the solute load. Gypsum and anhydrite are close to saturation in places but generally undersaturated in the SSW. Calcite and dolomite are close to saturation or supersaturated in some samples.

5.6.3 Durov Plots

Durov plots were prepared to display water quality characteristics of major cations and anions, TDS, and pH. These water chemistry trends are illustrated by the Durov plots in Figures 24 and 25. Figure 24 presents all of the historical data for events where complete sets of cation and anion measurements are reported. Most of the carbonate species were reported as total inorganic carbon. Figure 25 presents "representative" data for each well for ease of comparison. The representative samples are defined as those with sulfate and chloride concentrations near the median values for each well, as these analytes capture most of the historical variability for each well. Dates are variable for the representative samples because complete datasets are available for only periodic samples.



Explanation

Symbol	Location ID
○	C-2505
□	C-2506
■	C-2507
▽	C-2811
★	PZ-01
■	PZ-02
⧗	PZ-03
⧗	PZ-04
☆	PZ-05
▲	PZ-06
●	PZ-07
•	PZ-08
☆	PZ-09
▼	PZ-10
■	PZ-11
○	PZ-12
◇	PZ-13
☆	PZ-14
◆	PZ-15
○	WQSP-6A

WIPP SHALLOW SUBSURFACE WATER

Durov Plot of Water Chemistry (1995 - 2007)

Figure 24

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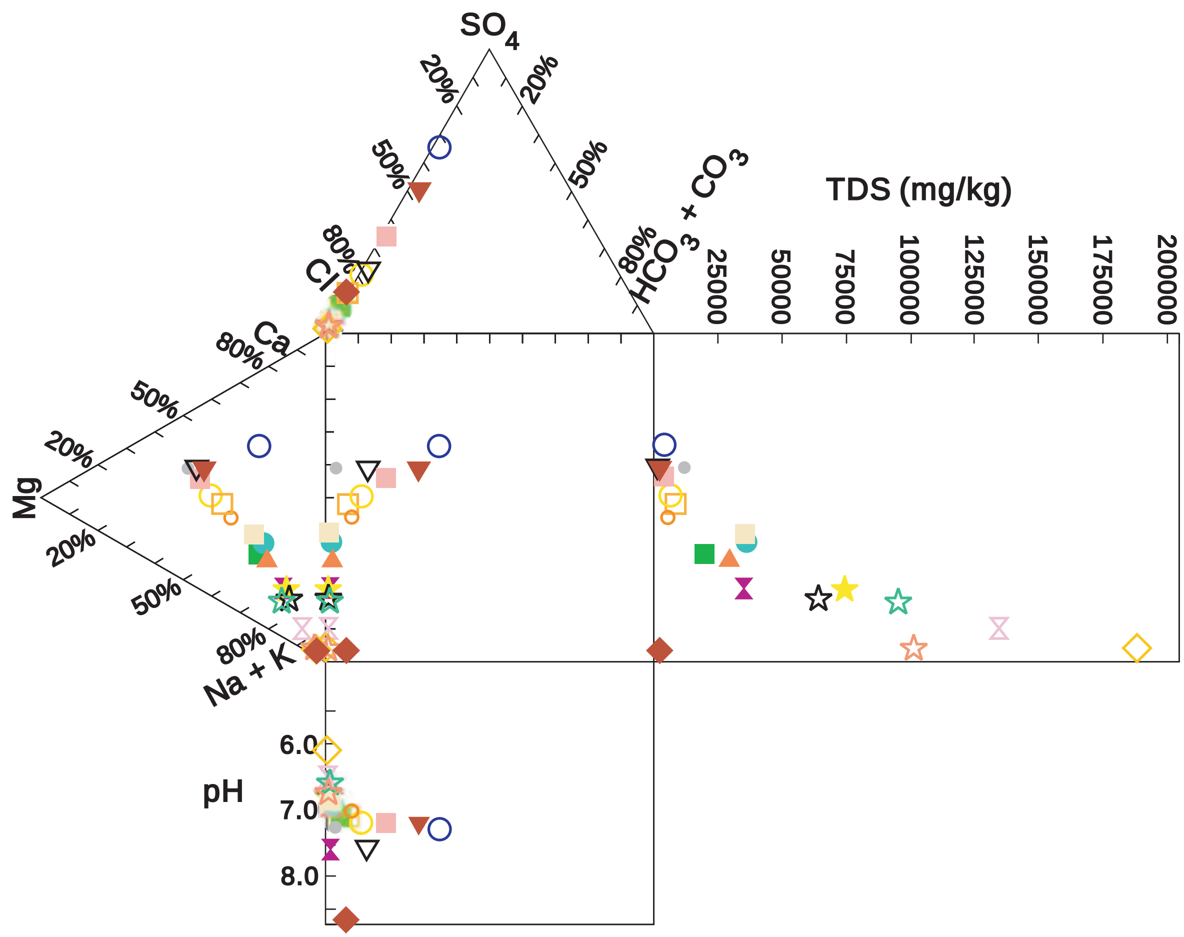
8-25-08
JN ES08.0072



Explanation

Symbol	Location ID	Sample date
○	C-2505	2/8/1999
□	C-2506	10/12/1998
■	C-2507	10/12/1998
▽	C-2811	12/19/2001
★	PZ-01	8/9/1999
■	PZ-02	1/13/1998
⧖	PZ-03	2/9/1999
⧗	PZ-04	10/141998
☆	PZ-05	1/14/1998
▲	PZ-06	4/13/1998
●	PZ-07	8/11/1999
•	PZ-08	10/15/2007
☆	PZ-09	8/12/1999
▼	PZ-10	7/23/1998
■	PZ-11	8/11/1999
○	PZ-12	7/23/1998
◇	PZ-13	10/10/2007
☆	PZ-14	10/15/2007
◆	PZ-15	10/15/2007
○	WQSP-6A	11/3/1998

WIPP SHALLOW SUBSURFACE WATER

Durov Plot of Representative Water Chemistry

Figure 25

Daniel B. Stephens & Associates, Inc.
8-25-08
JN ES08.0072

The data in Figures 24 and 25 plot along straight lines in the triangular cation and anion spaces. The anion data fall along the axis between chloride and sulfate, showing little relative contribution from the carbonate species (even though the SSW is saturated with respect to carbonate minerals). The cation data show varying contributions of sodium plus potassium and of a roughly 1:1 mixture of calcium and magnesium.

Monitor well WQSP-6A, a distant well screened in the middle Dewey Lake, is a notable exception to the general water quality trends. At this well, water is perched above the sulfate cementation zone in the middle Dewey Lake. The relatively high proportions of calcium and sulfate in the samples indicate that the water may have dissolved secondary sulfate minerals in the Dewey Lake, or that it may have followed a distinct pathway through a zone containing gypsum or anhydrite. The finding that WQSP-6A is distinguished by higher proportions of calcium and sulfate, as well as relatively low TDS concentrations, demonstrates the potential ability of cation and anion measurements to distinguish SSW from other sources of water or to predict characteristics of hypothetical mixtures of SSW and other waters.

On the other hand, the ion data do not distinguish monitor well C-2811 from nearby SSW wells. C-2811 is screened in the upper Dewey Lake, and it remains uncertain whether it is in direct hydrologic connection with the SSW. The consistency of C-2811 water quality with that of other SSW monitor wells suggests that the water may be connected. The TDS concentration in C-2811 does not exhibit any obvious relationship to the well hydrograph, which has been continuously rising over the period of record (Figure 14).

The central square space in the Durov plots in Figures 24 and 25 shows a trend across the site of halite-dominated water mixing with water containing a higher proportion of calcium, magnesium, and sulfate. The rectangular TDS space shows a trend across the site in the overall solute load corresponding to the compositional trend in the central space. The only exception is the sample from PZ-15, which is dominated by halite dissolution, but has relatively low TDS concentration. PZ-15 is the only well that is screened in the Gatuña; therefore, the water quality in PZ-15 is not determined by water quality elsewhere in the SSW. The PZ-15 sample also had a distinct, possibly anomalous pH that appears to have been measured in the laboratory. Degassing of carbon dioxide from a water sample during handling and holding may result in a rise in pH of roughly one-half standard unit, but PZ-15 would still have a relatively high pH after adjusting for such a shift. The sample's carbonate alkalinity was reported to be twice that of its total alkalinity, indicating unusually high uncertainty in the data. This new well will be subject to additional monitoring to confirm the water quality data.

5.7 Moisture Redistribution Calculations

It is expected that there will be some time before the construction of infiltration control systems at the former SSW recharge sources causes noticeable changes to the SSW conditions. The surficial sediment and formations that make up the vadose zone beneath the recharge sources will initially have a high moisture content that will gradually drain to lower moisture content after the source of recharge from the surface is removed. This moisture redistribution is also referred to as draindown or transient drainage. The moisture redistribution rate was calculated in order to estimate the duration and magnitude of continued moisture input to the SSW even after the infiltration controls were constructed in 2004 and 2005.

In the WIPP water budget analysis presented by DBS&A (2003), hydrologic modeling was performed to examine the effects of implementing seepage controls. This modeling assumed that moisture redistribution or transient drainage would continue for at least one year after implementing infiltration controls. Predictive modeling simulations found that implementing infiltration controls would lead to a gradual response in declining SSW water levels. The primary benefit of implementing the infiltration controls is prevention of continued recharge, which was predicted to more than double the SSW saturated volume over the WIPP operating period to 2035.

This section presents the methods used to calculate moisture redistribution in the vadose zone beneath the stormwater retention ponds and in the Salt Storage Area and underlying vadose zone following construction of infiltration controls. The calculation method presents a range of results to better understand the processes and likely duration of moisture redistribution. However, uncertainties regarding untested unsaturated flow properties of the vadose zone and salt pile materials prevent definitive quantification of results. Within the range of results, reasonable values were selected for hydraulic parameters to develop a likely best estimate for vadose zone moisture redistribution rates based on available information.

5.7.1 Calculation Method

The moisture redistribution calculation method follows the method presented by Stephens (1996) based on Mualem's equation for unsaturated flow. The calculation assumes that there is one-dimensional downward flow under a gravitational unit gradient for a uniform moisture content across the depth profile. A spreadsheet calculation was set up to calculate residual drainage at daily or hourly time steps over a 5-year duration. Details of the calculation spreadsheet and results are provided in Appendix G.

The rate of water flow in unsaturated porous media is governed by a form of Darcy's equation for unsaturated flow, as follows:

$$Q = -K_\theta A (dh/dz) C \qquad (4)$$

where Q = volumetric discharge (gallons per minute [gal/min])

K_θ = unsaturated hydraulic conductivity (cm/s)

A = area across which flow occurs (i.e., seepage area) (acres)

dh/dz = drainage gradient, assumed equal to –1 under gravity flow (dimensionless)

C = constant for unit conversions

The results of this calculation, included in Appendix G, provide the flow rate of transient drainage, expressed in terms of gallons per minute, and the total quantity of drainage over a 5-year duration, expressed in terms of acre-feet.

In soil or rock materials, the unsaturated hydraulic conductivity (K_θ) is less than the saturated hydraulic conductivity. In the calculation spreadsheets, K_θ is recalculated at daily or hourly time steps as the moisture content decreases.

Mualem's equation calculates unsaturated hydraulic conductivity based on the change in hydraulic conductivity that occurs with changing moisture content. In this equation, the unsaturated hydraulic conductivity is expressed relative to the pressure potential of the pore water, as follows:

$$K_r(\psi) = \frac{\left\{1 - |\alpha_v \psi|^{N-1} \left[1 + |\alpha_v \psi|^N\right]^{-m}\right\}^2}{\left[1 + |\alpha_v \psi|^N\right]^{m/2}} \tag{5}$$

where K_r = relative hydraulic conductivity (cm/s)

Ψ = calculated pressure potential, negative in unsaturated zone (cm)

α_v = van Genuchten fitting parameter (cm^{-1})

N = van Genuchten fitting parameter (dimensionless)

m = 1-1/N (dimensionless)

The fitting parameters in this equation (α_v and N) are derived from moisture retention (θ–Ψ) curves from laboratory test results. Based on theoretical models of the porous medium, van Genuchten (1978 and 1980) developed a solution for calculating conductivity based on the following equation that must be fitted to the measured moisture retention curve:

$$S_e = \left[1 + |\alpha_v \psi|^N\right]^{-m} \tag{6}$$

where S_e = effective saturation (dimensionless)

The effective saturation is expressed as follows:

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \tag{7}$$

where θ = volumetric moisture content (dimensionless)

θ_r = residual moisture content, from laboratory results (dimensionless)

θ_s = saturated moisture content, from laboratory results (dimensionless)

The moisture redistribution calculation uses hydrologic parameters that are representative of the vadose zone and salt pile characteristics where unsaturated residual drainage occurs. In order to consider the sensitivity of input parameters and examine a range of possible moisture redistribution results, hydrologic parameters were selected for cases outside the expected range of most likely material properties. Hydrologic parameters for unsaturated materials were selected from standard values reported in Carsel and Parrish (1988). This reference includes a compilation of soil unsaturated flow hydrologic parameters from test results on numerous soil samples exhibiting a broad spectrum of material properties, from fine-grained to coarse-grained soils.

The moisture redistribution calculation uses van Genuchten parameters that were initially selected based on the parameters used to represent vadose zone materials in the 2003 water budget analysis (DBS&A, 2003). The vadose zone is comprised primarily of Gatuña sediments, which consists of silt, sand, and clay that is moderately hard, forming sandstone and interbedded siltstone layers. The hydrologic parameters selected as the best fit for the Gatuña are based on a sandy clay loam soil. Other materials selected for sensitivity analysis calculations include silt, clay loam, clay, and sand. These materials represent finer- and coarser-grained characteristics than the representative sandy clay loam. Table 5 provides the unsaturated flow parameters selected for each material type.

Table 5. Unsaturated Flow Parameters Used in Moisture Redistribution Calculations

Unit Parameters	Gatuña Formation	Additional Material Types			
Material Type	*Sandy clay loam*	*Silt*	*Clay loam*	*Clay*	*Sand*
K_{sat} (cm/s)	3.63×10^{-4}	6.94×10^{-5}	7.22×10^{-5}	5.56×10^{-5}	8.25×10^{-3}
α	0.059	0.016	0.019	0.008	0.145
N	1.48	1.37	1.31	1.09	2.68
θ_s (v/v)	0.39	0.46	0.41	0.38	0.43
θ_r (v/v)	0.100	0.034	0.095	0.068	0.045

K_{sat} = Saturated hydraulic conductivity
cm/s = Centimeters per second
α = Fitting parameter
N = Fitting parameter
θ_s = Saturated moisture content
v/v = Volume per volume
θ_r = Residual moisture content

The calculation spreadsheets in Appendix G were set up to account for the physical properties of moisture redistribution conditions in the vadose zone at WIPP beneath the former recharge sources after infiltration controls were implemented. The total area of the stormwater recharge ponds is approximately 10.6 acres, with the vadose zone thickness approximately 30 feet between the pond bottom and the SSW water table. The Salt Storage Area covers approximately 18.8 acres, where the salt pile is approximately 30 feet thick and the vadose zone below is approximately 35 feet thick above the SSW water table. The moisture redistribution calculation determines the residual drainage from these profiles and calculates the total drainage quantity and the quantity of water that remains in the profile after 5 years.

The initial moisture content of the vadose zone profile is a variable that has not been tested. Beneath the stormwater retention ponds, recharge rates of 1 to 30 feet per year (ft/yr) are estimated to occur (DBS&A, 2003). Therefore, a relatively wet vadose zone profile is expected. The initial moisture content beneath the ponds was set at 90 percent of saturation in the calculation. Within and beneath the Salt Storage Area, relatively high recharge rates of approximately 0.5 to 1 foot of water per year have been estimated (DBS&A, 2003). Therefore, the initial moisture content in the salt and underlying vadose zone was set at 80 percent of saturation. Residual drainage brings the moisture content toward a residual moisture content, below which moisture is retained in the porous medium and moisture movement becomes very slow. The residual moisture content is based on values published by Carsel and Parrish (1988) as shown in Table 5. As a check on the calculation sensitivity to the initial moisture condition, calculations were also performed for initial moisture contents set at 60 percent and 30 percent of saturation.

5.7.2 Calculation Results

The moisture redistribution calculation spreadsheets provided in Appendix G include the following information:

- Input parameters
- Initial water storage volume in the profile (acre-feet [ac-ft])
- Total water drainage after 5 years (ac-ft)

- Residual water storage after 5 years (ac-ft)
- Initial and final moisture content (percent)

The full spreadsheets include thousands of calculations at daily or hourly time steps. The spreadsheets in Appendix G show only the initial five time steps and the final time step. The results sum up the total outflow from the profile at the end of 5 years.

The results of the moisture redistribution calculations are summarized in Table 6, which shows all of the residual drainage results for each case of initial moisture content at 30, 60, 80, and 90 percent.

The results show a wide range of drainage responses depending on the material type and initial moisture. Many of the cases tested show significant drainage over a period of months to years. The material type controls the drainage behavior, with sand rapidly draining large quantities of water while very little drains from the clay profile. The other soil types produce intermediate results. For each case tested, Appendix G includes a graph of changes in moisture content and discharge flow rate over time. These graphs show that drainage generally begins rapidly and then slows to a low rate of drainage after a period of time. The coarser-grained materials drain rapidly, while the fine-grained materials drain very little in 5 years.

Table 6. Moisture Redistribution Calculation Results

Initial Moisture Content (%)	5-Year Residual Drainage (acre-feet)				
	Sandy Clay Loam	Silt	Clay Loam	Clay	Sand
Redistribution Beneath Stormwater Ponds					
30	1.31×10^{-5}	0.004	8.84×10^{-8}	5.93×10^{-20}	21.2
60	6.98	3.02	0.316	1.44×10^{-6}	62.2
80	29.4	20.4	9.44	2.20×10^{-2}	89.6
90	41.7	33.8	20.68	0.913	103.3
Redistribution Within and Beneath the Salt Storage Area					
30	1.31×10^{-5}	0.004	8.84×10^{-8}	5.93×10^{-20}	68.0
60	10.6	3.41	0.316	1.44×10^{-6}	225.1
80	78.7	37.3	14.8	2.20×10^{-2}	330.1
90	124.5	78.3	45.9	1.01	382.7

The following sets of conditions are likely to be representative of actual field conditions:

- Vadose zone below stormwater retention ponds
  - Sandy clay loam
  - Initial moisture 90 percent of saturation

  The initial moisture content is 0.35, which drains to a moisture content of 0.22 after 5 years. The moisture content changes very slowly after 5 years, although the moisture content is still well above the residual moisture content of 0.10 set in the equation (Carsel and Parrish, 1988). Of the initial 79.9 ac-ft of moisture available for drainage in the profile, 41.7 ac-ft drains out of the profile in 5 years.

- Salt Storage Area and underlying vadose zone
  - Sandy clay loam
  - Initial moisture 80 percent of saturation

  The initial moisture content is 0.31, which drains to a moisture content of 0.25 after 5 years. Of the initial 259 ac-ft of moisture available for drainage in the profile, 78.8 ac-ft drains out of the profile in 5 years.

Because the Salt Storage Area covers a larger area and has a thicker vadose zone profile than the stormwater ponds, the overall drainage is 2 to 3 times greater. The moisture in the profile within and below the Salt Storage Area is likely to be near saturation with respect to halite dissolution as it leaches downward through the salt. Therefore, a substantial additional input of sodium and chloride to the SSW may be expected for a period of time after the final cover was constructed over the Salt Storage Area. The amount of highly saline drainage is expected to exceed the amount of relatively fresh drainage beneath the stormwater ponds.

Although significant uncertainties exist with the moisture redistribution conditions because laboratory testing of unsaturated hydrologic properties and initial moisture content are unavailable, the calculation results frame the conditions that may be expected. Drainage is expected to occur over a period of months to years. The total drainage quantity is expected to be on the order of tens of ac-ft to more than 100 ac-ft. Based on likely parameters that are representative of field conditions, a total of approximately 120 ac-ft of drainage occurs. It has been 3 years since the infiltration controls were completed (in 2005). Under all cases tested, most of the rapid transient drainage should have occurred by this time, with drainage reaching slow rates (but continuing) beyond three years.

5.7.3 Transient Drainage Impact on SSW

The transient drainage that redistributes downward from the vadose zone beneath the infiltration controls provides a significant water addition to the SSW. The effect on the SSW was estimated based on the most likely case for drainage calculated to represent field conditions.

When water drains from beneath the former recharge areas, the water reaches the water table of the SSW, causing the water table to rise and saturating a greater volume of the previously unsaturated Santa Rosa. The amount of water level rise depends on the amount of drainage, as well as the formation hydrologic properties, including the following:

- Porosity
- Initial moisture content
- Hydraulic conductivity

DBS&A (2003) reported that few data are available on porosity and moisture content of the Santa Rosa. Porosity of the Santa Rosa in the vicinity of the WIPP site is reported from a pumping test of a supply well in the Santa Rosa (Nicholson and Clebsch, 1961), which indicated an average porosity of 13 percent. No test data are available on the Santa Rosa initial moisture content at the WIPP. Assuming this average 13 percent porosity and a residual moisture content of 3 percent (23 percent saturation), saturation in the SSW zone would be achieved when the remaining porosity of 10 percent is filled by additional water. Despite uncertainties, filling 10 percent porosity to bring the unsaturated sandstone to saturation is a reasonable assumption, regardless of the absolute value of porosity.

An estimate was calculated for the SSW water table rise based on the likely case of 120 ac-ft of water addition. The SSW volume has been previously estimated at between 108 and 315 million gallons (331 to 966 ac-ft), covering 150 to 520 acres. Thus, the transient drainage adds approximately 12 to 33 percent additional water to the SSW. The transient drainage can be expected to first affect the central portion of the SSW saturated lens, before spreading radially toward the perimeter of the lens. The estimated water table rise from 120 ac-ft of transient drainage is as follows:

- 8 feet of water table rise over the 150-acre immediate area
- 2 feet of water table rise over the 520-acre SSW lens

These estimates contain significant uncertainties, but show that based on reasonable assumptions, a significant water table rise can be expected following construction of the infiltration controls. The water table rise may take place over a period of 3 to 5 years before the transient drainage slows to low rates. Even after the transient drainage slows, water levels may continue to rise in monitor wells some distance from the former recharge sources as the water table rise in the SSW saturated lens propagates radially outward.

6. Summary and Conclusions

This hydrologic assessment of SSW at WIPP provides an update to previous SSW investigations, including recent monitoring data, and examines the effects of infiltration controls that have been implemented to halt recharge to the SSW. The purpose of the SSW hydrologic assessment is to support WIPP regulatory compliance efforts and provide a basis to understand the efficacy of actions to control and monitor the SSW.

Through an analysis of the SSW hydrology and geochemical conditions, the hydrologic assessment refines the conceptual model of the SSW hydrologic system. The hydrologic assessment considered the complete monitoring record from before and after implementation of infiltration controls to evaluate the impact of the infiltration controls with regard to SSW water quality and quantity. A comprehensive database was assembled for the hydrologic assessment to bring together all of the relevant SSW monitoring data from 1996 to 2008. The database was used to analyze trends in water quality over time and compare conditions before and after infiltration control systems were put in place in 2004 and 2005.

6.1 Infiltration Control Systems

In order to reduce or eliminate recharge to the SSW, engineered infiltration control systems have been constructed for all WIPP stormwater retention ponds and salt storage areas. The infiltration controls include the following:

- Salt Pile Evaporation Pond liner
- Detention Basin A liner
- Stormwater retention pond 1 liner
- Stormwater retention pond 2 liner
- SPDV pile cover
- Salt Storage Area cover
- SSE liner
- SSE Evaporation Pond liner

These liners and covers should be effective at halting the SSW recharge that has occurred in the past from these sources. In particular, infiltration of saline water that has contacted salt through leaching or runoff will be virtually eliminated. Past modeling of infiltration controls has shown that the infiltration controls will prevent the SSW saturated volume from more than doubling over the upcoming years of WIPP operation. However, the infiltration controls will not eliminate the existing SSW lens, which will persist in the Santa Rosa and potentially migrate laterally or downward into the Dewey Lake. The hydrologic assessment examined SSW monitoring data to consider the effects of the infiltration controls.

6.2 Time-Series Analysis of Water Level Trends

The time-series analysis completed to examine SSW water level trends shows that the water table has risen since the first monitor wells were installed in 1996. Recharge causing a rising water table is correlated with precipitation rates. Water level rises occur 6 to 9 months after periods of heavy precipitation. SSW water levels increased sharply in 1996 to 1998, during above-average precipitation years. During the ensuing years from 1999 to 2004, total annual precipitation was below average and water levels remained relatively constant in most monitor wells. Following a heavy precipitation year in 2004, when precipitation was nearly twice the annual average, a sharp water level rise was observed in many of the wells in 2005. Infiltration control systems were constructed in 2004 and 2005 to limit SSW recharge. Water levels fluctuated, but remained relatively constant in 2006 and 2007. In the most recent monitoring event in June 2008, water levels declined in most wells. This recent water level decline may indicate the first sign of a response to the infiltration controls, following a 3-year period of transient drainage beneath the former recharge sources; however, it is too early to reach a conclusion.

Monitor wells that appear to be at the fringes of the SSW saturated lens show rising water levels and increasing saturated thickness. Monitor well C-2811 has exhibited a water table rise of 12 feet since the well was installed in 2001. This trend is consistent with the conceptual model of a saturated lens spreading laterally over time. Monitor well PZ-08 may be at the fringe of the SSW saturated lens east of the WIPP facilities area. Saturation was detected for the first time in PZ-08 in March 2007, and the water level rose 4 feet during the next year. Like monitor well

C-2811, the rising water level in PZ-08 is consistent with the conceptual model of the SSW lens gradually spreading and increasing the saturated thickness at the perimeter, a phenomenon that will continue until the water table mound diminishes.

Water levels at the three new monitor wells installed in 2007 around the SPDV pile suggest that the saturation found in this area is not directly hydrologically connected to the main SSW saturated lens. The saturated zone at monitor well PZ-15 exists in the Gatuña at an elevation higher than at any of the other SSW monitor wells. The two other SPDV monitor wells, PZ-13 and -14, are distinguished from the other SSW monitor wells based on water levels, apparent gradient, and geochemistry.

6.3 Water Level Contour Maps

Water level contour maps for the SSW, prepared for approximately annual time steps, show that the SSW flow direction and gradient have remained consistent over the complete monitoring record since 1997. Each of the contour maps shows a similar pattern of contours, although water levels have consistently risen by approximately 2 to 4 feet. The water level contour maps were prepared using equivalent freshwater head elevations that were calculated based on the salinity and water density at each monitor well.

6.3.1 Water Table Conditions

The water level contour maps indicate that a water table mound exists near the Salt Pile Evaporation Pond and Salt Storage Area, with a generally radial pattern of flow outward from the high point near PZ-07. In the area where most SSW monitor wells are located, the SSW flows south and east from the apex of the water table mound. The SSW conditions are influenced by geologic controls including the irregular surface of the Santa Rosa/Dewey Lake contact and the hydraulic conductivity of the formations where SSW occurs.

Away from the central portion of the SSW saturated lens where most monitor wells are located, the hydrologic connection to monitor wells PZ-08, -13, and -14 and C-2811 remains uncertain. The increasing water level in C-2811 and detection of saturation in PZ-08 for the first time in

2007 appear consistent with a radially spreading SSW lens. In contrast, monitor wells PZ-13 and -14 exhibit higher water levels than those at PZ-08 to the west, suggesting that local recharge at the SPDV pile has resulted in a minor water level mound (although this mound may be dissipating since the SPDV pile was capped in 2000). Based on differences in water levels and water quality, the water encountered at PZ-08 appears distinct from the water at PZ-13 and -14, although between these wells, it is uncertain whether unsaturated conditions exist or whether there is a saturated zone of commingled water.

6.4 Water Quality Contour Maps

Water quality contour maps for the SSW prepared for approximately annual time steps show that the SSW water quality has become generally more saline over the monitoring record since 1997. Overall salinity reached a maximum in 2004 and has declined slightly by 2008.

The SSW water quality is dominated by highly saline brine that is representative of halite (NaCl) dissolution. In the main SSW lens, TDS concentrations range from less than 10,000 mg/L to more than 150,000 mg/L. Higher TDS concentrations are found in the northern half of the WIPP facilities area, near the Salt Storage Area and Salt Pile Evaporation Pond. Currently, the highest TDS concentration within the main SSW lens is 150,000 mg/L in PZ-09, a decline from the highest previous TDS concentration measured within the main SSW lens (185,000 mg/L in PZ-03). TDS concentrations are much lower in the southern half of the site, where low-TDS water recharged the SSW from stormwater retention ponds prior to lining the ponds and subsequent transient drainage. Relatively low TDS concentrations of 1,000 to 3,000 mg/L have been measured in monitor well PZ-10, adjacent to Detention Basin A.

New monitor wells around the SPDV pile have water quality that is chemically distinct from the SSW. SPDV monitor well PZ-13 has the highest salinity level measured thus far, with a TDS concentration of 245,500 mg/L. In contrast, SPDV monitor well PZ-15 has a low TDS concentration of 2,060 mg/L in a saturated zone in the lower Gatuña.

6.5 Moisture Redistribution Calculations

Calculations of moisture redistribution were completed to estimate the duration and magnitude of transient drainage that provides continued moisture input to the SSW even after the infiltration controls were constructed in 2004 and 2005. The initially high moisture content of the vadose zone materials beneath the recharge sources will gradually drain to lower moisture content after the source of recharge from the surface is removed. Because test results for unsaturated hydrologic properties of the vadose zone and salt pile materials are not available, moisture redistribution calculations were completed for a range of vadose zone hydrologic properties and initial moisture conditions to estimate a range of transient drainage results. Within the range of hydrologic properties used in the calculations, hydrologic parameters were selected as the likely best fit for the Gatuña and salt pile to produce a reasonable estimate of the transient drainage quantity and duration.

The hydrologic parameters selected as the best fit for the Gatuña and salt pile are based on published values for sandy clay loam soil. A broad range of additional hydrologic properties were selected for sensitivity analysis calculations, including silt, clay loam, clay, and sand. These materials represent finer- and coarser-grained characteristics than the representative sandy clay loam. Moisture redistribution calculations were completed for each material type for initial moisture conditions set at 30, 60, 80, and 90 percent saturation. The likely best fit calculations used an initial moisture content of 90 percent saturation below the stormwater retention ponds and 80 percent saturation within and beneath the salt pile.

6.5.1 Transient Drainage Results

The moisture redistribution results show a wide range of transient drainage responses depending on the material type and initial moisture. The test cases were analyzed for a period of 5 years, and the results show significant transient drainage over a period of months to years. The material type controls the drainage behavior; the sand profile rapidly drains large quantities of water within days, while very little drains from the clay profile over 5 years.

For the set of likely hydrologic parameters that is representative of actual field conditions, the calculations produce reasonable results in terms of the drainage quantity, duration, and amount of residual moisture remaining in the profile after 5 years. The results for each of the two profiles are as follows:

- Vadose zone below stormwater retention ponds
  - 41.7 ac-ft transient drainage in 5 years
  - Most of the drainage within 1 year
  - Initial moisture content of 0.35 (90 percent of saturation), drains to a moisture content of 0.22
- Salt Storage Area and underlying vadose zone
  - 78.8 ac-ft transient drainage in 5 years
  - Most of the drainage within 2 years
  - Initial moisture content of 0.31 (80 percent of saturation), drains to a moisture content of 0.25

The moisture content changes very slowly after 1 to 3 years until the end of the 5-year calculation, although the moisture content remains well above the residual moisture content of 0.10 set in the equation. Over a longer duration, additional water is available to drain from the vadose zone profile, although the rates become slow as the unsaturated hydraulic conductivity declines with decreasing moisture content.

Because the Salt Storage Area covers a larger area and has a thicker vadose zone profile than the stormwater ponds, the overall drainage is 2 to 3 times greater that the total drainage below all four stormwater retention ponds. The residual drainage below the Salt Storage Area is expected to provide substantial additional input of sodium and chloride to the SSW, exceeding the amount of relatively fresh drainage beneath the stormwater ponds.

Although the moisture redistribution calculations contain significant uncertainties, the results frame a range of conditions that can be expected. Transient drainage quantities on the order of tens of ac-ft to more than 100 ac-ft are expected over a period of months to years. Based on likely hydrologic parameters that are representative of field conditions, a total of approximately 120 ac-ft of transient drainage occurs. During the 3 years since the infiltration controls were completed in 2005, most of the rapid transient drainage should have occurred. Under all cases tested for variable hydrologic properties, transient drainage reaches slow (but continuing) rates beyond three years.

6.5.2 Transient Drainage Impact on SSW

Based on the estimated transient drainage quantities, a significant water addition to the SSW is expected following completion of the infiltration controls. The transient drainage volume of 120 ac-ft for the most likely conditions will add approximately 12 to 33 percent additional water to the SSW (based on previous SSW volume estimates of 330 to 970 ac-ft [108 and 315 million gallons], covering 150 to 520 acres).

The amount of water table rise depends on the amount of drainage, as well as the Santa Rosa sandstone hydrologic properties. Considering that the porosity within the Santa Rosa sandstone is partially filled with water when it is unsaturated, only about 10 percent moisture addition (per sandstone unit volume) is needed to reach saturation. The SSW water table rise is estimated to be between 8 feet over the 150-acre immediate area around the former recharge sources and 2 feet of water table rise over the 520-acre SSW lens.

These estimates contain significant uncertainties, but show that based on reasonable assumptions, a significant water table rise can be expected following construction of the infiltration controls. The water table rise may take place over a period of 3 to 5 years before the transient drainage slows to low rates. The water table rise can be expected to first affect the central portion of the SSW saturated lens before spreading radially toward the perimeter of the lens. Water levels may continue to rise over a longer duration in monitor wells some distance from the former recharge sources as the water table rise in the SSW saturated lens propagates radially outward.

The primary benefit of implementing the infiltration controls is prevention of continued recharge that was predicted to continue increasing the SSW saturated volume. However, the moisture redistribution process involves a period of transient drainage when SSW water levels continue to rise. The declining water levels measured in 2008 may represent the first indication that a gradual response toward declining SSW water levels is beginning; however, any conclusions regarding a trend toward water level declines will require a longer monitoring record.

References

Bachman, G.O. 1980. *Regional geology and Cenozoic history of Pecos Region, southeastern New Mexico.* United States Department of the Interior Geological Survey. Open-File Report 80-1099. 116p.

Bachman, G.O. 1984. *Regional geology of Ochoan evaporites, northern part of Delaware Basin.* New Mexico Bureau of Mines & Mineral Resources Circular 184. Socorro, New Mexico. 22p. and figures.

Campbell, A.R., F.M. Phillips, and R.J. Vanlandingham. 1996. Stable isotope study of soil water, WIPP Site New Mexico: Estimation of recharge to Rustler aquifers. *Radioactive Waste Management and Environmental Restoration* 20:153-165.

Carsel, R.F. and R.S. Parrish. 1988. Developing joint probability distributions of soil water retention characteristics. *Water Resources Research* 24(5):755-769.

Daniel B. Stephens & Associates, Inc. (DBS&A). 1996. *Characterization of the Site Preliminary Design Validation salt pile*. January 5, 1996.

DBS&A. 2003. *Water budget analysis of shallow subsurface water at the Waste Isolation Pilot Plan.* Prepared for U.S. Department of Energy Carlsbad Field Office. September 30, 2003.

Guo, W. and C.D. Langevin. 2002. *User's guide to SEAWAT: a computer program for simulation of three-dimensional variable-density ground-water flow.* U.S. Geological Survey Techniques of Water-Resources Investigations 6-A7.

Hendrickson, G.E. and R.S. Jones. 1952. *Geology and ground-water resources of Eddy County, New Mexico*. New Mexico Bureau of Mines & Mineral Resources Ground-Water Report 3. Socorro, New Mexico. 169p. and plates.

Hunter, R.L. 1985. *A regional water balance for the Waste Isolation Pilot Plan (WIPP) site and surrounding area*. Prepared for Sandia National Laboratories. Sandia report SAND84-2233. December 1985. 83p.

Intera. 1996. *Exhaust shaft hydraulic assessment data report.* Prepared for Westinghouse. DOE/WIPP 97-2219. November 1996.

Intera. 1997a. *Exhaust shaft: Phase II hydraulic assessment data report involving drilling, installation, water-quality sampling, and testing of piezometers 1-12*. Prepared for Westinghouse. DOE/WIPP 97-2219. September 26, 1997.

Intera. 1997b. *Exhaust shaft data report: 72-hour pumping test on C-2506 and 24-hour pumping test on C-2505*. DOE/WIPP 97-2219. May 1997.

Mercer, J.W. 1983. *Geohydrology of the proposed Waste Isolation Pilot Plant site, Los Medaños area, southeastern New Mexico*. Prepared in cooperation with the U.S. Department of Energy. U.S. Geological Survey Water-Resources Investigations Report 83-4016.

National Academy of Sciences. 2008. *Desalination: a national perspective* [prepublication copy]. Committee on Advancing Desalination Technology, Water Science and Technology Board, Division of Earth and Life Studies. The National Academies Press, Washington, DC.

New Mexico Environment Department (NMED). 2008. *Ground water discharge permit renewal and modification, U.S. Department of Energy, Waste Isolation Pilot Plant, DP-831*. September 9, 2008.

Nicholson, A., Jr. and A. Clebsch, Jr. 1961. *Geology and ground-water conditions in southern Lea County, New Mexico*. New Mexico Bureau of Mines & Mineral Resources Ground-Water Report 6. Socorro, New Mexico. 123p. and plates.

Parkhurst, D.L. 1995. *User's guide to PHREEQC–A computer program for speciation, reaction-path, advective-transport, and inverse geochemical calculations.* U.S. Geological Survey Water-Resources Investigations Report 95-4227.

Phillips, R.H. 1987. *The prospects for regional groundwater contamination due to Karst Landforms in Mescalero caliche at the WIPP site near Carlsbad, New Mexico.* Dissertation to the Department of Geography, University of Oregon. June 1987.

Powers, D.W. 1995. *An initial evaluation of sources for water inflow to the upper Exhaust Shaft*. Prepared for Westinghouse Electric Corp. June 30, 1995.

Powers, D.W. 2002. *Basic data report for drillhole C-2811 (Waste Isolation Pilot Plant - WIPP)*. Dennis W. Powers, Consulting Geologist. Anthony, Texas. October 2002. 24p.

Powers, D.W. 2003a. *Geohydrological conceptual model for the Dewey Lake Formation in the vicinity of the Waste Isolation Pilot Plant (WIPP), Test plan TP 02-05., Rev. 0.* BOE 1.3.5.3.1, Sandia Corporation. March 17, 2003

Powers, D.W. 2003b. Personal communication between Dr. Dennis W. Powers, consulting geologist, and Derek Blazer, DBS&A. June 2003.

Roush, P. 2008. E-mail from Parrish Roush, Washington TRU Solutions LLC (WTS), to Mark Miller, DBS&A. July 17, 2008.

Sergent, Hauskins & Beckwith, 1979. *Subsurface exploration and laboratory testing, plant site*, Waste Isolation Pilot Plant, Volume 1. Prepared for Bechtel National, Inc. Bechtel Job No. 12484. May 11, 1979.

Stensrud, W.A. 1995. *Culebra Transport Program test plan: Hydraulic tests at wells WQSP-1, WQSP-2, WQSP-3, WQSP-4, WQSP-5, WQSP-6, and WQSP-6A at the Waste Isolation Pilot Plant (WIPP) Site*. Intera Inc. Austin, Texas. October 6, 1995.

Stephens, D.B. 1996. *Vadose zone hydrology.* Lewis Publishers, Boca Raton, Florida.

U.S. Department of Energy (DOE). 1993. WIPP National pollutant discharge elimination system storm water pollution prevention plan. WP 12-14. April 1, 1993.

U.S. DOE. 1996. *Title 40 CFR Part 191 compliance certification application for the Waste Isolation Pilot Plant, Chapters 1-9.* Docket No. A-93-02 II-G-1.

U.S. DOE. 2000. *Exhaust shaft Phase III hydraulic assessment data report, October 1997–October 1998, Waste Isolation Pilot Plant, Carlsbad, New Mexico.* DOE-WIPP 99-2302. March 2000.

U.S. DOE. 2002. *Geotechnical analysis report for July 2000 – June 2001.* DOE/WIPP 02-3177, Volume 1. Waste Isolation Pilot Plant Project Office, Carlsbad, New Mexico. September 2002.

U.S. DOE. 2003. Discharge plan 831 modification application*.* April 24, 2003.

U.S. DOE. 2004. *Title 40 CFR 191 Subparts B & C Compliance Recertification Application.* DOE/WIPP 2004-3231, Chapter 2, Fig. 2-20.

U.S. DOE. 2004-2008. WIPP SSW inspection reports from May 2004 through March 2008.

U.S. DOE. 2008. *Basic data report for piezometers PZ-13, PZ-14, and PZ-15 and shallow subsurface water.* DOE/WIPP-08-3375, Revision 3. October 2008.

van Genuchten, M.T. 1978. *Numerical solutions of the one-dimensional saturated-unsaturated flow equatio*n. Princeton University Report 78-WR-09.

van Genuchten, M.T. 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society of America Journal* 44:892.

Washington TRU Solutions (WTS). 2005. Design drawings for infiltration controls at Waste Isolation Pilot Plant, Carlsbad, New Mexico. December 2005.

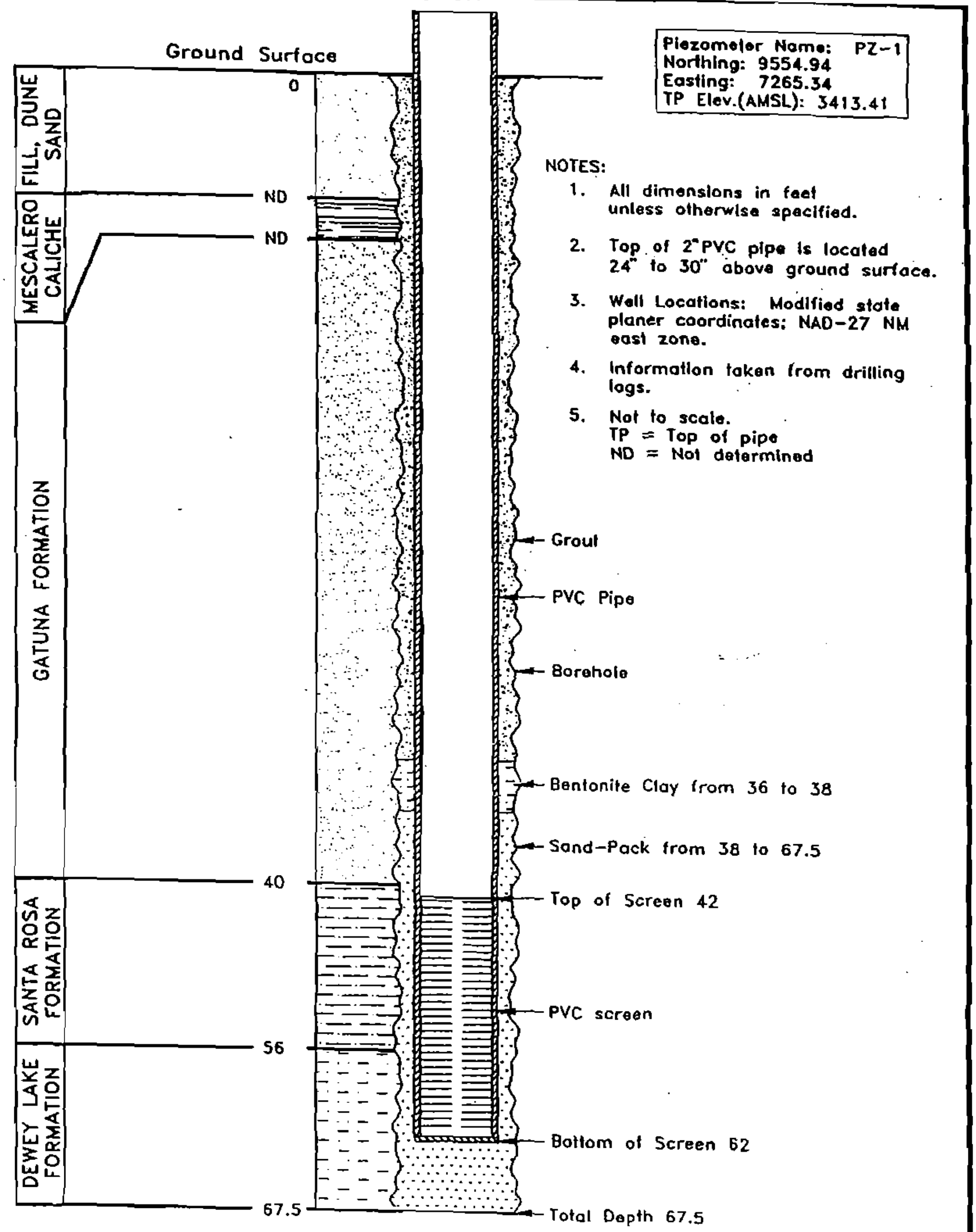
Western Regional Climate Center (WRCC). 2008. *Waste Isoltn Pilot Plt, New Mexico, monthly total precipitation*. <http://www.wrcc.dri.edu/cgi-bin/cliMONtpre.pl?nm9569>. Last updated August 20, 2008.

Westinghouse Electric Corporation. 1992. Letter from L.L. Reed to Dr. J.A. Mewhinney, U.S. Department of Energy, regarding Discussion of NPDES stormwater permit exemption request, package alternatives. March 23, 1992.

Yager, R.M., W.M. Kappel, and L.N. Plummer. 2007. *Halite brine in the Onondaga Trough near Syracuse, New York: characterization and simulation of variable-density flow.* Prepared in cooperation with the Onondaga Lake Partnership and the Onondaga Environmental Institute. U.S. Geological Survey Scientific Investigations Report 2007-5058.

Appendix A

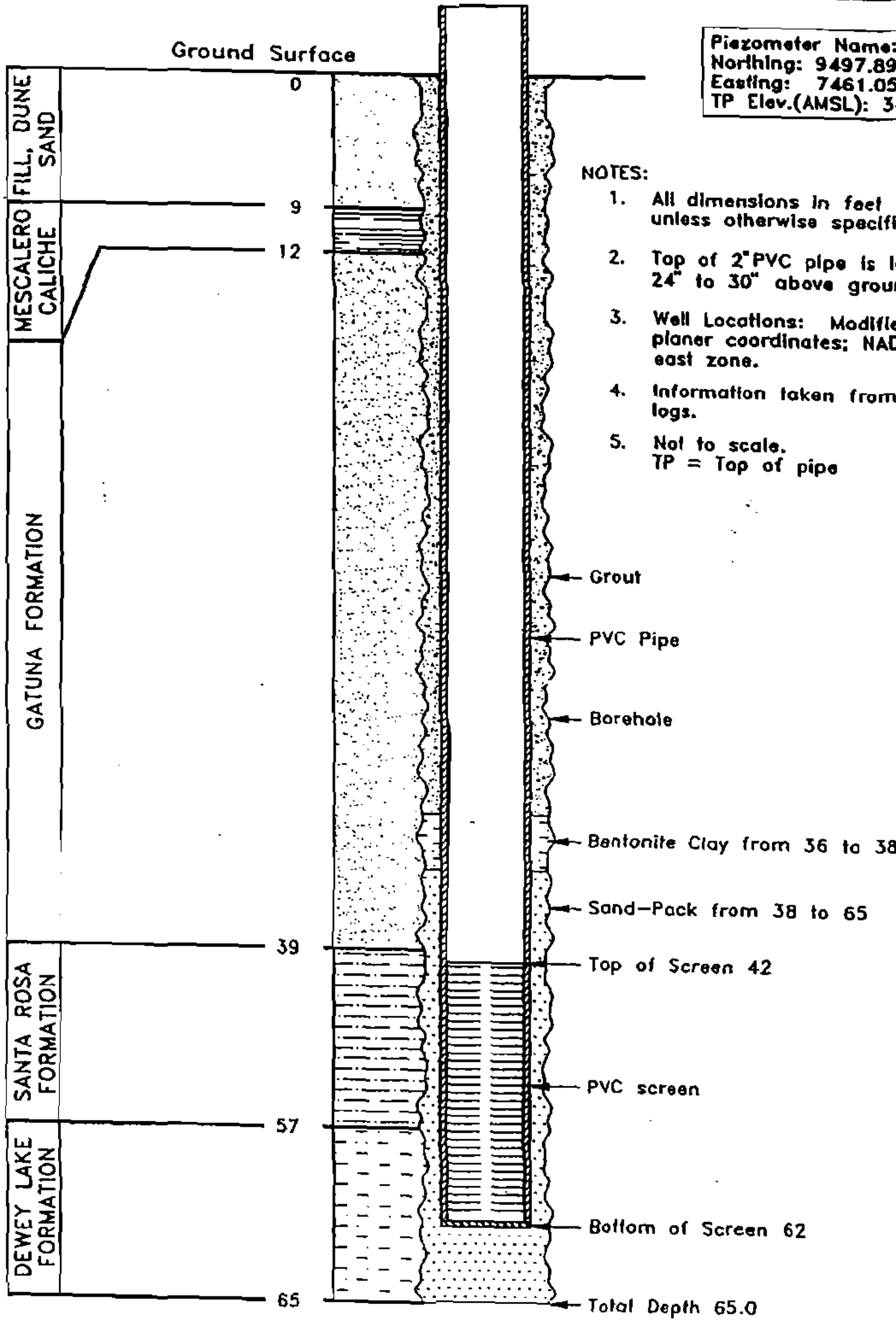
Well Logs
Santa Rosa/Dewey Lake
Contact Contours



INTERA

PZ-1 Piezometer Completion Diagram

DATE: 07/28/97 REV: A
REF: JBP/PZ-1

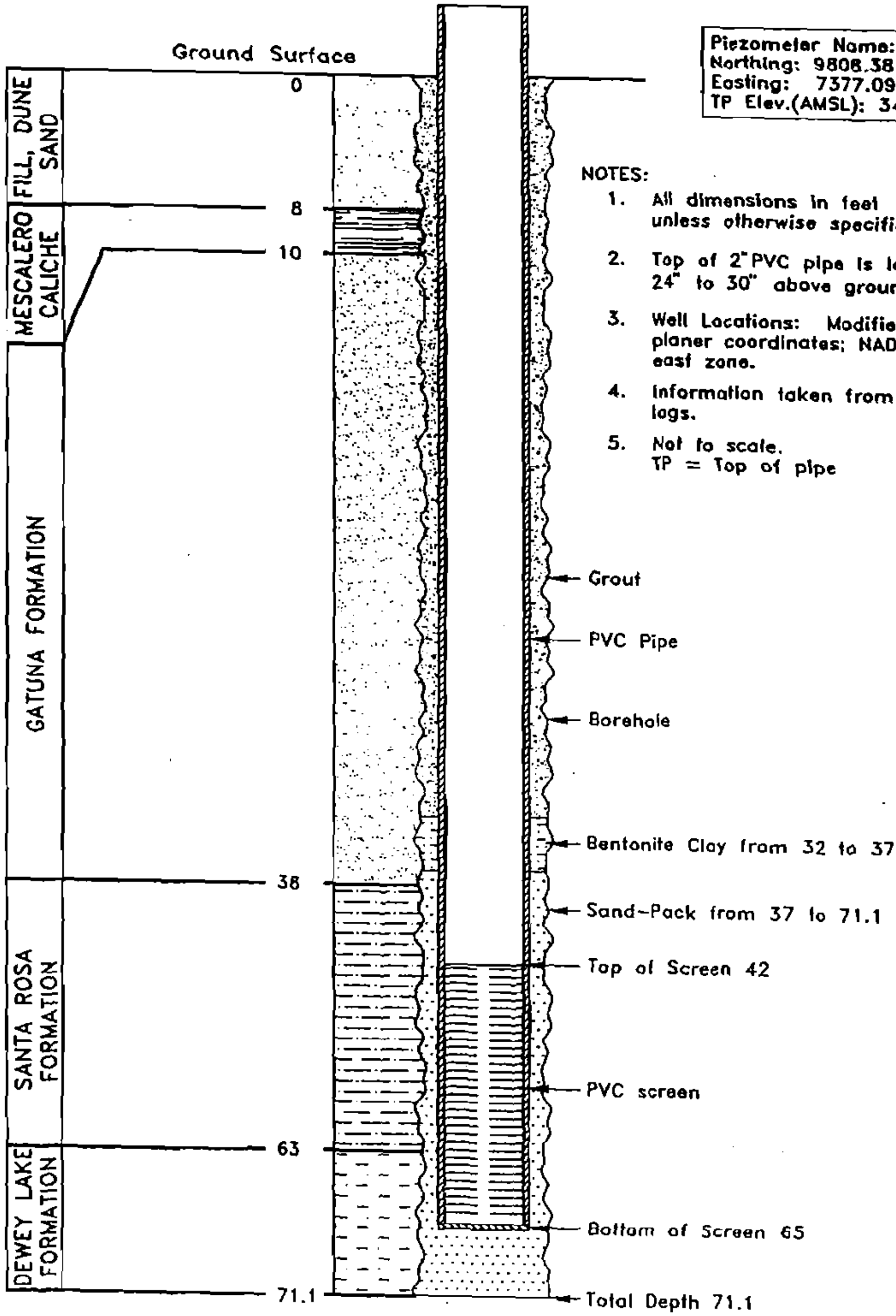


Piezometer Name: PZ-2
Northing: 9497.89
Easting: 7461.05
TP Elev.(AMSL): 3413.42

NOTES:

1. All dimensions in feet unless otherwise specified.
2. Top of 2" PVC pipe is located 24" to 30" above ground surface.
3. Well Locations: Modified state planer coordinates: NAD-27 NM east zone.
4. Information taken from drilling logs.
5. Not to scale.
   TP = Top of pipe

INTERA	PZ-2 Piezometer Completion Diagram	DATE: 07/28/97	REV: A
		REF: JBP/PZ-2	

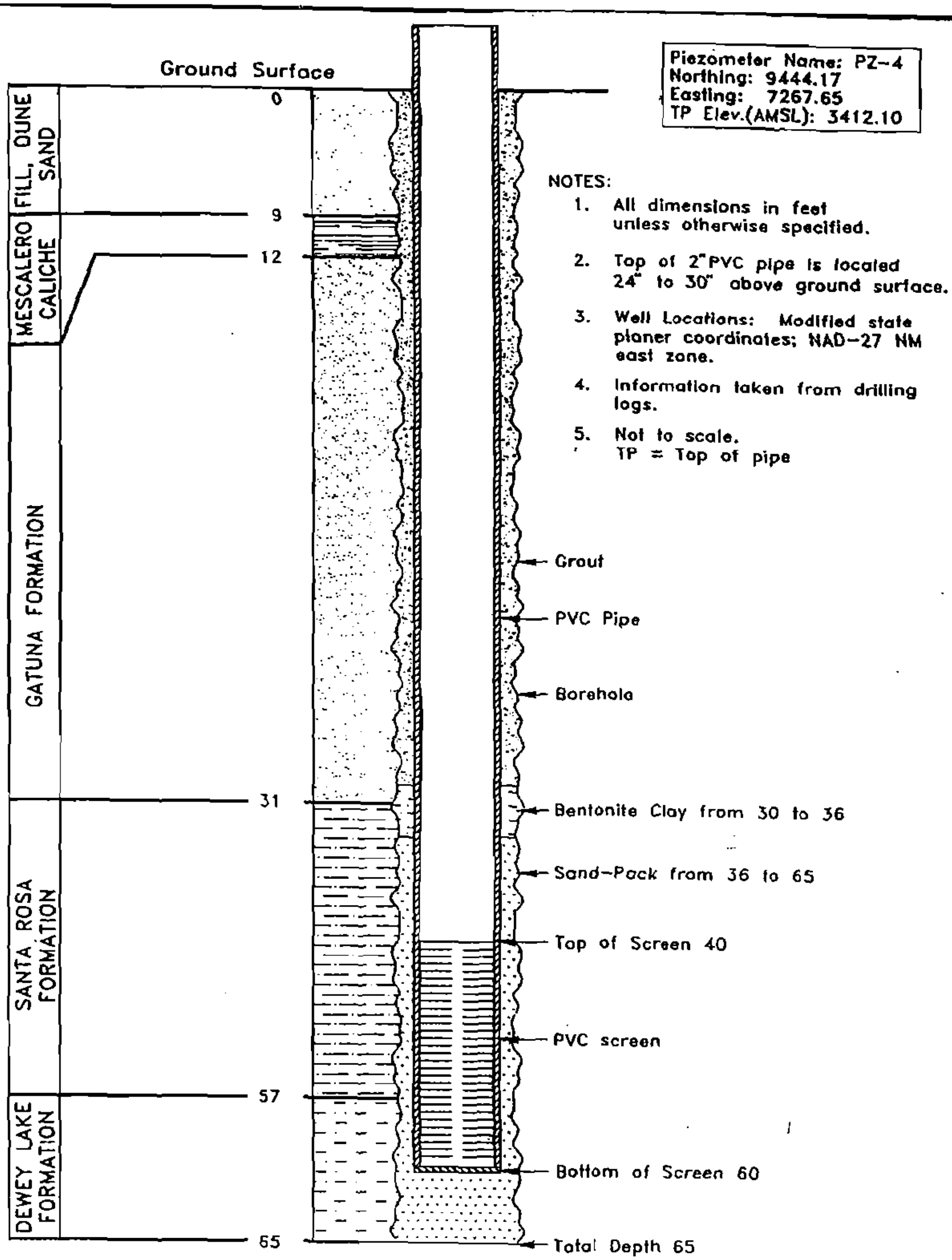


Piezometer Name: PZ-3
Northing: 9808.38
Easting: 7377.09
TP Elev.(AMSL): 3416.15

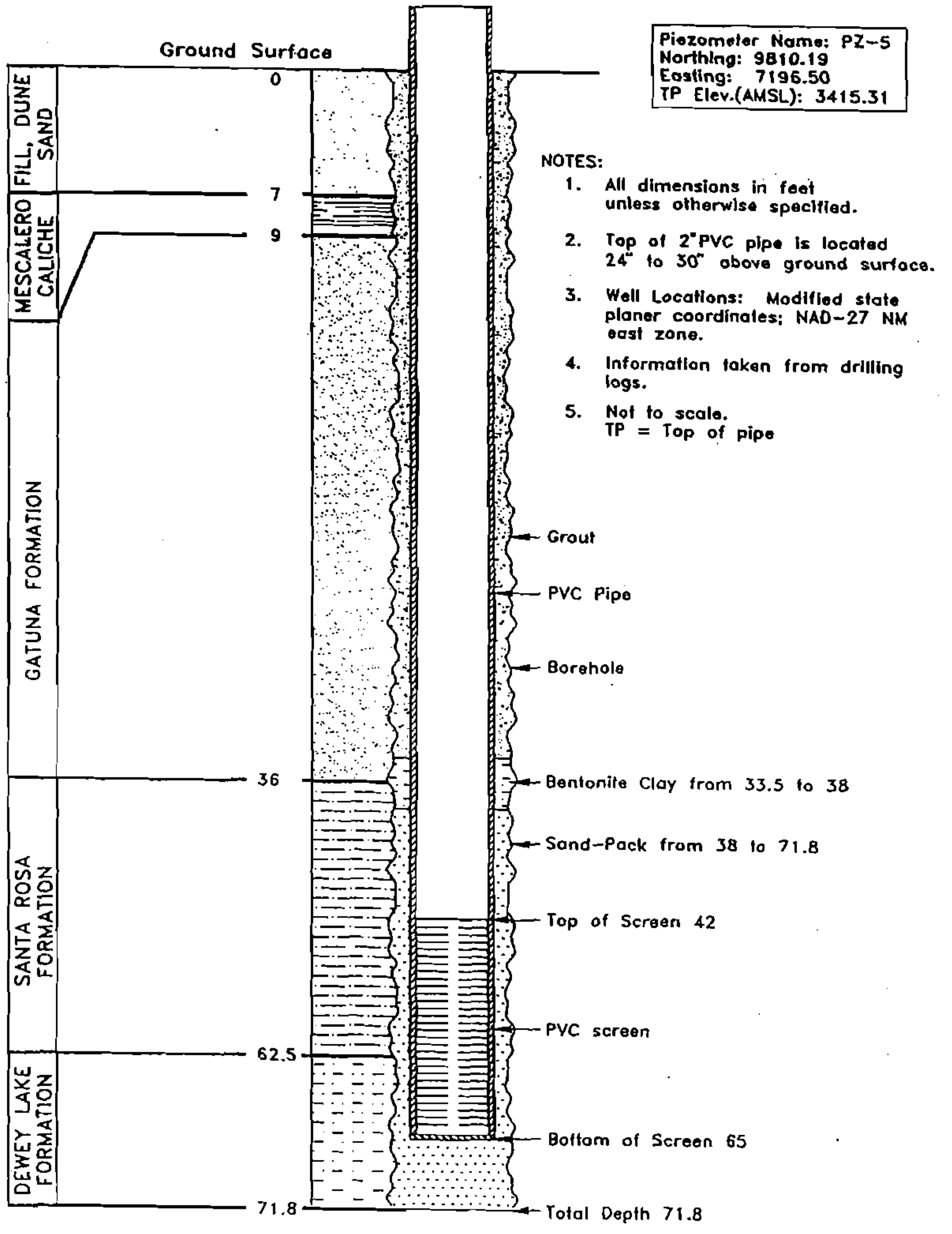
NOTES:

1. All dimensions in feet unless otherwise specified.
2. Top of 2" PVC pipe is located 24" to 30" above ground surface.
3. Well Locations: Modified state planer coordinates; NAD-27 NM east zone.
4. Information taken from drilling logs.
5. Not to scale.
   TP = Top of pipe

INTERA	PZ-3 Piezometer Completion Diagram	DATE: 07/28/97	REV: A
		REF: JBP/PZ-3	



INTERA	PZ-4 Piezometer Completion Diagram	DATE: 07/28/97	REV: A
		REF: JBP/PZ-4	



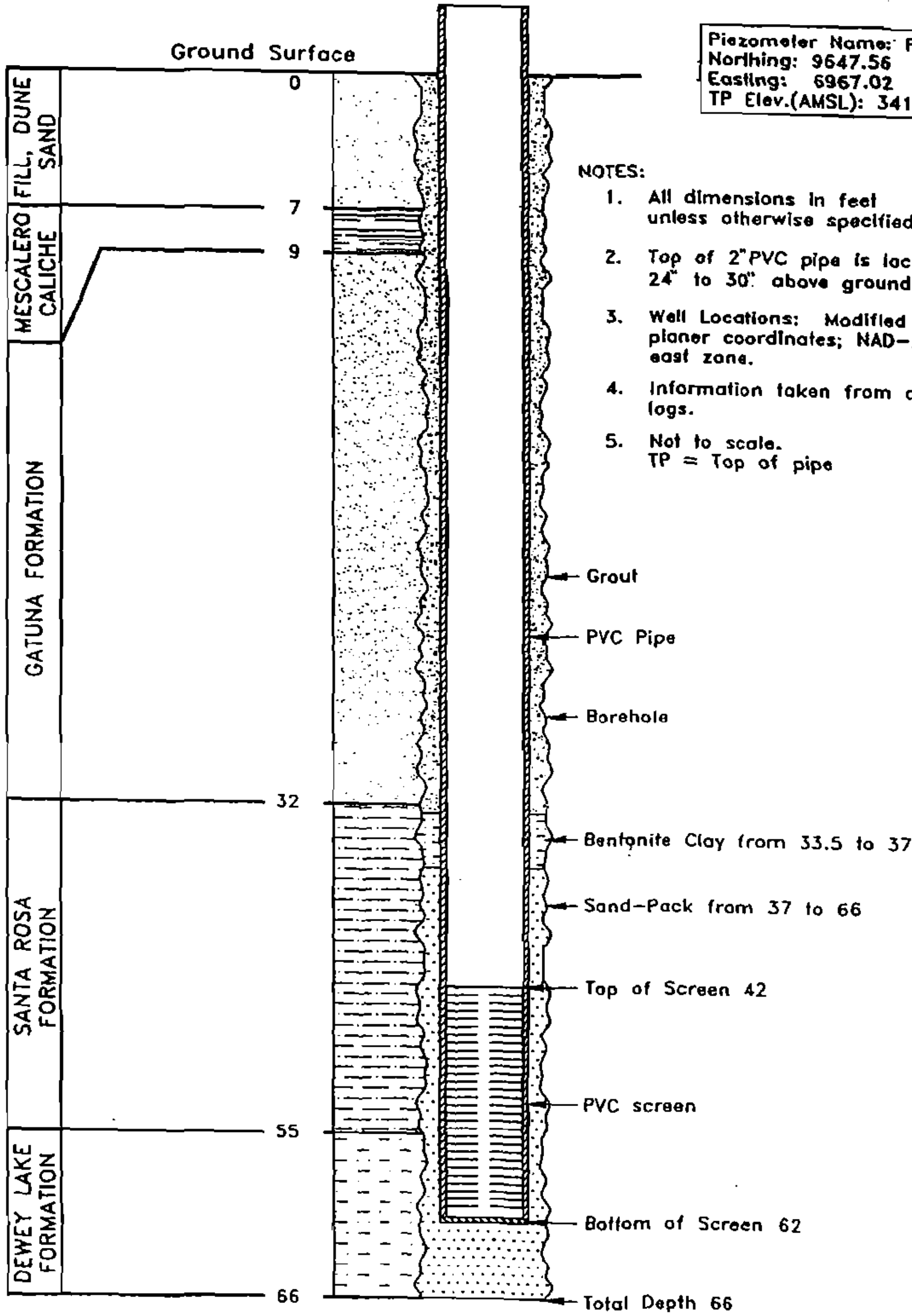
INTERA

PZ-5 Piezometer Completion Diagram

DATE: 07/28/97 | REV: A

REF: JBP/PZ-5

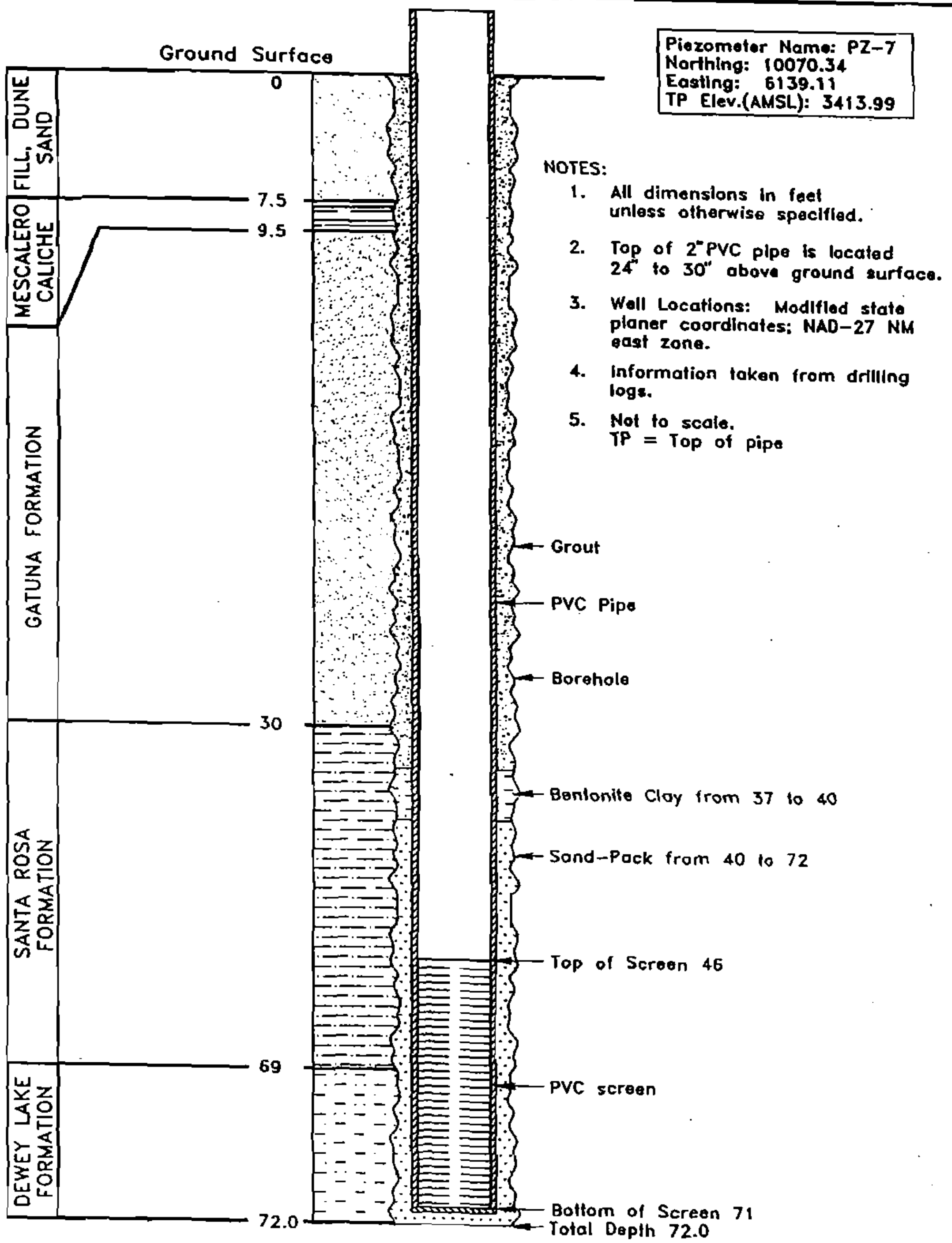
Piezometer Name: PZ-6
Northing: 9647.56
Easting: 6967.02
TP Elev.(AMSL): 3413.49



NOTES:

1. All dimensions in feet unless otherwise specified.
2. Top of 2"PVC pipe is located 24" to 30" above ground surface.
3. Well Locations: Modified state planer coordinates; NAD-27 NM east zone.
4. Information taken from drilling logs.
5. Not to scale.
   TP = Top of pipe

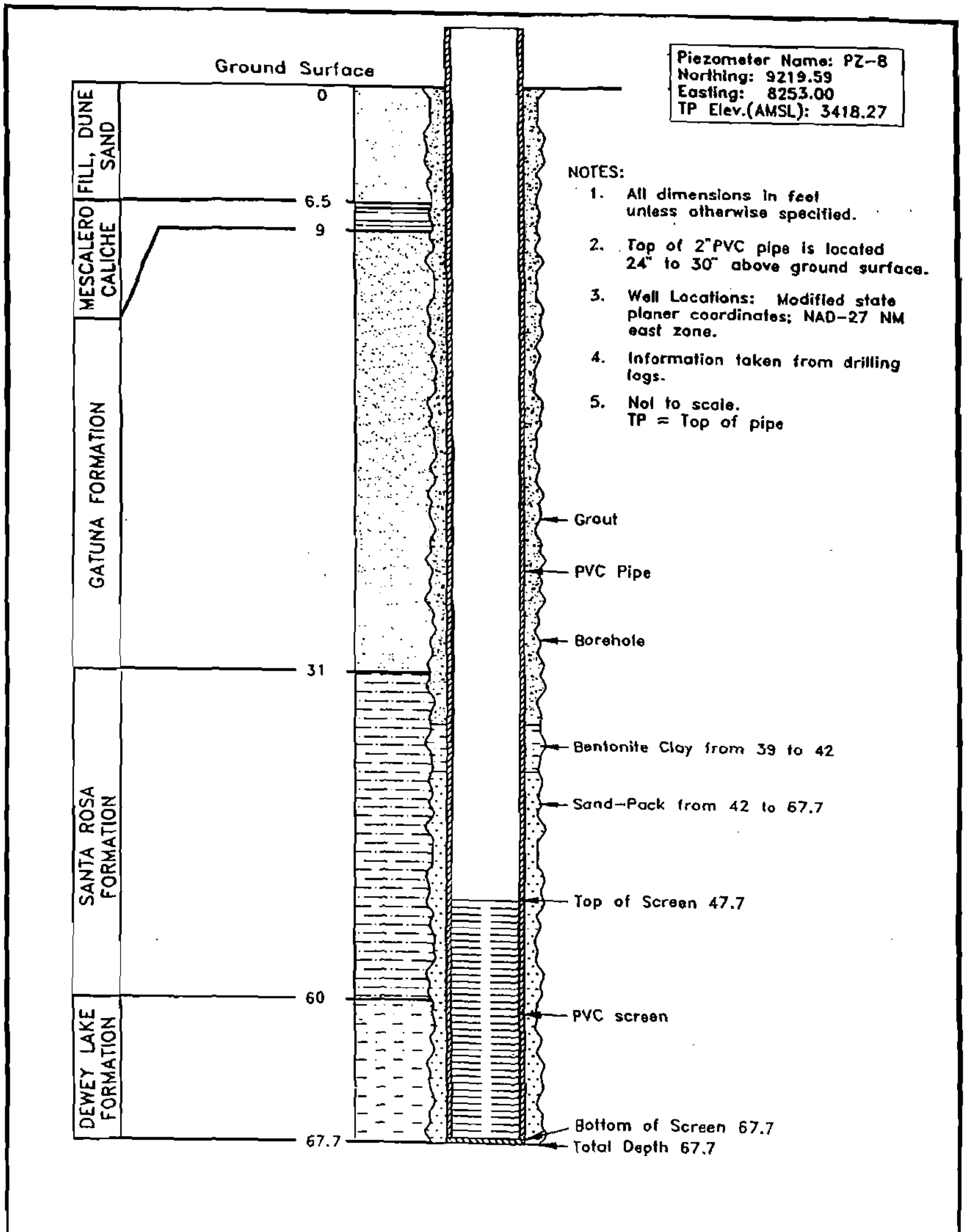
INTERA	PZ-6 Piezometer Completion Diagram	DATE: 07/28/97	REV: A
		REF: JBP/PZ-6	



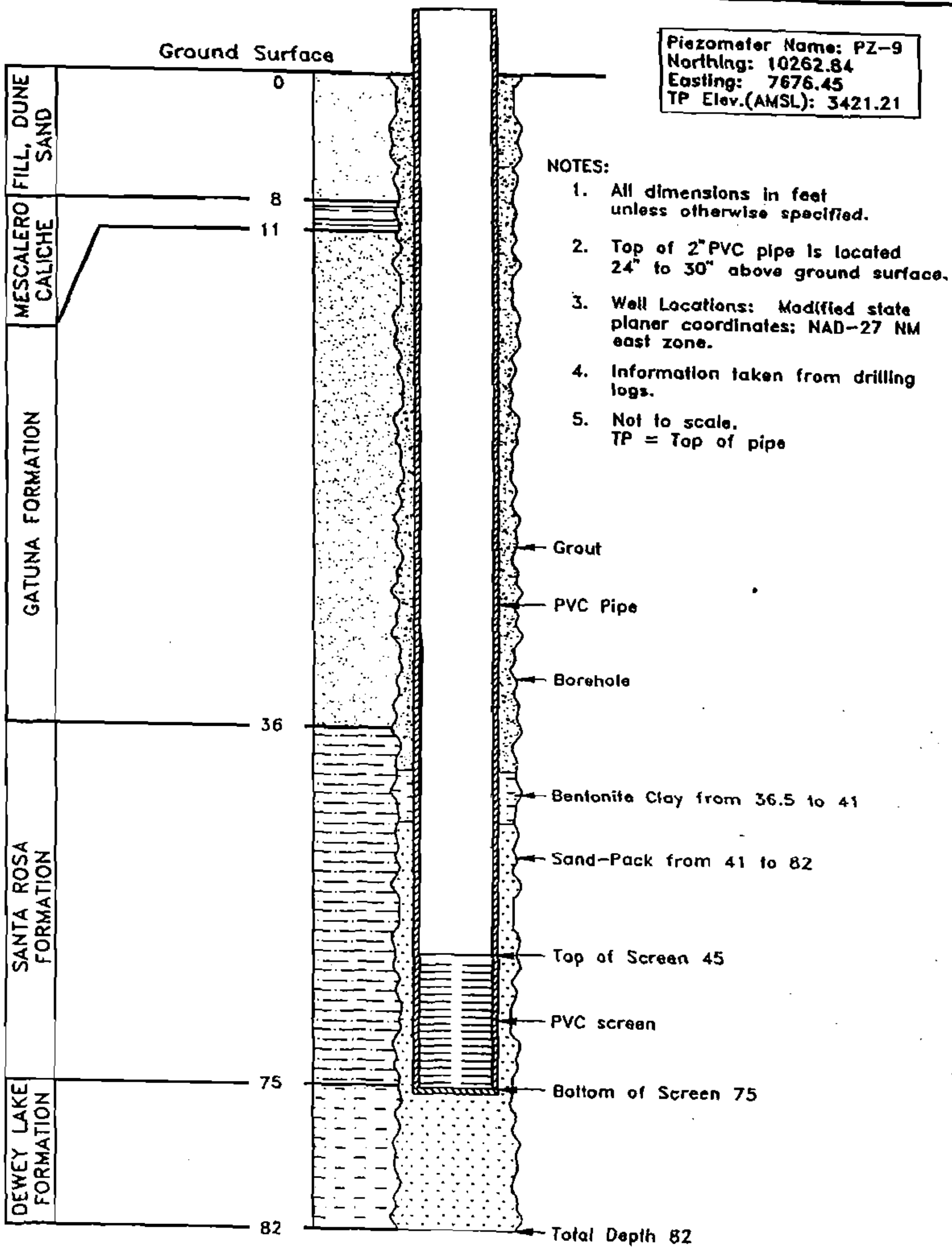
INTERA

PZ-7 Piezometer Completion Diagram

DATE: 07/28/97 REV: A
REF: JBP/PZ-7



INTERA	PZ-8 Piezometer Completion Diagram	DATE: 07/28/97	REV: A
		REF: JBP/PZ-8	

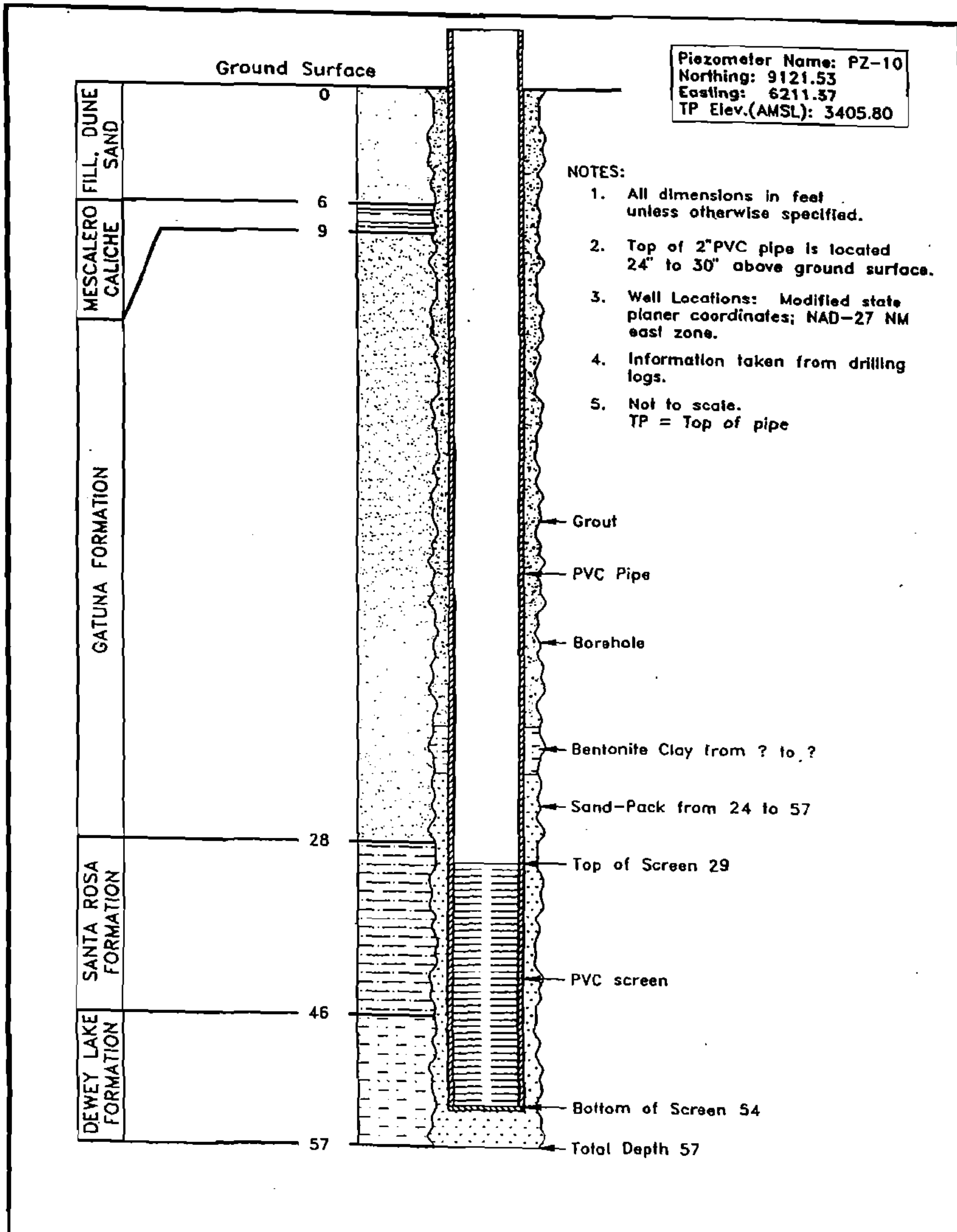


INTERA

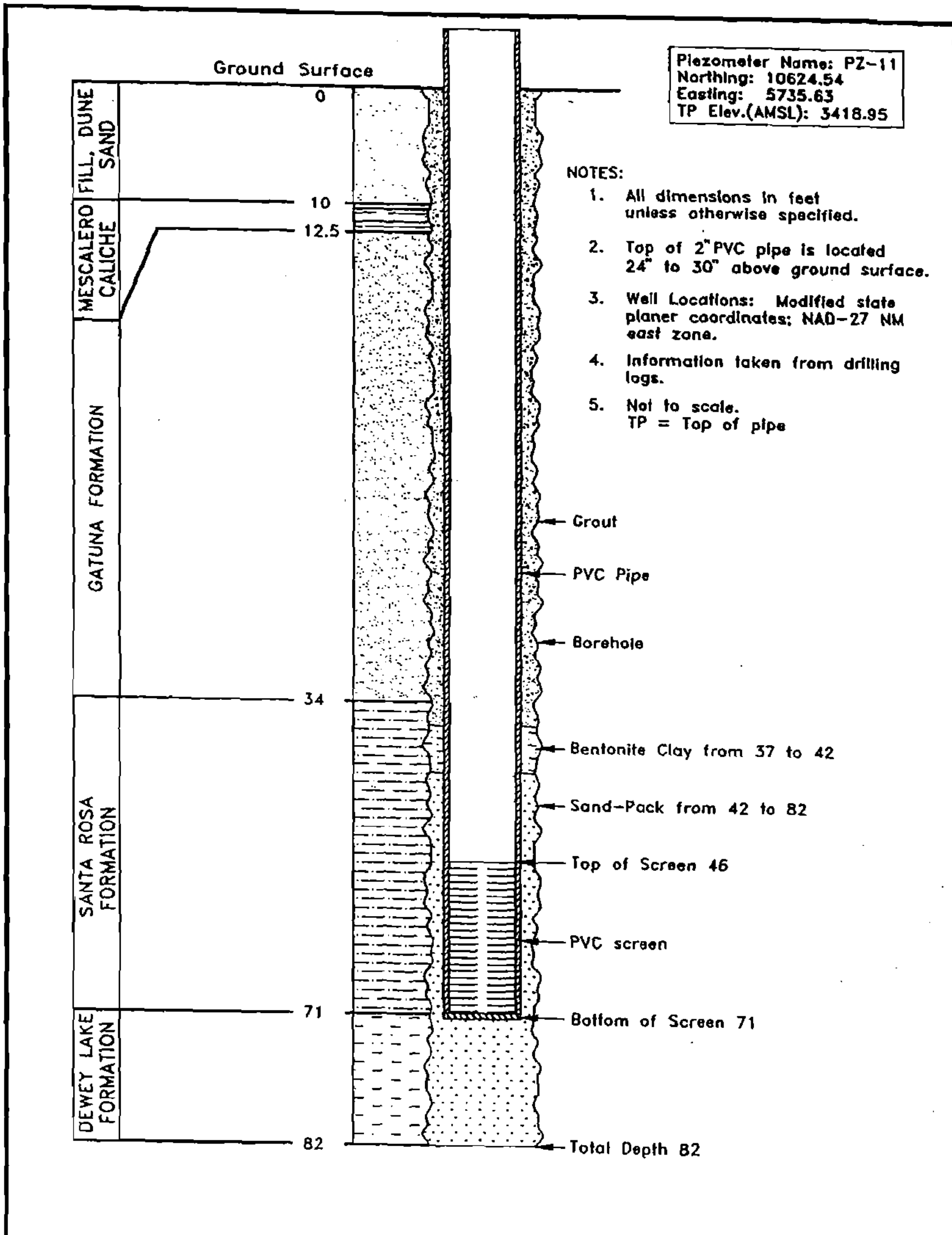
PZ-9 Piezometer Completion Diagram

DATE: 07/28/97 REV: A

REF: JBP/PZ-9



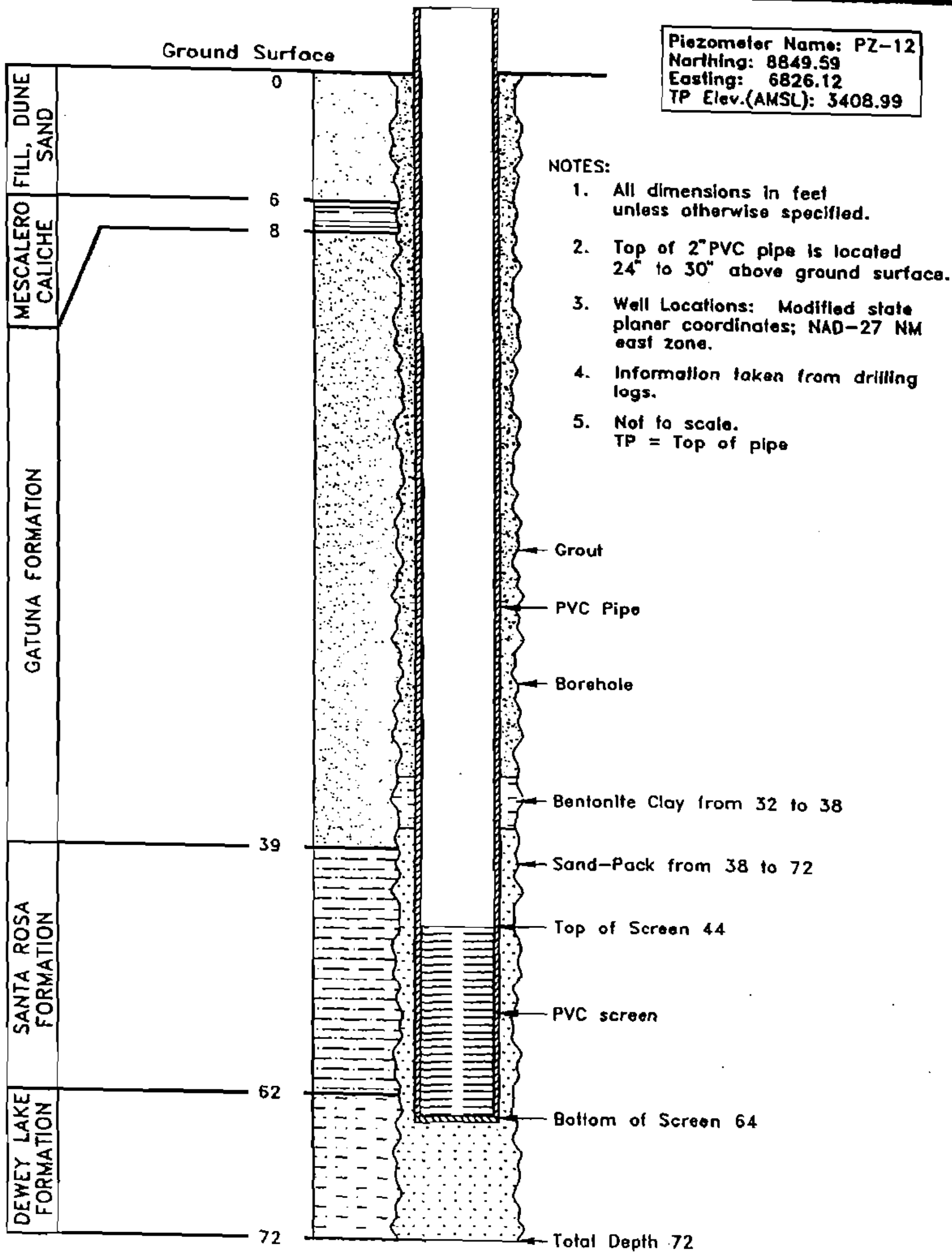
INTERA	PZ-10 Piezometer Completion Diagram	DATE: 07/28/97 REV: A REF: JBP/PZ-10



INTERA

PZ-11 Piezometer Completion Diagram

DATE: 07/28/97	REV: A
REF: JBP/PZ-11	



INTERA	PZ-12 Piezometer Completion Diagram	DATE: 07/28/97	REV: A
		REF: JBP/PZ-12	

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	?
PZ-11	82	42-82	42-82	37-42
PZ-12	72	38-72	38-72	32-38

CORE LOG

Sheet 1 of 2

Hole ID: PZ-13	Location: WIPP Site - SPDV Pile

Drill Date: 8/13 to 8/21 2007	Drill Method: Hollow-Stem/Air Rotary	Drill Make/Model: CME 75
Drill Crew: Stewart Brothers Drilling Company	Hole Diameter: 9.88 - Inch	Barrel Specs: 3-inch split spoon
	Hole Depth: 77 feet	Drill Fluid: NA
	Hole Orient: NA	Core Preserv: NA

Logged by: J. Maly, P.G./R.Salness, P.G.	Date: 8/13 to 8/21 2007	Scale: 1" = 10 '

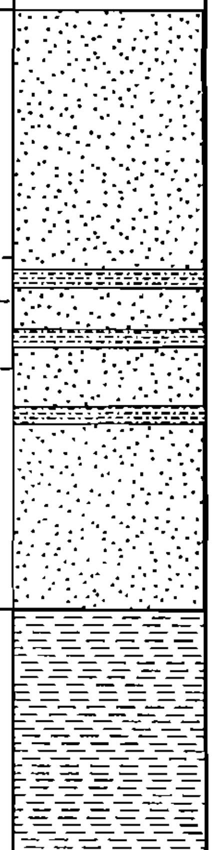
	Northing	Easting	Top of Casing Elevation
Survey Coordinate: (Ft)	498742.63	668947.27	3422.24

Comments:

Depth Number	Depth (feet)	% Recovered	Well Construction	Profile (Rock Type)	Description	Lithology
		100	Well Casing	Dune Sand	[5YR 6/4, LT Reddish Brown], sand, fine grained, loose, moist to dry, friable.	
5		80		Berino Soil	[2.5YR 5/8 - 4/8; Red], sandy, 3' - 6' calcareous sand, 6' - 6.5' stiff, indurated, low moisture.	
		100				
10		80		Mescalero Caliche	[5YR 8/3; Pink], sandy limestone or calcareous sandstone, low moisture, stiff with pebbles and weak laminar structure, at 7.5' to 9', 9'-10' Gatuna inclusions, chert pebbles throughout.	
		80		Gatuna Sandstone	[5YR 7/4; Pink], Gatuna Sandstone with Mescalero Caliche overprint, dry to slightly moist, loose to very stiff clasts with caliche, altered manganese oxide throughout, more argillaceous and calcareous than above.	
15		100				
		100			[2.5YR 5/8; Red], Gatuna Sanstone with argillaceous matrix, chert pebbles throughout, root casts coated in manganese oxide, dry, carlcareous, less argillaceous matrix dominated by sand, increased bedding structure with depth, stiff, platy structures, dry, stiff, moderately indurated.	
20		100				
		100				
25		100				
		100				
30		100				
		100			[2.5YR 6/6, LT Red], lighter color, more indurated slightly moist.	
		100				
35		100			[2.5YR 4/8, Red], Carbonate intraclasts incorporated in matrix.	
		100		Santa Rosa Sandstone	[2.5YR 4/8, Red], [10YR 7/1, LT Gray], interbedded Red and LT Gray sanstone, dessication cracks with carbonate fill, slickensided surfaces (subhorizontal), dry, moderately indurated. Hard at 35' - 39', 39'-39.2' very hard consolidated, well indurated sandstone, dry [2.5YR 4/4; Reddish Brown] 40'-47' Moderately indurated, moist, platy. Changed over to tricone bit on hollow-stem lead auger limiting samples. Steam and condensate apparent when drilling at 55-60' 59.5-59.7 [2.5YR 4/4; Reddish Brown] , moisture content increasing with depth, fine to med sandstone	
40		100				
		<5				
		100				
		100				
45		100				
		100				
		100				
50						

Hole ID: PZ-13 | CORE LOG (cont. sheet) | Sheet 2 of 2

Logged by: J. Maly, P.G./R.Salness, P.G. | Date: 8/13 to 8/21 2007

Depth Number	Depth (ft)	% Recovered	Well Construction	Profile (Rock Type)	Description	Lithology
50		100		Santa Rosa Sandstone	Same as previous page	
55		100	Well Casing	Interbedded sandstone and siltstone In	Steam and condensate apparent when drilling at 55-60' 59.5-59.7 [2.5YR 4/4; Reddish Brown] , moisture content increasing with depth. fine to med sandstone	
60						
65		100			[5YR 8/2. Pinkish White], sandy siltstone. poorly indurated, fine to medium sand, argillaceous, (64'-65')	
					[5YR 5/6, Yellowish Red], sandy, argillaceous siltstone, poorly indurated, fine sand, calcareous, white, yellowish, and orange grains, saturated, (65'-67.5')	
70					[10YR 6/2, Light Brownish Gray], sandy siltstone, moderately indurated, fine sand, clear, greenish gray, pink, reddish brown and black grains, saturated.	
75		100			[5YR 6/6, Reddish Yellow], silty sandstone, poorly indurated, fine to medium sand, less moisture than above.	
80			Sump		[2.5YR 5/4, Reddish Brown], silty argillaceous sandstone, well indurated, fine grains, hard layer, low moisture, similar to 50'-60' interval, softer at 72'-75'; possibly more argillaceous (thin interbedded clay layers between fine grained sandstone).	
				Dewey Lake Formation	[2.5YR 3/4. Dark Reddish Brown] 75'-75.5' mudstone, silty, micaceous with greenish gray reduction spots, moist. [2.5YR 5/6 - 4/6, Red] 75.5 '- 75.75' silty mudstone with greenish gray reduction spots, dryer than above. [5Y 5/1 - 5/2, Gray to Olive Gray] 76.5' - 76.6' mudstone, silty, moist.	

Total Depth 77' terminated in the Dewey Lake Formation

CORE LOG

Sheet 1 of 2

Hole ID: PZ-14	Location: WIPP Site - SPDV Pile

Drill Date: 8/24 to 8/25 2007	Drill Method: Hollow-Stem/Air Rotary	Drill Make/Model: CME 75
Drill Crew: Stewart Brothers Drilling Company	Hole Diameter: 9.88 - Inch	Barrel Specs: 3-inch split spoon
	Hole Depth: 77 feet	Drill Fluid: NA
	Hole Orient: NA	Core Preserv: NA

Logged by: J. Maly, P.G./R.Salness, P.G.	Date: 8/24 to 8/25 2007	Scale: 1" = 10 '

	Northing	Easting	Elevation
Survey Coordinate: (Ft)	499335.30	668667.57	3420.58

Comments:

Depth Number	Depth (feet)	% Recovered	Well Construction	Profile (Rock Type)	Description	Lithology
		30	Well Casing	Dune Sand	[5YR 6/4, LT Reddish Brown], sand, fine grained, loose.	
				Berino Soil	[2.5YR 5/8 - 4/8; Red], sandy, calcareous sand.	
5		100		Mescalero Caliche	[5YR 8/2-8/3; Pinkish White to Pink] sandy limestone or calcareous sandstone, low moisture, stiff with pebbles, weak laminar structure, hard surface cap	
10		100		Gatuna Sandstone	[5YR 8/4 Pink] Gatuna Sandstone with Mescalero Caliche overprint, dry, gatuna inclusions and chert pebbles throughout, more argillaceous and clacareous than above.	
		100			[2.5YR 4/8-5/8, Red]; Gatuna sandstone with argillaceous calcareous matrix, chert pebbles throughout, root casts coated with manganese oxide,	
15		100				
		100			[2.5YR 7/4-8/4; Light Reddish Brown to pink interbedded], platy, moist, Gatuna sandstone sediments, calcareous cementation.	
20		100			[2.5YR 4/8-5/8, Red], Gatuna sandstone, platy, dry and moist alternating between layers, becomes harder with depth to 25'	
		100				
25		100				
		100			[2.5YR 4/8; Red], Platy Gatuna sandstone, poorly indurated, moist, fine grained, argillaceous, silica cementation, root casts with manganese oxide, chert pebbles, very hard at 30'	
		100				
		100				
30		100				
		100		Santa Rosa Sandstone	[2.5YR 7/4-8/4, Pink to Light Reddish Brown], [Gley 1 8/1; Light Greenish Gray], interbedded Reddish and LT Gray sanstone, desication cracks with carbonate fill, slickensided surfaces (subhorizontal), dry, poorly to moderately indurated.	
35					Hard at 35.5'-drilled with center bit only to 40 feet; no recovery at 40 feet; drilled with center bit only to 50 feet.	
40		0%			[5YR 5/4-4/6; Reddish Brown],Very hard, silt sandstone, argillaceous. (50'-50.5'), pulverized by sample barrel	
45					Used center bit drilling only instead of wireline to 56 feet. Hit hard, competent Santa Rosa at 56 feet then switched to air rotary until softer Dewey Lake FM. encountered at depth. Center bit at 56 feet is dry.	
50					Assume similar geology to that seen in PZ-13	

Hole ID: PZ-14 | CORE LOG (cont. sheet) | Sheet 2 of 2

Logged by: J. Maly, P.G./R.Salness, P.G. | Date: 8/24 to 8/25 2007

Depth Number	Depth (ft)	% Recovered	Well Construction	Profile (Rock Type)	Description	Lithology
50			Well Casing	Santa Rosa Sandstone		
55				Interbedded sandstone and siltstone In	Same as previous page	
60						
65						
70		80 90 90			[2.5YR 3/6, Dark Red], silty sand, very loose/unconsolidated, very argillaceous, saturated (70'-70.5'). 70.5' - 70.8 ' Saturated Gravel Lens comprised of angular claystone and siltstone fragments. Claystone: [2.5YR 3/3; Dark Reddish Brown] Siltstone: [2.5YR 5/1; Reddish Gray]	
75						
80			Sump	Dewey Lake Formation	70.8 - 71 feet [5YR 5/1 and 2.5YR 4/6; Gray and Red], siltstone, very hard, competent, platy (very coarse), dry, saturation occurs ontop of this layer. 71 - 72 feet [2.5YR 5/6 - 4/6; Red], claystone, loose/unconsolidated, argillaceous with some silt with gray to greenish spots [Gley2 8/10G, Light Greenish Gray], damp, but not saturated. 72 - 73 feet [2.5YR 5/6, Red], siltstone, very hard, dry, micaceous, platy (fine to coarse with depth), friable at 72 feet, greenish gray spots.	

Total Depth 73' terminated in the Dewey Lake Formation

CORE LOG

Sheet 1 of 1

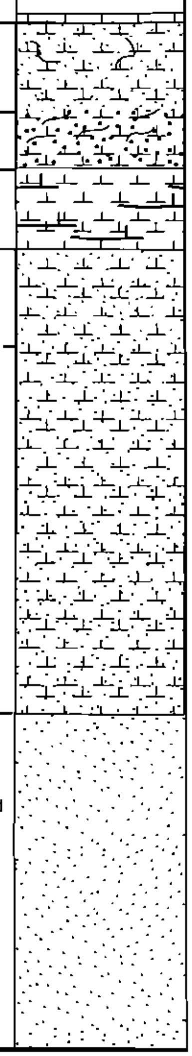
Hole ID: PZ-15	Location: WIPP Site - SPDV Pile	
Drill Date: 8/21 to 8/22 2007	Drill Method: Hollow-Stem/Air Rotary	Drill Make/Model: CME 75
Drill Crew: Stewart Brothers Drilling Company	Hole Diameter: 9.88 - Inch	Barrel Specs: 3-inch split spoon
	Hole Depth: 77 feet	Drill Fluid: NA
	Hole Orient: NA	Core Preserv: NA

Logged by: J. Maly, P.G./R.Salness, P.G.	Date: 8/21 to 8/22 2007	Scale: 1" = 10 '

	Northing	Easting	Elevation
Survey Coordinate: (Ft)	498898.39	669371.61	3430.86

Comments:

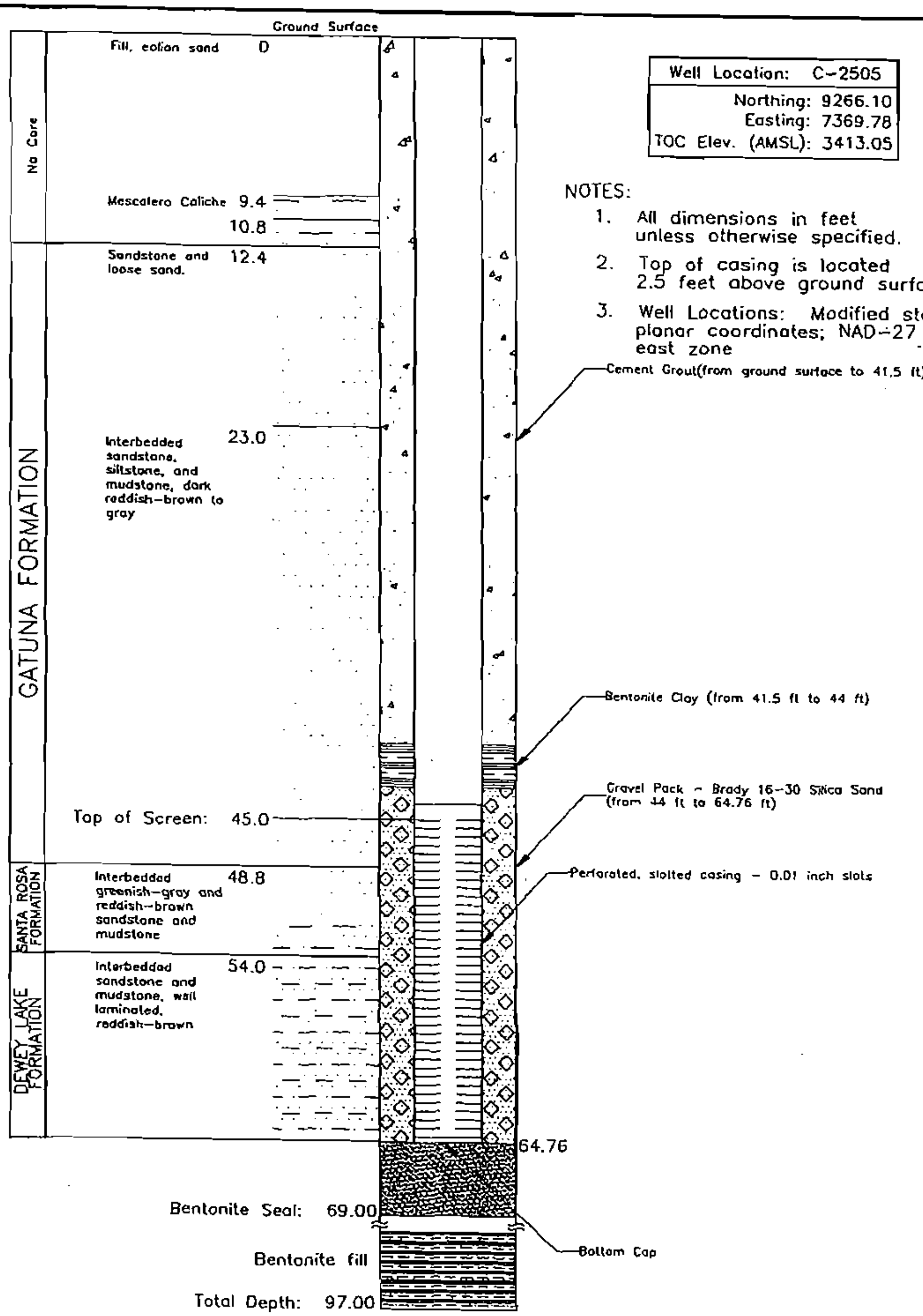
Depth Number	Depth (feet)	% Recovered	Well Construction	Profile (Rock Type)	Description	Lithology
		100		Dune Sand	[5YR 6/4, LT Reddish Brown], sand, fine grained, loose, moist to dry, friable.	
5		100				
		80		Berino Soil	[2.5YR 5/4; Reddish Brown], sandy, 7.8'-8' calcareous sand, indurated, low moisture, small roots, damp. [5YR 8/3 Pink] at 7.5'	
		80		Mescalero Caliche	[7.5YR 8/2-8/4; Pink], sandy limestone or calcareous sandstone, low moisture, stiff with chert pebbles and weak laminar structure (friable), moist in friable portions; pedogenic Gatuna interbedded identified by manganese oxide alterations	
10		100				
		100				
		100		Gatuna Sandstone	[5YR 7/4; Pink], Gatuna Sandstone with Mescalero Caliche overprint, dry to slightly moist, loose to very stiff clasts with caliche, altered manganese oxide throughout, less argillaceous/loose matrix, caliche clasts throughout.	
15		100				
		100				
		100				
		50	Well Casing		[2.5YR 4/6; Red at 16'] [2.5YR 5/8 at 16.6'], Gatuna Sandstone, chert pebbles throughout, root casts coated in manganes oxide, dry, carlcareous, less argillaceous matrix dominated by sand, increased bedding structure with depth, stiff, platy structures, dry, stiff, moderately indurated. 17.5-20' damp, loose, cabonaceous, more argillaceous 20-22.5' no bedding structure, inc. manganese oxide, damp 22.5' -27.5 platy bedding structure, bcame hard at 24' 26.1'-45' [2.5YR 4/6-4/8; Red], siliceous, friable, more argellacaous matrix interbedded with loose matrix. 45'-50.5' Saturated Gatuna Formation sitting on hard Santa Rosa Formation.	
20		80				
		80				
		90				
25		100				
		100				
30		100				
		100				
35						
40		100			[2.5YR 4/8, Red], [10YR 7/1, LT Gray], interbedded Red and LT Gray sandstone, dessication cracks with carbonate fill, slickensided surfaces (subhorizontal), dry, moderately indurated, Wet/saturated at top and dries with depth/perched. 51.3-51.5 soft sandier zone 51.5 Very hard Santa Rosa Sandstone, very hard consolidated, well indurated sandstone, dry [2.5YR 4/4; Reddish Brown]. Total Depth 55 feet terminated in the Santa Rosa Sandstone	
45		100				
		90				
		100				
50		100		Santa Rosa Sandstone		
55						



Well Location:	C-2505
Northing:	9266.10
Easting:	7369.78
TOC Elev. (AMSL):	3413.05

NOTES:

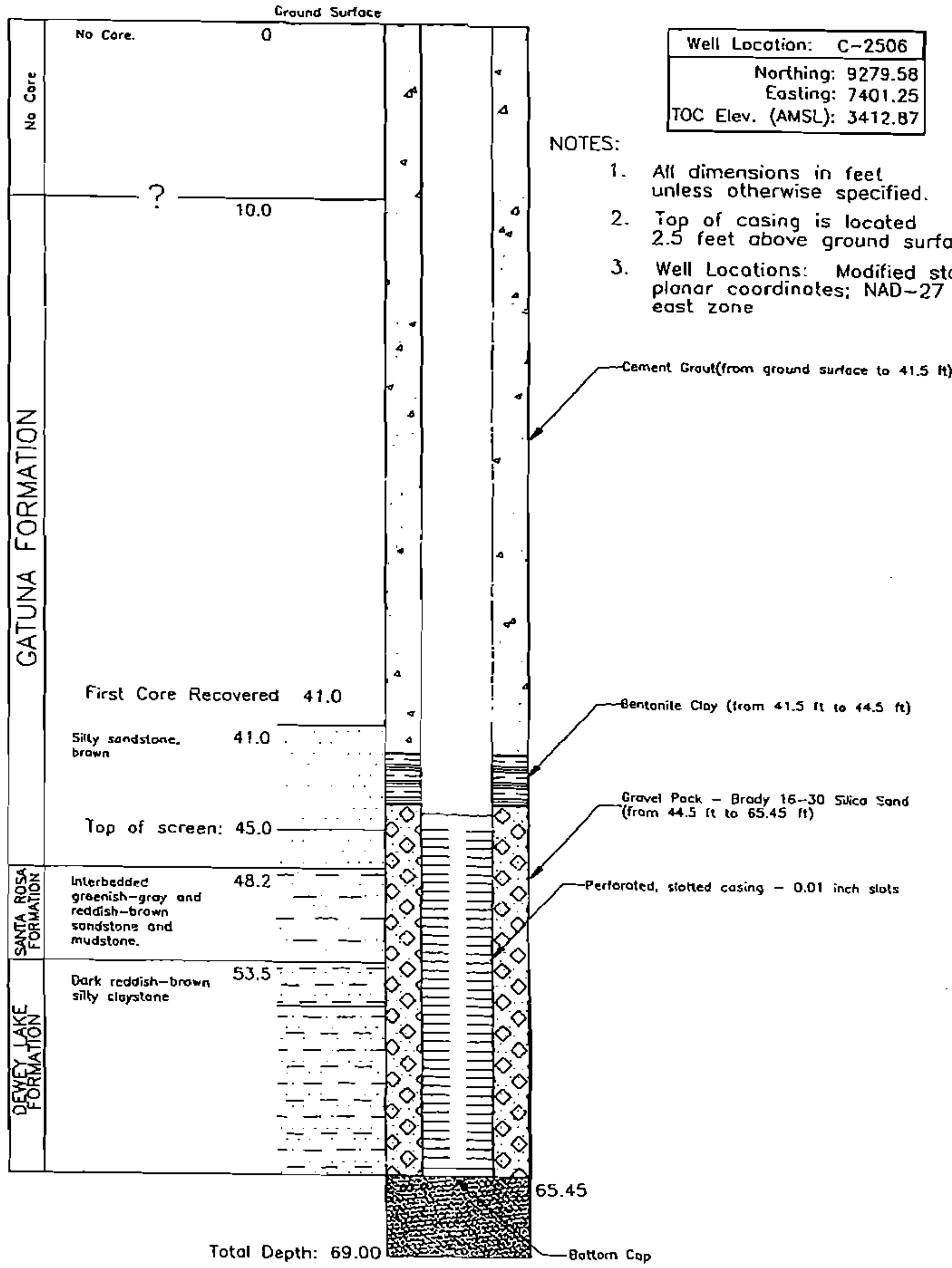
1. All dimensions in feet unless otherwise specified.
2. Top of casing is located 2.5 feet above ground surface.
3. Well Locations: Modified state planar coordinates; NAD-27 NM east zone



INTERA
A Duke Engineering & Services Company

C-2505
Well Completion Diagram

Created By:	Date:
Curtis A. Chester	10/16/96
Part Number:	Revision:
SK-WIP005	01



Well Location:	C-2506
Northing:	9279.58
Easting:	7401.25
TOC Elev. (AMSL):	3412.87

NOTES:

1. All dimensions in feet unless otherwise specified.
2. Top of casing is located 2.5 feet above ground surface.
3. Well Locations: Modified state planar coordinates; NAD-27 NM east zone

INTERA
A Duke Engineering & Services Company

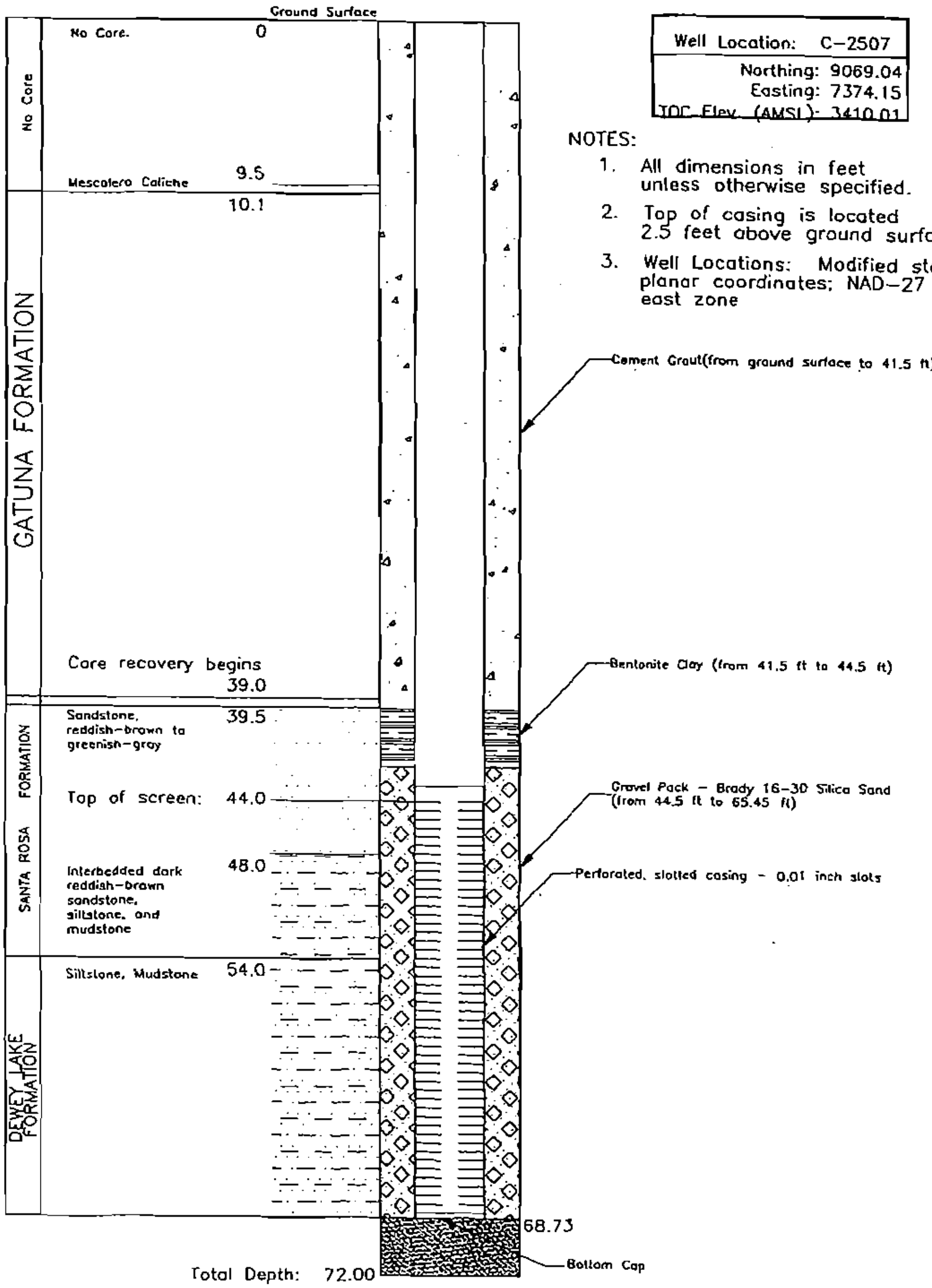
C-2506
Well Completion Diagram

Created By:	Date:
Curtis A. Chester	10/16/96
Part Number:	Revision:
SK-WIP006	01

Well Location:	C-2507
Northing:	9069.04
Easting:	7374.15
TOC Elev. (AMSL):	3410.01

NOTES:

1. All dimensions in feet unless otherwise specified.
2. Top of casing is located 2.5 feet above ground surface.
3. Well Locations: Modified state planar coordinates; NAD-27 NM east zone



INTERA
A Duke Engineering & Services Company

C-2507
Well Completion Diagram

Created By:	Date:
Curtis A. Chester	10/16/96
Part Number:	**Revision:**
SK-WIP007	01

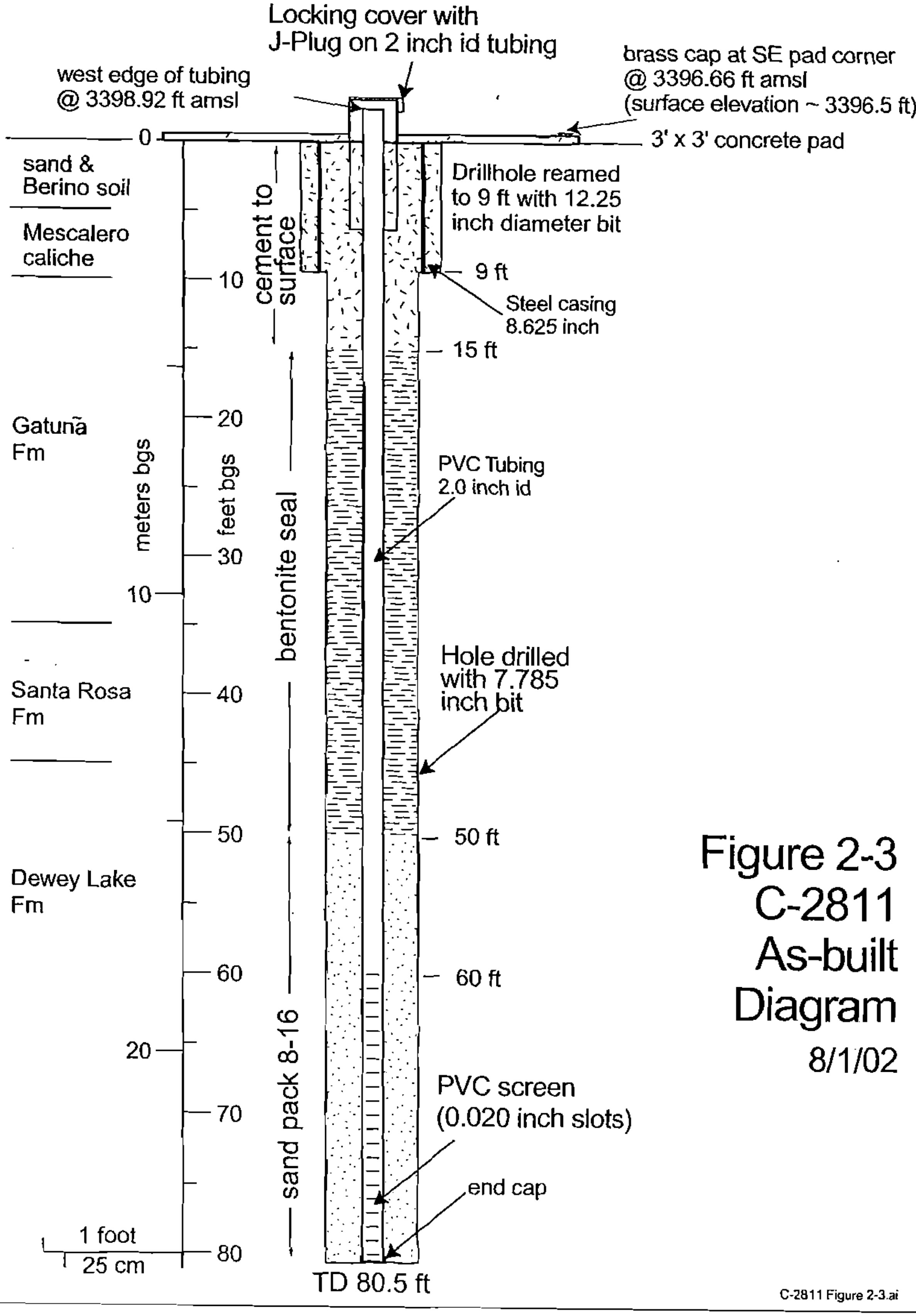


Figure 2-3
C-2811
As-built
Diagram
8/1/02

C-2811 Figure 2-3.ai

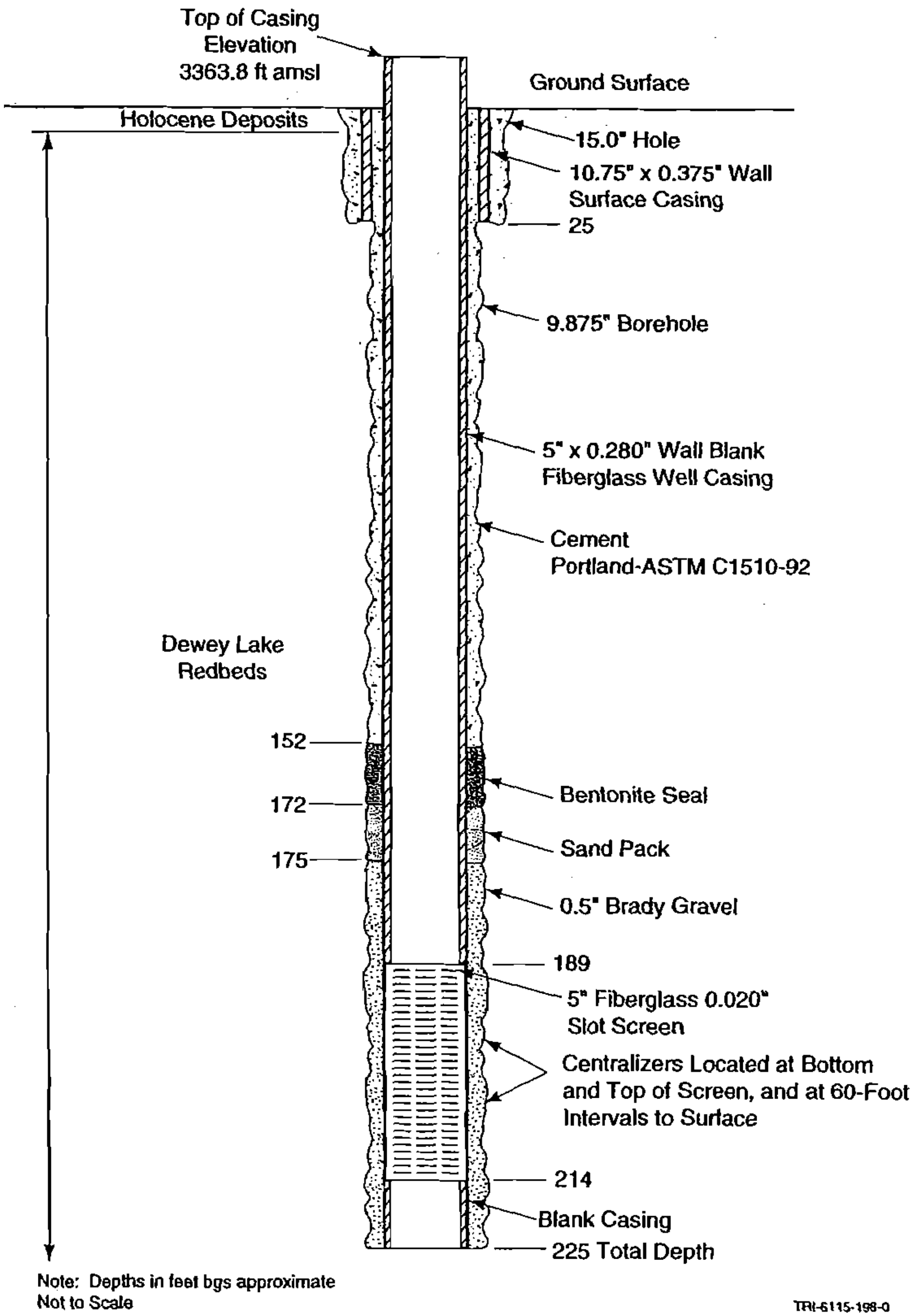
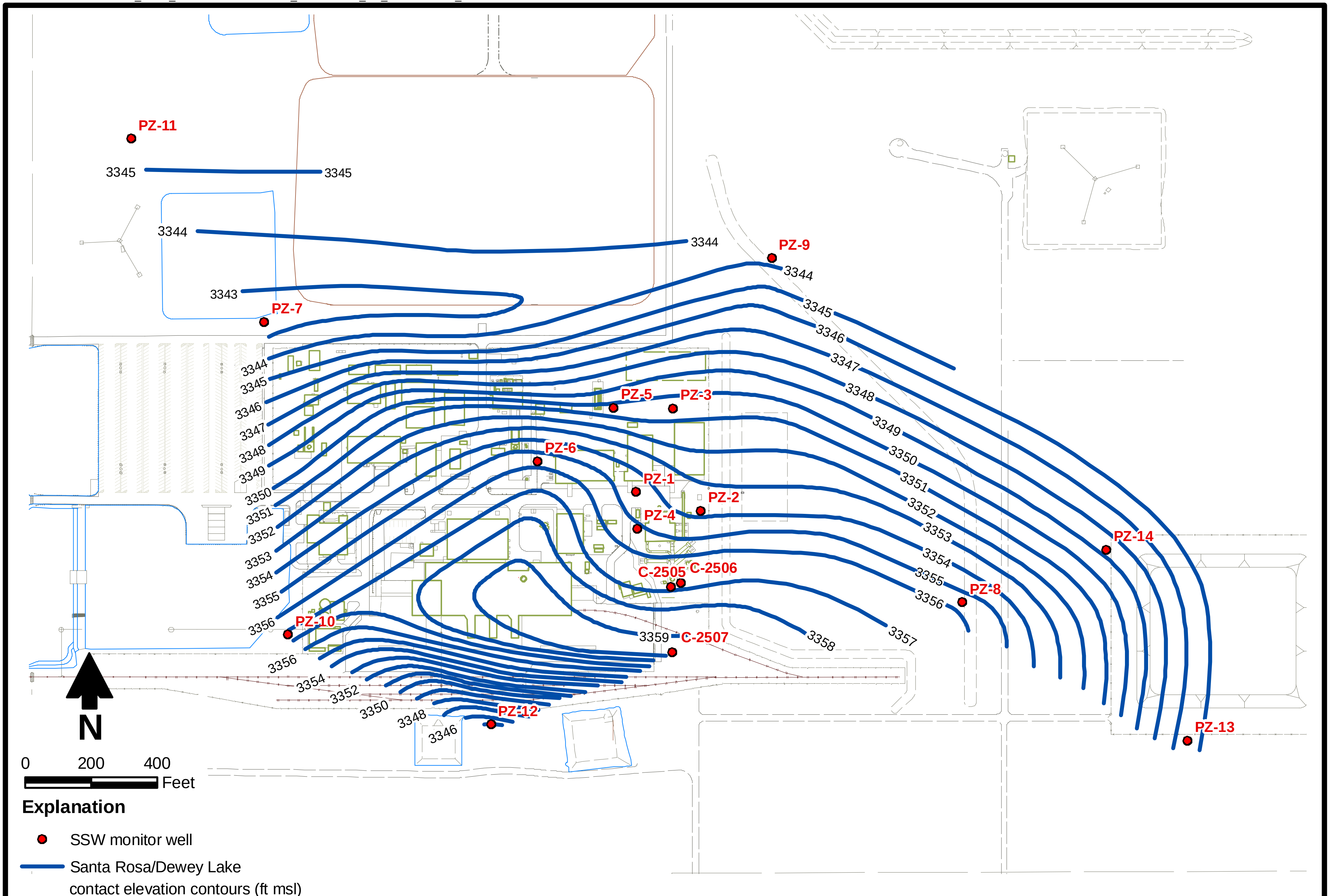


Figure 5-7. As-built configuration of well WQSP-6A.

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/FIG20_CONTOURS_OF_SANTAROSA_DEWEYLAKE.MXD 803090



WIPP SHALLOW SUBSURFACE WATER

Contours of Santa Rosa/Dewey Lake Contact

Daniel B. Stephens & Associates, Inc.
11-19-08
JN ES08.0072

Figure A-1

Appendix B

Water Quality Monitoring Data

Appendix B. Water Quality Monitoring Data

Notes

[a] pH measured in standard units
[b] Specific conductance measured in microSiemens per centimeter (uS/cm) at 25 degrees Celsius
[c] Temperature measured in degrees Celsius
NE = Normal environmental sample
DUP = Duplicate sample
DD = Discrete depth sample
LF = Low flow sample
BLR = Bailer sample

Qualifier Definitions

<	Actual value is known to be less than the value shown.
INT	Estimated value due to interference.
J	The result is an estimated quantity (due either to the quality of the data, or the concentration of the anlayte was below the quantitation limit).
MS	Matrix spike/matrix spike duplicate sample recovery not within acceptance limits.
R	The sample results are unusable due to the quality of the data generated because certain criteria were not met. The analyte may or may not be present.
REP	Duplicate analysis not within limits.
U	The analyte was analyzed for, but was not detected above the level of the reported sample quantitation limit.

C-2505 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)															
		Ammonium	Arsenic	Barium	Boron	Bromide	Cadmium	Calcium	Chloride	Chromium, Total	Iron	Lead	Magnesium	Mercury	Nitrate	Nitrite	pH [a]
9/23/1996	NE, DD	0.3	0.00043 JMS	0.0982 J	1.2	9	<0.00056	789	3,810	0.0048 JINT	0.0146 JINTMS	0.0016 J	641	<0.0002 UMS	15.6	<0.1	7.54
9/23/1996	DUP, DD	0.38	0.00042 JMS	0.0957 J	0.2 J	9	<0.00056	772	3,800	0.018 INT	0.0937 JINTMS	0.001 J	625	<0.0002 UMS	15.3	0.15 J	7.47
9/24/1996	NE, DD	0.26	0.0012 JMS	0.0941 J	0.19 J	9.1	<0.00056	809	3,830	0.0089 JINT	0.0353 JINTMS	0.00076 J	653	<0.0002 UMS	16	0.13 J	7.47
9/24/1996	DUP, DD	0.21	0.00099 JMS	0.0945 J	0.19 J	9.2	<0.00056	812	3,840	0.0034 JINT	0.0098 JINTMS	0.001 J	653	<0.0002 UMS	16.1	0.12 J	7.43
9/26/1996	NE	0.1	---	---	---	---	---	---	---	---	---	---	---	---	17.9	1.2	---
3/6/1997	NE	1	<0.0011	0.0694 J	<1	6.6	<0.0011	508	1,400	0.0032 J	2.96	<0.0011	390	<0.0002 UMS	26.2	---	7.24
3/6/1997	DUP	1	0.0011 J	0.0705 J	<1	6.6	<0.0011	511	1,400	0.0027 J	3.98	<0.0011	392	<0.0002 UMS	26.6	---	7.46
5/14/1997	NE	0.0079 J	0.0028 J	0.0662 J	0.27 J	6.3	<0.0011	437	1,260	0.0034 J	0.0916	<0.0011	336	<0.0002 UMS	26.3	---	7.1
5/14/1997	DUP	<0.007	0.0029 J	0.0675 J	0.27 J	6.2	<0.0011	434	1,230	0.0093 J	0.0781	<0.0011	331	<0.0002 UMS	26.3	---	7.1
6/18/1997	NE	<0.007	0.0024 J	0.0676 J	0.27 J	5.9	<0.0011	446	1,370	<0.0011	0.0943 REP	<0.0011	345	<0.0002	27.6	---	7.1
6/18/1997	DUP	0.0089	0.0022 J	0.0675 J	0.26 J	5.9	<0.0011	444	1,380	<0.0011	0.0489 REP	<0.0011	348	<0.0002	28.1	---	7.2
7/16/1997	NE	0.0074 J	0.0023 J	0.0702 J	0.25 J	6.1	<0.0011	480	1,520	0.0022 J	0.0587 J	0.0021 J	362	<0.0002	25.7	---	7
7/16/1997	DUP	0.0074 J	0.0023 J	0.0734 J	0.26 J	6	<0.0011	487	1,550	0.0017 J	<0.0078	0.0018 J	372	<0.0002	25.9	---	7.1
8/25/1997	NE	0.0148 J	0.0019 J	0.0595 J	0.23 J	5.7	<0.0011	457	1,570	0.004 J	0.12	<0.0011	342	<0.0002	24	---	7.3
10/13/1997	NE	0.098 J	0.0022 J	0.0673 J	0.24 J	5.2	<0.0011	425	1,490	0.0032 J	<0.0089	<0.0011	332	<0.0002	24.8	---	7.1
1/12/1998	NE	0.0182 J	0.0024 JMS	0.0672 J	0.22 J	5.7	<0.0011	444	1,440	0.0034 J	0.0289 J	<0.0011	343	<0.0002	26.7	---	7.2
4/13/1998	NE	0.0416	0.0022 J	0.0674 J	0.23 J	7.1	<0.0011	441	1,780	0.0064 J	<0.0122	0.0023 J	341	<0.0002	27.3	---	7.3
4/13/1998	DUP	0.0812	0.0021 J	0.0622 J	0.23 J	5	<0.0011	453	1,290 R	0.0078 J	0.0139 J	<0.0011	347	0.00021 J	27.2	---	7.2
7/20/1998	NE	0.0545	0.0019 J	0.085 J	0.22 J	6.6	<0.0011	521	1,860	0.0053 J	0.013 J	0.0011 J	399	<0.0002	24.1	---	6.8
10/12/1998	NE	0.0064 J	0.0013 J	0.0992 J	0.22 J	7.1	<0.001	610	2,350	0.0064 J	<0.005	<0.001	462	<0.0002	24.4	---	7.1
2/8/1999	NE	0.0448	0.0015 J	0.109 J	0.2 J	9.1	<0.001	700	2,920	0.0022 J	0.0131 J	0.0059	545	<0.0002	23	---	7.2
2/8/1999	DUP	0.0269	0.0016 J	0.111 J	0.2 J	9.1 J	<0.001	729	3,040	0.0073 J	0.0352 J	0.0027 J	554	<0.0002	23.3	---	7.1
8/9/1999	NE	1.53	<0.005	0.119 J	<1	9.8	<0.003	871	4,070	0.0116 J	<0.132	<0.002	623	<0.001	23.1	---	7.31
2/8/2000	NE, LF	0.265 MS	<0.002	0.114 J	<1	10	<0.003	887	5,080	<0.003	<0.144	<0.002	640	<0.001	22.6	---	7.52
10/10/2000	NE, LF	0.144 MS	0.0018 J	0.133 JINT	0.13 J	9.1 J	<0.003	844	4,970	0.0463 JINT	<0.084	0.0203 JINT	593	<0.001	21.7	---	7.13
12/17/2001	NE, LF	0.097	<0.003	0.103 JINT	0.17 JINT	9.9 J	<0.001	943	6,230	0.0141 J	<0.008	0.0048 J	646	<0.0002	23.2	---	7.28
12/4/2002	NE, LF	0.359 MS	0.0018 J	0.0885 J	0.0002 JINT	10	<0.001	833	5,920	0.0201 JINT	0.0161 J	<0.001	574	<0.001	24.2	---	7.21

C-2505 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)										
		Potassium	Selenium	Silicon	Silver	Sodium	Sulfate	Total Dissolved Solids	Total Inorganic Carbon	Total Organic Carbon	Total Suspended Solids	Zinc
9/23/1996	NE, DD	36.7 J	0.0636 MS	---	0.00036 JMS	1,100	853	8,550	45.8	9.2	16 J	<0.0033
9/23/1996	DUP, DD	23.9 J	0.0605 MS	---	0.00059 JMS	1,040	852	8,530	39.9	6.4	15 J	0.0047 J
9/24/1996	NE, DD	30.9 J	0.0635 MS	---	<0.00022 UMS	996	853	8,580	45.7	7.3	22	<0.0033
9/24/1996	DUP, DD	31.4 J	0.0672 MS	---	<0.00022 UMS	996	856	8,690	47.1	10.5	24	0.0056 J
9/26/1996	NE	---	---	---	---	---	---	---	---	---	---	---
3/6/1997	NE	6 J	0.0883	---	<0.0011	337	945	4,440	90.2	8	---	<0.02
3/6/1997	DUP	6 J	0.0807	---	<0.0011	337	944	4,510	88.7	2	---	0.0262 J
5/14/1997	NE	5.4 J	0.0829	25.3	<0.0011	292	900	3,920	94.8	6.9	---	<0.0022
5/14/1997	DUP	5.5 J	0.0807	25.4	<0.0011	294	883	3,910	95.1	7.1	---	<0.0022
6/18/1997	NE	5.8	0.0853	27.1	<0.0011	333	880	4,320	70.6	8.5	---	0.0113 J
6/18/1997	DUP	5.9	0.0811	27.1	<0.0011	334	877	4,510	88.1	9.9	---	0.0086 J
7/16/1997	NE	5.5 J	0.0877 MS	26.2	<0.0011	356	884	5,280	87.4	8	---	<0.0033
7/16/1997	DUP	6.1	0.0837 MS	26.5	<0.0011	368	865	5,290	88.9	7.6	---	<0.0033
8/25/1997	NE	5.6	0.0827	23.7	<0.0011	327	844	4,520	76.8	12.5	---	0.0082 J
10/13/1997	NE	5.9	0.0697	23.8	<0.0011	347	815	4,280	80.8	10.4	---	<0.0056
1/12/1998	NE	5.9	0.074	25.1	<0.0011	340	873	4,210	72	6.6	---	<0.00989
4/13/1998	NE	5.8	0.0638	25	<0.0011	333	1,070	3,780	75.1	0.97 JMS	---	0.014 J
4/13/1998	DUP	5.9	0.0664	24.7	<0.0011	337	768	3,800	73	<0.3 UMS	---	0.0128 J
7/20/1998	NE	6.2	0.085	25.2	<0.0062	465	934	5,060	64.2	3.7	---	<0.0199
10/12/1998	NE	6.6	0.0868	23.6	<0.001	546	934	6,360	58.3	3.5	---	0.0311
2/8/1999	NE	7.7	0.0974		<0.001	771	1,040	7,650	54	6.7	---	0.0091 J
2/8/1999	DUP	7.7	0.0939		<0.001	753	1,030	7,640	55.3	4.6	---	<0.005
8/9/1999	NE	9	0.111		<0.003	1,130	970	11,100	51.6	19.7	---	<0.046
2/8/2000	NE, LF	10	0.126	21.6	<0.003	1,430	1,200	10,600	47.3	0.49 J	---	<0.047
10/10/2000	NE, LF	10	0.0904	22.3	<0.001	1,510	1,120	10,630	51.3	33.2	---	<0.091
12/17/2001	NE, LF	11.3 J	0.112	22.7	<0.001	2,030	1,290	13,000	---	---	---	<0.05
12/4/2002	NE, LF	11 J	0.0895	23.2	<0.001	2,090	1,200	12,000	53.5	3.4	---	<0.01

C-2506 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)															
		Ammonium	Arsenic	Barium	Boron	Bromide	Cadmium	Calcium	Chloride	Chromium, Total	Iron	Lead	Magnesium	Mercury	Nitrate	pH [a]	Potassium
9/26/1996	NE, DD	---	0.0015 JMS	0.234	0.18 J	10.2	<0.00056	1,010	5,390	0.0128 INT	0.717 INTMS	0.0018 J	744	<0.0002 UMS	---	7.29	18.3 J
2/28/1997	NE	1	<0.0014	0.0074 J	<1	6.8	<0.0011	580	2,130	<0.0028	3.11	<0.0011	434 J	<0.0002	23.9	7.08	4.7 J
2/28/1997	DUP	0.5 J	<0.0013	0.0725 J	<1	6.8	<0.0011	590	2,140	0.0032 J	3.16	<0.0011	430	<0.0002	0.8 R	7.16	5.2 J
5/13/1997	NE	0.0104 J	0.0028 J	0.0639 J	0.24 J	6.3	<0.0011	568	2,220	0.0048 J	0.0539	<0.0011	425	<0.0002	22.8	7.1	6.6
5/13/1997	DUP	0.0079 J	0.003 J	0.0641 J	0.24 J	6.2	<0.0011	566	2,180	0.0039 J	0.0594	<0.0011	425	<0.0002	22.8	7.1	6.6
6/18/1997	NE	<0.007	0.0025 J	0.0751 J	0.23 J	6.8	<0.0011	687	2,840	0.0019 J	0.0371 REP	<0.0011	496	<0.0002	22	7.1	7.2
6/18/1997	DUP	<0.007	0.0022 J	0.0731 J	0.23 J	6.7	<0.0011	682	2,860	0.0019 J	0.0848 REP	<0.0011	498	<0.0002	22.1	7	7.2
7/16/1997	NE	0.0123 J	0.0024 J	0.0808 J	0.22 J	7.4	<0.0011	772	3,240	0.0033 J	0.0277 J	0.0026 J	557	<0.0002	20.5	7	7.5
7/16/1997	DUP	0.0123 J	0.0021 J	0.0817 J	0.22 J	7.2	<0.0011	781	3,250	0.0033 J	0.024 J	0.0021 J	563	<0.0002	20.7	7	7.4
8/25/1997	NE	7.6 J	0.0023 J	0.0692 J	0.19 J	6.8	<0.0011	632	2,940	0.003 J	0.038 J	<0.0011	465	<0.0002	17	7.2	7.2
10/13/1997	NE	14.8 J	0.0023 J	0.065 J	0.2 J	5.7	<0.0011	529	2,620	0.0043 J	<0.009	<0.0011	399	<0.0002	16.8	7.1	6.9
1/12/1998	NE	0.0159 J	0.0025 JMS	0.0679 J	0.18 J	6.2	<0.0011	537	2,460	0.0044 J	<0.0056	<0.0011	403	<0.0002	17.3	7.2	7
4/13/1998	NE	0.0882	0.0024 J	0.0712 J	0.19 J	7.3	<0.0011	651	3,070	0.0123	<0.0122	<0.0011	461	0.00094	18.8	7.3	7.1
7/20/1998	NE	0.482	<0.02	0.12 J	<1	7.9	0.01 J	921	3,920	0.0344 JMSREP	0.357 J	0.001 REP	659	<0.001	19.3	7.1	6.2 J
10/12/1998	NE	0.0013 J	<0.002	0.107 J	<1	8.2 J	<0.01	910	4,480	<0.01	<0.05	<0.01	658	<0.001	22.4	7.1	9
2/8/1999	NE	0.0269	0.001 J	0.122 J	<1	10.8	<0.01	1,110	5,820	0.0276 J	0.0831 J	<0.01	785	<0.0002	21.5	7.1	10.3
8/9/1999	NE	1.65	<0.005	0.127 J	<1	10 J	<0.003	1,090	5,840	0.0094 J	<0.132	<0.002	751	<0.001	20.7	7.01	10
2/8/2000	NE, LF	0.0868 MS	<0.002	0.118 J	<1	11.6	<0.003	1,250	8,490	0.0052 J	<0.144	<0.002	848	<0.001	22.4	7.34	12.4
10/10/2000	NE, LF	0.158 MS	0.0014 J	0.122 JINT	0.17 J	9.2 J	<0.003	1,130	7,920	0.0312 JINT	<0.084	0.0041 JINT	746	<0.001	22	7.14	12
12/17/2001	NE, LF	0.0967	<0.003	0.0914 JINT	0.12 JINT	9.5 J	<0.001	1,250	9,240	0.0099 J	<0.008	<0.001	820	<0.0002	23.2	7.2	14.5 J
12/4/2002	NE, LF	0.341 MS	0.0018 J	0.0969 J	0.078 JINT	6 J	<0.001	1,150	8,870	0.0156 JINT	<0.014	<0.001	753	<0.001	25.7	7.09	14.6 J

C-2506 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)									
		Selenium	Silicon	Silver	Sodium	Sulfate	Total Dissolved Solids	Total Inorganic Carbon	Total Organic Carbon	Total Suspended Solids	Zinc
9/26/1996	NE, DD	0.0821 MS	---	<0.00022 UMS	1,660	973	11,500	47.2	---	32	0.0138 J
2/28/1997	NE	0.0869	---	<0.0011	626	926	6,050	78	7.2	---	0.0655 J
2/28/1997	DUP	0.086	---	<0.0011	613	928	5,800	80.1	8	---	0.0837 J
5/13/1997	NE	0.0767	24.8	<0.0011	586	904	5,580	77	10.1	---	0.0023 J
5/13/1997	DUP	0.0773	24.7	<0.0011	583	894	5,590	80.4	9.3	---	<0.0022
6/18/1997	NE	0.0834	25.7	<0.0011	713	909	8,050	58.1	6.4	---	0.0043 J
6/18/1997	DUP	0.0838	25.8	<0.0011	722	907	7,560	58.3	5	---	<0.0033
7/16/1997	NE	0.0907 MS	25.3	<0.0011	839	913	8,560	69.2	6.6	---	<0.0033
7/16/1997	DUP	0.0916 MS	26.3	<0.0011	842	903	8,580	69.7	7.1	---	<0.0033
8/25/1997	NE	0.0847	22.7	<0.0011	753	825	6,870	60	4.1	---	0.0059 J
10/13/1997	NE	0.071	22.3	<0.0011	712	756	6,240	64.1	6.5	---	<0.0056
1/12/1998	NE	0.0703	23.3	<0.0011	662	776	5,700	61.7	4.8	---	<0.0089
4/13/1998	NE	0.0679	23.3	<0.0011	772	911	6,030	59.5	4.3 MSREP	---	0.0069 J
7/20/1998	NE	0.103 J	23.9	<0.01	1,080	976	10,200	54.2	4.3 J	---	0.06 J
10/12/1998	NE	0.105	22.5	<0.01	1,200	974	10,400	45.2	3.3	---	<0.06
2/8/1999	NE	0.113		<0.01	1,630	1,120	13,300	46	3.2	---	<0.05
8/9/1999	NE	0.116		<0.003	1,720	988	14,800	44.5	9.7	---	<0.046
2/8/2000	NE, LF	0.127	20.9	<0.003	2,690	1,260	17,000	42.2	0.78 J	---	<0.047
10/10/2000	NE, LF	0.0882	21.6	0.0021 J	2,730	1,070	15,920	46.4	2.3	---	<0.091
12/17/2001	NE, LF	0.0447	22.3	<0.001	3,230	1,300	18,000	---	---	---	<0.05
12/4/2002	NE, LF	0.0911	22.1	<0.001	3,240	1,280	17,700	49.1	3.3	---	<0.01

C-2507 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)														
		Ammonium	Arsenic	Barium	Boron	Bromide	Cadmium	Calcium	Chloride	Chromium, Total	Iron	Lead	Magnesium	Mercury	Nitrate	Nitrite
10/2/1996	NE	0.05	0.0018 JMS	0.122 J	0.23 J	10.1	<0.00056	446	1,170	0.0076 JINT	4.16 INTMS	0.0019 J	340	<0.0002 UMS	9.5	7.7
5/14/1997	NE	0.0104 J	0.0029 J	0.0523 J	0.23 J	8.3	<0.0011	449	1,180	0.014	0.263	<0.0011	332	<0.0002	17.4	---
5/14/1997	DUP	0.0079 J	0.003 J	0.0541 J	0.24 J	8.4	<0.0011	449	1,160	0.0138	0.188	<0.0011	333	<0.0002	17.5	---
6/18/1997	NE	0.0112	0.0025 J	0.0508 J	0.24 J	7.8	<0.0011	436	1,160	0.013	0.378 REP	0.003 J	330	<0.0002	19	---
6/18/1997	DUP	0.0135	0.0024 J	0.0502 J	0.24 J	7.9	<0.0011	438	1,150	0.0128	0.189 REP	<0.0011	330	<0.0002	19	---
7/16/1997	NE	0.0074 J	0.0024 J	0.0453 J	0.24 J	7.8	<0.0011	436	1,130	0.0107 J	0.239	0.0019 J	319	<0.0002	18.4	---
7/16/1997	DUP	0.0074 J	0.0025 J	0.0463 J	0.23 J	7.8	<0.0011	436	1,150	0.0098 J	0.179	0.0021 J	319	<0.0002	18.3	---
8/25/1997	NE	<0.007	<0.002	0.0442 J	0.23 J	7	<0.0011	426	1,090	0.0144	0.123	<0.0011	310	<0.0002	18.8	---
8/25/1997	DUP	0.007	<0.002	0.0419 J	0.22 J	7.2	<0.0011	417	1,110	0.0123	0.0969	<0.0011	306	<0.0002	18.8	---
10/13/1997	NE	0.0073 J	0.0023 J	0.0431 J	0.24 J	7.2	<0.0011	411	1,130	0.025	0.0438 J	<0.0011	308	<0.0002	21.1	---
10/13/1997	DUP	0.0123 J	0.0022 J	0.0454 J	0.24 J	7.3	<0.0011	401	1,110	0.0261	0.185	0.0014 J	302	<0.0002	19.4	---
1/12/1998	NE	0.0182 J	0.0023 JMS	0.0489 J	0.24 J	9.6 R	<0.0011	466	1,320	0.0215	0.0334	<0.0011	338	<0.0002	18	---
1/12/1998	DUP	0.009 J	0.0025 JMS	0.0494 J	0.23 J	7.7	<0.0011	464	1,320	0.0231	0.0474 J	<0.0011	340	<0.0002	18	---
4/13/1998	NE	0.107	0.0023 J	0.0469 J	0.25 J	7.3	<0.0011	476	1,440	0.0887	0.0215 J	<0.0011	347	<0.0002	20.1	---
7/21/1998	NE	0.184	0.0016 J	0.045 J	0.25 J	6.8	<0.0011	464	1,400	0.14	0.0232 J	<0.0011	356	<0.0002	20.8	---
10/12/1998	NE	0.0064 J	0.0013 J	0.0438 J	0.46 J	6.1	<0.001	447	1,340	0.133	0.0243 J	0.003 J	343	<0.0002	21.2	---
10/12/1998	DUP	0.0064 J	0.0013 J	0.0465 J	0.26 J	6	<0.001	462	1,320	0.127	<0.005	<0.001	339	<0.0002	21.4	---
2/8/1999	NE	0.0289	0.0013 J	0.0453 J	0.26 J	7.2	<0.001	461	1,380	0.121	0.0142 J	0.0021 J	342	<0.0002	21.8	---
8/9/1999	NE	0.0216	0.0024 J	0.0483 J	0.24 J	7.3 J	<0.0003	517	1,710	0.126	<0.0132	0.0022 J	361	<0.0002	20.5	---
8/9/1999	DUP	0.0753	0.0022 J	0.0483 J	0.25 J	7.2 J	0.00033 J	522	1,690	0.131	<0.0132	0.00066 J	358	<0.0002	20.7	---
2/7/2000	NE, LF	0.0275	0.0018 J	0.0423 J	0.23 J	6.6	<0.0003	432	1,320	0.0725	<0.0144	0.00063 J	317	<0.0002	21.9	---
2/7/2000	DUP, LF	0.0196 J	0.0018 J	0.0399 J	0.3 J	6.6	<0.0003	424	1,330	0.0713	<0.0144	0.00056 J	308	<0.0002	23.4	---
10/10/2000	NE, LF	0.0242	0.0018 J	0.0504 J	0.24 J	6.4 J	<0.0003	467	1,560	0.1	<0.0084	0.00044 J	348	<0.0002	23.5	---
12/17/2001	NE, LF	<0.0042	0.0015 J	0.0386 J	0.27 JINT	5.6	<0.0001	418	1,300	0.0491	<0.0008	0.00012 J	337	<0.0002	26	---
12/4/2002	NE, LF	0.0097 JMS	0.0017 J	0.0453 J	0.27 JINT	4.4 J	0.00012 J	446	1,520	0.0421	0.0019 J	0.00052 J	338	<0.0002	25.9	---
6/21/2004	NE, LF	---	---	---	---	---	---	---	1,300	0.028	---	---	---	---	7.55	---
11/9/2004	NE, LF	---	---	---	---	---	---	---	1,380	0.014	---	---	---	---	7.58	---
5/17/2005	NE, LF	---	---	---	---	---	---	---	1,370	0.078	---	---	---	---	7.94	---
10/10/2005	NE, LF	---	---	---	---	---	---	---	1,630	0.01	---	---	---	---	6.13	---
5/16/2006	NE, LF	---	---	---	---	---	---	---	1,930	<0.01	---	---	---	---	7.37	---
10/10/2006	NE, LF	---	---	---	---	---	---	---	1,740	<0.025	---	---	---	---	2.9	---
5/9/2007	NE, LF	---	---	---	---	---	---	---	3,060	<0.025	---	---	---	---	6.62	---
10/9/2007	NE, LF	---	---	---	---	---	---	---	3,500	0.007	---	---	---	---	<1	---
6/5/2008	NE, LF	---	---	---	---	---	---	---	2,800	0.00493	---	---	---	---	6.9	---

C-2507 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)													
		pH [a]	Potassium	Selenium	Silicon	Silver	Sodium	Specific Conductance [b]	Sulfate	Temperature [c]	Total Dissolved Solids	Total Inorganic Carbon	Total Organic Carbon	Total Suspended Solids	Zinc
10/2/1996	NE	7.55	11.9 J	0.0334 MS	---	<0.00022 UMS	268	---	994	---	4,000	57.9	5.6	125	0.0272
5/14/1997	NE	7.4	5.6	0.091	23.2	<0.0011	270	---	1,080	---	3,930	67.8	8.5	---	<0.002
5/14/1997	DUP	7.3	5.5 J	0.0924	23	<0.0011	274	---	1,060	---	3,930	66.7	7.9	---	0.0039 J
6/18/1997	NE	7.3	5.7	0.0981	24.9	<0.0011	283	---	1,050	---	4,110	52.5	7.2	---	<0.0033
6/18/1997	DUP	7.3	5.7	0.101	24.7	<0.0011	285	---	1,050	---	4,180	59.9	7.6	---	<0.0033
7/16/1997	NE	7.2	5.5 J	0.098 MS	24.6	<0.0011	278	---	1,020	---	4,940	69.6	8.2	---	0.0079 J
7/16/1997	DUP	7.2	5.3 J	0.097 MS	24.5	<0.0011	281	---	1,030	---	4,720	71.7	7.4	---	0.0045 J
8/25/1997	NE	7.3	5.4 J	0.0857	23.1	<0.0011	262	---	971	---	4,020	62.2	8.6	---	0.0215 J
8/25/1997	DUP	7.4	5.4 J	0.0827	23.2	<0.0011	259	---	984	---	4,000	68.2	13.2 R	---	0.018 J
10/13/1997	NE	7.2	5.7	0.0686	22.6	<0.0011	285	---	963	---	3,700	65.7	8.8	---	0.0071 J
10/13/1997	DUP	7.2	5.8	0.0681	22.5	<0.0011	277	---	936	---	3,580	68.8	9.7	---	0.0078 J
1/12/1998	NE	7.1	6	0.0686	24.1	<0.0011	330	---	1,060	---	4,320	69.7	10.2 R	---	<0.0089
1/12/1998	DUP	7.1	6	0.0697	24.5	<0.0011	332	---	1,060	---	4,580	80.3	7	---	<0.0089
4/13/1998	NE	7.3	5.9	0.063	24.4	<0.0011	340	---	1,080	---	3,820	72.4	4.3 MSREP	---	0.0136 J
7/21/1998	NE	7.2	6.2	0.078	24	<0.0096	351	---	1,030	---	4,230	62.8	3.6	---	<0.0092
10/12/1998	NE	7.2	5.7	0.0751	23.2	<0.001	326	---	953	---	4,570	68.7	3.7	---	0.0351
10/12/1998	DUP	7.2	5.6	0.0702	22.9	<0.001	322	---	968	---	4,525	64	3.4	---	0.02
2/8/1999	NE	7.2	6.2	0.0759	---	<0.001	337	---	994	---	4,300	57.6	7	---	<0.005
8/9/1999	NE	7.21	6.5	0.0798	---	<0.0003	467	---	948	---	6,120	57	5.3	---	0.0208
8/9/1999	DUP	7.08	6.8	0.0793	---	<0.0003	471	---	942	---	6,590	72	6.6	---	0.0225
2/7/2000	NE, LF	7.84	6.2	0.0926	22.8	<0.0003	321	---	1,000	---	3,770	59.6	4.7 REP	---	<0.0047
2/7/2000	DUP, LF	7.58	5.8	0.0921	22.4	0.00085 J	316	---	1,020	---	4,080	72	1.6 REP	---	<0.0047
10/10/2000	NE, LF	7.1	6.6	0.0702	22.9	0.00021 J	348	---	972	---	4,115	64.5	4.2	---	0.0098 J
12/17/2001	NE, LF	7.61	6.5	0.075	25	<0.0001	328	---	970	---	4,170	75.1	3	---	0.0438
12/4/2002	NE, LF	7.15	6.7	0.0646	24.6	0.00053 J	348	---	996	---	3,650	82.7	3.4	---	0.0125 J
6/21/2004	NE, LF	---	---	0.029	---	---	---	---	717	---	3,830	---	---	---	---
11/9/2004	NE, LF	---	---	0.08	---	---	---	---	824	---	3,350	---	---	---	---
5/17/2005	NE, LF	---	---	0.063	---	---	---	---	860	---	3,340	---	---	---	---
10/10/2005	NE, LF	---	---	0.047	---	---	---	---	920	---	3,240	---	---	---	---
5/16/2006	NE, LF	---	---	0.051	---	---	---	---	1,040	---	5,300	---	---	---	---
10/10/2006	NE, LF	---	---	<0.05	---	---	---	---	943	---	3,640	---	---	---	---
5/9/2007	NE, LF	---	---	<0.05	---	---	---	---	1,110	---	5,485	---	---	---	---
10/9/2007	NE, LF	6.88	---	0.055	---	---	---	9,410	1,220	20	5,540	---	---	---	---
6/5/2008	NE, LF	---	---	0.0637	---	---	---	---	990	---	5,800	---	---	---	---

C-2811 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)													
		Ammonium	Arsenic	Barium	Boron	Bromide	Cadmium	Calcium	Chloride	Chromium, Total	Iron	Lead	Magnesium	Mercury	Nitrate
12/19/2001	NE, LF	<0.0042	0.0014 J	0.0934 J	0.17 JINT	2.8	<0.0001	283	956	0.0017 J	<0.0008	<0.0001	207	<0.0002	27.9
12/10/2002	NE, LF	0.0125 JMS	0.0021 J	0.102 J	0.17 JINT	1.9 J	<0.0001	272	899	0.003 J	<0.0014	<0.0001	206	<0.0002	27.6
6/14/2004	NE, LF	---	---	---	---	---	---	---	769	<0.005	---	---	---	---	6.06
11/8/2004	NE, LF	---	---	---	---	---	---	---	1,030	<0.01	---	---	---	---	7.63
5/16/2005	NE, LF	---	---	---	---	---	---	---	1,930	0.053	---	---	---	---	6.02
10/10/2005	NE, LF	---	---	---	---	---	---	---	2,250	<0.01	---	---	---	---	7.48
5/15/2006	NE, LF	---	---	---	---	---	---	---	1,760	<0.01	---	---	---	---	6.94
10/9/2006	NE, LF	---	---	---	---	---	---	---	1,310	<0.005	---	---	---	---	6.05
5/7/2007	NE, LF	---	---	---	---	---	---	---	1,760	0.031	---	---	---	---	5.31
10/8/2007	NE, LF	---	---	---	---	---	---	---	2,980	<0.005	---	---	---	---	<1
6/4/2008	NE, LF	---	---	---	---	---	---	---	1,300	0.035	---	---	---	---	5.7

C-2811 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)												
		pH [a]	Potassium	Selenium	Silicon	Silver	Sodium	Specific Conductance [b]	Sulfate	Temperature [c]	Total Dissolved Solids	Total Inorganic Carbon	Total Organic Carbon	Zinc
12/19/2001	NE, LF	7.56	4.6 J	0.0243	22.3	<0.0001	163	---	379	---	2,630	49.5	1.4	0.0357
12/10/2002	NE, LF	7.4	4.3 J	0.0246	21.8	<0.0001	134	---	355	---	2,400	50	1.9	<0.001
6/14/2004	NE, LF	---	---	0.047	---	---	---	---	299	---	2,022	---	---	---
11/8/2004	NE, LF	---	---	0.054	---	---	---	---	305	---	1,996	---	---	---
5/16/2005	NE, LF	---	---	0.058	---	---	---	---	524	---	3,740	---	---	---
10/10/2005	NE, LF	---	---	0.034	---	---	---	---	584	---	4,410	---	---	---
5/15/2006	NE, LF	---	---	0.031	---	---	---	---	511	---	3,740	---	---	---
10/9/2006	NE, LF	---	---	<0.01	---	---	---	---	402	---	2,100	---	---	---
5/7/2007	NE, LF	---	---	<0.02	---	---	---	---	516	---	4,205	---	---	---
10/8/2007	NE, LF	7.05	---	0.051	---	---	---	6,400	635	20.3	3,860	---	---	---
6/4/2008	NE, LF	---	---	0.0017	---	---	---	---	390	---	2,800	---	---	---

PZ-01 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)														
		Ammonium	Arsenic	Barium	Boron	Bromide	Cadmium	Calcium	Chloride	Chromium, Total	Iron	Lead	Magnesium	Mercury	Nitrate	pH [a]
9/11/1997	NE	0.96	<0.02	0.235 J	<1	17.3 J	<0.01	4,100	41,500	0.0374 J	2.51	<0.01	2,130	0.002	5.6	6.9
9/11/1997	DUP	0.525	<0.02	0.413 J	<1	17.6 J	<0.01	4,010	45,200	0.106	12.5	0.0165 J	2,080	0.0025	5.4	6.9
10/15/1997	NE	0.073 J	<0.02	0.255 J	<1	14.2 J	<0.01	4,390	58,600	0.0394 J	<0.08	0.0185 J	2,300	<0.001	5.8	6.8
10/15/1997	DUP	0.073 J	<0.02	0.244 J	<1	16.5 J	<0.01	4,340	59,400	0.0423 J	<0.08	0.0108 J	2,280	<0.001	5.9	6.8
11/13/1997	NE	0.0222	<0.02	0.219 J	<1 UMS	18.6 J	<0.01	4,300	53,900	0.0888 J	0.083 J	<0.01	2,150	0.0014 J	5.6	6.8
1/13/1998	NE	<0.007	<0.02	0.227 J	<1	16.9 J	<0.01	4,590	54,700	0.0211 J	0.546 J	0.0159 J	2,290	0.0021 MS	5.8 J	6.8
1/13/1998	DUP	<0.007	<0.02	0.233 J	<1	16.3 J	<0.01	4,800	53,700	<0.02	0.149 J	<0.01	2,400	0.0019 JMS	5.8 J	6.8
4/14/1998	NE	0.307	<0.02	0.195 J	<1	18.2 J	<0.01	4,490	48,200	0.0455 J	<0.11	<0.01	2,300	0.007	5.8	7
7/21/1998	NE	0.892	<0.02	0.203 J	<1	15.8 J	<0.01	4,700	43,500	0.0802 MSREP	0.771 J	0.01 JREP	2,280	0.001 J	8 J	6.9
10/13/1998	NE	0.0013 J	<0.002	0.211 J	<1	18.2 JMS	<0.01	4,580	53,400	0.068 J	<0.05	<0.01	2,260	<0.001	9.66 J	6.7
10/13/1998	DUP	0.097 J	<0.002	0.217 J	<1	19.2 J	<0.01	4,570	57,900	0.0774 J	<0.05	<0.01	2,240	<0.001	10.2 J	6.7
2/8/1999	NE	0.0548	<0.001	0.194 J	<1	19.6 J	<0.01	4,110	46,800	0.0195 J	0.0975 J	<0.01	2,140	0.0021	6.21 J	6.8
8/9/1999	NE	0.339	<0.005	0.2 J	<1	<30	<0.003	4,290	48,600	0.0172 J	<0.132	0.0084 J	2,220	0.003	7.2 J	6.81
2/7/2000	NE, LF	0.0264 MS	<0.002	0.132 J	<1	11.7 J	<0.003	3,610	32,400	0.01 J	<0.144	<0.002	1,940	0.001 J	4.55	7.16
10/11/2000	NE, LF	0.153 MS	<0.001	0.13 JINT	0.11 J	14.4 J	<0.003	3,450	31,400	0.0444 JINT	<0.084	0.0039 JINT	1,840	<0.001	4.68	6.96
12/17/2001	NE, LF	0.699	<0.003	0.125 JINT	0.079 JINT	19.2 J	<0.001	4,250	33,100	0.0108 J	<0.008	<0.001	2,310	0.0016	4.9	6.94
12/5/2002	NE, LF	---	0.0013 J	0.173 J	---	2.9 J	0.0014 J	---	48,500	0.0179 JINT	---	<0.001	---	0.0012 J	6.16	6.8
6/21/2004	NE, LF	---	---	---	---	---	---	---	36,300	<0.005	---	---	---	---	<10	---
11/9/2004	NE, LF	---	---	---	---	---	---	---	45,700	<0.01	---	---	---	---	1.3	---
5/17/2005	NE, LF	214 MS	---	---	<0.011 UINT	---	---	5,140	62,300	0.077	<0.014	---	2,700	---	1.47	---
10/10/2005	NE, LF	---	---	---	---	---	---	---	54,900	<0.01	---	---	---	---	2.59	---
5/16/2006	NE, LF	---	---	---	---	---	---	---	62,400	<0.01	---	---	---	---	<2.5	---
10/10/2006	NE, LF	---	---	---	---	---	---	---	55,300	<0.025	---	---	---	---	<1	---
5/9/2007	NE, LF	---	---	---	---	---	---	---	63,000	<0.025	---	---	---	---	2.7	---
10/9/2007	NE, LF	---	---	---	---	---	---	---	83,200	<0.025	---	---	---	---	<1	6.34
6/5/2008	NE, LF	---	---	---	---	---	---	---	57,000	0.00218	---	---	---	---	<2	---

PZ-01 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)											
		Potassium	Selenium	Silicon	Silver	Sodium	Specific Conductance [b]	Sulfate	Temperature [c]	Total Dissolved Solids	Total Inorganic Carbon	Total Organic Carbon	Zinc
9/11/1997	NE	44.5 J	0.0568 J	14.5	<0.01	21,800	---	1,110	---	73,400	26.5	3.6 J	0.139 J
9/11/1997	DUP	48.2 J	0.0586 J	17.3	<0.01	23,100	---	1,170	---	79,200	26.6	3.9 J	0.175 J
10/15/1997	NE	50.9	0.0668 J	13.1	<0.01	28,400	---	1,450	---	101,000	26.1	8.1 JREP	<0.05
10/15/1997	DUP	50.8	0.0632 J	13.1	<0.01	28,600	---	1,460	---	103,000	25.1	8.1 JREP	<0.05
11/13/1997	NE	42.2 J	0.0688 J	13.9	<0.01	25,600	---	1,410	---	91,900	25.5	4.6	<0.05 UREP
1/13/1998	NE	45.6 J	0.0762 J	13.8	<0.01	25,300	---	1,430	---	98,300	23.5	4.4	<0.08
1/13/1998	DUP	44.8 J	0.0734 J	14.2	<0.01	25,300	---	1,420	---	97,200	23.8	5.7	<0.08
4/14/1998	NE	39.6	0.0744 J	15	<0.01	22,800	---	1,420	---	80,900	25.2	8.4 J	<0.03
7/21/1998	NE	35.2 J	0.0854 J	15.8	<0.01	21,600	---	1,330	---	79,600	25.2	3.5 J	<0.06
10/13/1998	NE	41.8	0.0777	14.9	<0.01	24,300	---	1,600	---	98,800	22.1	2.2	0.109 J
10/13/1998	DUP	44.4	0.0735	14.6	<0.01	28,100	---	1,630	---	108,800	21.6	4.1	0.193 J
2/8/1999	NE	39.6	0.0918		<0.01	22,000	---	1,420	---	87,800	25.3	5.8	<0.05
8/9/1999	NE	39.7	0.0799		<0.003	23,300	---	1,420	---	107,000	24.2	6.7	0.234
2/7/2000	NE, LF	41.2	0.115	17.2	<0.003	13,100	---	1,440	---	60,200	26.8	6.9	<0.047
10/11/2000	NE, LF	27.2	0.0966	17.2	0.0017 J	12,300	---	1,510	---	54,000	26.2	4.1	<0.091
12/17/2001	NE, LF	32 J	0.0753	19.4	<0.001	12,700	---	1,610	---	62,200	---	---	<0.05
12/5/2002	NE, LF	---	0.0801	---	0.0029 J	---	---	1,790	---	86,700	---	---	---
6/21/2004	NE, LF	---	0.044	---	---	---	---	1,530	---	79,600	---	---	---
11/9/2004	NE, LF	---	0.106	---	---	---	---	6,530	---	85,800	---	---	---
5/17/2005	NE, LF	41.3 J	0.06	21	---	19,000	---	2,640	---	100,500	25	3.5	<0.01
10/10/2005	NE, LF	---	0.043	---	---	---	---	1,950	---	74,800	---	---	---
5/16/2006	NE, LF	---	0.051	---	---	---	---	2,490	---	113,000	---	---	---
10/10/2006	NE, LF	---	<0.05	---	---	---	---	1,390	---	70,200	---	---	---
5/9/2007	NE, LF	---	<0.05	---	---	---	---	2,220	---	107,000	---	---	---
10/9/2007	NE, LF	---	<0.1	---	---	---	113,500	2,820	22.6	99,500	---	---	---
6/5/2008	NE, LF	---	0.667	---	---	---	---	2,100	---	98,000	---	---	---

PZ-02 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)													
		Ammonium	Arsenic	Barium	Boron	Bromide	Cadmium	Calcium	Chloride	Chromium, Total	Iron	Lead	Magnesium	Mercury	Nitrate
7/17/1997	NE	0.0196 J	<0.02	0.268 J	<1	10.4 J	<0.01	2,580	16,700	0.016 J	<0.07	0.0211 J	1,730	<0.001	10.9
9/8/1997	NE	0.81	<0.02	0.47 J	<1	11.5 J	<0.01	3,580	25,100	0.0668 J	7.03	0.0677	2,290	0.0038	7.7
10/14/1997	NE	0.0073 J	<0.02	0.134 J	<1	12.5 J	<0.01	1,750	12,800	<0.01	<0.08	0.0106 J	1,180	<0.001	5
11/14/1997	NE	0.0126 J	<0.02	0.208 J	<1 UMS	11.4 J	<0.01	2,310	21,200	0.039 J	<0.08	<0.01	1,520	0.0011 J	6.5
1/13/1998	NE	0.009 J	<0.02	0.112 J	<1	12.6 J	0.0164 J	1,550	11,800	0.0232 J	0.634 J	<0.01	1,010	<0.001 UMS	6.3
4/14/1998	NE	0.0206	0.0013 J	0.039 J	0.18 J	12.3	<0.0011	858 R	3,950 R	0.0156	<0.012	<0.0011	608 R	0.00044	3.5
4/14/1998	DUP	0.505	<0.02	0.0997 J	<1	12.2 J	<0.01	1,440	3,950 R	0.0197 J	<0.11	<0.01	970	0.0012 J	4.4
7/21/1998	NE	0.514	<0.02	0.166 J	<1	11	<0.01	2,110	14,900	0.0174 JMSREP	0.13 J	<0.01 UREP	1,310	<0.001	4.9 J
10/13/1998	NE	0.0097 J	<0.02	0.0972 J	<1	12.1	<0.01	1,330	9,140	0.0162 J	<0.05	<0.01	841	<0.001	4.21
2/9/1999	NE	0.0468	<0.001	0.0452 J	<1	11.8	<0.01	869	4,470	<0.01	0.0616 J	<0.01	597	<0.0002	3.92
8/10/1999	NE	0.397	<0.005	0.165 J	<1	<15	<0.003	2,030	15,300	0.0094 J	<0.132	0.0022 J	1,230	0.0012 J	6.35 J
8/10/1999	DUP	0.428	<0.005	0.164 J	<1	<15	<0.003	2,090	16,700	0.0091 J	<0.132	<0.002	1,270	0.0023	5.78 J
2/7/2000	NE, LF	<0.005 UMS	<0.002	0.0631 J	<1	10	<0.003	983	6,910	0.0034 J	<0.144	<0.002	639	<0.001	4.32
10/11/2000	NE, LF	0.185 MS	0.0012 J	0.0476 JINT	0.18 J	9.1 J	<0.003	757	4,700	0.0368 JINT	<0.084	0.0044 JINT	504	<0.001	5.41
12/5/2002	NE, LF	0.129	0.0019 J	0.0191 J	0.13 JINT	7.4	0.00052 J	997	1,230	0.0088 J	<0.008	0.00011 J	626	<0.0002	9.68

PZ-02 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)										
		pH [a]	Potassium	Selenium	Silicon	Silver	Sodium	Sulfate	Total Dissolved Solids	Total Inorganic Carbon	Total Organic Carbon	Zinc
7/17/1997	NE	7.1	26.9 J	0.084 J	17.3	<0.01	6,840	997	33,600	52.7	5.7	<0.03
9/8/1997	NE	6.8	35.5 J	0.0802 J	16.9	<0.01	11,500	1,080	47,600	36.4	8	0.0914 J
10/14/1997	NE	7	20.2 J	0.135	17.1	<0.01	4,380	1,350	24,500	46.9	4.9 REP	<0.05
11/14/1997	NE	7	21.8 J	0.118	17.6	<0.01	6,270	1,230	38,000	39.6	6.4	<0.05 UREP
1/13/1998	NE	7.1	21.3 J	0.141	16.3	<0.01	4,560	1,560	23,700	46.3	5.4	<0.08
4/14/1998	NE	7.4	12.3	0.147	18.1	<0.0011	1,360 R	1,900	8,810 R	53.8	5.1 MSREP	0.0136 J
4/14/1998	DUP	7.2	15.4 J	0.148	17.2	<0.01	3,740	1,720	21,500	48.2	7.4 J	<0.03
7/21/1998	NE	7.2	20.3 J	0.142	19.1	<0.01	6,210	1,560	33,400	45.8	<3	<0.06
10/13/1998	NE	7	14.4	0.301 R	18.6	<0.01	3,500	1,680	20,900	45.8	5.5	<0.06
2/9/1999	NE	7.4	10.8	0.161	---	<0.01	1,710	1,700	13,700	48.7	10.6	<0.05
8/10/1999	NE	6.98	20.3	0.124	---	<0.003	6,940	1,190	36,200	43.8	6	<0.046
8/10/1999	DUP	7.2	21.3	0.124	---	<0.003	7,320	1,260	36,800	44	<0.3	<0.046
2/7/2000	NE, LF	7.34	11.6	0.153	20.2	<0.003	<3,840	1,610	14,600	49.4	0.57 J	<0.047
10/11/2000	NE, LF	7.28	10	0.129	19.5	<0.001	1,780	1,700	11,130	51.5	3.4	<0.091
12/5/2002	NE, LF	7.43	13.7 J	0.121	20.4	<0.0001	3,880	1,550	4,260	---	---	<0.05

PZ-03 Analytical Results

Date	Sample Type	Ammonium	Arsenic	Barium	Boron	Bromide	Cadmium	Calcium	Chloride	Chromium, Total	Iron	Lead	Magnesium	Mercury	Nitrate
		Concentration (mg/L unless otherwise noted)													
7/17/1997	NE	0.254	<0.02	0.287 J	<1	43 J	<0.01	4,030	88,200	0.0552 J	0.174 J	0.0224 J	2,850	0.0023	19.6
9/8/1997	NE	2	<0.02	0.303 J	<1	38.9 J	<0.01	3,870	89,600	0.0647 J	4.11	0.0166 J	2,770	0.0023	20.3
9/8/1997	DUP	2.82	<0.02	0.282 J	<1	42.7 J	<0.01	3,800	90,200	0.0382 J	1.82	0.0136 J	2,720	0.0023	20.2
10/14/1997	NE	0.374	<0.02	0.3 J	<1	45.8	<0.01	3,790	91,800	0.0761 J	<0.08	0.0177 J	2,770	0.001 J	20.7
11/13/1997	NE	0.197	<0.02	0.283 J	<1 UMS	41.7 J	<0.01	4,020	91,000	0.143	0.278 J	<0.01	2,790	0.0025	19.8
1/13/1998	NE	0.0963	<0.02	0.294 J	<1	44.1 J	0.0131 J	3,970	93,600	0.0781 J	0.449 J	<0.01	2,720	0.0025 MS	19.7
4/14/1998	NE	0.582	<0.02	0.263 J	<1	45.7 J	<0.01	3,670	100,000	0.0747 J	<0.11	<0.01	2,670	0.0038	19
7/22/1998	NE	1.27	<0.02	0.279 J	<1	38.9	0.0104 J	4,020	97,100	0.208 MSREP	0.215 J	<0.01 UREP	2,750	0.0023	18.7
7/22/1998	DUP	1.33	<0.02	0.277 J	<1	19.7 J	<0.01	3,930	97,700	0.202 MSREP	0.168 J	<0.01 UREP	2,700	0.0023	19.7
10/13/1998	NE	0.198	<0.002	0.254 J	<1	50.6 J	<0.01	3,680	94,900	0.111	<0.05	<0.01	2,520	<0.001	20.4
2/9/1999	NE	0.357	<0.001	0.268 J	<1	46.3 J	<0.01	3,500	91,200	0.0148 J	0.0988 J	<0.01	2,560	0.0014	19.6 J
2/9/1999	DUP	0.308	<0.001	0.268 J	<1	46.5 J	<0.01	3,580	91,500	0.0131 J	<0.05	<0.01	2,580	0.0012	19.1 J
8/10/1999	NE	0.171	<0.005	0.241 J	<1	<60	0.0066 J	3,530	90,800	0.0236 J	<0.132	0.01 J	2,360	0.0017 J	21.5 J
2/8/2000	NE, LF	0.245 MS	<0.002	0.202 J	<1	39 J	<0.003	3,300	94,800	0.0295 J	<0.144	0.0036 J	2,270	0.0023	15.3
10/11/2000	NE, LF	0.177 MS	<0.001	0.155 JINT	0.25 J	26.8 J	<0.003	2,170	48,400	0.0645 JINT	<0.084	0.0059 JINT	1,440	<0.001	14.9
12/17/2001	NE, LF	0.101	<0.003	0.0816 JINT	0.16 JINT	7.5 J	<0.001	1,230	23,500	0.0119 J	<0.008	<0.001	839	<0.0002	16.3
12/9/2002	NE, LF	0.264 MS	0.0014 J	0.0746 J	0.093 JINT	7.2 J	<0.001	933	16,100	0.0141 JINT	<0.014	<0.001	635	<0.001	14.9

Date	Sample Type	Concentration (mg/L unless otherwise noted)										
		pH [a]	Potassium	Selenium	Silicon	Silver	Sodium	Sulfate	Total Dissolved Solids	Total Inorganic Carbon	Total Organic Carbon	Zinc
7/17/1997	NE	6.4	236	0.046 J	12	<0.01	50,100	2,330	166,000	74.4	5.6 J	0.0653 J
9/8/1997	NE	6.5	269	0.0476 J	12.1	<0.01	48,200	2,300	162,000	31.7	5.3 J	0.0533 J
9/8/1997	DUP	6.4	260	0.046 J	11.8	<0.01	47,800	2,320	164,000	32.6	5.8 J	0.0916 J
10/14/1997	NE	6.5	294	0.05 J	11.5	<0.01	50,700	2,570	158,000	32.1	3 J	<0.05
11/13/1997	NE	6.3	296	0.0458 J	11.5	<0.01	51,900	2,460	161,000	29.2	5.2	<0.05 UREP
1/13/1998	NE	6.5	316	0.0472 J	11.3	<0.01	50,300	2,560	162,000	29.8	4.2	<0.08
4/14/1998	NE	6.7	333	0.0454 J	11.4	<0.01	52,200	2,910	162,000	31.6	4.9 J	<0.03
7/22/1998	NE	6.4	356	0.0428 J	11.5	<0.01	52,800	2,790	169,000	34.4	6.5 J	<0.06
7/22/1998	DUP	6.7	345	0.0432 J	11.7	<0.01	52,200	2,790	170,000	31	4.4 J	<0.06
10/13/1998	NE	6.4	337	0.0481	11.4	<0.01	50,900	2,640	169,000	29.1	4	0.149 J
2/9/1999	NE	6.5	363	0.051	---	<0.01	52,800	2,510	167,000	30.8	<0.3	<0.05
2/9/1999	DUP	6.5	368	0.0508	---	<0.01	51,500	2,520	185,000	30.6	<0.3	<0.05
8/10/1999	NE	6.62	371	0.0523	---	0.0031 J	50,100	2,660	174,000	30.2	1	0.317
2/8/2000	NE, LF	7.19	398	0.0597	11.1	<0.003	51,000	2,730	168,000	27	1.4	<0.047
10/11/2000	NE, LF	6.93	212	0.0909	13.1	0.0035 J	26,800	1,840	88,400	36.8	3.6	<0.091
12/17/2001	NE, LF	7.23	95 J	0.102	18.3	<0.001	11,800	1,660	41,800	---	---	<0.05
12/9/2002	NE, LF	7.03	65.2 J	0.123	18.9	0.001	7,890	1,410	29,700	40.3	3.4	<0.01

PZ-04 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)													
		Ammonium	Arsenic	Barium	Boron	Bromide	Cadmium	Calcium	Chloride	Chromium, Total	Iron	Lead	Magnesium	Mercury	Nitrate
7/18/1997	NE	0.0123 J	<0.02	0.207 J	<1	8.5 J	<0.01	2,150	21,800	0.0131 J	<0.07	0.0596	1,260	0.002	22.5
9/8/1997	NE	0.126	<0.02	0.221 J	<1	8.5 J	<0.01	2,220	21,600	0.0215 J	0.529 J	<0.01	1,300	0.0028	19.2
10/14/1997	NE	0.0098 J	<0.02	0.208 J	<1	7.4 J	<0.01	1,990	22,100	0.0162 J	<0.08	<0.01	1,190	<0.001	20.2 J
10/14/1997	DUP	0.0198 J	<0.02	0.221 J	<1	8.8 J	<0.01	2,060	23,600	0.01 J	0.363 J	<0.01	1,230	0.0023	19.5
11/13/1997	NE	0.0318	<0.02	0.222 J	<1 UMS	8.4 J	<0.01	2,150	21,500	0.0543 J	0.104 J	<0.01	1,250	0.002	19.6
1/14/1998	NE	<0.007	<0.02	0.172 J	<1	6.8 J	<0.01	1,660	16,500	0.0161 J	<0.05	<0.01	960	0.0012 J	21.7
1/14/1998	DUP	0.009 J	<0.02	0.181 J	<1	7.4 J	<0.01	1,760	17,700	0.0134 J	<0.05	<0.01	1,000	0.0015 J	20.9
4/15/1998	NE	0.412	<0.02	0.175 J	<1	8.4 J	<0.01	1,980	20,400	0.022 J	0.224 J	<0.01	1,170	0.0022	18.3
7/21/1998	NE	0.955 R	<0.02	0.201 J	<1	8.1 J	<0.01	2,230	21,600	0.0482 JMSREP	0.05 J	<0.01 UREP	1,220	0.0017 J	18
7/21/1998	DUP	0.64	<0.02	0.203 J	<1	8.2 J	<0.01	2,230	22,000	0.04612 JMSREP	0.496 J	<0.01 UREP	1,230	0.0018 J	30.7 R
10/14/1998	NE	0.0013 J	<0.002	0.174 J	<1	10.1 J	<0.01	1,980	23,600	0.0338	<0.05	<0.01	1,110	<0.001	18.3
2/9/1999	NE	0.0408	<0.001	0.204 J	<1	11.9 J	<0.01	2,280	26,800	<0.01	<0.05	<0.01	1,310	0.002	18.4
8/11/1999	NE	0.228	<0.005	0.21 J	<1	<15	<0.003	2,450	28,200	0.0095 J	<0.132	0.0038 J	1,310	0.0025	16.4
2/7/2000	NE	0.0264 MS	0.002 J	0.169 J	<1	9.3 J	<0.003	1,970	27,700	0.011 J	<0.144	<0.002	1,060	<0.001	17.3
10/11/2000	NE	0.161 MS	0.001 J	0.161 JINT	0.15 J	8.4 J	<0.003	1,700	23,500	0.0408 JINT	<0.084	0.0037 JINT	908	<0.001	19.6
12/18/2001	NE	0.112	<0.003	0.151 JINT	0.15 JINT	7.1 J	<0.001	2,110	34,200	0.0134 J	<0.008	<0.001	1,090	0.0016	17.2
12/5/2002	NE	0.606 MS	0.0015 J	0.18 J	0.064 JINT	6.1 J	0.0011 J	2,370	39,300	0.0209 JINT	<0.014	<0.001	1,210	<0.001	16.3

PZ-04 Analytical Results
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Date	Sample Type	Concentration (mg/L unless otherwise noted)										
		pH [a]	Potassium	Selenium	Silicon	Silver	Sodium	Sulfate	Total Dissolved Solids	Total Inorganic Carbon	Total Organic Carbon	Zinc
7/18/1997	NE	7.1	21.2 J	0.0454 J	18.8	<0.01	9,290	980	43,400	59.9	4.9	<0.03
9/8/1997	NE	7	22.3 J	0.057 J	19.2	<0.01	9,740	1,000	40,400	39.9	4.3	<0.03
10/14/1997	NE	7	22.4	0.0542 J	18.5	<0.01	9,170	1,030	38,500	42.2	4.8 REP	<0.05
10/14/1997	DUP	7	23.7 J	0.0556 J	18.7	<0.01	9,470	1,070	42,300	40.2	6.8 REP	<0.05
11/13/1997	NE	6.9	21 J	0.0628 J	19.8	<0.01	9,330	1,030	38,200	42.3	4.1	<0.05 UREP
1/14/1998	NE	7.2	19.2 J	0.053 J	21.9	<0.01	7,170	955	30,500	44.1	3.4	<0.08
1/14/1998	DUP	7.1	20.4	0.0528 J	20.7	<0.01	7,710	970	32,300	43.8	3.9	<0.08
4/15/1998	NE	7	19.8 J	0.0558 J	17.6	<0.01	9,200	1,130	34,200	43.7	<3	<0.03
7/21/1998	NE	7	20.5 J	0.0624 J	20.3	<0.0162	10,600	1,030	42,100	40	<3	<0.06
7/21/1998	DUP	7	23.9 J	0.0604 J	19.4	<0.01	10,500	1,030	41,100	41.3	<3	<0.06
10/14/1998	NE	7.6	23.2	0.0588	19.2	<0.01	10,400	1,110	45,600	30.3	2	0.187 J
2/9/1999	NE	6.9	25.4	0.0602	---	<0.01	12,900	1,100	49,700	41.2	0.31 J	<0.05
8/11/1999	NE	7.28	28.2	0.0634	---	<0.003	14,300	1,070	62,500	39	<0.3	<0.046
2/7/2000	NE	7.3	39.7	0.0627	18.7	<0.003	13,000	1,150	51,400	43	<0.3	<0.047
10/11/2000	NE	7.18	27	0.0481	19.3	<0.001	11,000	1,010	42,050	42.5	<0.3	<0.091
12/18/2001	NE	7.33	39.8 J	0.0431	20.5	<0.001	16,000	1,290	58,600	---	---	<0.05
12/5/2002	NE	7.14	47.5 J	0.0533	20.6	0.0012 J	19,000	1,420	69,000	43.7	1.9	<0.01

PZ-05 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)													
		Ammonium	Arsenic	Barium	Boron	Bromide	Cadmium	Calcium	Chloride	Chromium, Total	Iron	Lead	Magnesium	Mercury	Nitrate
7/18/1997	NE	0.105	<0.02	0.201 J	<1	23.7 J	<0.01	3,740	45,800	0.0328 J	0.618 J	0.0402	2,260	0.0016 J	15.4
7/18/1997	DUP	0.0953	<0.02	0.199 J	<1	25.6 J	<0.01	3,700	48,200	0.0358 J	1.04	0.0158	2,250	0.0017 J	15.5
9/8/1997	NE	0.386	<0.02	0.178 J	<1	26.4 J	<0.01	3,280	52,600	0.0297 J	0.75 J	<0.01	2,030	0.0022	15.6
10/14/1997	NE	0.123 J	<0.02	0.186 J	<1	26 J	<0.01	3,400	54,700	0.0507 J	<0.08	<0.01	2,170	<0.001	16
11/14/1997	NE	0.0749	<0.02	0.173 J	<1 UMS	25.8 J	<0.01	3,370	46,700	0.0885 J	<0.08	<0.01	2,080	0.002	14.9
11/14/1997	DUP	0.0821	<0.02	0.176 J	<1 UMS	26.4 J	<0.01	3,380	48,200	0.0909 J	0.169 J	<0.01	2,100	0.002	15.9
1/14/1998	NE	0.0526	<0.02	0.165 J	<1	46.6 J	<0.01	3,120	43,200	0.0203 J	<0.05	<0.01	1,850	0.0021	14.8
4/15/1998	NE	0.417	<0.02	0.122 J	<1	23.8 J	<0.01	2,810	36,300	0.0356 J	<0.11	<0.01	1,700	0.0026	12.7
4/15/1998	DUP	0.379	<0.02	0.119 J	<1	22.8 J	<0.01	2,830	36,500	0.0301 J	<0.11	0.0177 J	1,720	0.0024	12.6
7/22/1998	NE	0.042	<0.02	0.119 J	<1	18.6 J	<0.01	2,900	33,400	0.102 MSREP	0.106 J	0.0113 JREP	1,680	0.0014 J	13.5
10/14/1998	NE	0.0826	<0.002	0.121 J	<1	25.1 J	<0.01	2,730	37,900	0.0474 J	<0.05	<0.01	1,650	<0.001	13.5
2/10/1999	NE	0.0707	<0.001	0.1 J	<1	18.9 J	<0.01	2,430	24,300	<0.01	<0.05	<0.01	1,390	0.0016	13.1
8/10/1999	NE	0.266	<0.005	0.105 J	<1	<30	0.0033 J	2,580	29,000	0.0093 J	<0.132	0.0044 J	1,480	0.0012 J	15.1 J
2/8/2000	NE, LF	0.0437 MS	<0.002	0.125 J	<1	19.5 J	<0.003	2,920	38,500	0.016 J	<0.144	0.0021 J	1,700	<0.001	14.9
2/8/2000	DUP, LF	0.035 MS	<0.002	0.121 J	<1	20.6 J	<0.003	2,920	40,700	0.0114 J	<0.144	<0.002	1,700	<0.001	15.3
10/10/2000	NE, LF	0.172 MS	<0.001	0.138 JINT	<0.073	22.8 J	<0.003	3,180	48,700	0.0654 JINT	<0.084	0.0057 JINT	1,820	<0.001	14
12/18/2001	NE, LF	0.0578	<0.003	0.0977 JINT	0.1 JINT	23.1 J	<0.001	3,070	37,500	0.0117 J	<0.008	0.0018 J	1,760	0.0014	14.4
12/5/2002	NE, LF	---	0.00095 J	0.0882 J	---	15.2 J	0.0014 J	---	30,900	0.0155 JINT	---	<0.001	---	<0.001	13.2
6/21/2004	NE, LF	---	---	---	---	---	---	---	28,800	<0.005	---	---	---	---	20.7
11/9/2004	NE, LF	---	---	---	---	---	---	---	47,800	<0.01	---	---	---	---	<2.5
5/17/2005	NE, LF	---	---	---	---	---	---	---	46,000	0.093	---	---	---	---	2.96
10/10/2005	NE, LF	---	---	---	---	---	---	---	14,000	<0.01	---	---	---	---	5.14
5/16/2006	NE, LF	---	---	---	---	---	---	---	18,300	<0.01	---	---	---	---	2.56
10/10/2006	NE, LF	---	---	---	---	---	---	---	28,800	<0.025	---	---	---	---	5.04
5/9/2007	NE, LF	---	---	---	---	---	---	---	17,300	<0.025	---	---	---	---	4.6
10/9/2007	NE, LF	---	---	---	---	---	---	---	19,400	<0.005	---	---	---	---	<1
6/5/2008	NE, LF	---	---	---	---	---	---	---	19,000	0.00317	---	---	---	---	5.7

PZ-05 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)												
		pH [a]	Potassium	Selenium	Silicon	Silver	Sodium	Specific Conductance [b]	Sulfate	Temperature [c]	Total Dissolved Solids	Total Inorganic Carbon	Total Organic Carbon	Zinc
7/18/1997	NE	6.9	93.9	0.0676 J	17.9	<0.01	22,100	---	1,340	---	84,700	29.3	3.9 J	<0.03
7/18/1997	DUP	6.9	98.4	0.071 J	18.7	<0.01	22,600	---	1,400	---	91,800	29.8	3.4 J	<0.03
9/8/1997	NE	6.7	105	0.0688 J	16.1	<0.01	22,200	---	1,510	---	95,400	31.1	4 J	0.0583 J
10/14/1997	NE	6.8	127	0.066 J	15.7	<0.01	25,800	---	1,630	---	99,300	30.3	3.1 J	0.0591 J
11/14/1997	NE	6.7	123	0.067 J	16.3	<0.01	25,200	---	1,440	---	84,200	29.3	5.2	0.0685 JREP
11/14/1997	DUP	6.6	130	0.068 J	15.9	<0.01	26,500	---	1,480	---	87,300	30.4	4.4	<0.05 UREP
1/14/1998	NE	6.8	112	0.0766 J	16.4	<0.01	20,600	---	1,390	---	79,000	29.4	3.2	<0.08
4/15/1998	NE	6.7	75.5	0.0806 J	18.1	<0.01	15,600	---	1,370	---	53,400	30.6	12.7 R	<0.03
4/15/1998	DUP	6.7	75.3	0.083 J	17.6	<0.01	15,500	---	1,370	---	53,100	31	9.4 J	<0.03
7/22/1998	NE	6.7	76.3	0.0824 J	18.3	<0.01	15,100	---	1,360	---	60,100	31	<3	<0.06
10/14/1998	NE	7.2	98.5	0.0922	17.9	<0.01	17,000	---	1,450	---	68,100	28.7	3.4	<0.06
2/10/1999	NE	6.9	67.1	0.102	---	<0.01	11,700	---	1,120	---	48,800	31	<0.3	<0.05
8/10/1999	NE	6.92	84.6	0.0944	---	<0.003	13,600	---	1,310	---	64,700	30.9	<0.3	0.0507 J
2/8/2000	NE, LF	7	91.7	0.0966	16.6	<0.003	19,200	---	1,360	---	71,800	30.4	<0.3	<0.047
2/8/2000	DUP, LF	7.15	91.4	0.0978	16.8	<0.003	19,100	---	1,450	---	73,800	30	0.8 J	<0.047
10/10/2000	NE, LF	6.85	106	0.0716	15.3	0.0052 J	23,700	---	1,530	---	84,800	29.3	1.8 J	<0.091
12/18/2001	NE, LF	7.04	68.8 J	0.069	18.7	<0.001	16,200	---	1,510	---	65,200	---	---	<0.05
12/5/2002	NE, LF	6.88	---	0.0839	---	<0.001	---	---	1,550	---	55,200	---	---	---
6/21/2004	NE, LF	---	---	0.067	---	---	---	---	1,340	---	55,200	---	---	---
11/9/2004	NE, LF	---	---	0.094	---	---	---	---	1,820	---	86,000	---	---	---
5/17/2005	NE, LF	---	---	0.067	---	---	---	---	3,260	---	65,400	---	---	---
10/10/2005	NE, LF	---	---	0.062	---	---	---	---	769	---	32,800	---	---	---
5/16/2006	NE, LF	---	---	0.071	---	---	---	---	1,520	---	32,600	---	---	---
10/10/2006	NE, LF	---	---	<0.05	---	---	---	---	1,330	---	47,400	---	---	---
5/9/2007	NE, LF	---	---	<0.05	---	---	---	---	1,640	---	32,400	---	---	---
10/9/2007	NE, LF	6.8	---	0.071	---	---	---	37,500	1,880	21.2	28,700	---	---	---
6/5/2008	NE, LF	---	---	0.0801	---	---	---	---	1,500	---	33,000	---	---	---

PZ-06 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)													
		Ammonium	Arsenic	Barium	Boron	Bromide	Cadmium	Calcium	Chloride	Chromium, Total	Iron	Lead	Magnesium	Mercury	Nitrate
7/17/1997	NE	0.0196 J	<0.02	0.103 J	<1	12.7 J	<0.01	2,190	14,700	0.0185 J	0.112 J	0.0496	1,250	<0.001	19.8
7/17/1997	DUP	0.0245	<0.02	0.107 J	<1	12.7 J	<0.01	2,160	14,700	0.0137 J	0.145 J	0.0161 J	1,230	<0.001	19.8
8/26/1997	NE	0.107	<0.02	0.107 J	<1	12 J	<0.01	2,100	13,600	<0.01	<0.07	<0.01	1,180	<0.001	20.2
10/13/1997	NE	0.0173 J	<0.02	0.102 J	<1	13.1 J	<0.01	2,070	15,100	0.0242 J	<0.08	<0.01	1,190	0.001 J	20.8
11/13/1997	NE	0.0126 J	<0.02	0.102 J	<1 UMS	12.5 J	<0.01	2,230	15,300	0.0346 J	<0.08	<0.01	1,270	<0.001	20.9
11/13/1997	DUP	0.0102 J	<0.02	0.106 J	<1 UMS	12.6 J	<0.01	2,250	15,600	0.0338 J	<0.08	<0.01	1,270	<0.001	21.3
1/12/1998	NE	<0.007	<0.02	0.113 J	<1	12.8 J	<0.01	2,290	16,300	0.0164 J	<0.05	<0.01	1,290	<0.001 UMS	21.4
4/13/1998	NE	0.347	<0.02	0.107 J	<1	14.6 J	<0.01	2,260	19,300	0.0298 J	0.114 J	<0.01	1,310	0.0021	21
7/20/1998	NE	0.608	<0.02	0.135 J	<1	11.8	<0.01	2,460	18,300	0.0498 JMSREP	0.0582 J	<0.01 UREP	1,380	<0.001	20.9
7/20/1998	DUP	0.577	<0.02	0.126	<1	12.4 REP	<0.01	2,490	18,500	0.0475	0.357 R	<0.01 UREP	1,380	<0.001	20.6
10/12/1998	NE	0.0013 J	<0.002	0.0982 J	<1	11.5 J	<0.01	2,220	18,400	0.0284 J	<0.05	<0.01	1,250	<0.001	21.6
2/8/1999	NE	0.0428	<0.001	0.105 J	<1	15 J	<0.01	2,420	19,900	<0.01	<0.05	<0.01	1,400	0.00067	22
8/9/1999	NE	0.257	0.0062 J	0.106 J	<1	<15	<0.003	2,750	21,400	0.0112 J	<0.132	0.0036 J	1,510	0.0033	23
2/7/2000	NE, LF	0.0235 MS	<0.002	0.104 J	<1	14.4 J	<0.003	2,720	27,000	0.0076 J	<0.144	<0.002	1,530	<0.001	23.5
10/10/2000	NE, LF	0.153 MS	<0.001	0.12 JINT	0.15 J	14.3 J	<0.003	2,510	31,300	0.0461 JINT	<0.084	0.0046 JINT	1,420	<0.001	27.6
12/18/2001	NE, LF	0.0345	<0.003	0.0931 JINT	0.11 JINT	16.6 J	<0.001	2,240	36,200	0.0156 J	<0.008	0.0048 J	1,330	0.00021 J	25.2
12/5/2002	NE, LF	0.585 MS	0.00088 J	0.108 J	0.063 JINT	5.2 J	0.0018 J	2,160	47,400	0.0191 JINT	<0.014	<0.001	1,340	<0.001	25.5
6/21/2004	NE, LF	---	---	---	---	---	---	---	70,500	<0.005	---	---	---	---	21.2
11/9/2004	NE, LF	---	---	---	---	---	---	---	75,400	<0.01	---	---	---	---	4.89
5/17/2005	NE, LF	0.599 MS	---	---	0.034 JINT	---	---	2,150	109,000	0.054	<0.014	---	1,340	---	4.25
10/10/2005	NE, LF	---	---	---	---	---	---	---	83,800	<0.01	---	---	---	---	20
5/16/2006	NE, LF	---	---	---	---	---	---	---	68,800	<0.01	---	---	---	---	7.69
10/10/2006	NE, LF	---	---	---	---	---	---	---	79,800	<0.025	---	---	---	---	252
5/9/2007	NE, LF	---	---	---	---	---	---	---	73,500	<0.025	---	---	---	---	6.65
10/9/2007	NE, LF	---	---	---	---	---	---	---	81,000	<0.025	---	---	---	---	<1
6/5/2008	NE, LF	---	---	---	---	---	---	---	47,000	0.00259	---	---	---	---	6.1

PZ-06 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)												
		pH [a]	Potassium	Selenium	Silicon	Silver	Sodium	Specific Conductance [b]	Sulfate	Temperature [c]	Total Dissolved Solids	Total Inorganic Carbon	Total Organic Carbon	Zinc
7/17/1997	NE	6.9	23.1 J	0.0764 J	23.3	<0.01	5,320	---	1,000	---	30,100	43.4	3.3	<0.03
7/17/1997	DUP	6.9	21.9 J	0.0744 J	21.8	0.0413 J	5,280	---	1,000	---	29,900	43.3	4	<0.03
8/26/1997	NE	6.8	20.3 J	0.0794 J	21.1	<0.01	4,440	---	1,030	---	25,600	43.9	8.4	0.0423 J
10/13/1997	NE	7.2	25.4 J	0.0736 J	20.4	<0.01	5,220	---	1,040	---	27,700	41.6	5.7	<0.05
11/13/1997	NE	6.8	25.8 J	0.0662 J	21.3	<0.01	5,710	---	1,040	---	28,100	34.8	5.9	0.212 REP
11/13/1997	DUP	6.8	25.2 J	0.0692 J	21	<0.01	5,860	---	1,050	---	28,800	41.9	6.5	0.279 REP
1/12/1998	NE	6.9	28.2 J	0.072 J	20.4	<0.01	6,110	---	1,090	---	30,800	40.7	4.6	<0.08
4/13/1998	NE	7	30.5 J	0.0658 J	20.4	<0.01	7,350	---	1,250	---	31,300	44.1	6.6 J	0.0423 J
7/20/1998	NE	6.8	32.6 J	0.0654 J	21	0.311 R	8,080	---	1,130	---	36,600	42.2	<3	<0.06
7/20/1998	DUP	6.8	32.6	0.0668	21.1	<0.01	8,150 J	---	1,140	---	36,800	41.9	3	0.0703
10/12/1998	NE	6.8	37	0.0672	20.2	<0.01	7,670	---	1,080	---	39,400	38.4	6.2	<0.06
2/8/1999	NE	6.8	38.7	0.0727	---	<0.01	8,160	---	1,240	---	38,600	41.4	3.2	<0.05
8/9/1999	NE	6.97	41.4	0.078	---	<0.003	9,680	---	1,190	---	50,200	34.1	6	<0.046
2/7/2000	NE, LF	7.08	58.8	0.0894	18.9	<0.003	11,700	---	1,530	---	51,400	39.6	<0.3	<0.047
10/10/2000	NE, LF	6.89	65.3	0.0662	18.3	0.004 J	15,100	---	1,660	---	55,100	42.2	2.4	<0.091
12/18/2001	NE, LF	6.94	170 J	0.0607	20.3	0.0024 J	17,700	---	2,040	---	65,700	---	---	<0.05
12/5/2002	NE, LF	7.02	344 J	0.0589	20.4	0.0012 J	24,600	---	2,610	---	86,400	43.6	2.1	<0.01
6/21/2004	NE, LF	---	---	0.17	---	---	---	---	2,860	---	134,000	---	---	---
11/9/2004	NE, LF	---	---	0.06	---	---	---	---	13,000	---	113,000	---	---	---
5/17/2005	NE, LF	---	349 J	0.05	20.2	---	24,600	---	3,610	---	160,500	44.3	2.3	<0.01
10/10/2005	NE, LF	---	---	0.021	---	---	---	---	2,850	---	106,000	---	---	---
5/16/2006	NE, LF	---	---	<0.01	---	---	---	---	3,050	---	115,000	---	---	---
10/10/2006	NE, LF	---	---	<0.05	---	---	---	---	2,790	---	134,000	---	---	---
5/9/2007	NE, LF	---	---	<0.05	---	---	---	---	2,840	---	122,500	---	---	---
10/9/2007	NE, LF	6.3	---	<0.1	---	---	---	128,000	3,080	21.4	105,000	---	---	---
6/5/2008	NE, LF	---	---	0.0412	---	---	---	---	2,100	---	81,000	---	---	---

PZ-07 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)														
		Ammonium	Arsenic	Barium	Boron	Bromide	Cadmium	Calcium	Chloride	Chromium, Total	Iron	Lead	Magnesium	Mercury	Nitrate	pH [a]
7/18/1997	NE	0.0245	<0.02	0.0746 J	<1	14.3 J	<0.01	2,320	9,170	0.0161 J	0.502 J	0.0118 J	1,240	<0.001	19	7
7/18/1997	DUP	0.0123 J	<0.02	0.0743 J	<1	12.8 J	<0.01	2,300	9,080	0.0196 J	0.371 J	0.0125 J	1,220	<0.001	19	7
9/9/1997	NE	0.112	<0.02	0.0821 J	<1	13.3 J	<0.01	2,400	10,400	0.0192 J	0.484 J	<0.01	1,290	<0.001	18.8	6.8
9/9/1997	DUP	0.222	<0.02	0.0791 J	<1	13.8 J	<0.01	2,430	10,300	0.0224 J	0.347 J	<0.01	1,320	<0.001	18.7	6.7
10/15/1997	NE	0.0148 J	<0.02	0.0866 J	<1	15.7 J	<0.01	2,600	11,700	0.013 J	<0.08	<0.01	1,400	<0.001	20.3	6.8
10/15/1997	DUP	0.0123 J	<0.02	0.0957 J	<1	16 J	<0.01	2,620	11,900	0.0126 J	<0.08	<0.01	1,370	<0.001	20	6.7
11/17/1997	NE	0.0198 J	<0.02	0.0935 J	<1 UMS	14.9 J	<0.01	2,790	12,300	0.0297 J	<0.08	<0.01	1,440	<0.001	20.7	6.7
1/14/1998	NE	<0.007	<0.02	0.11 J	<1	15.5 J	<0.01	2,850	13,000	0.0108 J	<0.05	<0.01	1,420	0.001 J	21.1	6.9
4/15/1998	NE	0.386	<0.02	0.0858 J	<1	15.7 J	<0.01	2,600	12,500	0.023 J	<0.11	<0.01	1,300	<0.001	19.1	6.7
7/22/1998	NE	0.64	<0.02	0.0928 J	<1	15 J	<0.01	2,760	13,100	0.0658 JMSREP	0.136 J	0.0205 JREP	1,380	<0.001	21.8	6.8
10/14/1998	NE	0.0125 J	<0.002	0.0845 J	<1	17.3	<0.01	2,770	15,700	0.0365 J	<0.05	<0.01	1,420	<0.001	18.6	7
10/14/1998	DUP	0.0125 J	<0.002	0.0875 J	<1	17.2	<0.01	2,810	15,800	0.023 J	<0.05	<0.01	1,430	<0.001	18.5	6.9
2/10/1999	NE	0.0488	<0.001	0.0823 J	<1	17.6 J	<0.01	3,500	19,700	<0.01	<0.05	<0.01	1,740	0.0008	22.5	6.7
8/11/1999	NE	0.244	<0.005	0.0822 J	<1	16.1 J	<0.003	3,350	21,500	0.0099 J	<0.132	0.0031 J	1,770	0.0011 J	19.8	6.91
8/11/1999	DUP	0.216	<0.005	0.119 J	<1	18 J	0.0031 J	4,090	29,400	0.011 J	<0.132	0.0036 J	2,210	0.002 J	20.5	6.87
2/9/2000	NE, LF	0.0868 MS	<0.002	0.0668 J	<1	17.6 J	<0.003	3,230	26,400	0.0092 J	<0.144	<0.002	1,760	<0.001	19.3	7
2/9/2000	DUP, LF	0.035 MS	<0.002	0.0653 J	<1	16 J	<0.003	3,280	24,500	0.0082 J	<0.144	<0.002	1,800	<0.001	20.4	6.93
10/16/2000	NE, LF	0.163 MS	<0.001	0.0704 JINT	0.08 J	16.8 J	<0.003	3,110	25,600	0.0377 JINT	<0.084	0.0037 JINT	1,710	<0.001	20.3	6.86
12/19/2001	NE, LF	0.0466	<0.003	0.0598 JINT	0.064 JINT	18 J	<0.001	3,340	38,900	0.0126 J	<0.008	<0.001	2,010	0.0016	20.2	6.75
12/5/2002	NE, LF	0.378 MS	0.001 J	0.0605 J	0.054 JINT	9.1 J	0.0017 J	3,020	33,200	0.0202 JINT	<0.014	<0.001	1,760	<0.001	19.9	6.7
6/21/2004	NE, LF	---	---	---	---	---	---	---	53,000	<0.005	---	---	---	---	20.7	---
11/8/2004	NE, LF	---	---	---	---	---	---	---	43,600	<0.01	---	---	---	---	2.89	---
5/16/2005	NE, LF	---	---	---	---	---	---	---	42,100	0.082	---	---	---	---	4.02	---
10/10/2005	NE, LF	---	---	---	---	---	---	---	61,000	<0.01	---	---	---	---	6.37	---
5/15/2006	NE, LF	---	---	---	---	---	---	---	54,100	<0.01	---	---	---	---	<5.3	---
10/9/2006	NE, LF	0.399 MS	---	---	0.03 JINT	---	---	3,030	66,800	<0.005	<0.014	---	1,790	---	<1	---
5/7/2007	NE, LF	---	---	---	---	---	---	---	64,800	0.02	---	---	---	---	5.15	---
10/8/2007	NE, LF	---	---	---	---	---	---	---	45,600	<0.005	---	---	---	---	<1	6.44
6/4/2008	NE, LF	---	---	---	---	---	---	---	49,000	0.00257	---	---	---	---	5	---

PZ-07 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)											
		Potassium	Selenium	Silicon	Silver	Sodium	Specific Conductance [b]	Sulfate	Temperature [c]	Total Dissolved Solids	Total Inorganic Carbon	Total Organic Carbon	Zinc
7/18/1997	NE	14.7 J	0.115	23.1	<0.01	1,950	---	1,340	---	20,100	43.6	5.4	<0.03
7/18/1997	DUP	15.9 J	0.112	22.9	<0.01	1,920	---	1,330	---	20,100	43.4	4.5	0.0754 J
9/9/1997	NE	15.5 J	0.108	21.4	<0.01	2,200	---	1,300	---	21,700	39.2	6.2	<0.03
9/9/1997	DUP	14.5 J	0.114	21.2	<0.01	2,210	---	1,300	---	22,700	40.5	7.1	<0.03
10/15/1997	NE	17.9 J	0.111	20.5	<0.01	2,600	---	1,450	---	23,100	39.6	11.2 REP	0.326
10/15/1997	DUP	18.3 J	0.116	20.8	<0.01	2,530	---	1,510	---	24,200	41.2	10.3 REP	<0.05
11/17/1997	NE	16.8 J	0.108	20.6	<0.01	2,890	---	1,460	---	24,200	39.2	7.4	<0.05 UREP
1/14/1998	NE	18.7 J	0.116	20.3	<0.01	3,100	---	1,530	---	25,400	42.1	5.3	<0.08
4/15/1998	NE	14.7 J	0.113	21.2	<0.01	3,230	---	1,660	---	20,700	47.4	14.9	<0.03
7/22/1998	NE	16.8 J	0.108	20.1	<0.01	3,470	---	1,590	---	26,340	43.5	7.1 J	<0.06
10/14/1998	NE	17.5	0.124	20.8	<0.01	4,410	---	1,690	---	31,400	41.1	4.8	0.219 R
10/14/1998	DUP	17.8	0.119	20.8	<0.01	4,470	---	1,710	---	31,250	42.7	4.5	0.0893 J
2/10/1999	NE	24.3	0.108	---	<0.01	6,270	---	1,580	---	40,100	40.7	<0.3	<0.05
8/11/1999	NE	23.6	0.106	---	<0.003	8,030	---	1,450	---	49,800	40.1	7.5	<0.046
8/11/1999	DUP	30	0.11	---	<0.003	11,300	---	1,540	---	66,400	37	<0.3	<0.046
2/9/2000	NE, LF	33.4	0.13	19.3	<0.003	9,590	---	1,750	---	47,700	39	0.76 J	<0.047
2/9/2000	DUP, LF	33.1	0.128	19.1	<0.003	9,790	---	1,600	---	48,100	39.2	0.38 J	<0.047
10/16/2000	NE, LF	33.8	0.0981	19.5	0.001 J	9,290	---	1,710	---	48,000	33.9	2.7	<0.091
12/19/2001	NE, LF	61 J	0.0916	20	<0.001	17,000	---	2,180	---	70,200	---	---	<0.05
12/5/2002	NE, LF	57.8 J	0.0908	22.2	0.0011 J	13,600	---	2,040	---	61,000	40.4	6.2	<0.01
6/21/2004	NE, LF	---	0.041	---	---	---	---	2,620	---	109,000	---	---	---
11/8/2004	NE, LF	---	0.088	---	---	---	---	7,460	---	80,400	---	---	---
5/16/2005	NE, LF	---	0.094	---	---	---	---	2,530	---	65,900	---	---	---
10/10/2005	NE, LF	---	0.047	---	---	---	---	2,770	---	88,000	---	---	---
5/15/2006	NE, LF	---	0.068	---	---	---	---	3,190	---	139,000	---	---	---
10/9/2006	NE, LF	59 J	<0.01	22.2		13,700	---	2,890	---	81,500	39.5	6	<0.01
5/7/2007	NE, LF	---	<0.02	---	---	---	---	3,190	---	119,000	---	---	---
10/8/2007	NE, LF	---	0.064	---	---	---	78,700	2,660	22.2	65,000	---	---	---
6/4/2008	NE, LF	---	0.0635	---	---	---	---	2,300	---	86,000	---	---	---

PZ-08 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)												
		Alkalinity, Bicarbonate	Alkalinity, Carbonate	Alkalinity, Hydroxide	Alkalinity, Total	Arsenic, Dissolved	Barium, Dissolved	Cadmium, Dissolved	Calcium, Dissolved	Chloride	Chromium, Total	Fluoride	Lead, Dissolved	Magnesium, Dissolved
10/15/2007	NE, BLR	150	<1	<1	150	<0.01	0.251	<0.001	1,530	7,440	<0.005	<1	<0.01	1,260
6/6/2008	NE, LF	---	---	---	---	---	---	---	---	11,000	<0.001	---	---	---

PZ-08 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)									
		Mercury, Dissolved	Nitrate	pH [a]	Potassium, Dissolved	Selenium	Silver, Dissolved	Sodium, Dissolved	Specific Conductance [b]	Sulfate	Total Dissolved Solids
10/15/2007	NE, BLR	<0.0002	0.677	7.26	17.2	0.039	<0.002	842	18,100	500	15,000
6/6/2008	NE, LF	---	1.8	---	---	0.0655	---	---	---	630	16,000

PZ-09 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)													
		Ammonium	Arsenic	Barium	Boron	Bromide	Cadmium	Calcium	Chloride	Chromium, Total	Iron	Lead	Magnesium	Mercury	Nitrate
7/22/1997	NE	0.11	<0.02	0.31 J	<1	62.2 J	<0.01	4,340	61,200	0.0495 J	1.83	0.0173 J	3,650	0.0013 J	18.3
7/22/1997	DUP	0.088	<0.02	0.34 J	<1	63.7 J	<0.01	4,360	62,200	0.0755 J	4.15	0.0154 J	3,660	0.0017 J	18.4
9/10/1997	NE	1.99	<0.02	0.255 J	<1	60.3 J	<0.01	4,160	61,900	0.0465 J	2.85	0.0152 J	3,560	0.0014 J	20.3
10/15/1997	NE	0.098 J	<0.02	0.258 J	<1	62.6 J	<0.01	4,130	64,400	0.0391 J	0.153 J	<0.01	3,630	<0.001	18.9
10/15/1997	DUP	0.324	<0.02	0.294 J	<1	65.6 J	<0.01	4,130	65,300	0.0587 J	0.501 J	<0.01	3,650	<0.0017	19.1
11/17/1997	NE	0.0462	<0.02	0.311 J	<1 UMS	62.6 J	<0.01	4,280	64,300	0.107	0.219 J	<0.01	3,590	0.0026	18.1
1/15/1998	NE	0.0136 J	<0.02	0.291 J	<1	63.2 J	<0.01	4,190	62,600	0.021 J	<0.05	<0.01	3,470	0.002	18.5
4/16/1998	NE	0.458	<0.02	0.264 J	<1	55.5	<0.01	3,850	55,400	0.0464 J	<0.11	0.017 J	3,440	0.003	18
7/23/1998	NE	1.11	<0.02	0.29 J	<1	54.8	<0.01	3,990	62,300	0.141 MSREP	0.171 J	0.0136 JREP	3,490	0.0022	18.5
10/15/1998	NE	0.0181 J	<0.002	0.278 J	<1	60.4 J	<0.01	3,750	57,600	0.0805 J	<0.05	<0.01	3,320	0.0014 J	16.7
2/11/1999	NE	0.0747	<0.001	0.187 J	<1	56.7	<0.01	3,860	56,900	0.0181 J	0.148 J	<0.01	3,390	0.0009	17.5 J
8/12/1999	NE	0.12	0.0011 J	0.256	0.19 J	59.6 J	0.004 J	3,910	64,300	0.0087 J	<0.0132	0.0044	3,410	0.0023	17 J
2/24/2000	NE, LF	0.0983 MS	<0.002	0.213 J	<1	53.6 J	<0.003	3,860	66,500	0.0169 J	<0.144	0.0021 J	3,450	0.0032	15.4
10/16/2000	NE, LF	0.163 MS	<0.001	0.18 JINT	0.1 J	47.3 J	0.0031 J	3,890	70,100	0.0476 JINT	<0.084	0.0044 JINT	3,530	0.001 J	16.3
12/19/2001	NE, LF	0.267	<0.003	0.185 JINT	0.17 JINT	57.1	<0.001	3,550	72,400	0.0181 J	49.2	<0.001	3,550	0.00079	14.4
12/10/2002	NE, LF	0.159 MS	<0.0005	0.21 J	0.082 JINT	35 J	0.005 J	3,250	73,800	0.0219 JINT	<0.014	0.004 J	3,360	0.0027	14
6/21/2004	NE, LF	---	---	---	---	---	---	---	58,100	<0.005	---	---	---	---	20.8
11/9/2004	NE, LF	---	---	---	---	---	---	---	92,400	<0.01	---	---	---	---	1.4
5/17/2005	NE, LF	---	---	---	---	---	---	---	182,000	0.071	---	---	---	---	2.82
10/11/2005	NE, LF	---	---	---	---	---	---	---	85,500	<0.01	---	---	---	---	<20
5/16/2006	NE, LF	---	---	---	---	---	---	---	84,700	<0.01	---	---	---	---	3.01
10/10/2006	NE, LF	---	---	---	---	---	---	---	102,000	<0.025	---	---	---	---	<20
5/9/2007	NE, LF	---	---	---	---	---	---	---	89,600	<0.025	---	---	---	---	3.28
10/9/2007	NE, LF	---	---	---	---	---	---	---	116,000	<0.005	---	---	---	---	<20
6/5/2008	NE, LF	---	---	---	---	---	---	---	87,000	0.00492	---	---	---	---	2.2

PZ-09 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)												
		pH [a]	Potassium	Selenium	Silicon	Silver	Sodium	Specific Conductance [b]	Sulfate	Temperature [c]	Total Dissolved Solids	Total Inorganic Carbon	Total Organic Carbon	Zinc
7/22/1997	NE	6.7	140	0.0572 J	16.2	<0.01	29,300	---	2,250	---	117,000	41.4	5.1 J	0.0324 J
7/22/1997	DUP	6.7	145	0.0582 J	19.5	<0.01	29,100	---	2,280	---	118,000	40.6	6.1 J	0.059 J
9/10/1997	NE	6.6	139	0.0522 J	15	<0.01	28,200	---	2,260	---	110,000	37.9	10.1 J	0.0627 J
10/15/1997	NE	6.6	146	0.0516 J	11.6	<0.01	29,900	---	2,420	---	114,000	43	6.2 J	<0.05
10/15/1997	DUP	6.5	153	0.052 J	12.5	<0.01	30,600	---	2,460	---	117,000	42.8	5.7 J	<0.05
11/17/1997	NE	6.4	165	0.0552 J	12.7	<0.01	30,800	---	2,460	---	93,900	40.5	5.7	0.0515 JREP
1/15/1998	NE	6.7	176	0.0556 J	12.5	<0.01	28,800	---	2,470	---	113,000	40.4	3.6	<0.08
4/16/1998	NE	6.4	189	0.052 J	12.7	<0.01	29,300	---	2,840	---	95,700	45.4	8.8 J	<0.03
7/23/1998	NE	6.8	233	0.0498 J	13.5	<0.01	30,200	---	2,850	---	115,000	41.8	<3	<0.06
10/15/1998	NE	6.8	260	0.0564	13.2	<0.01	29,600	---	2,710	---	123,000	43.1	4.4	0.179 J
2/11/1999	NE	6.7	205	0.0547	---	<0.01	25,000	---	2,570	---	104,000	42.3	4.6	<0.05
8/12/1999	NE	6.56	316	0.0538	---	0.0031 J	31,200	---	2,770	---	132,000	43.3	3.6 REP	0.027
2/24/2000	NE, LF	7.04	308	0.0615	11.8	<0.003	31,000	---	3,000	---	118,000	24.9	0.72 J	<0.047
10/16/2000	NE, LF	6.67	367	0.0497	11.3	0.004 J	32,700	---	3,090	---	128,400	39.9	1.3 J	<0.091
12/19/2001	NE, LF	5.99	499 J	0.0516	10.6	<0.001	36,100	---	3,470	---	134,000	---	---	<0.05
12/10/2002	NE, LF	6.49	523	0.0466	14.8	0.0033 J	34,800	---	3,560	---	135,000	41.4	1.5	<0.01
6/21/2004	NE, LF	---	---	<0.01	---	---	---	---	2,220	---	123,000	---	---	---
11/9/2004	NE, LF	---	---	0.066	---	---	---	---	14,500	---	144,000	---	---	---
5/17/2005	NE, LF	---	---	0.05	---	---	---	---	5,090	---	164,000	---	---	---
10/11/2005	NE, LF	---	---	0.022	---	---	---	---	3,930	---	107,000	---	---	---
5/16/2006	NE, LF	---	---	0.023	---	---	---	---	4,350	---	153,000	---	---	---
10/10/2006	NE, LF	---	---	<0.05	---	---	---	---	3,370	---	135,000	---	---	---
5/9/2007	NE, LF	---	---	<0.05	---	---	---	---	4,320	---	164,000	---	---	---
10/9/2007	NE, LF	6.22	---	<0.02	---	---	---	155,000	4,720	20	144,000	---	---	---
6/5/2008	NE, LF	---	---	0.0351	---	---	---	---	4,400	---	150,000	---	---	---

PZ-10 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)													
		Ammonium	Arsenic	Barium	Boron	Bromide	Cadmium	Calcium	Chloride	Chromium, Total	Iron	Lead	Magnesium	Mercury	Nitrate	pH [a]
7/21/1997	NE	<0.007	0.0024 J	0.138 J	0.26 J	2.8	<0.0011	338	650	0.009 J	4.7	0.0039	230	<0.0002	31.8	7.3
7/21/1997	DUP	<0.007	0.002 J	0.118 J	0.25 J	3	<0.0011	344	670	0.008 J	3.91	0.0038	235	<0.0002	31.5	7.3
9/10/1997	NE	0.0335	0.002 J	0.0659 J	0.27 J	3.2	<0.0011	302	647	0.0035 J	0.609	<0.0011	201	<0.0002	44.2	7.2
9/10/1997	DUP	0.028	0.0019 J	0.0695 J	0.25 J	3.3	<0.0011	331	663	0.0028 J	0.137	0.002 J	226	<0.0002	37.2	7.2
10/16/1997	NE	0.0073 J	0.0019 J	0.0621 J	0.27 J	3.3 J	<0.0011	318	624	0.0016 J	0.2	0.0015 J	219	<0.0002	43.3	7.2
11/18/1997	NE	0.0102 J	0.0018 J	0.0587 J	0.28 J	2.8	<0.0011	309	588	0.0021 J	0.0174 J	<0.0011	205	<0.0002	46.6	7.2
11/18/1997	DUP	0.0078 J	0.0018 J	0.0585 J	0.28 J	2.9	<0.0011	305	583	0.0018 J	<0.0089	<0.0011	203	<0.0002	45.8	7.2
1/15/1998	NE	<0.007	0.0018 J	0.0575 J	0.26 J	2.6	<0.0011	282	525	0.0046 J	<0.0056	<0.0011	184	<0.0002	46.1	7.4
4/16/1998	NE	0.0742	0.0018 J	0.0562 J	0.25 J	3.2	<0.0011	299	604	0.0043 J	<0.0122	<0.0011	205	<0.0002	30.2	7.1
7/23/1998	NE	0.0766	0.002 J	0.0622 J	0.28 J	2.8 J	<0.0011	302	543	0.005 J	0.0194 J	<0.0011	208	0.00025 J	27.4	7.2
7/23/1998	DUP	0.0766	0.0019 J	0.0627 J	0.23 J	3.1 J	<0.0011	299	536	0.0052 J	0.124	<0.0011	206	<0.0002	27	7
10/14/1998	NE	0.0064 J	0.001	0.0552	0.26 J	3.1	0.0014 J	270	585	0.0033 J	<0.005	<0.001	196	<0.0002	22.2	7.6
2/11/1999	NE	0.0149 J	0.0014 J	0.0628 J	0.26 J	2.7	<0.001	305	549	0.006 J	0.0461 J	<0.001	204	<0.0002	22.5	7.2
2/11/1999	DUP	0.0129 J	0.0014 J	0.0658 J	0.27 J	2.8	<0.001	301	550	0.0091 J	0.0602 J	<0.001	204	<0.0002	22.4	7.2
8/12/1999	NE	0.009 J	0.0014 J	0.0537 J	0.27 J	2.5	<0.0003	271	495	0.0035 J	<0.0132	<0.0002	181	<0.0002	19.2	7.41
8/12/1999	DUP	0.0216	0.0011 J	0.054 J	0.26 J	2.5	<0.0003	278	494	0.0047 J	<0.0132	0.0003 J	188	<0.0002	19.5	7.38
2/11/2000	NE, LF	0.0302	0.0015 J	0.0555 J	0.26 J	2.3	<0.0003	245	516	<0.0003	0.024 J	0.0012 J	168	<0.0002	13.6	7.6
2/11/2000	DUP, LF	0.0328	0.0016 J	0.0555 J	0.25 J	2.2	<0.0003	252	521	<0.0003	<0.0144	<0.0002	172	<0.0002	14.1	7.51
10/16/2000	NE, LF	0.0048 J	0.0014 J	0.0563 J	0.25 J	2.3	<0.0003	272	526	0.0015 J	<0.0084	0.00027 J	180	<0.0002	12.9	7.33
12/19/2001	NE, LF	<0.0042	0.0014 J	0.0479 J	0.28 JINT	2.2	<0.0001	254	468	0.00083 J	<0.0008	<0.0001	177	<0.0002	18.3	7.45
12/9/2002	NE, LF	0.0145 JMS	0.0017 J	0.0484 J	0.29 JINT	2.2	<0.0001	242	445	0.0019 J	0.0042	<0.0001	163	<0.0002	20.9	7.37
6/14/2004	NE, LF	---	---	---	---	---	---	---	368	<0.005	---	---	---	---	3.81	---
11/8/2004	NE, LF	---	---	---	---	---	---	---	353	<0.01	---	---	---	---	3.69	---
5/16/2005	NE, LF	---	---	---	---	---	---	---	416	0.037	---	---	---	---	3.63	---
10/10/2005	NE, LF	---	---	---	---	---	---	---	318	<0.01	---	---	---	---	3.34	---
5/15/2006	NE, LF	---	---	---	---	---	---	---	460	<0.01	---	---	---	---	3.42	---
10/9/2006	NE, LF	---	---	---	---	---	---	---	350	<0.005	---	---	---	---	5.5	---
5/7/2007	NE, LF	---	---	---	---	---	---	---	274	0.02	---	---	---	---	14.8	---
10/8/2007	NE, LF	---	---	---	---	---	---	---	186	<0.005	---	---	---	---	<1	7.08
6/4/2008	NE, LF	---	---	---	---	---	---	---	300	0.00119	---	---	---	---	4.5	---

PZ-10 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)											
		Potassium	Selenium	Silicon	Silver	Sodium	Specific Conductance [b]	Sulfate	Temperature [c]	Total Dissolved Solids	Total Inorganic Carbon	Total Organic Carbon	Zinc
7/21/1997	NE	7	0.0498 MS	27.8	<0.0011	204	---	917	---	3,080	83.2	10	0.018 J
7/21/1997	DUP	6.5	0.0511 MS	28.7	<0.0011	202	---	945	---	3,100	82.1	8.7	0.0143 J
9/10/1997	NE	4.5 J	0.0386	22.6	<0.0011	214	---	937	---	2,790	65.1	11.5	0.0317
9/10/1997	DUP	4.3 J	0.0446	20.8	<0.0011	215	---	949	---	2,700	44.9	12.2	0.0045 J
10/16/1997	NE	4.4 J	0.0428	20.9	<0.0011	219	---	960	---	2,950	70.6	8.5	<0.0056
11/18/1997	NE	4.2 J	0.0441	22.6	<0.0011	215	---	906	---	2,750	83	5.9	0.0065 J
11/18/1997	DUP	4.4 J	0.0429	22.7	<0.0011	217	---	901	---	2,760	82.8	6.1	0.01 J
1/15/1998	NE	4.6 J	0.0368	23.7	<0.0011	204	---	828	---	2,540	81.1	6.8	<0.0089
4/16/1998	NE	4 J	0.0366	22.1	<0.0011	193	---	900	---	1,840	82.1	3.9 MSREP	<0.0033
7/23/1998	NE	4 J	0.0323	22.3	<0.0011	189	---	803	---	2,655	78.5	3.1	0.0251
7/23/1998	DUP	4 J	0.0311		<0.0011	191	---	789	---	2,612	79.8	3.9	<0.0067
10/14/1998	NE	3.7 J	0.0392	21.9	<0.001	183	---	828	---	2,750	75.1	2.6	<0.006
2/11/1999	NE	4.1 J	0.0388	---	<0.001	183	---	792	---	2,640	77.9	3.8	0.0096 J
2/11/1999	DUP	4.2 J	0.0388	---	<0.001	184	---	792	---	2,600	81.7	2.7	<0.005
8/12/1999	NE	3.8 J	0.0395	---	<0.0003	186	---	718	---	2,810	85.1	<0.3 UREP	0.0065 J
8/12/1999	DUP	3.8 J	0.0388	---	<0.0003	183	---	718	---	2,840	83.8	<0.3 UREP	0.0092 J
2/11/2000	NE, LF	3.9 J	0.0391	21.3	<0.0003	177	---	730	---	2,430	82	16.7 REP	0.0202
2/11/2000	DUP, LF	4.1 J	0.0392	21.5	<0.0003	182	---	736	---	2,390	87.9	10 REP	<0.0047
10/16/2000	NE, LF	4.3 J	0.0312	21.4	<0.0001	188	---	754	---	2,467	90.4	3.4	<0.091
12/19/2001	NE, LF	4.2 J	0.031	22.3	<0.0001	188	---	730	---	2,320	93.1	2.5	0.0409
12/9/2002	NE, LF	3.9 J	0.0256	21.7	<0.0001	178	---	650	---	2,160	99	2.7	<0.001
6/14/2004	NE, LF	---	0.02	---	---	---	---	469	---	1,714	---	---	---
11/8/2004	NE, LF	---	<0.05	---	---	---	---	431	---	1,576	---	---	---
5/16/2005	NE, LF	---	0.044	---	---	---	---	572	---	1,756	---	---	---
10/10/2005	NE, LF	---	0.02	---	---	---	---	515	---	1,720	---	---	---
5/15/2006	NE, LF	---	0.014	---	---	---	---	539	---	1,830	---	---	---
10/9/2006	NE, LF	---	<0.01	---	---	---	---	549	---	1,600	---	---	---
5/7/2007	NE, LF	---	<0.02	---	---	---	---	407	---	1,504	---	---	---
10/8/2007	NE, LF	---	0.026	---	---	---	1,450	211	22.3	968	---	---	---
6/4/2008	NE, LF	---	0.0144	---	---	---	---	390	---	1,500	---	---	---

PZ-11 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)														
		Ammonium	Arsenic	Barium	Boron	Bromide	Cadmium	Calcium	Chloride	Chromium, Total	Iron	Lead	Magnesium	Mercury	Nitrate	pH [a]
7/21/1997	NE	0.0294	<0.02	0.226 J	<1	8.1 J	<0.01	2,870	16,000	0.0313 J	7.71	0.0143 J	1,490	<0.001	22.9	6.9
7/21/1997	DUP	0.044	<0.02	0.221 J	<1	8.3 J	<0.01	2,890	16,200	0.0322 J	8.36	0.014 J	1,510	<0.001	22.8	6.9
9/9/1997	NE	0.112	<0.02	0.191 J	<1	5.7 J	<0.01	1,890	13,200	0.0228 J	1.59	<0.01	958	<0.001	16.4	6.9
10/16/1997	NE	0.0098 J	<0.02	0.148 J	<1	5.3 J	<0.01	1,870	13,800	0.015 J	<0.08	0.0179 J	948	<0.001	17.6	6.9
10/16/1997	DUP	0.0073 J	<0.02	0.158 J	1 J	4.4 J	<0.01	1,910	13,900	0.0108 J	<0.08	0.0198 J	965	<0.001	17.5	6.9
11/17/1997	NE	<0.007	<0.02	0.141 J	<1 UMS	5.2 J	<0.01	1,740	12,800	0.0346 J	0.113 J	<0.01	868	<0.001	16.4	6.9
11/17/1997	DUP	0.0078 J	<0.02	0.148 J	<1 UMS	5 J	<0.01	1,740	12,700	0.032 J	0.107 J	<0.01	867	<0.001	16.4	6.9
1/14/1998	NE	0.0365	<0.02	0.143 J	<1	5.6 J	<0.01	1,680	12,400	0.0103 J	<0.05	<0.01	840	<0.001	17	7
1/14/1998	DUP	0.0388	<0.02	0.14 J	<1	5 J	<0.01	1,700	12,500	0.0112 J	<0.05	<0.01	840	<0.001	17	7
4/16/1998	NE	0.503	<0.02	0.137 J	<1	5.4 J	<0.01	1,930	14,200	0.0176 J	0.222 J	<0.01	981	<0.001	36.8 R	6.8
7/22/1998	NE	0.482	<0.02	0.155 J	<1	5.9 J	<0.01	2,230	15,000	0.0605 JMSREP	0.104 J	0.122 REP	1,140	<0.001	19.1	6.8
10/14/1998	NE	0.0125 J	<0.002	0.158 J	<1	9.4 J	<0.01	2,370	15,900	0.0244 J	<0.05	<0.01	1,240	<0.001	20.1	7.1
2/10/1999	NE	0.0548	<0.001	0.186 J	<1	9.9 J	<0.01	2,900	17,600	<0.01	<0.05	<0.01	1,530	0.00061	22.4	6.8
2/10/1999	DUP	0.0548	<0.001	0.198 J	<1	8.9 J	<0.01	2,990	17,500	<0.01	<0.05	<0.01	1,580	0.00061	23.8	6.8
8/11/1999	NE	0.424	<0.005	0.194 J	<1	<15	<0.003	3,640	23,000	0.0086 J	<0.132	0.0027 J	2,020	0.0011 J	23.3	6.85
2/23/2000	NE, LF	0.0811 MS	<0.002	0.26 J	<1	17.6 J	<0.003	4,450	37,400	0.0126 J	<0.144	<0.002	2,760	<0.001	25.5	7.03
10/16/2000	NE, LF	0.123 MS	<0.001	0.166 JINT	0.1 J	9.6 J	<0.003	3,020	25,100	0.038 JINT	<0.084	0.0038 JINT	1,750	<0.001	19.8	6.95
12/19/2001	NE, LF	0.142	<0.003	0.246 JINT	0.062 JINT	21.4 J	<0.001	3,980	56,700	0.0112 J	<0.008	<0.001	2,950	0.0022	28.2	6.62
12/9/2002	NE, LF	0.116 MS	0.00088 J	0.229 J	<0.011 UINT	17 J	0.0047 J	3,430	55,800	0.0217 JINT	<0.014	0.0014 J	2,720	0.0034	28.2	6.62
6/21/2004	NE, LF	---	---	---	---	---	---	---	58,100	<0.005	---	---	---	---	20.8	---
11/8/2004	NE, LF	---	---	---	---	---	---	---	84,100	<0.01	---	---	---	---	3.15	---
5/16/2005	NE, LF	---	---	---	---	---	---	---	66,000	<0.01	---	---	---	---	4.63	---
10/10/2005	NE, LF	---	---	---	---	---	---	---	84,300	<0.01	---	---	---	---	<10	---
5/15/2006	NE, LF	---	---	---	---	---	---	---	71,000	<0.01	---	<0.01	---	---	<5.3	---
10/9/2006	NE, LF	---	---	---	---	---	---	---	85,800	<0.005	---	---	---	---	<1	---
5/7/2007	NE, LF	---	---	---	---	---	---	---	68,700	<0.01	---	---	---	---	3.84	---
10/8/2007	NE, LF	---	---	---	---	---	---	---	94,400	<0.005	---	---	---	---	<1	6.34
6/4/2008	NE, LF	---	---	---	---	---	---	---	65,000	0.00216	---	---	---	---	3.9	---

PZ-11 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)											
		Potassium	Selenium	Silicon	Silver	Sodium	Specific Conductance [b]	Sulfate	Temperature [c]	Total Dissolved Solids	Total Inorganic Carbon	Total Organic Carbon	Zinc
7/21/1997	NE	25.6 J	0.025 J	28.7	<0.01	5,190	---	1,070	---	33,000	44.6	6.1	0.0427 J
7/21/1997	DUP	25.6 J	0.027 J	32.1	<0.01	5,110	---	1,080	---	34,300	43.8	5	<0.03
9/9/1997	NE	16.6 J	<0.02	19.7	<0.01	4,900	---	703	---	25,400	44.6	8	<0.03
10/16/1997	NE	18.1 J	<0.02	18.5	<0.01	5,160	---	763	---	25,600	43.7	8.3	<0.05
10/16/1997	DUP	25.9 J	<0.02	18.2	<0.01	5,180	---	777	---	25,100	44.8	10.8	<0.05
11/17/1997	NE	17.3 J	<0.02	19.2	<0.01	4,990	---	736	---	24,800	46.8	4.6	<0.05 UREP
11/17/1997	DUP	16.9 J	<0.02	19	<0.01	4,980	---	734	---	24,600	46.8	4.8	<0.05 UREP
1/14/1998	NE	18.9 J	<0.02	19	<0.01	4,510	---	756	---	23,300	47.4	3.4	<0.08
1/14/1998	DUP	18.5 J	<0.02	19	<0.01	4,600	---	756	---	22,900	47.6	3.8	<0.08
4/16/1998	NE	16 J	<0.02	18.8	<0.01	5,400	---	893	---	22,900	50.4	8.2 J	0.0302 J
7/22/1998	NE	17.6 J	<0.02	19.2	<0.01	5,240	---	1,000	---	28,420	45.4	3.4 J	0.0602 J
10/14/1998	NE	18	0.0217	19.2	<0.01	5,280	---	1,070	---	30,400	39.4	2.4	<0.06
2/10/1999	NE	20.6	0.0269 J	---	<0.01	6,200	---	1,040	---	34,500	39.8	<0.3	<0.05
2/10/1999	DUP	21	0.0269 J	---	<0.01	5,990	---	1,030	---	34,800	39.8	2.1	<0.05
8/11/1999	NE	23.6	0.033	---	<0.003	7,540	---	1,200	---	53,600	37.8	<0.3	<0.046
2/23/2000	NE, LF	32.5	0.0373	14.5	<0.003	15,200	---	1,790	---	72,000	29.2	0.65 J	<0.047
10/16/2000	NE, LF	27.6	0.0264	17	<0.001	8,660	---	1,290	---	44,250	35	<0.3	<0.091
12/19/2001	NE, LF	62.9 J	0.0289	12.5	<0.001	24,300	---	2,380	---	99,000	---	---	<0.05
12/9/2002	NE, LF	73.3 J	0.0264	18.2	<0.0022	26,200	---	2,410	---	104,000	34.5	1.7	<0.01
6/21/2004	NE, LF	---	<0.01	---	---	---	---	2,220	---	123,000	---	---	---
11/8/2004	NE, LF	---	<0.05	---	---	---	---	13,000	---	119,000	---	---	---
5/16/2005	NE, LF	---	<0.01	---	---	---	---	2,890	---	100,000	---	---	---
10/10/2005	NE, LF	---	0.013	---	---	---	---	2,950	---	129,000	---	---	---
5/15/2006	NE, LF	---	<0.01	---	---	---	---	3,090	---	133,000	---	---	---
10/9/2006	NE, LF	---	<0.01	---	---	---	---	2,550	---	123,000	---	---	---
5/7/2007	NE, LF	---	<0.02	---	---	---	---	2,620	---	135,000	---	---	---
10/8/2007	NE, LF	---	<0.02	---	---	---	127,100	2,970	23.4	108,000	---	---	---
6/4/2008	NE, LF	---	0.0149	---	---	---	---	2,100	---	110,000	---	---	---

PZ-12 Analytical Results
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Date	Sample Type	Concentration (mg/L unless otherwise noted)													
		Ammonium	Arsenic	Barium	Boron	Bromide	Cadmium	Calcium	Chloride	Chromium, Total	Iron	Lead	Magnesium	Mercury	Nitrate
7/21/1997	NE	<0.007	0.0029 J	0.269	0.23 J	3.6 J	<0.0011	356	1,540	0.0083 J	3.8	0.0036	278	<0.0002	21
7/21/1997	DUP	<0.007	0.0028 J	0.249	0.23 J	3.7 J	<0.0011	359	1,550	0.0061 J	2	0.0027 J	280	<0.0002	21
9/10/1997	NE	0.0335	0.0022 J	0.135	0.21 J	3.2	<0.0011	325	1,430	0.0039 J	0.0933 J	<0.0011	237	<0.0002	14.9
10/16/1997	NE	<0.007	0.0019 J	0.127 J	0.21 J	4.4	<0.0011	313	1,420	0.0029 J	0.0213 J	<0.0011	233	<0.0002	13.9
10/16/1997	DUP	<0.007	0.0024 J	0.134 J	0.22 J	4.3	<0.0011	316	1,420	0.0034 J	0.138	<0.0011	233	<0.0002	13.8
11/18/1997	NE	0.0102 J	0.002 J	0.127 J	0.22 J	3.8	<0.0011	303	1,250	0.002 J	<0.0089	<0.0011	223	<0.0002	13.4
1/15/1998	NE	0.009 J	0.002 J	0.137 J	0.21 J	3.8	0.0012 J	320	1,370	0.0035 J	<0.0056	<0.0011	229	<0.0002	15.7
1/15/1998	DUP	0.0136 J	0.002 J	0.138 J	0.2 J	4	<0.0011	325	1,380	0.0047 J	<0.0056	<0.0011	230	<0.0002	15.5
4/16/1998	NE	0.08435	0.0018 J	0.121 J	0.21 J	4.3	<0.0011	376	1,720	0.0076 J	<0.0122	<0.0011	271	<0.0002	20
4/16/1998	DUP	0.0719	0.002 J	0.118 J	0.21 J	4.2	<0.0011	378	1,790	0.0075 J	<0.0122	0.0021 J	271	<0.0002	20
7/23/1998	NE	0.42	0.0018 J	0.148 J	0.22 J	14.6 R	<0.0011	497	2,620	0.0101 J	0.0176 J	<0.0011	357	<0.0002	24.8
10/15/1998	NE	0.0064 J	0.0011 J	0.151 J	0.23 J	6.1	<0.001	557	3,320	0.0054 J	<0.005	0.0015 J	406	<0.0002	25.6
10/15/1998	DUP	0.0064 J	0.0012 J	0.152 J	0.22 J	6.2	<0.001	566	3,340	0.0079 J	<0.005	<0.001	414	<0.0002	25.6
2/11/1999	NE	0.0488	0.0016 J	0.183 J	<1	5.7	<0.001	728	3,810	0.0057 J	0.0486 J	<0.001	510	<0.0002	30.8
8/12/1999	NE	0.342	<0.005	0.138 J	<1	5.5	<0.003	717	3,870	0.01 J	<0.132	<0.002	496	<0.001	28.2
2/11/2000	NE, LF	0.369 MS	<0.002	0.142 J	<1	5.9 J	<0.003	804	5,150	0.0061 J	<0.144	<0.002	564	<0.001	31.7
10/16/2000	NE, LF	<0.0047	0.0015 J	0.118 J	0.2 J	5.2	<0.0003	684	4,400	0.005 J	<0.0084	0.00026 J	469	<0.0002	29.4
12/19/2001	NE, LF	0.124	<0.003	0.115 JINT	0.21 JINT	4.9 J	<0.001	868	6,560	0.0114 J	<0.008	<0.001	608	<0.0002	29.5
12/10/2002	NE, LF	0.826 MS	0.0012 J	0.116 J	0.13 JINT	4.1 J	<0.001	771	6,300	0.0166 JINT	<0.014	<0.001	549	<0.001	30.9
6/14/2004	NE, LF	---	---	---	---	---	---	---	5,320	<0.005	---	---	---	---	11.2
11/8/2004	NE, LF	---	---	---	---	---	---	---	7,170	<0.001	---	---	---	---	19.8
5/16/2005	NE, LF	---	---	---	---	---	---	---	3,730	0.054	---	---	---	---	8.85
10/10/2005	NE, LF	---	---	---	---	---	---	---	318	<0.01	---	---	---	---	3.34
5/15/2006	NE, LF	---	---	---	---	---	---	---	4,510	<0.01	---	---	---	---	20.6
10/9/2006	NE, LF	---	---	---	---	---	---	---	5,340	<0.005	---	---	---	---	13.2
5/7/2007	NE, LF	---	---	---	---	---	---	---	3,780	0.024	---	---	---	---	10.8
10/8/2007	NE, LF	---	---	---	---	---	---	---	4,310	<0.005	---	---	---	---	<1
6/4/2008	NE, LF	---	---	---	---	---	---	---	3,300	0.00132	---	---	---	---	11

PZ-12 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)												
		pH [a]	Potassium	Selenium	Silicon	Silver	Sodium	Specific Conductance [b]	Sulfate	Temperature [c]	Total Dissolved Solids	Total Inorganic Carbon	Total Organic Carbon	Zinc
7/21/1997	NE	7.3	7.4	0.0256 MS	22.2	<0.0011	386	---	404	---	4,060	56.9	1.9	0.0154 J
7/21/1997	DUP	7.3	6.4	0.026 MS	22.1	<0.0011	388	---	404	---	3,860	55.4	2.1	0.0101 J
9/10/1997	NE	7.2	6.3	0.0262	20.3	<0.0011	436	---	448	---	3,290	61.4	5.7	<0.0033
10/16/1997	NE	7.3	6.4	0.0315	20.2	<0.0011	410	---	483	---	3,400	53.5	6.4	<0.0056
10/16/1997	DUP	7.2	6.2	0.0304	20.3	<0.0011	408	---	481	---	3,440	58.4	8.4	<0.0056
11/18/1997	NE	7.2	5.7	0.0314	21.3	<0.0011	354	---	469	---	3,140	62.8	4.3	0.0066 J
1/15/1998	NE	7.5	6.3	0.0332	21.3	<0.0011	409	---	500	---	3,460	62.9	3.2	0.0143 J
1/15/1998	DUP	7.4	6.7	0.0323	21.3	<0.0011	409	---	497	---	3,510	64.2	3.3	0.0104 J
4/16/1998	NE	7	7.3	0.031	21.1	<0.0011	544	---	578	---	3,610	68.9	0.68 JMS	<0.0033
4/16/1998	DUP	7	7.4	0.0313	21	<0.0011	549	---	577	---	4,960	68.8	<0.3 UMS	<0.0033
7/23/1998	NE	7	9.5	0.0294	21.2	<0.0011	812	---	595	---	5,965	67.5	2.3	<0.0067
10/15/1998	NE	7.4	10.8	0.038	20.6	<0.001	926	---	686	---	7,430	63.8	2.4	<0.006
10/15/1998	DUP	7.4	10.8	0.0391	20.4	<0.001	953	---	694	---	7,340	64.2	2.1	<0.006
2/11/1999	NE	7	13.5	0.0388	---	<0.001	1,190	---	700	---	8,500	69.2	4	<0.005
8/12/1999	NE	7.23	13.8	0.0418	---	<0.003	1,280	---	685	---	10,000	73.4	6.3 REP	<0.046
2/11/2000	NE, LF	7.31	18.4	0.0478	20.7	<0.003	<3,840	---	826	---	10,700	70.4	0.79 J	<0.047
10/16/2000	NE, LF	7.06	17.1	0.0361	20.4	0.00015 J	1,500	---	740	---	9,650	70.9	3.8	<0.0091
12/19/2001	NE, LF	7.28	24.5 J	0.0378	20.2	<0.001	2,290	---	843	---	12,800	---	---	<0.05
12/10/2002	NE, LF	6.97	24.8 J	0.0372	21.2	<0.001	2,260	---	809	---	12,500	71.6	2.9	<0.01
6/14/2004	NE, LF	---	---	0.077	---	---	---	---	773	---	9,700	---	---	---
11/8/2004	NE, LF	---	---	0.066	---	---	---	---	879	---	9,540	---	---	---
5/16/2005	NE, LF	---	---	0.051	---	---	---	---	679	---	5,890	---	---	---
10/10/2005	NE, LF	---	---	0.02	---	---	---	---	515	---	7,740	---	---	---
5/15/2006	NE, LF	---	---	0.019	---	---	---	---	866	---	8,790	---	---	---
10/9/2006	NE, LF	---	---	<0.01	---	---	---	---	795	---	9,150	---	---	---
5/7/2007	NE, LF	---	---	<0.02	---	---	---	---	831	---	7,010	---	---	---
10/8/2007	NE, LF	6.85	---	0.026	---	---	---	10,760	958	20.7	6,200	---	---	---
6/4/2008	NE, LF	---	---	0.0291	---	---	---	---	760	---	6,800	---	---	---

PZ-13 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)												
		Alkalinity, Bicarbonate	Alkalinity, Carbonate	Alkalinity, Hydroxide	Alkalinity, Total	Arsenic, Dissolved	Barium, Dissolved	Cadmium, Dissolved	Calcium, Dissolved	Chloride	Chromium, Total	Fluoride	Lead, Dissolved	Magnesium, Dissolved
10/10/2007	NE, LF	144	<1	<1	144	<0.01	0.116	<0.001	2,220	150,000	0.005	22.2	0.25	1,250
6/6/2008	NE, LF	---	---	---	---	---	---	---	---	170,000	0.00316	---	---	---

PZ-13 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)										
		Mercury, Dissolved	Nitrate	pH [a]	Potassium, Dissolved	Selenium	Silver, Dissolved	Sodium, Dissolved	Specific Conductance [b]	Sulfate	Temperature [c]	Total Dissolved Solids
10/10/2007	NE, LF	<0.0002	12.4	6.09	618	0.1	<0.002	86,100	200,000 >	2,670	22.8	245,500
6/6/2008	NE, LF	---	<200	---	---	0.0118	---	---	---	2,600	---	240,000

PZ-14 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)												
		Alkalinity, Bicarbonate	Alkalinity, Carbonate	Alkalinity, Hydroxide	Alkalinity, Total	Arsenic, Dissolved	Barium, Dissolved	Cadmium, Dissolved	Calcium, Dissolved	Chloride	Chromium, Total	Fluoride	Lead, Dissolved	Magnesium, Dissolved
10/15/2007	NE, BLR	146	<1	<1	146	<0.01	0.298	<0.001	1,060	71,500	<0.005	<1	<0.01	696
6/7/2008	NE, LF	---	---	---	---	---	---	---	---	130,000	0.00168	---	---	---

PZ-14 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)									
		Mercury, Dissolved	Nitrate	pH [a]	Potassium, Dissolved	Selenium	Silver, Dissolved	Sodium, Dissolved	Specific Conductance [b]	Sulfate	Total Dissolved Solids
10/15/2007	NE, BLR	<0.0002	1.41	6.74	649	<0.01	<0.002	41,500	184,000	2,140	106,000
6/7/2008	NE, LF	---	<100	---	---	0.0201	---	---	---	3,300	180,000

PZ-15 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)												
		Alkalinity, Bicarbonate	Alkalinity, Carbonate	Alkalinity, Hydroxide	Alkalinity, Total	Arsenic, Dissolved	Barium, Dissolved	Cadmium, Dissolved	Calcium, Dissolved	Chloride	Chromium, Total	Fluoride	Lead, Dissolved	Magnesium, Dissolved
10/15/2007	NE, BLR	<4	1,100	<1	550	<0.01	0.051	<0.001	14.2	764	<0.05	9.01	<0.01	10.1
6/7/2008	NE, LF	---	---	---	---	---	---	---	---	460	<0.001	---	---	---

PZ-15 Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)									
		Mercury, Dissolved	Nitrate	pH [a]	Potassium, Dissolved	Selenium	Silver, Dissolved	Sodium, Dissolved	Specific Conductance [b]	Sulfate	Total Dissolved Solids
10/15/2007	NE, BLR	<0.0002	2.97	8.66	7.15	0.022	<0.002	779	3,380	169	2,060
6/7/2008	NE, LF	---	12	---	---	0.00372	---	---	---	160	1,600

WQSP-6A Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)													
		Alkalinity, Total	Antimony	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chloride	Chromium, Total	Iron	Lead	Magnesium	Mercury	Nickel
7/13/1995	NE	111	---	<0.006	<0.02	<0.01	<0.0013	681	1,040	<0.0025	<0.4	<0.0125	181	<0.0002	---
3/28/1996	NE	101	---	---	---	---	---	564	507	---	0.145	---	155	---	---
7/11/1996	NE	104.2	<0.013	<0.013	0.01	<0.003	<0.003	645	6,748	<0.025	<0.5	0.017	155	<0.002	<0.025
10/31/1996	NE	---	<0.013	---	---	---	---	---	---	---	---	---	---	---	---
11/1/1996	NE	---	---	<0.013	---	---	---	---	---	---	---	---	---	---	---
11/2/1996	NE	---	---	---	0.009	---	---	---	---	---	---	---	---	---	---
11/3/1996	NE	---	---	---	---	<0.0025	---	---	---	---	---	---	---	---	---
11/4/1996	NE	---	---	---	---	---	<0.0025	---	---	---	---	---	---	---	---
11/5/1996	NE	---	---	---	---	---	---	---	---	<0.025	---	---	---	---	---
11/8/1996	NE	---	---	---	---	---	---	---	---	---	---	<0.013	---	---	---
11/9/1996	NE	---	---	---	---	---	---	---	---	---	---	---	---	<0.002	---
11/10/1996	NE	---	---	---	---	---	---	---	---	---	---	---	---	---	<0.025
11/11/1996	NE	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11/12/1996	NE	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11/13/1996	NE	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11/15/1996	NE	---	---	---	---	---	---	---	---	---	---	---	---	---	---
4/10/1997	NE	106	<0.013	<0.013	<0.005	<0.0025	<0.0025	563	675	<0.025	0.261	<0.013	150	<0.002	<0.025
7/10/1997	NE	102	<0.05	<0.05	<0.02	<0.01	<0.01	675	660	<0.1	<1	<0.05	173	<0.002	<0.1
6/10/1998	NE	103	<0.001	<0.001	0.007	<0.001	<0.001	649	644	0.0015	0.019	<0.001	173	<0.0002	<0.019
11/3/1998	NE	100	<0.05	<0.5	<1	<0.01	<0.05	646	770	<0.5	<0.3	<0.05	166	<0.001	<0.1
5/26/1999	NE	102	0.14	0.08	<1	<0.01	<0.05	654	540	<0.05	<1	<0.05	172	<0.0002	<0.5
11/10/1999	NE	100	0.48	0.187	<0.1	<0.01	<0.01	613	540	<0.05	0.511	<0.02	167	<0.0002	0.284
5/24/2000	NE	108	<0.01	<0.01	<0.008	<0.004	<0.005	681	530	<0.02	0.0037	<0.005	167	<0.0002	<0.02
11/30/2000	NE	---	<0.013	0.01	<0.02	---	<0.01	655	480	<0.025	<0.5	<0.02	187	<0.0002	<0.025
12/5/2000	NE	108	---	---	---	---	---	---	---	---	---	---	---	---	---
6/6/2001	NE	104	<0.013	<0.05	<0.02	<0.01	<0.01	570	536	<0.025	<0.5	<0.02	150	<0.0002	<0.025
11/14/2001	NE	102	<0.025	<0.01	<0.1	<0.0025	<0.005	622	414	<0.01	<0.05	<0.01	186	<0.0002	<0.025
11/30/2001	NE	---	---	---	---	<0.01	---	---	---	---	---	---	---	---	---
5/22/2002	NE	106	<0.025	<0.05	<0.1	<0.0025	<0.005	573	487	<0.01	---	<0.01	151	<0.0002	<0.025
11/20/2002	NE	100	<0.025	<0.05	<0.1	<0.0025	<0.005	588	419	<0.01	<0.05	<0.01	170	<0.0002	<0.025
5/21/2003	NE	104	<0.124	<0.249	<0.05	<0.0125	<0.025	588	384	<0.05	<0.25	<0.075	159	<0.0002	<0.125
11/19/2003	NE	106	<0.25	<0.1	<0.1	<0.01	<0.01	616	391	<0.025	<0.5	<0.05	164	<0.0002	<0.05
5/26/2004	NE	104	<0.25	<0.1	<0.1	<0.01	<0.01	590	416	<0.025	<0.5	<0.05	156	<0.0002	<0.05
11/17/2004	NE	106	<0.25	<0.1	<0.1	<0.01	<0.01	575	491	<0.025	<0.5	<0.05	166	<0.0002	<0.05
4/20/2005	NE	104	<0.013	<0.1	<0.02	<0.01	<0.01	628	432	<0.025	<0.5	<0.02	173	<0.0002	<0.025
10/19/2005	NE	106	<0.013	<0.1	<0.02	<0.01	<0.01	580	360	<0.025	<0.5	<0.02	156	<0.0002	<0.025
5/3/2006	NE	106	<0.013	<0.1	<0.02	<0.01	<0.01	510	450	<0.025	<0.5	<0.02	151	<0.0002	<0.025
9/20/2006	NE	108	<0.013	<0.1	<0.02	<0.01	<0.01	635	360	<0.025	<0.5	<0.02	171	<0.0002	<0.025
3/7/2007	NE	102	<0.013	<0.1	<0.02	<0.01	<0.01	606	484	<0.025	<0.5	<0.02	148	<0.0002	0.031
9/12/2007	NE	112	<0.013	<0.1	<0.02	<0.01	<0.01	606	350	<0.025	<0.5	<0.02	158	<0.0002	0.033

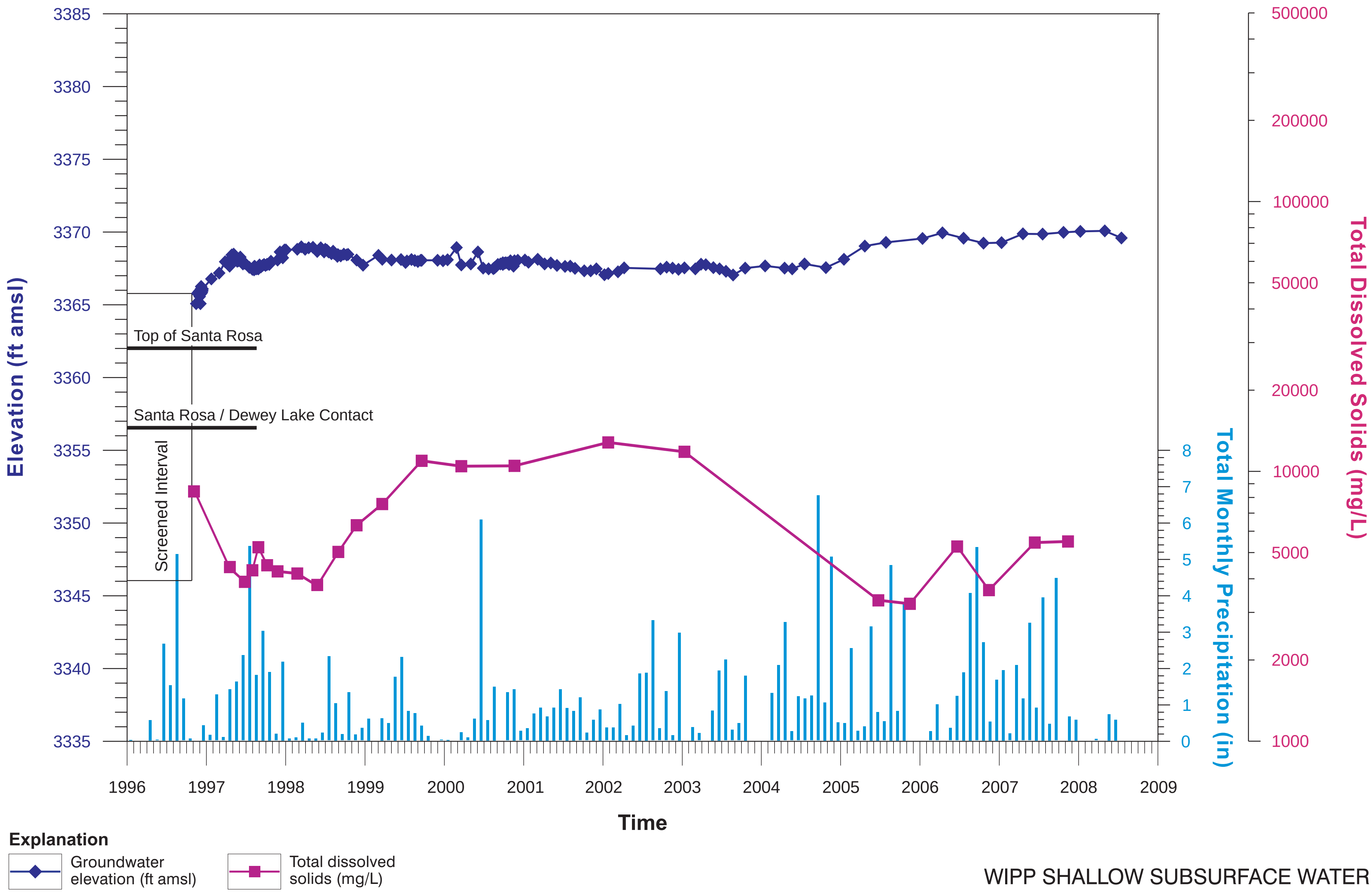
WQSP-6A Analytical Results

Date	Sample Type	Concentration (mg/L unless otherwise noted)													
		Nitrate	pH [a]	Potassium	Selenium	Silver	Sodium	Specific Conductance [b]	Sulfate	Thallium	Total Dissolved Solids	Total Organic Carbon	Total Organic Halides (TOX)	Total Suspended Solids	Vanadium
7/13/1995	NE	33.73	7.66	4.82	<0.006	0.0028	347	4,968	1,905	---	11,000	1.1	0.088	91	---
3/28/1996	NE	17.62	7.24	3.93	---	---	282	4,306	1,810	---	3,920	1.73	0.0665	<10	---
7/11/1996	NE	12.17	7.63	5	0.02	<0.013	314	4,512.60	1,970.50	<0.013	4,500	1.14	0.0443	<10	0.053
10/31/1996	NE	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11/1/1996	NE	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11/2/1996	NE	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11/3/1996	NE	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11/4/1996	NE	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11/5/1996	NE	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11/8/1996	NE	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11/9/1996	NE	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11/10/1996	NE	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11/11/1996	NE	---	---	---	<0.013	---	---	---	---	---	---	---	---	---	---
11/12/1996	NE	---	---	---	---	<0.013	---	---	---	---	---	---	---	---	---
11/13/1996	NE	---	---	---	---	---	---	---	---	<0.013	---	---	---	---	---
11/15/1996	NE	---	---	---	---	---	---	---	---	---	---	---	---	---	0.05
4/10/1997	NE	20.54	7.325	4.24	0.017	<0.013	292	4,634	2,240	<0.013	3,960	15.6	<0.01	<10	0.05
7/10/1997	NE	17.88	7.835	4.49	<0.05	<0.05	311	4,450	2,560	<0.05	3,840	0.8855	0.1814	<10	<0.1
6/10/1998	NE	27.40	7.47	4.49	0.016	<0.001	335	4,770	1,950	<0.001	4,120	<0.1	---	<10	0.053
11/3/1998	NE	48.69	7.3	7.5	0.22	<0.5	313	4,600	2,100	<0.1	4,100	<5	0.054	<1	<0.5
5/26/1999	NE	30.99	7.2	10	<0.1	<0.5	291	5,000	1,900	<0.01	3,800	<1	0.1	<1	<0.01
11/10/1999	NE	41.61	7.2	<10	<0.05	0.08	269	4,400	1,900	0.058	3,800	3.1	0.076	<1	<0.1
5/24/2000	NE	33.20	7.39	5.2	0.0129	<0.01	279	4,500	2,100	0.0176	3,800	<1	0.046	<1	0.0411
11/30/2000	NE	29.66	7.8	3.28	<0.013	<0.013	258	4,300	1,900	<0.013	3,700	<1	0.054	<1	<0.025
12/5/2000	NE	---	---	---	---	---	---	---	---	---	---	---	---	---	---
6/6/2001	NE	28.20	7.4	7.2	0.0385	<0.013	260	4,400	1,900	<0.013	3,680	1.28	0.029	<1	0.052
11/14/2001	NE	16.25	7.52	7.55	<0.05	<0.0125	302	4,160	1,900	<0.05	4,600	<1	0.039	<1	0.046
11/30/2001	NE	---	---	---	---	---	---	---	---	---	---	---	---	---	---
5/22/2002	NE	24.44	7.4	7.27	<0.05	<0.0125	253	4,210	1,930	<0.05	3,540	<1	0.44	<1	<0.025
11/20/2002	NE	24.83	7.7	6.15	<0.05	<0.0125	279	4,050	2,090	<0.05	3,685	1.59	2.3	<1	0.0482
5/21/2003	NE	20.98	7.3	5.71	<0.123	<0.0625	290	4,060	1,950	<0.229	3,650	<1	0.12	<1	<0.125
11/19/2003	NE	<0.044	7.3	6.16	<0.219	<0.025	231	4,070	1,950	<0.025	3,955	<1	4	<1	0.065
5/26/2004	NE	42.54	7.4	5.43	<0.025	<0.025	193	4,080	1,970	<0.025	3,646	<1	1.1	<1	<0.05
11/17/2004	NE	29.75	7.42	7.85	<0.025	<0.025	215	4,227	1,960	<0.025	3,655	<1	<0.03	<1	<0.05
4/20/2005	NE	26.47	7.62	6.21	0.057	<0.013	205	3,970	1,920	<0.025	3,700	<1	<0.15	<1	<0.05
10/19/2005	NE	<0.044	7.57	8.99	<0.025	<0.013	226	3,710	1,940	<0.025	3,430	<1	<0.06	<1	<0.05
5/3/2006	NE	11.07	7.55	6.35	<0.025	<0.013	212	3,870	2,210	<0.025	3,200	2.9	<0.077	18	<0.05
9/20/2006	NE	26.56	7.22	4.98	<0.025	<0.013	127	3,960	2,120	<0.025	3,515	<1	<0.06	<1	0.056
3/7/2007	NE	25.59	7.09	3.77	<0.025	<0.013	243	4,100	2,170	0.04	3,355	<1	<0.06	<1	0.056
9/12/2007	NE	24.21	7.09	4.58	<0.025	<0.013	241	4,000	1,950	<0.025	3,400	<1	<0.06	<1	<0.05

Appendix C

Hydrographs

S:\PROJECTS\ES08.0072_WIPP_SSW\VR_DRAWINGS\ES08_0072_01W.CDR (PG 1)



WIPP SHALLOW SUBSURFACE WATER

Hydrograph at C-2505

Monthly Precipitation and Total Dissolved Solids

Figure C-1

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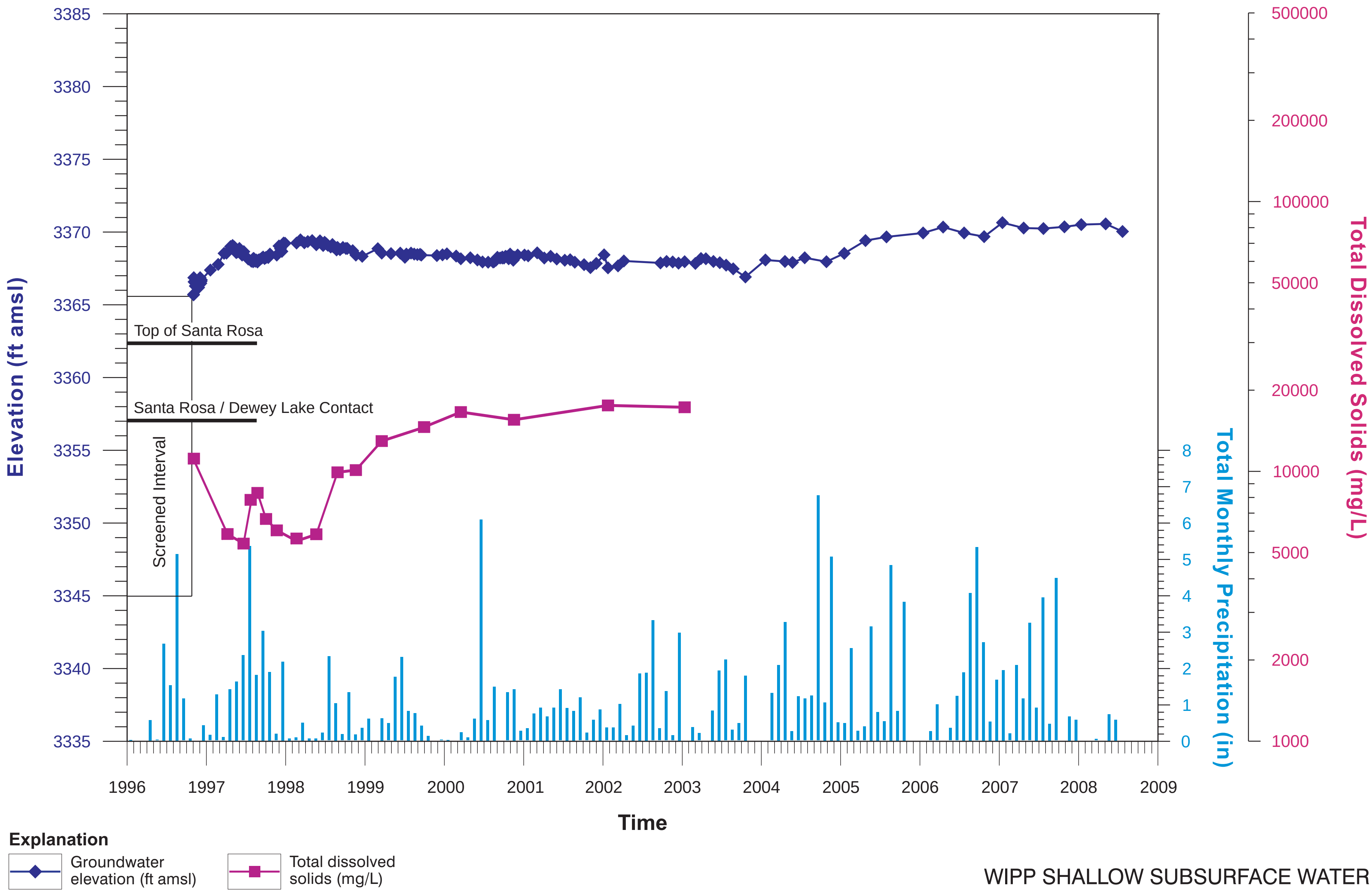
8-28-08

JN ES08.0072



WIPP SHALLOW SUBSURFACE WATER

Hydrograph at C-2506

Monthly Precipitation and Total Dissolved Solids

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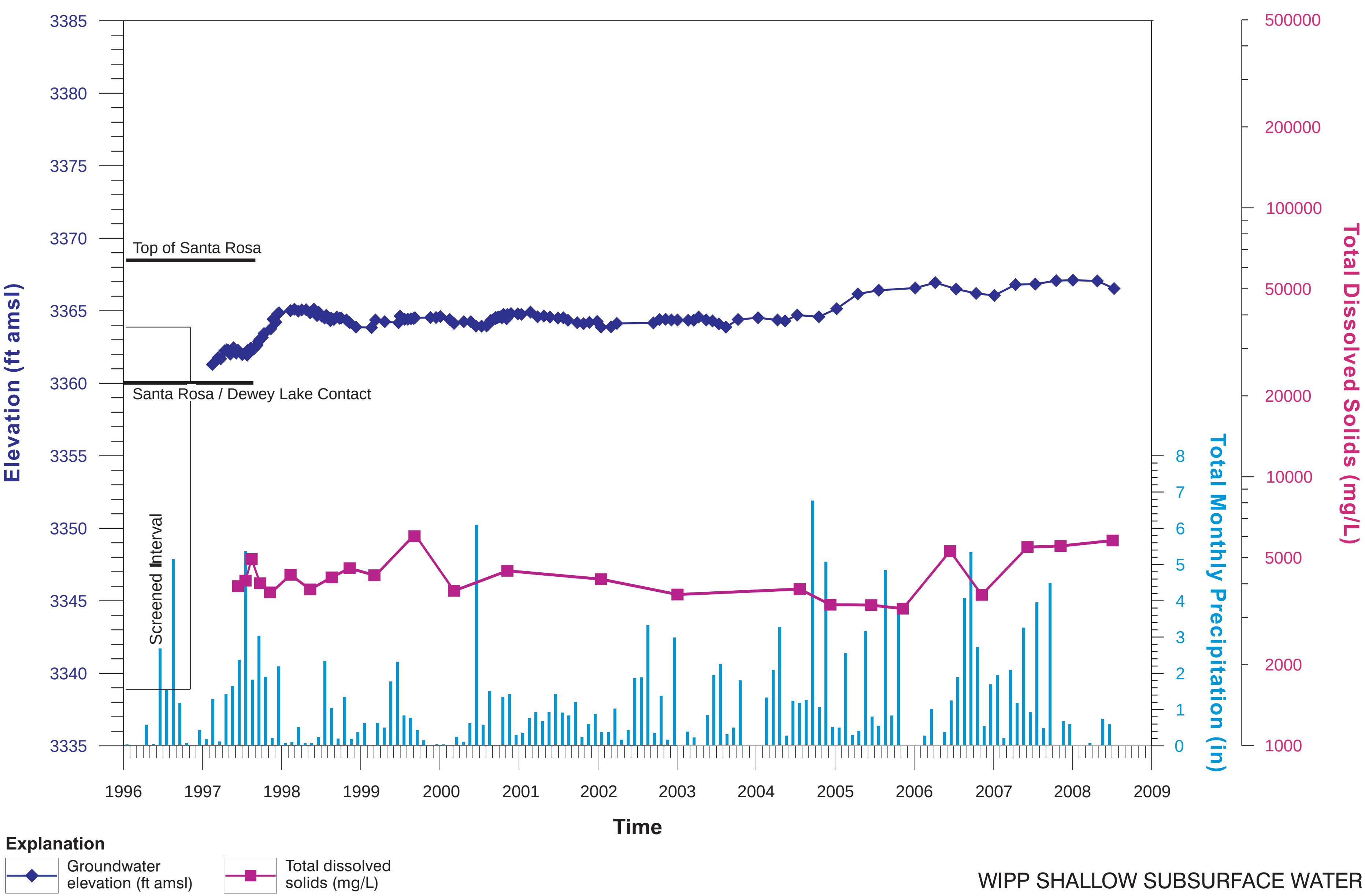
8-28-08

JN ES08.0072

Figure C-2

S:\PROJECTS\ES08.0072_WIPP_SSW\VR_DRAWINGS\ES08_0072_01W.CDR (PG 3)



WIPP SHALLOW SUBSURFACE WATER

Hydrograph at C-2507

Monthly Precipitation and Total Dissolved Solids

Daniel B. Stephens & Associates, Inc.

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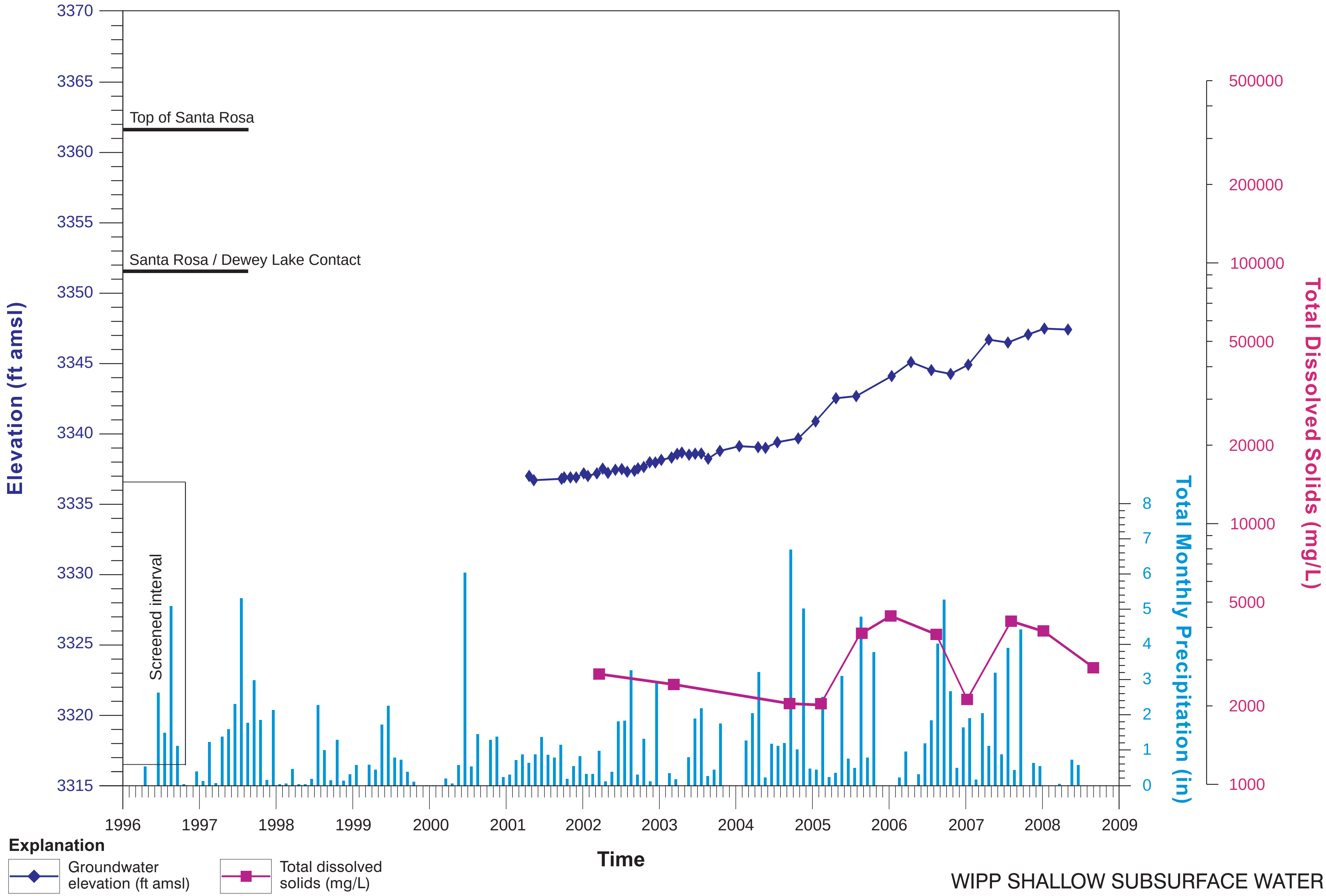
JN ES08.0072

Figure C-3

S:\PROJECTS\ES08.0072_WIPP_SSW\VR_DRAWINGS\ES08_0072_01W.CDR (PG 4)



WIPP SHALLOW SUBSURFACE WATER

Hydrograph at C-2811

Monthly Precipitation and Total Dissolved Solids

Daniel B. Stephens & Associates, Inc.

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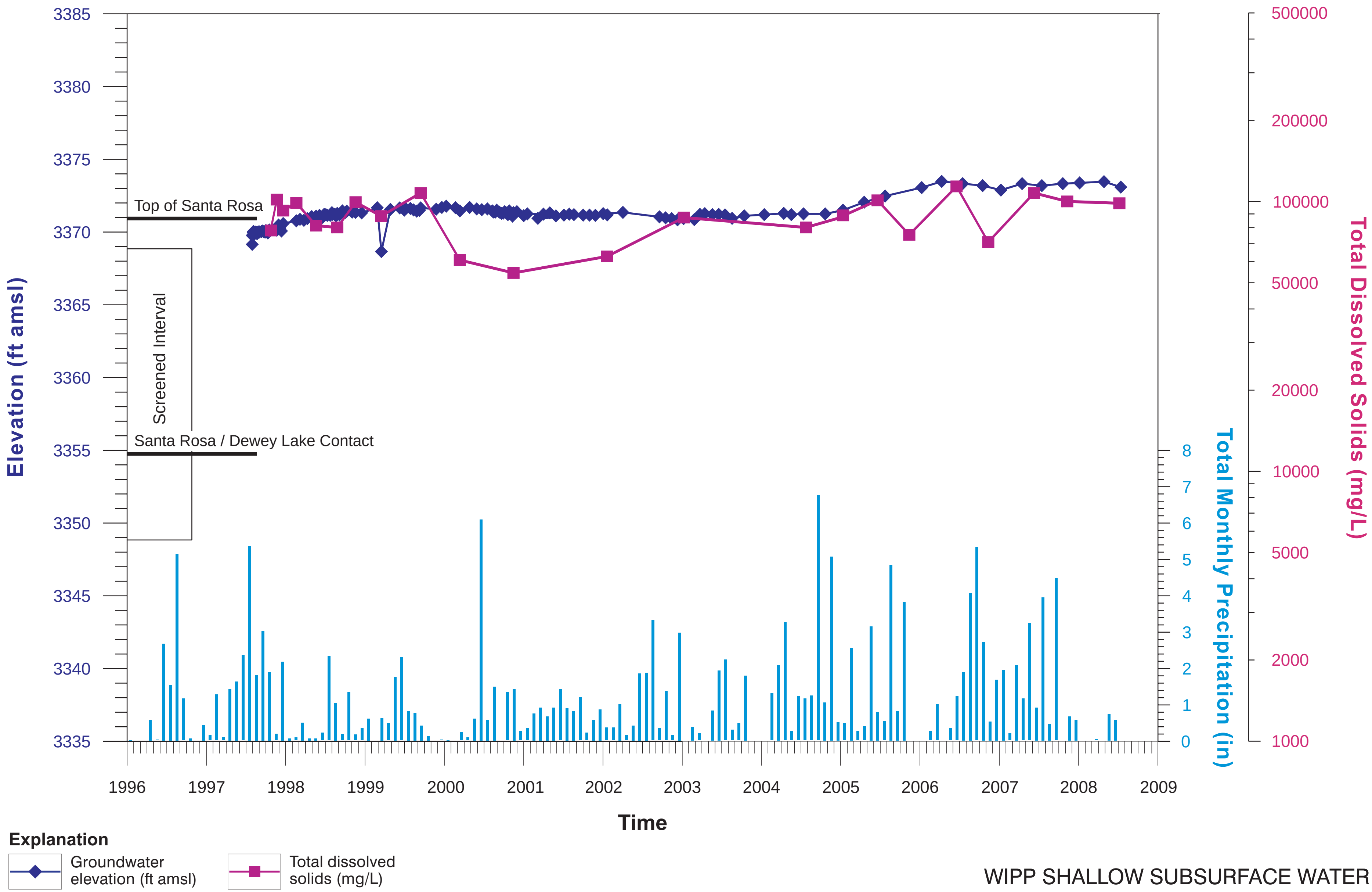
JN ES08.0072

Figure C-4

S:\PROJECTS\ES08.0072_WIPP_SSW\VR_DRAWINGS\ES08_0072_01W.CDR (PG 5)



WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-01

Monthly Precipitation and Total Dissolved Solids

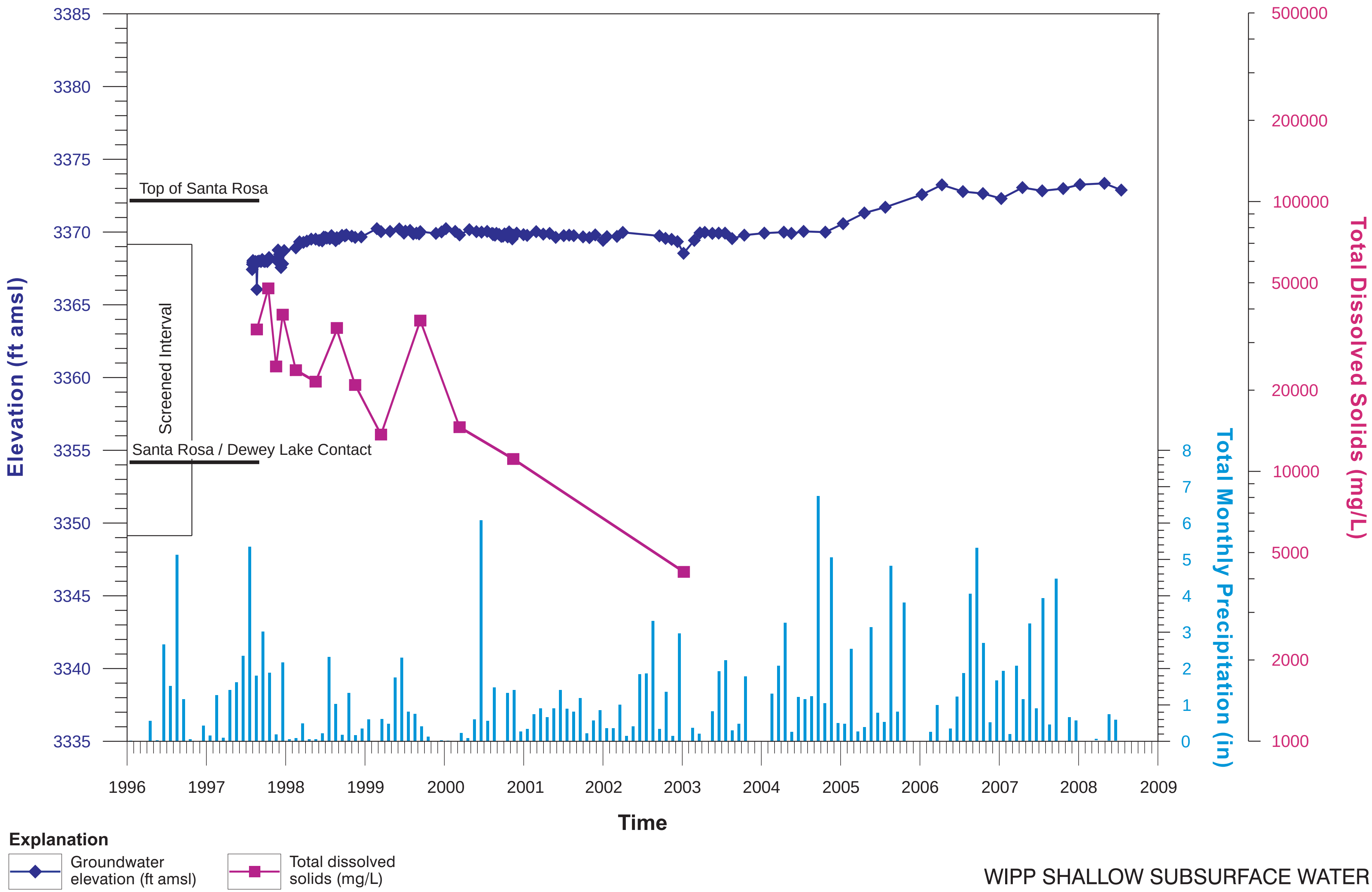
Daniel B. Stephens & Associates, Inc.

8-28-08

JN ES08.0072

Figure C-5

S:\PROJECTS\ES08.0072_WIPP_SSW\VR_DRAWINGS\ES08_0072_01W.CDR (PG 6)



WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-02

Monthly Precipitation and Total Dissolved Solids

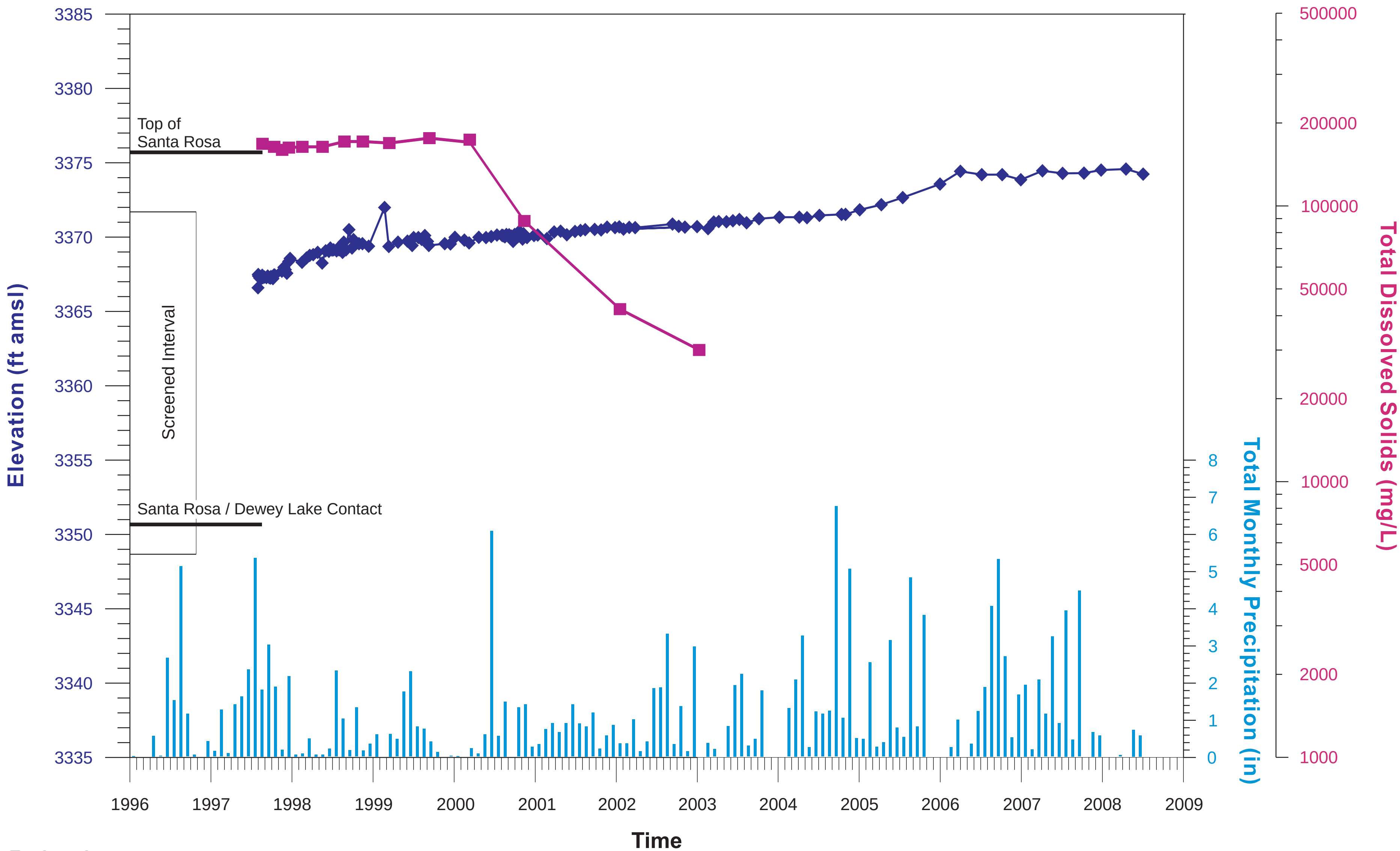
Daniel B. Stephens & Associates, Inc.

8-28-08

JN ES08.0072

Figure C-6

S:\PROJECTS\ES08.0072_WIPP_SSW\VR_DRAWINGS\ES08_0072_01W.CDR (PG 7)



Explanation

Groundwater elevation (ft amsl)

Total dissolved solids (mg/L)

WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-03

Monthly Precipitation and Total Dissolved Solids

Figure C-7

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WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-04

Monthly Precipitation and Total Dissolved Solids

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JN ES08.0072

Figure C-8

S:\PROJECTS\ES08.0072_WIPP_SSW\VR_DRAWINGS\ES08_0072_01W.CDR (PG 9)

WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-05

Monthly Precipitation and Total Dissolved Solids

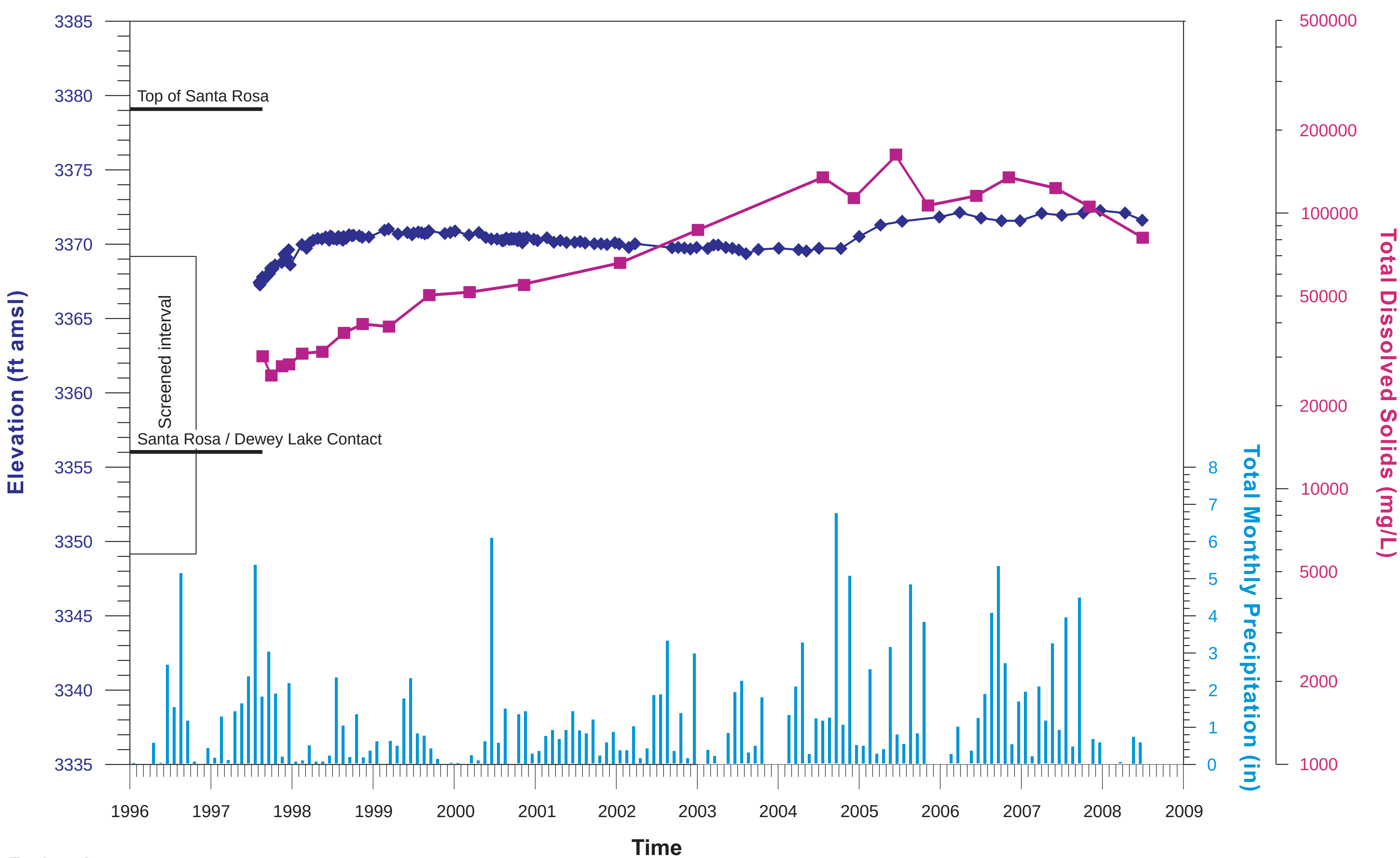
Daniel B. Stephens & Associates, Inc.

8-28-08

JN ES08.0072

Figure C-9

S:\PROJECTS\ES08.0072_WIPP_SSW\VR_DRAWINGS\ES08_0072_01W.CDR (PG 10)



Explanation

Groundwater elevation (ft amsl)

Total dissolved solids (mg/L)

WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-06

Monthly Precipitation and Total Dissolved Solids

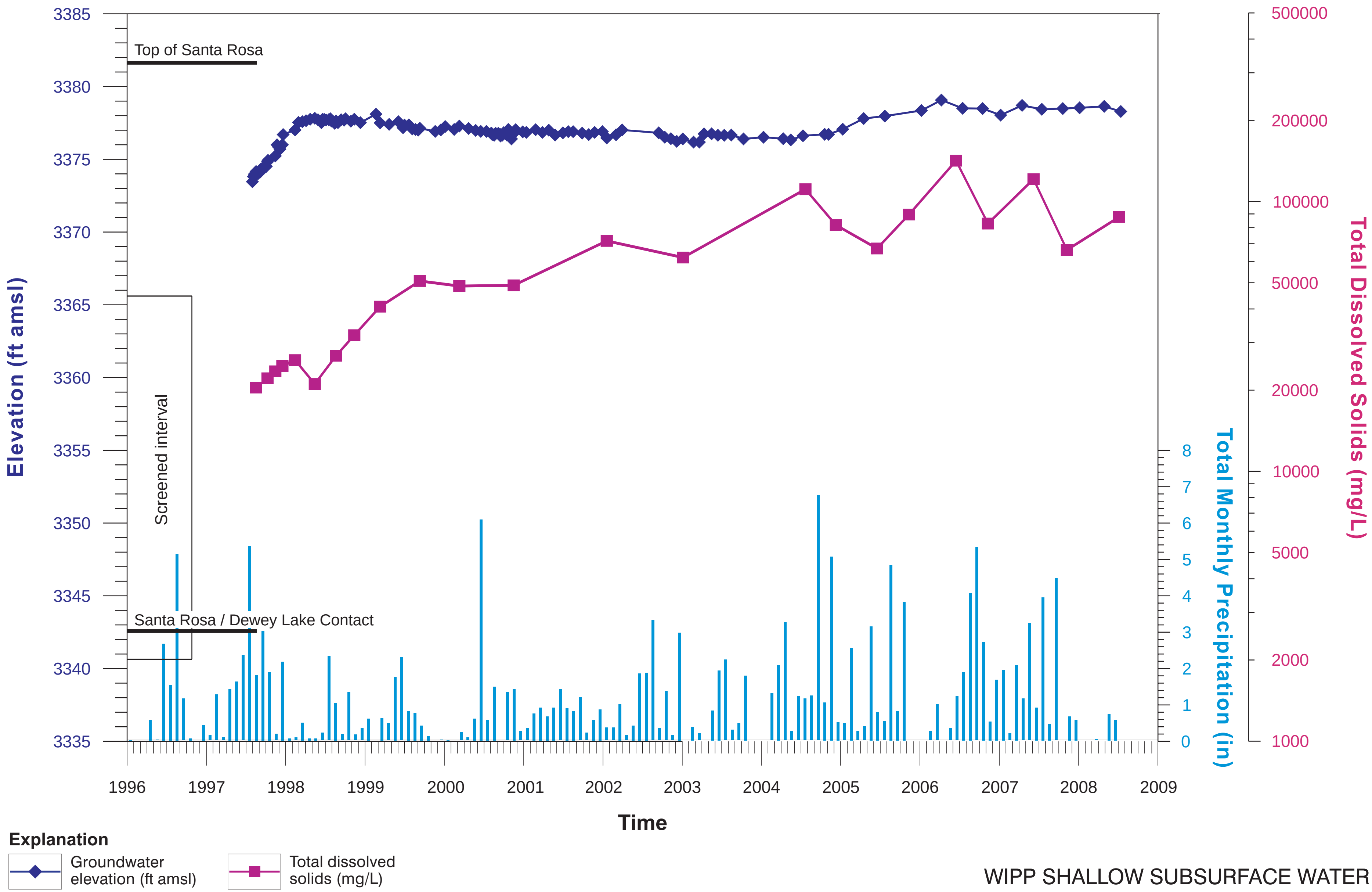
Daniel B. Stephens & Associates, Inc.

8-28-08

JN ES08.0072

Figure C-10

S:\PROJECTS\ES08.0072_WIPP_SSW\VR_DRAWINGS\ES08_0072_01W.CDR (PG 11)



WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-07

Monthly Precipitation and Total Dissolved Solids

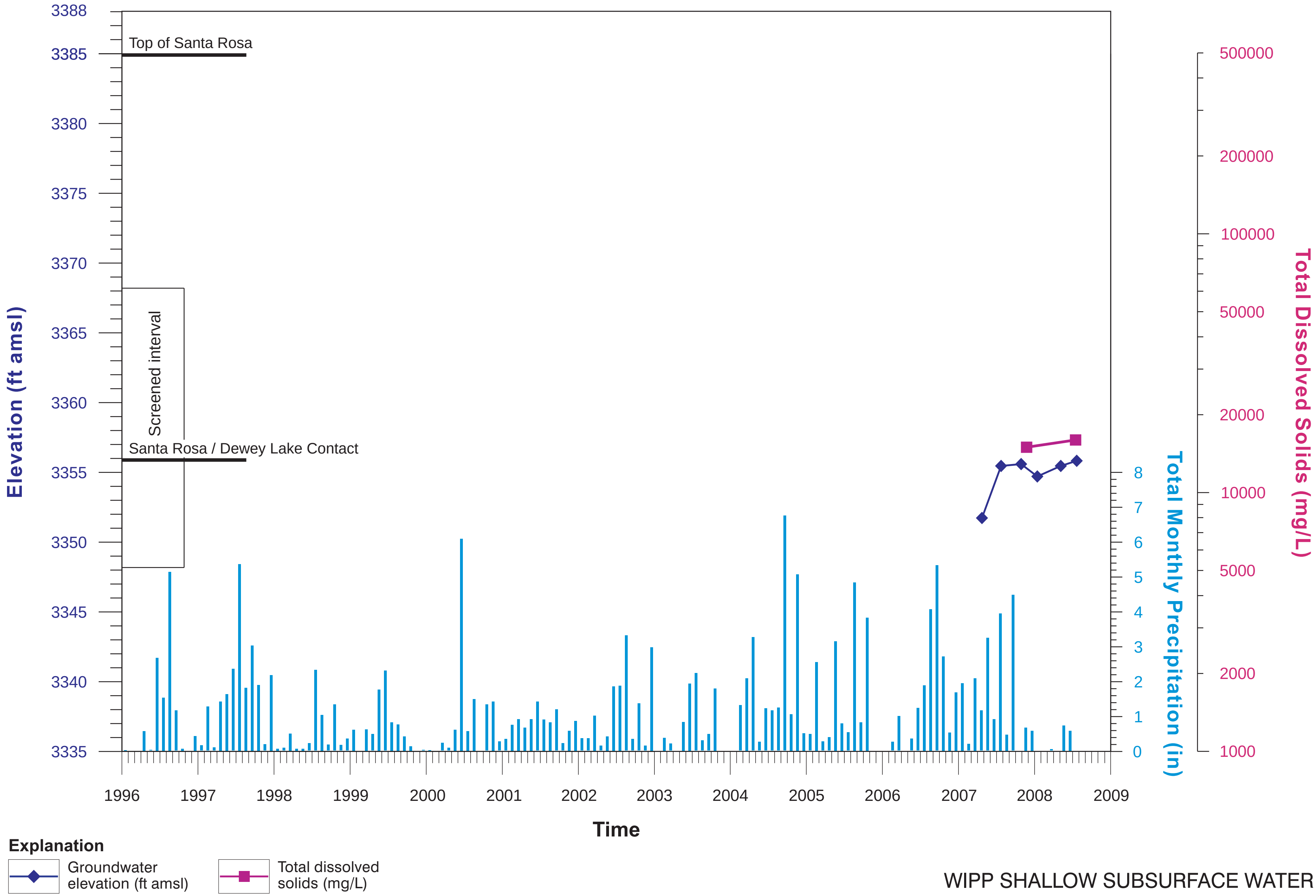
Figure C-11

Daniel B. Stephens & Associates, Inc.

8-28-08

JN ES08.0072

S:\PROJECTS\ES08.0072_WIPP_SSW\VR_DRAWINGS\ES08_0072_01W.CDR (PG 12)



WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-08

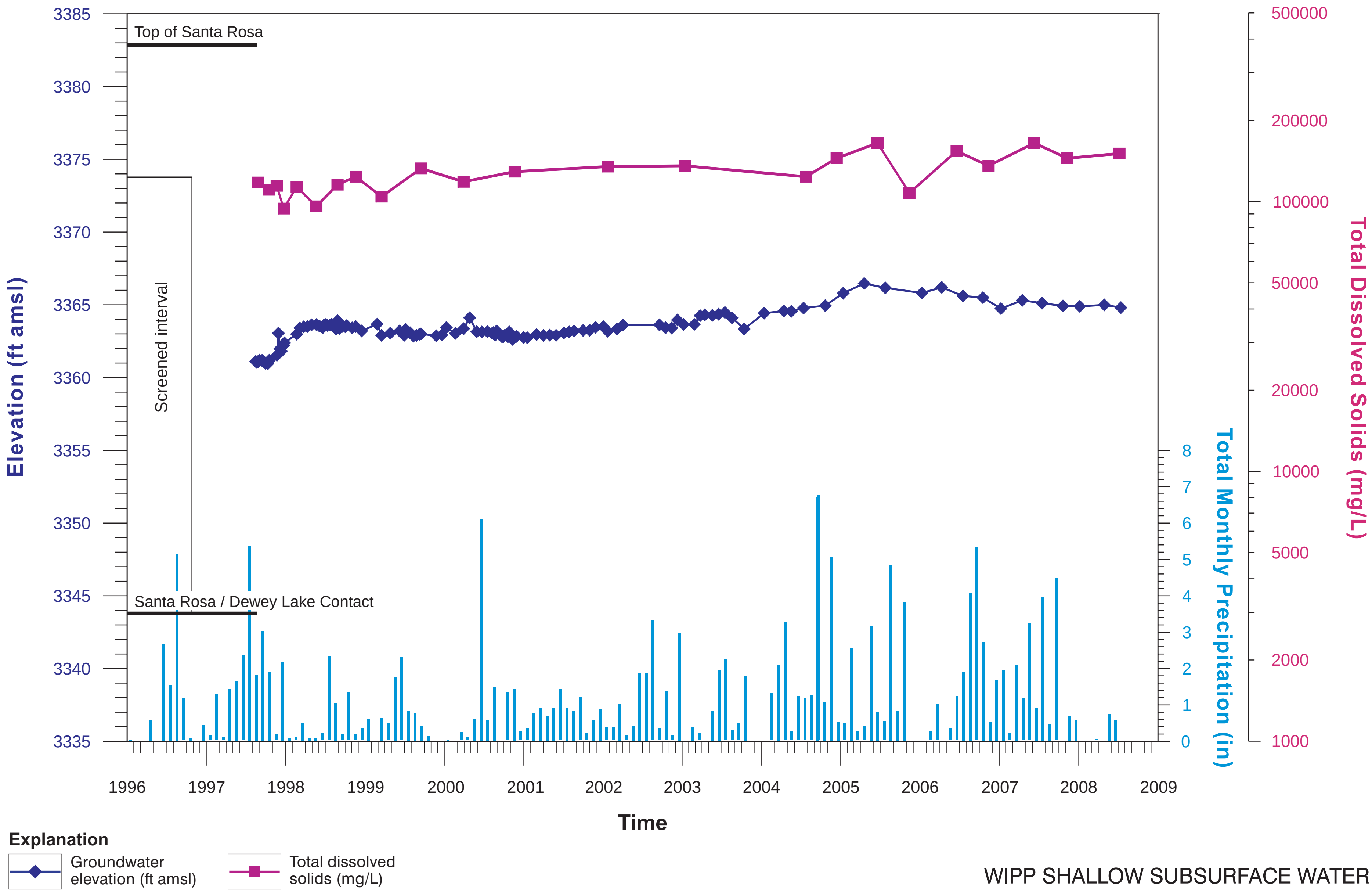
Monthly Precipitation and Total Dissolved Solids

Daniel B. Stephens & Associates, Inc.

8-28-08

JN ES08.0072

Figure C-12



WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-09

Monthly Precipitation and Total Dissolved Solids

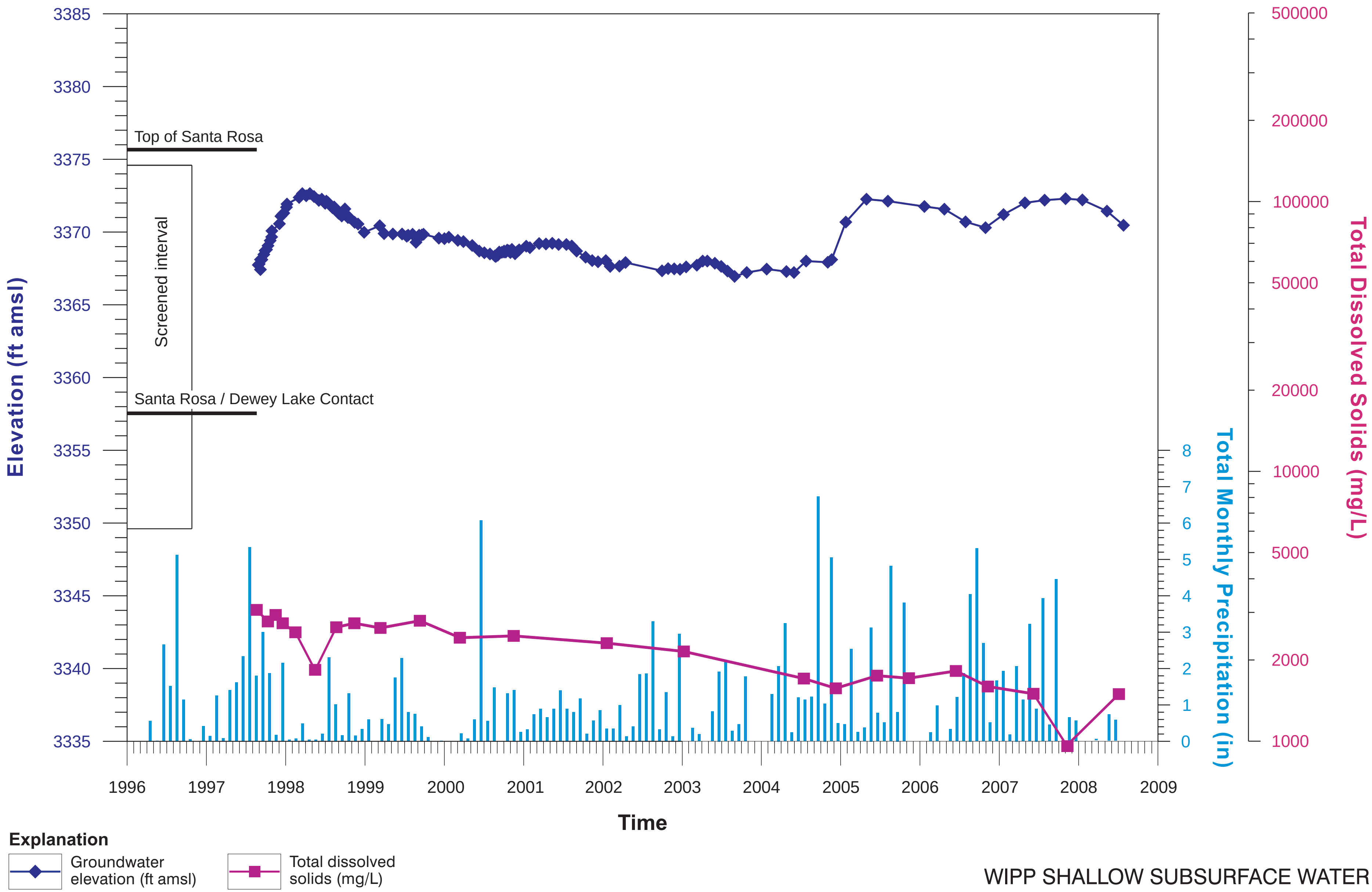
Daniel B. Stephens & Associates, Inc.

8-28-08

JN ES08.0072

Figure C-13

S:\PROJECTS\ES08.0072_WIPP_SSW\VR_DRAWINGS\ES08_0072_01W.CDR (PG 14)



WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-10

Monthly Precipitation and Total Dissolved Solids

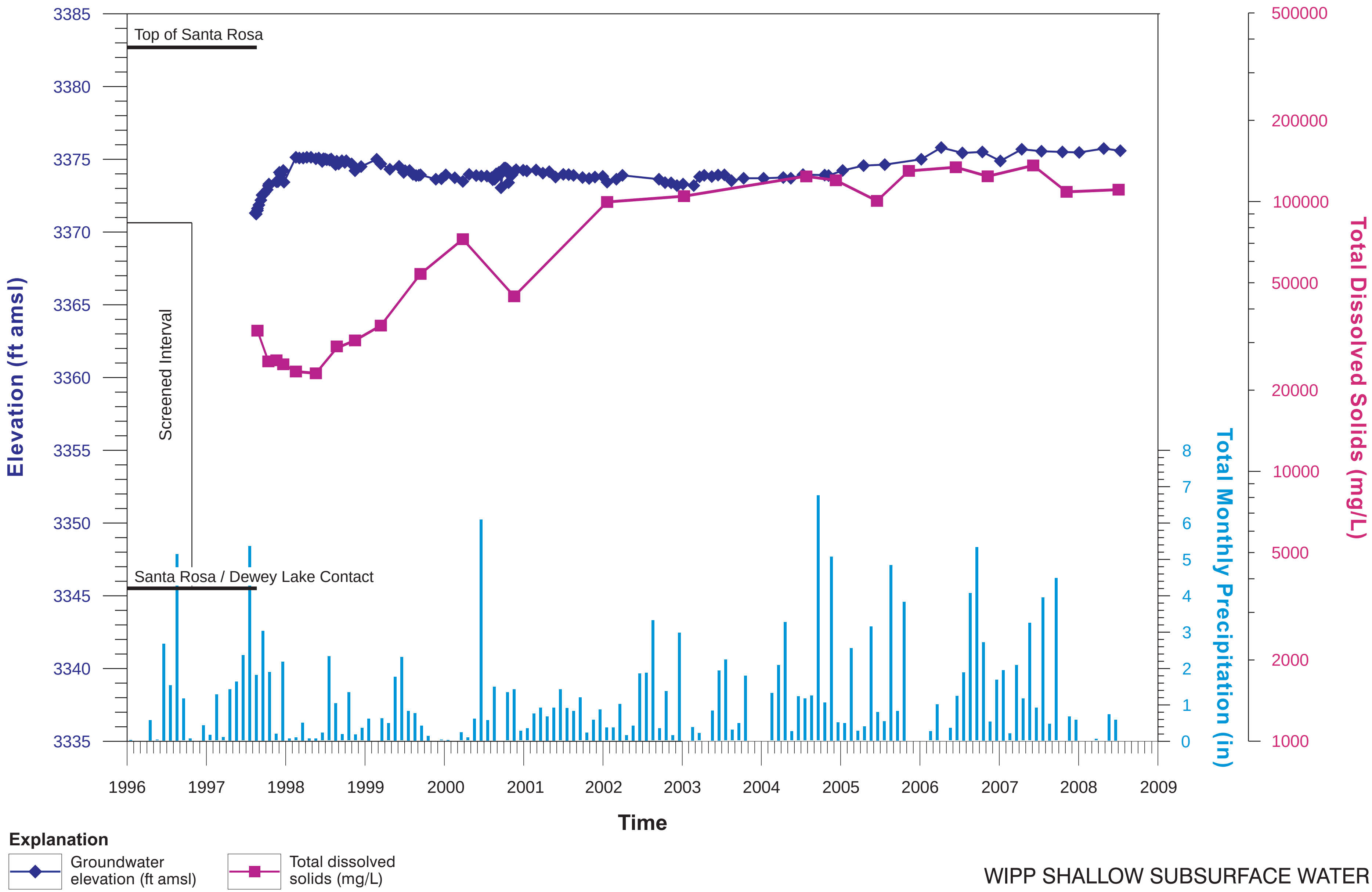
Daniel B. Stephens & Associates, Inc.

8-28-08

JN ES08.0072

Figure C-14

S:\PROJECTS\ES08.0072_WIPP_SSW\VR_DRAWINGS\ES08_0072_01W.CDR (PG 15)



WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-11

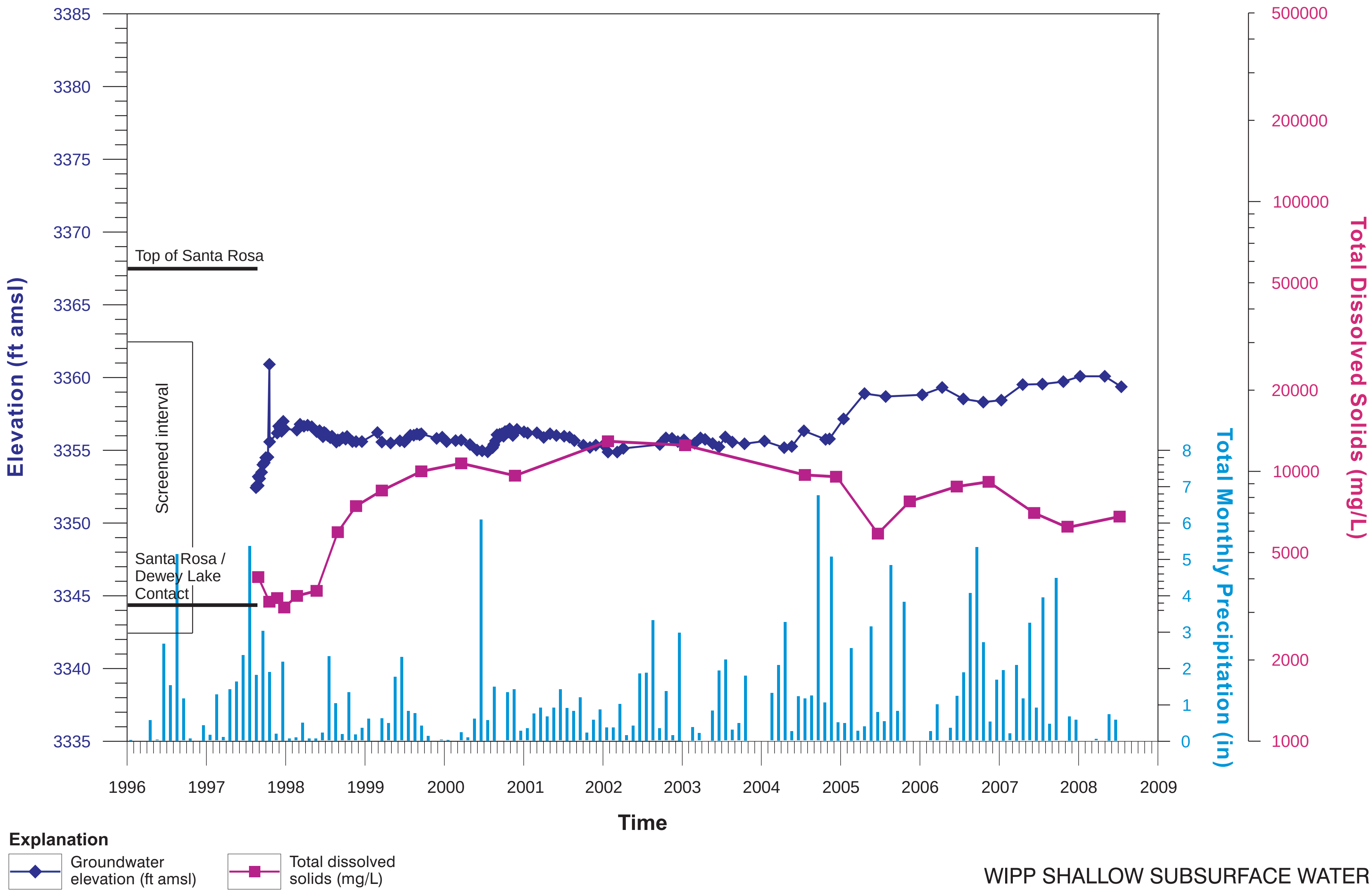
Monthly Precipitation and Total Dissolved Solids

Daniel B. Stephens & Associates, Inc.

8-28-08

JN ES08.0072

Figure C-15



WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-12

Monthly Precipitation and Total Dissolved Solids

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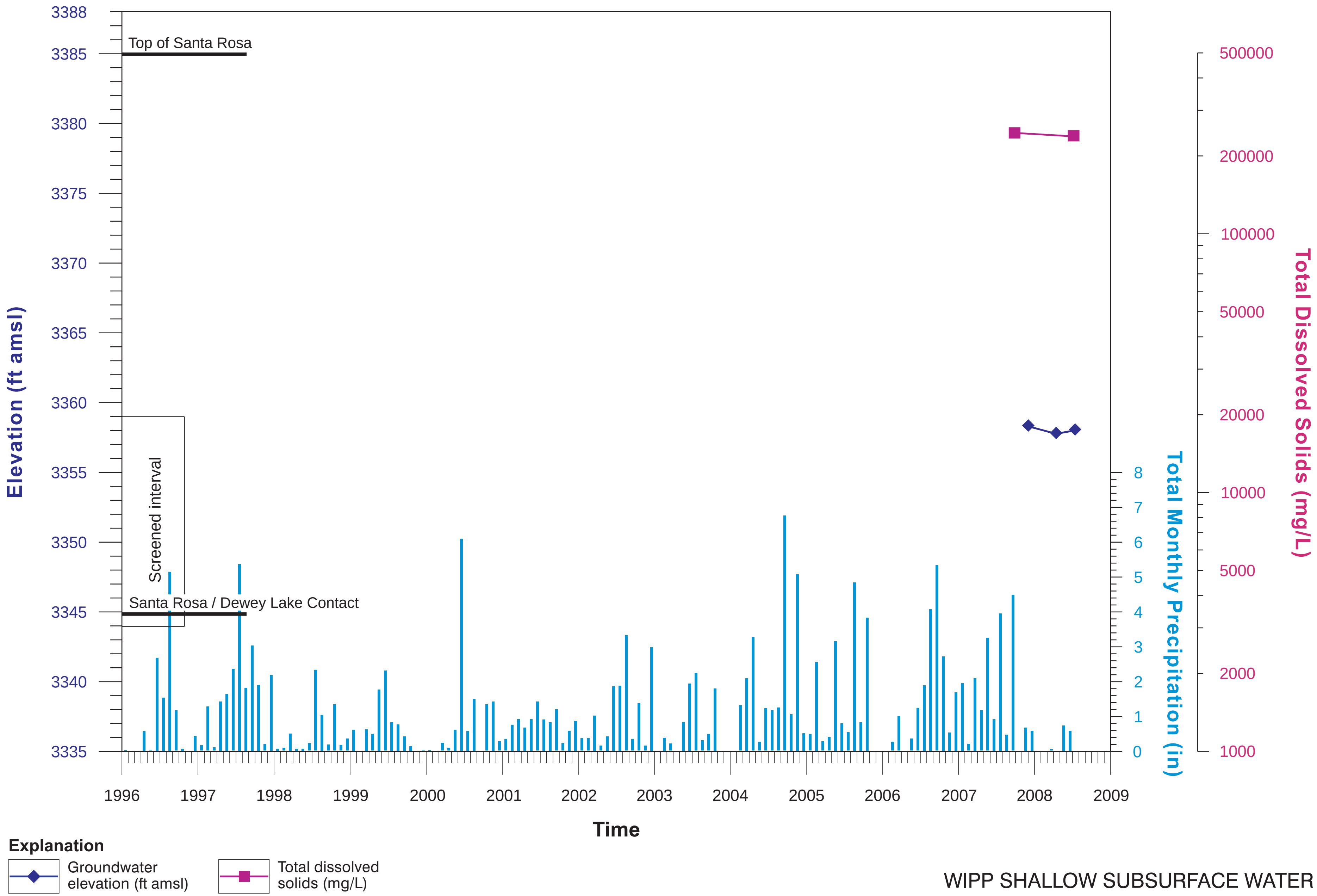
8-28-08

JN ES08.0072



WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-13

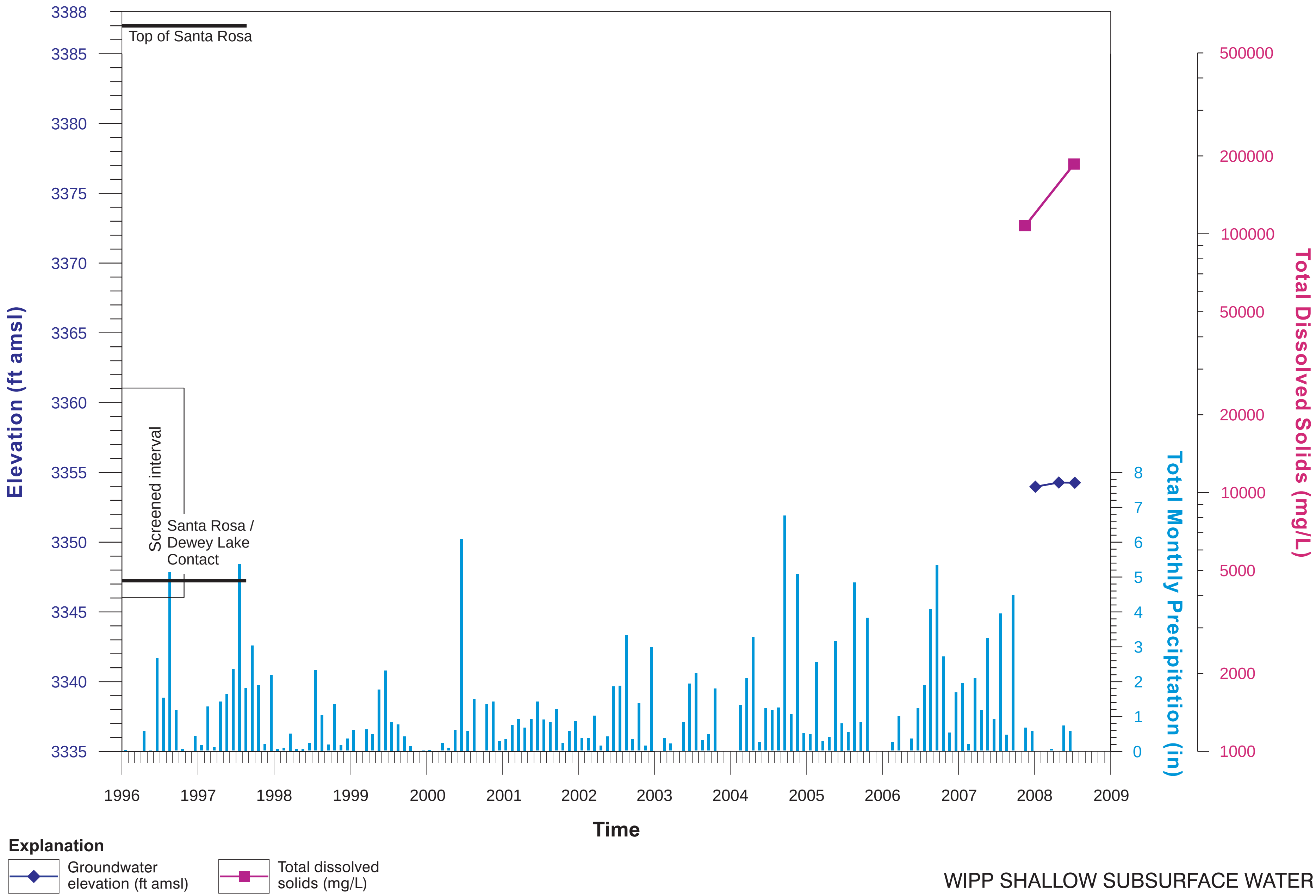
Monthly Precipitation and Total Dissolved Solids

Daniel B. Stephens & Associates, Inc.

8-28-08

JN ES08.0072

S:\PROJECTS\ES08.0072_WIPP_SSW\VR_DRAWINGS\ES08_0072_01W.CDR (PG 18)



WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-14

Monthly Precipitation and Total Dissolved Solids

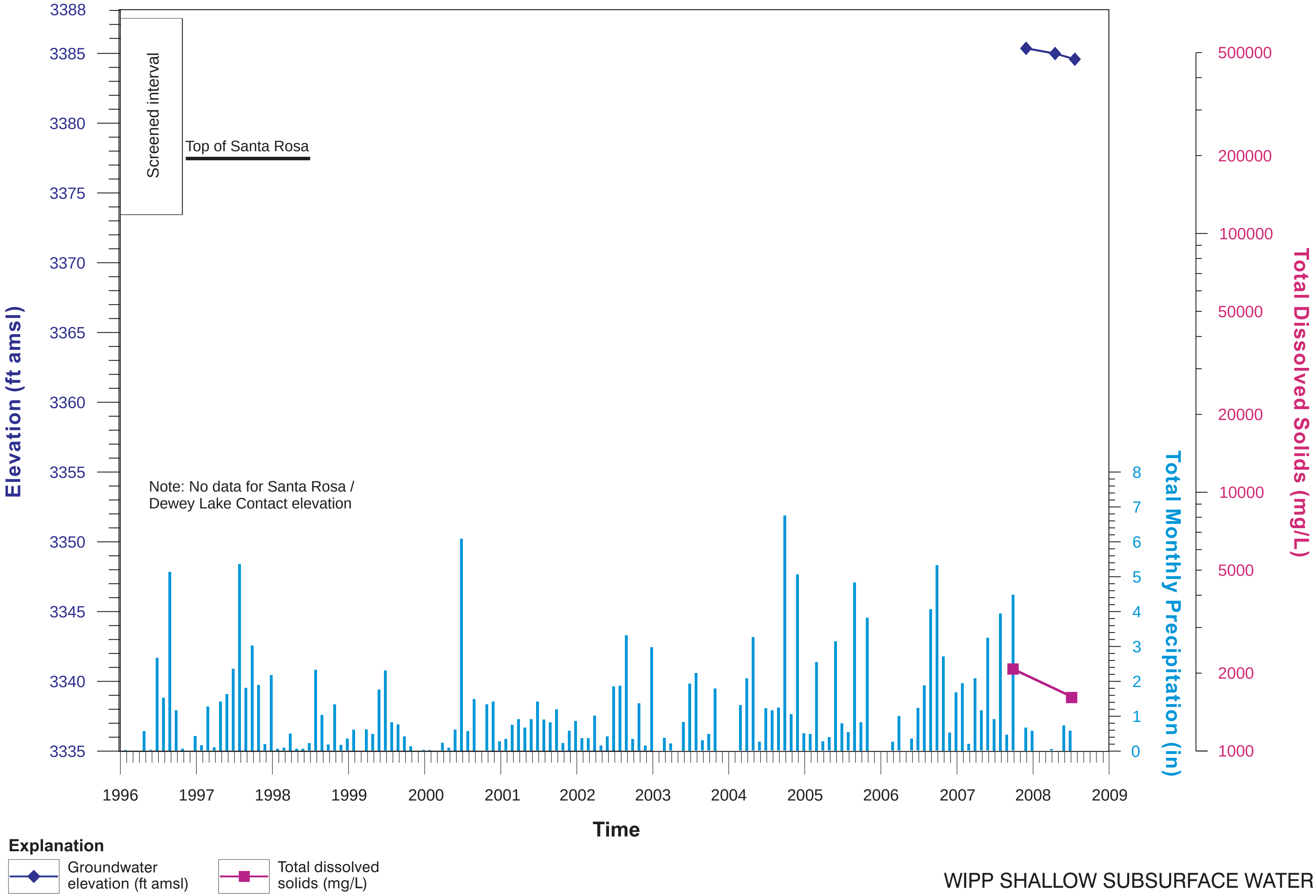
Daniel B. Stephens & Associates, Inc.

8-28-08

JN ES08.0072

Figure C-18

S:\PROJECTS\ES08.0072_WIPP_SSW\VR_DRAWINGS\ES08_0072_01W.CDR (PG 19)



WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-15

Monthly Precipitation and Total Dissolved Solids

Daniel B. Stephens & Associates, Inc.

8-28-08

JN ES08.0072

Figure C-19

Appendix D

Cross Correlation Calculations

Calculation Sheet - Time Series Analysis

Location: Piezometer PZ-07
Time Range: 09/1997 - 06/2004 (UnLined)

Objective

Perform correlation analyses to qualitatively assess the response of water levels in wells to precipitation.

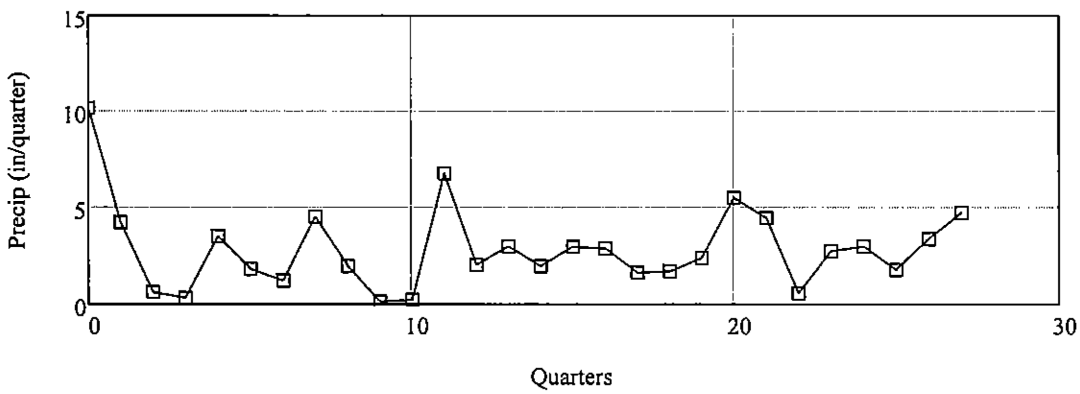
Methods

Auto-Correlation: Qualitatively shows the dependence of water-level or precipitation on time. Data series where this is no relation between measurements will show a sharply peaked graph of autocorrelation over lag (common for precipitation). Data series that are dependent to some degree on the previous measurement will have a more gradual (exponential) slope (common for water-level).

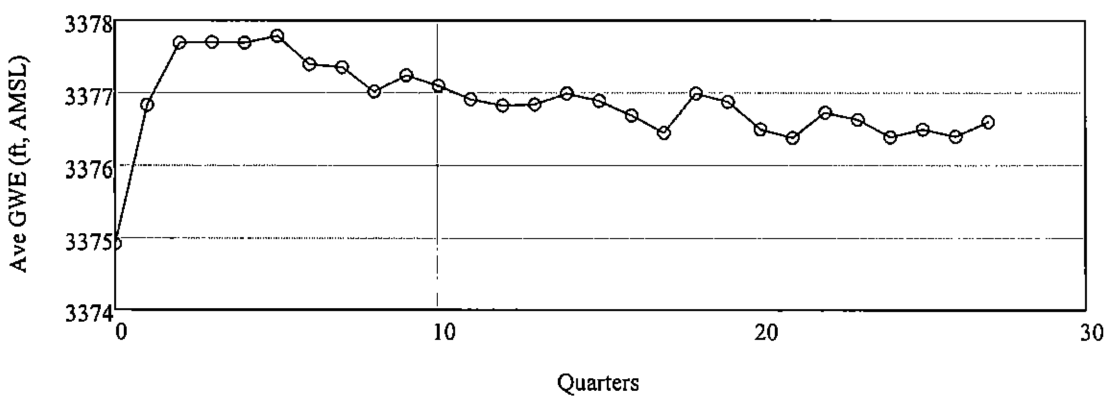
Cross-Correlation: Qualitatively shows the inter-dependence of water-level and precipitation. The lag distance from 0 to the peak is the approximate delay between precipitation and water-level response. The height of the peak qualitatively indicates the degree of "connection" between precipitation and water-level response.

Input Data

Total precipitation per quarter (in/quarter).



Quarterly average water level elevation (ft, AMSL).



Summary Statistics

Precipitation (in/quarter)

Mean: $\mu_x := mean(x)$ $\mu_x = 2.86$

Variance: $\sigma 2_x := var(x)$ $\sigma 2_x = 4.565$

Count: $N = 28$

Maximum: $max(x) = 10.15$

Minimum: $min(x) = 0.14$

Quarterly Average Water Elevation (ft, AMSL)

Mean: $\mu_y := mean(y)$ $\mu_y = 3376.87$

Variance: $\sigma 2_y := var(y)$ $\sigma 2_y = 0.313$

Count: $N = 28$

Maximum: $max(y) = 3377.78$

Minimum: $min(y) = 3374.92$

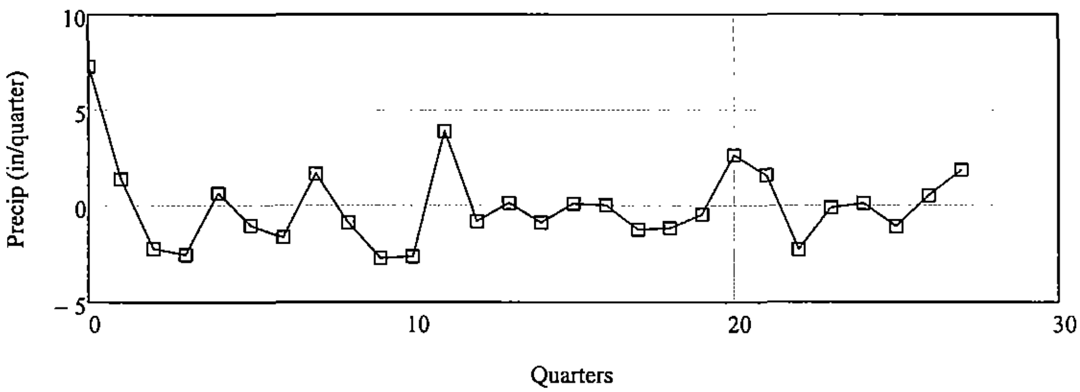
Zero-Mean Perturbation

Remove mean from data to obtain zero-mean perturbation for calculations.

Precipitation

Remove mean: $x0_i := x_i - \mu_x$

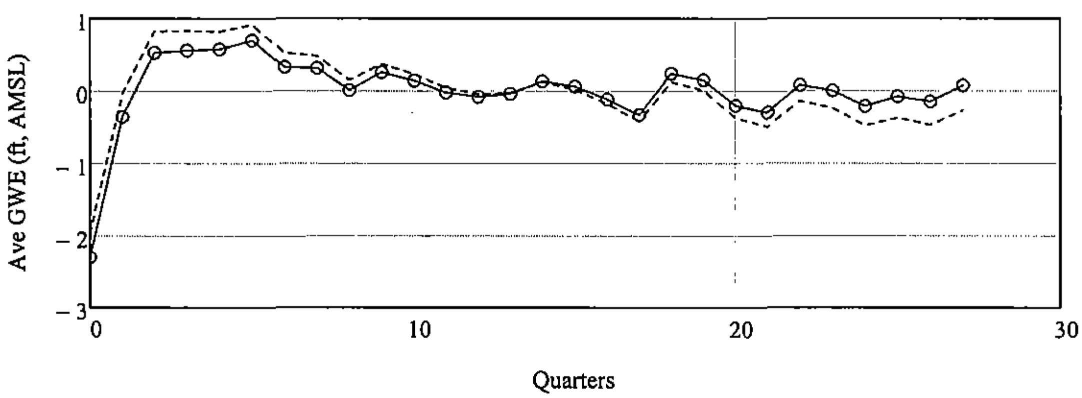
Zero-mean perturbation of total precipitation per quarter (in/quarter).



Quarterly Average Water Elevation

Remove mean: $y1_i := y_i - \mu_y$ Remove trend: $I_i := i \cdot 1$ $y0_i := y1_i - (slope(I, y1) \cdot i + intercept(I, y1))$

Zero-mean perturbation of quarterly average water level elevation (ft, AMSL).



Global Correlation Parameters

Count: $N = 28$

Maximum Lag: $MaxLag := 5$

Autocorrelation

Fast Fourier Transform Method for Discrete Covariance Estimate (Press et al., 1992)

Autocorrelation of Precipitation

Calculate the Complex Fast Fourier Transform (doesn't require zero padding)

$\Xi := CFFT(x0)$

Calculate the product of the transform with its complex conjugate

$j := 0 .. rows(\Xi) - 1$ $\quad Z_j := \Xi_j \cdot \overline{\Xi_j}$

The inverse gives the Autocovariance. Correlation = covariance / variance

$Corr := ICFFT(Z)$ $\quad r := 0 .. MaxLag$ $\quad Rx_{est_r} := Corr_r$

Autocorrelation of Average Quarterly Water Level

Calculate the Complex Fast Fourier Transform (doesn't require zero padding)

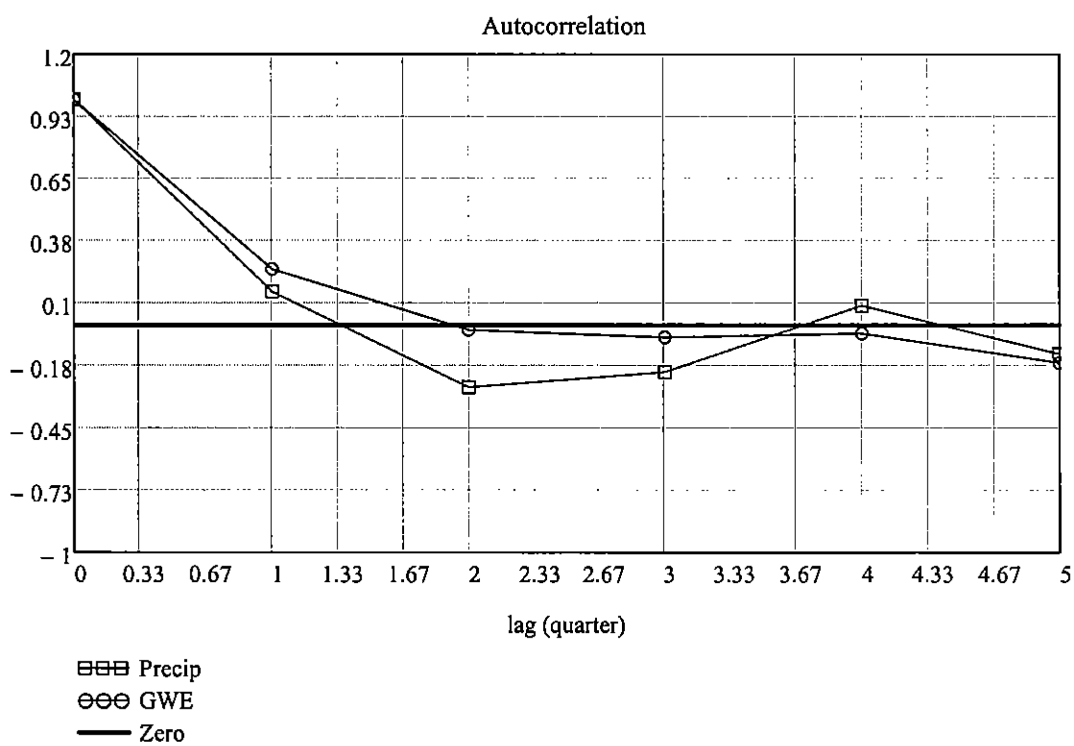
$\Psi := CFFT(y0)$

Calculate the product of the transform with its complex conjugate

$j := 0 .. rows(\Psi) - 1$ $\quad Z_j := \Psi_j \cdot \overline{\Psi_j}$

The inverse gives the Autocovariance

$Corr := ICFFT(Z)$ $\quad MaxLag = 5$ $\quad r := 0 .. MaxLag$ $\quad Ry_{est_r} := Corr_r$



Cross-Correlation

Use Complex Fast Fourier Transforms from above. Calculate the product of the x transform with the complex conjugate of the y transform (x leads y)

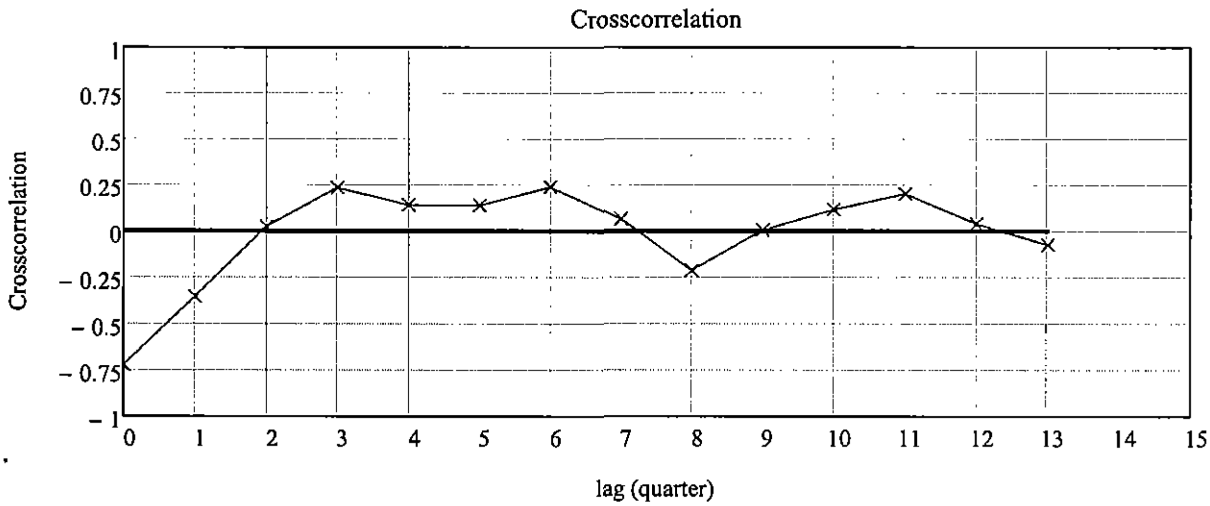
$j := 0 .. \text{rows}(\Xi) - 1$ $\quad Z_j := \Psi_j \cdot \overline{\Xi_j}$

The inverse gives the Cross-covariance (Not necessarily symmetrical so index r must be adjusted to show negative lags. CrossCorr array contains positive lag results from 0 to N/2 and negative lag results from N to N/2 [in reverse]. CrossCorr results are then mapped into the Rxy array from 0 to N-1)

$\text{CrossCorr} := \text{ICFFT}(Z)$

$r := 0 .. \frac{N}{2} - 1 \quad Rxy_{est_r} := \text{CrossCorr}_{\frac{N}{2}+r}$

$r := \frac{N}{2} .. N - 1 \quad Rxy_{est_r} := \text{CrossCorr}_{r-\frac{N}{2}}$



References

Press, W. H., S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery, Numerical Recipes in C, 2n edition (revised 1995), Cambridge Univ. Press, New York, N. Y., 1992

DATA :=

	0	1
0	$3.375 \cdot 10^3$	10.15
1	$3.377 \cdot 10^3$	4.22
2	$3.378 \cdot 10^3$	0.62
3	$3.378 \cdot 10^3$	0.31
4	$3.378 \cdot 10^3$	3.5
5	$3.378 \cdot 10^3$	1.82
6	$3.377 \cdot 10^3$	1.21
7	$3.377 \cdot 10^3$	4.51
8	$3.377 \cdot 10^3$	1.97
9	$3.377 \cdot 10^3$	0.14
10	$3.377 \cdot 10^3$	0.23
11	$3.377 \cdot 10^3$	6.75
12	$3.377 \cdot 10^3$	2.04
13	$3.377 \cdot 10^3$	2.99
14	$3.377 \cdot 10^3$	1.97
15	$3.377 \cdot 10^3$	...

$N := \text{rows}(DATA)$ $N = 28$ $i := 0..\text{rows}(DATA) - 1$

$x_i := DATA_{i,1}$ $y_i := DATA_{i,0}$

$f(X) := X \cdot 0$

Calculation Sheet - Time Series Analysis

Location: Piezometer PZ-07
Time Range: 06/2005 - 03/2008 (Lined)

Objective

Perform correlation analyses to qualitatively assess the response of water levels in wells to precipitation.

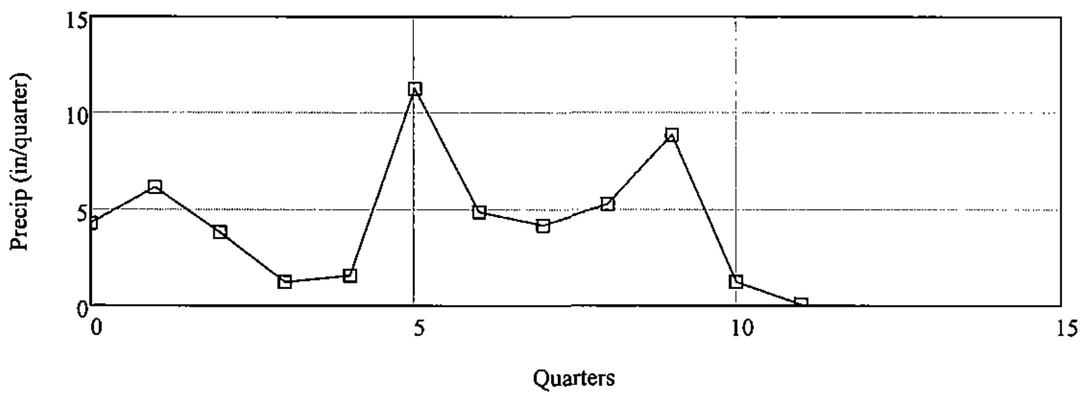
Methods

Auto-Correlation: Qualitatively shows the dependence of water-level or precipitation on time. Data series where this is no relation between measurements will show a sharply peaked graph of autocorrelation over lag (common for precipitation). Data series that are dependent to some degree on the previous measurement will have a more gradual (exponential) slope (common for water-level).

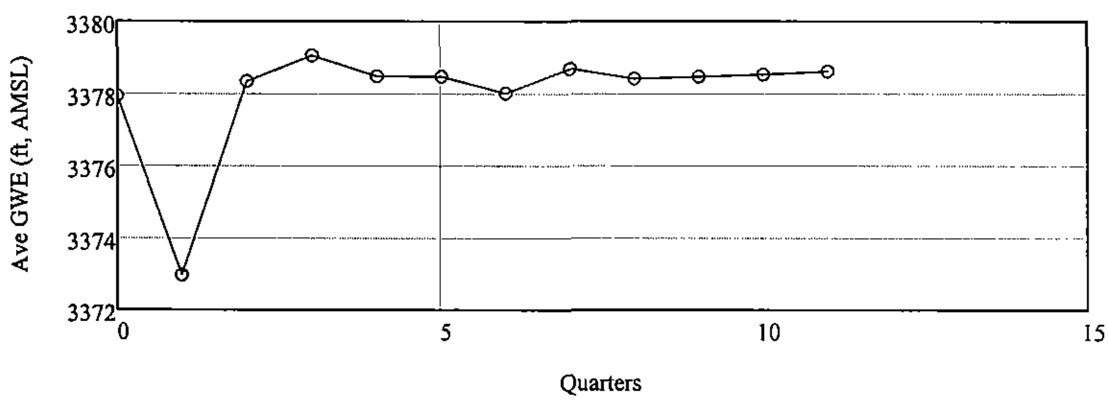
Cross-Correlation: Qualitatively shows the inter-dependence of water-level and precipitation. The lag distance from 0 to the peak is the approximate delay between precipitation and water-level response. The height of the peak qualitatively indicates the degree of "connection" between precipitation and water-level response.

Input Data

Total precipitation per quarter (in/quarter).



Quarterly average water level elevation (ft, AMSL).



Summary Statistics

Precipitation (in/quarter)

Mean: $\mu_x := \text{mean}(x)$ $\mu_x = 4.399$

Variance: $\sigma2_x := \text{var}(x)$ $\sigma2_x = 9.815$

Count: $N = 12$

Maximum: $\max(x) = 11.23$

Minimum: $\min(x) = 0.07$

Quarterly Average Water Elevation (ft, AMSL)

Mean: $\mu_y := \text{mean}(y)$ $\mu_y = 3378$

Variance: $\sigma2_y := \text{var}(y)$ $\sigma2_y = 2.384$

Count: $N = 12$

Maximum: $\max(y) = 3379.06$

Minimum: $\min(y) = 3372.97$

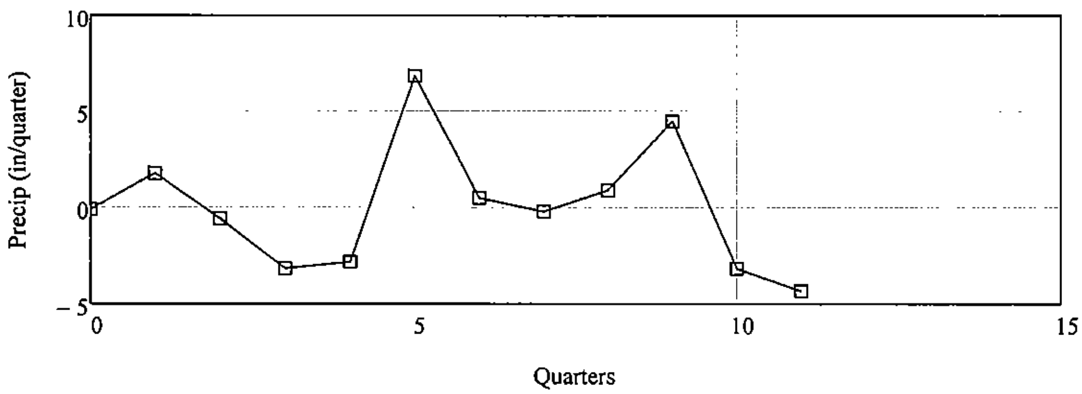
Zero-Mean Perturbation

Remove mean from data to obtain zero-mean perturbation for calculations.

Precipitation

Remove mean: $x0_i := x_i - \mu_x$

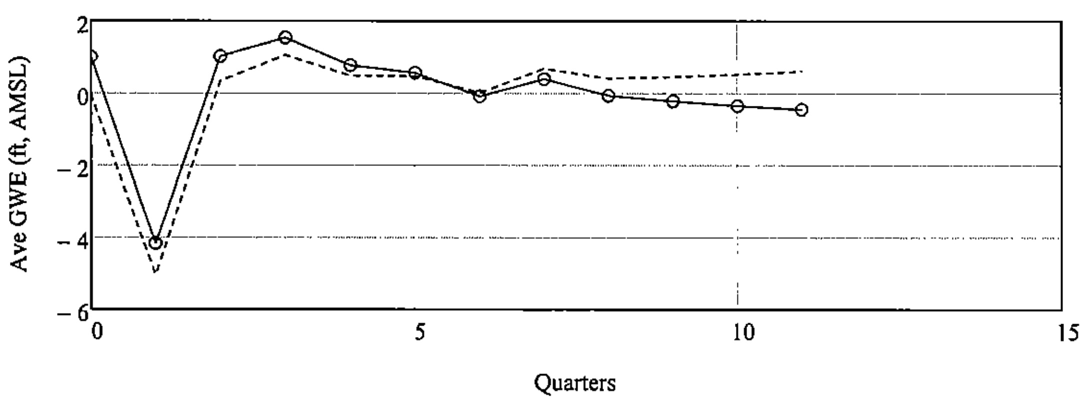
Zero-mean perturbation of total precipitation per quarter (in/quarter).



Quarterly Average Water Elevation

Remove mean: $y1_i := y_i - \mu_y$ Remove trend: $I_i := i \cdot 1$ $y0_i := y1_i - (\text{slope}(I, y1) \cdot i + \text{intercept}(I, y1))$

Zero-mean perturbation of quarterly average water level elevation (ft, AMSL).



Global Correlation Parameters

Count: $N = 12$

Maximum Lag: $MaxLag := 5$

Autocorrelation

Fast Fourier Transform Method for Discrete Covariance Estimate (Press et al., 1992)

Autocorrelation of Precipitation

Calculate the Complex Fast Fourier Transform (doesn't require zero padding)

$\Xi := CFFT(x0)$

Calculate the product of the transform with its complex conjugate

$j := 0 .. rows(\Xi) - 1$ $\quad Z_j := \Xi_j \cdot \overline{\Xi_j}$

The inverse gives the Autocovariance. Correlation = covariance / variance

$Corr := ICFFT(Z)$ $\quad r := 0 .. MaxLag$ $\quad Rx_{est_r} := Corr_r$

Autocorrelation of Average Quarterly Water Level

Calculate the Complex Fast Fourier Transform (doesn't require zero padding)

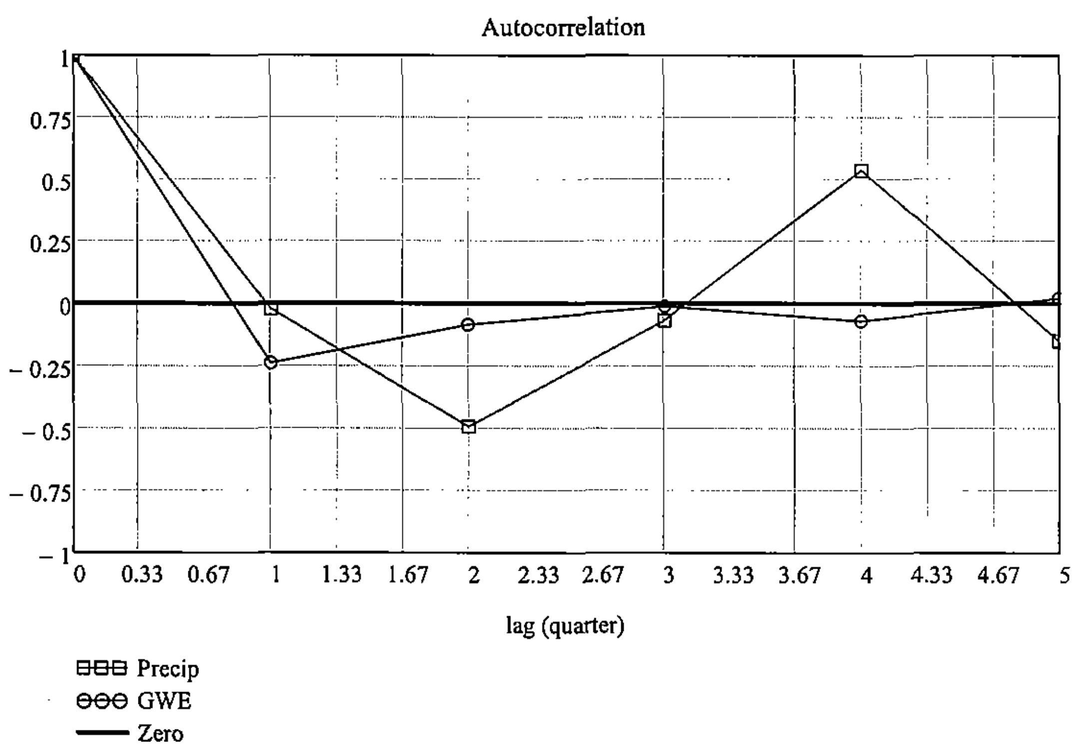
$\Psi := CFFT(y0)$

Calculate the product of the transform with its complex conjugate

$j := 0 .. rows(\Psi) - 1$ $\quad Z_j := \Psi_j \cdot \overline{\Psi_j}$

The inverse gives the Autocovariance

$Corr := ICFFT(Z)$ $\quad MaxLag = 5$ $\quad r := 0 .. MaxLag$ $\quad Ry_{est_r} := Corr_r$



Cross-Correlation

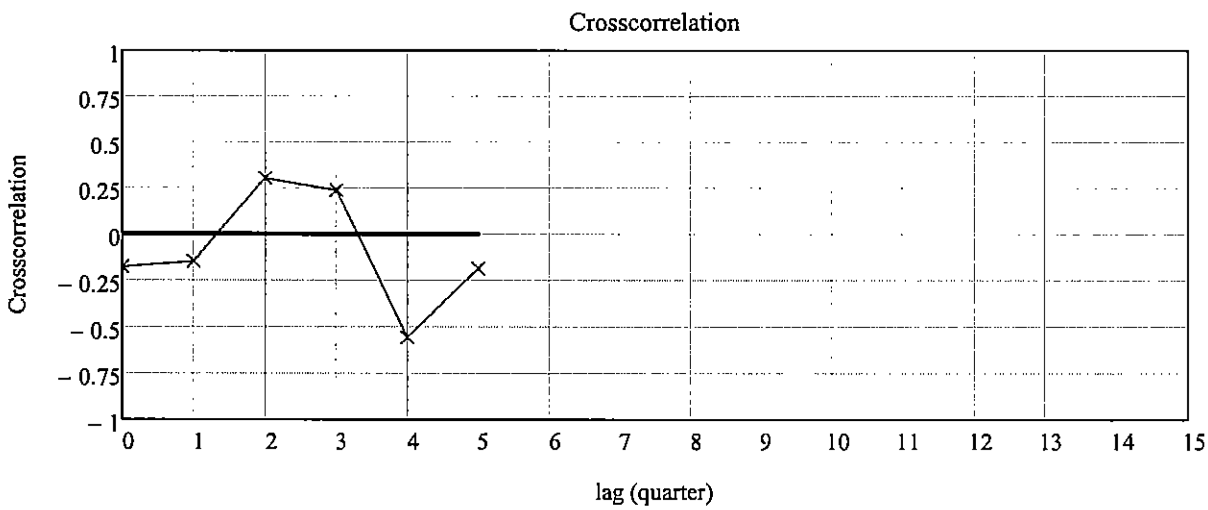
Use Complex Fast Fourier Transforms from above. Calculate the product of the x transform with the complex conjugate of the y transform (x leads y)

$j := 0 .. \text{rows}(\Xi) - 1$ $\quad\quad Z_j := \Psi_j \cdot \overline{\Xi_j}$

The inverse gives the Cross-covariance (Not necessarily symmetrical so index r must be adjusted to show negative lags. CrossCorr array contains positive lag results from 0 to N/2 and negative lag results from N to N/2 [in reverse]. CrossCorr results are then mapped into the Rxy array from 0 to N-1)

$\text{CrossCorr} := \text{ICFFT}(Z)$ $\quad\quad r := 0 .. \frac{N}{2} - 1$ $\quad\quad Rxy_{est_r} := \text{CrossCorr}_{\frac{N}{2}+r}$

$r := \frac{N}{2} .. N - 1$ $\quad\quad Rxy_{est_r} := \text{CrossCorr}_{r-\frac{N}{2}}$



References

Press, W. H., S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery, Numerical Recipes in C, 2n edition (revised 1995), Cambridge Univ. Press, New York, N. Y., 1992

DATA :=

	0	1
0	$3.378\cdot10^3$	4.29
1	$3.373\cdot10^3$	6.15
2	$3.378\cdot10^3$	3.81
3	$3.379\cdot10^3$	1.24
4	$3.378\cdot10^3$	1.56
5	$3.378\cdot10^3$	11.23
6	$3.378\cdot10^3$	4.888
7	$3.379\cdot10^3$	4.19
8	$3.378\cdot10^3$	5.28
9	$3.378\cdot10^3$	8.85
10	$3.379\cdot10^3$	1.23
11	$3.379\cdot10^3$	0.07

$N := \text{rows}(DATA)$ $N = 12$ $i := 0..\text{rows}(DATA) - 1$

$x_i := DATA_{i,1}$ $y_i := DATA_{i,0}$

$f(X) := X\cdot0$

Calculation Sheet - Time Series Analysis

Location: Piezometer PZ-09
Time Range: 09/1997 - 06/2004 (UnLined)

Objective

Perform correlation analyses to qualitatively assess the response of water levels in wells to precipitation.

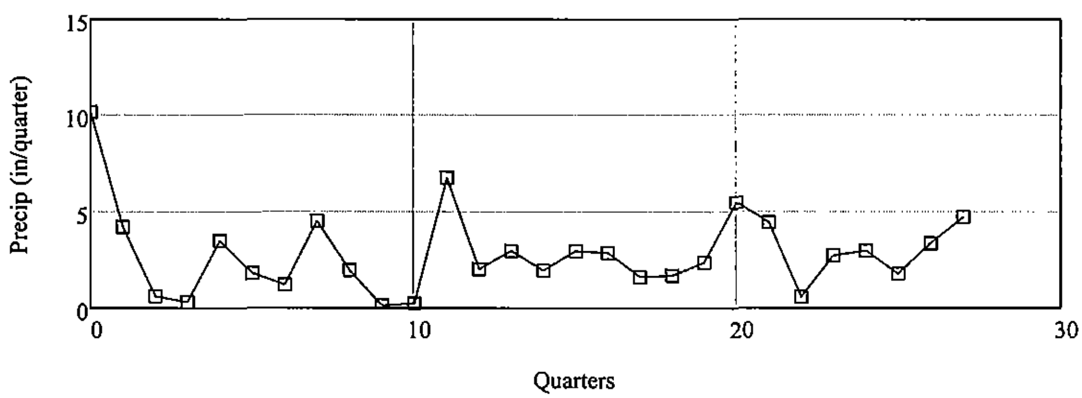
Methods

Auto-Correlation: Qualitatively shows the dependence of water-level or precipitation on time. Data series where this is no relation between measurements will show a sharply peaked graph of autocorrelation over lag (common for precipitation). Data series that are dependent to some degree on the previous measurement will have a more gradual (exponential) slope (common for water-level).

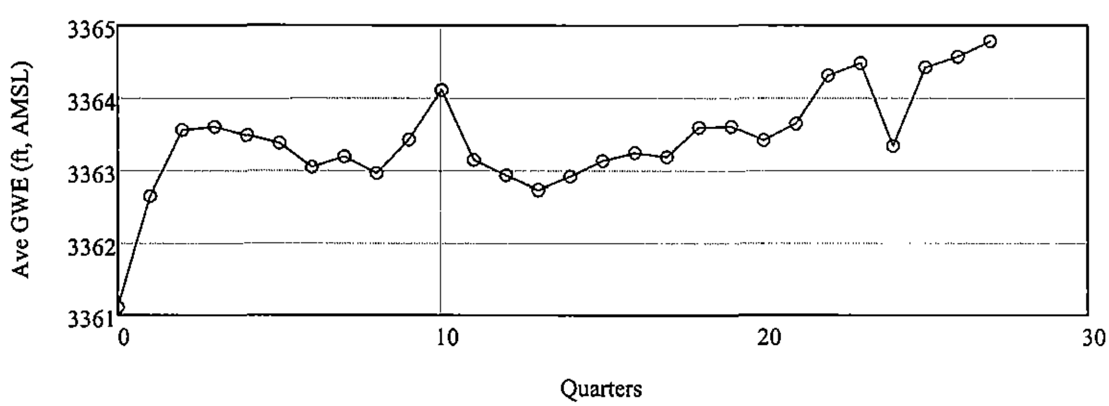
Cross-Correlation: Qualitatively shows the inter-dependence of water-level and precipitation. The lag distance from 0 to the peak is the approximate delay between precipitation and water-level response. The height of the peak qualitatively indicates the degree of "connection" between precipitation and water-level response.

Input Data

Total precipitation per quarter (in/quarter).



Quarterly average water level elevation (ft, AMSL).



Summary Statistics

Precipitation (in/quarter)

Mean: $\mu_x := \text{mean}(x)$ $\mu_x = 2.86$

Variance: $\sigma2_x := \text{var}(x)$ $\sigma2_x = 4.565$

Count: $N = 28$

Maximum: $\max(x) = 10.15$

Minimum: $\min(x) = 0.14$

Quarterly Average Water Elevation (ft, AMSL)

Mean: $\mu_y := \text{mean}(y)$ $\mu_y = 3363.43$

Variance: $\sigma2_y := \text{var}(y)$ $\sigma2_y = 0.509$

Count: $N = 28$

Maximum: $\max(y) = 3364.78$

Minimum: $\min(y) = 3361.11$

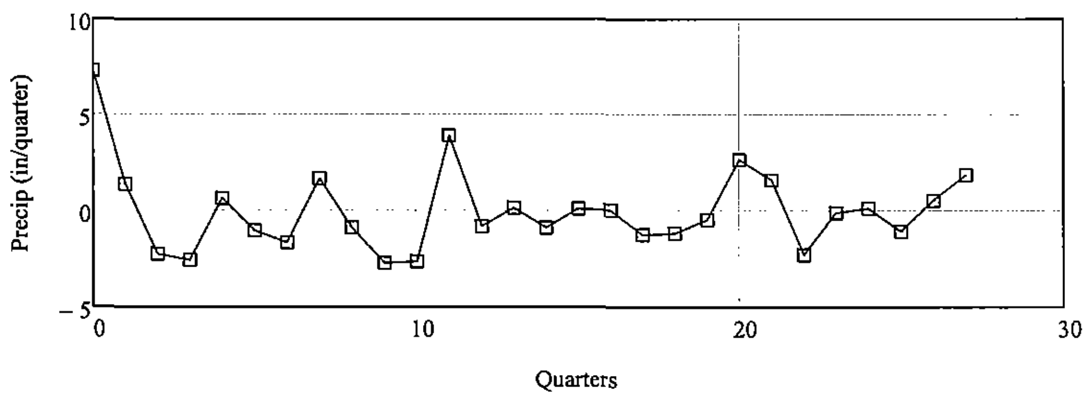
Zero-Mean Perturbation

Remove mean from data to obtain zero-mean perturbation for calculations.

Precipitation

Remove mean: $x0_i := x_i - \mu_x$

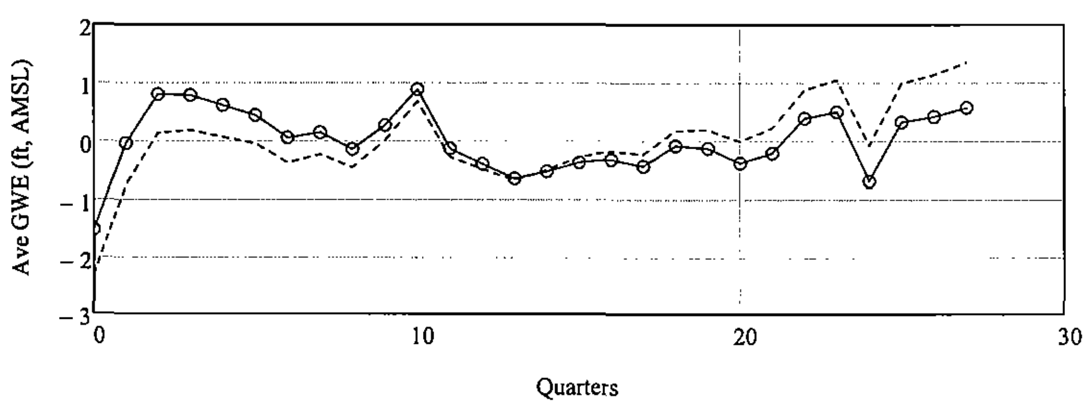
Zero-mean perturbation of total precipitation per quarter (in/quarter).



Quarterly Average Water Elevation

Remove mean: $y1_i := y_i - \mu_y$ Remove trend: $I_i := i \cdot 1$ $y0_i := y1_i - (\text{slope}(I, y1) \cdot i + \text{intercept}(I, y1))$

Zero-mean perturbation of quarterly average water level elevation (ft, AMSL).



Global Correlation Parameters

Count: $N = 28$

Maximum Lag: $MaxLag := 5$

Autocorrelation

Fast Fourier Transform Method for Discrete Covariance Estimate (Press et al., 1992)

Autocorrelation of Precipitation

Calculate the Complex Fast Fourier Transform (doesn't require zero padding)

$\Xi := CFFT(x0)$

Calculate the product of the transform with its complex conjugate

$j := 0..rows(\Xi) - 1$ $\quad Z_j := \Xi_j \cdot \overline{\Xi_j}$

The inverse gives the Autocovariance. Correlation = covariance / variance

$Corr := ICFFT(Z)$ $\quad r := 0..MaxLag$ $\quad Rx_{est_r} := Corr_r$

Autocorrelation of Average Quarterly Water Level

Calculate the Complex Fast Fourier Transform (doesn't require zero padding)

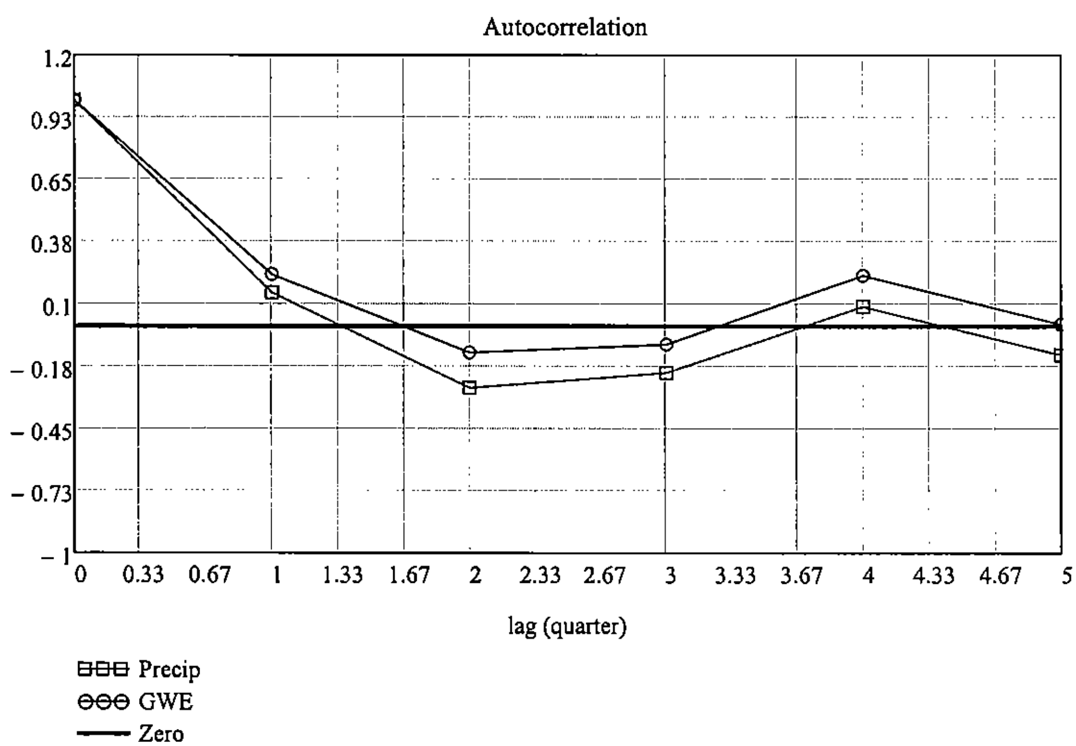
$\Psi := CFFT(y0)$

Calculate the product of the transform with its complex conjugate

$j := 0..rows(\Psi) - 1$ $\quad Z_j := \Psi_j \cdot \overline{\Psi_j}$

The inverse gives the Autocovariance

$Corr := ICFFT(Z)$ $\quad MaxLag = 5$ $\quad r := 0..MaxLag$ $\quad Ry_{est_r} := Corr_r$



Cross-Correlation

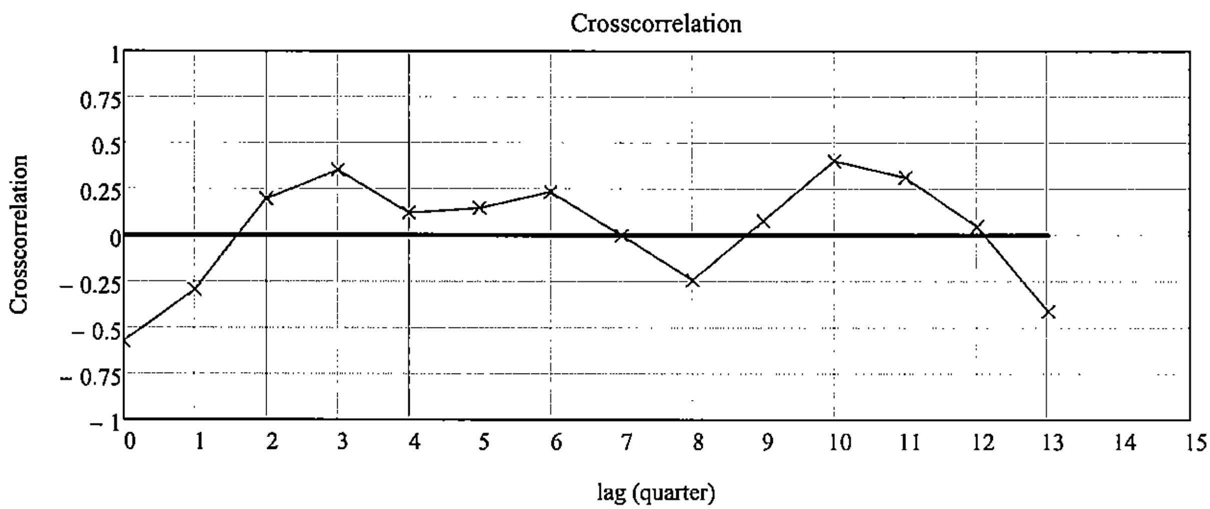
Use Complex Fast Fourier Transforms from above. Calculate the product of the x transform with the complex conjugate of the y transform (x leads y)

$j := 0 .. \mathrm{rows}(\Xi) - 1 \qquad Z_j := \Psi_j \cdot \overline{\Xi_j}$

The inverse gives the Cross-covariance (Not necessarily symmetrical so index r must be adjusted to show negative lags. CrossCorr array contains positive lag results from 0 to N/2 and negative lag results from N to N/2 [in reverse]. CrossCorr results are then mapped into the Rxy array from 0 to N-1)

$\mathrm{CrossCorr} := \mathrm{ICFFT}(Z) \qquad r := 0 .. \frac{N}{2} - 1 \qquad Rxy_{est_r} := \mathrm{CrossCorr}_{\frac{N}{2}+r}$

$r := \frac{N}{2} .. N - 1 \qquad Rxy_{est_r} := \mathrm{CrossCorr}_{r-\frac{N}{2}}$



References

Press, W. H., S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery, Numerical Recipes in C, 2n edition (revised 1995), Cambridge Univ. Press, New York, N. Y., 1992

DATA :=

	0	1
0	$3.361 \cdot 10^3$	10.15
1	$3.363 \cdot 10^3$	4.22
2	$3.364 \cdot 10^3$	0.62
3	$3.364 \cdot 10^3$	0.31
4	$3.363 \cdot 10^3$	3.5
5	$3.363 \cdot 10^3$	1.82
6	$3.363 \cdot 10^3$	1.21
7	$3.363 \cdot 10^3$	4.51
8	$3.363 \cdot 10^3$	1.97
9	$3.363 \cdot 10^3$	0.14
10	$3.364 \cdot 10^3$	0.23
11	$3.363 \cdot 10^3$	6.75
12	$3.363 \cdot 10^3$	2.04
13	$3.363 \cdot 10^3$	2.99
14	$3.363 \cdot 10^3$	1.97
15	$3.363 \cdot 10^3$	...

$N := \text{rows}(DATA)$ $N = 28$ $i := 0 .. \text{rows}(DATA) - 1$

$x_i := DATA_{i,1}$ $y_i := DATA_{i,0}$

$f(X) := X \cdot 0$

Calculation Sheet - Time Series Analysis

Location: Piezometer PZ-09
Time Range: 06/2005 - 03/2008 (Lined)

Objective

Perform correlation analyses to qualitatively assess the response of water levels in wells to precipitation.

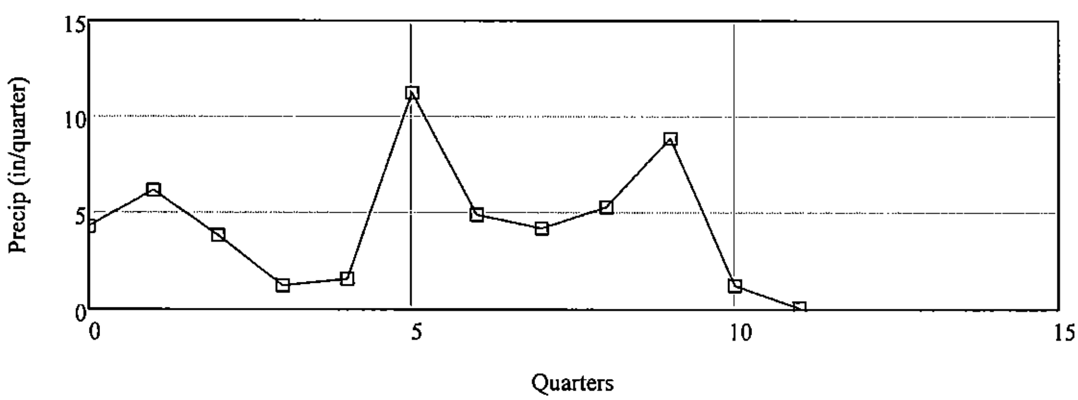
Methods

Auto-Correlation: Qualitatively shows the dependence of water-level or precipitation on time. Data series where this is no relation between measurements will show a sharply peaked graph of autocorrelation over lag (common for precipitation). Data series that are dependent to some degree on the previous measurement will have a more gradual (exponential) slope (common for water-level).

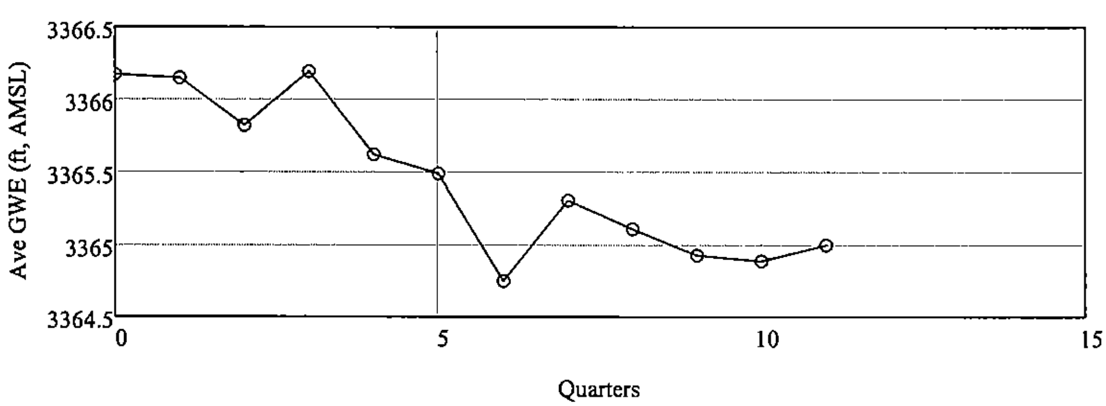
Cross-Correlation: Qualitatively shows the inter-dependence of water-level and precipitation. The lag distance from 0 to the peak is the approximate delay between precipitation and water-level response. The height of the peak qualitatively indicates the degree of "connection" between precipitation and water-level response.

Input Data

Total precipitation per quarter (in/quarter).



Quarterly average water level elevation (ft, AMSL).



Summary Statistics

<u>Precipitation</u> (in/quarter)

Mean: $\mu_x := \text{mean}(x)$ $\mu_x = 4.399$

Variance: $\sigma2_x := \text{var}(x)$ $\sigma2_x = 9.815$

Count: $N = 12$

Maximum: $\max(x) = 11.23$

Minimum: $\min(x) = 0.07$

<u>Quarterly Average Water Elevation</u> (ft, AMSL)

Mean: $\mu_y := \text{mean}(y)$ $\mu_y = 3365.45$

Variance: $\sigma2_y := \text{var}(y)$ $\sigma2_y = 0.261$

Count: $N = 12$

Maximum: $\max(y) = 3366.19$

Minimum: $\min(y) = 3364.75$

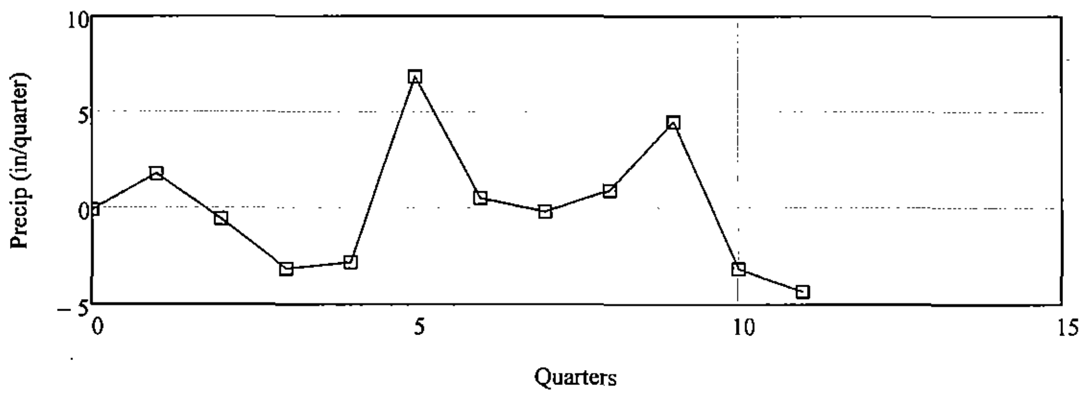
Zero-Mean Perturbation

Remove mean from data to obtain zero-mean perturbation for calculations.

<u>Precipitation</u>

Remove mean: $x0_i := x_i - \mu_x$

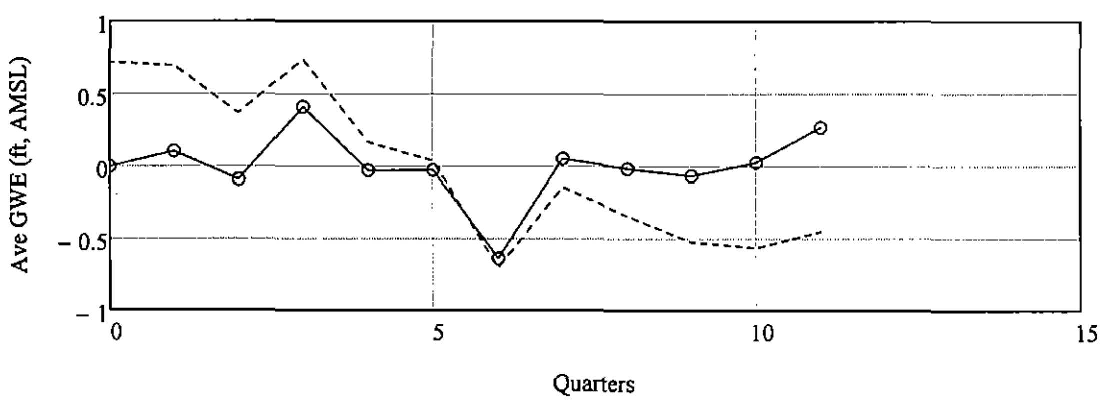
Zero-mean perturbation of total precipitation per quarter (in/quarter).



<u>Quarterly Average Water Elevation</u>

Remove mean: $y1_i := y_i - \mu_y$ Remove trend: $I_i := i \cdot 1$ $y0_i := y1_i - (\text{slope}(I, y1) \cdot i + \text{intercept}(I, y1))$

Zero-mean perturbation of quarterly average water level elevation (ft, AMSL).



Global Correlation Parameters

Count: $N = 12$

Maximum Lag: $MaxLag := 5$

Autocorrelation

Fast Fourier Transform Method for Discrete Covariance Estimate (Press et al., 1992)

Autocorrelation of Precipitation

Calculate the Complex Fast Fourier Transform (doesn't require zero padding)

$\Xi := CFFT(x0)$

Calculate the product of the transform with its complex conjugate

$j := 0..rows(\Xi) - 1$ $\quad Z_j := \Xi_j \cdot \overline{\Xi_j}$

The inverse gives the Autocovariance. Correlation = covariance / variance

$Corr := ICFFT(Z)$ $\quad r := 0..MaxLag$ $\quad Rx_{est_r} := Corr_r$

Autocorrelation of Average Quarterly Water Level

Calculate the Complex Fast Fourier Transform (doesn't require zero padding)

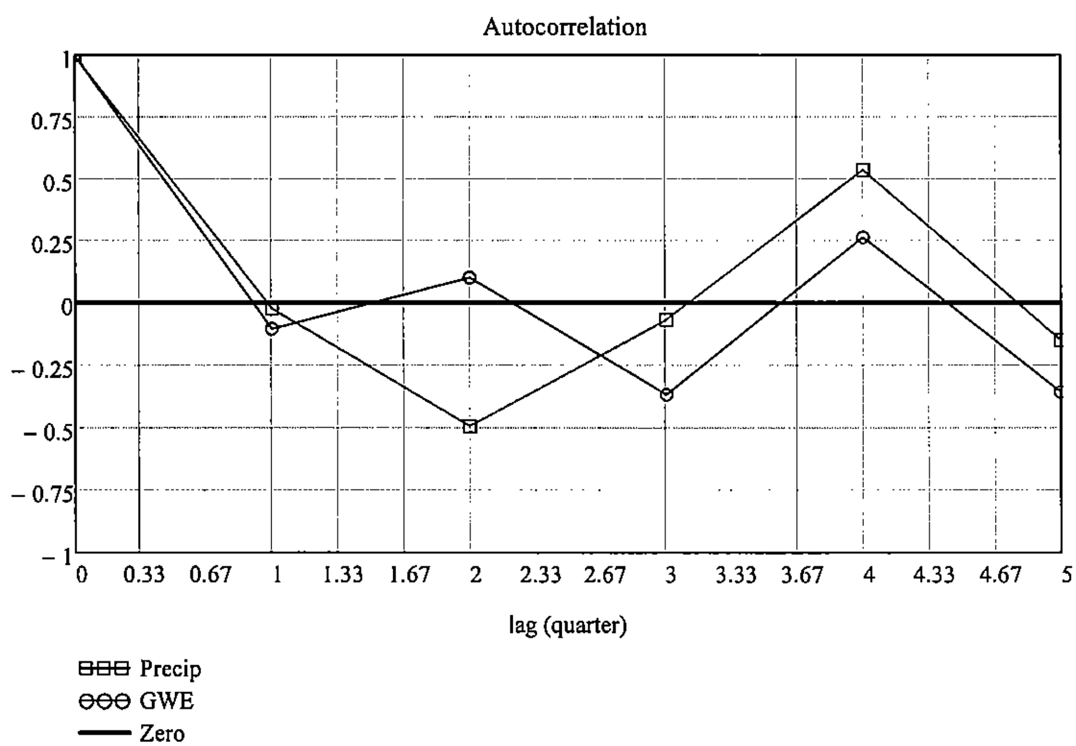
$\Psi := CFFT(y0)$

Calculate the product of the transform with its complex conjugate

$j := 0..rows(\Psi) - 1$ $\quad Z_j := \Psi_j \cdot \overline{\Psi_j}$

The inverse gives the Autocovariance

$Corr := ICFFT(Z)$ $\quad MaxLag = 5$ $\quad r := 0..MaxLag$ $\quad Ry_{est_r} := Corr_r$



Cross-Correlation

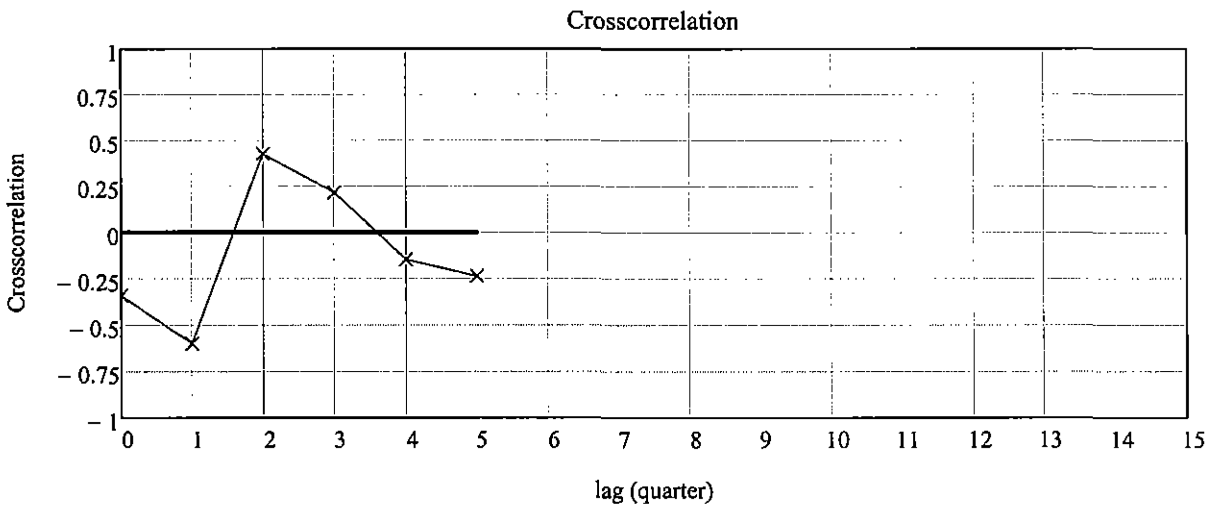
Use Complex Fast Fourier Transforms from above. Calculate the product of the x transform with the complex conjugate of the y transform (x leads y)

$j := 0 .. \mathrm{rows}(\Xi) - 1$ $\qquad$ $Z_j := \Psi_j \cdot \overline{\Xi_j}$

The inverse gives the Cross-covariance (Not necessarily symmetrical so index r must be adjusted to show negative lags. CrossCorr array contains positive lag results from 0 to N/2 and negative lag results from N to N/2 [in reverse]. CrossCorr results are then mapped into the Rxy array from 0 to N-1)

$\mathrm{CrossCorr} := \mathrm{ICFFT}(Z)$ $\qquad$ $r := 0 .. \frac{N}{2} - 1$ $\qquad$ $\mathrm{Rxy}_{est_r} := \mathrm{CrossCorr}_{\frac{N}{2}+r}$

$r := \frac{N}{2} .. N - 1$ $\qquad$ $\mathrm{Rxy}_{est_r} := \mathrm{CrossCorr}_{r-\frac{N}{2}}$



References

Press, W. H., S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery, Numerical Recipes in C, 2n edition (revised 1995), Cambridge Univ. Press, New York, N. Y., 1992

DATA :=

	0	1
0	$3.366 \cdot 10^3$	4.29
1	$3.366 \cdot 10^3$	6.15
2	$3.366 \cdot 10^3$	3.81
3	$3.366 \cdot 10^3$	1.24
4	$3.366 \cdot 10^3$	1.56
5	$3.365 \cdot 10^3$	11.23
6	$3.365 \cdot 10^3$	4.888
7	$3.365 \cdot 10^3$	4.19
8	$3.365 \cdot 10^3$	5.28
9	$3.365 \cdot 10^3$	8.85
10	$3.365 \cdot 10^3$	1.23
11	$3.365 \cdot 10^3$	0.07

$N := \text{rows}(DATA)$ $N = 12$ $i := 0 .. \text{rows}(DATA) - 1$

$x_i := DATA_{i,1}$ $y_i := DATA_{i,0}$

$f(X) := X \cdot 0$

Calculation Sheet - Time Series Analysis

Location: Piezometer PZ-10
Time Range: 09/1997 - 06/2004 (UnLined)

Objective

Perform correlation analyses to qualitatively assess the response of water levels in wells to precipitation.

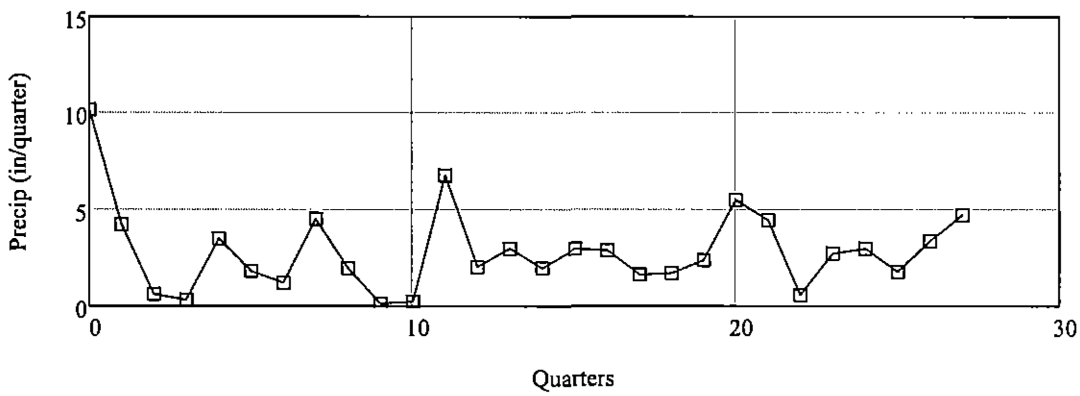
Methods

Auto-Correlation: Qualitatively shows the dependence of water-level or precipitation on time. Data series where this is no relation between measurements will show a sharply peaked graph of autocorrelation over lag (common for precipitation). Data series that are dependent to some degree on the previous measurement will have a more gradual (exponential) slope (common for water-level).

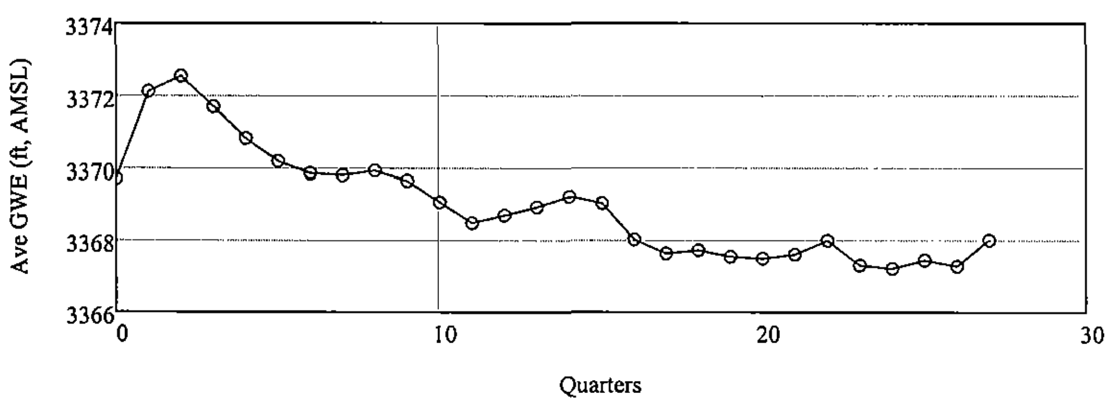
Cross-Correlation: Qualitatively shows the inter-dependence of water-level and precipitation. The lag distance from 0 to the peak is the approximate delay between precipitation and water-level response. The height of the peak qualitatively indicates the degree of "connection" between precipitation and water-level response.

Input Data

Total precipitation per quarter (in/quarter).



Quarterly average water level elevation (ft, AMSL).



Summary Statistics

Precipitation (in/quarter)

Mean: $\mu_x := \text{mean}(x)$ $\mu_x = 2.86$

Variance: $\sigma2_x := \text{var}(x)$ $\sigma2_x = 4.565$

Count: $N = 28$

Maximum: $\max(x) = 10.15$

Minimum: $\min(x) = 0.14$

Quarterly Average Water Elevation (ft, AMSL)

Mean: $\mu_y := \text{mean}(y)$ $\mu_y = 3368.97$

Variance: $\sigma2_y := \text{var}(y)$ $\sigma2_y = 2.22$

Count: $N = 28$

Maximum: $\max(y) = 3372.54$

Minimum: $\min(y) = 3367.22$

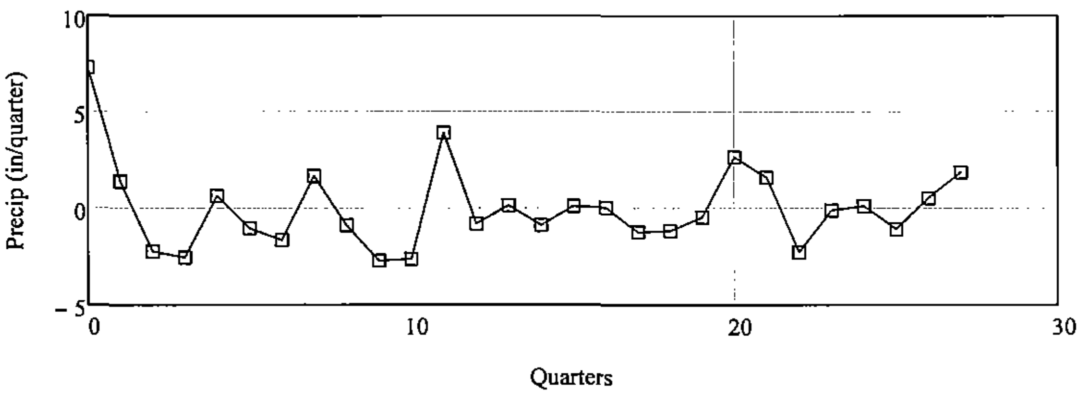
Zero-Mean Perturbation

Remove mean from data to obtain zero-mean perturbation for calculations.

Precipitation

Remove mean: $x0_i := x_i - \mu_x$

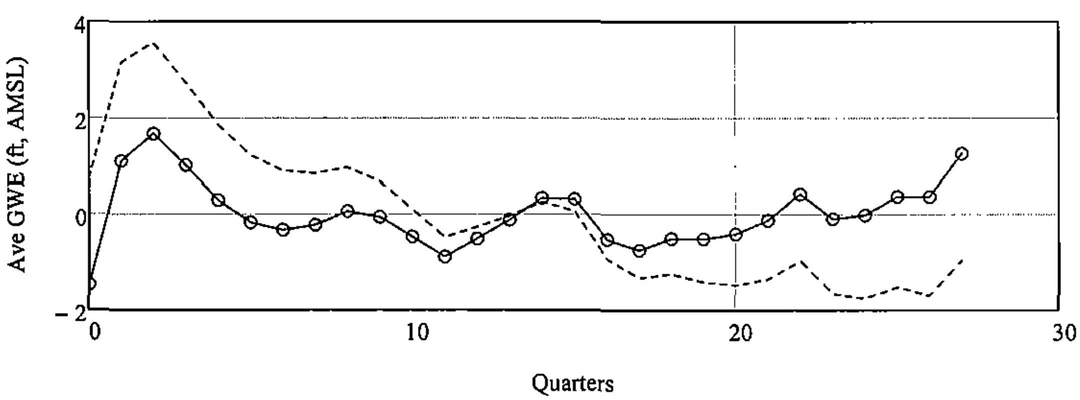
Zero-mean perturbation of total precipitation per quarter (in/quarter).



Quarterly Average Water Elevation

Remove mean: $y1_i := y_i - \mu_y$ Remove trend: $I_i := i \cdot 1$ $y0_i := y1_i - (\text{slope}(I, y1) \cdot i + \text{intercept}(I, y1))$

Zero-mean perturbation of quarterly average water level elevation (ft, AMSL).



Global Correlation Parameters

Count: $N = 28$

Maximum Lag: $MaxLag := 5$

Autocorrelation

Fast Fourier Transform Method for Discrete Covariance Estimate (Press et al., 1992)

Autocorrelation of Precipitation

Calculate the Complex Fast Fourier Transform (doesn't require zero padding)

$\Xi := CFFT(x0)$

Calculate the product of the transform with its complex conjugate

$j := 0..rows(\Xi) - 1$ $\quad Z_j := \Xi_j \cdot \overline{\Xi_j}$

The inverse gives the Autocovariance. Correlation = covariance / variance

$Corr := ICFFT(Z)$ $\quad r := 0..MaxLag$ $\quad Rx_{est_r} := Corr_r$

Autocorrelation of Average Quarterly Water Level

Calculate the Complex Fast Fourier Transform (doesn't require zero padding)

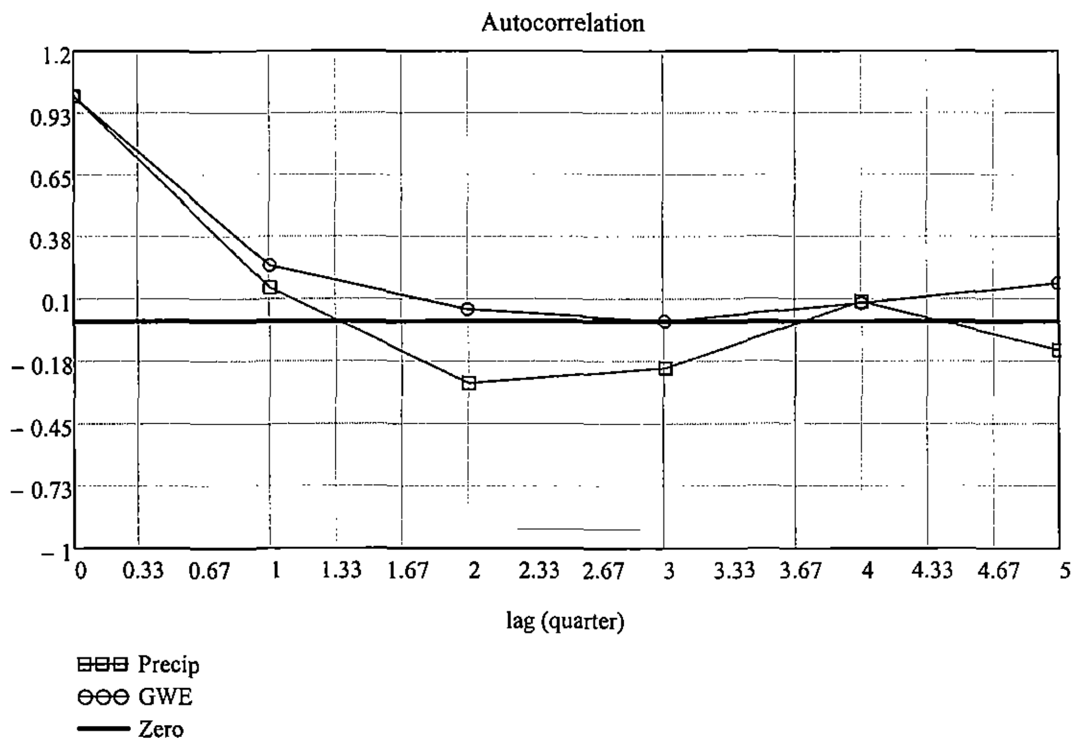
$\Psi := CFFT(y0)$

Calculate the product of the transform with its complex conjugate

$j := 0..rows(\Psi) - 1$ $\quad Z_j := \Psi_j \cdot \overline{\Psi_j}$

The inverse gives the Autocovariance

$Corr := ICFFT(Z)$ $\quad MaxLag = 5$ $\quad r := 0..MaxLag$ $\quad Ry_{est_r} := Corr_r$



Cross-Correlation

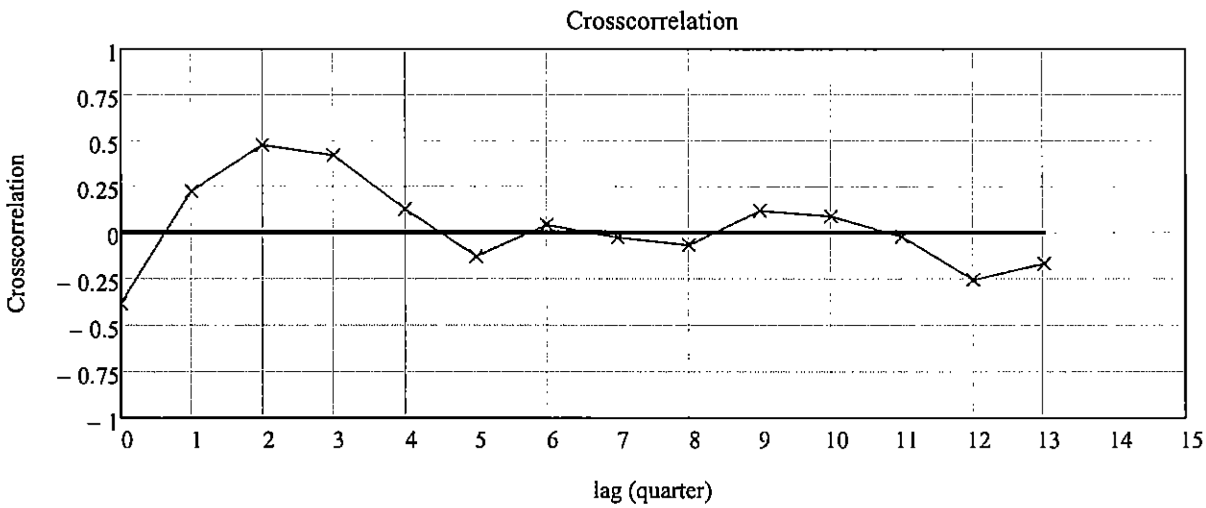
Use Complex Fast Fourier Transforms from above. Calculate the product of the x transform with the complex conjugate of the y transform (x leads y)

$j := 0..\text{rows}(\Xi) - 1$ $\qquad Z_j := \Psi_j \cdot \overline{\Xi_j}$

The inverse gives the Cross-covariance (Not necessarily symmetrical so index r must be adjusted to show negative lags. CrossCorr array contains positive lag results from 0 to N/2 and negative lag results from N to N/2 [in reverse]. CrossCorr results are then mapped into the Rxy array from 0 to N-1)

$\text{CrossCorr} := \text{ICFFT}(Z)$ $\qquad r := 0..\frac{N}{2} - 1 \qquad Rxy_{est_r} := \text{CrossCorr}_{\frac{N}{2}+r}$

$r := \frac{N}{2}..N - 1 \qquad Rxy_{est_r} := \text{CrossCorr}_{r-\frac{N}{2}}$



References

Press, W. H., S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery, Numerical Recipes in C, 2n edition (revised 1995), Cambridge Univ. Press, New York, N. Y., 1992

DATA :=

	0	1
0	$3.37 \cdot 10^3$	10.15
1	$3.372 \cdot 10^3$	4.22
2	$3.373 \cdot 10^3$	0.62
3	$3.372 \cdot 10^3$	0.31
4	$3.371 \cdot 10^3$	3.5
5	$3.37 \cdot 10^3$	1.82
6	$3.37 \cdot 10^3$	1.21
7	$3.37 \cdot 10^3$	4.51
8	$3.37 \cdot 10^3$	1.97
9	$3.37 \cdot 10^3$	0.14
10	$3.369 \cdot 10^3$	0.23
11	$3.368 \cdot 10^3$	6.75
12	$3.369 \cdot 10^3$	2.04
13	$3.369 \cdot 10^3$	2.99
14	$3.369 \cdot 10^3$	1.97
15	$3.369 \cdot 10^3$	...

$N := \text{rows(DATA)}$ $N = 28$ $i := 0 .. \text{rows(DATA)} - 1$

$x_i := DATA_{i,1}$ $y_i := DATA_{i,0}$

$f(X) := X \cdot 0$

Calculation Sheet - Time Series Analysis

Location: Piezometer PZ-10
Time Range: 06/2005 - 03/2008 (Lined)

Objective

Perform correlation analyses to qualitatively assess the response of water levels in wells to precipitation.

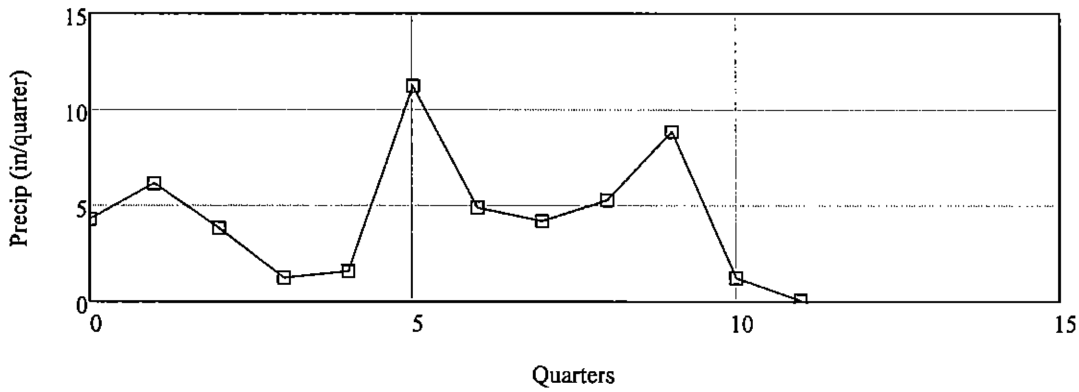
Methods

Auto-Correlation: Qualitatively shows the dependence of water-level or precipitation on time. Data series where this is no relation between measurements will show a sharply peaked graph of autocorrelation over lag (common for precipitation). Data series that are dependent to some degree on the previous measurement will have a more gradual (exponential) slope (common for water-level).

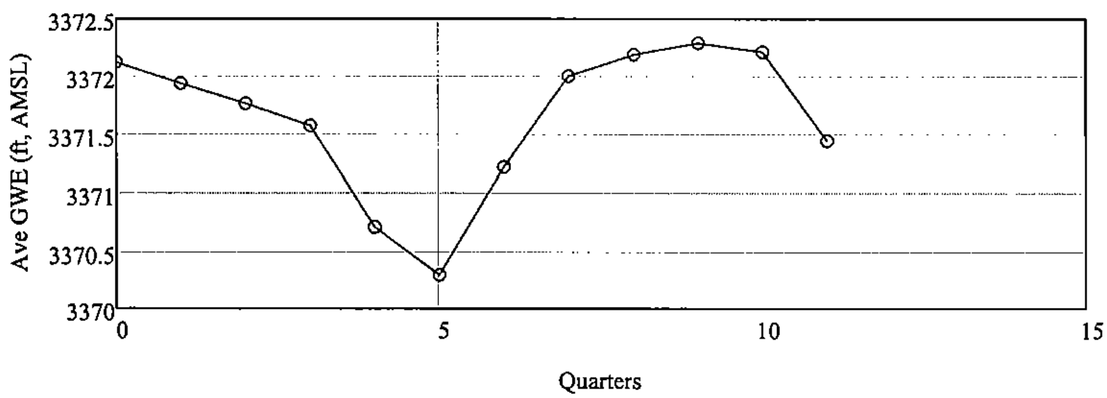
Cross-Correlation: Qualitatively shows the inter-dependence of water-level and precipitation. The lag distance from 0 to the peak is the approximate delay between precipitation and water-level response. The height of the peak qualitatively indicates the degree of "connection" between precipitation and water-level response.

Input Data

Total precipitation per quarter (in/quarter).



Quarterly average water level elevation (ft, AMSL).



Summary Statistics

Precipitation (in/quarter)

Mean: $\mu_x := \text{mean}(x)$ $\mu_x = 4.399$

Variance: $\sigma2_x := \text{var}(x)$ $\sigma2_x = 9.815$

Count: $N = 12$

Maximum: $\max(x) = 11.23$

Minimum: $\min(x) = 0.07$

Quarterly Average Water Elevation (ft, AMSL)

Mean: $\mu_y := \text{mean}(y)$ $\mu_y = 3371.64$

Variance: $\sigma2_y := \text{var}(y)$ $\sigma2_y = 0.371$

Count: $N = 12$

Maximum: $\max(y) = 3372.29$

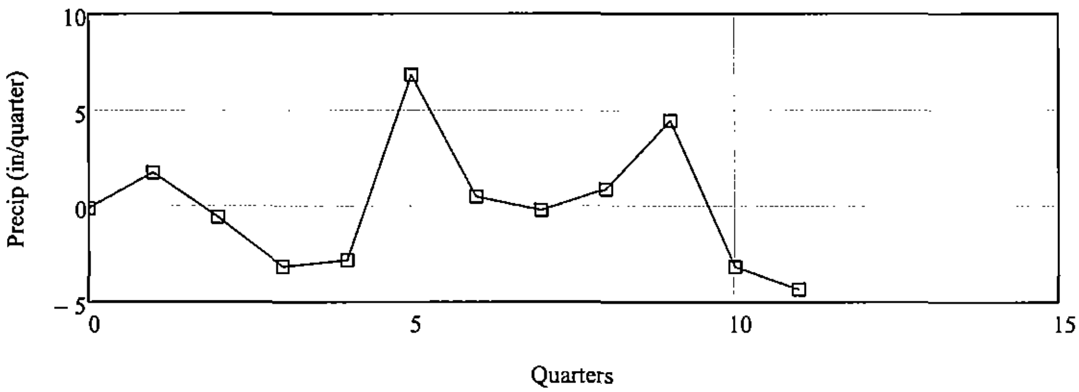
Minimum: $\min(y) = 3370.29$

Zero-Mean Perturbation
Remove mean from data to obtain zero-mean perturbation for calculations.

Precipitation

Remove mean: $x0_i := x_i - \mu_x$

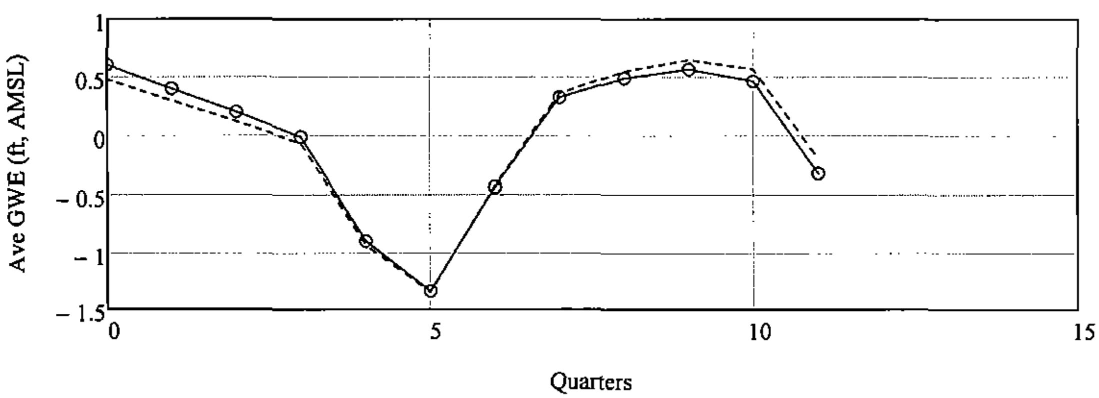
Zero-mean perturbation of total precipitation per quarter (in/quarter).



Quarterly Average Water Elevation

Remove mean: $y1_i := y_i - \mu_y$ Remove trend: $I_i := i \cdot 1$ $y0_i := y1_i - (\text{slope}(I, y1) \cdot i + \text{intercept}(I, y1))$

Zero-mean perturbation of quarterly average water level elevation (ft, AMSL).



Global Correlation Parameters

Count: $N = 12$

Maximum Lag: $MaxLag := 5$

Autocorrelation

Fast Fourier Transform Method for Discrete Covariance Estimate (Press et al., 1992)

Autocorrelation of Precipitation

Calculate the Complex Fast Fourier Transform (doesn't require zero padding)

$\Xi := CFFT(x0)$

Calculate the product of the transform with its complex conjugate

$j := 0..rows(\Xi) - 1$ $\quad Z_j := \Xi_j \cdot \overline{\Xi_j}$

The inverse gives the Autocovariance. Correlation = covariance / variance

$Corr := ICFFT(Z)$ $\quad r := 0..MaxLag$ $\quad Rx_{est_r} := Corr_r$

Autocorrelation of Average Quarterly Water Level

Calculate the Complex Fast Fourier Transform (doesn't require zero padding)

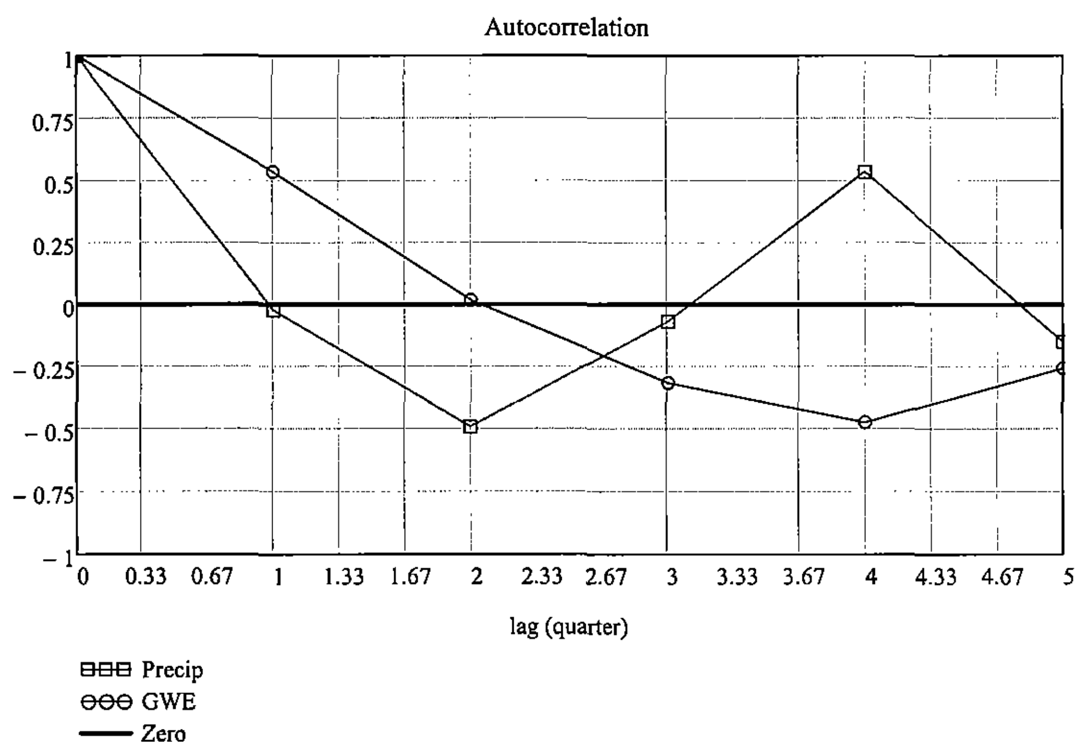
$\Psi := CFFT(y0)$

Calculate the product of the transform with its complex conjugate

$j := 0..rows(\Psi) - 1$ $\quad Z_j := \Psi_j \cdot \overline{\Psi_j}$

The inverse gives the Autocovariance

$Corr := ICFFT(Z)$ $\quad MaxLag = 5$ $\quad r := 0..MaxLag$ $\quad Ry_{est_r} := Corr_r$



Cross-Correlation

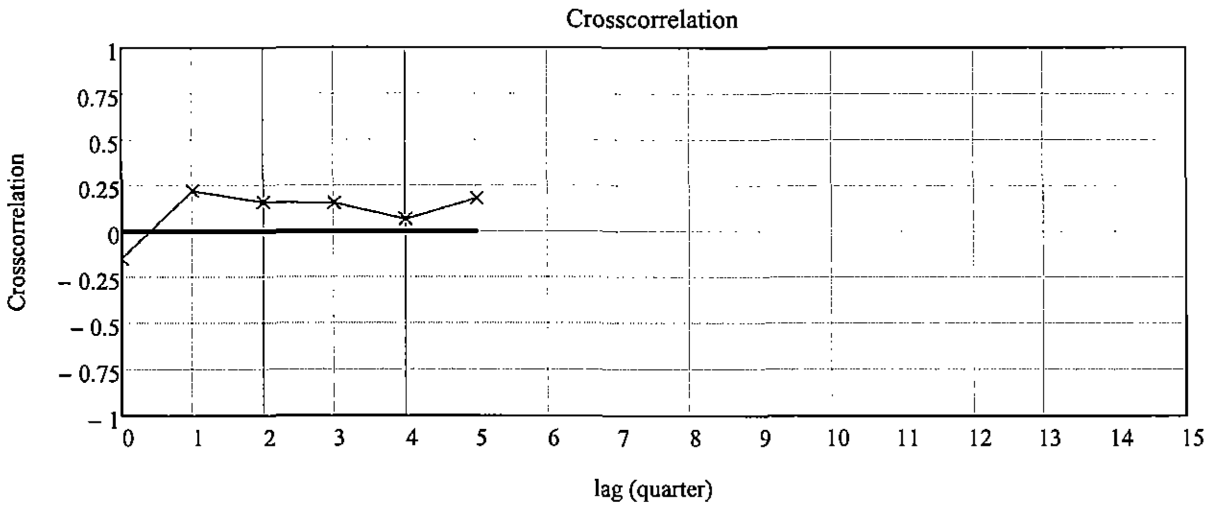
Use Complex Fast Fourier Transforms from above. Calculate the product of the x transform with the complex conjugate of the y transform (x leads y)

$j := 0 .. \text{rows}(\Xi) - 1 \qquad Z_j := \Psi_j \cdot \overline{\Xi_j}$

The inverse gives the Cross-covariance (Not necessarily symmetrical so index r must be adjusted to show negative lags. CrossCorr array contains positive lag results from 0 to N/2 and negative lag results from N to N/2 [in reverse]. CrossCorr results are then mapped into the Rxy array from 0 to N-1)

$\text{CrossCorr} := \text{ICFFT}(Z) \qquad r := 0 .. \frac{N}{2} - 1 \qquad \text{Rxy}_{\text{est}_r} := \text{CrossCorr}_{\frac{N}{2}+r}$

$r := \frac{N}{2} .. N - 1 \qquad \text{Rxy}_{\text{est}_r} := \text{CrossCorr}_{r-\frac{N}{2}}$



References

Press, W. H., S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery, Numerical Recipes in C, 2n edition (revised 1995), Cambridge Univ. Press, New York, N. Y., 1992

DATA :=

	0	1
0	$3.372 \cdot 10^3$	4.29
1	$3.372 \cdot 10^3$	6.15
2	$3.372 \cdot 10^3$	3.81
3	$3.372 \cdot 10^3$	1.24
4	$3.371 \cdot 10^3$	1.56
5	$3.37 \cdot 10^3$	11.23
6	$3.371 \cdot 10^3$	4.888
7	$3.372 \cdot 10^3$	4.19
8	$3.372 \cdot 10^3$	5.28
9	$3.372 \cdot 10^3$	8.85
10	$3.372 \cdot 10^3$	1.23
11	$3.371 \cdot 10^3$	0.07

$N := \text{rows}(DATA)$ $N = 12$ $i := 0 .. \text{rows}(DATA) - 1$

$x_i := DATA_{i,1}$ $y_i := DATA_{i,0}$

$f(X) := X \cdot 0$

Calculation Sheet - Time Series Analysis

Location: Piezometer PZ-12
Time Range: 09/1997 - 06/2004 (UnLined)

Objective

Perform correlation analyses to qualitatively assess the response of water levels in wells to precipitation.

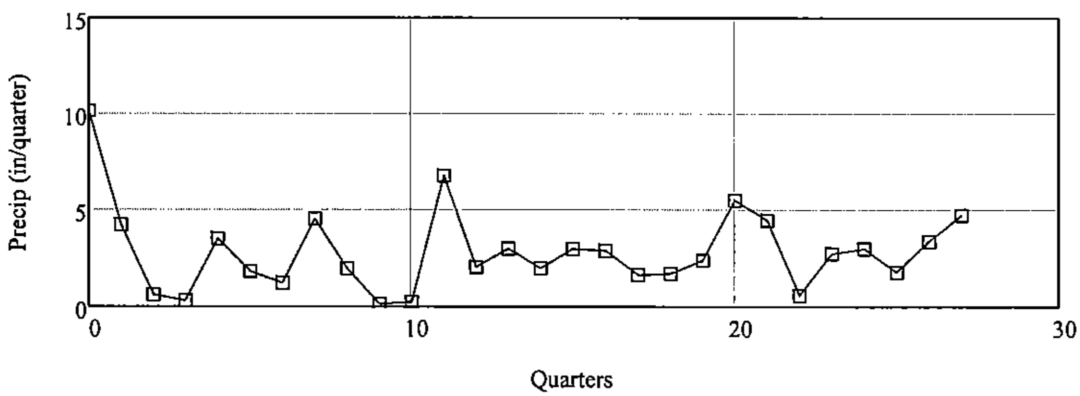
Methods

Auto-Correlation: Qualitatively shows the dependence of water-level or precipitation on time. Data series where this is no relation between measurements will show a sharply peaked graph of autocorrelation over lag (common for precipitation). Data series that are dependent to some degree on the previous measurement will have a more gradual (exponential) slope (common for water-level).

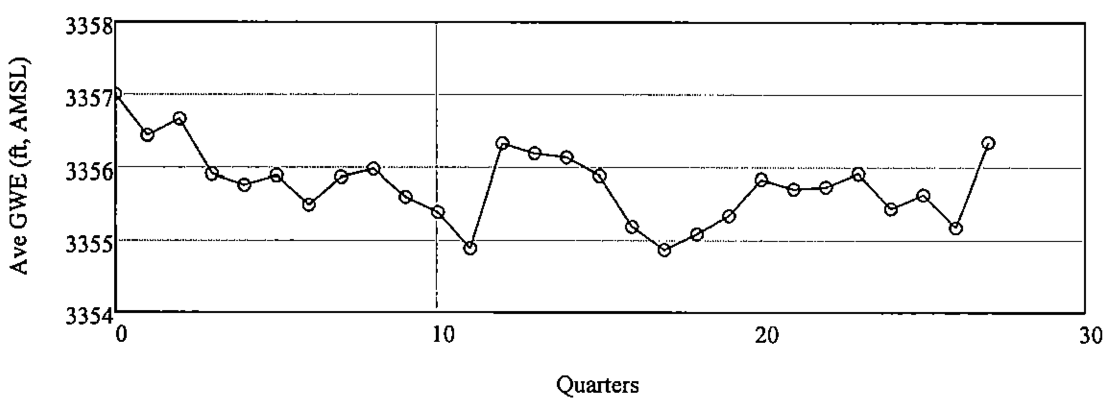
Cross-Correlation: Qualitatively shows the inter-dependence of water-level and precipitation. The lag distance from 0 to the peak is the approximate delay between precipitation and water-level response. The height of the peak qualitatively indicates the degree of "connection" between precipitation and water-level response.

Input Data

Total precipitation per quarter (in/quarter).



Quarterly average water level elevation (ft, AMSL).



Summary Statistics

Precipitation (in/quarter)

Mean: $\mu_x := \text{mean}(x)$ $\mu_x = 2.86$

Variance: $\sigma2_x := \text{var}(x)$ $\sigma2_x = 4.565$

Count: $N = 28$

Maximum: $\max(x) = 10.15$

Minimum: $\min(x) = 0.14$

Quarterly Average Water Elevation (ft, AMSL)

Mean: $\mu_y := \text{mean}(y)$ $\mu_y = 3355.78$

Variance: $\sigma2_y := \text{var}(y)$ $\sigma2_y = 0.255$

Count: $N = 28$

Maximum: $\max(y) = 3357$

Minimum: $\min(y) = 3354.87$

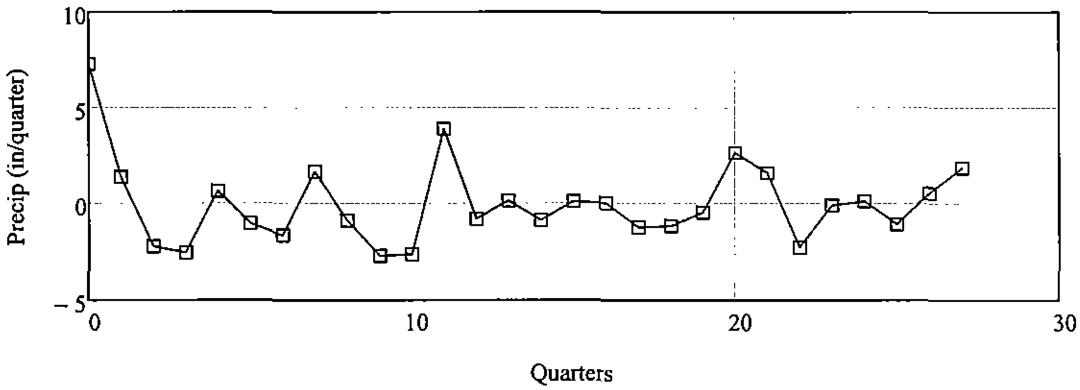
Zero-Mean Perturbation

Remove mean from data to obtain zero-mean perturbation for calculations.

Precipitation

Remove mean: $x0_i := x_i - \mu_x$

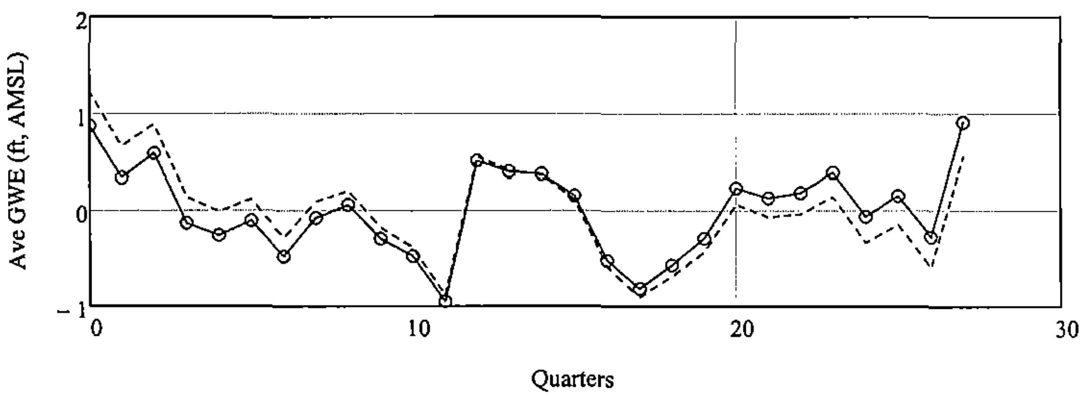
Zero-mean perturbation of total precipitation per quarter (in/quarter).



Quarterly Average Water Elevation

Remove mean: $y1_i := y_i - \mu_y$ Remove trend: $I_i := i \cdot 1$ $y0_i := y1_i - (\text{slope}(I, y1) \cdot i + \text{intercept}(I, y1))$

Zero-mean perturbation of quarterly average water level elevation (ft, AMSL).



Global Correlation Parameters

Count: $N = 28$

Maximum Lag: $MaxLag := 5$

Autocorrelation

Fast Fourier Transform Method for Discrete Covariance Estimate (Press et al., 1992)

Autocorrelation of Precipitation

Calculate the Complex Fast Fourier Transform (doesn't require zero padding)

$\Xi := CFFT(x0)$

Calculate the product of the transform with its complex conjugate

$j := 0..rows(\Xi) - 1$ $Z_j := \Xi_j \cdot \overline{\Xi_j}$

The inverse gives the Autocovariance. Correlation = covariance / variance

$Corr := ICFFT(Z)$ $r := 0..MaxLag$ $Rx_{est_r} := Corr_r$

Autocorrelation of Average Quarterly Water Level

Calculate the Complex Fast Fourier Transform (doesn't require zero padding)

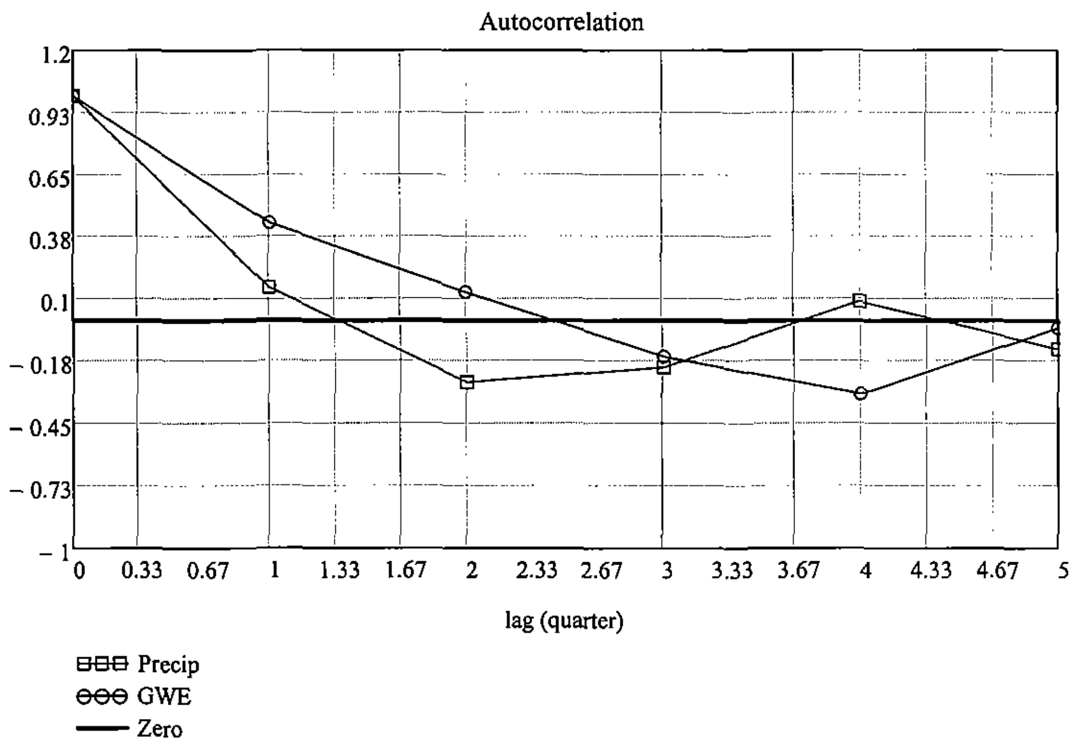
$\Psi := CFFT(y0)$

Calculate the product of the transform with its complex conjugate

$j := 0..rows(\Psi) - 1$ $Z_j := \Psi_j \cdot \overline{\Psi_j}$

The inverse gives the Autocovariance

$Corr := ICFFT(Z)$ $MaxLag = 5$ $r := 0..MaxLag$ $Ry_{est_r} := Corr_r$



 PZ12_UnLined_edit1.xmcd

Cross-Correlation

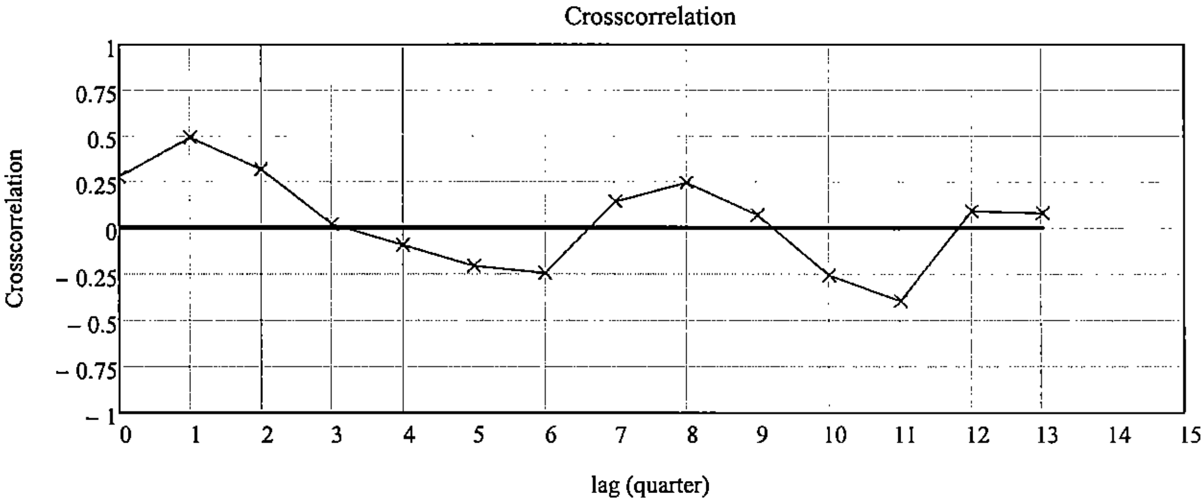
Use Complex Fast Fourier Transforms from above. Calculate the product of the x transform with the complex conjugate of the y transform (x leads y)

$j := 0..\text{rows}(\Xi) - 1$ $\quad\quad Z_j := \Psi_j \cdot \overline{\Xi_j}$

The inverse gives the Cross-covariance (Not necessarily symmetrical so index r must be adjusted to show negative lags. CrossCorr array contains positive lag results from 0 to N/2 and negative lag results from N to N/2 [in reverse]. CrossCorr results are then mapped into the Rxy array from 0 to N-1)

$\text{CrossCorr} := \text{ICFFT}(Z)$ $\quad\quad r := 0..\frac{N}{2} - 1$ $\quad\quad Rxy_{est_r} := \text{CrossCorr}_{\frac{N}{2}+r}$

$r := \frac{N}{2}..N - 1$ $\quad\quad Rxy_{est_r} := \text{CrossCorr}_{r-\frac{N}{2}}$



References

Press, W. H., S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery, Numerical Recipes in C, 2n edition (revised 1995), Cambridge Univ. Press, New York, N. Y., 1992

DATA :=

	0	1
0	$3.357 \cdot 10^3$	10.15
1	$3.356 \cdot 10^3$	4.22
2	$3.357 \cdot 10^3$	0.62
3	$3.356 \cdot 10^3$	0.31
4	$3.356 \cdot 10^3$	3.5
5	$3.356 \cdot 10^3$	1.82
6	$3.355 \cdot 10^3$	1.21
7	$3.356 \cdot 10^3$	4.51
8	$3.356 \cdot 10^3$	1.97
9	$3.356 \cdot 10^3$	0.14
10	$3.355 \cdot 10^3$	0.23
11	$3.355 \cdot 10^3$	6.75
12	$3.356 \cdot 10^3$	2.04
13	$3.356 \cdot 10^3$	2.99
14	$3.356 \cdot 10^3$	1.97
15	$3.356 \cdot 10^3$	...

$N := \text{rows}(DATA)$ $N = 28$ $i := 0 .. \text{rows}(DATA) - 1$

$x_i := DATA_{i,1}$ $y_i := DATA_{i,0}$

$f(X) := X \cdot 0$

Calculation Sheet - Time Series Analysis

Location: Piezometer PZ-12
Time Range: 06/2005 - 03/2008 (Lined)

Objective

Perform correlation analyses to qualitatively assess the response of water levels in wells to precipitation.

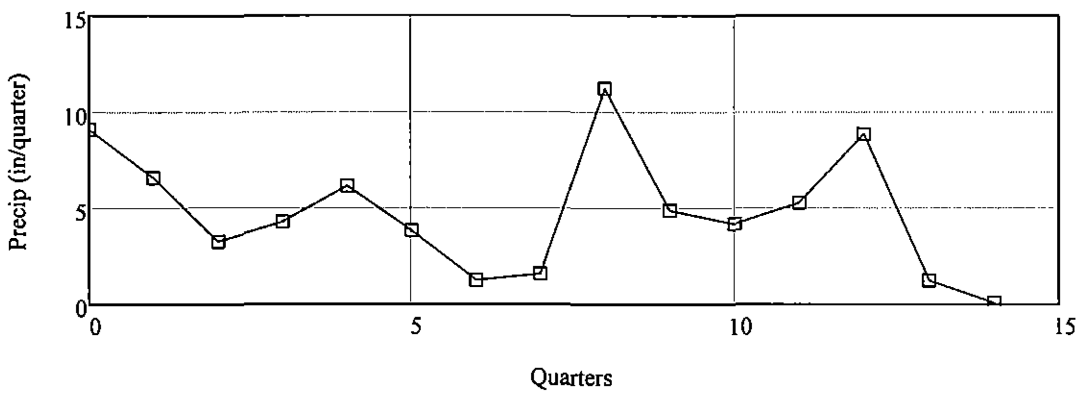
Methods

Auto-Correlation: *Qualitatively shows the dependence of water-level or precipitation on time. Data series* where this is no relation between measurements will show a sharply peaked graph of autocorrelation over lag (common for precipitation). Data series that are dependent to some degree on the previous measurement will have a more gradual (exponential) slope (common for water-level).

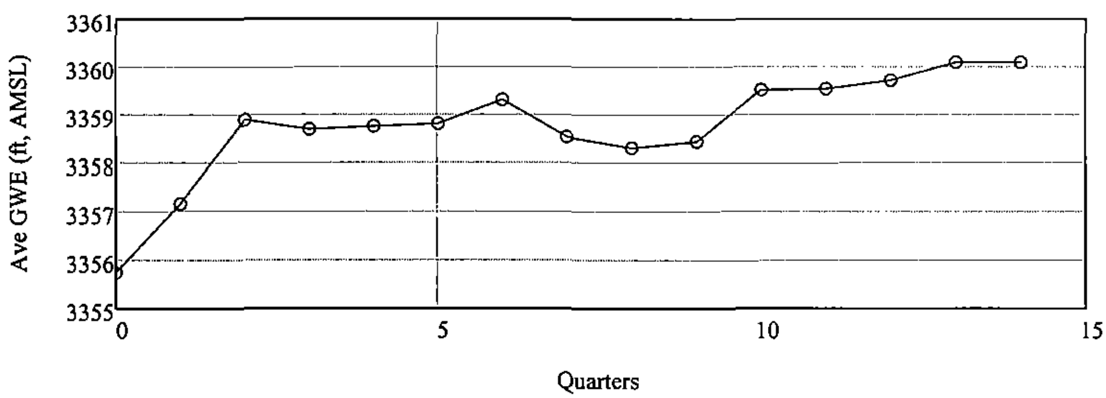
Cross-Correlation: Qualitatively shows the inter-dependence of water-level and precipitation. The lag distance from 0 to the peak is the approximate delay between precipitation and water-level response. The height of the peak qualitatively indicates the degree of "connection" between precipitation and water-level response.

Input Data

Total precipitation per quarter (in/quarter).



Quarterly average water level elevation (ft, AMSL).



Summary Statistics

Precipitation (in/quarter)

Mean: $\mu_x := \text{mean}(x)$ $\mu_x = 4.784$

Variance: $\sigma2_x := \text{var}(x)$ $\sigma2_x = 9.588$

Count: $N = 15$

Maximum: $\max(x) = 11.23$

Minimum: $\min(x) = 0.07$

Quarterly Average Water Elevation (ft, AMSL)

Mean: $\mu_y := \text{mean}(y)$ $\mu_y = 3358.77$

Variance: $\sigma2_y := \text{var}(y)$ $\sigma2_y = 1.201$

Count: $N = 15$

Maximum: $\max(y) = 3360.09$

Minimum: $\min(y) = 3355.74$

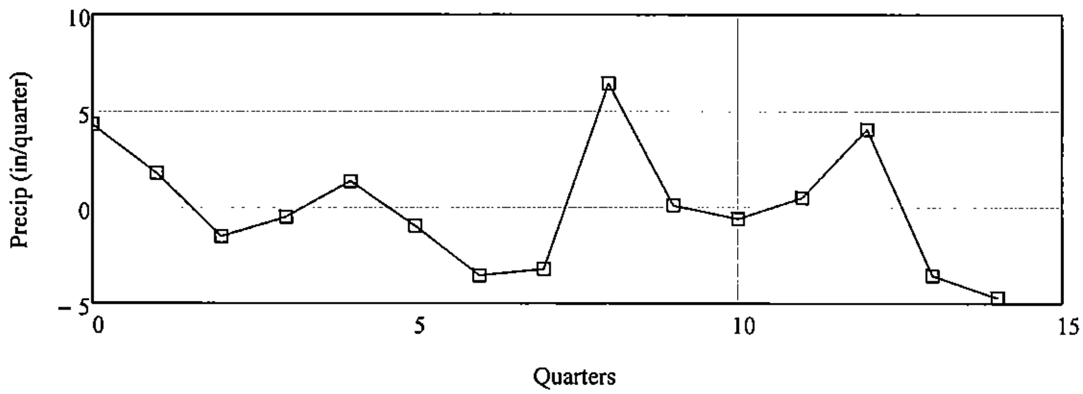
Zero-Mean Perturbation

Remove mean from data to obtain zero-mean perturbation for calculations.

Precipitation

Remove mean: $x0_i := x_i - \mu_x$

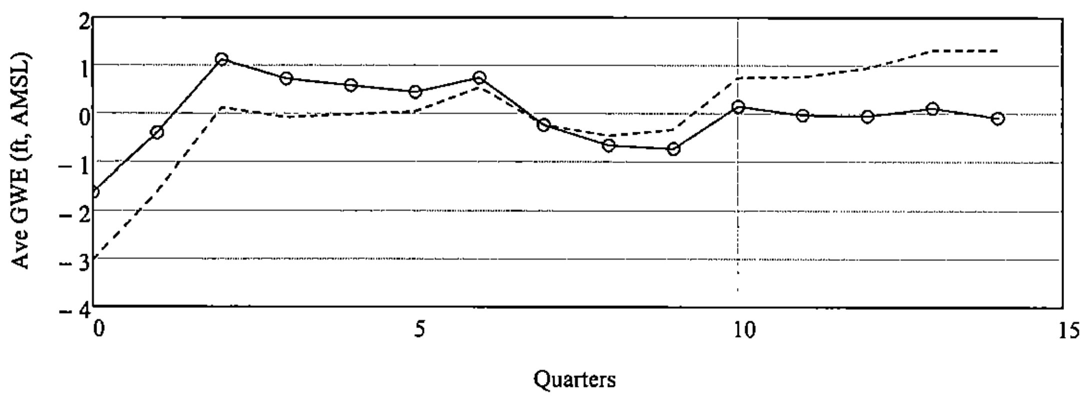
Zero-mean perturbation of total precipitation per quarter (in/quarter).



Quarterly Average Water Elevation

Remove mean: $y1_i := y_i - \mu_y$ Remove trend: $I_i := i \cdot 1$ $y0_i := y1_i - (\text{slope}(I, y1) \cdot i + \text{intercept}(I, y1))$

Zero-mean perturbation of quarterly average water level elevation (ft, AMSL).



Global Correlation Parameters

Count: $N = 15$

Maximum Lag: $MaxLag := 5$

Autocorrelation

Fast Fourier Transform Method for Discrete Covariance Estimate (Press et al., 1992)

Autocorrelation of Precipitation

Calculate the Complex Fast Fourier Transform (doesn't require zero padding)

$\Xi := CFFT(x0)$

Calculate the product of the transform with its complex conjugate

$j := 0..rows(\Xi) - 1$ $\quad Z_j := \Xi_j \cdot \overline{\Xi_j}$

The inverse gives the Autocovariance. Correlation = covariance / variance

$Corr := ICFFT(Z)$ $\quad r := 0..MaxLag$ $\quad Rx_{est_r} := Corr_r$

Autocorrelation of Average Quarterly Water Level

Calculate the Complex Fast Fourier Transform (doesn't require zero padding)

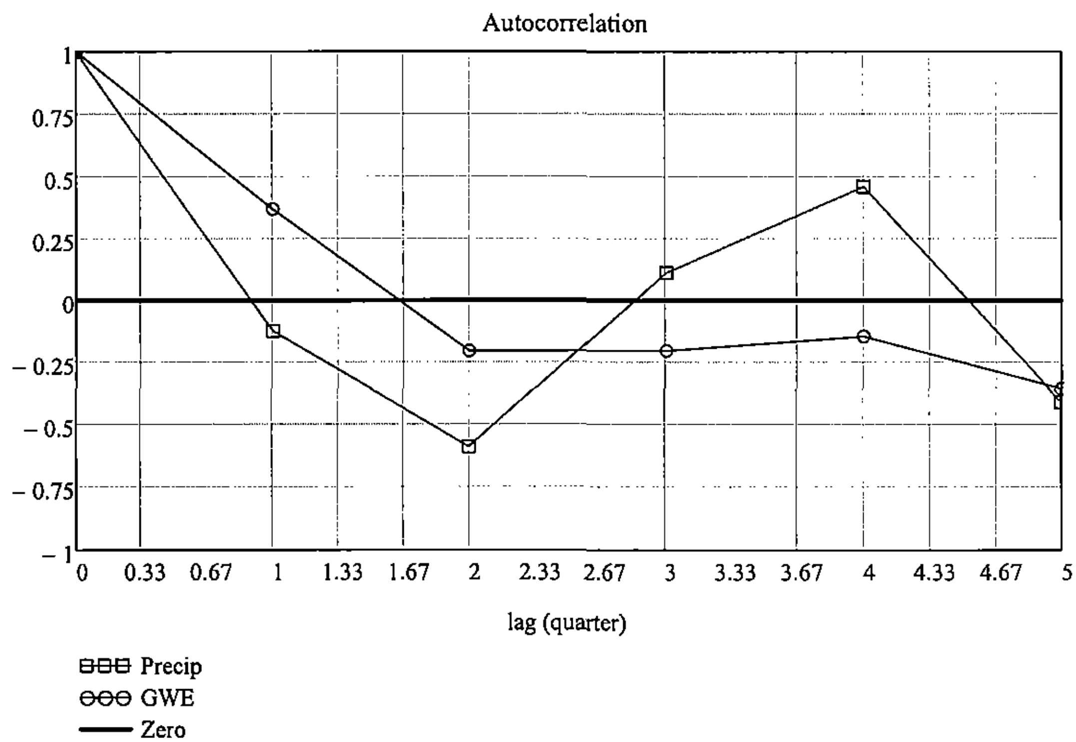
$\Psi := CFFT(y0)$

Calculate the product of the transform with its complex conjugate

$j := 0..rows(\Psi) - 1$ $\quad Z_j := \Psi_j \cdot \overline{\Psi_j}$

The inverse gives the Autocovariance

$Corr := ICFFT(Z)$ $\quad MaxLag = 5$ $\quad r := 0..MaxLag$ $\quad Ry_{est_r} := Corr_r$



Cross-Correlation

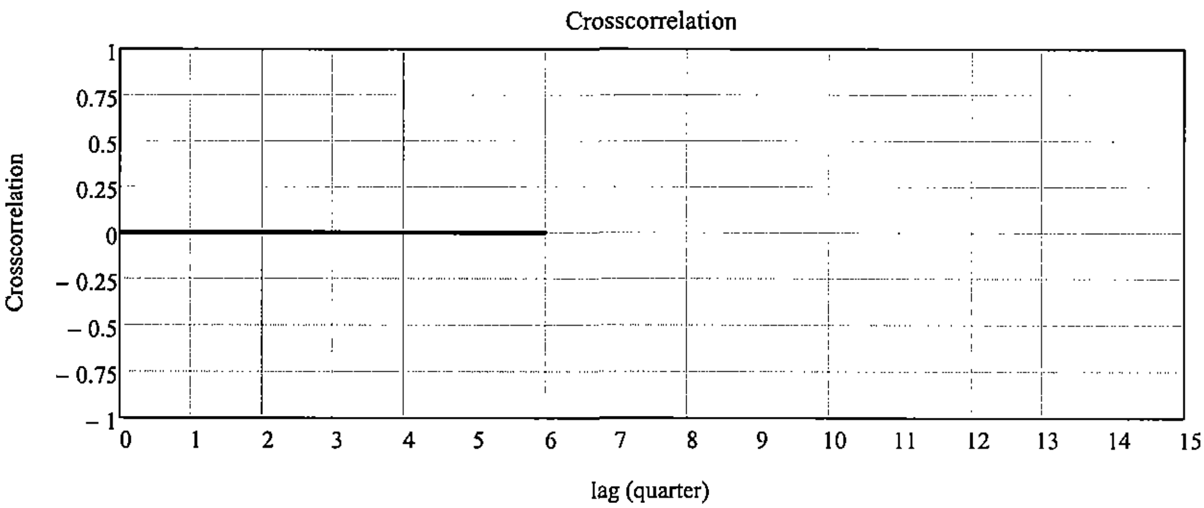
Use Complex Fast Fourier Transforms from above. Calculate the product of the x transform with the complex conjugate of the y transform (x leads y)

$j := 0 .. \text{rows}(\Xi) - 1 \qquad Z_j := \Psi_j \cdot \overline{\Xi_j}$

The inverse gives the Cross-covariance (Not necessarily symmetrical so index r must be adjusted to show negative lags. CrossCorr array contains positive lag results from 0 to N/2 and negative lag results from N to N/2 [in reverse]. CrossCorr results are then mapped into the Rxy array from 0 to N-1)

$\text{CrossCorr} := \text{ICFFT}(Z) \qquad r := 0 .. \frac{N}{2} - 1 \qquad \text{Rxy}_{est_r} := \text{CrossCorr}_{\frac{N}{2}+r}$

$r := \frac{N}{2} .. N - 1 \qquad \text{Rxy}_{est_r} := \text{CrossCorr}_{r-\frac{N}{2}}$



References

Press, W. H., S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery, Numerical Recipes in C, 2n edition (revised 1995), Cambridge Univ. Press, New York, N. Y., 1992

DATA :=

	0	1
0	$3.356\cdot10^3$	9.11
1	$3.357\cdot10^3$	6.59
2	$3.359\cdot10^3$	3.27
3	$3.359\cdot10^3$	4.29
4	$3.359\cdot10^3$	6.15
5	$3.359\cdot10^3$	3.81
6	$3.359\cdot10^3$	1.24
7	$3.359\cdot10^3$	1.56
8	$3.358\cdot10^3$	11.23
9	$3.358\cdot10^3$	4.888
10	$3.36\cdot10^3$	4.19
11	$3.36\cdot10^3$	5.28
12	$3.36\cdot10^3$	8.85
13	$3.36\cdot10^3$	1.23
14	$3.36\cdot10^3$	0.07

$N := \text{rows}(DATA)$ $N = 15$ $i := 0..\text{rows}(DATA) - 1$

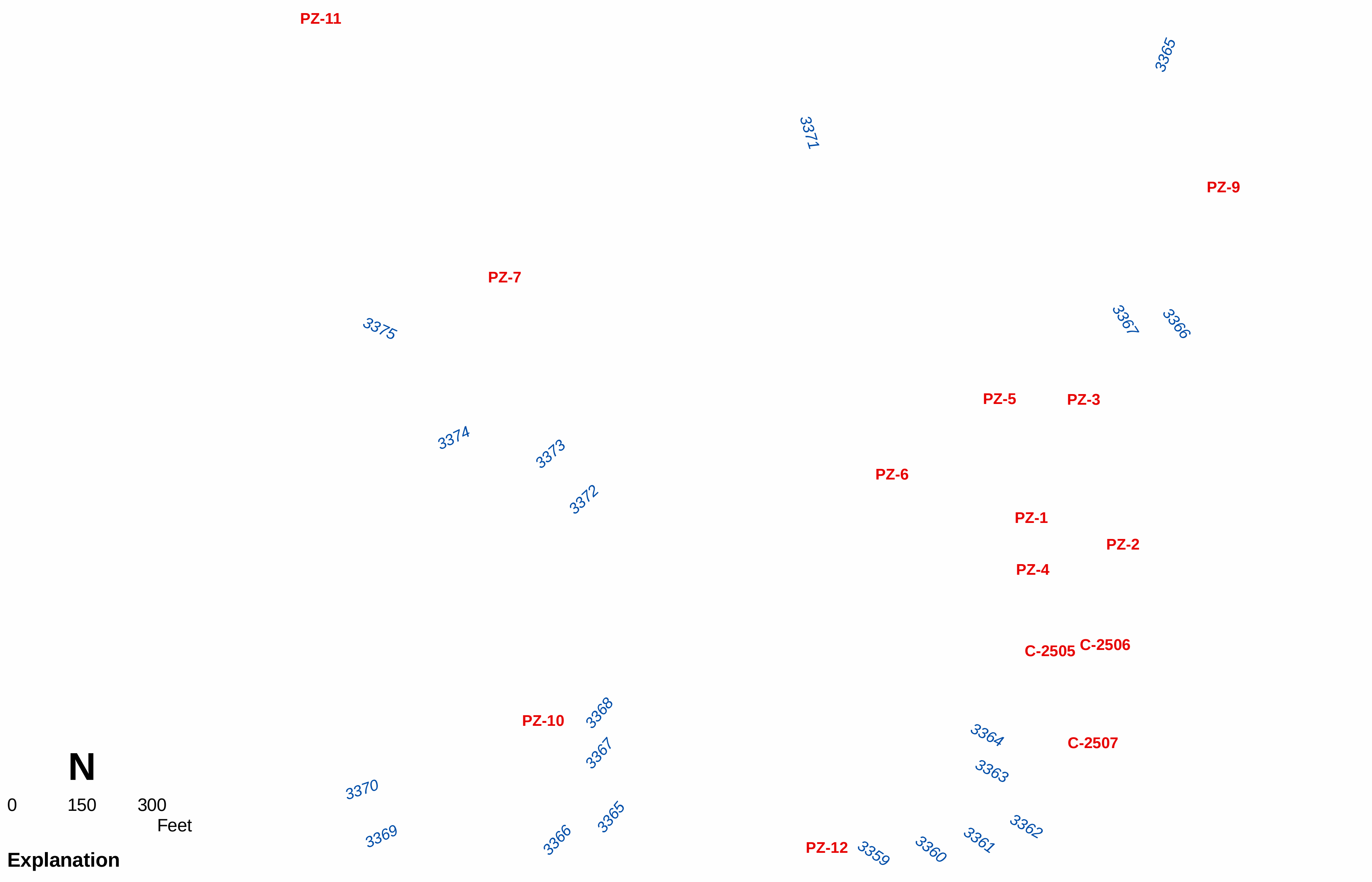
$x_i := DATA_{i,1}$ $y_i := DATA_{i,0}$

$f(X) := X\cdot 0$

Appendix E

Water Level Contour Maps

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/WATER_1997_OCT.MXD 808270



Explanation

SSW monitor well

Water level elevation (ft msl)

Figure E-1

WIPP SHALLOW SUBSURFACE WATER

Water Level Elevation, October 1997

Daniel B. Stephens & Associates, Inc.
9/3/2008
JN ES08.0072

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/WATER_1998_OCT.MXD 808270

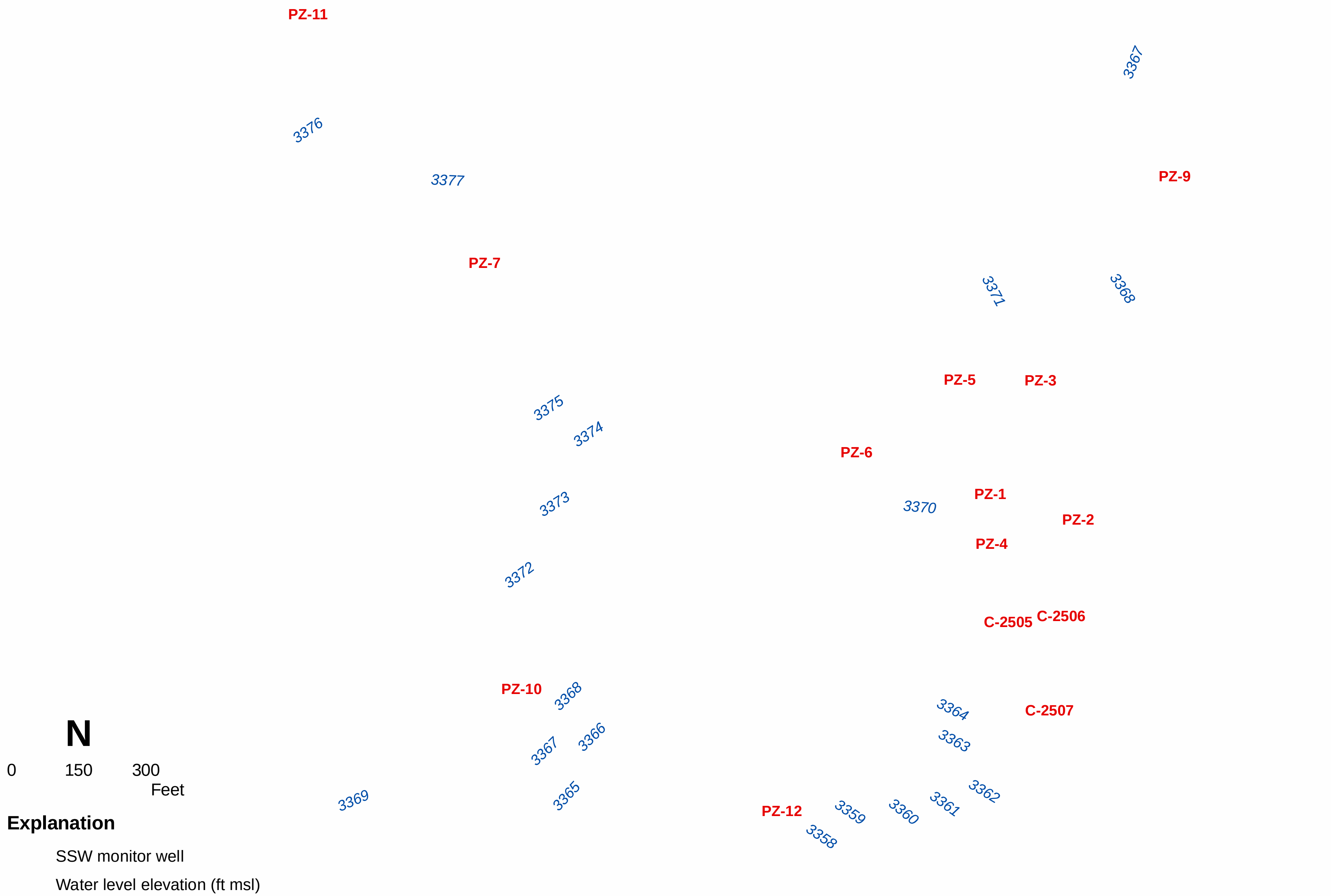


Figure E-2

WIPP SHALLOW SUBSURFACE WATER

Water Level Elevation, October 1998

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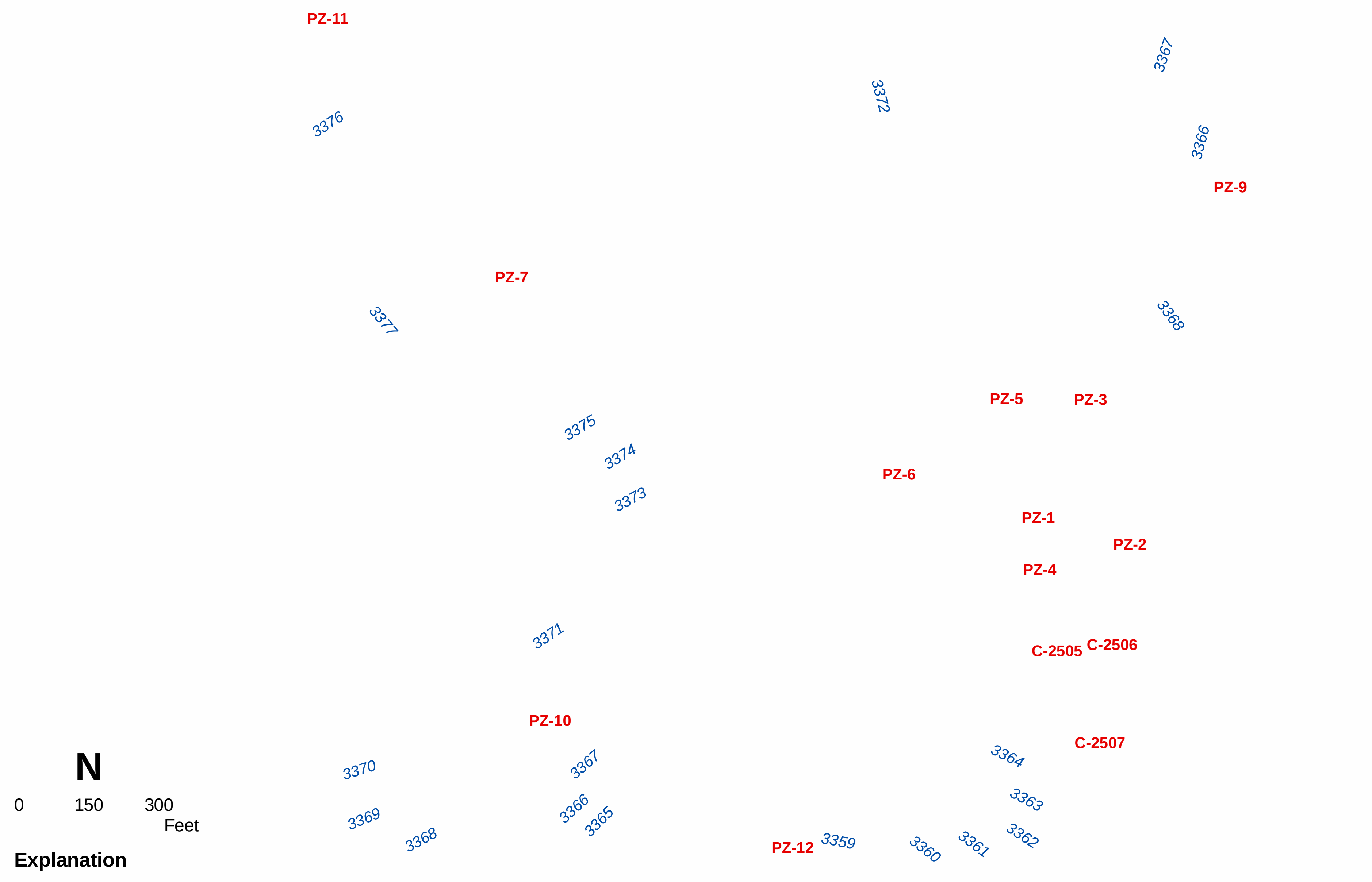
9/3/2008

JN ES08.0072

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/WATER_1999_AUG.MXD 808270



Explanation

SSW monitor well

Water level elevation (ft msl)

WIPP SHALLOW SUBSURFACE WATER

Water Level Elevation, August 1999

Daniel B. Stephens & Associates, Inc.

9/3/2008

JN ES08.0072

Figure E-3

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/WATER_2000_OCT.MXD 808270

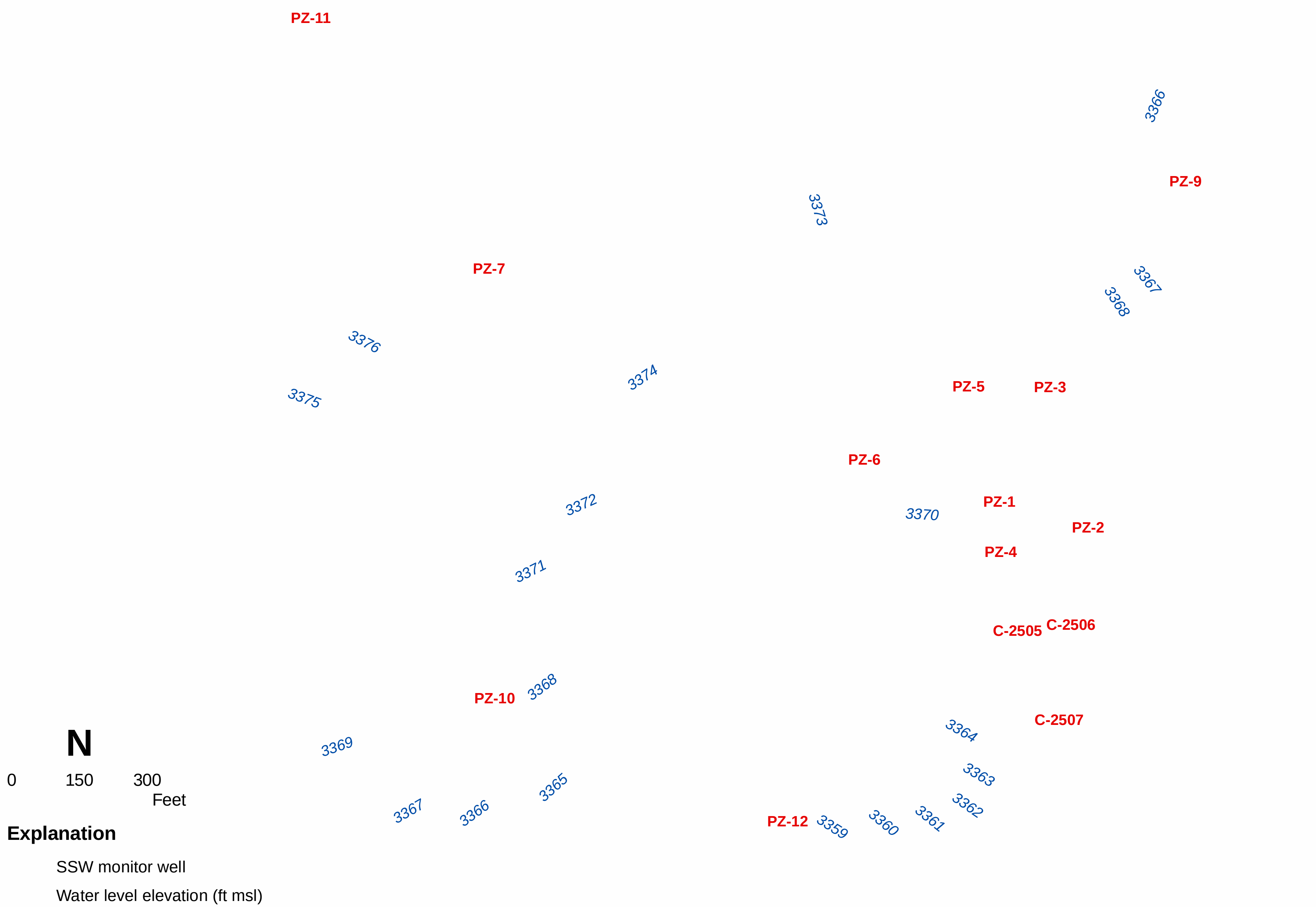


Figure E-4

WIPP SHALLOW SUBSURFACE WATER

Water Level Elevation, October 2000

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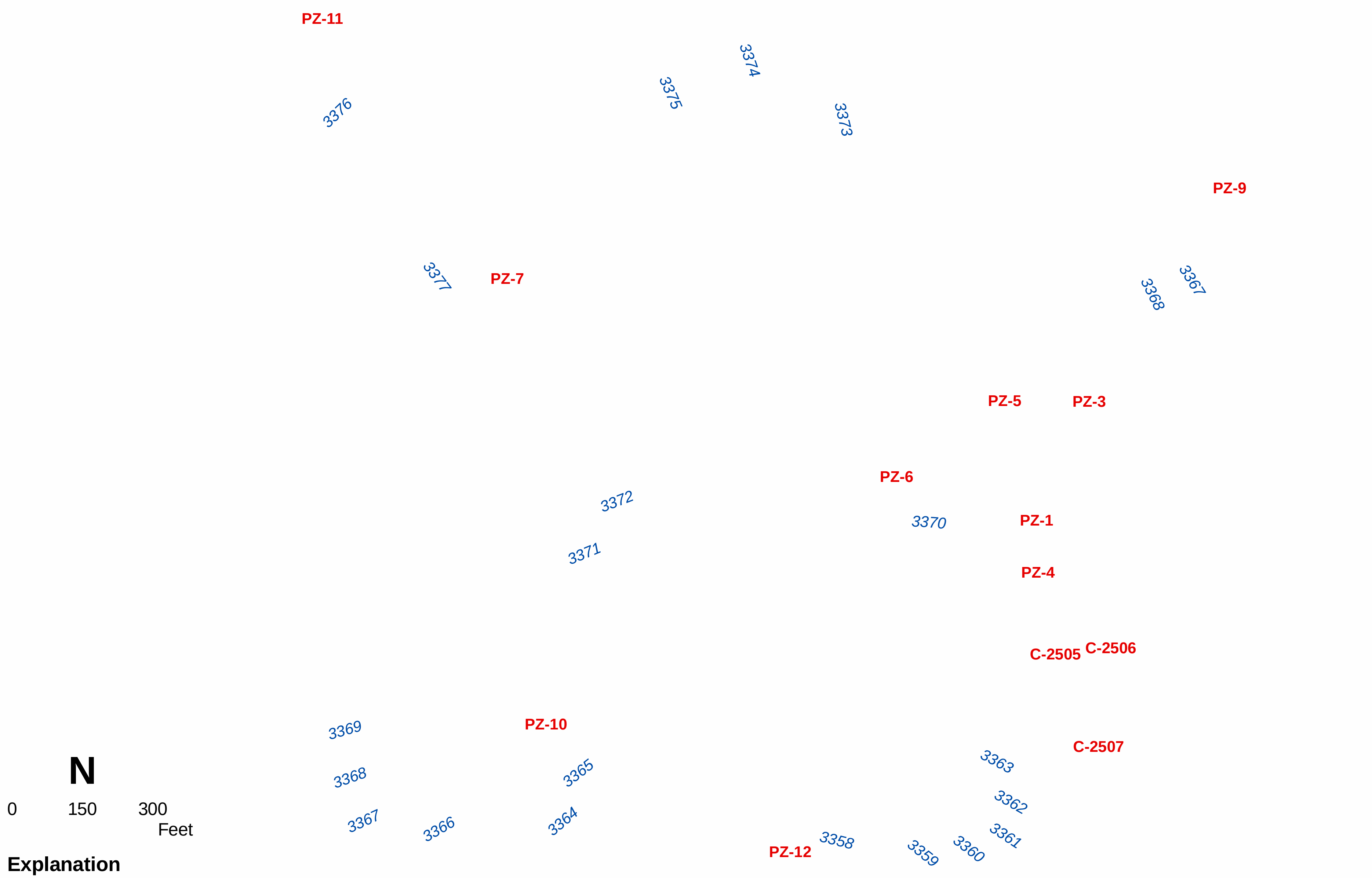
JN ES08.0072

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/WATER_2001_DEC.MXD 808270



Explanation

SSW monitor well

Water level elevation (ft msl)

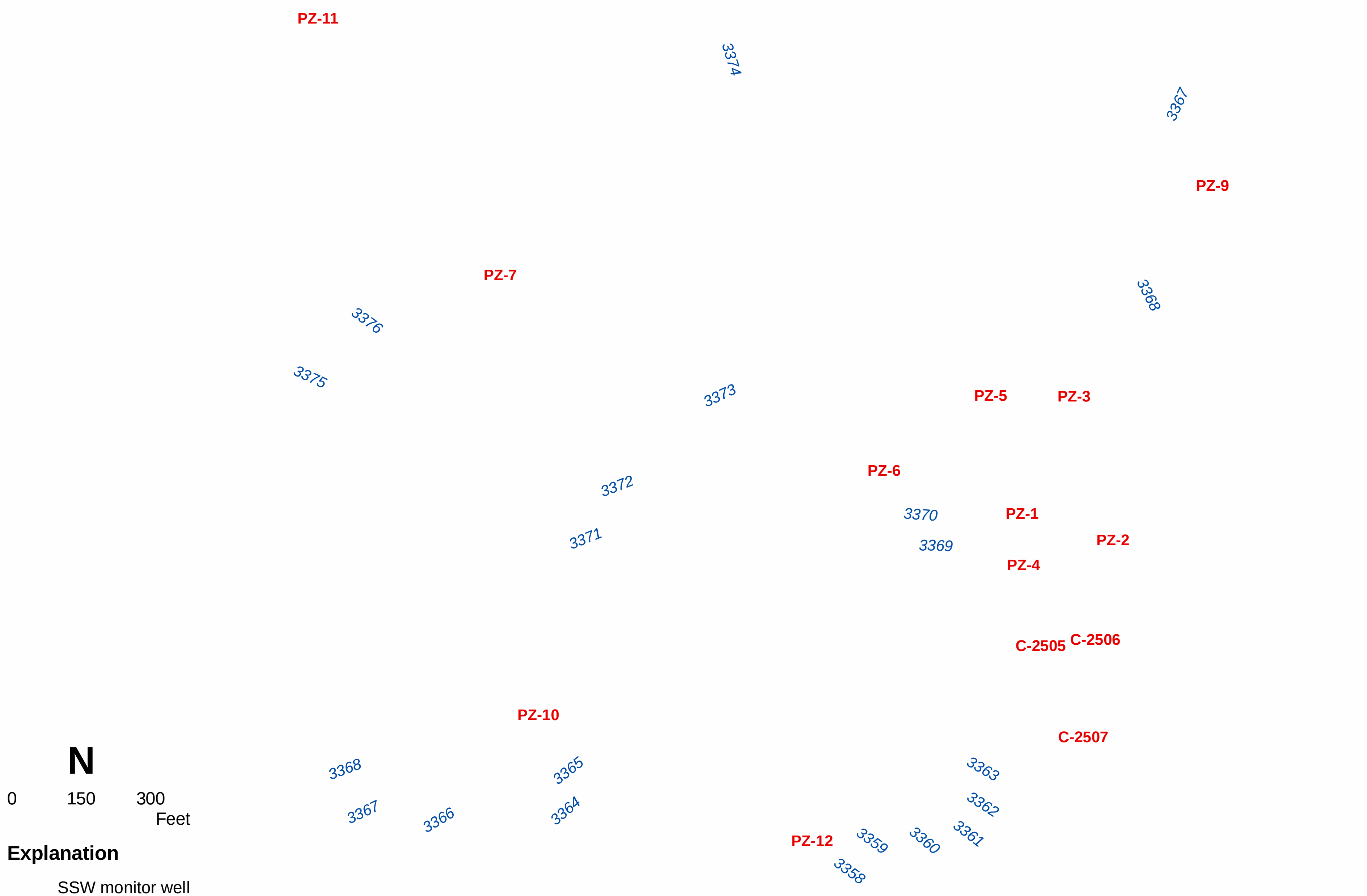
WIPP SHALLOW SUBSURFACE WATER

Water Level Elevation, December 2001

Daniel B. Stephens & Associates, Inc.
9/3/2008
JN ES08.0072

Figure E-5

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/WATER_2002_DEC.MXD 808270



Explanation

SSW monitor well

Water level elevation (ft msl)

WIPP SHALLOW SUBSURFACE WATER

Water Level Elevation, December 2002

Daniel B. Stephens & Associates, Inc.
9/3/2008
JN ES08.0072

Figure E-6

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/WATER_2004_JUNE.MXD 808270

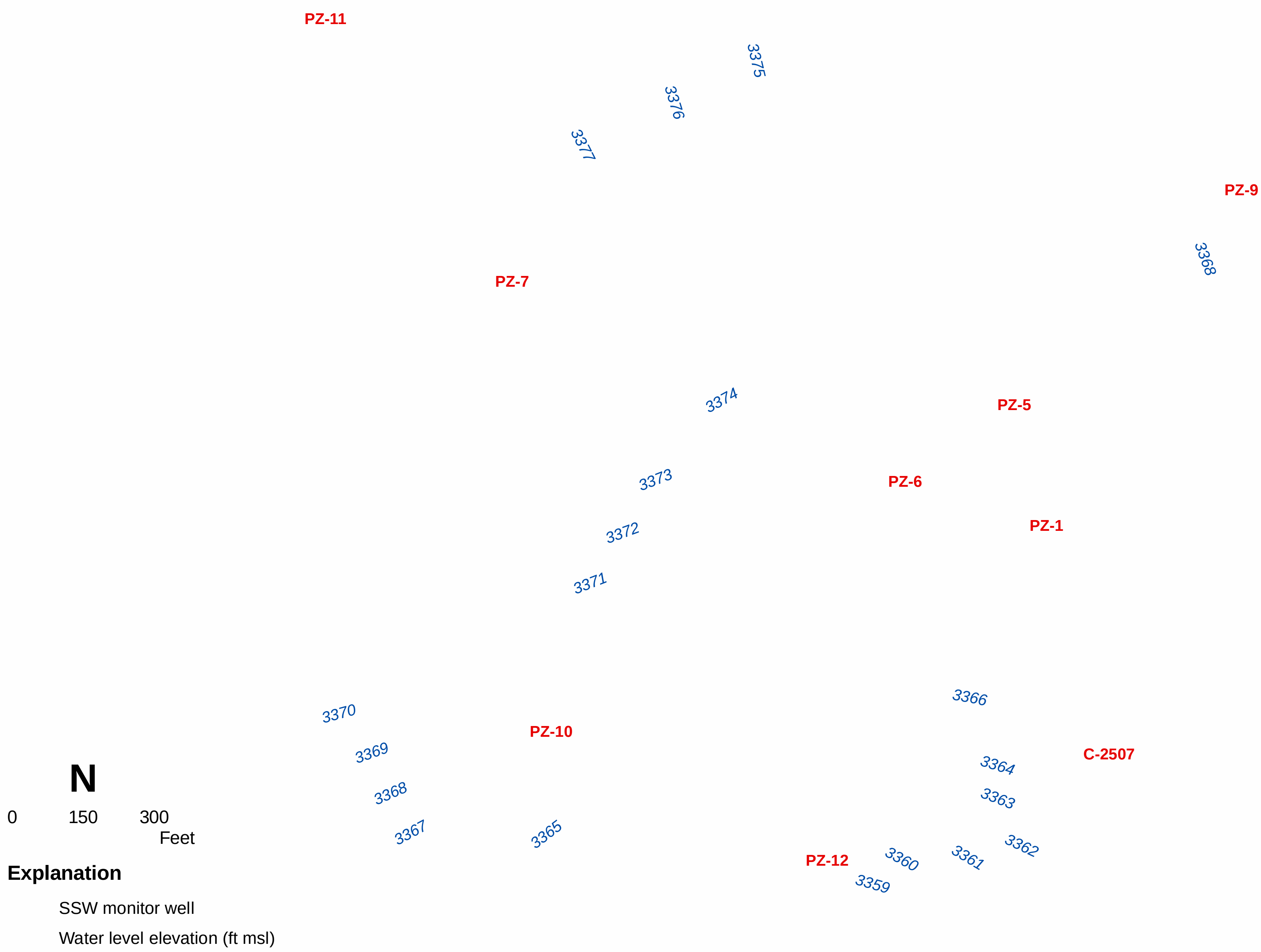


Figure E-7

WIPP SHALLOW SUBSURFACE WATER

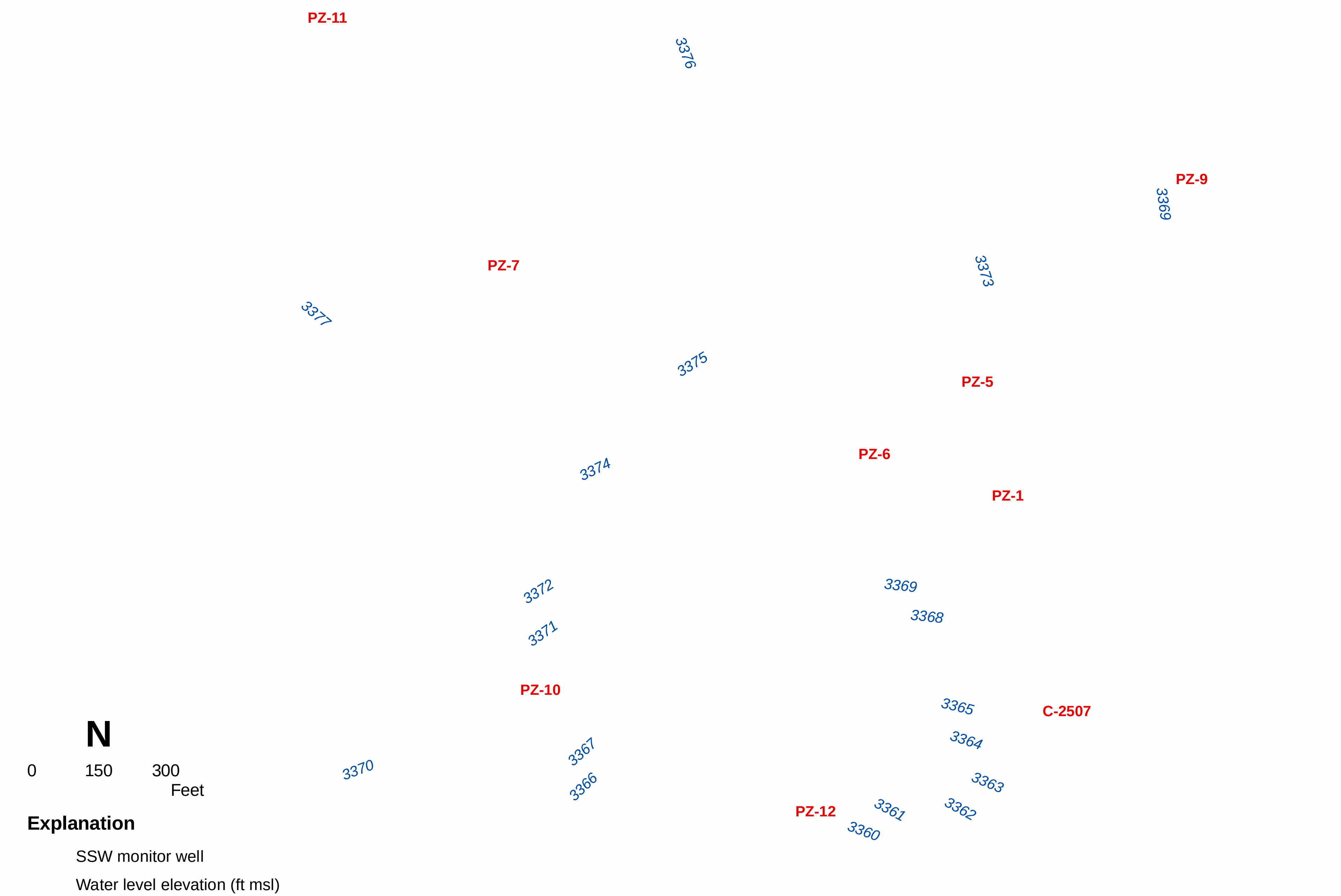
Water Level Elevation, June 2004

Daniel B. Stephens & Associates, Inc.

9/3/2008

JN ES08.0072

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/WATER_2004_NOV.MXD 808270



WIPP SHALLOW SUBSURFACE WATER

Water Level Elevation, November 2004

Daniel B. Stephens & Associates, Inc.
9/3/2008
JN ES08.0072

Figure E-8

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/WATER_2005_OCT.MXD 808270

N

0 150 300
Feet

Explanation

SSW monitor well

Water level elevation (ft msl)

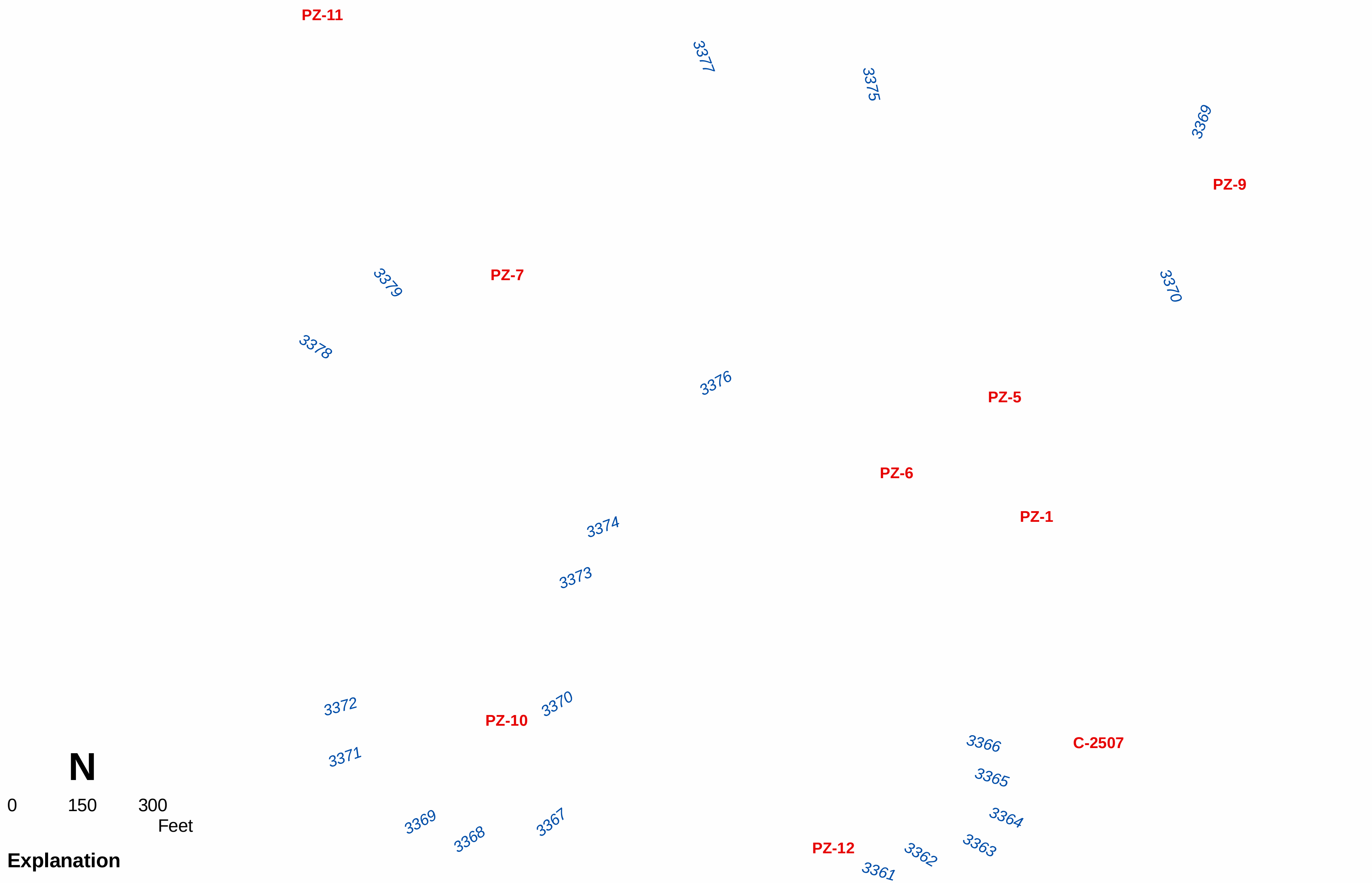
WIPP SHALLOW SUBSURFACE WATER

Water Level Elevation, October 2005

Daniel B. Stephens & Associates, Inc.
9/3/2008
JN ES08.0072

Figure E-9

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/WATER_2006_OCT.MXD 808270



Explanation

SSW monitor well

Water level elevation (ft msl)

Figure E-10

WIPP SHALLOW SUBSURFACE WATER

Water Level Elevation, October 2006

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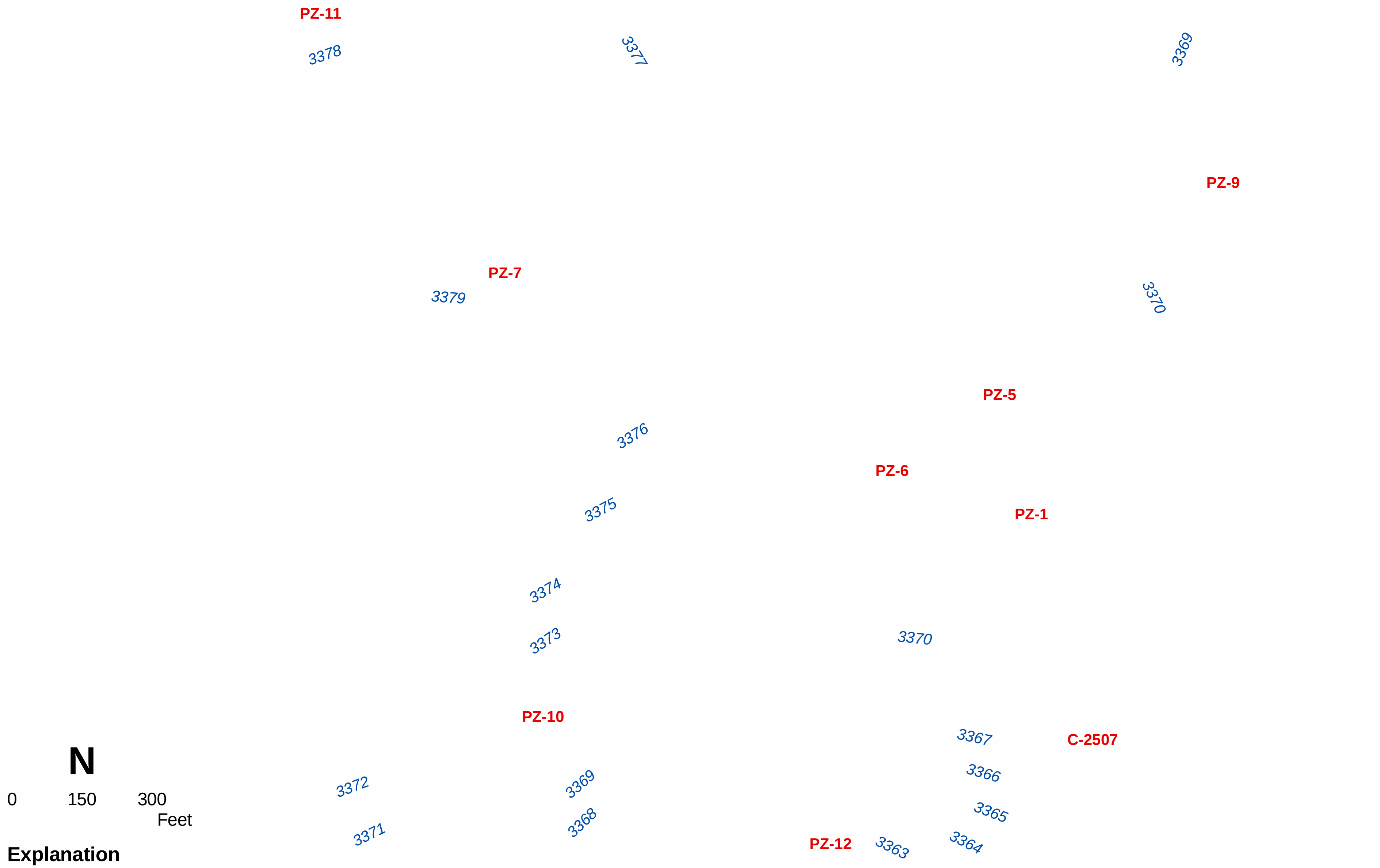
9/3/2008

JN ES08.0072

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/WATER_2007_OCT.MXD



Explanation

SSW monitor well

Water level elevation (ft msl)

Figure E-11

WIPP SHALLOW SUBSURFACE WATER

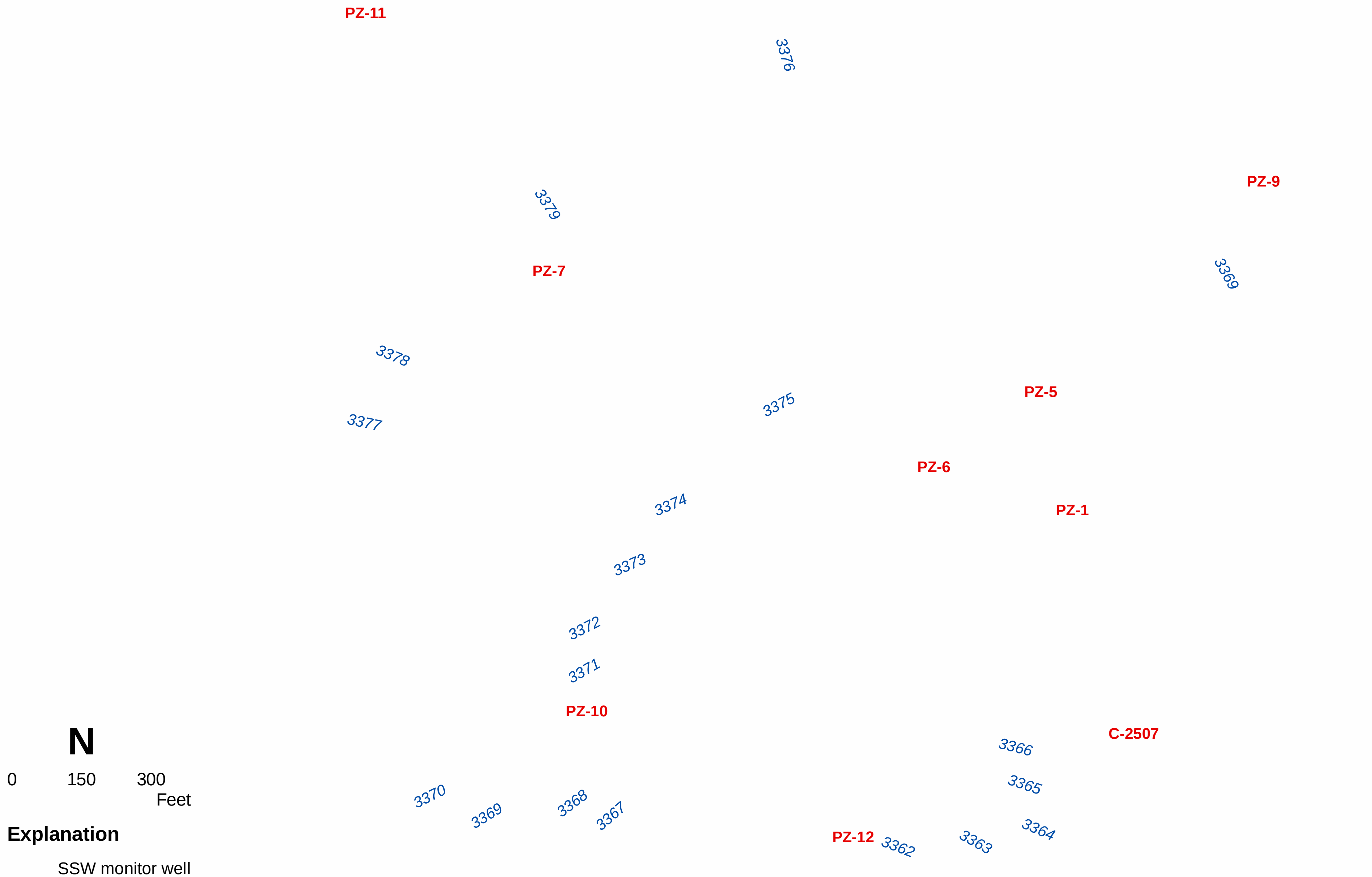
Water Level Elevation, October 2007

Daniel B. Stephens & Associates, Inc.

9/3/2008

JN ES08.0072

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/WATER_2008_JUNE.MXD



Explanation

SSW monitor well

Water level elevation (ft msl)

WIPP SHALLOW SUBSURFACE WATER

Water Level Elevation, June 2008

Daniel B. Stephens & Associates, Inc.

9/3/2008

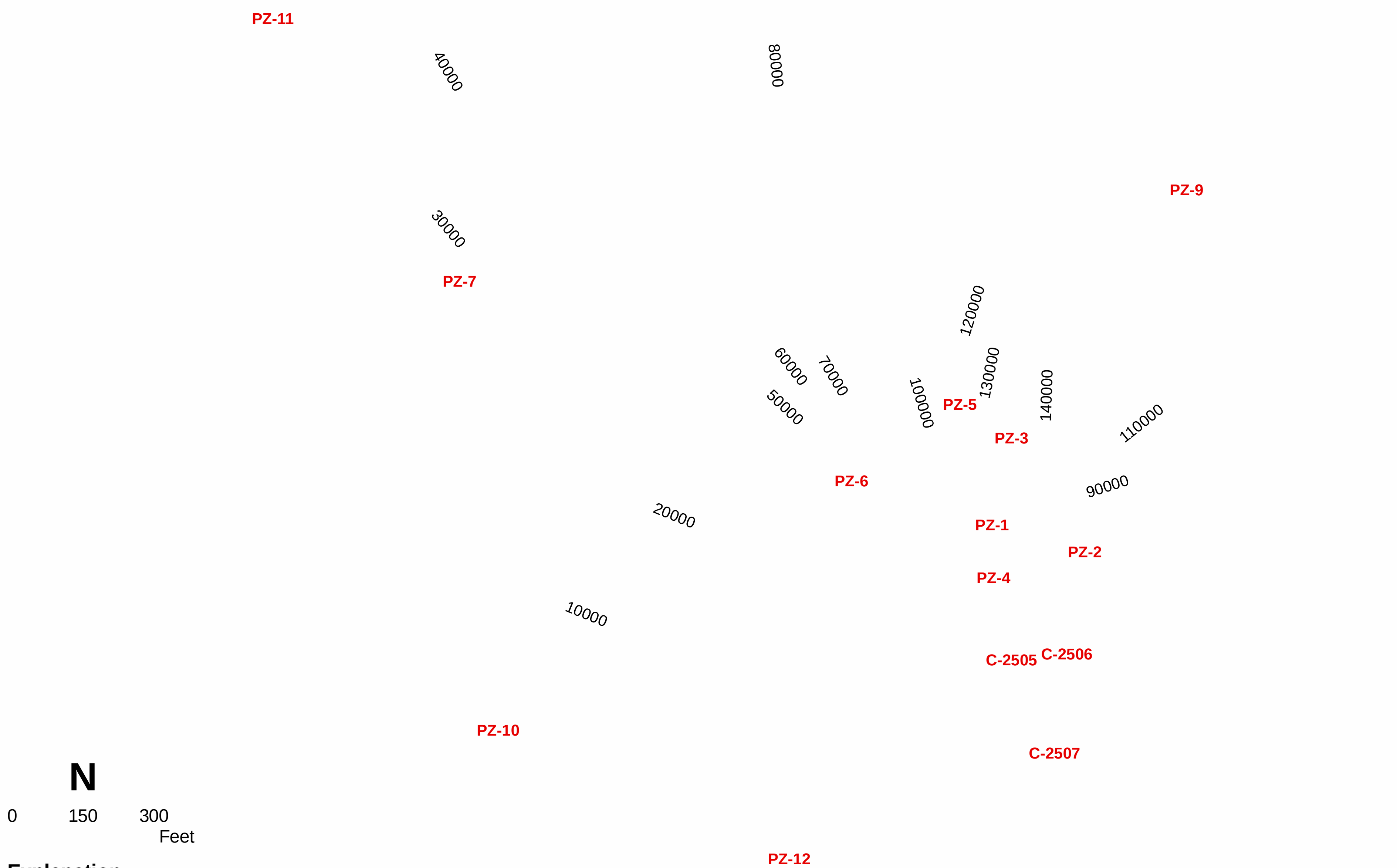
JN ES08.0072

Figure E-12

Appendix F

Water Quality Contour Maps

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/TDS_1997_OCT.MXD



Explanation

SSW monitor well

Total dissoved solids (mg/L)

Figure F-1

WIPP SHALLOW SUBSURFACE WATER

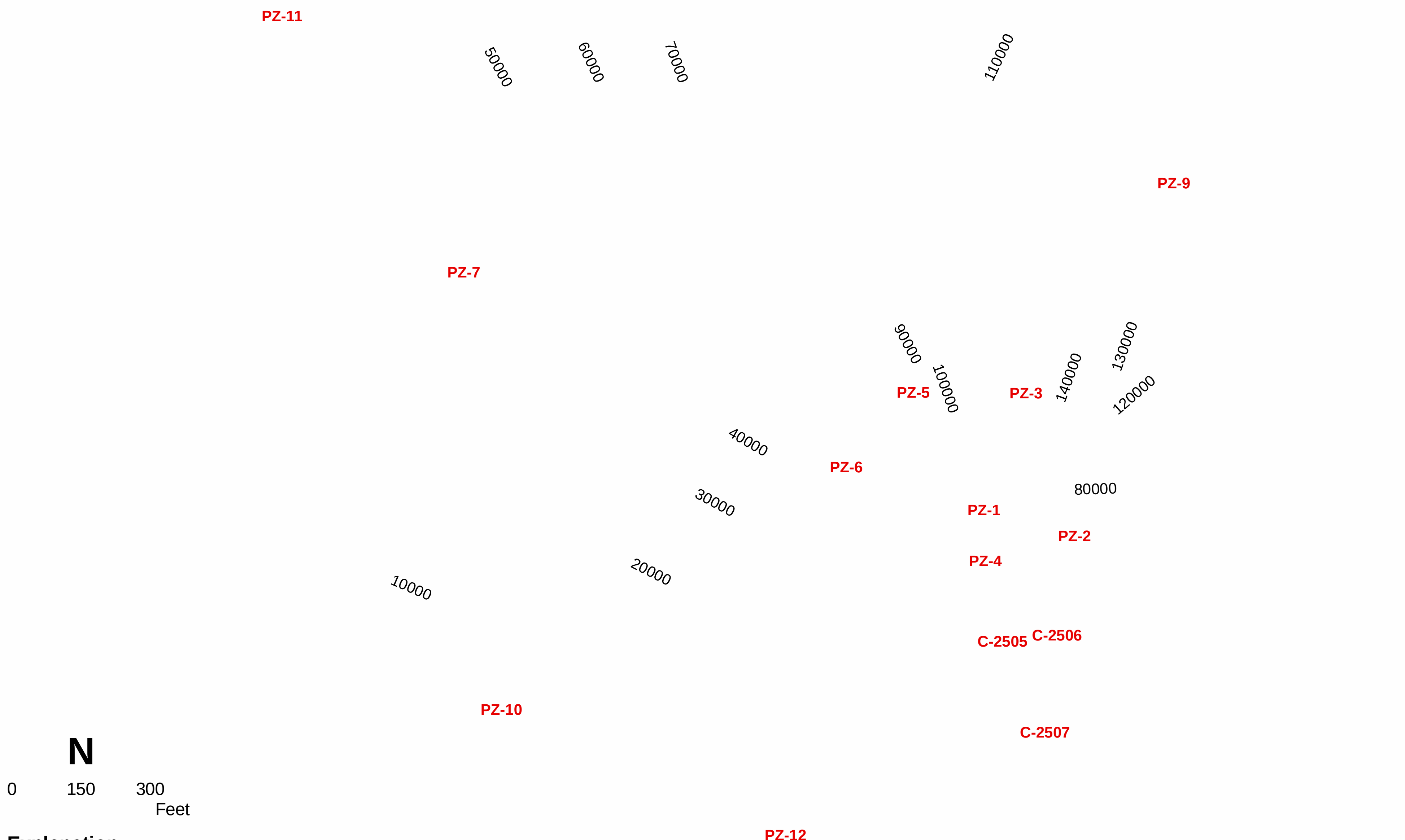
Total Dissolved Solids, October 1997

Daniel B. Stephens & Associates, Inc.

9/3/2008

JN ES08.0072

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/TDS_1998_OCT.MXD



Explanation

SSW monitor well

Total dissoved solids (mg/L)

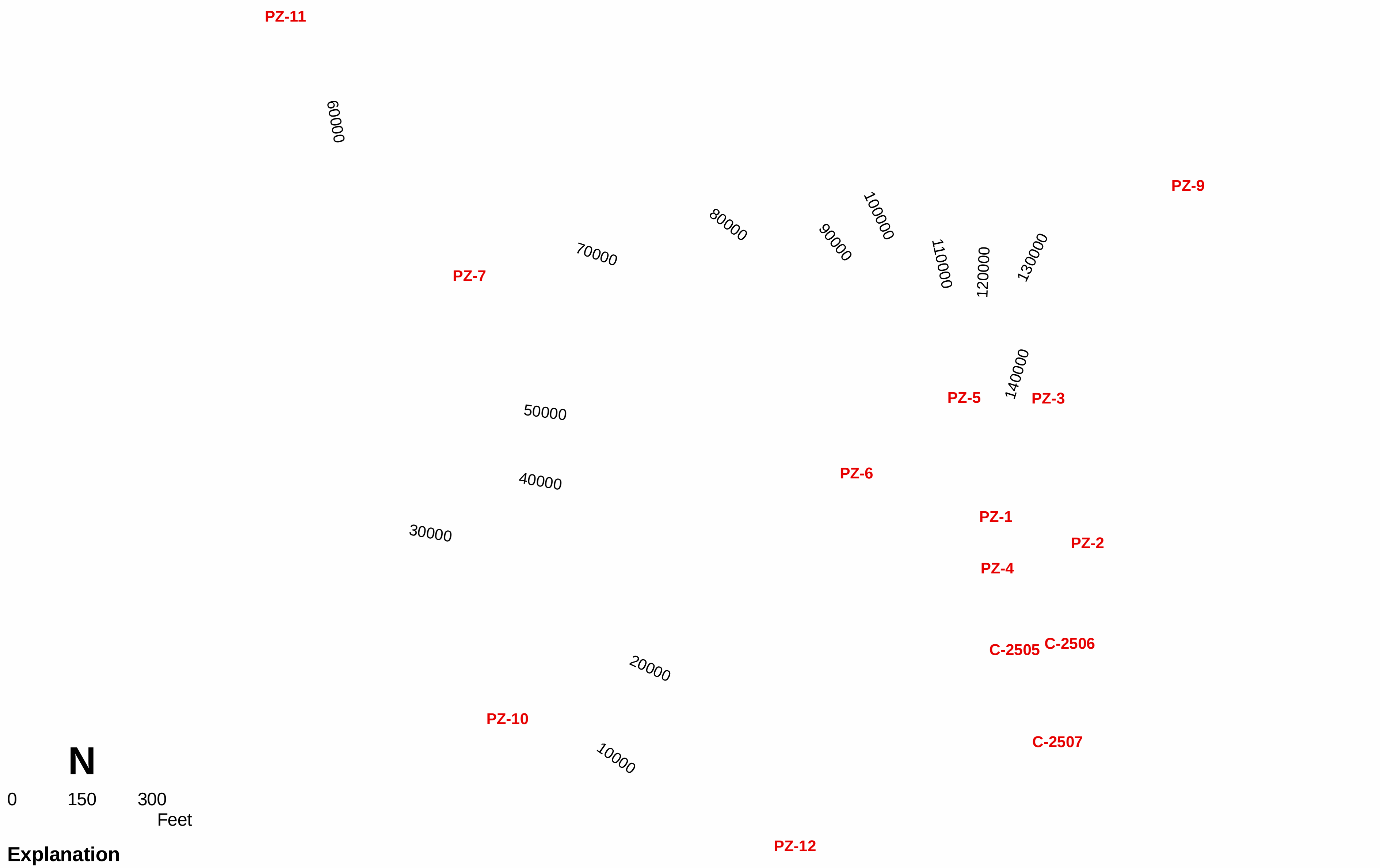
WIPP SHALLOW SUBSURFACE WATER

Total Dissolved Solids, October 1998

Daniel B. Stephens & Associates, Inc.
9/3/2008
JN ES08.0072

Figure F-2

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/TDS_1999_AUG.MXD



Explanation

SSW monitor well

Total dissoved solids (mg/L)

Figure F-3

WIPP SHALLOW SUBSURFACE WATER

Total Dissolved Solids, August 1999

Daniel B. Stephens & Associates, Inc.

9/3/2008

JN ES08.0072

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/TDS_2000_OCT.MXD

PZ-11

50000
60000
70000
80000
110000
120000

PZ-9

PZ-7

100000
90000

PZ-5
PZ-3

40000

PZ-6

30000
20000

PZ-1
PZ-2
PZ-4

10000

C-2505
C-2506

PZ-10

C-2507

N

0 150 300
Feet

PZ-12

Explanation

SSW monitor well

Total dissoved solids (mg/L)

Figure F-4

WIPP SHALLOW SUBSURFACE WATER

Total Dissolved Solids, October 2000

Daniel B. Stephens & Associates, Inc.

9/3/2008

JN ES08.0072

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/TDS_2001_DEC.MXD

PZ-11

130000
120000
110000
PZ-9
80000
90000
100000
70000
PZ-7

PZ-5
PZ-3
60000
PZ-6
50000
PZ-1
40000
PZ-4
30000
C-2505
C-2506
20000
PZ-10
C-2507
10000
10000
PZ-12

N

0 150 300
Feet

Explanation

SSW monitor well

Total dissoved solids (mg/L)

Figure F-5

Daniel B. Stephens & Associates, Inc.
9/3/2008
JN ES08.0072

WIPP SHALLOW SUBSURFACE WATER

Total Dissolved Solids, December 2001

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/TDS_2002_DEC.MXD

PZ-11
110000
130000
120000
80000
90000
100000
PZ-9
70000
PZ-7
PZ-5
PZ-3
40000
60000
PZ-6
80000
PZ-1
50000
PZ-2
PZ-4
C-2505
C-2506
30000
10000
20000
PZ-10
C-2507
10000

N

0 150 300
Feet

PZ-12

Explanation

SSW monitor well

Total dissoved solids (mg/L)

WIPP SHALLOW SUBSURFACE WATER

Total Dissolved Solids, December 2002

Figure F-6

Daniel B. Stephens & Associates, Inc.
9/3/2008
JN ES08.0072

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/TDS_2004_JUNE.MXD

PZ-11
120000
110000
PZ-9
100000
PZ-7
90000
PZ-5
70000
120000
PZ-6
PZ-1
80000
60000
50000
40000
30000
PZ-10
20000
C-2507
10000
PZ-12

N

0 150 300
Feet

Explanation

SSW monitor well

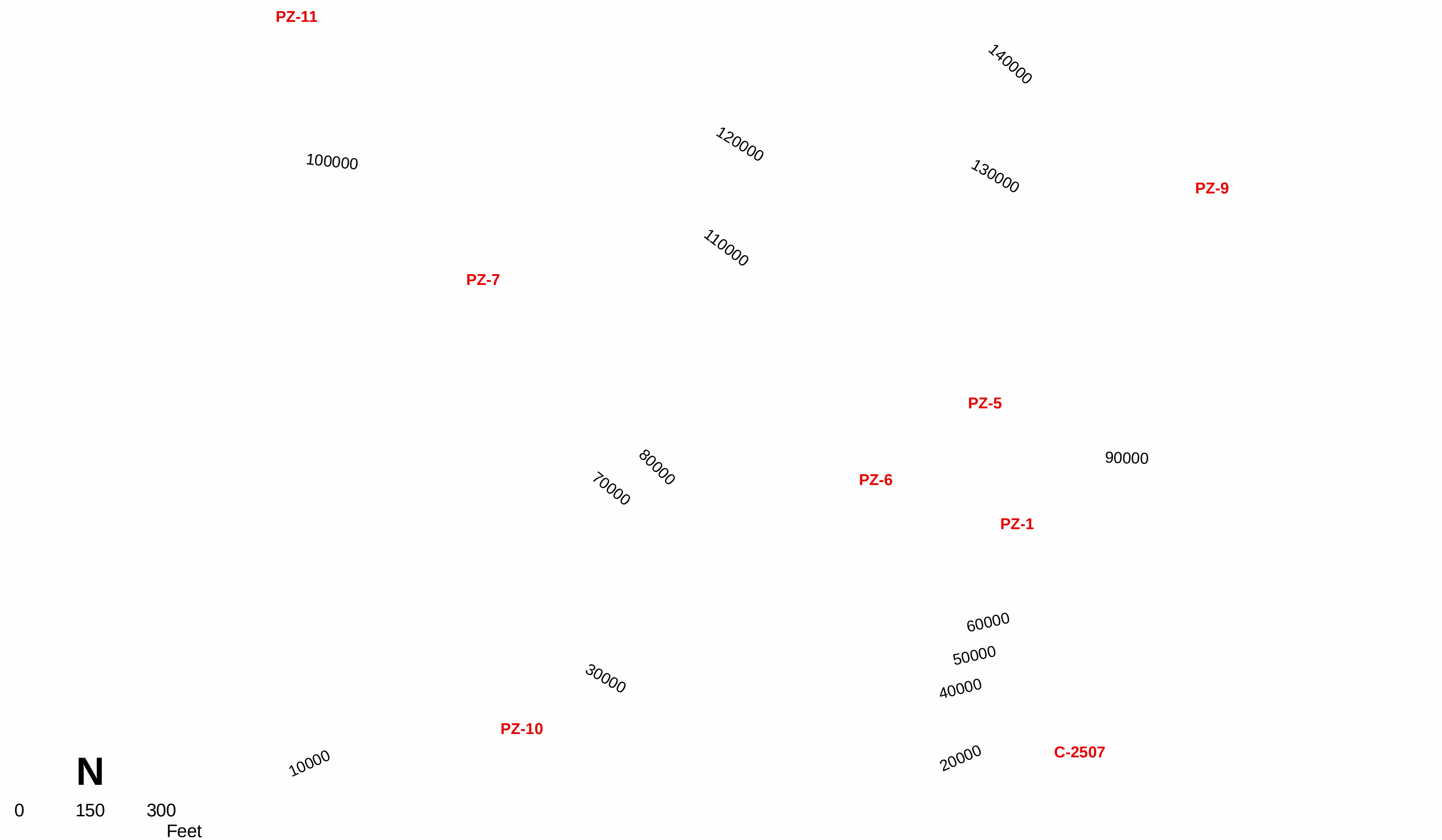
Total dissoved solids (mg/L)

Figure F-7

Daniel B. Stephens & Associates, Inc.
9/3/2008
JN ES08.0072

WIPP SHALLOW SUBSURFACE WATER
Total Dissolved Solids, June 2004

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/TDS_2004_NOV.MXD



Explanation

SSW monitor well

Total dissoved solids (mg/L)

WIPP SHALLOW SUBSURFACE WATER

Total Dissolved Solids, November 2004

Daniel B. Stephens & Associates, Inc.

9/3/2008

JN ES08.0072

Figure F-8

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/TDS_2005_OCT.MXD

PZ-11
120000
110000
110000
PZ-9
100000
PZ-7
90000
80000
50000
PZ-5
90000
PZ-6
PZ-1
70000
60000
50000
40000
30000
PZ-10
20000
C-2507
10000
PZ-12

N

0 150 300
Feet

Explanation

SSW monitor well

Total dissolved solids (mg/L)

WIPP SHALLOW SUBSURFACE WATER

Total Dissolved Solids, October 2005

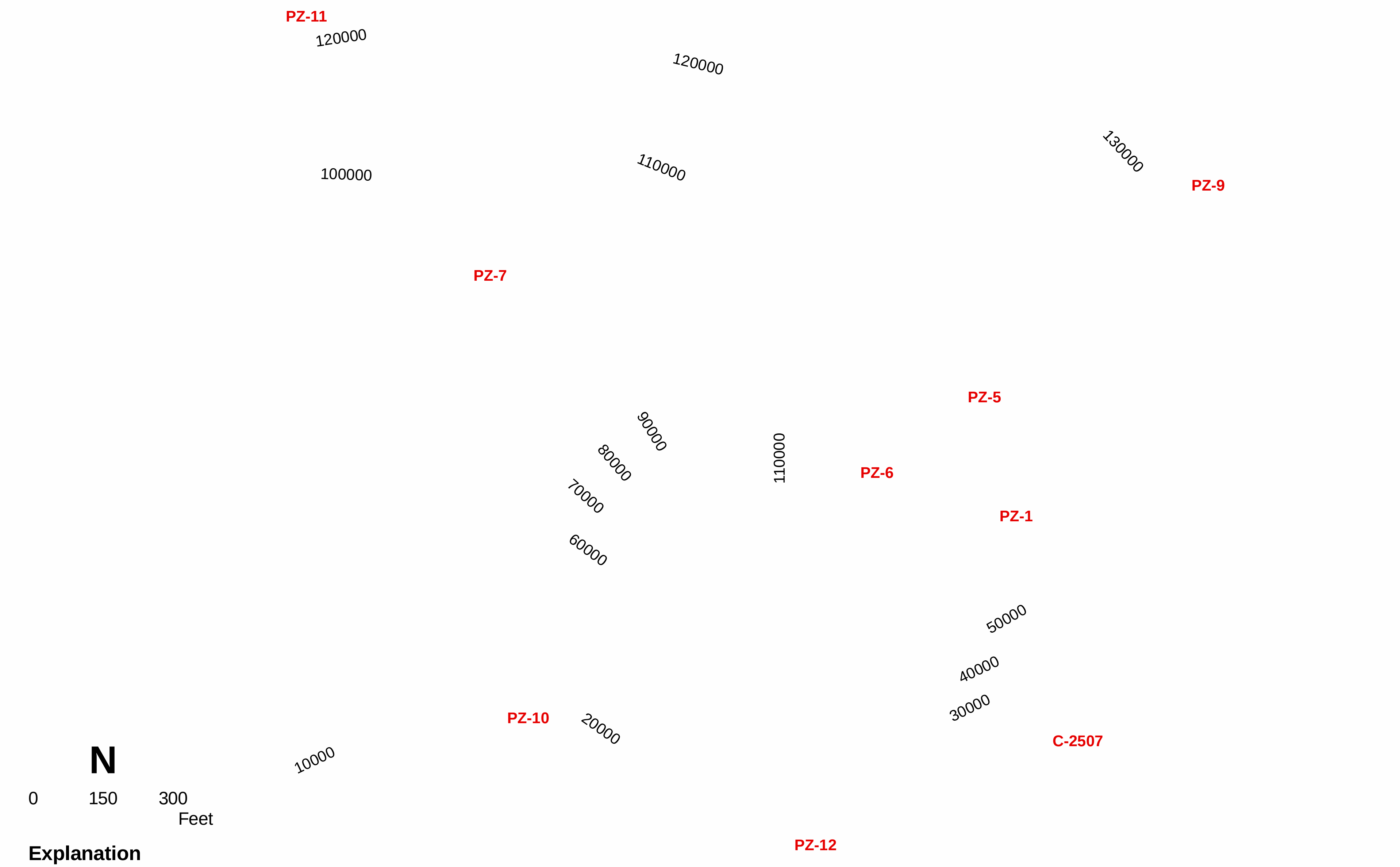
Daniel B. Stephens & Associates, Inc.

9/3/2008

JN ES08.0072

Figure F-9

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/TDS_2006_OCT.MXD



Explanation

SSW monitor well

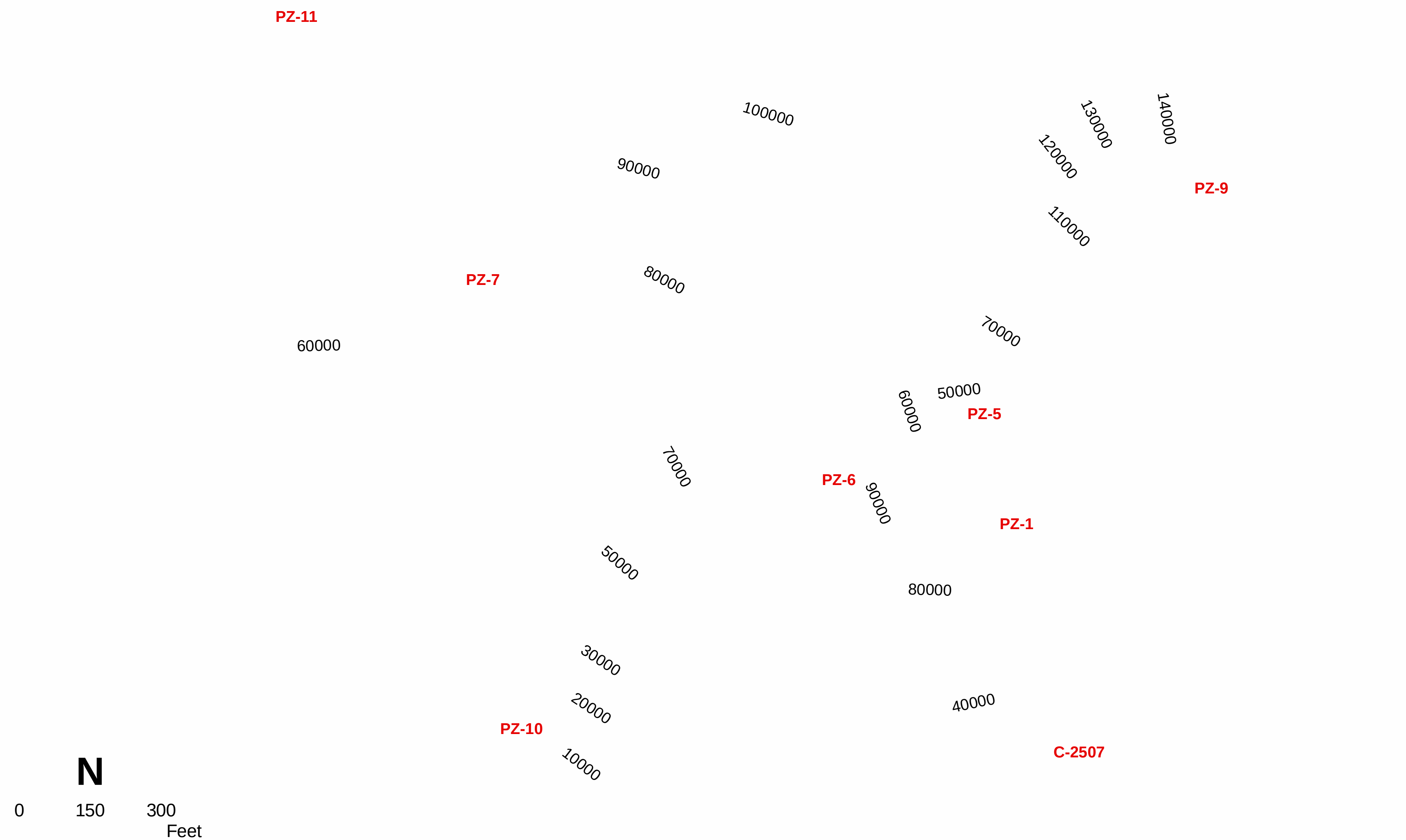
Total dissolved solids (mg/L)

WIPP SHALLOW SUBSURFACE WATER
Total Dissolved Solids, October 2006

Daniel B. Stephens & Associates, Inc.
9/3/2008
JN ES08.0072

Figure F-10

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/TDS_2007_OCT.MXD



Explanation

SSW monitor well

Total dissolved solids (mg/L)

Figure F-11

Daniel B. Stephens & Associates, Inc.
9/3/2008
JN ES08.0072

WIPP SHALLOW SUBSURFACE WATER

Total Dissolved Solids, October 2007

S:/PROJECTS/ES08.0072_WIPP_SSW/GIS/MXDS/MODEL_OUTPUT_FIGURES/TDS_2008_JUNE.MXD

PZ-11

110000

140000

130000

100000

120000

PZ-9

90000

PZ-7

80000

70000

PZ-5

50000

60000

70000

60000

PZ-6

50000

PZ-1

30000

40000

20000

PZ-10

C-2507

N

10000

0 150 300
Feet

PZ-12

Explanation

SSW monitor well

Total dissoved solids (mg/L)

Figure F-12

WIPP SHALLOW SUBSURFACE WATER

Total Dissolved Solids, June 2008

Daniel B. Stephens & Associates, Inc.

9/3/2008

JN ES08.0072

Appendix G

Moisture Redistribution Calculations

Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Sandy Clay Loam (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

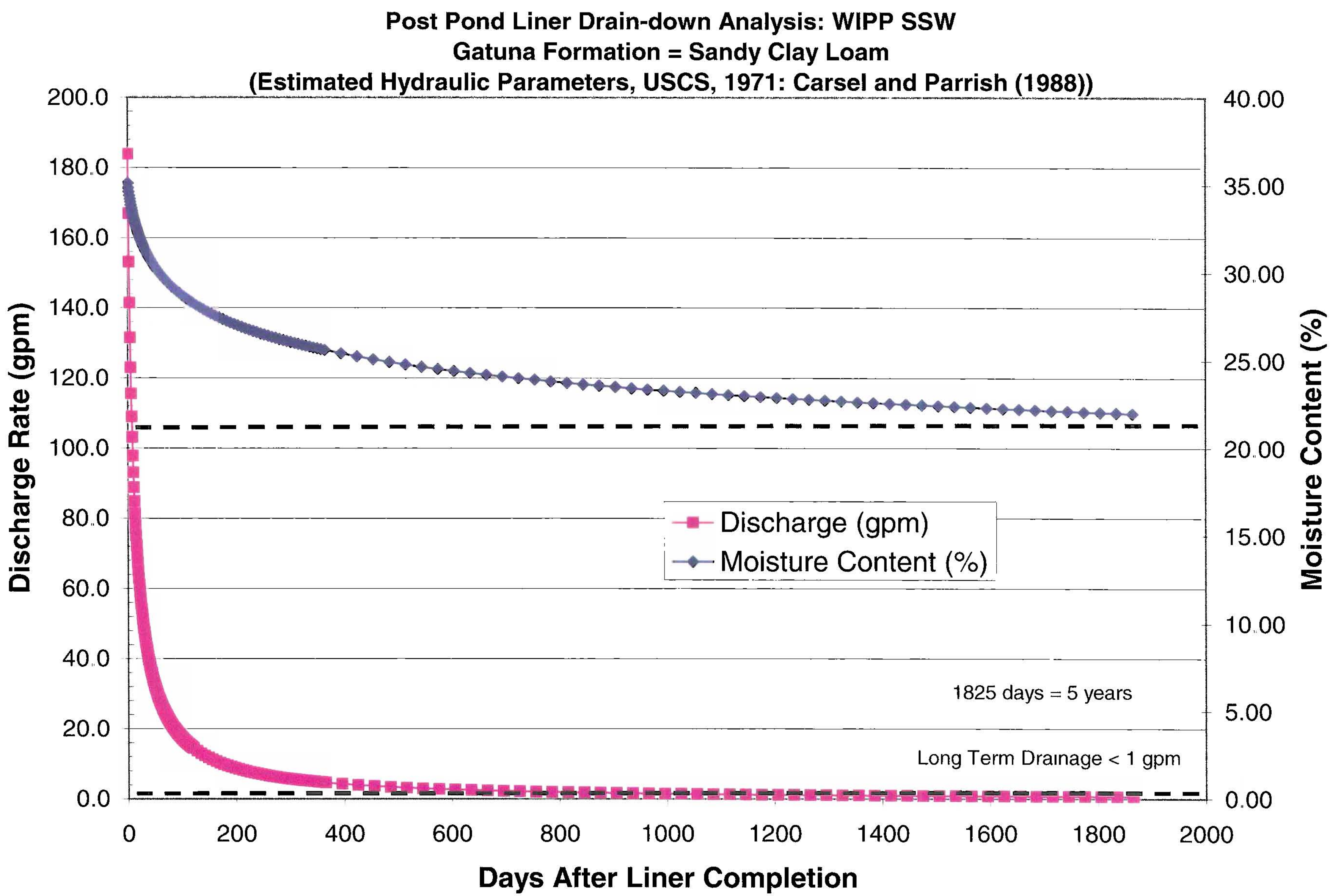
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.39**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.351**	**fraction**	**90% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**111.7**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.1**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**79.9**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**41.7**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	35.10	34 84	34.61	34.40	34 20	34 02		22 03
	Discharge (gpm)	1.84E+02	1.67E+02	1.53E+02	1.41E+02	1.31E+02	1.23E+02		7.71E-01
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	2.70E-05	2.45E-05	2.25E-05	2.08E-05	1.93E-05	1.81E-05		1.13E-07
Effective Saturation (Stephens, 1995)	Se	0.865517	0.856718	0.848729	0.841405	0.834638	0.828346	Daily Time Steps for 5 Years	0.414688
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.48	1.48	1.48	1.48	1.48	1.48		1.48
Mualem model (Stephens, 1995)	m	0.324324	0.324324	0.324324	0.324324	0.324324	0 324324		0.324324
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0 059	0 059	0.059	0.059	0.059	0.059		0 059
Pressure head (Stephens, 1995)	P-head (-cm)	11.46892	12.14953	12.77624	13.35892	13 90482	14.4194		101.2609
Relative hydraulic conductivity	Kr	0.074217	0.067381	0.061772	0.057074	0.053074	0.04962		0.000311
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	3.64E-04	3.64E-04	3.64E-04	3.64E-04	3.64E-04	3 64E-04		3.64E-04
Drainage Volume (acre-ft)		0.00E+00	8.12E-01	7.37E-01	6.76E-01	6.25E-01	5.81E-01		1.04E-01

References.

Carsel, R.F and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B , 1996 Vadose Zone Hydrology CRC Press.



T:\Projects\9184\Sheets\Final Water Balance\Vadose Zone Redistribution Estimate Ponds 90 DRAFT 7-22-08_working_copy.xls_Drain-down Chart (SCL, CP)

Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Silt (Carsel and Parrish, 1988, Tables, 2, 3, 4, 5)

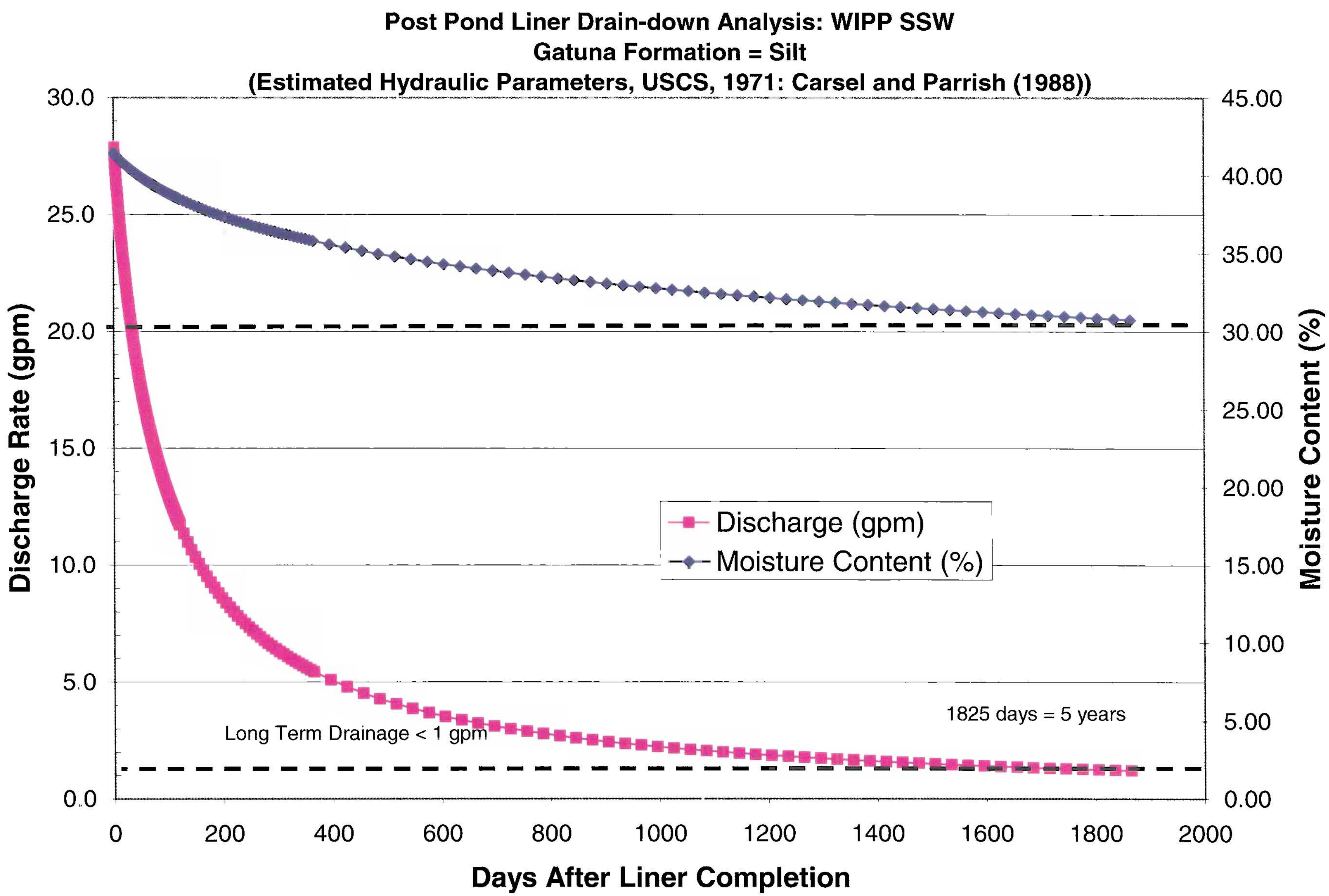
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.46**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.414**	**fraction**	**90% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**131.8**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.034**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**121.0**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**33.8**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	41.40	41.36	41.32	41.29	41.25	41.21		30.84
	Discharge (gpm)	2.79E+01	2.75E+01	2.72E+01	2.69E+01	2.66E+01	2.63E+01		1.24E+00
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	4.09E-06	4.04E-06	4.00E-06	3.95E-06	3.90E-06	3.86E-06		1.83E-07
Effective Saturation (Stephens, 1995)	Se	0.892019	0.891111	0.890214	0.889328	0.888452	0.887586	Daily Time Steps for 5 Years	0.64403
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.37	1.37	1.37	1.37	1.37	1.37		1.37
Mualem model (Stephens, 1995)	m	0.270073	0.270073	0.270073	0.270073	0.270073	0.270073		0.270073
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.016	0.016	0.016	0.016	0.016	0.016		0.016
Pressure head (Stephens, 1995)	P-head (-cm)	39.14123	39.45359	39.76276	40.06883	40.37189	40.67199		175.0498
Relative hydraulic conductivity	Kr	0.058938	0.058229	0.057538	0.056865	0.056209	0.055569		0.00263
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	6.94E-05	6.94E-05	6.94E-05	6.94E-05	6.94E-05	6.94E-05		6.94E-05
Drainage Volume (acre-ft)		0.00E+00	1.23E-01	1.22E-01	1.20E-01	1.19E-01	1.17E-01		1.67E-01

References.

Carsel, R.F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D B., 1996 Vadose Zone Hydrology CRC Press.



T:\Projects\9184\Sheets\Final Water Balance\Vadose Zone Redistribution Estimate Ponds 90 DRAFT 7-22-08_working_copy.xls_Drain-down Chart (Silt, CP)

Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Clay Loam (Carsel and Parrish, 1988, Tables, 2, 3, 4, 5)

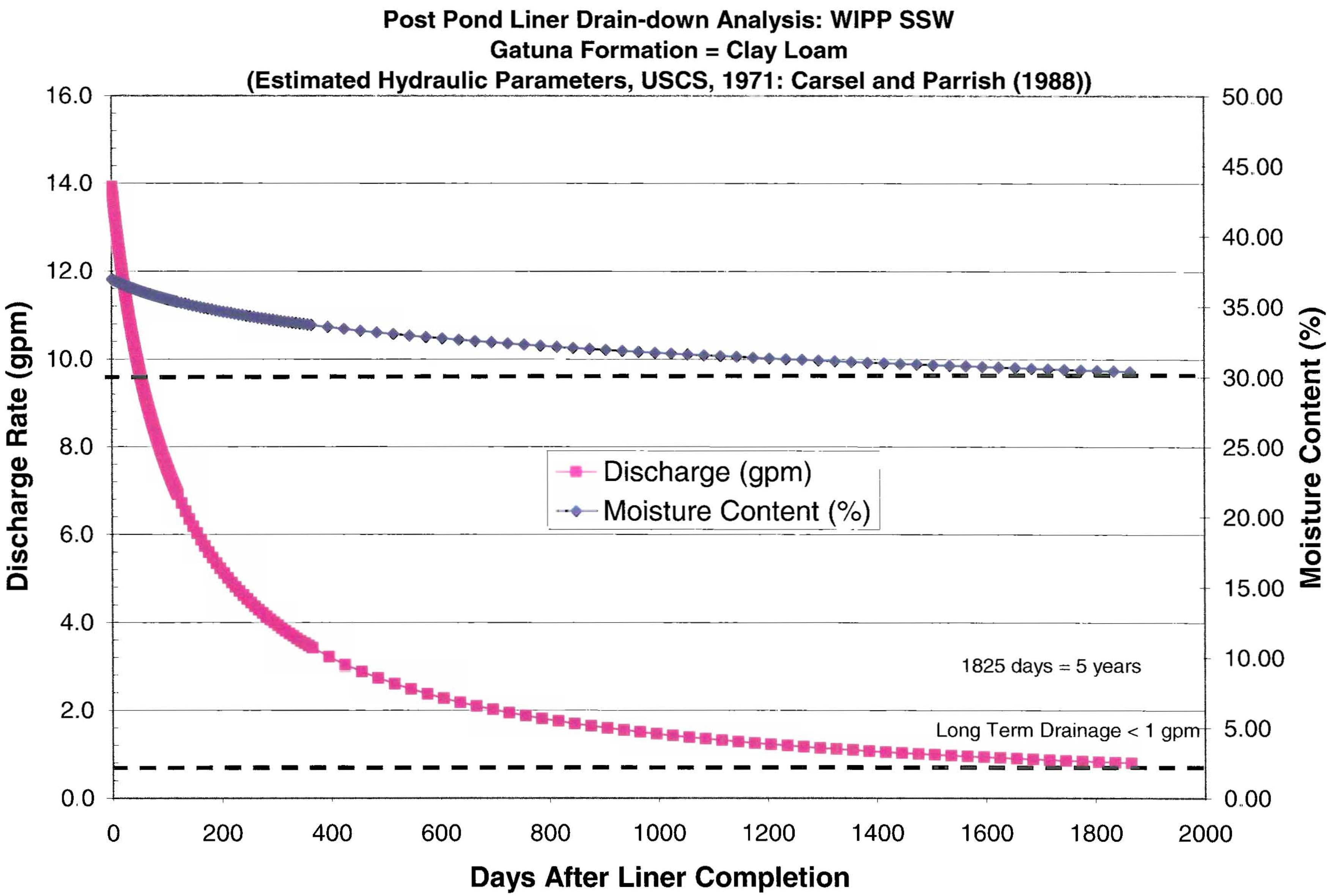
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.41**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.369**	**fraction**	**90% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**117.5**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.095**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**87.2**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**20.7**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	36.90	36.88	36.86	36.84	36.82	36.81		30.44
	Discharge (gpm)	1.39E+01	1.38E+01	1.37E+01	1.36E+01	1.35E+01	1.33E+01		8.23E-01
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	2.05E-06	2.03E-06	2.01E-06	1.99E-06	1.98E-06	1.96E-06		1.21E-07
Effective Saturation (Stephens, 1995)	Se	0.869841	0.869228	0.86862	0.868017	0.867419	0.866826		0.6647
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.31	1.31	1.31	1.31	1.31	1.31	Daily Time Steps for 5 Years	1.31
Mualem model (Stephens, 1995)	m	0.236641	0.236641	0.236641	0.236641	0.236641	0.236641		0.236641
van Genuchten Parameter. Carsel and Parrish, 1988	$alpha_{(v)}$	0.019	0.019	0.019	0.019	0.019	0.019		0.019
Pressure head (Stephens, 1995)	P-head (-cm)	44.50117	44.72879	44.95492	45.17958	45.4028	45.6246		169.213
Relative hydraulic conductivity	Kr	0.028318	0.028073	0.027833	0.027597	0.027365	0.027138		0.001675
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	7.22E-05	7.22E-05	7.22E-05	7.22E-05	7.22E-05	7.22E-05		7.22E-05
Drainage Volume (acre-ft)		0.00E+00	6.15E-02	6.10E-02	6.05E-02	5.99E-02	5.94E-02		1.11E-01

References.

Carsel, R.F and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v 24, no. 5 p. 755-769

Stephens, D.B., 1996. Vadose Zone Hydrology. CRC Press.



T:\Projects\9184\Sheets\Final Water Balance\Vadose Zone Redistribution Estimate Ponds 90 DRAFT 7-22-08_working_copy.xls_Drain-down Chart (CL CP)

Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Clay (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

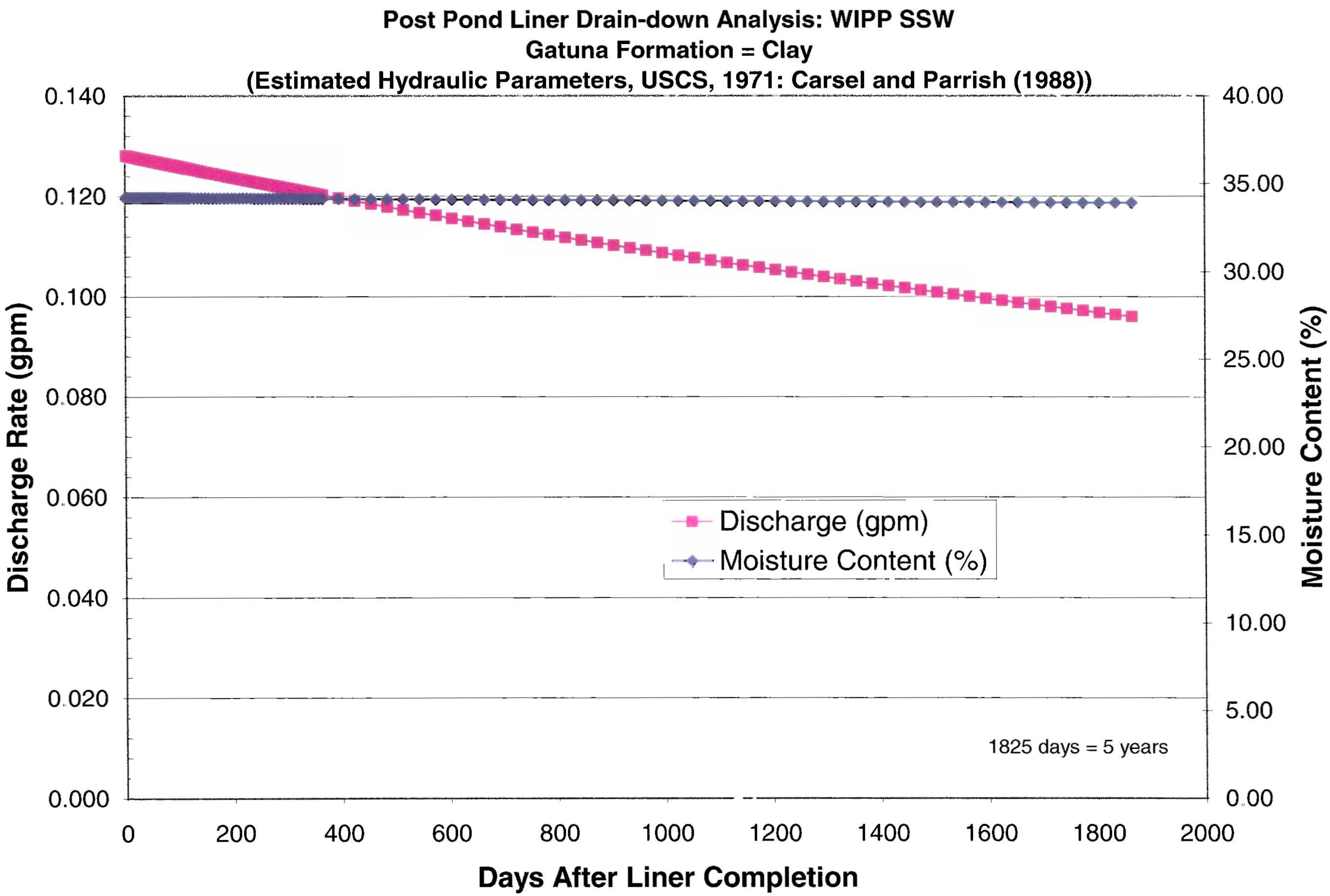
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.38**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.342**	**fraction**	**90% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**108.9**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.068**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**87.2**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**0.9**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	34.20	34.20	34.20	34.20	34.20	34.20		33.92
	Discharge (gpm)	1.28E-01	1.28E-01	1.28E-01	1.28E-01	1.28E-01	1.28E-01		9.65E-02
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	1.88E-08	1.88E-08	1.88E-08	1.88E-08	1.88E-08	1.88E-08		1.42E-08
Effective Saturation (Stephens, 1995)	Se	0.878205	0.878199	0.878194	0.878188	0.878182	0.878177		0.869142
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.09	1.09	1.09	1.09	1.09	1.09	Daily Time Steps for 5 Years	1.09
Mualem model (Stephens, 1995)	m	0.082569	0.082569	0.082569	0.082569	0.082569	0.082569		0.082569
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.008	0.008	0.008	0.008	0.008	0.008		0.008
Pressure head (Stephens, 1995)	P-head (-cm)	427.5553	427.5942	427.6331	427.672	427.7109	427.7498		493.3751
Relative hydraulic conductivity	Kr	0.000339	0.000339	0.000339	0.000339	0.000339	0.000338		0.000255
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	5.56E-05	5.56E-05	5.56E-05	5.56E-05	5.56E-05	5.56E-05		5.56E-05
Drainage Volume (acre-ft)		0.00E+00	5.66E-04	5.66E-04	5.66E-04	5.66E-04	5.66E-04		1.28E-02

References:

Carsel, R F and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B., 1996. Vadose Zone Hydrology. CRC Press.



T:\Projects\9184\Sheets\Final Water Balance\Vadose Zone Redistribution Estimate Ponds 90 DRAFT 7-22-08_working_copy.xls_Drain-down Chart (Clay, CP)

Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Sand (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

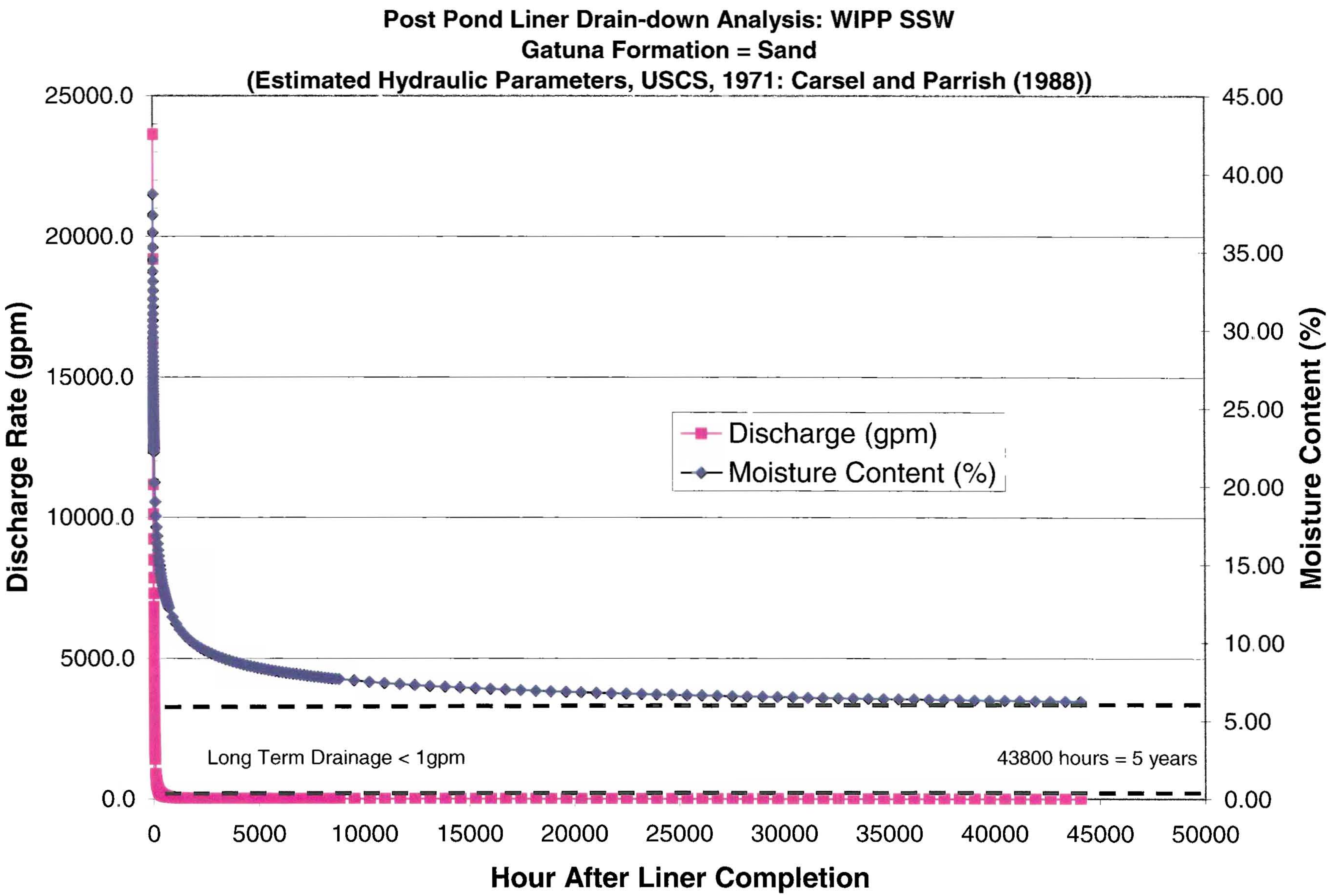
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.43**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.387**	**fraction**	**90% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**123.2**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.045**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**108.9**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**103.3**	**(acre-ft)**	**5 Year Drainage**

Hour after Pond Liner Installation		0	1	2	3	4	5		44076
Incremental Steady State Assumption*	Moisture Content (%)	38.70	37.33	36.22	35.29	34.47	33.75		6.25
	Discharge (gpm)	2.36E+04	1.92E+04	1.62E+04	1.41E+04	1.25E+04	1.12E+04		2.48E-01
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	3.47E-03	2.82E-03	2.39E-03	2.07E-03	1.83E-03	1.64E-03		3.65E-08
Effective Saturation (Stephens, 1995)	Se	0.888312	0.852821	0.824	0.799611	0.778435	0.759714	Hourly	0.045582
van Genuchten Parameter (Carsel and Parrish, 1988)	N	2.68	2.68	2.68	2.68	2.68	2.68	Time	2.68
Mualem model (Stephens, 1995)	m	0.626866	0.626866	0.626866	0.626866	0.626866	0.626866	Steps for 5	0.626866
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.145	0.145	0.145	0.145	0.145	0.145	Years	0.145
Pressure head (Stephens, 1995)	P-head (-cm)	3.83833	4.340595	4.719385	5.027641	5.289558	5.518424		43.2306
Relative hydraulic conductivity	Kr	0.420678	0.341629	0.289093	0.251008	0.221898	0.198823		4.42E-06
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	8.25E-03	8.25E-03	8.25E-03	8.25E-03	8.25E-03	8.25E-03		8.25E-03
Drainage Volume (acre-ft)		0.00E+00	4.35E+00	3.53E+00	2.99E+00	2.60E+00	2.29E+00		3.37E-02

References.

Carsel, R F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B. 1996. Vadose Zone Hydrology. CRC Press.



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Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Sandy Clay Loam (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

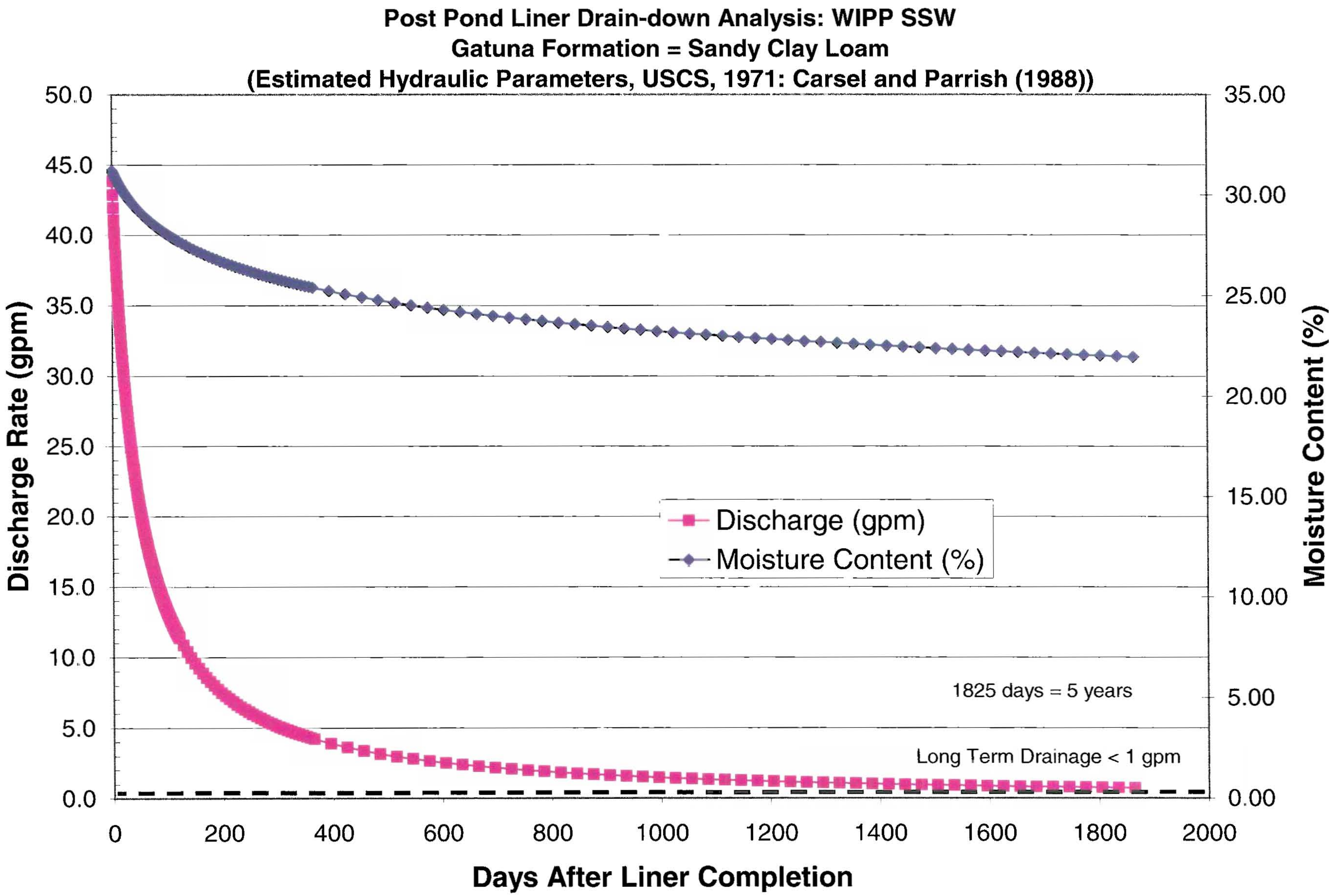
Parameter	Value	Units	Notes
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.39**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.312**	**fraction**	**80% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**99.3**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.1**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**67.5**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**29.4**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	31.20	31 14	31.08	31.02	30 96	30 91	Daily Time Steps for 5 Years	21.99
	Discharge (gpm)	4.38E+01	4.29E+01	4.19E+01	4 10E+01	4 02E+01	3.94E+01		7.57E-01
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	6.44E-06	6.30E-06	6.16E-06	6.03E-06	5.90E-06	5.78E-06		1.11E-07
Effective Saturation (Stephens, 1995)	Se	0.731034	0.728936	0 726883	0.724876	0.722911	0.720987		0.413522
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.48	1.48	1 48	1 48	1 48	1.48		1.48
Mualem model (Stephens, 1995)	m	0.324324	0 324324	0 324324	0.324324	0 324324	0.324324		0.324324
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0 059	0 059	0.059	0 059	0.059	0 059		0.059
Pressure head (Stephens, 1995)	P-head (-cm)	23.5531	23 78136	24.00613	24 22755	24.44574	24.66083		101.8987
Relative hydraulic conductivity	Kr	0.017702	0 017309	0.016933	0.016573	0.016227	0.015896		0.000306
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	3.64E-04	3.64E-04	3.64E-04	3.64E-04	3.64E-04	3.64E-04		3.64E-04
Drainage Volume (acre-ft)		0.00E+00	1.94E-01	1.89E-01	1 85E-01	1 81E-01	1.78E-01		1 02E-01

References:

Carsel, R.F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B., 1996. Vadose Zone Hydrology. CRC Press.



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Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Silt (Carsel and Parrish, 1988, Tables, 2, 3, 4, 5)

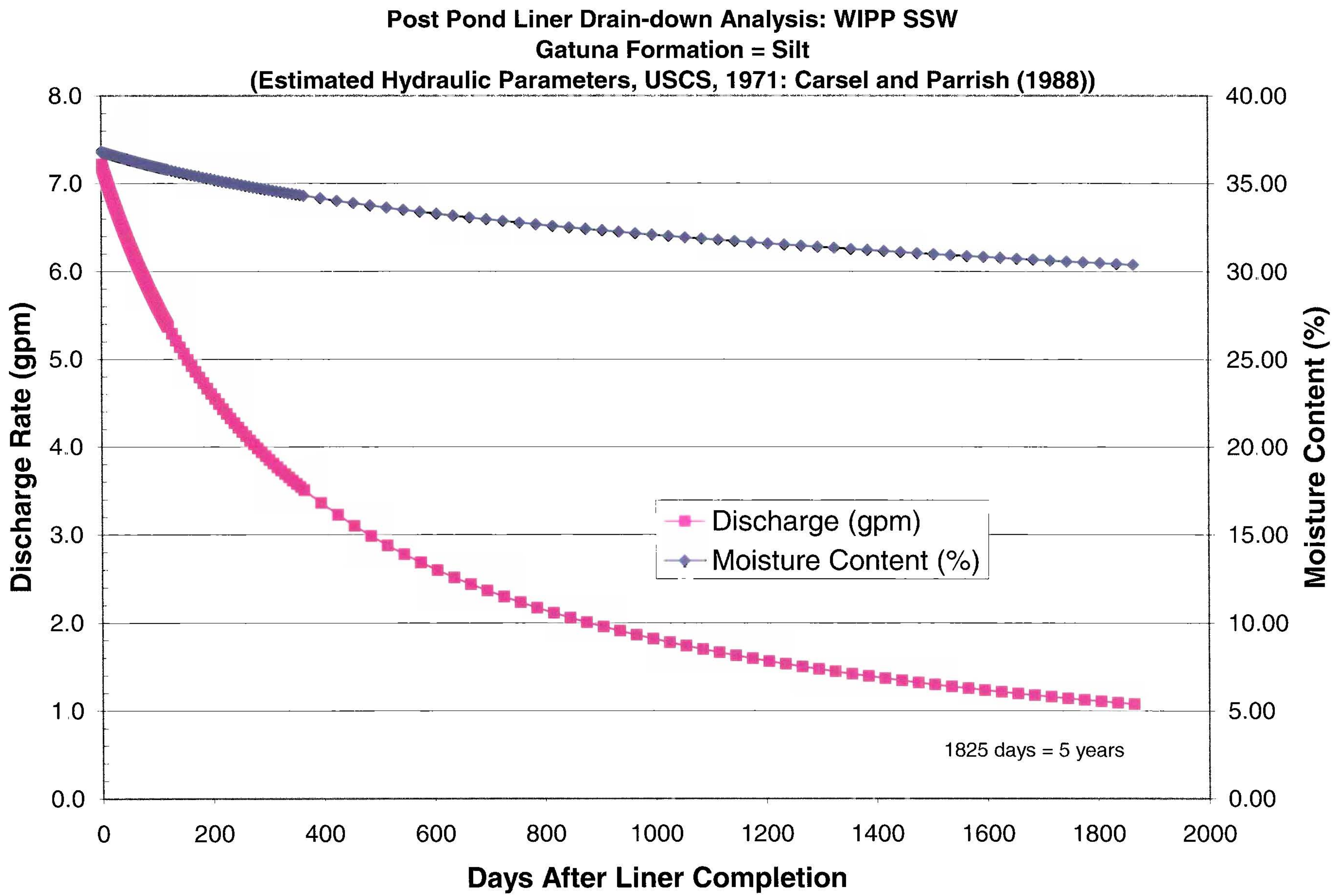
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.46**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.368**	**fraction**	**80% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**117.1**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.034**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**106.3**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**20.4**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption* {	Moisture Content (%)	36.80	36.79	36.78	36 77	36.76	36.75		30.43
	Discharge (gpm)	7.22E+00	7.20E+00	7.17E+00	7.15E+00	7.13E+00	7 11E+00		1.10E+00
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	1.06E-06	1.06E-06	1.05E-06	1.05E-06	1.05E-06	1.05E-06		1.61E-07
Effective Saturation (Stephens, 1995)	Se	0.784038	0.783802	0.783568	0.783334	0.783101	0 782868	Daily TIme Steps for 5 Years	0.634609
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.37	1.37	1.37	1.37	1 37	1 37		1.37
Mualem model (Stephens, 1995)	m	0.270073	0.270073	0.270073	0.270073	0.270073	0.270073		0.270073
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0 016	0 016	0.016	0 016	0.016	0.016		0.016
Pressure head (Stephens, 1995)	P-head (-cm)	82.45547	82.5681	82.68051	82.7927	82.90467	83.01642		183.8819
Relative hydraulic conductivity	Kr	0.015268	0.015225	0.015181	0.015138	0.015095	0.015053		0.002319
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	6.94E-05	6.94E-05	6.94E-05	6.94E-05	6.94E-05	6.94E-05		6.94E-05
Drainage Volume (acre-ft)		0 00E+00	3.19E-02	3.18E-02	3.17E-02	3.16E-02	3 15E-02		1.47E-01

References.

Carsel, R.F. and Parrish, R.S., 1988. Developıng Joint Probability Distributions of Soil Water Retention Characteristıcs. Water Resources Research, v 24, no. 5 p. 755-769.

Stephens, D B , 1996. Vadose Zone Hydrology CRC Press.



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Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Clay Loam (Carsel and Parrish, 1988, Tables, 2, 3, 4, 5)

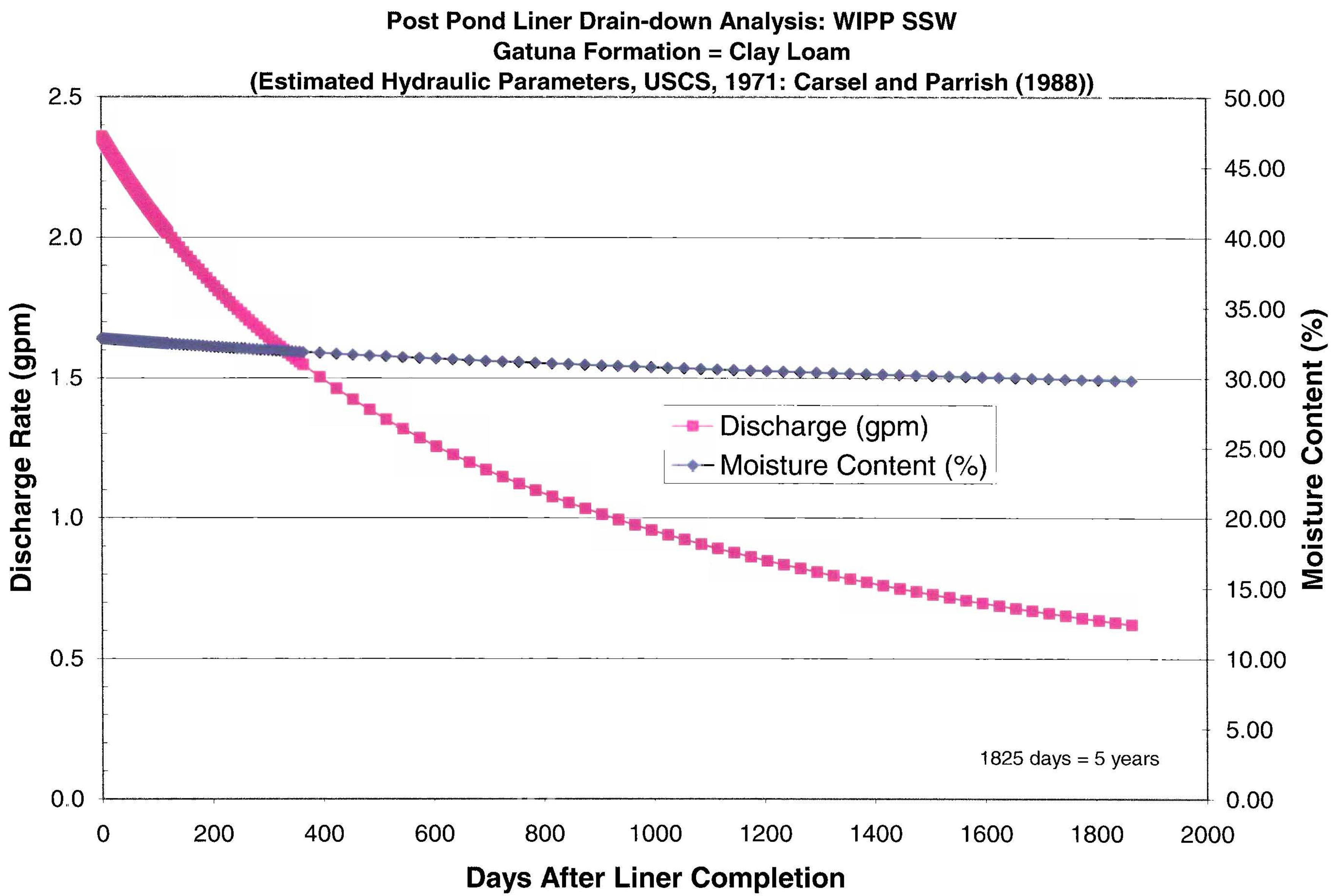
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.41**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.328**	**fraction**	**80% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**104.4**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.095**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**74.2**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**9.4**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	32 80	32.80	32 79	32 79	32 79	32.78		29.86
	Discharge (gpm)	2.36E+00	2 35E+00	2 35E+00	2 35E+00	2 34E+00	2 34E+00		6.30E-01
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	3.46E-07	3.46E-07	3.45E-07	3.45E-07	3.45E-07	3.44E-07		9.26E-08
Effective Saturation (Stephens, 1995)	Se	0.739683	0 739579	0.739475	0 739371	0.739268	0 739164	Daily Time Steps for 5 Years	0 6464
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.31	1.31	1.31	1 31	1 31	1 31		1.31
Mualem model (Stephens, 1995)	m	0.236641	0.236641	0.236641	0.236641	0.236641	0.236641		0.236641
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.019	0.019	0.019	0.019	0.019	0.019		0 019
Pressure head (Stephens, 1995)	P-head (-cm)	108 3768	108.445	108.5132	108.5813	108.6493	108.7173		188.5548
Relative hydraulic conductivity	Kr	0.004797	0.00479	0.004784	0.004777	0.00477	0 004763		0.001282
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	7.22E-05	7.22E-05	7.22E-05	7.22E-05	7.22E-05	7.22E-05		7.22E-05
Drainage Volume (acre-ft)		0.00E+00	1 04E-02	1 04E-02	1.04E-02	1.04E-02	1 04E-02		8.46E-02

References.

Carsel, R F and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B., 1996. Vadose Zone Hydrology. CRC Press.



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Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Clay (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

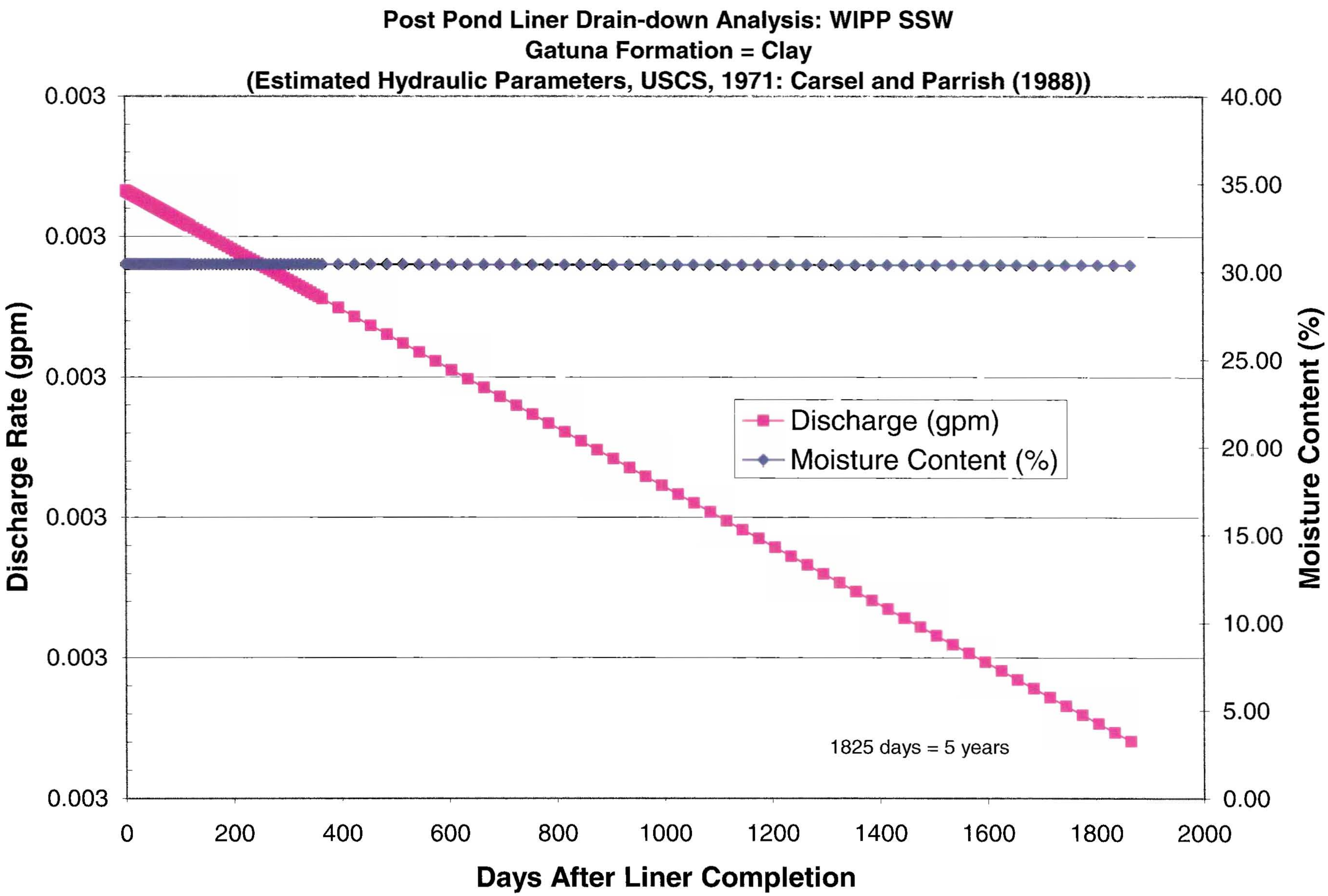
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.38**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.304**	**fraction**	**80% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**96.8**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.068**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**75.1**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**2.20E-02**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	30.40	30.40	30.40	30.40	30.40	30.40		30.39
	Discharge (gpm)	2.68E-03	2.68E-03	2.68E-03	2.68E-03	2.68E-03	2.68E-03		2.66E-03
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	3.93E-10	3.93E-10	3.93E-10	3.93E-10	3.93E-10	3.93E-10		3.90E-10
Effective Saturation (Stephens, 1995)	Se	0.75641	0.75641	0.75641	0.75641	0.75641	0.75641	Daily Time Steps for 5 Years	0.756192
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.09	1.09	1.09	1.09	1.09	1.09		1.09
Mualem model (Stephens, 1995)	m	0.082569	0.082569	0.082569	0.082569	0.082569	0.082569		0.082569
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.008	0.008	0.008	0.008	0.008	0.008		0.008
Pressure head (Stephens, 1995)	P-head (-cm)	2693.165	2693.17	2693.175	2693.18	2693.185	2693.19		2702.1
Relative hydraulic conductivity	Kr	7.08E-06	7.08E-06	7.08E-06	7.08E-06	7.08E-06	7.08E-06		7.03E-06
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	5.56E-05	5.56E-05	5.56E-05	5.56E-05	5.56E-05	5.56E-05		5.56E-05
Drainage Volume (acre-ft)		0.00E+00	1.18E-05	1.18E-05	1.18E-05	1.18E-05	1.18E-05		3.52E-04

References:

Carsel, R.F and Parrish, R S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B., 1996. Vadose Zone Hydrology CRC Press.



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Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Sand (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

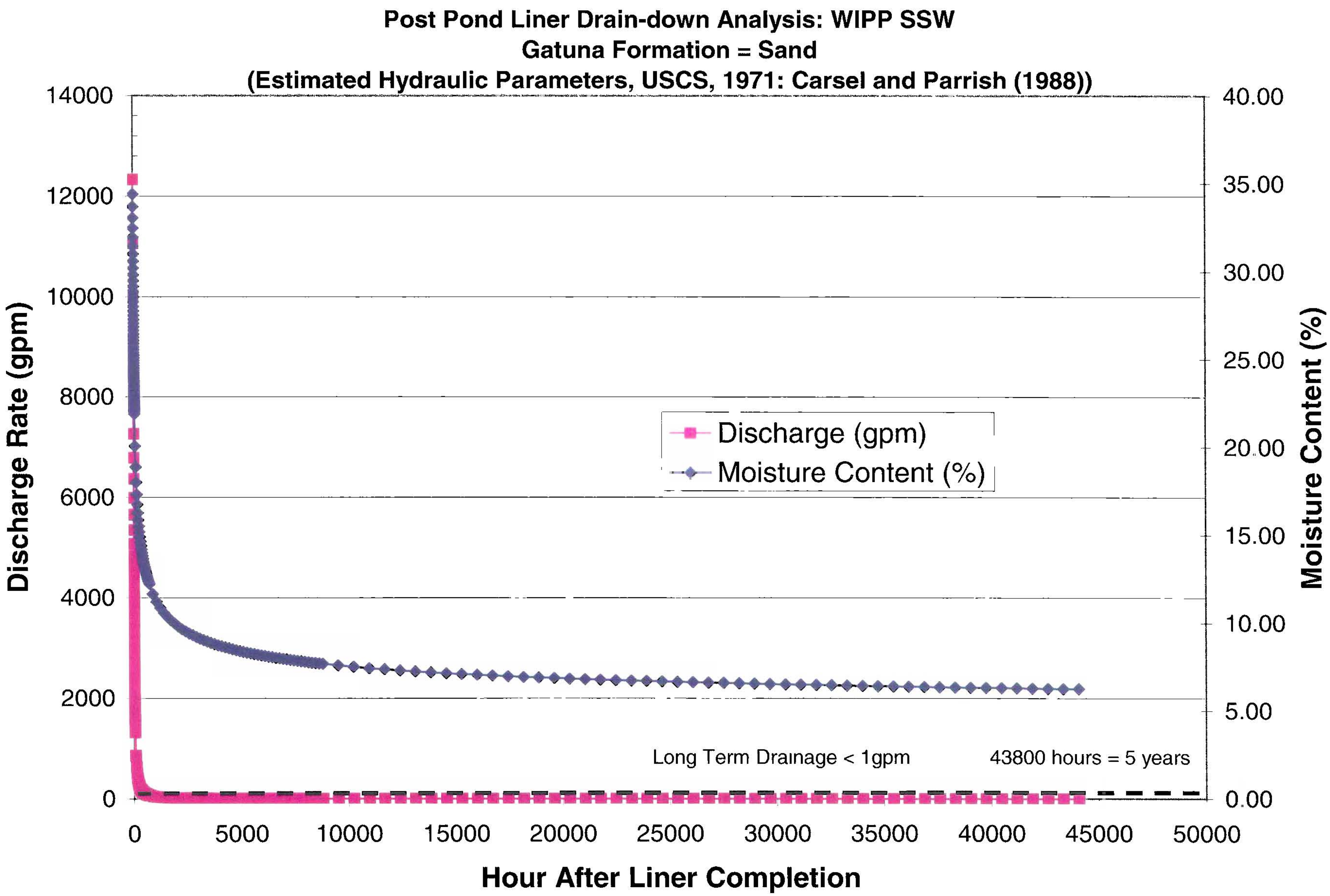
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.43**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.344**	**fraction**	**80% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**109.5**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.045**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**95.2**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**89.6**	**(acre-ft)**	**5 Year Drainage**

Hour after Pond Liner Installation		0	1	2	3	4	5		44076
Incremental Steady State Assumption*	Moisture Content (%)	34.40	33.69	33.05	32.47	31.94	31.45		6.25
	Discharge (gpm)	1.23E+04	1.11E+04	1.00E+04	9.16E+03	8.43E+03	7.80E+03		2.48E-01
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	1.81E-03	1.62E-03	1.47E-03	1.35E-03	1.24E-03	1.15E-03		3.65E-08
Effective Saturation (Stephens, 1995)	Se	0.776623	0.7581	0.741485	0.726428	0.712667	0.700004	Hourly	0.045581
van Genuchten Parameter (Carsel and Parrish, 1988)	N	2.68	2.68	2.68	2.68	2.68	2.68	Time	2.68
Mualem model (Stephens, 1995)	m	0.626866	0.626866	0.626866	0.626866	0.626866	0.626866	Steps for 5	0.626866
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.145	0.145	0.145	0.145	0.145	0.145	Years	0.145
Pressure head (Stephens, 1995)	P-head (-cm)	5.311788	5.538082	5.740059	5.922926	6.090333	6.244947		43.23115
Relative hydraulic conductivity	Kr	0.219562	0.19694	0.178481	0.163109	0.150097	0.138934		4.42E-06
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	8.25E-03	8.25E-03	8.25E-03	8.25E-03	8.25E-03	8.25E-03		8.25E-03
Drainage Volume (acre-ft)		0.00E+00	2.27E+00	2.04E+00	1.85E+00	1.69E+00	1.55E+00		3.37E-02

References:

Carsel, R.F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B., 1996. Vadose Zone Hydrology. CRC Press



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Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Sandy Clay Loam (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

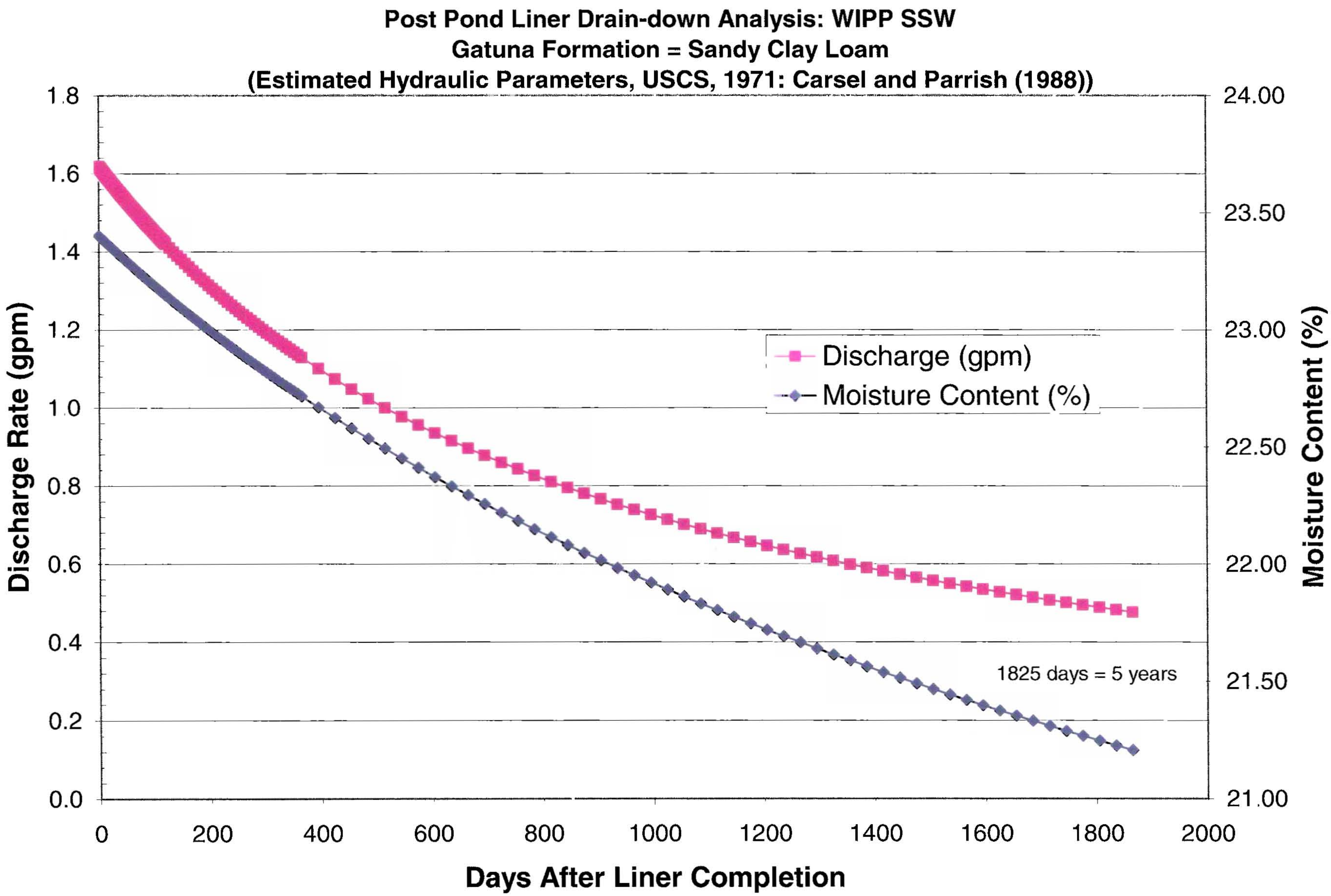
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.39**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.234**	**fraction**	**60% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**74.5**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.1**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**42.7**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**7.0**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	23.40	23.40	23.40	23.39	23.39	23.39		21.23
	Discharge (gpm)	1.62E+00	1.62E+00	1 61E+00	1.61E+00	1.61E+00	1.61E+00		4.84E-01
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	2.38E-07	2.37E-07	2 37E-07	2.37E-07	2.36E-07	2 36E-07		7.11E-08
Effective Saturation (Stephens, 1995)	Se	0.462069	0.461992	0.461914	0.461837	0.46176	0.461683	Daily Time Steps for 5 Years	0.387162
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.48	1.48	1.48	1.48	1.48	1 48		1.48
Mualem model (Stephens, 1995)	m	0 324324	0.324324	0 324324	0.324324	0.324324	0.324324		0.324324
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.059	0.059	0.059	0 059	0.059	0.059		0.059
Pressure head (Stephens, 1995)	P-head (-cm)	79 28498	79.31548	79 34596	79.37642	79.40686	79.43728		117.9051
Relative hydraulic conductivity	Kr	0.000653	0.000652	0.000651	0.000651	0.00065	0.000649		0.000195
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	3.64E-04	3.64E-04	3.64E-04	3.64E-04	3.64E-04	3.64E-04		3.64E-04
Drainage Volume (acre-ft)		0.00E+00	7.15E-03	7 14E-03	7.13E-03	7.12E-03	7 11E-03		6.49E-02

References:

Carsel, R.F and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769

Stephens, D B , 1996. Vadose Zone Hydrology CRC Press



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Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Silt (Carsel and Parrish, 1988, Tables, 2, 3, 4, 5)

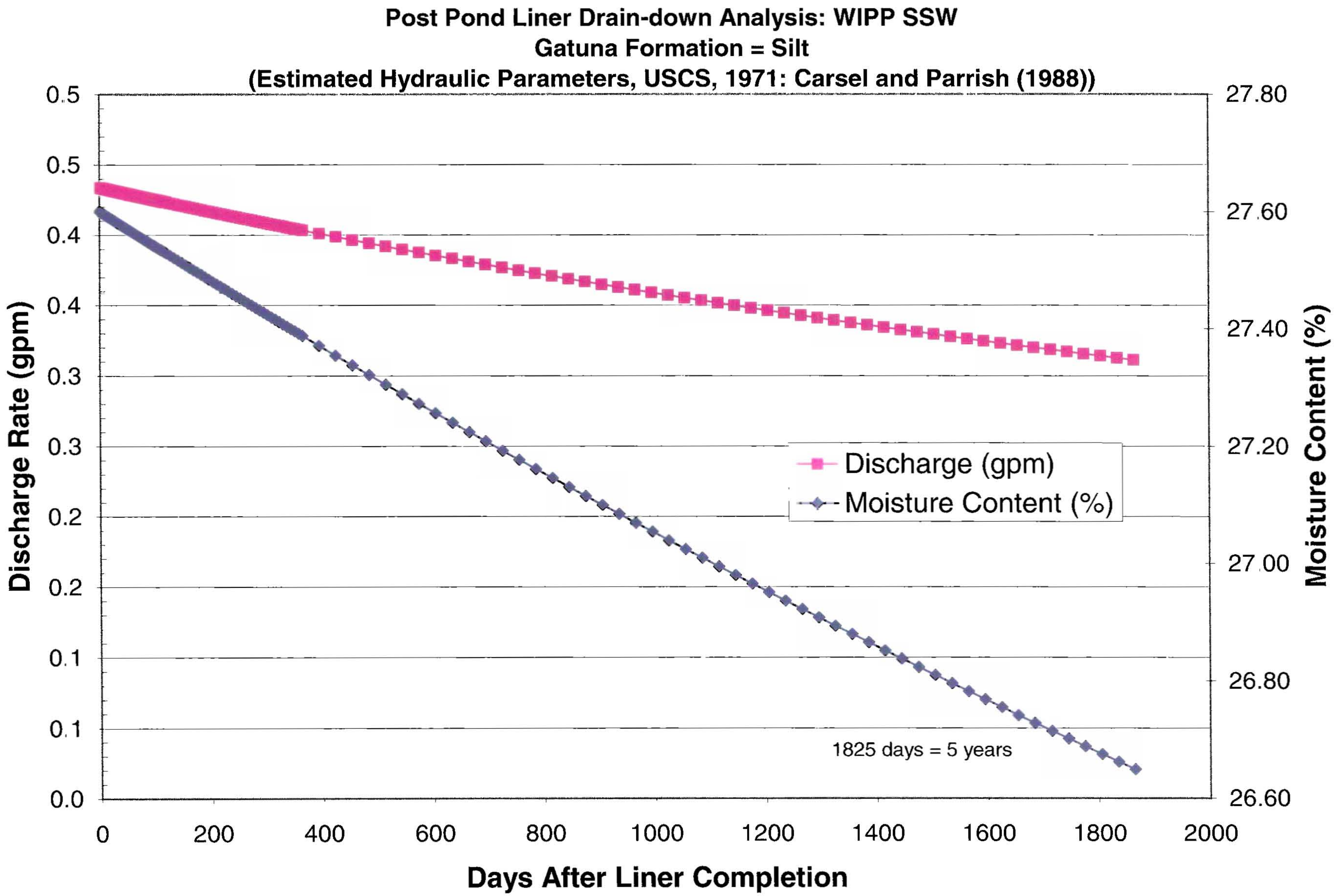
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.46**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.276**	**fraction**	**60% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**87.9**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.034**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**77.0**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**3.0**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	27.60	27.60	27.60	27.60	27.60	27.60		26.66
	Discharge (gpm)	4 34E-01	4.33E-01	4 33E-01	4.33E-01	4 33E-01	4.33E-01		3.13E-01
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	6.37E-08	6.37E-08	6.37E-08	6.37E-08	6.37E-08	6.36E-08		4.60E-08
Effective Saturation (Stephens, 1995)	Se	0.568075	0.568061	0.568047	0.568033	0.568019	0 568004	Daily Time Steps for 5 Years	0.546073
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.37	1.37	1.37	1 37	1 37	1.37		1.37
Mualem model (Stephens, 1995)	m	0.270073	0.270073	0.270073	0.270073	0.270073	0.270073		0.270073
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.016	0.016	0.016	0.016	0.016	0.016		0.016
Pressure head (Stephens, 1995)	P-head (-cm)	261 7984	261.8185	261.8386	261.8586	261.8787	261.8988		295.3491
Relative hydraulic conductivity	Kr	0 000917	0.000917	0.000917	0.000917	0 000917	0.000916		0.000662
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	6.94E-05	6.94E-05	6.94E-05	6.94E-05	6.94E-05	6.94E-05		6.94E-05
Drainage Volume (acre-ft)		0.00E+00	1.92E-03	1.92E-03	1.92E-03	1.91E-03	1.91E-03		4.17E-02

References:

Carsel, R.F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B., 1996. Vadose Zone Hydrology. CRC Press.



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Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Clay Loam (Carsel and Parrish, 1988, Tables, 2, 3, 4, 5)

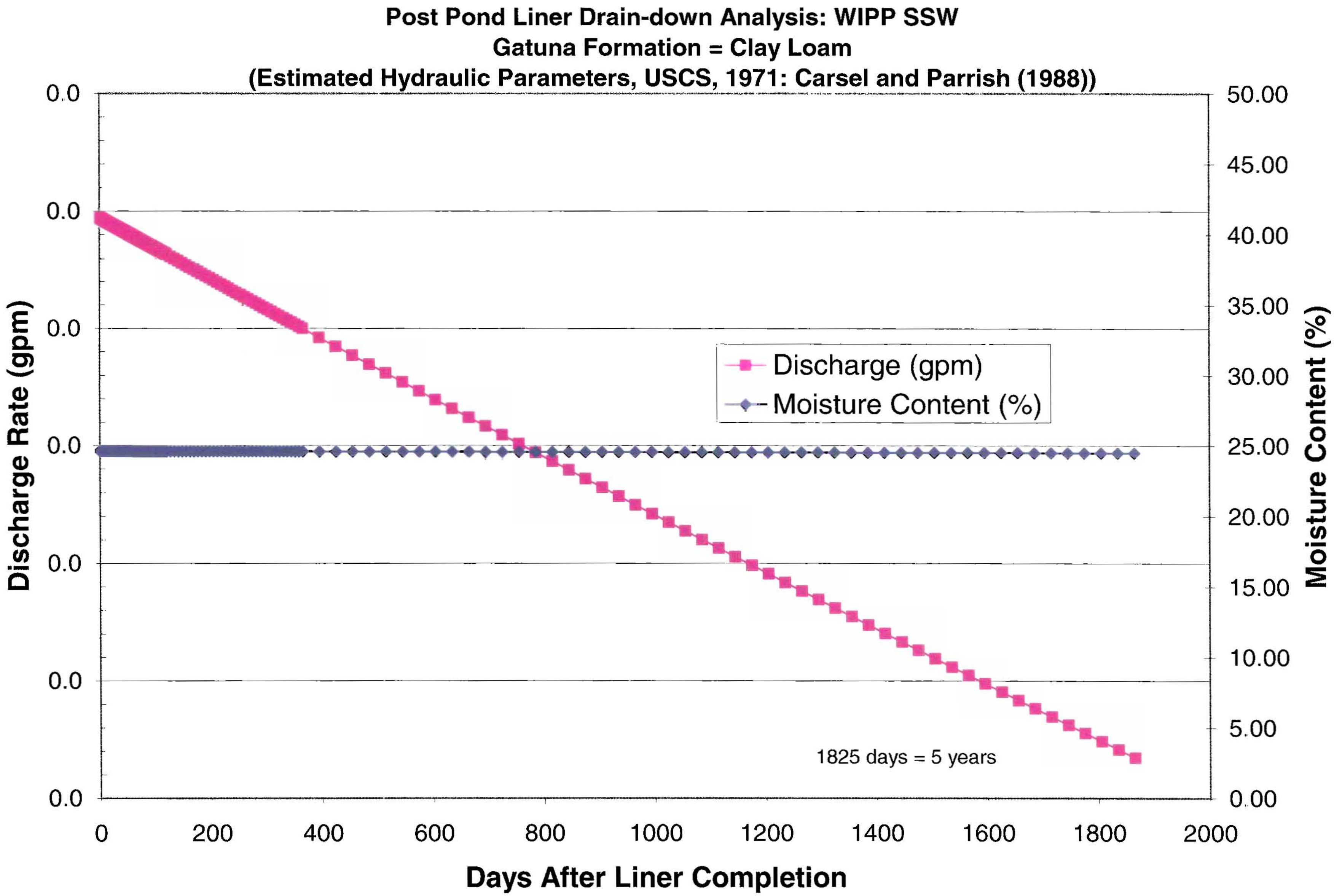
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.41**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.246**	**fraction**	**60% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**78.3**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.095**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**48.1**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**0.3**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	24.60	24.60	24.60	24.60	24 60	24 60		24.50
	Discharge (gpm)	3.95E-02	3.95E-02	3.95E-02	3.95E-02	3.95E-02	3.95E-02		3.72E-02
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	5.80E-09	5.80E-09	5.80E-09	5.80E-09	5.80E-09	5.80E-09		5.47E-09
Effective Saturation (Stephens, 1995)	Se	0.479365	0.479363	0.479362	0.47936	0.479358	0.479356	Daily Time Steps for 5 Years	0.476265
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1 31	1.31	1 31	1.31	1.31	1.31		1.31
Mualem model (Stephens, 1995)	m	0.236641	0.236641	0.236641	0.236641	0.236641	0.236641		0.236641
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0 019	0.019	0.019	0.019	0.019	0.019		0.019
Pressure head (Stephens, 1995)	P-head (-cm)	544.7351	544.7418	544.7485	544 7552	544.7618	544 7685		556.7947
Relative hydraulic conductivity	Kr	8.03E-05	8.03E-05	8.03E-05	8.03E-05	8 03E-05	8.03E-05		7.57E-05
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	7.22E-05	7.22E-05	7.22E-05	7.22E-05	7.22E-05	7.22E-05		7.22E-05
Drainage Volume (acre-ft)		0.00E+00	1.74E-04	1.74E-04	1 74E-04	1.74E-04	1.74E-04		4.94E-03

References.

Carsel, R F and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v 24, no. 5 p. 755-769.

Stephens, D.B , 1996 Vadose Zone Hydrology. CRC Press



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Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Clay (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

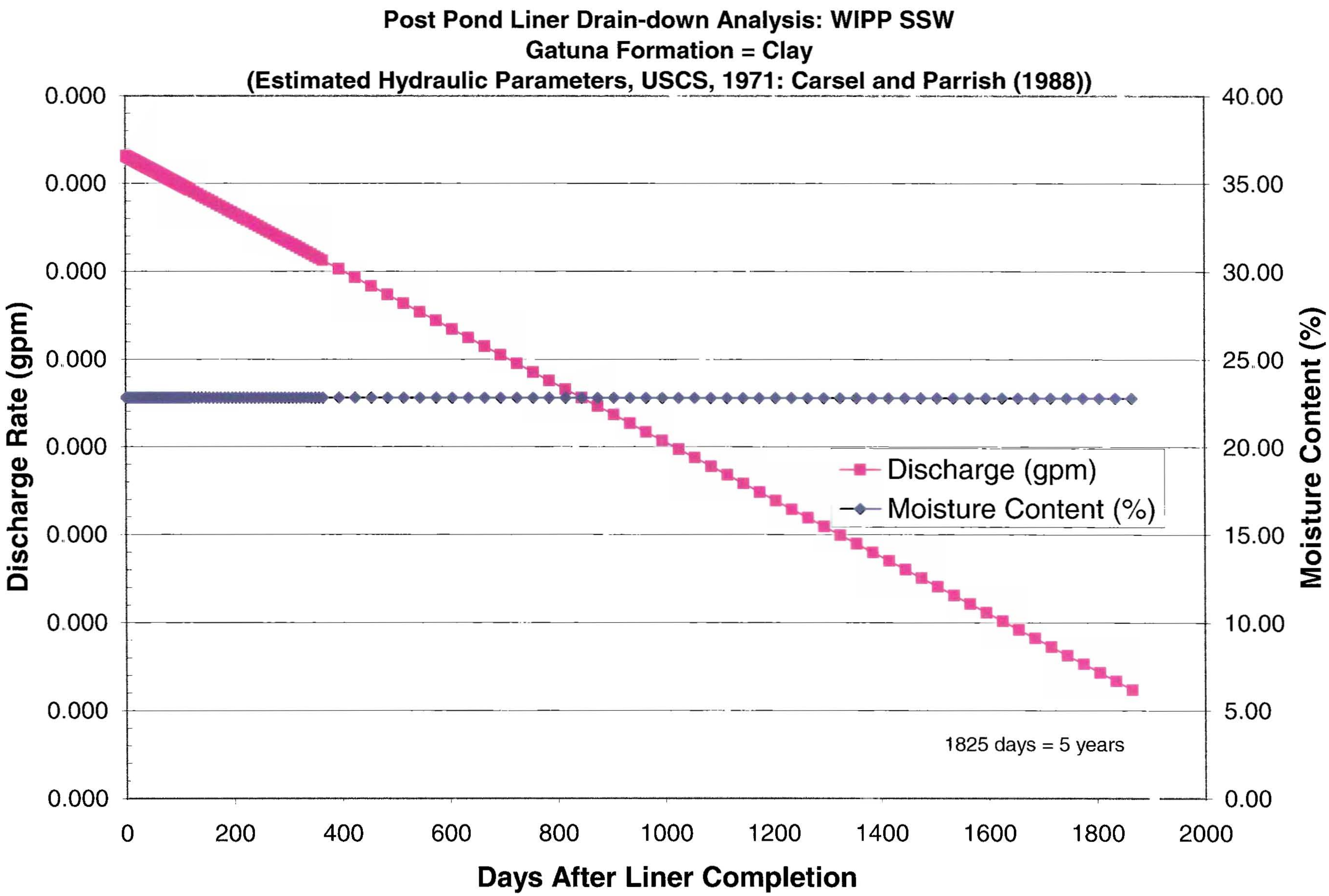
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.38**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.228**	**fraction**	**60% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**72.6**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.068**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**50.9**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**1.44E-06**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	22.80	22.80	22.80	22.80	22.80	22.80		22.80
	Discharge (gpm)	1.74E-07	1.74E-07	1.74E-07	1.74E-07	1.74E-07	1.74E-07		1.74E-07
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	2.56E-14	2.56E-14	2.56E-14	2.56E-14	2.56E-14	2.56E-14		2.56E-14
Effective Saturation (Stephens, 1995)	Se	0.512821	0.512821	0.512821	0.512821	0.512821	0.512821	Daily Time Steps for 5 Years	0.51282
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.09	1.09	1.09	1.09	1.09	1.09		1.09
Mualem model (Stephens, 1995)	m	0.082569	0.082569	0.082569	0.082569	0.082569	0.082569		0.082569
van Genuchten Parameter Carsel and Parrish, 1988	$alpha_{(v)}$	0.008	0.008	0.008	0.008	0.008	0.008		0.008
Pressure head (Stephens, 1995)	P-head (-cm)	208638.5	208638.5	208638.5	208638.5	208638.5	208638.5		208638.5
Relative hydraulic conductivity	Kr	4.61E-10	4.61E-10	4.61E-10	4.61E-10	4.61E-10	4.61E-10		4.61E-10
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	5.56E-05	5.56E-05	5.56E-05	5.56E-05	5.56E-05	5.56E-05		5.56E-05
Drainage Volume (acre-ft)		0.00E+00	7.70E-10	7.70E-10	7.70E-10	7.70E-10	7.70E-10		2.31E-08

References.

Carsel, R.F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v 24, no. 5 p. 755-769.

Stephens, D.B., 1996. Vadose Zone Hydrology. CRC Press.



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Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Sand (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

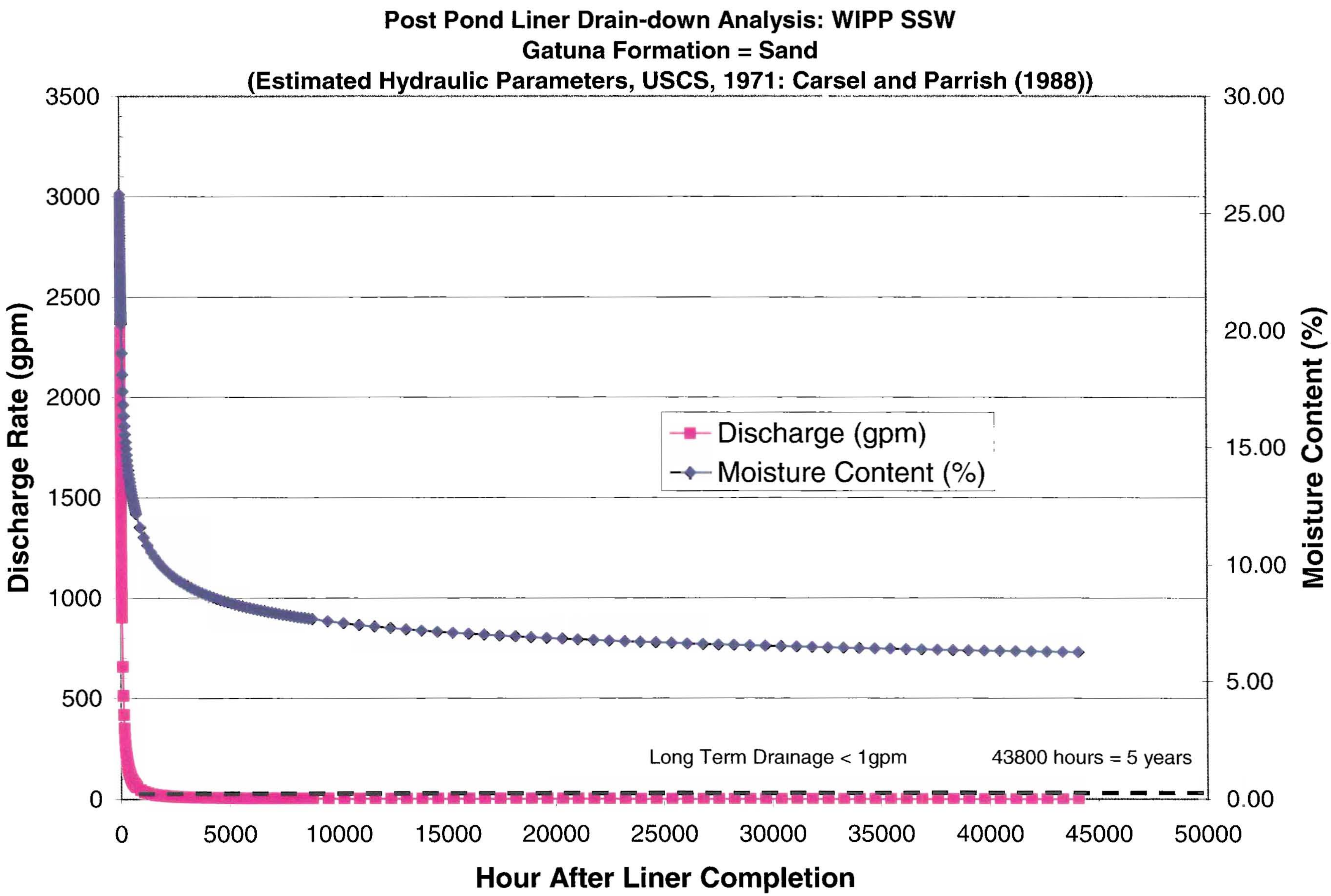
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.43**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.258**	**fraction**	**60% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**82.1**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.045**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**67.8**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**62.2**	**(acre-ft)**	**5 Year Drainage**

Hour after Pond Liner Installation		0	1	2	3	4	5		44076
Incremental Steady State Assumption*	Moisture Content (%)	25.80	25.63	25.46	25.30	25.15	25.00		6.25
	Discharge (gpm)	2.95E+03	2.85E+03	2.77E+03	2.68E+03	2.60E+03	2.53E+03		2.48E-01
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	4.33E-04	4.19E-04	4.06E-04	3.94E-04	3.82E-04	3.71E-04		3.65E-08
Effective Saturation (Stephens, 1995)	Se	0.553247	0.548818	0.54453	0.540375	0.536345	0.532435	Hourly	0.045574
van Genuchten Parameter (Carsel and Parrish, 1988)	N	2.68	2.68	2.68	2.68	2.68	2.68	Time	2.68
Mualem model (Stephens, 1995)	m	0.626866	0.626866	0.626866	0.626866	0.626866	0.626866	Steps for 5	0.626866
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.145	0.145	0.145	0.145	0.145	0.145	Years	0.145
Pressure head (Stephens, 1995)	P-head (-cm)	8.162707	8.226603	8.288949	8.349827	8.409313	8.467477		43.23476
Relative hydraulic conductivity	Kr	0.052493	0.050826	0.049252	0.047764	0.046356	0.04502		4.42E-06
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	8.25E-03	8.25E-03	8.25E-03	8.25E-03	8.25E-03	8.25E-03		8.25E-03
Drainage Volume (acre-ft)		0.00E+00	5.43E-01	5.25E-01	5.09E-01	4.94E-01	4.79E-01		3.37E-02

References.

Carsel, R F. and Parrish, R S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B , 1996 Vadose Zone Hydrology CRC Press



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Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Sandy Clay Loam (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

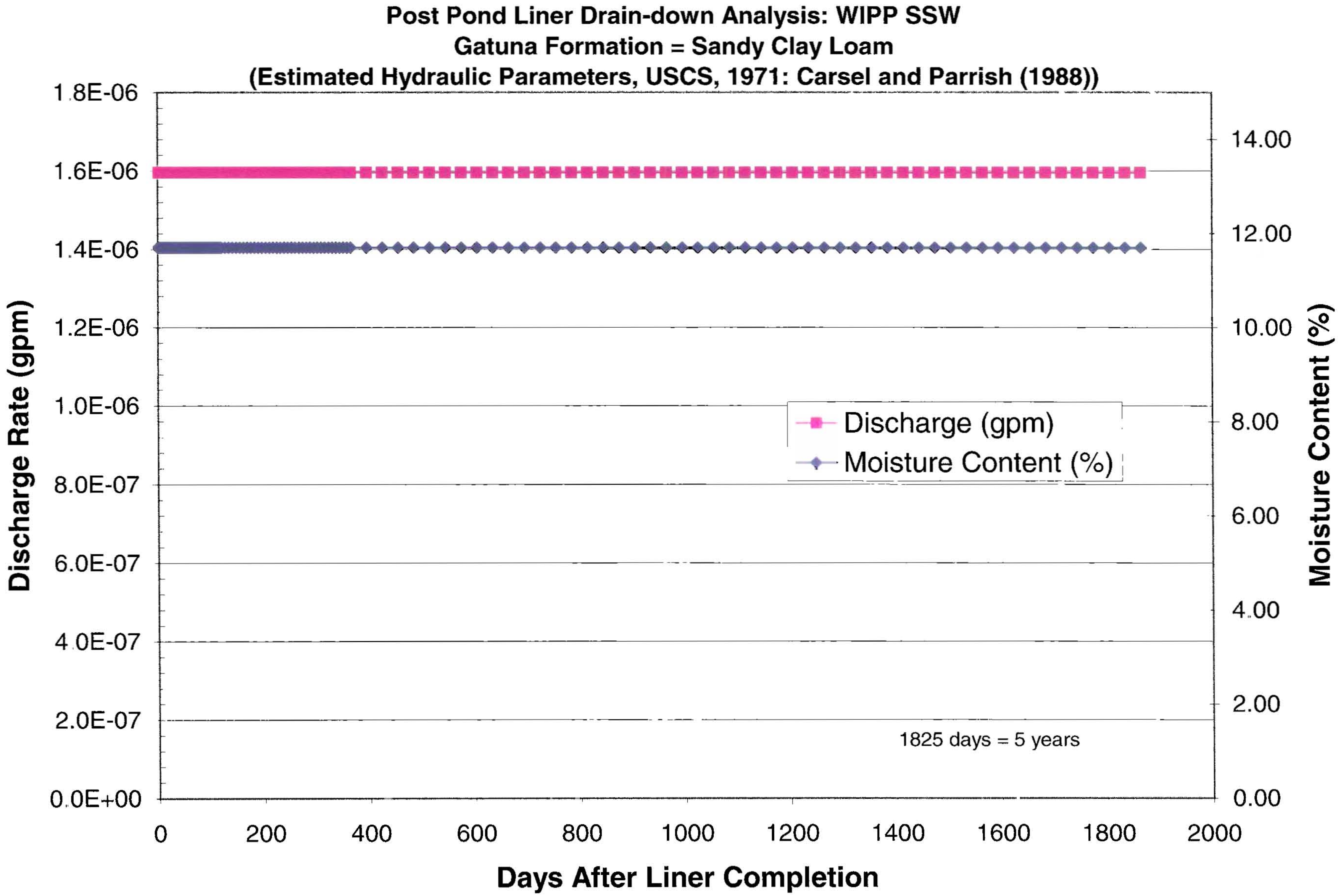
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.39**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.117**	**fraction**	**30% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**37.2**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.1**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**5.4**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**1.31E-05**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	11 70	11 70	11 70	11.70	11 70	11 70		11 70
	Discharge (gpm)	1.60E-06	1.60E-06	1.60E-06	1.60E-06	1.60E-06	1 60E-06		1.60E-06
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	2.34E-13	2 34E-13	2.34E-13	2.34E-13	2.34E-13	2.34E-13		2.34E-13
Effective Saturation (Stephens, 1995)	Se	0.058621	0.058621	0.058621	0.058621	0.058621	0.058621	Daily Time Steps for 5 Years	0.058621
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.48	1 48	1 48	1.48	1.48	1.48		1.48
Mualem model (Stephens, 1995)	m	0.324324	0 324324	0.324324	0 324324	0.324324	0 324324		0.324324
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.059	0 059	0.059	0.059	0 059	0.059		0.059
Pressure head (Stephens, 1995)	P-head (-cm)	6246.862	6246.862	6246.862	6246.862	6246.862	6246 862		6246.893
Relative hydraulic conductivity	Kr	6.44E-10	6.44E-10	6.44E-10	6.44E-10	6.44E-10	6.44E-10		6.44E-10
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	3 64E-04	3 64E-04	3.64E-04	3.64E-04	3.64E-04	3 64E-04		3.64E-04
Drainage Volume (acre-ft)		0 00E+00	7 05E-09	7.05E-09	7 05E-09	7.05E-09	7.05E-09		2.11E-07

References:

Carsel, R.F and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B., 1996. Vadose Zone Hydrology. CRC Press.



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Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Silt (Carsel and Parrish, 1988, Tables, 2, 3, 4, 5)

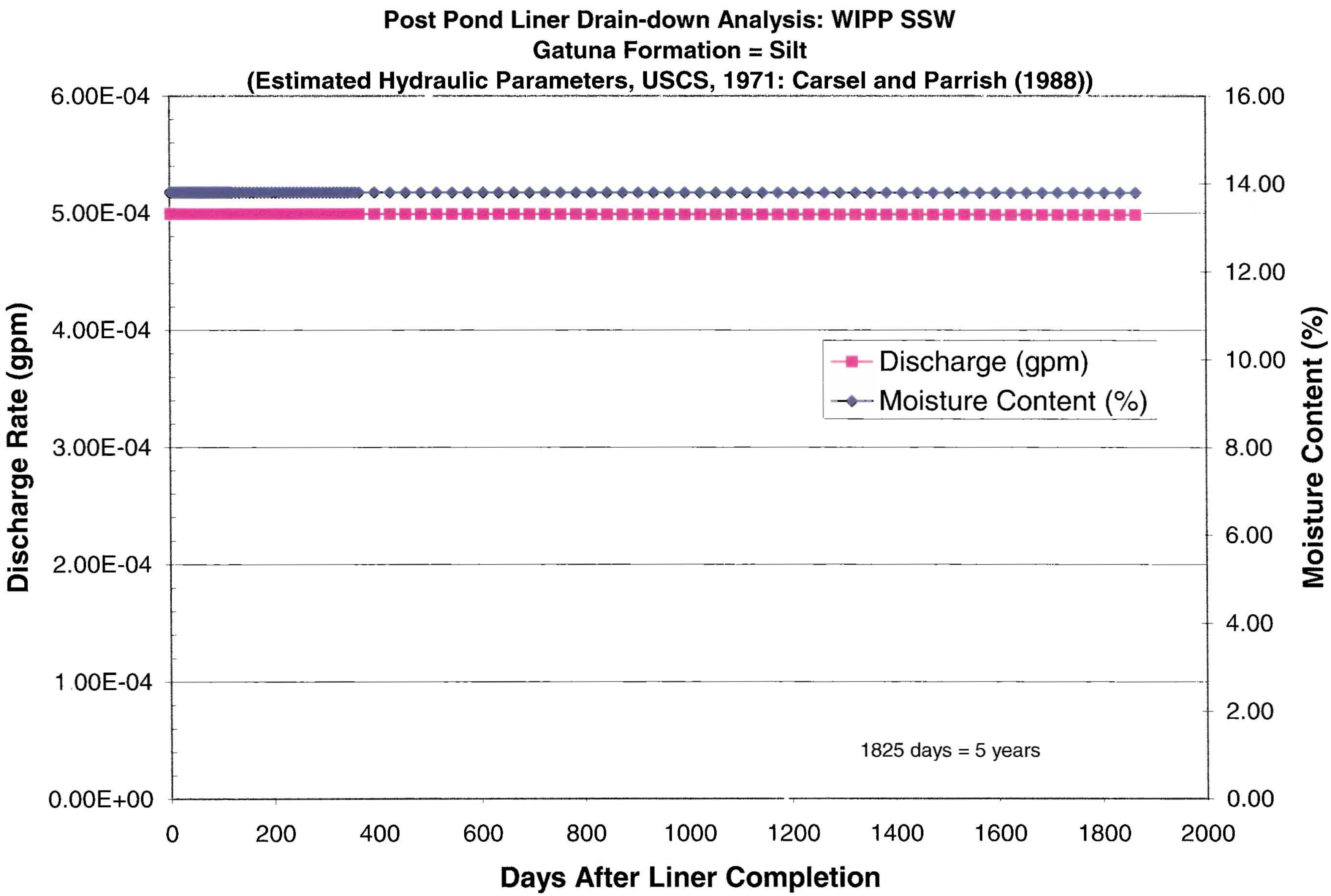
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.46**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.138**	**fraction**	**30% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**43.9**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.034**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**33.1**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**4.11E-03**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	13.80	13.80	13.80	13.80	13.80	13.80		13.80
	Discharge (gpm)	4.99E-04	4.99E-04	4.99E-04	4.99E-04	4.99E-04	4.99E-04		4.99E-04
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	7.33E-11	7.33E-11	7.33E-11	7.33E-11	7.33E-11	7.33E-11		7.33E-11
Effective Saturation (Stephens, 1995)	Se	0.244131	0.244131	0.244131	0.244131	0.244131	0.244131	Daily Time Steps for 5 Years	0.244102
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.37	1.37	1.37	1.37	1.37	1.37		1.37
Mualem model (Stephens, 1995)	m	0.270073	0.270073	0.270073	0.270073	0.270073	0.270073		0.270073
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.016	0.016	0.016	0.016	0.016	0.016		0.016
Pressure head (Stephens, 1995)	P-head (-cm)	2813.416	2813.416	2813.417	2813.417	2813.418	2813.418		2814.35
Relative hydraulic conductivity	Kr	1.06E-06	1.06E-06	1.06E-06	1.06E-06	1.06E-06	1.06E-06		1.05E-06
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	6.94E-05	6.94E-05	6.94E-05	6.94E-05	6.94E-05	6.94E-05		6.94E-05
Drainage Volume (acre-ft)		0.00E+00	2.21E-06	2.21E-06	2.21E-06	2.21E-06	2.21E-06		6.61E-05

References:

Carsel, R.F and Parrish, R S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v 24, no. 5 p. 755-769.

Stephens, D.B , 1996. Vadose Zone Hydrology CRC Press



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Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Clay Loam (Carsel and Parrish, 1988, Tables, 2, 3, 4, 5)

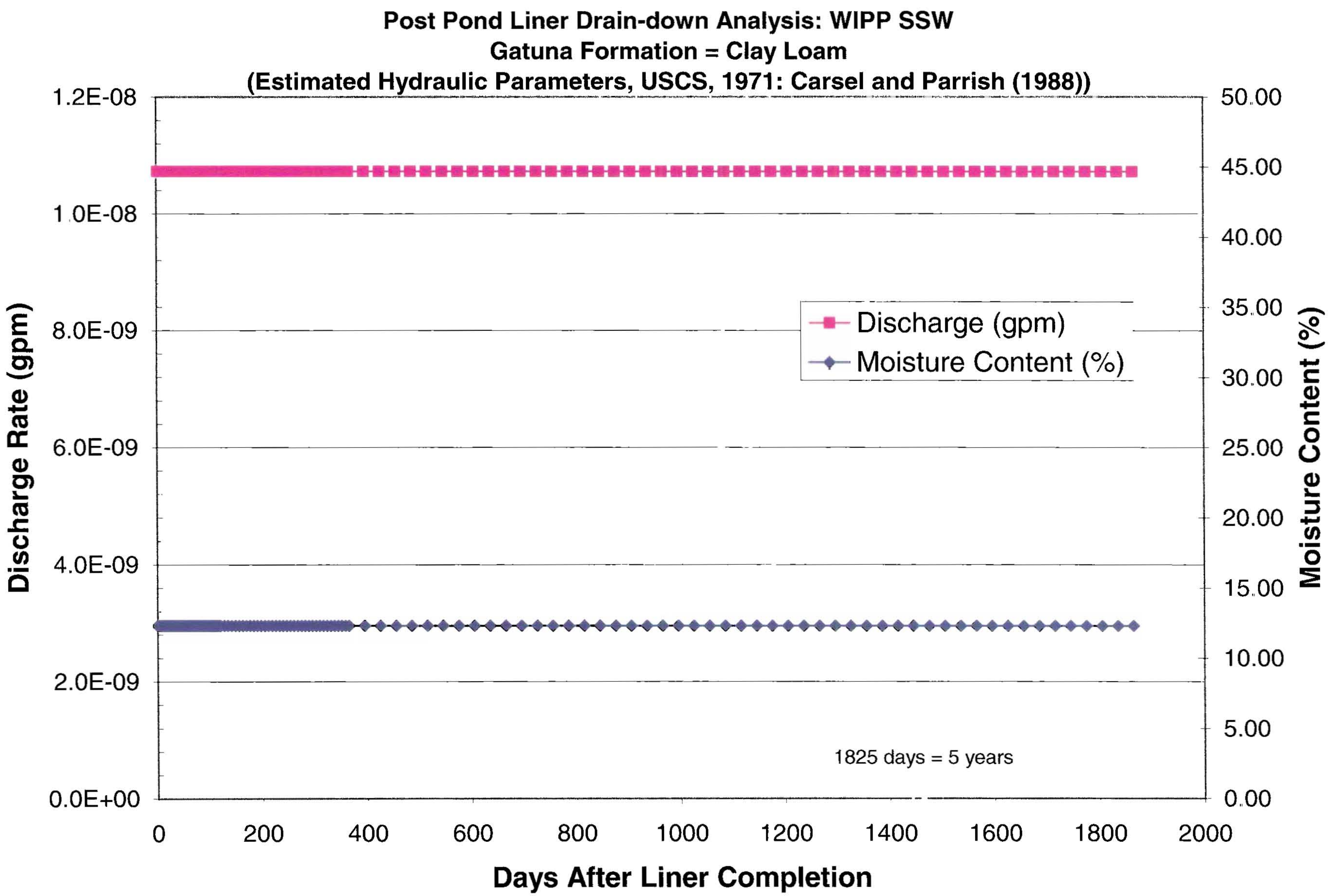
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.41**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.123**	**fraction**	**30% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**39.2**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.095**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**8.9**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**8.84E-08**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption* {	Moisture Content (%)	12.30	12.30	12.30	12.30	12.30	12.30		12 30
	Discharge (gpm)	1.07E-08	1.07E-08	1 07E-08	1.07E-08	1.07E-08	1.07E-08		1.07E-08
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	1.58E-15	1.58E-15	1.58E-15	1.58E-15	1.58E-15	1.58E-15		1.58E-15
Effective Saturation (Stephens, 1995)	Se	0.088889	0.088889	0.088889	0.088889	0.088889	0.088889	Daily Time Steps for 5 Years	0.088889
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.31	1.31	1.31	1.31	1 31	1.31		1.31
Mualem model (Stephens, 1995)	m	0.236641	0.236641	0.236641	0.236641	0.236641	0.236641		0.236641
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.019	0 019	0.019	0.019	0 019	0.019		0 019
Pressure head (Stephens, 1995)	P-head (-cm)	129434 2	129434 2	129434.2	129434 2	129434.2	129434.2		129434 2
Relative hydraulic conductivity	Kr	2 18E-11	2.18E-11	2.18E-11	2.18E-11	2.18E-11	2.18E-11		2.18E-11
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	7.22E-05	7.22E-05	7.22E-05	7.22E-05	7.22E-05	7.22E-05		7.22E-05
Drainage Volume (acre-ft)		0.00E+00	4.74E-11	4 74E-11	4.74E-11	4.74E-11	4.74E-11		1.42E-09

References.

Carsel, R F and Parrish, R S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v 24, no. 5 p. 755-769.

Stephens, D.B , 1996 Vadose Zone Hydrology CRC Press.



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Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Clay (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

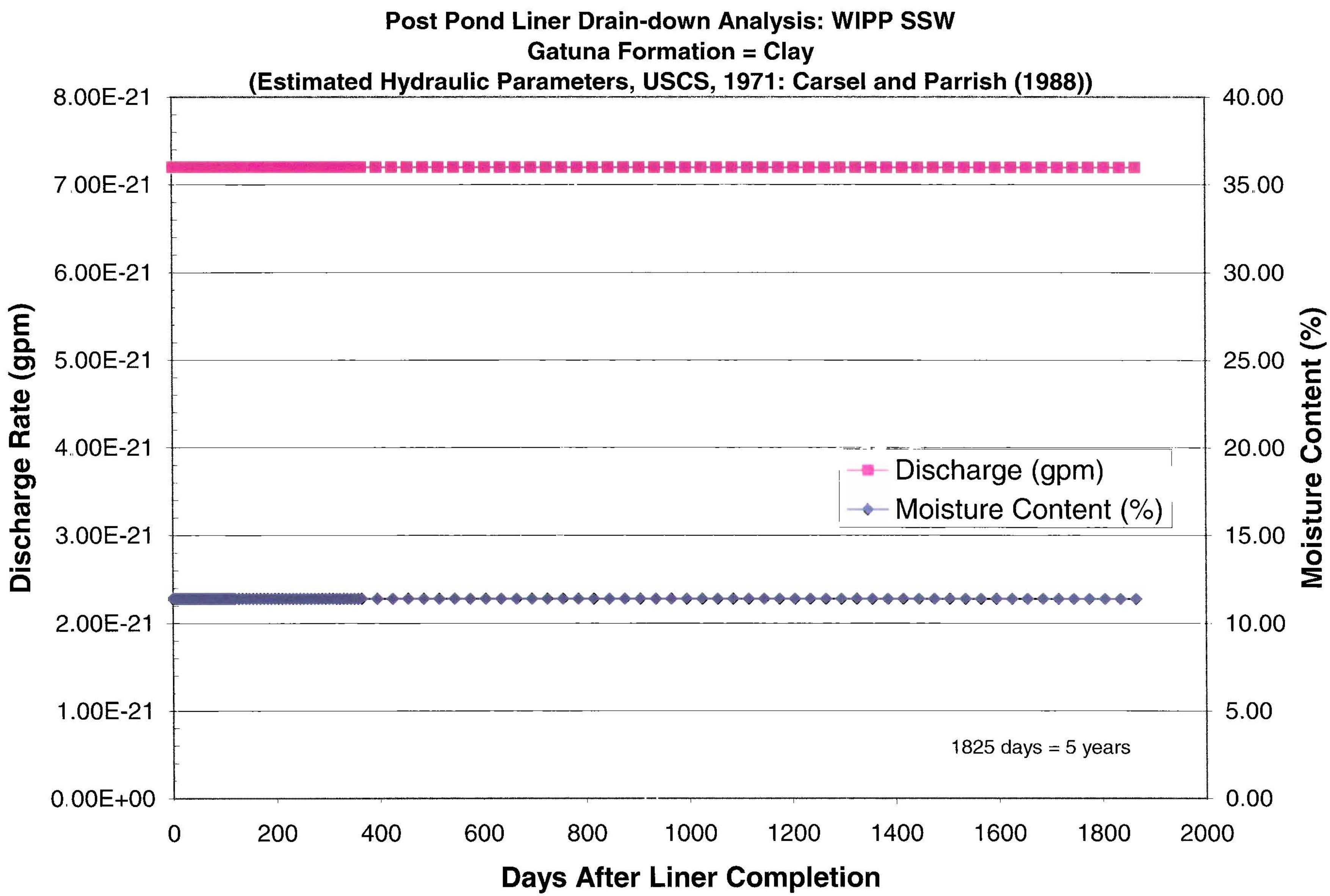
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.38**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.114**	**fraction**	**30% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**36.3**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.068**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**14.6**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**5.93E-20**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption* {	Moisture Content (%)	11.40	11.40	11 40	11.40	11 40	11.40		11 40
	Discharge (gpm)	7.20E-21	7.20E-21	7.20E-21	7.20E-21	7.20E-21	7.20E-21		7.20E-21
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	1.06E-27	1.06E-27	1.06E-27	1.06E-27	1.06E-27	1.06E-27		1.06E-27
Effective Saturation (Stephens, 1995)	Se	0.147436	0 147436	0.147436	0 147436	0 147436	0 147436		0.147436
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.09	1.09	1.09	1.09	1.09	1 09	Daily Time Steps for 5 Years	1.09
Mualem model (Stephens, 1995)	m	0.082569	0 082569	0.082569	0 082569	0.082569	0.082569		0.082569
van Genuchten Parameter Carsel and Parrish, 1988	$alpha_{(v)}$	0.008	0.008	0 008	0.008	0.008	0.008		0.008
Pressure head (Stephens, 1995)	P-head (-cm)	2 16E+11	2 16E+11	2.16E+11	2 16E+11	2 16E+11	2 16E+11		2.16E+11
Relative hydraulic conductivity	Kr	1 9E-23	1.9E-23	1.9E-23	1.9E-23	1 9E-23	1.9E-23		1.9E-23
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	5.56E-05	5.56E-05	5.56E-05	5.56E-05	5.56E-05	5.56E-05		5.56E-05
Drainage Volume (acre-ft)		0.00E+00	3 18E-23	3.18E-23	3.18E-23	3 18E-23	3.18E-23		9.54E-22

References.

Carsel, R F. and Parrish, R S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v 24, no. 5 p. 755-769

Stephens, D.B., 1996. Vadose Zone Hydrology. CRC Press.



T:\Projects\9184\Sheets\Final Water Balance\Vadose Zone Redistribution Estimate Ponds 30 DRAFT 7-22-08_working_copy.xls_Drain-down Chart (Clay, CP)

Post Pond Liner Drain-down Analysis: WIPP SSW

Gatuna Formation = Sand (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

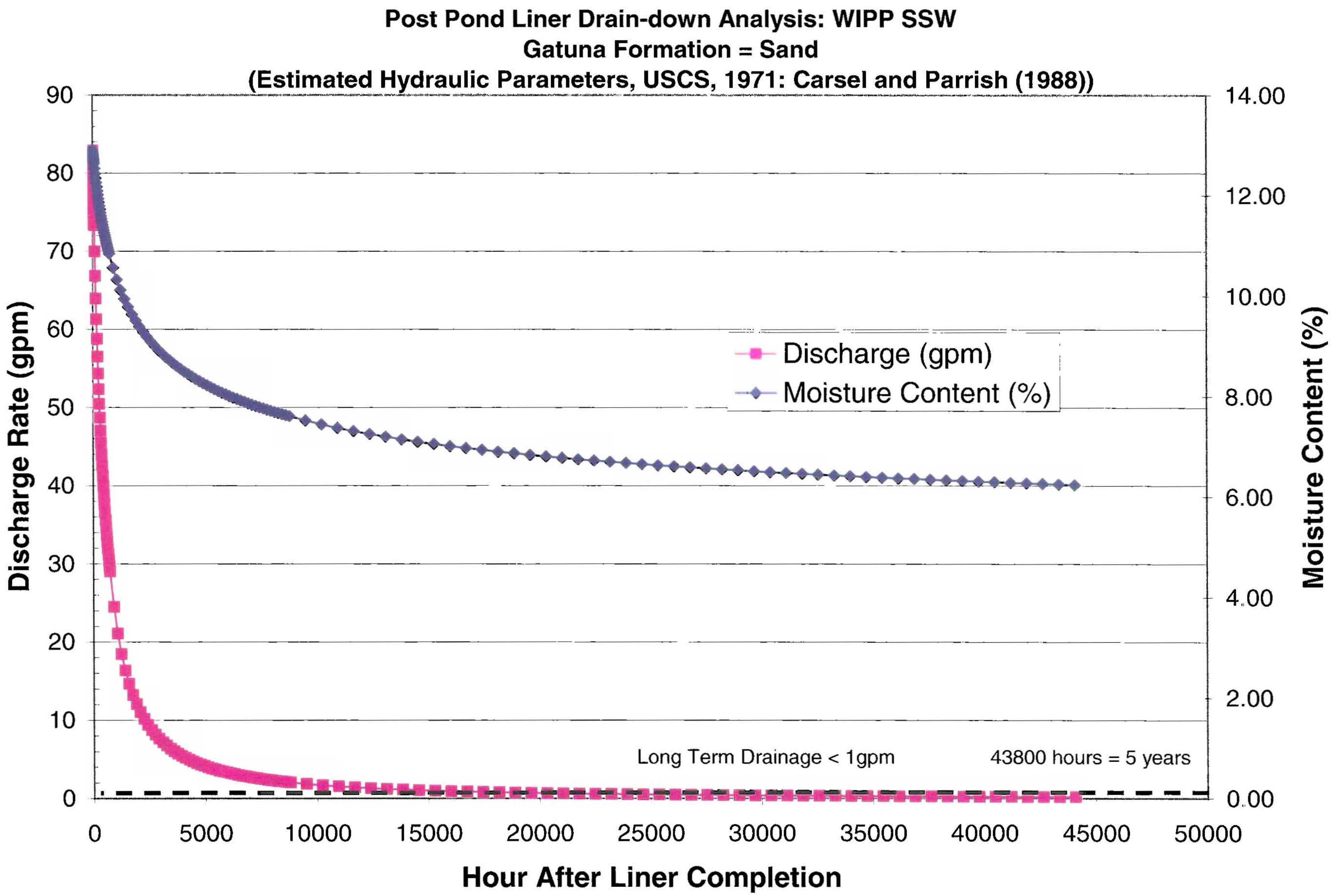
Parameter	*Value*	*Units*	*Notes*
Area	**10.61**	**(acres)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Thickness	**30**	**(ft)**	**Gatuna Formation**
Total Bulk Volume of Saturation	**318.3**	**(acre-ft)**	**Gatuna Formation**
Porosity	**0.43**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.129**	**fraction**	**30% of Saturated Moisture Content (Estimated)**
Initial Storage Volume (Gatuna Formation)	**41.1**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.045**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**26.7**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**21.2**	**(acre-ft)**	**5 Year Drainage**

Hour after Pond Liner Installation		0	1	2	3	4	5		44076
Incremental Steady State Assumption*	Moisture Content (%)	12.90	12.90	12.89	12.89	12.88	12.88		6.25
	Discharge (gpm)	8.29E+01	8.27E+01	8.25E+01	8.23E+01	8.22E+01	8.20E+01		2.45E-01
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	1.22E-05	1.21E-05	1.21E-05	1.21E-05	1.21E-05	1.20E-05		3.60E-08
Effective Saturation (Stephens, 1995)	Se	0.218182	0.218057	0.217933	0.217809	0.217685	0.217562	Hourly	0.045397
van Genuchten Parameter (Carsel and Parrish, 1988)	N	2.68	2.68	2.68	2.68	2.68	2.68	Time	2.68
Mualem model (Stephens, 1995)	m	0.626866	0.626866	0.626866	0.626866	0.626866	0.626866	Steps for 5	0.626866
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.145	0.145	0.145	0.145	0.145	0.145	Years	0.145
Pressure head (Stephens, 1995)	P-head (-cm)	16.49063	16.49677	16.50291	16.50904	16.51516	16.52128		43.33614
Relative hydraulic conductivity	Kr	0.001476	0.001473	0.00147	0.001466	0.001463	0.00146		4.36E-06
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	8.25E-03	8.25E-03	8.25E-03	8.25E-03	8.25E-03	8.25E-03		8.25E-03
Drainage Volume (acre-ft)		0.00E+00	1.53E-02	1.52E-02	1.52E-02	1.52E-02	1.51E-02		3.32E-02

References:

Carsel, R.F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B., 1996. Vadose Zone Hydrology CRC Press



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Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Sandy Clay Loam (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

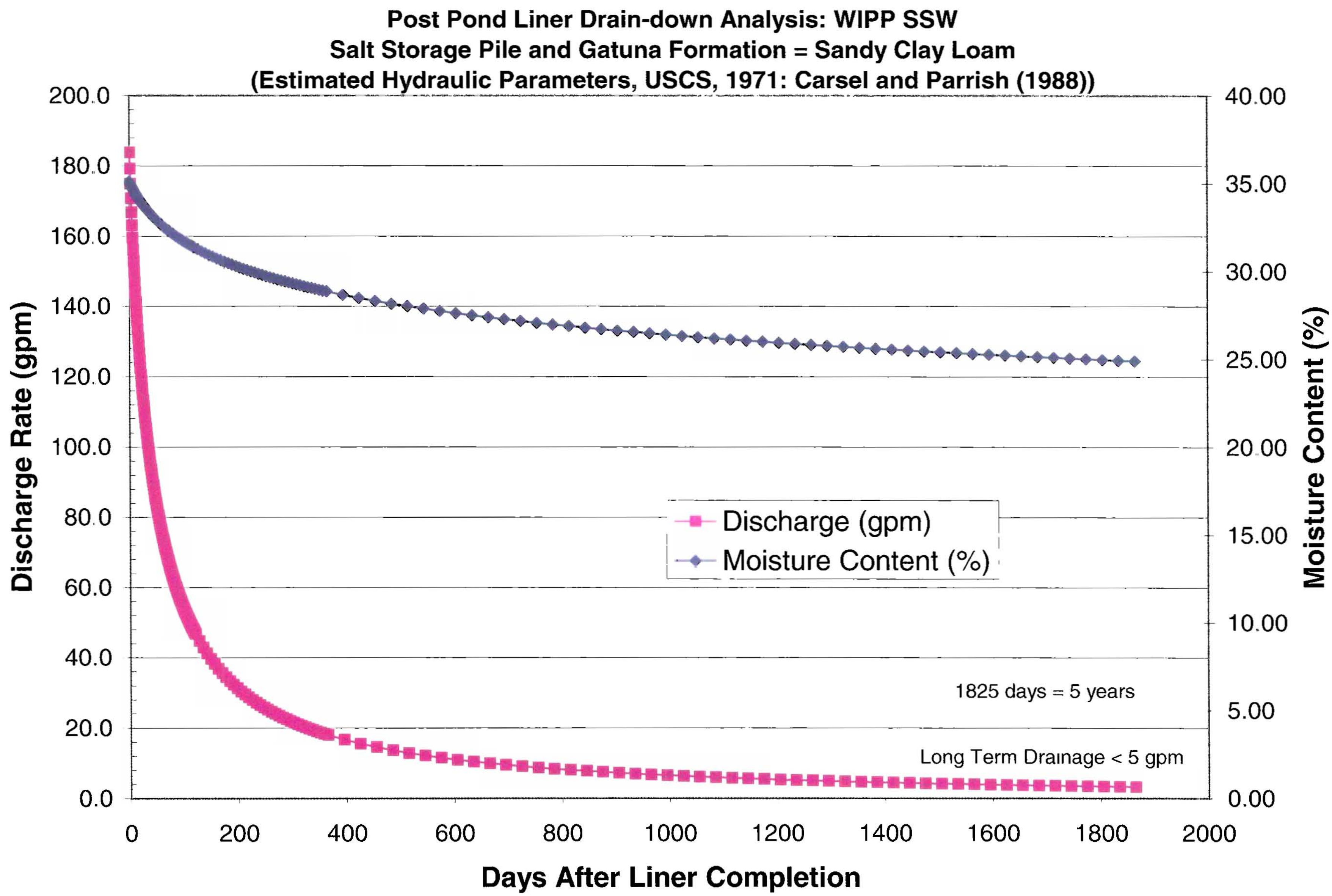
Parameter	Value	Units	Notes
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.39**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.351**	**fraction**	**90% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**428.9**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.1**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**306.7**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**124.5**	**(acre-ft)**	**~ 5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	35 10	35.03	34.97	34.91	34 84	34 78		24 95
	Discharge (gpm)	1.84E+02	1.79E+02	1 75E+02	1.71E+02	1.67E+02	1.63E+02		3.44E+00
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	2.70E-05	2.63E-05	2.57E-05	2.51E-05	2.45E-05	2.40E-05		5.06E-07
Effective Saturation (Stephens, 1995)	Se	0.865517	0.863225	0.86099	0 85881	0.856681	0.854601	Daily Time Steps for 5 Years	0.515446
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1 48	1.48	1.48	1 48	1.48	1 48		1.48
Mualem model (Stephens, 1995)	m	0.324324	0.324324	0.324324	0.324324	0.324324	0.324324		0.324324
van Genuchten Parameter. Carsel and Parrish, 1988	$alpha_{(v)}$	0 059	0.059	0 059	0 059	0.059	0.059		0.059
Pressure head (Stephens, 1995)	P-head (-cm)	11.46892	11.64529	11.81787	11 98685	12.15242	12 31477		61.38197
Relative hydraulic conductivity	Kr	0.074217	0.072365	0.070609	0.068941	0.067354	0.065842		0.001391
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	3.64E-04	3.64E-04	3.64E-04	3.64E-04	3.64E-04	3.64E-04		3.64E-04
Drainage Volume (acre-ft)		0.00E+00	8.12E-01	7.92E-01	7.73E-01	7.54E-01	7.37E-01		4.65E-01

References:

Carsel, R.F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D B , 1996. Vadose Zone Hydrology CRC Press.



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Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Silt (Carsel and Parrish, 1988, Tables, 2, 3, 4, 5)

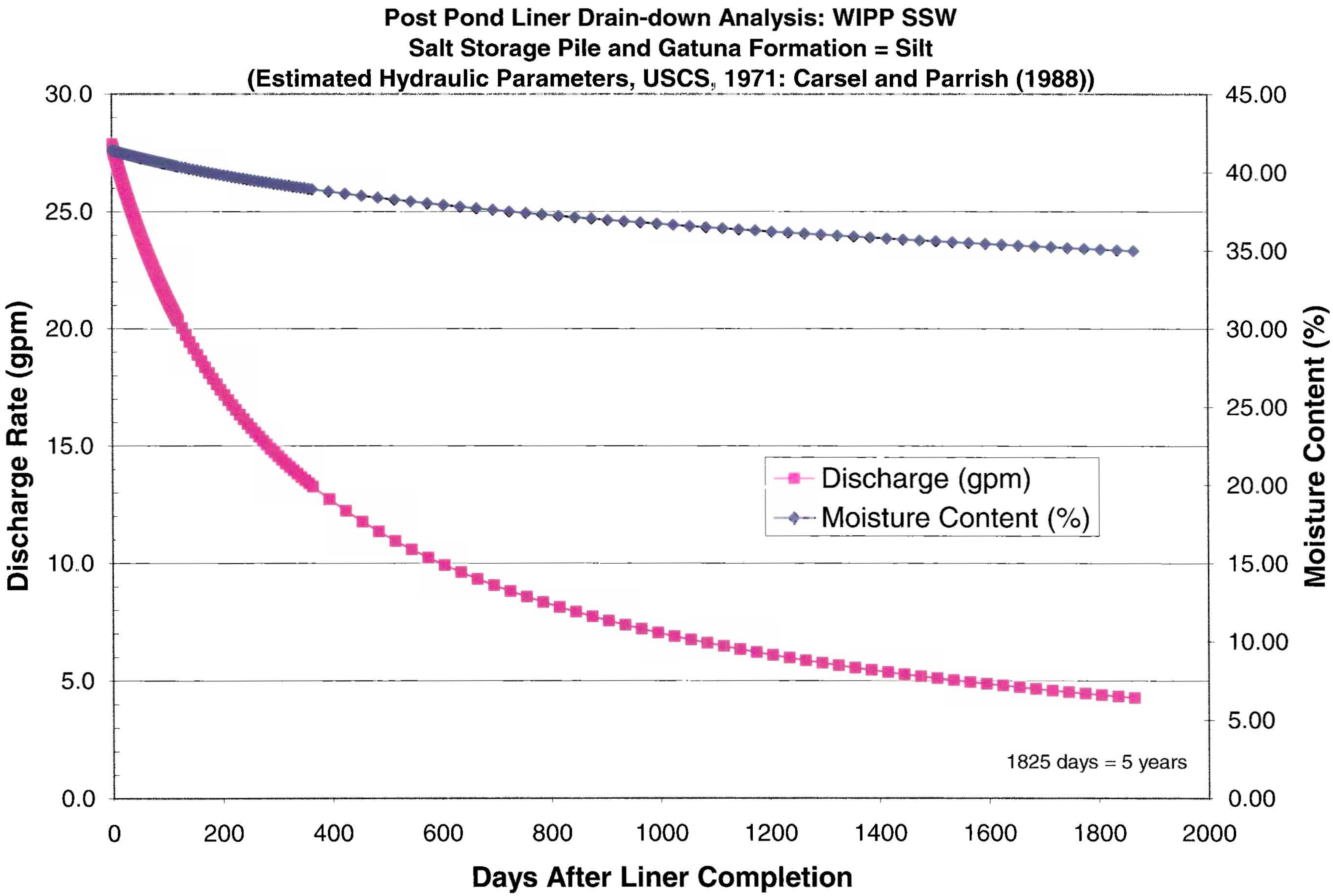
Parameter	*Value*	*Units*	*Notes*
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.46**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.414**	**fraction**	**90% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**505.9**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.034**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**464.4**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**78.3**	**(acre-ft)**	**~ 5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	41.40	41.39	41.38	41.37	41.36	41.35		35.04
	Discharge (gpm)	2.79E+01	2.78E+01	2.77E+01	2.76E+01	2.75E+01	2.74E+01		4.35E+00
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	4.09E-06	4.08E-06	4.07E-06	4.05E-06	4.04E-06	4.03E-06		6.40E-07
Effective Saturation (Stephens, 1995)	Se	0.892019	0.891782	0.891547	0.891312	0.891077	0.890844	Daily Time Steps for 5 Years	0.742692
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.37	1.37	1.37	1.37	1.37	1.37		1.37
Mualem model (Stephens, 1995)	m	0.270073	0.270073	0.270073	0.270073	0.270073	0.270073		0.270073
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.016	0.016	0.016	0.016	0.016	0.016		0.016
Pressure head (Stephens, 1995)	P-head (-cm)	39.14123	39.22253	39.30362	39.3845	39.46516	39.5456		103.9828
Relative hydraulic conductivity	Kr	0.058938	0.058752	0.058568	0.058385	0.058203	0.058022		0.00921
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	6.94E-05	6.94E-05	6.94E-05	6.94E-05	6.94E-05	6.94E-05		6.94E-05
Drainage Volume (acre-ft)		0.00E+00	1.23E-01	1.23E-01	1.22E-01	1.22E-01	1.22E-01		5.85E-01

References.

Carsel, R F and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769

Stephens, D.B., 1996. Vadose Zone Hydrology. CRC Press



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Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Clay Loam (Carsel and Parrish, 1988, Tables, 2, 3, 4, 5)

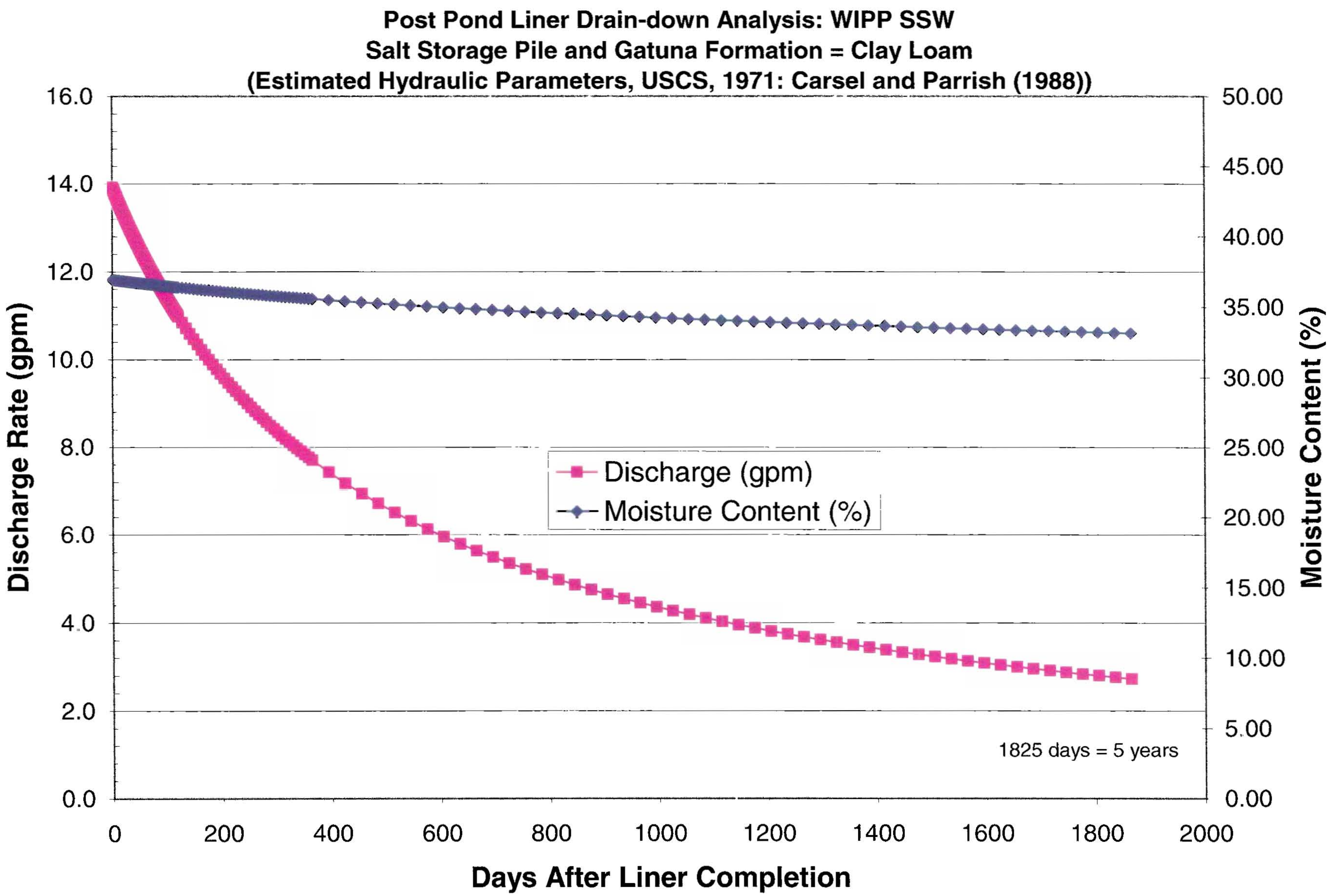
Parameter	*Value*	*Units*	*Notes*
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.41**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.369**	**fraction**	**90% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**450.9**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.095**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**334.8**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**45.9**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	36.90	36.89	36.89	36.88	36.88	36.87		33.17
	Discharge (gpm)	1.39E+01	1.39E+01	1.39E+01	1.38E+01	1.38E+01	1.38E+01		2.77E+00
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	2.05E-06	2.04E-06	2.04E-06	2.03E-06	2.03E-06	2.02E-06		4.07E-07
Effective Saturation (Stephens, 1995)	Se	0.869841	0.869681	0.869522	0.869363	0.869204	0.869046	Daily Time Steps for 5 Years	0.751544
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.31	1.31	1.31	1.31	1.31	1.31		1.31
Mualem model (Stephens, 1995)	m	0.236641	0.236641	0.236641	0.236641	0.236641	0.236641		0.236641
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.019	0.019	0.019	0.019	0.019	0.019		0.019
Pressure head (Stephens, 1995)	P-head (-cm)	44.50117	44.56042	44.61956	44.6786	44.73754	44.79638		100.827
Relative hydraulic conductivity	Kr	0.028318	0.028254	0.02819	0.028127	0.028064	0.028001		0.00564
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	7.22E-05	7.22E-05	7.22E-05	7.22E-05	7.22E-05	7.22E-05		7.22E-05
Drainage Volume (acre-ft)		0.00E+00	6.15E-02	6.14E-02	6.12E-02	6.11E-02	6.10E-02		3.72E-01

References:

Carsel, R.F and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B., 1996. Vadose Zone Hydrology. CRC Press.



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Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Clay (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

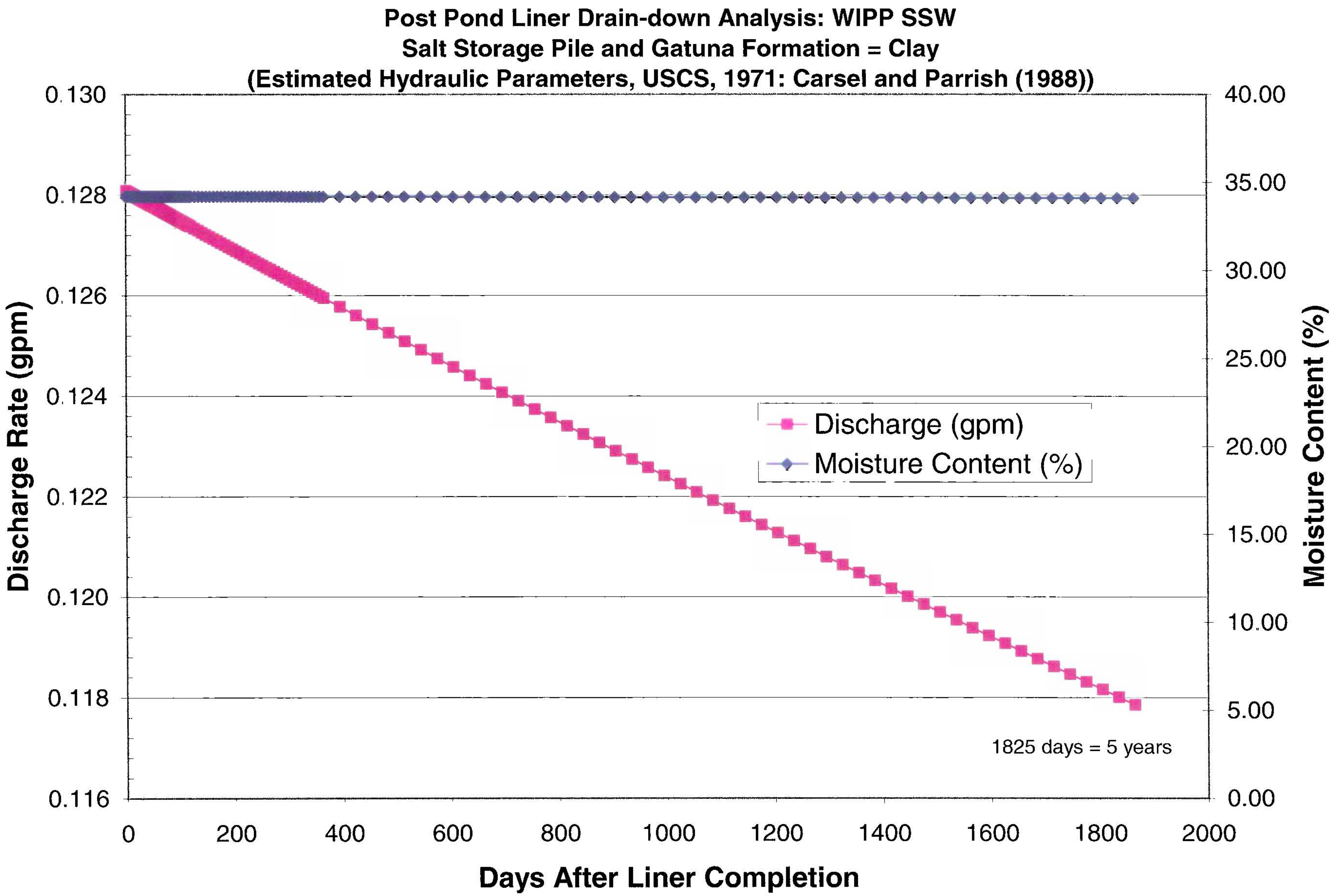
Parameter	*Value*	*Units*	*Notes*
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.38**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.342**	**fraction**	**90% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**417.9**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.068**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**334.8**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**1.0**	**(acre-ft)**	**~ 5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption* {	Moisture Content (%)	34.20	34.20	34.20	34.20	34.20	34.20		34 12
	Discharge (gpm)	1.28E-01	1.28E-01	1.28E-01	1 28E-01	1.28E-01	1.28E-01		1 18E-01
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	1.88E-08	1.88E-08	1.88E-08	1.88E-08	1.88E-08	1.88E-08		1 73E-08
Effective Saturation (Stephens, 1995)	Se	0.878205	0.878204	0.878202	0.878201	0.878199	0.878198		0 87559
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.09	1.09	1.09	1.09	1.09	1 09	Daily Time Steps for 5 Years	1.09
Mualem model (Stephens, 1995)	m	0.082569	0.082569	0.082569	0 082569	0.082569	0.082569		0 082569
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0 008	0 008	0.008	0 008	0 008	0.008		0.008
Pressure head (Stephens, 1995)	P-head (-cm)	427.5553	427.5655	427.5756	427.5857	427.5959	427.606		445.7269
Relative hydraulic conductivity	Kr	0.000339	0.000339	0.000339	0 000339	0.000339	0.000339		0.000312
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	5.56E-05	5.56E-05	5.56E-05	5.56E-05	5 56E-05	5.56E-05		5.56E-05
Drainage Volume (acre-ft)		0.00E+00	5.66E-04	5.66E-04	5.66E-04	5.66E-04	5 66E-04		1 57E-02

References.

Carsel, R F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B , 1996. Vadose Zone Hydrology. CRC Press



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Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Sand (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

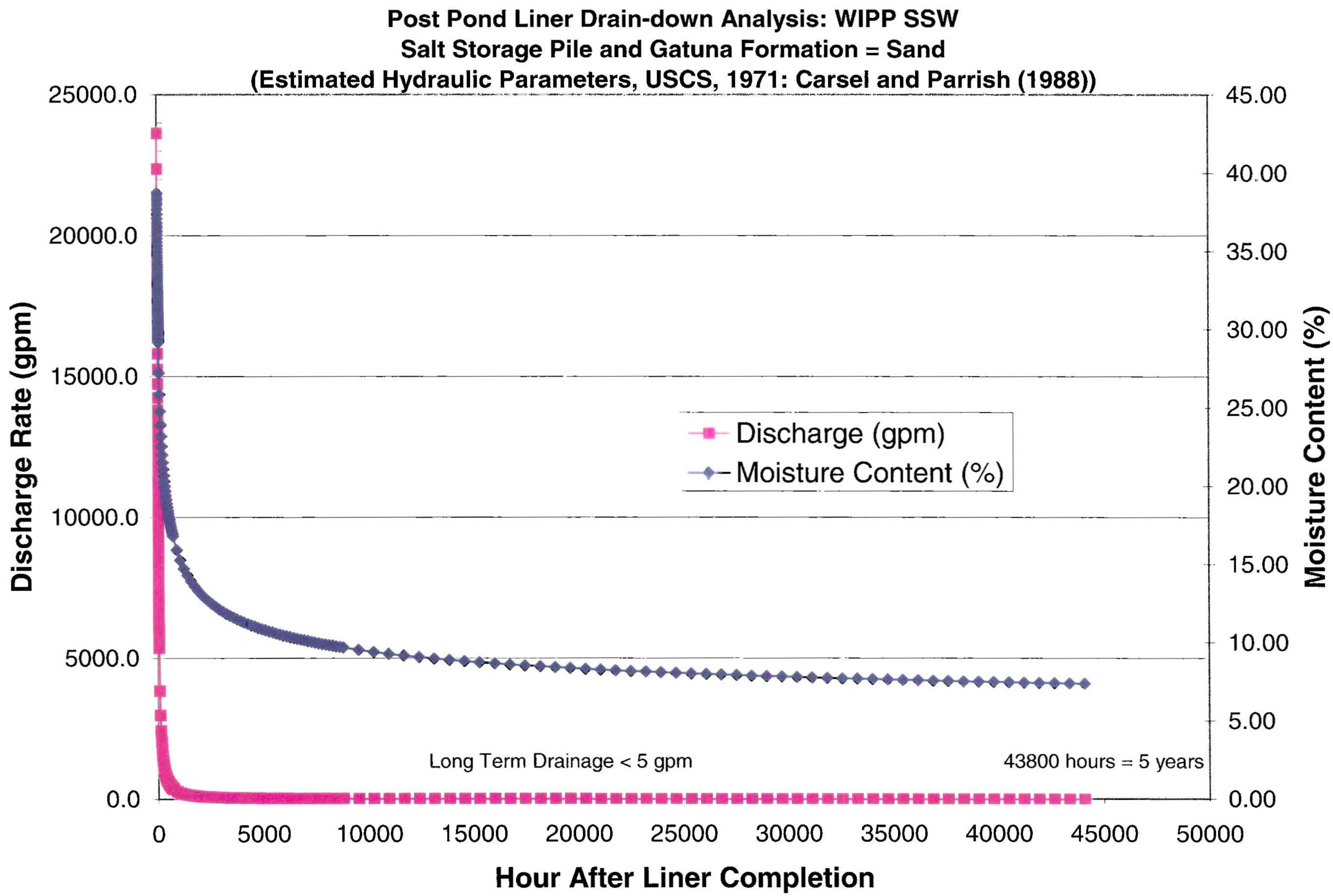
Parameter	*Value*	*Units*	*Notes*
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.43**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.387**	**fraction**	**90% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**472.9**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.045**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**417.9**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**382.9**	**(acre-ft)**	**~ 5 Year Drainage**

Hour after Pond Liner Installation		0	1	2	3	4	5		44076
Incremental Steady State Assumption*	Moisture Content (%)	38.70	38.34	38.01	37.69	37.38	37.09		7.38
	Discharge (gpm)	2.36E+04	2.24E+04	2.12E+04	2.02E+04	1.93E+04	1.85E+04		1.56E+00
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	3.47E-03	3.29E-03	3.12E-03	2.97E-03	2.84E-03	2.72E-03		2.29E-07
Effective Saturation (Stephens, 1995)	Se	0.888312	0.879067	0.870315	0.862001	0.854082	0.84652	Hourly	0.074925
van Genuchten Parameter (Carsel and Parrish, 1988)	N	2.68	2.68	2.68	2.68	2.68	2.68	Time	2.68
Mualem model (Stephens, 1995)	m	0.626866	0.626866	0.626866	0.626866	0.626866	0.626866	Steps for 5	0.626866
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.145	0.145	0.145	0.145	0.145	0.145	Years	0.145
Pressure head (Stephens, 1995)	P-head (-cm)	3.83833	3.974254	4.09931	4.215284	4.323541	4.42515		32.05386
Relative hydraulic conductivity	Kr	0.420678	0.398287	0.378324	0.360381	0.344141	0.329357		2.78E-05
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	8.25E-03	8.25E-03	8.25E-03	8.25E-03	8.25E-03	8.25E-03		8.25E-03
Drainage Volume (acre-ft)		0.00E+00	4.35E+00	4.12E+00	3.91E+00	3.73E+00	3.56E+00		2.11E-01

References.

Carsel, R.F and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B , 1996. Vadose Zone Hydrology CRC Press.



T:\Projects\9184\Sheets\Final Water Balance\Vadose Zone Redistribution Estimate Salt Storage Area 90 DRAFT 7-22-08_working_copy xls_Drain-down Chart (Sand, CP)

Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Sandy Clay Loam (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

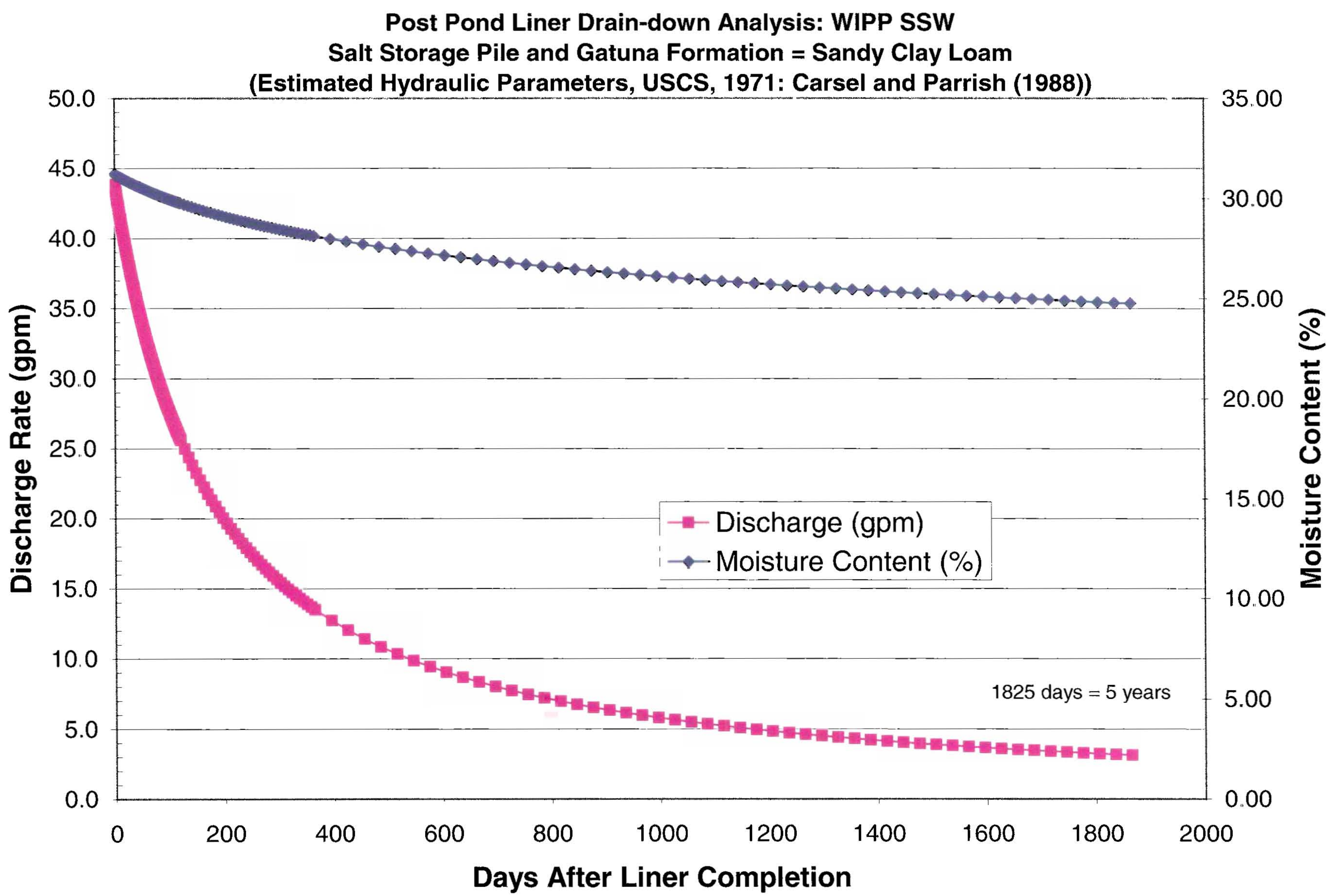
Parameter	*Value*	*Units*	*Notes*
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.39**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.312**	**fraction**	**80% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**381.3**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.1**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**259.1**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**78.7**	**(acre-ft)**	**~ 5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	31.20	31 18	31 17	31.15	31 14	31 12	Daily Time Steps for 5 Years	24.80
	Discharge (gpm)	4.38E+01	4 36E+01	4 33E+01	4.31E+01	4.28E+01	4.26E+01		3.21E+00
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	6.44E-06	6.40E-06	6.37E-06	6.33E-06	6.29E-06	6.26E-06		4.71E-07
Effective Saturation (Stephens, 1995)	Se	0.731034	0.730488	0 729944	0.729404	0.728867	0.728333		0.510217
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.48	1 48	1.48	1 48	1.48	1 48		1 48
Mualem model (Stephens, 1995)	m	0.324324	0.324324	0.324324	0.324324	0.324324	0.324324		0.324324
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.059	0.059	0 059	0.059	0.059	0.059		0.059
Pressure head (Stephens, 1995)	P-head (-cm)	23 5531	23.6124	23.67146	23.73029	23.78889	23.84725		62.89488
Relative hydraulic conductivity	Kr	0.017702	0.017599	0.017497	0.017396	0.017297	0.017198		0.001296
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	3.64E-04	3 64E-04	3.64E-04	3.64E-04	3.64E-04	3.64E-04		3.64E-04
Drainage Volume (acre-ft)		0.00E+00	1.94E-01	1.93E-01	1.91E-01	1.90E-01	1.89E-01		4 32E-01

References:

Carsel, R.F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v 24, no. 5 p. 755-769.

Stephens, D.B., 1996. Vadose Zone Hydrology. CRC Press.



T:\Projects\9184\Sheets\Final Water Balance\Vadose Zone Redistribution Estimate Salt Storage Area 80 DRAFT 7-22-08_working_copy xls_Drain-down Chart (SCL, CP)

Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Silt (Carsel and Parrish, 1988, Tables, 2, 3, 4, 5)

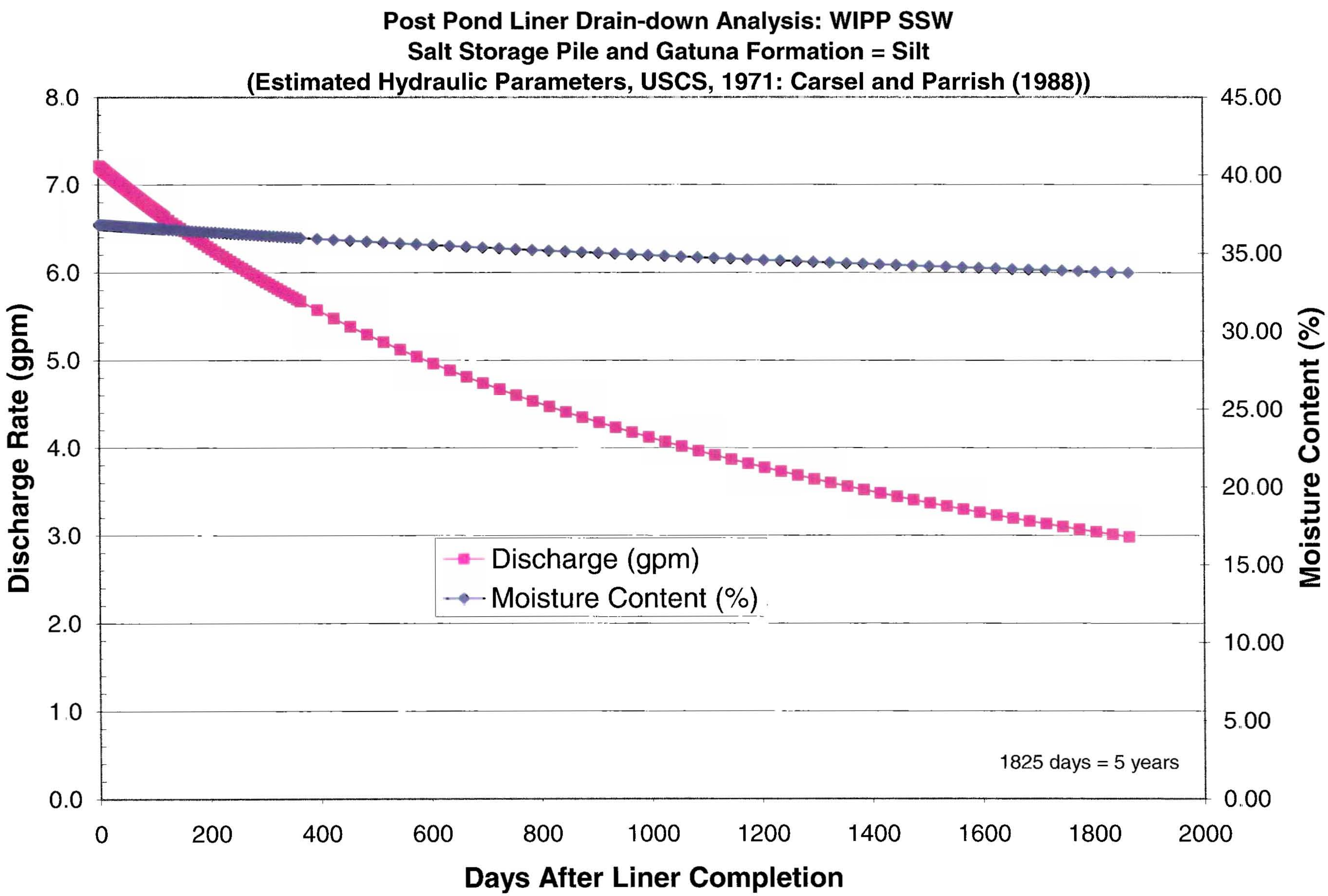
Parameter	*Value*	*Units*	*Notes*
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.46**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.368**	**fraction**	**80% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**449.7**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.034**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**408.1**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**37.3**	**(acre-ft)**	**~ 5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption* {	Moisture Content (%)	36.80	36.80	36.79	36 79	36 79	36.79		33.78
	Discharge (gpm)	7.22E+00	7.21E+00	7.21E+00	7.20E+00	7.19E+00	7.19E+00		3.02E+00
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	1.06E-06	1.06E-06	1.06E-06	1.06E-06	1.06E-06	1.06E-06		4.43E-07
Effective Saturation (Stephens, 1995)	Se	0.784038	0 783976	0.783915	0 783854	0.783793	0.783732	Daily Time Steps for 5 Years	0.713093
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.37	1 37	1 37	1.37	1 37	1.37		1.37
Mualem model (Stephens, 1995)	m	0.270073	0.270073	0.270073	0.270073	0.270073	0.270073		0.270073
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.016	0 016	0.016	0.016	0 016	0.016		0.016
Pressure head (Stephens, 1995)	P-head (-cm)	82.45547	82 4848	82.51411	82.54341	82.57269	82.60196		121 9067
Relative hydraulic conductivity	Kr	0.015268	0 015257	0.015246	0 015234	0.015223	0.015212		0.006382
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	6.94E-05	6.94E-05	6.94E-05	6.94E-05	6.94E-05	6.94E-05		6.94E-05
Drainage Volume (acre-ft)		0.00E+00	3.19E-02	3.19E-02	3 18E-02	3.18E-02	3.18E-02		4.04E-01

References:

Carsel, R F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v 24, no. 5 p. 755-769

Stephens, D B , 1996. Vadose Zone Hydrology. CRC Press.



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Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Clay Loam (Carsel and Parrish, 1988, Tables, 2, 3, 4, 5)

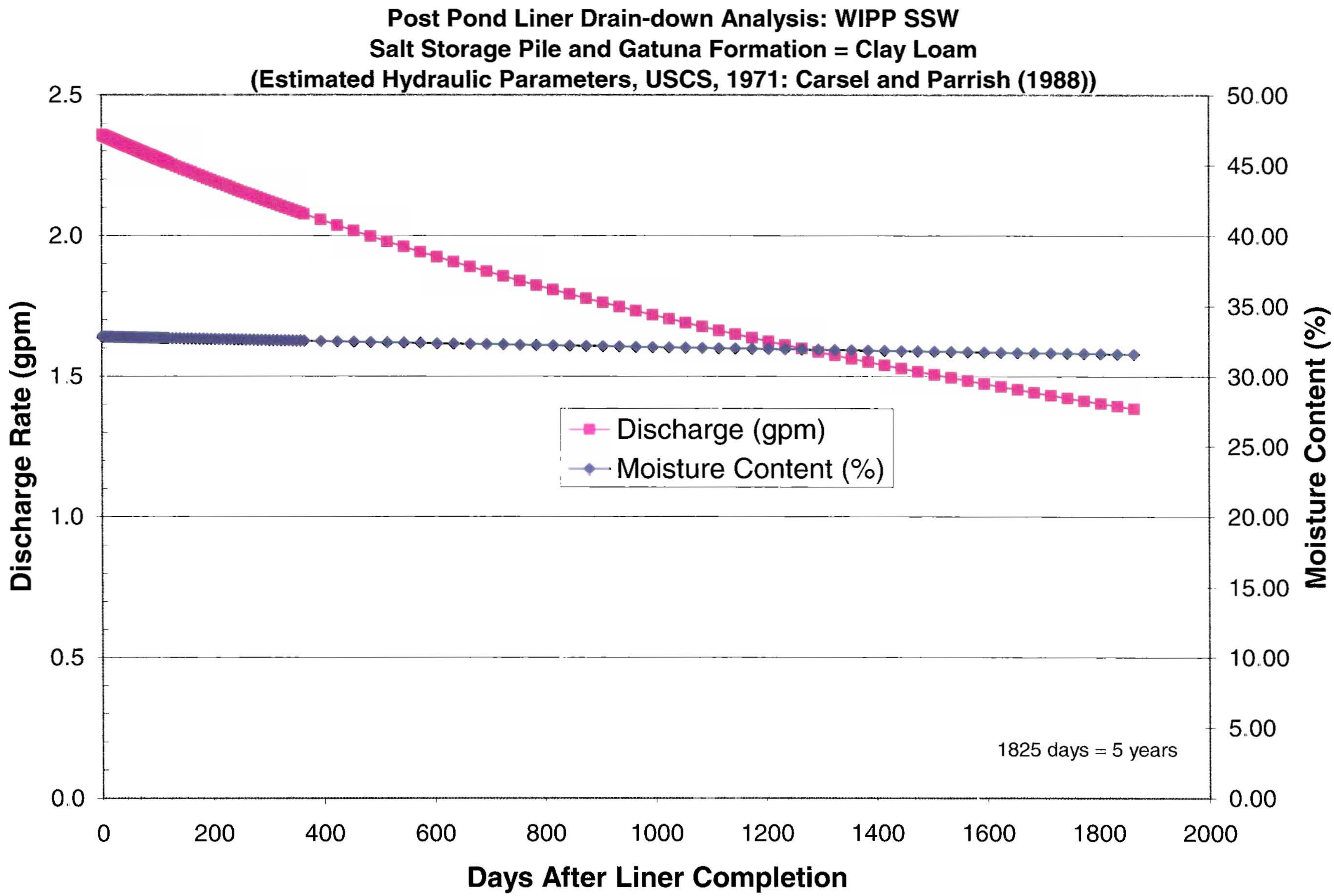
Parameter	*Value*	*Units*	*Notes*
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.41**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.328**	**fraction**	**80% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**400.8**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.095**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**284.7**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**14.8**	**(acre-ft)**	**~ 5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption* {	Moisture Content (%)	32.80	32.80	32.80	32.80	32.80	32.80	Daily Time Steps for 5 Years	31.60
	Discharge (gpm)	2.36E+00	2.36E+00	2.36E+00	2.36E+00	2.35E+00	2.35E+00		1.40E+00
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	3.46E-07	3.46E-07	3.46E-07	3.46E-07	3.46E-07	3.46E-07		2.05E-07
Effective Saturation (Stephens, 1995)	Se	0.739683	0.739655	0.739628	0.739601	0.739574	0.739547		0.70174
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.31	1.31	1.31	1.31	1.31	1.31		1.31
Maulem model (Stephens, 1995)	m	0.236641	0.236641	0.236641	0.236641	0.236641	0.236641		0.236641
van Genuchten Parameter. Carsel and Parrish, 1988	$alpha_{(v)}$	0.019	0.019	0.019	0.019	0.019	0.019		0.019
Pressure head (Stephens, 1995)	P-head (-cm)	108.3768	108.3946	108.4124	108.4301	108.4479	108.4656		135.9683
Relative hydraulic conductivity	Kr	0.004797	0.004796	0.004794	0.004792	0.00479	0.004788		0.002838
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	7.22E-05	7.22E-05	7.22E-05	7.22E-05	7.22E-05	7.22E-05		7.22E-05
Drainage Volume (acre-ft)		0.00E+00	1.04E-02	1.04E-02	1.04E-02	1.04E-02	1.04E-02		1.86E-01

References.

Carsel, R.F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B., 1996 Vadose Zone Hydrology. CRC Press.



T:\Projects\9184\Sheets\Final Water Balance\Vadose Zone Redistribution Estimate Salt Storage Area 80 DRAFT 7-22-08_working_copy xls_Drain-down Chart (CL. CP)

Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Clay (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

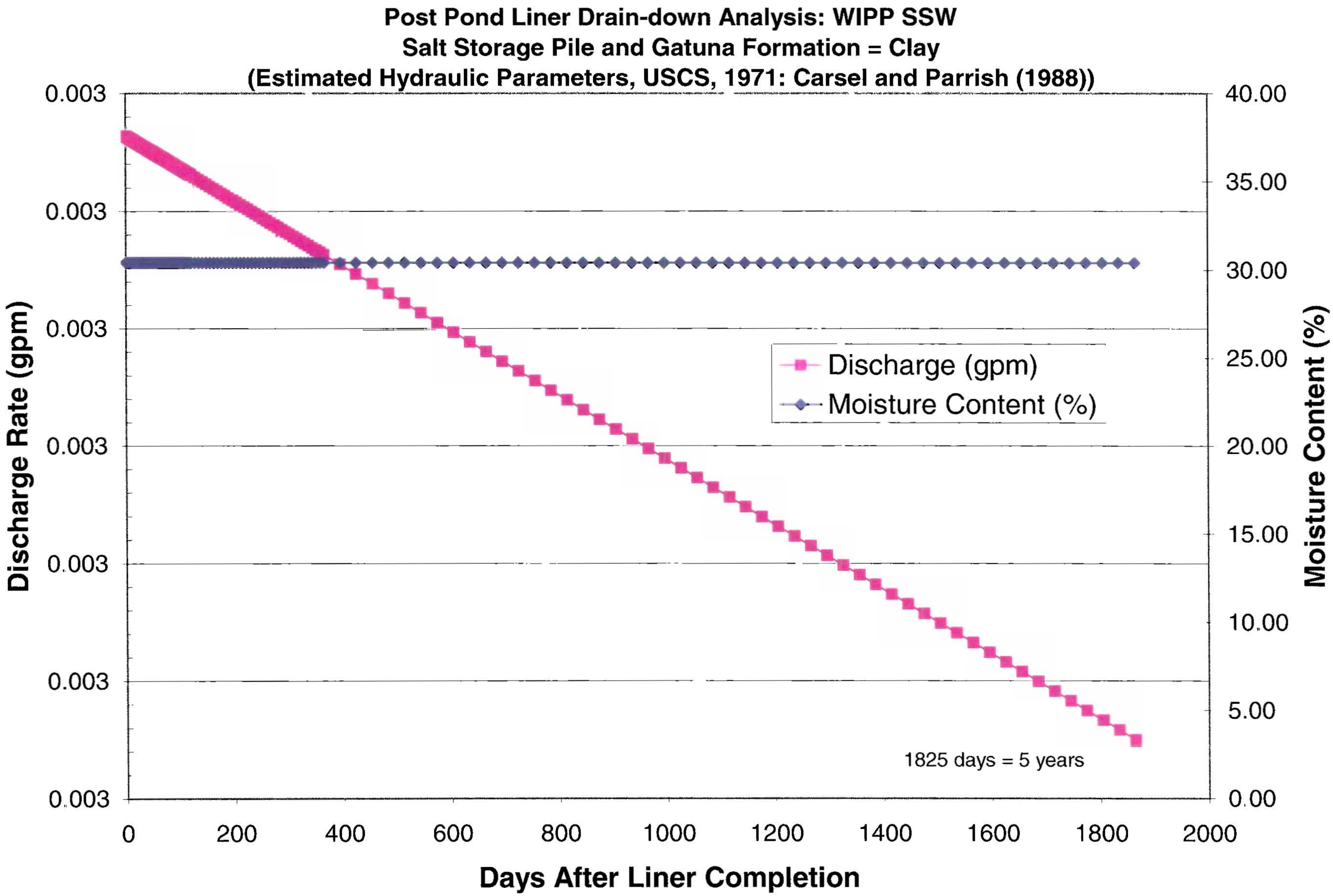
Parameter	Value	Units	Notes
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.38**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.304**	**fraction**	**80% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**371.5**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.068**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**288.4**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**0.02**	**(acre-ft)**	**~ 5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	30.40	30.40	30.40	30.40	30.40	30.40		30 40
	Discharge (gpm)	2.68E-03	2.68E-03	2.68E-03	2.68E-03	2.68E-03	2.68E-03		2 67E-03
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	3.93E-10	3.93E-10	3.93E-10	3.93E-10	3.93E-10	3.93E-10		3.93E-10
Effective Saturation (Stephens, 1995)	Se	0.75641	0.75641	0.75641	0.75641	0.75641	0.75641	Daily Time Steps for 5 Years	0.756353
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.09	1.09	1.09	1 09	1.09	1.09		1.09
Mualem model (Stephens, 1995)	m	0.082569	0.082569	0.082569	0.082569	0.082569	0.082569		0.082569
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.008	0.008	0.008	0 008	0.008	0.008		0.008
Pressure head (Stephens, 1995)	P-head (-cm)	2693.165	2693 166	2693.168	2693.169	2693 17	2693.171		2695.496
Relative hydraulic conductivity	Kr	7.08E-06	7.08E-06	7.08E-06	7.08E-06	7.08E-06	7.08E-06		7.07E-06
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	5.56E-05	5.56E-05	5.56E-05	5.56E-05	5.56E-05	5.56E-05		5.56E-05
Drainage Volume (acre-ft)		0.00E+00	1.18E-05	1.18E-05	1.18E-05	1.18E-05	1.18E-05		3.54E-04

References.

Carsel, R.F. and Parrish, R S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v 24, no. 5 p. 755-769.

Stephens, D.B , 1996. Vadose Zone Hydrology. CRC Press.



T \Projects\9184\Sheets\Final Water Balance\Vadose Zone Redistribution Estimate Salt Storage Area 80 DRAFT 7-22-08_working_copy.xls_Drain-down Chart (Clay, CP)

Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Sand (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

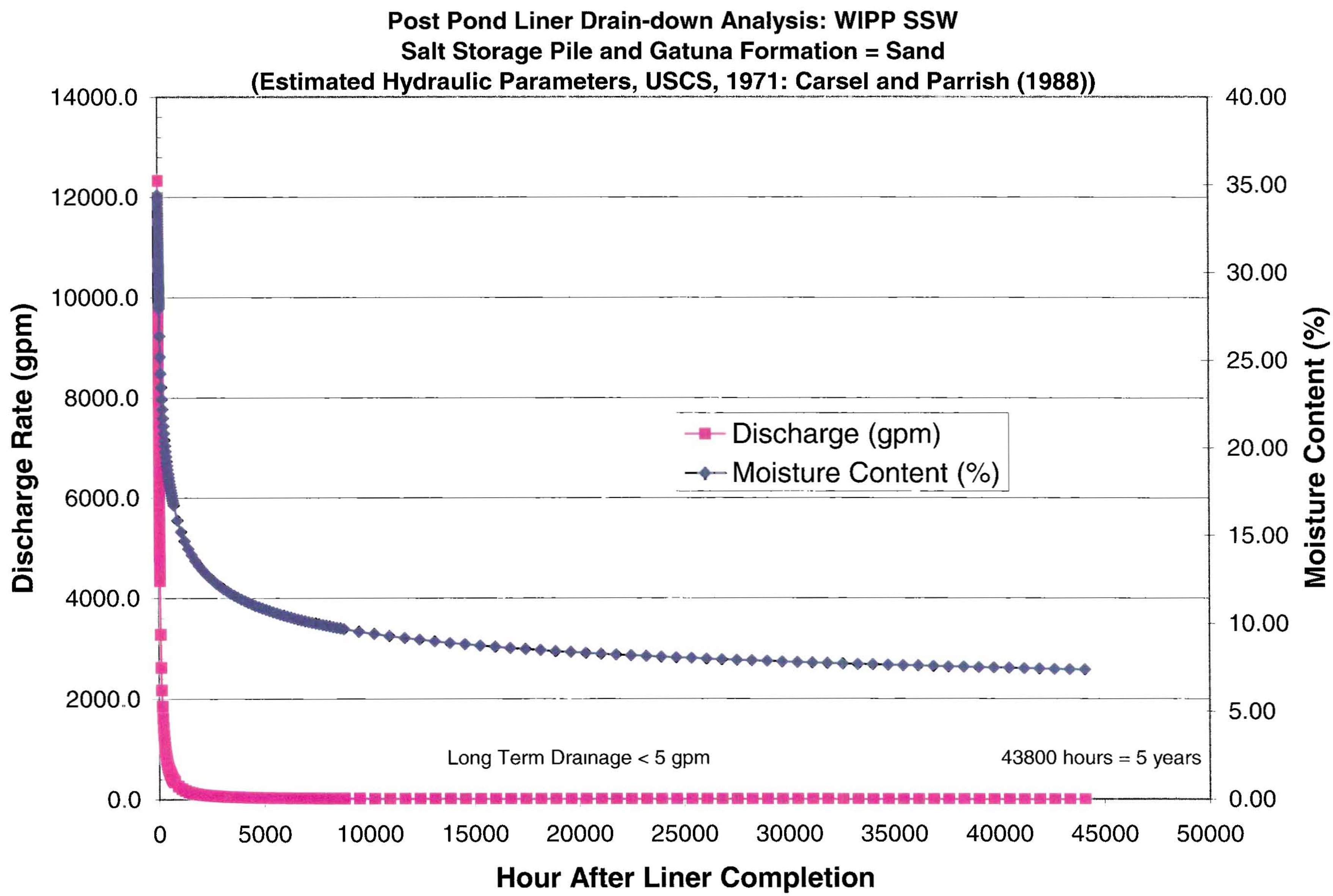
Parameter	*Value*	*Units*	*Notes*
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.43**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.344**	**fraction**	**80% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**420.4**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.045**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**365.4**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**330.3**	**(acre-ft)**	**~ 5 Year Drainage**

Hour after Pond Liner Installation		0	1	2	3	4	5		44076
Incremental Steady State Assumption*	Moisture Content (%)	34.40	34.21	34 03	33.86	33 69	33 52		7.38
	Discharge (gpm)	1.23E+04	1.20E+04	1.17E+04	1.14E+04	1.11E+04	1.08E+04		1.56E+00
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	1 81E-03	1 76E-03	1.71E-03	1.67E-03	1.62E-03	1.58E-03		2.29E-07
Effective Saturation (Stephens, 1995)	Se	0.776623	0.771799	0.767108	0.762545	0.758102	0.753774	Hourly	0.074918
van Genuchten Parameter (Carsel and Parrish, 1988)	N	2.68	2 68	2.68	2 68	2.68	2.68	Time	2 68
Mualem model (Stephens, 1995)	m	0.626866	0.626866	0.626866	0.626866	0.626866	0.626866	Steps for 5	0.626866
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.145	0 145	0 145	0.145	0.145	0 145	Years	0.145
Pressure head (Stephens, 1995)	P-head (-cm)	5.311788	5.370902	5.428244	5.483927	5.538056	5.590724		32.05572
Relative hydraulic conductivity	Kr	0.219562	0.213449	0.207658	0.202164	0.196943	0.191975		2.78E-05
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	8.25E-03	8.25E-03	8.25E-03	8.25E-03	8 25E-03	8.25E-03		8.25E-03
Drainage Volume (acre-ft)		0.00E+00	2.27E+00	2.21E+00	2.15E+00	2.09E+00	2.04E+00		2.11E-01

References:

Carsel, R.F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B., 1996. Vadose Zone Hydrology. CRC Press.



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Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Sandy Clay Loam (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

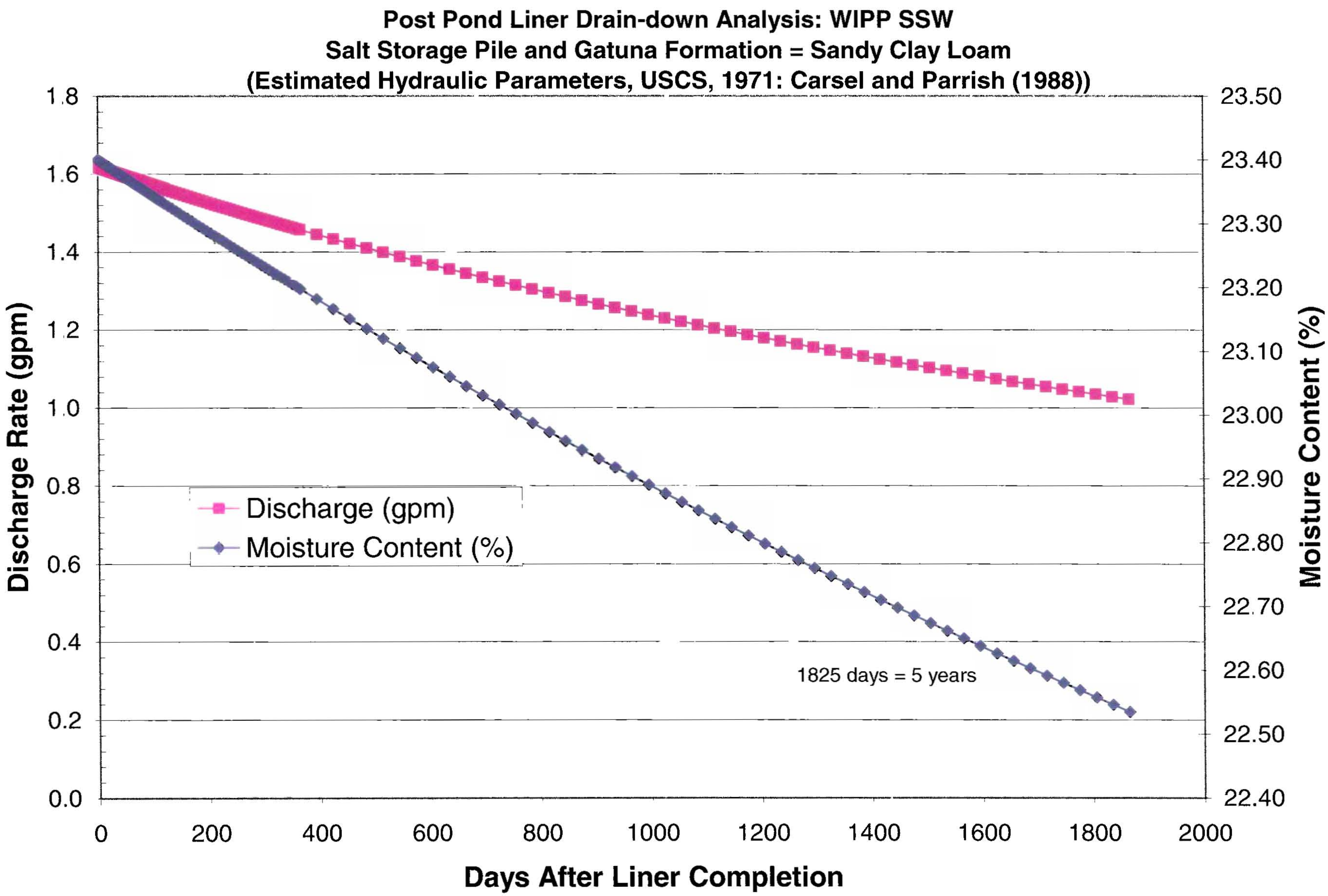
Parameter	Value	Units	Notes
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.39**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.234**	**fraction**	**60% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**285.9**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.1**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**163.7**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**10.6**	**(acre-ft)**	**~ 5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	23 40	23.40	23.40	23.40	23.40	23.40		22.55
	Discharge (gpm)	1.62E+00	1.62E+00	1.62E+00	1.62E+00	1.61E+00	1.61E+00		1.03E+00
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	2.38E-07	2.38E-07	2.37E-07	2.37E-07	2.37E-07	2.37E-07		1.51E-07
Effective Saturation (Stephens, 1995)	Se	0.462069	0.462049	0.462029	0.462008	0.461988	0.461968	Daily Time Steps for 5 Years	0.432635
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.48	1 48	1.48	1.48	1 48	1.48		1.48
Mualem model (Stephens, 1995)	m	0.324324	0.324324	0.324324	0.324324	0.324324	0.324324		0.324324
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.059	0 059	0 059	0.059	0.059	0.059		0.059
Pressure head (Stephens, 1995)	P-head (-cm)	79.28498	79.29292	79 30086	79.3088	79 31674	79.32468		92 08432
Relative hydraulic conductivity	Kr	0.000653	0.000653	0.000653	0.000652	0.000652	0.000652		0.000416
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	3.64E-04	3.64E-04	3.64E-04	3.64E-04	3.64E-04	3.64E-04		3.64E-04
Drainage Volume (acre-ft)		0.00E+00	7.15E-03	7.14E-03	7.14E-03	7.14E-03	7.14E-03		1.37E-01

References:

Carsel, R.F. and Parrish, R.S , 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769

Stephens, D B., 1996 Vadose Zone Hydrology CRC Press



T \Projects\9184\Sheets\Fınal Water Balance\Vadose Zone Redistributıon Estimate Salt Storage Area 60 DRAFT 7-22-08_workıng_copy xls_Drain-down Chart (SCL, CP)

Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Silt (Carsel and Parrish, 1988, Tables, 2, 3, 4, 5)

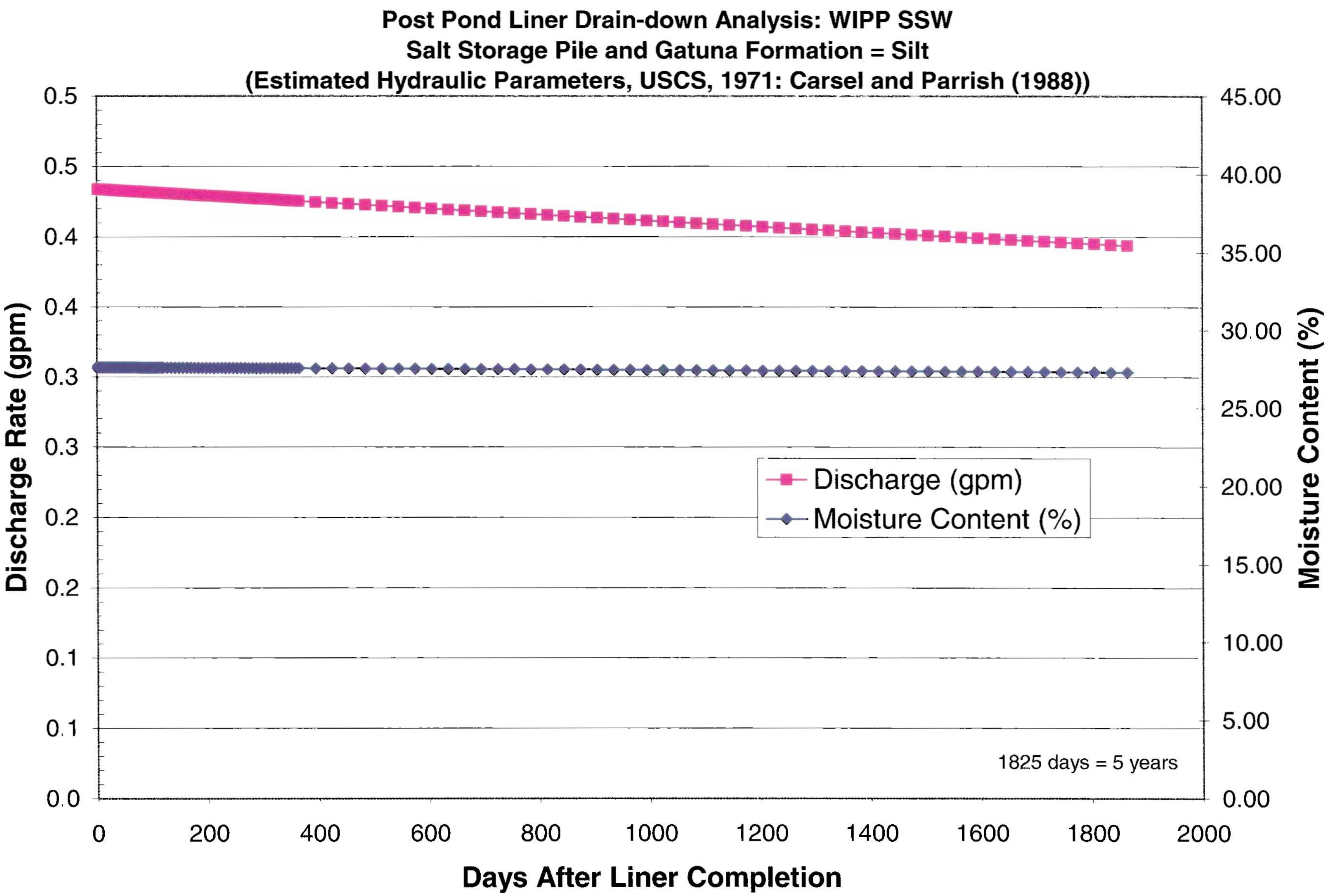
Parameter	*Value*	*Units*	*Notes*
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.46**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.276**	**fraction**	**60% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**337.3**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.034**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**295.7**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**3.4**	**(acre-ft)**	**~ 5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	27 60	27.60	27.60	27.60	27.60	27 60	Daily Time Steps for 5 Years	27.33
	Discharge (gpm)	4.34E-01	4.34E-01	4.34E-01	4.33E-01	4.33E-01	4.33E-01		3.95E-01
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	6.37E-08	6 37E-08	6.37E-08	6.37E-08	6.37E-08	6.37E-08		5.80E-08
Effective Saturation (Stephens, 1995)	Se	0.568075	0.568071	0.568068	0.568064	0.56806	0.568057		0 56163
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.37	1 37	1 37	1.37	1 37	1.37		1 37
Mualem model (Stephens, 1995)	m	0.270073	0.270073	0.270073	0.270073	0.270073	0.270073		0 270073
van Genuchten Parameter Carsel and Parrish, 1988	$alpha_{(v)}$	0 016	0 016	0.016	0 016	0.016	0.016		0 016
Pressure head (Stephens, 1995)	P-head (-cm)	261 7984	261 8036	261.8089	261.8141	261 8193	261.8246		271 1422
Relative hydraulic conductivity	Kr	0.000917	0 000917	0.000917	0.000917	0.000917	0.000917		0 000835
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	6.94E-05	6.94E-05	6.94E-05	6.94E-05	6.94E-05	6.94E-05		6.94E-05
Drainage Volume (acre-ft)		0.00E+00	1.92E-03	1.92E-03	1.92E-03	1.92E-03	1.92E-03		5.24E-02

References:

Carsel, R F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B., 1996 Vadose Zone Hydrology CRC Press



T:\Projects\9184\Sheets\Final Water Balance\Vadose Zone Redistribution Estimate Salt Storage Area 60 DRAFT 7-22-08_working_copy.xls_Drain-down Chart (Silt, CP)

Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Clay Loam (Carsel and Parrish, 1988, Tables, 2, 3, 4, 5)

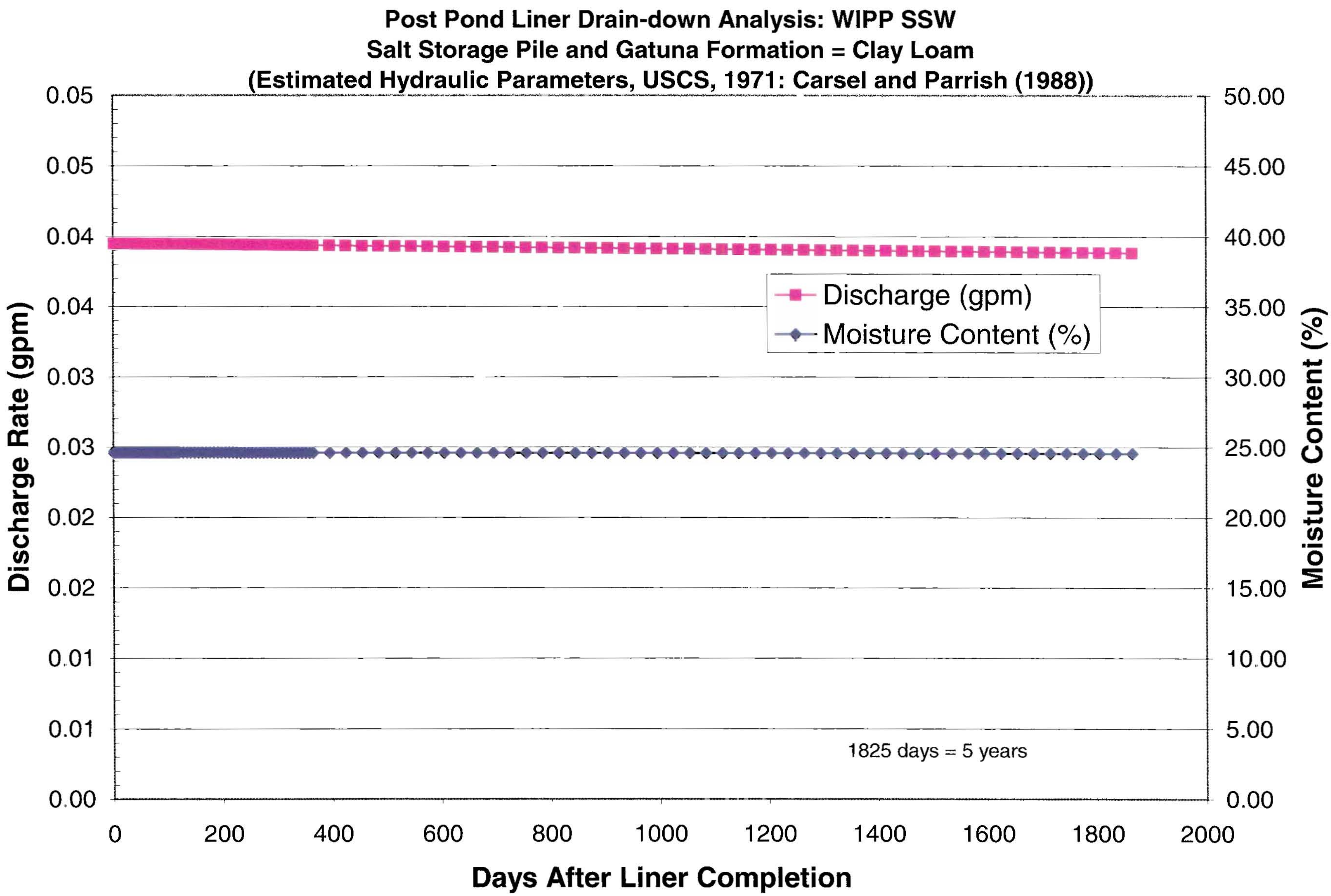
Parameter	*Value*	*Units*	*Notes*
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.41**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.246**	**fraction**	**60% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**300.6**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.095**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**184.5**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**0.3**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	24 60	24 60	24 60	24 60	24 60	24.60		24.57
	Discharge (gpm)	3.95E-02	3.95E-02	3.95E-02	3.95E-02	3 95E-02	3.95E-02		3.89E-02
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	5.80E-09	5.80E-09	5.80E-09	5.80E-09	5.80E-09	5.80E-09		5.71E-09
Effective Saturation (Stephens, 1995)	Se	0.479365	0.479365	0.479364	0.479364	0.479363	0.479363	Daily Time Steps for 5 Years	0.47854
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1 31	1.31	1.31	1 31	1 31	1.31		1.31
Mualem model (Stephens, 1995)	m	0.236641	0.236641	0.236641	0.236641	0.236641	0.236641		0.236641
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.019	0.019	0 019	0.019	0.019	0.019		0.019
Pressure head (Stephens, 1995)	P-head (-cm)	544.7351	544.7369	544.7386	544 7403	544.7421	544 7438		547.9127
Relative hydraulic conductivity	Kr	8.03E-05	8.03E-05	8 03E-05	8.03E-05	8.03E-05	8.03E-05		7.91E-05
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	7.22E-05	7.22E-05	7.22E-05	7.22E-05	7.22E-05	7.22E-05		7.22E-05
Drainage Volume (acre-ft)		0 00E+00	1.74E-04	1.74E-04	1.74E-04	1.74E-04	1.74E-04		5.15E-03

References.

Carsel, R.F. and Parrish, R.S , 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769

Stephens, D.B , 1996. Vadose Zone Hydrology CRC Press.



T:\Projects\9184\Sheets\Final Water Balance\Vadose Zone Redistribution Estimate Salt Storage Area 60 DRAFT 7-22-08_working_copy.xls_Drain-down Chart (CL. CP)

Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Clay (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

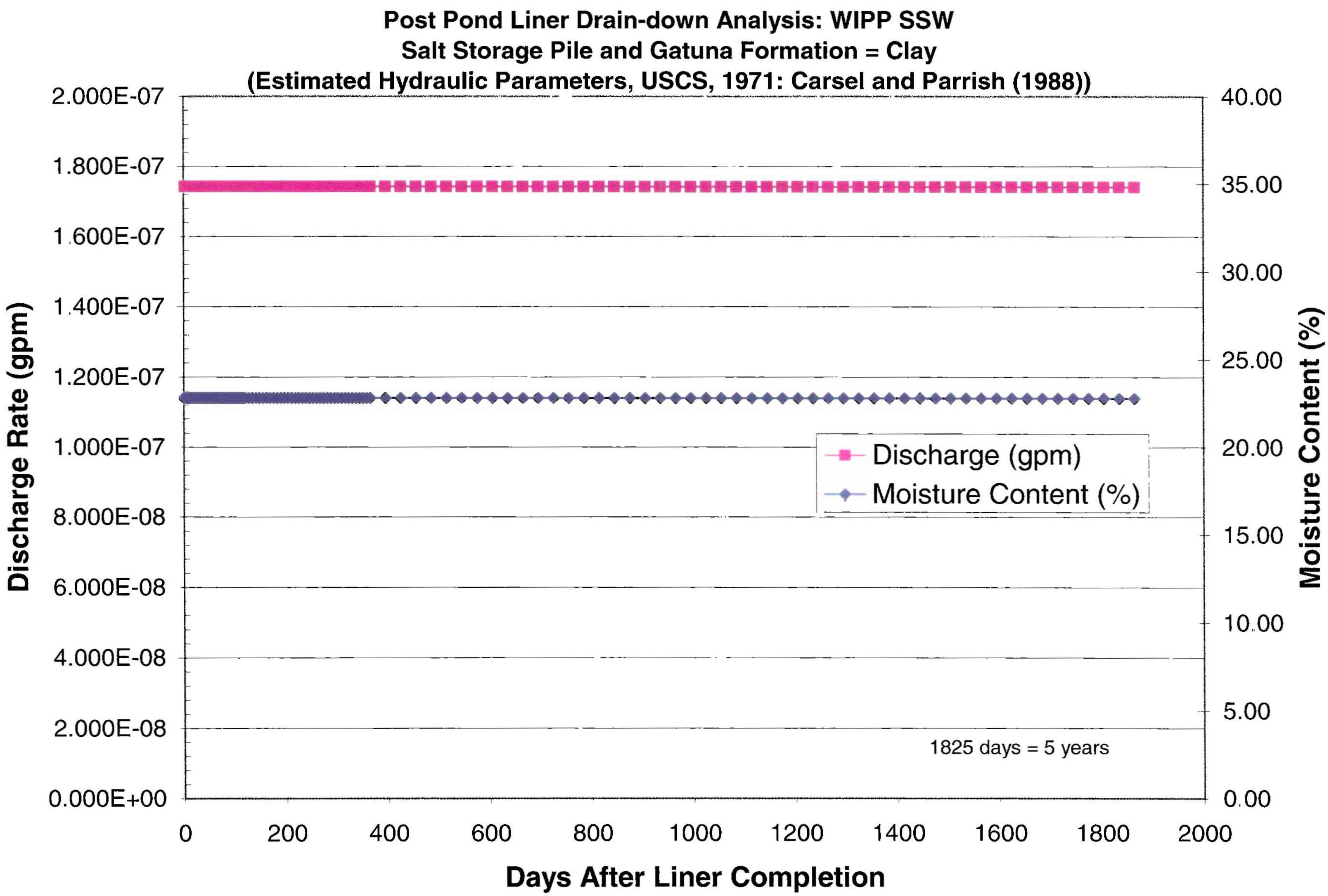
Parameter	*Value*	*Units*	*Notes*
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.38**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.228**	**fraction**	**60% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**278.6**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.068**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**195.5**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**1.44E-06**	**(acre-ft)**	**~ 5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	22.80	22.80	22 80	22.80	22 80	22.80	Daily Time Steps for 5 Years	22.80
Incremental Steady State Assumption*	Discharge (gpm)	1.74E-07	1.74E-07	1.74E-07	1.74E-07	1.74E-07	1.74E-07		1.74E-07
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	2.56E-14	2.56E-14	2.56E-14	2.56E-14	2.56E-14	2.56E-14		2.56E-14
Effective Saturation (Stephens, 1995)	Se	0 512821	0.512821	0.512821	0.512821	0.512821	0.512821		0.512821
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.09	1.09	1.09	1.09	1 09	1 09		1.09
Mualem model (Stephens, 1995)	m	0.082569	0.082569	0.082569	0.082569	0.082569	0.082569		0.082569
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.008	0 008	0 008	0 008	0.008	0.008		0.008
Pressure head (Stephens, 1995)	P-head (-cm)	208638.5	208638 5	208638.5	208638.5	208638 5	208638.5		208638 5
Relative hydraulic conductivity	Kr	4.61E-10	4.61E-10	4.61E-10	4.61E-10	4.61E-10	4.61E-10		4.61E-10
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	5.56E-05	5.56E-05	5.56E-05	5.56E-05	5.56E-05	5.56E-05		5.56E-05
Drainage Volume (acre-ft)		0 00E+00	7.70E-10	7.70E-10	7.70E-10	7.70E-10	7.70E-10		2.31E-08

References.

Carsel, R.F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769

Stephens, D B , 1996. Vadose Zone Hydrology CRC Press



T:\Projects\9184\Sheets\Final Water Balance\Vadose Zone Redistribution Estimate Salt Storage Area 60 DRAFT 7-22-08_working_copy.xls_Drain-down Chart (Clay, CP)

Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Sand (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

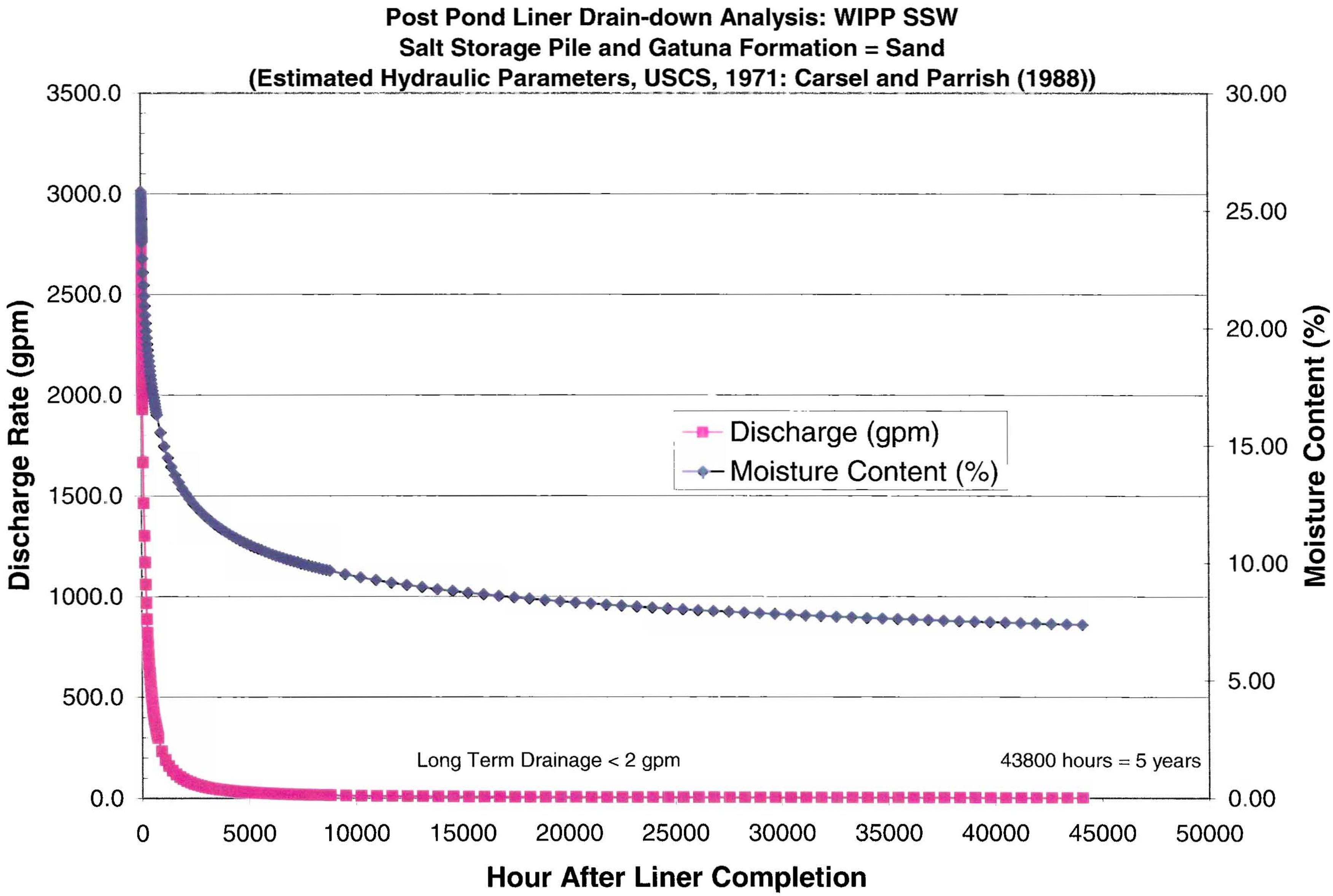
Parameter	*Value*	*Units*	*Notes*
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.43**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.258**	**fraction**	**60% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**315.3**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.045**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**260.3**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**225.3**	**(acre-ft)**	**~ 5 Year Drainage**

Hour after Pond Liner Installation		0	1	2	3	4	5		44076
Incremental Steady State Assumption*	Moisture Content (%)	25.80	25.76	25.71	25.67	25.62	25.58		7.38
	Discharge (gpm)	2 95E+03	2.92E+03	2 90E+03	2.87E+03	2.85E+03	2.83E+03		1.56E+00
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	4 33E-04	4.29E-04	4.26E-04	4.22E-04	4 19E-04	4.16E-04		2.29E-07
Effective Saturation (Stephens, 1995)	Se	0.553247	0.552093	0.550949	0.549815	0 54869	0.547574	Hourly	0.074871
van Genuchten Parameter (Carsel and Parrish, 1988)	N	2 68	2.68	2 68	2 68	2 68	2.68	Time	2 68
Mualem model (Stephens, 1995)	m	0 626866	0.626866	0.626866	0 626866	0.626866	0.626866	Steps for 5	0.626866
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0.145	0 145	0 145	0.145	0 145	0.145	Years	0.145
Pressure head (Stephens, 1995)	P-head (-cm)	8.162707	8.179303	8.195793	8.212179	8.228462	8.244644		32 06772
Relative hydraulic conductivity	Kr	0.052493	0.052055	0.051623	0.051198	0 050778	0.050365		2.77E-05
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	8.25E-03	8.25E-03	8.25E-03	8.25E-03	8.25E-03	8.25E-03		8.25E-03
Drainage Volume (acre-ft)		0.00E+00	5.43E-01	5.38E-01	5.34E-01	5 29E-01	5.25E-01		2.11E-01

References.

Carsel, R.F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v 24, no. 5 p. 755-769.

Stephens, D.B., 1996. Vadose Zone Hydrology. CRC Press.



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Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Sandy Clay Loam (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

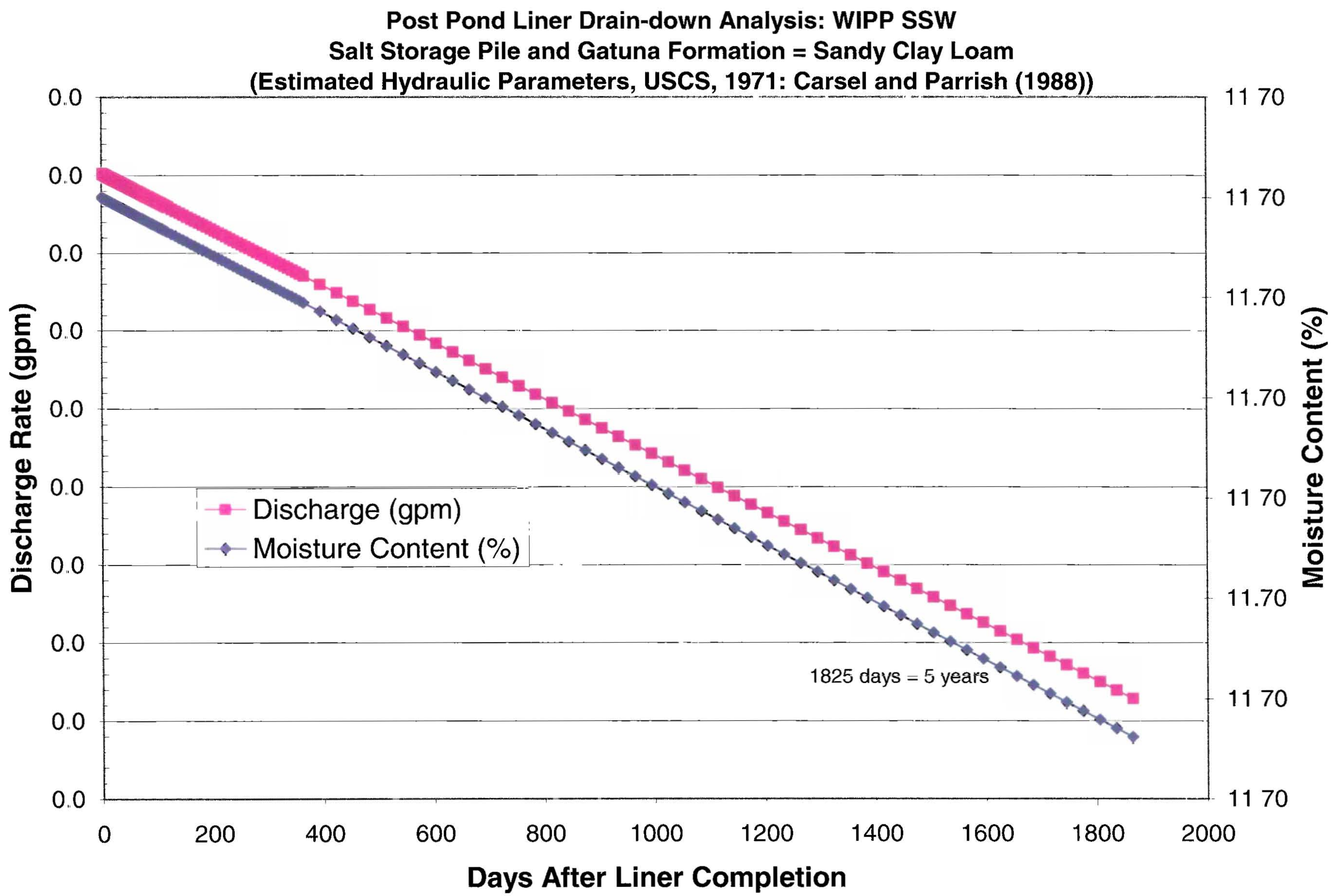
Parameter	*Value*	*Units*	*Notes*
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.39**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.117**	**fraction**	**30% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**143.0**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.1**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**20.8**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**1.31E-05**	**(acre-ft)**	**~ 5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	11 70	11 70	11 70	11 70	11 70	11 70	Daily Time Steps for 5 Years	11.70
	Discharge (gpm)	1.60E-06	1.60E-06	1.60E-06	1.60E-06	1.60E-06	1.60E-06		1.60E-06
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	2.34E-13	2.34E-13	2.34E-13	2.34E-13	2.34E-13	2.34E-13		2.34E-13
Effective Saturation (Stephens, 1995)	Se	0.058621	0.058621	0.058621	0.058621	0.058621	0.058621		0.058621
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.48	1.48	1.48	1.48	1.48	1.48		1.48
Mualem model (Stephens, 1995)	m	0.324324	0.324324	0 324324	0.324324	0.324324	0.324324		0.324324
van Genuchten Parameter. Carsel and Parrish, 1988	$alpha_{(v)}$	0.059	0.059	0.059	0.059	0 059	0.059		0 059
Pressure head (Stephens, 1995)	P-head (-cm)	6246.862	6246.862	6246.862	6246.862	6246.862	6246 862		6246.87
Relative hydraulic conductivity	Kr	6.44E-10	6.44E-10	6.44E-10	6.44E-10	6.44E-10	6.44E-10		6.44E-10
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	3.64E-04	3.64E-04	3 64E-04	3.64E-04	3.64E-04	3.64E-04		3.64E-04
Drainage Volume (acre-ft)		0.00E+00	7.05E-09	7.05E-09	7.05E-09	7.05E-09	7.05E-09		2.12E-07

References.

Carsel, R.F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v 24, no. 5 p. 755-769.

Stephens, D.B , 1996. Vadose Zone Hydrology. CRC Press.



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Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Silt (Carsel and Parrish, 1988, Tables, 2, 3, 4, 5)

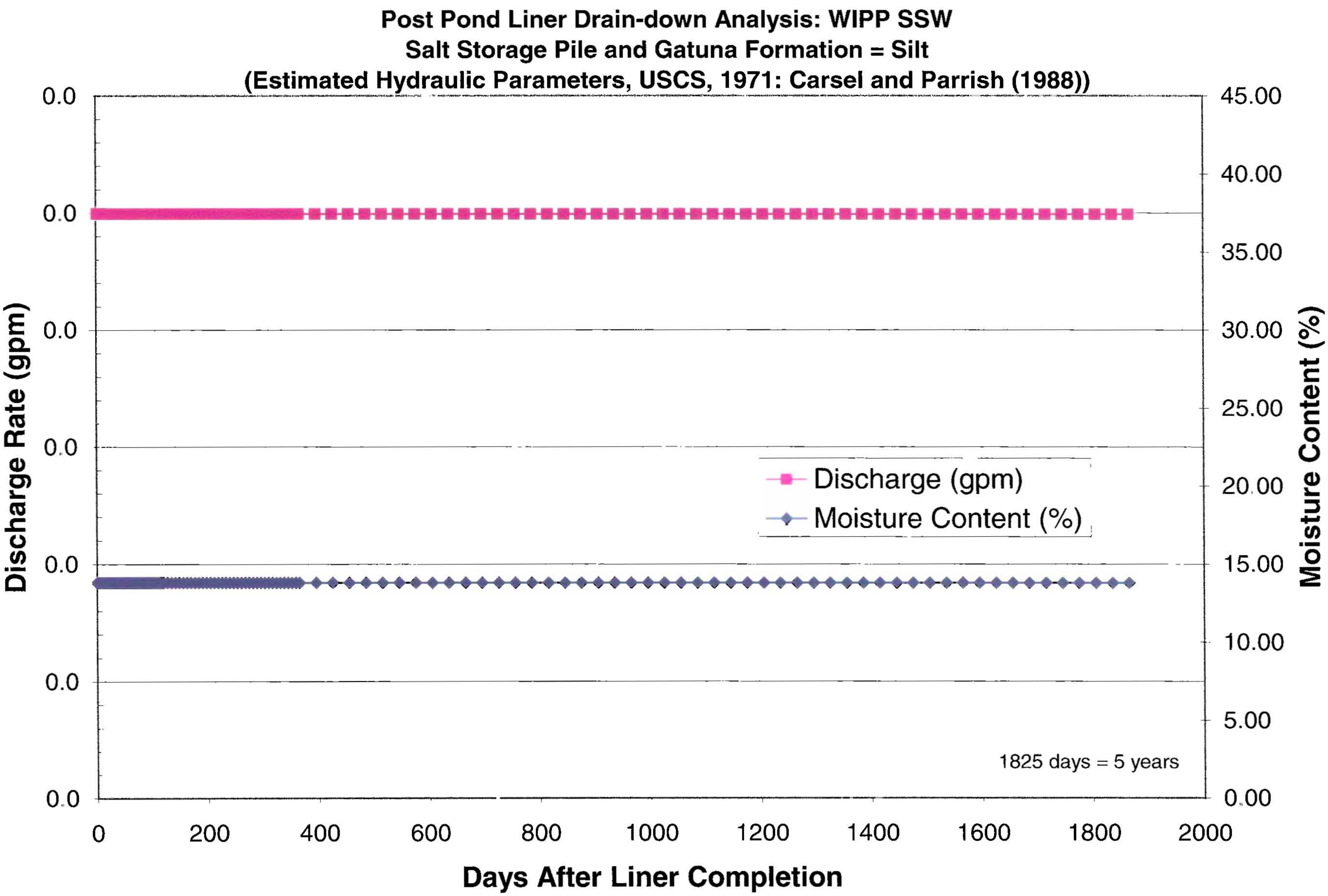
Parameter	Value	Units	Notes
Area	18.8	(acres)	Salt Storage Area
Thickness of Salt Pile	30	(ft)	Salt Storage Area
Thickness of Vadose Zone	35	(ft)	Gatuna Formation
Total Thickness	65	(ft)	Salt Pile and Gatuna Formation
Total Bulk Volume of Saturation	1222	(acre-ft)	Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2
Porosity	0.46	fraction	Carsel and Parrish, 1988
Initial Moisture Content	0.138	fraction	30% of Saturated Moisture Content (Estimated)
Initial Storage Volume	168.6	(acre-ft)	Water Filled porosity
Residual Moisture Content	0.034	fraction	Carsel and Parrish, 1988
Potential Drainage	127.1	(acre-ft)	Initial Storage Volume Minus Residual Moisture Content
Total Drainage	0.0041	(acre-ft)	~ 5 Year Drainage

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	13.80	13.80	13.80	13.80	13.80	13.80	Daily Time Steps for 5 Years	13.80
	Discharge (gpm)	4 99E-04	4 99E-04	4.99E-04	4.99E-04	4.99E-04	4.99E-04		4.99E-04
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	7.33E-11	7.33E-11	7.33E-11	7.33E-11	7.33E-11	7.33E-11		7.33E-11
Effective Saturation (Stephens, 1995)	Se	0.244131	0.244131	0.244131	0.244131	0.244131	0.244131		0.244124
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.37	1.37	1 37	1.37	1 37	1.37		1.37
Mualem model (Stephens, 1995)	m	0.270073	0.270073	0.270073	0.270073	0.270073	0.270073		0.270073
van Genuchten Parameter. Carsel and Parrish, 1988	$alpha_{(v)}$	0.016	0.016	0.016	0 016	0.016	0.016		0 016
Pressure head (Stephens, 1995)	P-head (-cm)	2813.416	2813.416	2813.416	2813.416	2813.416	2813.416		2813.659
Relative hydraulic conductivity	Kr	1.06E-06	1.06E-06	1.06E-06	1.06E-06	1.06E-06	1.06E-06		1.06E-06
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	6.94E-05	6.94E-05	6.94E-05	6.94E-05	6.94E-05	6.94E-05		6.94E-05
Drainage Volume (acre-ft)		0.00E+00	2.21E-06	2.21E-06	2.21E-06	2.21E-06	2.21E-06		6.61E-05

References.

Carsel, R.F and Parrish, R S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769.

Stephens, D.B , 1996. Vadose Zone Hydrology. CRC Press



T:\Projects\9184\Sheets\Final Water Balance\Vadose Zone Redistribution Estimate Salt Storage Area 30 DRAFT 7-22-08_working_copy.xls_Drain-down Chart (Silt, CP)

Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Clay Loam (Carsel and Parrish, 1988, Tables, 2, 3, 4, 5)

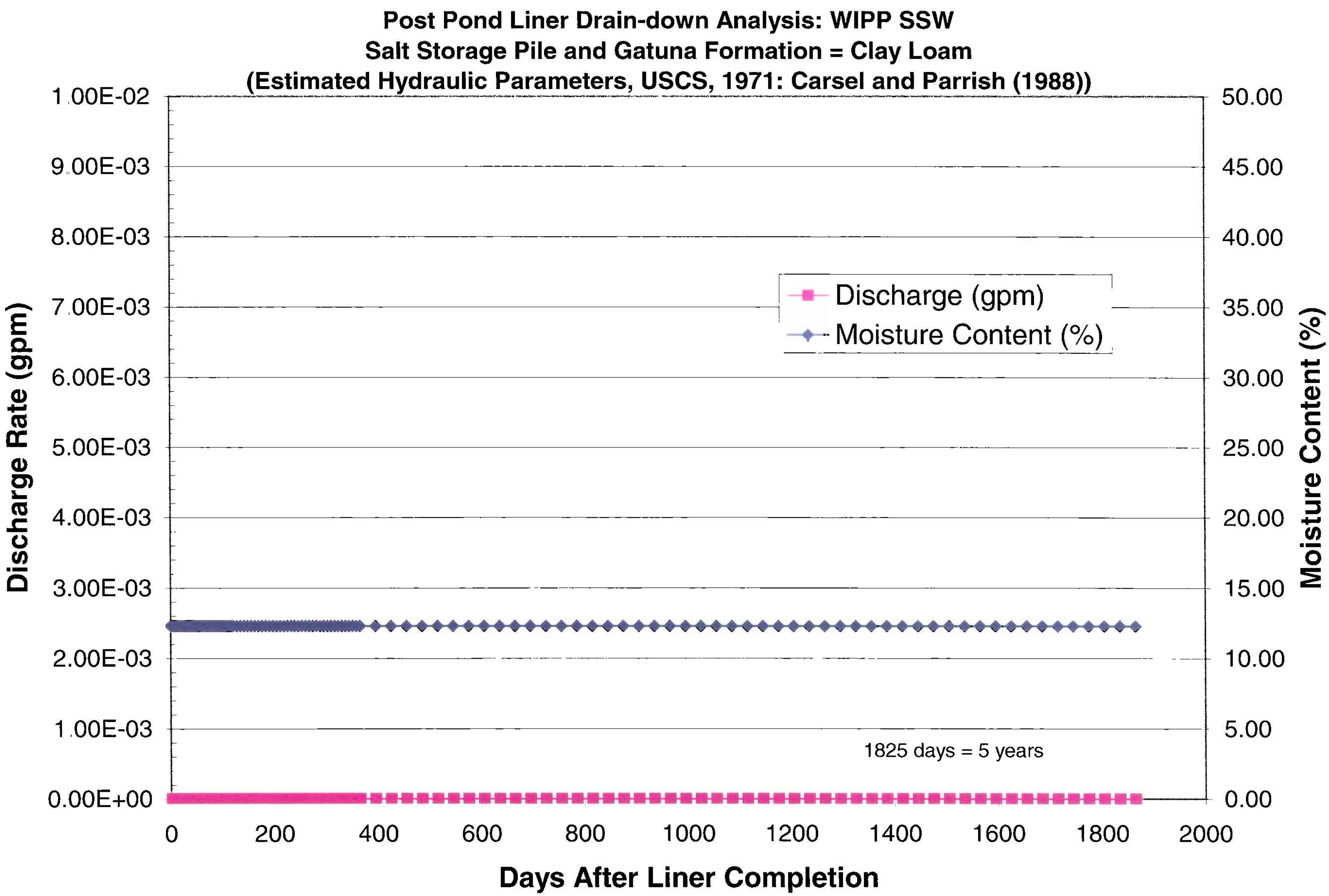
Parameter	*Value*	*Units*	*Notes*
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.41**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.123**	**fraction**	**30% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**150.3**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.095**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**34.2**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**8.84E-08**	**(acre-ft)**	**5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	12.30	12 30	12.30	12.30	12 30	12 30		12.30
	Discharge (gpm)	1.07E-08	1.07E-08	1.07E-08	1.07E-08	1.07E-08	1.07E-08		1.07E-08
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	1.58E-15	1.58E-15	1.58E-15	1.58E-15	1.58E-15	1.58E-15		1.58E-15
Effective Saturation (Stephens, 1995)	Se	0.088889	0.088889	0.088889	0.088889	0.088889	0.088889		0.088889
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.31	1 31	1.31	1.31	1 31	1 31	Daily Time Steps for 5 Years	1.31
Mualem model (Stephens, 1995)	m	0.236641	0.236641	0.236641	0.236641	0.236641	0.236641		0.236641
van Genuchten Parameter, Carsel and Parrish, 1988	$alpha_{(v)}$	0 019	0.019	0.019	0 019	0.019	0.019		0.019
Pressure head (Stephens, 1995)	P-head (-cm)	129434 2	129434.2	129434.2	129434.2	129434.2	129434.2		129434 2
Relative hydraulic conductivity	Kr	2.18E-11	2.18E-11	2.18E-11	2.18E-11	2.18E-11	2.18E-11		2 18E-11
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	7.22E-05	7.22E-05	7.22E-05	7.22E-05	7.22E-05	7.22E-05		7.22E-05
Drainage Volume (acre-ft)		0.00E+00	4.74E-11	4.74E-11	4.74E-11	4.74E-11	4.74E-11		1.42E-09

References:

Carsel, R.F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v 24, no. 5 p. 755-769.

Stephens, D.B., 1996. Vadose Zone Hydrology. CRC Press.



T:\Projects\9184\Sheets\Final Water Balance\Vadose Zone Redistribution Estimate Salt Storage Area 30 DRAFT 7-22-08_working_copy.xls_Drain-down Chart (CL. CP)

Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Clay (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

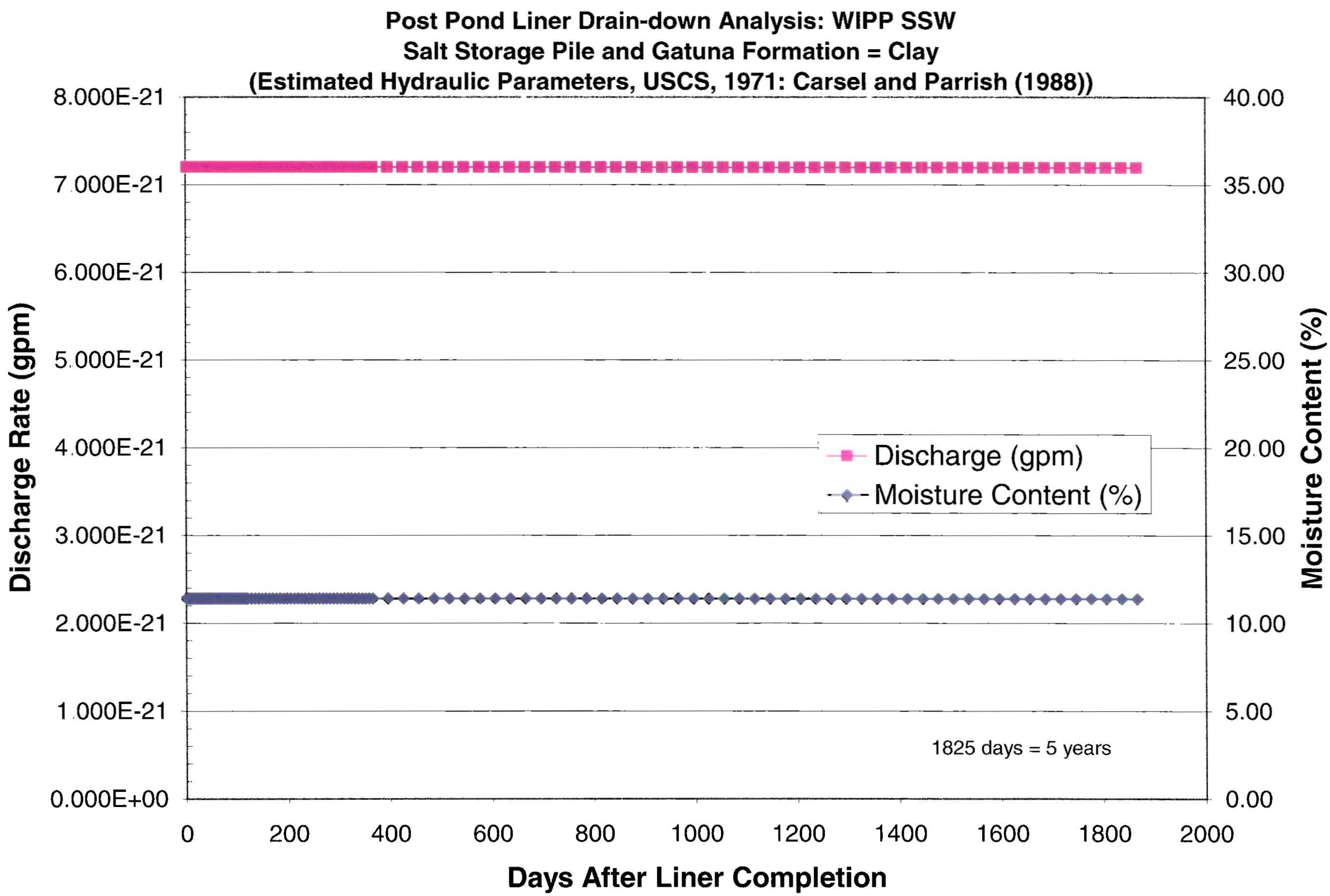
Parameter	*Value*	*Units*	*Notes*
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.38**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.114**	**fraction**	**30% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**139.3**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.068**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**56.2**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**5.93E-20**	**(acre-ft)**	**~ 5 Year Drainage**

Day after Pond Liner Installation		0	1	2	3	4	5		1835
Incremental Steady State Assumption*	Moisture Content (%)	11.40	11.40	11.40	11.40	11.40	11.40	Daily Time Steps for 5 Years	11.40
	Discharge (gpm)	7.20E-21	7.20E-21	7.20E-21	7.20E-21	7.20E-21	7.20E-21		7.20E-21
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	1.06E-27	1.06E-27	1.06E-27	1.06E-27	1.06E-27	1.06E-27		1.06E-27
Effective Saturation (Stephens, 1995)	Se	0 147436	0.147436	0.147436	0.147436	0.147436	0.147436		0 147436
van Genuchten Parameter (Carsel and Parrish, 1988)	N	1.09	1.09	1.09	1.09	1.09	1.09		1.09
Mualem model (Stephens, 1995)	m	0 082569	0.082569	0.082569	0.082569	0 082569	0.082569		0.082569
van Genuchten Parameter Carsel and Parrish, 1988	$alpha_{(v)}$	0.008	0.008	0.008	0.008	0.008	0.008		0 008
Pressure head (Stephens, 1995)	P-head (-cm)	2 16E+11	2.16E+11	2.16E+11	2.16E+11	2.16E+11	2.16E+11		2 16E+11
Relative hydraulic conductivity	Kr	1.9E-23	1 9E-23	1.9E-23	1 9E-23	1 9E-23	1.9E-23		1 9E-23
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	5.56E-05	5.56E-05	5.56E-05	5.56E-05	5.56E-05	5.56E-05		5.56E-05
Drainage Volume (acre-ft)		0 00E+00	3.18E-23	3.18E-23	3 18E-23	3.18E-23	3.18E-23		9.54E-22

References.

Carsel, R.F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Charactenstics. Water Resources Research, v. 24, no. 5 p. 755-769

Stephens, D.B., 1996. Vadose Zone Hydrology. CRC Press



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Post Pond Liner Drain-down Analysis: WIPP SSW

Salt Storage Pile and Gatuna Formation = Sand (Carsel and Parrish, 1988, Tables 2, 3, 4, 5)

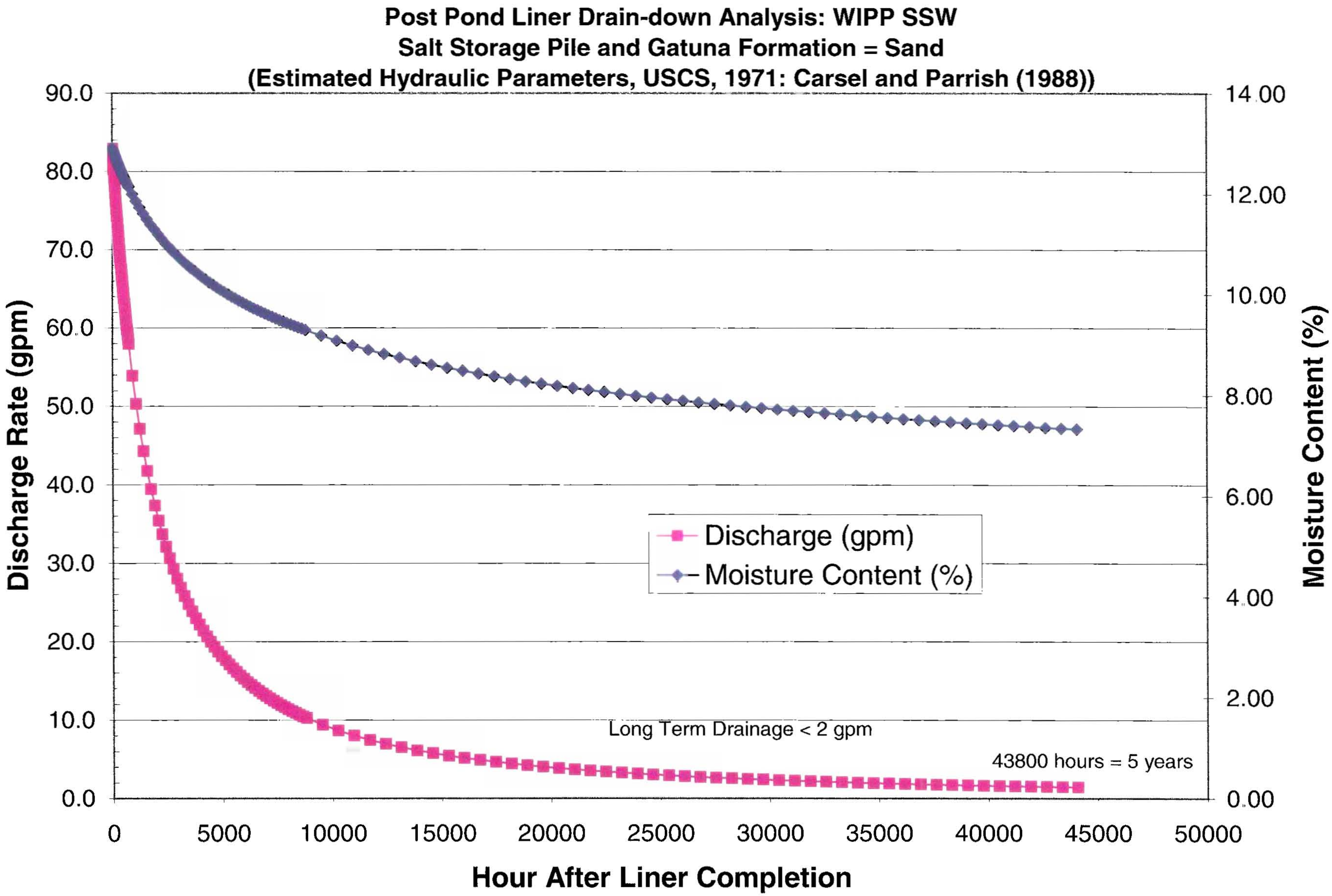
Parameter	*Value*	*Units*	*Notes*
Area	**18.8**	**(acres)**	**Salt Storage Area**
Thickness of Salt Pile	**30**	**(ft)**	**Salt Storage Area**
Thickness of Vadose Zone	**35**	**(ft)**	**Gatuna Formation**
Total Thickness	**65**	**(ft)**	**Salt Pile and Gatuna Formation**
Total Bulk Volume of Saturation	**1222**	**(acre-ft)**	**Salt Evaporation Pond, Detention Basin A, Pond 1, and Pond 2**
Porosity	**0.43**	**fraction**	**Carsel and Parrish, 1988**
Initial Moisture Content	**0.129**	**fraction**	**30% of Saturated Moisture Content (Estimated)**
Initial Storage Volume	**157.6**	**(acre-ft)**	**Water Filled porosity**
Residual Moisture Content	**0.045**	**fraction**	**Carsel and Parrish, 1988**
Potential Drainage	**102.6**	**(acre-ft)**	**Initial Storage Volume Minus Residual Moisture Content**
Total Drainage	**68.2**	**(acre-ft)**	**~ 5 Year Drainage**

Hour after Pond Liner Installation		0	1	2	3	4	5		44076
Incremental Steady State Assumption*{	Moisture Content (%)	12.90	12.90	12.90	12.90	12.90	12.89		7.34
	Discharge (gpm)	8.29E+01	8.28E+01	8.28E+01	8.27E+01	8.27E+01	8.26E+01		1.47E+00
Unsaturated hydralic conductivity (Stephens, 1995)	Kunsat (cm/s)	1.22E-05	1.22E-05	1.22E-05	1.22E-05	1.21E-05	1.21E-05		2.15E-07
Effective Saturation (Stephens, 1995)	Se	0.218182	0.218149	0.218117	0.218085	0.218052	0.21802	Hourly	0.073679
van Genuchten Parameter (Carsel and Parrish, 1988)	N	2.68	2.68	2.68	2.68	2.68	2.68	Time	2.68
Mualem model (Stephens, 1995)	m	0.626866	0.626866	0.626866	0.626866	0.626866	0.626866	Steps for 5	0.626866
van Genuchten Parameter. Carsel and Parrish, 1988	$alpha_{(v)}$	0.145	0.145	0.145	0.145	0.145	0.145	Years	0.145
Pressure head (Stephens, 1995)	P-head (-cm)	16.49063	16.49223	16.49383	16.49542	16.49702	16.49862		32.38045
Relative hydraulic conductivity	Kr	0.001476	0.001475	0.001474	0.001473	0.001473	0.001472		2.61E-05
Saturated Permeability, Carsel and Parrish, 1988	Ksat (cm/s)	8.25E-03	8.25E-03	8.25E-03	8.25E-03	8.25E-03	8.25E-03		8.25E-03
Drainage Volume (acre-ft)		0.00E+00	1.53E-02	1.52E-02	1.52E-02	1.52E-02	1.52E-02		1.99E-01

References.

Carsel, R F. and Parrish, R.S., 1988. Developing Joint Probability Distributions of Soil Water Retention Characteristics. Water Resources Research, v. 24, no. 5 p. 755-769

Stephens, D.B., 1996. Vadose Zone Hydrology. CRC Press.



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