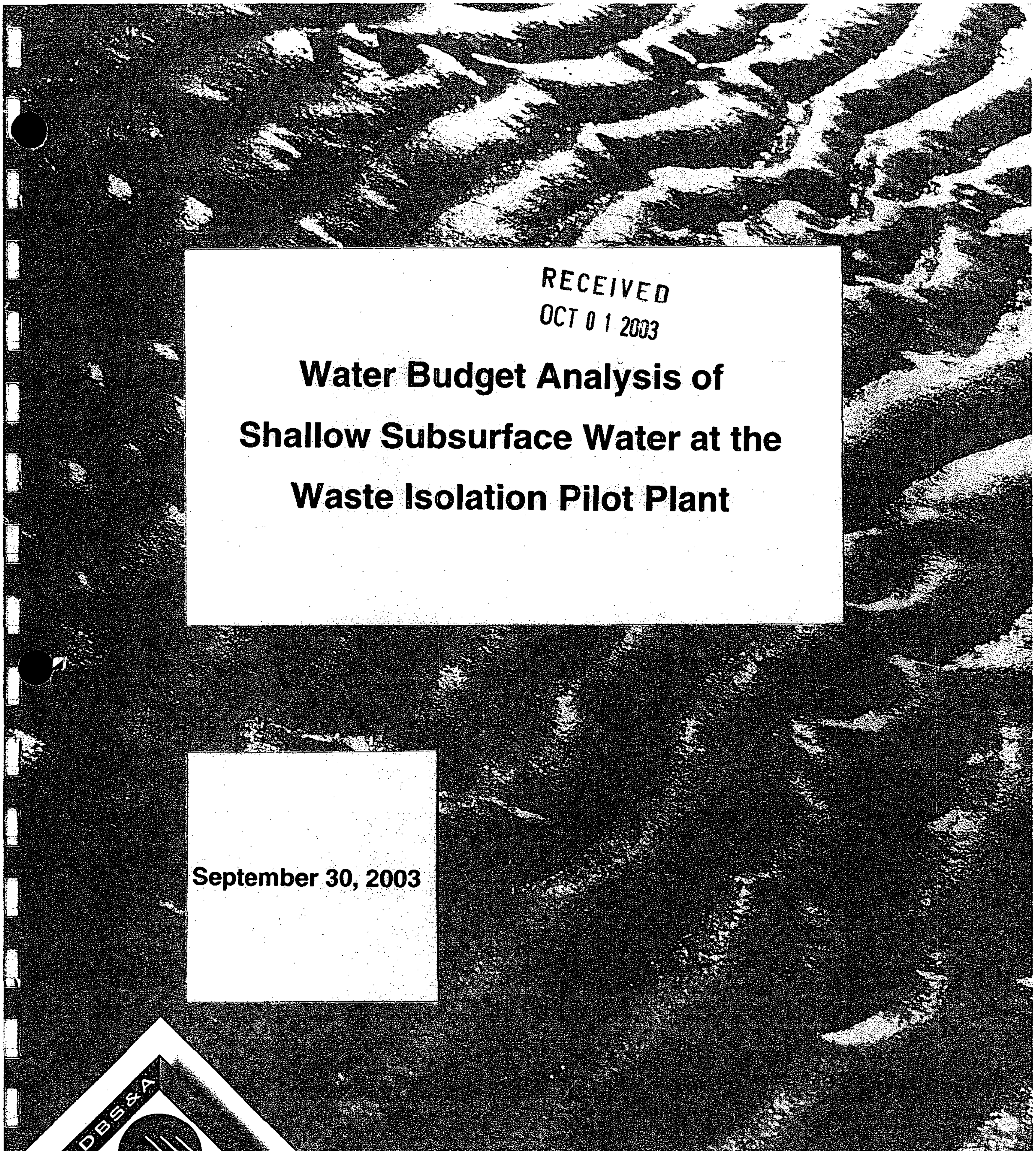
Controlled Recovery, Inc. Exhibits
Case 13586

EXHIBIT NO.	DESCRIPTION
A (1 – 38)	Material Safety Data Sheet Documentation
B	Photographs
C	I. Keith Gordon, P.E. Summary of Qualifications
D	Landfarm Materials
E	Well Recap – Mud Characteristics
F (1 & 2)	NMED Current and Current Solid Waste Management Rules
G	Waste Isolation Pilot Plant Discharge Monitoring Reports
H	Water Budget Analysis of Shallow Subsurface Water at the Waste Isolation Pilot Plant
I	Soil Remediation for Oil and Gas Producers
J	Executive Order 2005-2006/Environmental Justice Executive Order
K	Remediation of Salt-Affected Soils at Oil and Gas Production Facilities
L	IPEC Guidelines
M (1 & 2)	EPA documents regarding exempt waste
N (1 – 7)	Federal Statutes and Regulations regarding landfills



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Water Budget Analysis of Shallow Subsurface Water at the Waste Isolation Pilot Plant

September 30, 2003

DBS&A hydrology

Daniel B. Stephens
& Associates, Inc.

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List of Acronyms and Abbreviations

bgs	below ground surface
cm/s	centimeters per second
CTAC	Portage Environmental – Carlsbad Field Office Technical Assistance Contractor
DBS&A	Daniel B. Stephens & Associates, Inc.
DOE	U.S. Department of Energy
FAA	Federal Aviation Administration
ft^2	square feet
ft/d	feet per day
ft/ft	foot per foot
gpm	gallons per minute
in/yr	inches per year
K_h	horizontal hydraulic conductivity
K_{sat}	saturated hydraulic conductivity
K_v	vertical hydraulic conductivity
LAI	leaf area index
mg/L	milligrams per liter
MODFLOW	modular three-dimensional finite-difference ground-water flow model
NMED	New Mexico Environment Department
NOAA	National Oceanic and Atmospheric Administration
PNNL	Pacific Northwest National Laboratory
SSW	shallow subsurface water
TDS	total dissolved solids
UNSAT-H	computer model for calculating water and heat flow in unsaturated media
USGS	U.S. Geological Survey
WIPP	Waste Isolation Pilot Plant

Executive Summary

The water budget analysis of shallow subsurface water (SSW) underlying the central portion of the Waste Isolation Pilot Plant (WIPP) presents a comprehensive conceptual model of the SSW hydrologic characteristics. The water budget analysis was conducted for the U.S. Department of Energy (DOE) by Daniel B. Stephens & Associates, Inc. under contract to Portage Environmental — Carlsbad Field Office Technical Assistance Contractor. The water budget analysis is intended 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 proposed actions to address the SSW.

The objective of the water budget analysis was to quantify the SSW sources and consider the potential for migration and the effectiveness of planned controls. The water budget analyzed the important hydrologic processes controlling the SSW system and provided:

- 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 focuses on the sources of water introduced to the subsurface as a result of site development at the WIPP. 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 a saturated, perched zone within the Santa Rosa Sandstone Formation (Santa Rosa), with saturation typically found at depths of 40 to 60 feet below ground surface.

The water budget is a quantitative analysis of the primary inputs and losses of on-site water. The analyses include seepage estimates from five principal seepage sources within the WIPP surface facilities area: the Salt Storage Area, Salt Pile Evaporation Pond, Detention Basin A, and storm water retention Ponds 1 and 2. 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 includes 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, and sewage treatment.

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

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

- *Saturated flow modeling:* Saturated flow modeling was conducted to quantify recharge from the storm water retention ponds and Salt Storage Area and 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 timeframe 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 controls planned by DOE to prevent seepage and reduce SSW migration.

The water budget results indicate that seepage from the five primary sources provide sufficient recharge to account for the observed SSW saturated lens and that the lens is expected to spread. The water budget results quantify 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 storm water 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 are reasonably consistent, considering the uncertainties of the models and calculations. To develop a valid conceptual model of the SSW, 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, with the upper Layer 1 including the SSW perched lens in the Santa Rosa and the Gatuña Formations and the lower Layer 2 including the Dewey Lake Formation, which is the shallowest groundwater depth interval used for water supply near the WIPP boundary. The potential migration of SSW is a top-down process, with 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 conceptual model is conservative in simulating 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 water levels for the 1996 to 2002 record. The calibrated model was then run for two predictive simulations until 2102, with seepage in Simulation 1 stopping at facility closure in 2035, and seepage in Simulation 2 stopping in 2006, after the implementation of engineered seepage controls.

The long-term migration model simulations indicate that the engineered seepage controls being planned by DOE will substantially reduce the extent of migration. The simulations predict that without seepage controls, the SSW has the potential to migrate over a 100-year time frame 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. The predictive modeling results show that engineered seepage controls can reduce the SSW volume by more than half, from approximately 860 million gallons to 385 million gallons, and prevent migration from reaching the facility boundary.

1. Introduction

The water budget analysis presented in this report examines the sources and characteristics of the shallow subsurface water (SSW) underlying the central portion of the Waste Isolation Pilot Plant (WIPP) site near Carlsbad, New Mexico. The water budget builds on previous SSW investigations to develop a comprehensive conceptual model of the hydrogeologic conditions and flow regime. The water budget analysis was conducted on behalf of the U.S. Department of Energy (DOE) by Daniel B. Stephens & Associates, Inc. (DBS&A), under contract to Portage Environmental – Carlsbad Field Office Technical Assistance Contractor (CTAC).

1.1 Project Goals

The goal of the water budget analysis was to establish a conceptual model of the important hydrologic processes controlling the SSW hydrologic system. The water budget analysis provides:

- 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 controls that could be implemented at existing seepage sources

The purpose of this water budget analysis 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 proposed actions to address the SSW.

1.2 Water Budget Methodology

The concept of a water budget is to quantify the components of a closed hydrologic system. In principle, a hydrologic system can be described by a water budget that accounts for all inputs to and outputs from the system, with the difference being the change in water storage in the system.

The water budget analysis presented herein provides estimates of the primary water budget components, focusing on the sources of water introduced to the subsurface as a result of site development at the WIPP. 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 in the 1980s. Increases in on-site recharge have contributed to a saturated, perched zone within the Santa Rosa Sandstone Formation, with saturation typically found at depths of 40 to 60 feet below ground surface (bgs). The water budget addresses only the SSW and not the deep regional groundwater systems that occur several hundred feet underground.

The primary water budget components for the SSW system include the following:

- On-site precipitation
- Infiltration below ground surface and recharge to the SSW
- Original water in the subsurface formations and overlying sediments at a moisture content less than saturation
- Downward leakage into the Dewey Lake Redbeds Formation
- Historical water discharges to surface lagoons from sources such as shaft dewatering brine, drilling fluids, showers, and water line flushing
- Leakage from on-site water and sewer lines
- Seepage into the Exhaust Shaft
- Evaporation
- Plant transpiration

The analysis builds on previous SSW site investigation activities that have been completed and considers the local conditions where the SSW has been detected and the potential for migration in the broader hydrogeologic regime. Within the WIPP surface facilities area, the increased recharge from site development was estimated from five principal seepage sources: the Salt Storage Area, Salt Pile Evaporation Pond, Detention Basin A, and storm water retention Ponds 1 and 2. The analyses performed for the water budget include:

- *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, and sewage treatment.

- *Site drainage summary:* Storm water runoff calculations were completed to determine the volume of on-site storm water that drains to four storm water retention ponds that may contribute seepage to the SSW.

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

- *Saturated flow modeling:* Saturated flow modeling was conducted to quantify recharge from the storm water 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 timeframe 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 controls planned by DOE to prevent seepage and reduce SSW migration.

The water budget analyses are described in detail in Sections 3 through 7 of this report.

The water budget is based on available data from historical records and previous site investigations. No new data were collected for the water budget, and as noted in this report, various uncertainties and data limitations were identified. Considering the uncertainties that exist, the water budget used multiple analysis approaches and, where necessary, reasonable assumptions, to develop ranges of expected results to support the development of a valid conceptual model of the SSW.

1.3 History of Shallow Subsurface Water at WIPP

Early exploratory drilling at the site (Sergent, Hauskins & Beckwith, 1979; Mercer, 1983) and geologic mapping of the WIPP Exhaust Shaft in 1984 and 1985 (Powers, 1995) did not detect saturated conditions in the Santa Rosa Sandstone Formation at the WIPP site prior to site development. Seepage into the Exhaust Shaft was first detected in 1995 (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. The water budget analysis examines the occurrence of the SSW and the inputs to the system that have contributed to the perched zone where saturated conditions are observed.

2. Hydrologic Setting

The WIPP site is located in eastern Eddy County, New Mexico, in a remote area approximately 25 miles east of Carlsbad, New Mexico (Figure 1). The entire land withdrawal area for the WIPP site is 16 square miles, and the surface facilities area covers roughly 100 acres. A detailed site plan of the WIPP surface facilities is provided in Figure 2, and an aerial photograph of the WIPP surface facilities area from 2000 is provided in Figure 3.

2.1 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 12.10 inches per year (in/yr), based on records beginning in 1948 for the Carlsbad Federal Aviation Administration (FAA) Airport. Annual evaporation from surface water 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).

Climatic data used in the water budget analyses were obtained from the Carlsbad FAA Airport weather station and an on-site weather station (Table 1). The detailed climatic data required for some analyses are available only for more recent years; therefore, data from various time frames, as noted in Table 1, were used in the water budget analysis.

Table 1. Precipitation Summary Statistics

Station	Start Date	End Date	Duration (years)	Annual Precipitation (inches)		
				Mean	Maximum	Minimum
Carlsbad FAA [a]	Jan-48	Dec-02	55	12.10	25.48	5.53
Carlsbad FAA [a]	Jan-84	Dec-02	19	14.40	25.48	5.82
WIPP station [b]	Jan-86	Dec-02	17	13.24	21.28	6.53
WIPP station [c, d]	Jan-96	Dec-02	7	12.54	23.91	7.72
WIPP station [c]	Jan-97	Dec-02	6	12.74	23.91	7.72

FAA = Federal Aviation Administration WIPP = Waste Isolation Pilot Plant

[a] Excludes years with more than five days missing in any month.

[b] Annual data reported by the National Oceanic and Atmospheric Administration (NOAA).

[c] Detailed electronic files with data in 15-minute intervals were available for 1997 through August 2002. Monthly precipitation totals for September 2002 through December 2002 were not available at the time the water budget analyses were initiated. Averages of the monthly total precipitation for September, October, November, and December were obtained from the WIPP site data from 1996 through 2001 and were substituted for missing data in 2002.

[d] Less detailed daily data were available from the WIPP station for 1996.

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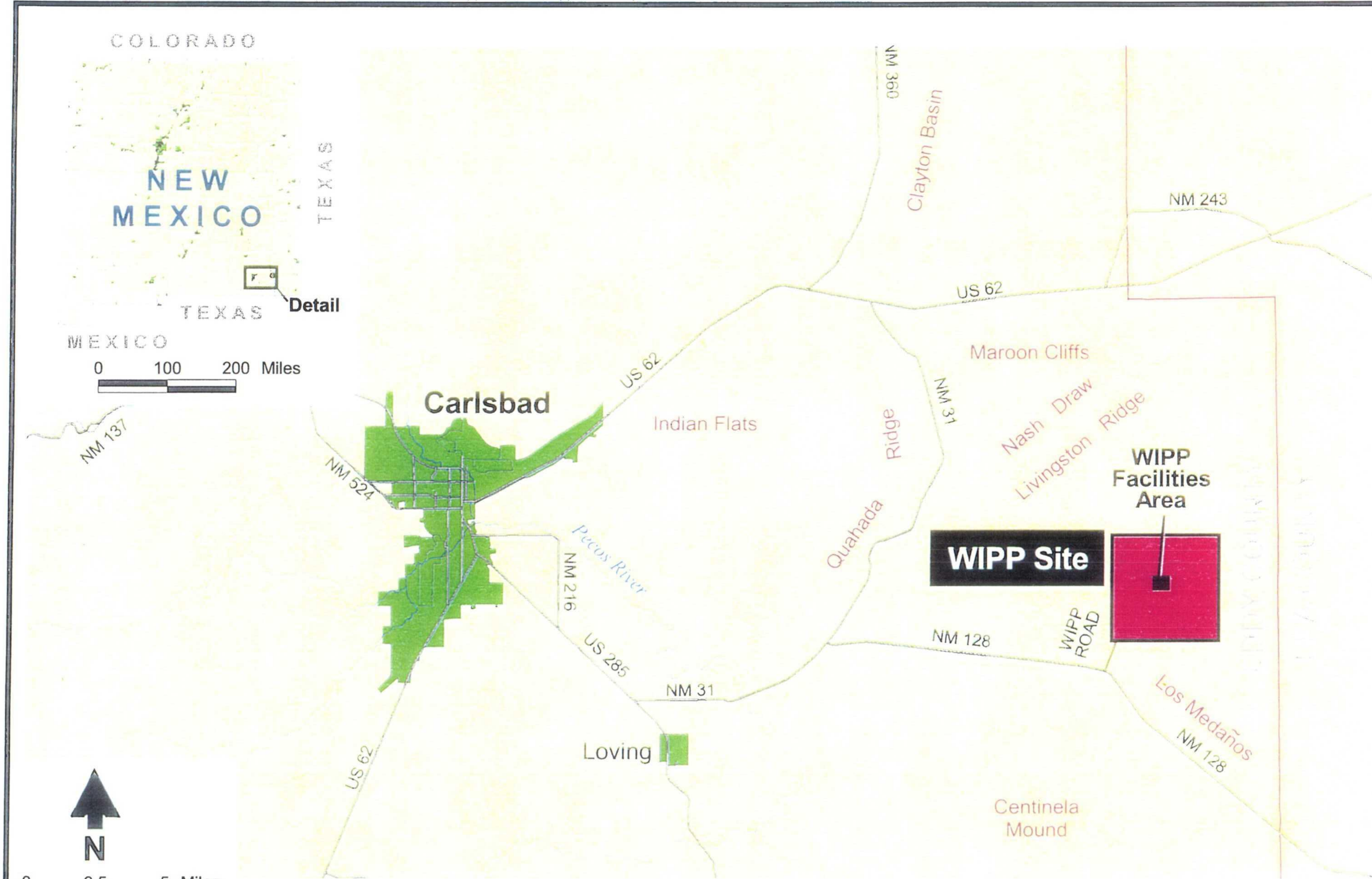

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Site Location

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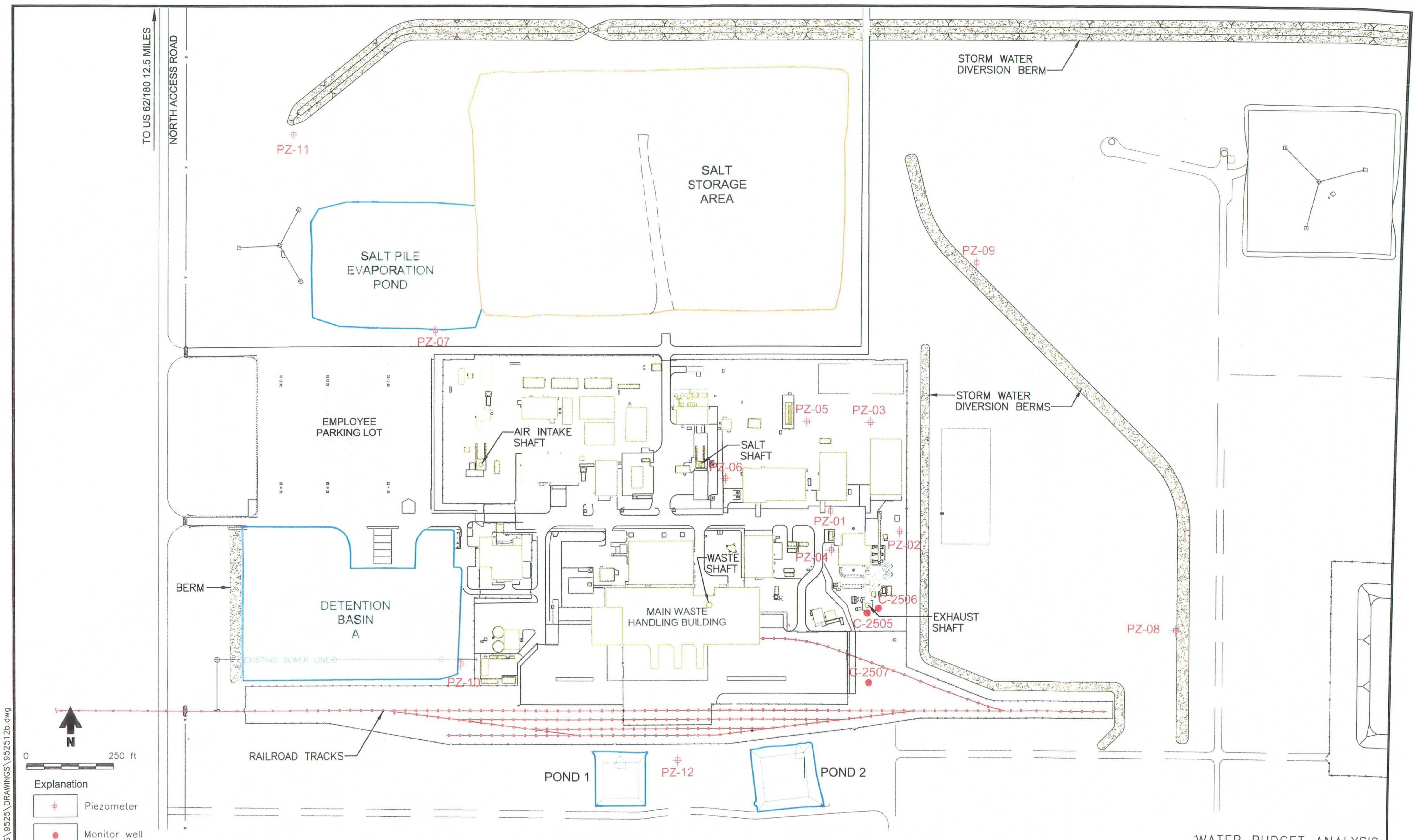
JN 9525

Figure 1



WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Facilities Area and Monitor Well Location Map

Figure 2

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WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Aerial Photograph of WIPP Facilities Area, 2000

Figure 3

The long-term record of precipitation data from the Carlsbad FAA Airport is illustrated in Figure 4. 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. Based on the long-term precipitation records available from the Carlsbad FAA Airport, from the initial development of the WIPP facilities in 1984 through 2002, the average annual precipitation has been 14.40 in/yr, approximately 19 percent above average (Table 1).

The climatic data input to the water budget models include daily records of precipitation, temperature, relative humidity, solar radiation, and wind speed. Detailed electronic files of climatic data from the on-site weather station at the WIPP, which provide the most reliable data set for the model, were available for the period from January 1997 to August 2002. The average annual precipitation for the seven-year period when SSW water level measurements were recorded (1996 through 2002) is 12.54 in/yr (Table 1). Precipitation was particularly high in 1997 (23.91 inches).

2.2 Surface Water and Drainage

The immediate area around the WIPP slopes gradually from the northeast to the southwest at approximately 1 percent. Surficial deposits, consisting of fine- to medium-grained dune sands known locally as the Mescalero sand, cover nearly the entire WIPP site (Mercer, 1983). No significant through-flowing streams or arroyos are present at the site (Mercer, 1983). On the north and east sides of the WIPP surface facilities (Figure 2), berms have been constructed to divert overland storm water flow and prevent runoff from reaching the site. Within the WIPP surface facilities area, surface water from on-site precipitation is routed to four storm water retention ponds, as described in Section 5.

2.3 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 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 Formation
54 to 546 feet bgs	Dewey Lake Formation
546 to 851 feet bgs	Rustler Formation
851 to 2,150(+) feet bgs	Salado Formation

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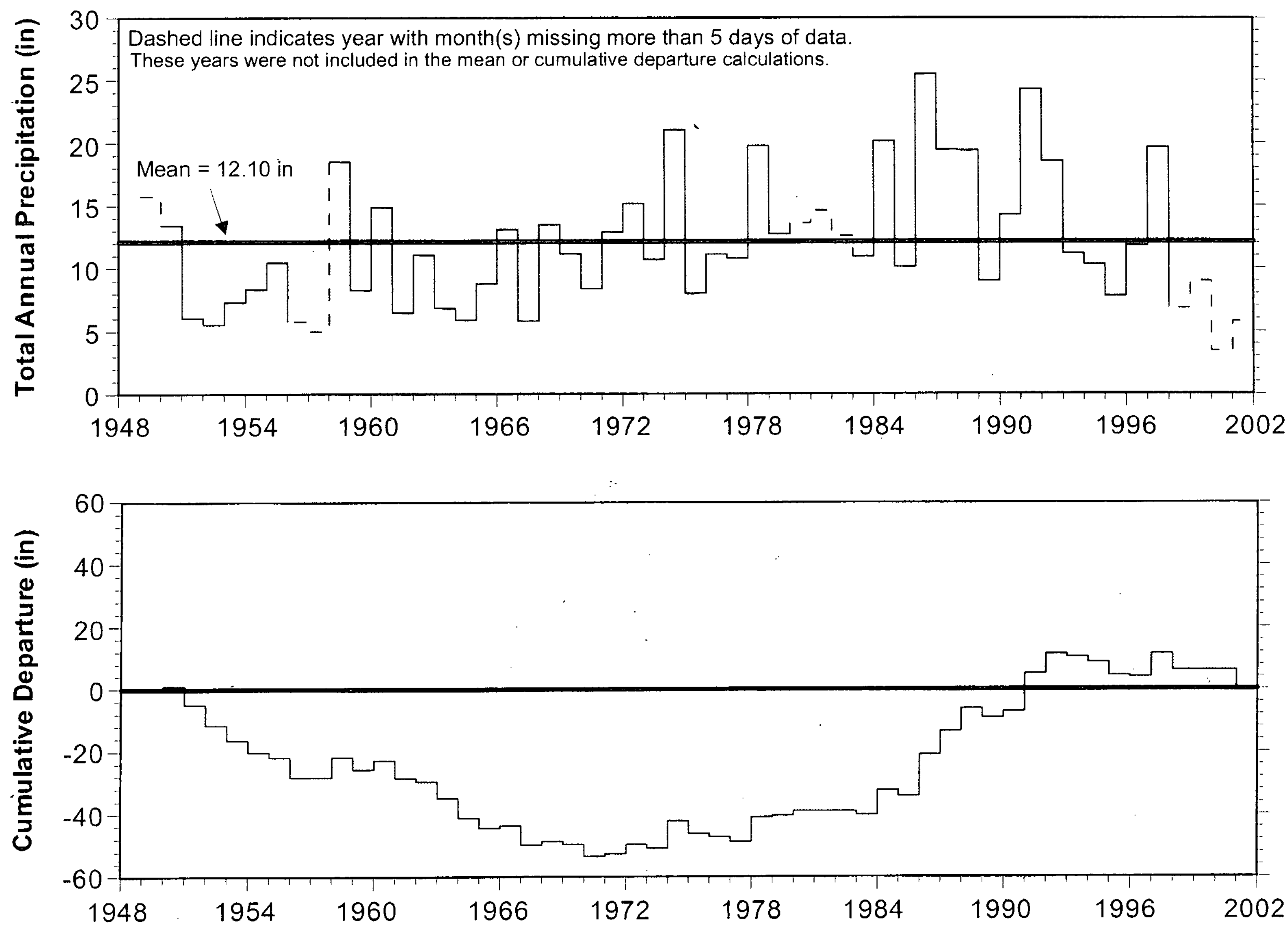


WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER

Total Annual Precipitation and Cumulative Departure from Mean
Carlsbad FAA Airport, Carlsbad, NM

Daniel B. Stephens & Associates, Inc.

Figure 4

The water budget focuses on the occurrence of SSW in the formations closer to the surface. This section describes the geologic units in these shallower formations, beginning with the Dewey Lake and the overlying geologic units.

The *Dewey Lake Redbeds Formation* (hereafter referred to as *Dewey Lake),* which consists of alternating thin beds of siltstone and fine-grained sandstone, is the deepest formation examined in the water budget. This formation is absent in some areas due to erosion before Triassic time, but is as much as 560 feet thick 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 for the water budget 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 unsaturated conditions and low permeabilities.

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 Formation 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 Formation generally does not yield a water supply to wells; however, in a localized area at the James Ranch (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).

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 can be 200 to 300 feet thick (Hendrickson and Jones, 1952), but due to erosion, it is absent to the west of the WIPP site (Mercer, 1983). 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 sandstone is the focus of the water budget. Earlier hydrogeologic investigations show that the Santa Rosa was generally not water-bearing at the WIPP site; however, further east, in southwestern Lea County, the Santa Rosa serves as a principal aquifer (Nicholson and Clebsch, 1961). 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).

Water in the Santa Rosa is perched on the relatively impermeable underlying Dewey Lake redbeds. Small amounts of water may discharge downward into the Dewey Lake through fractures and along bedding planes. However, Nicholson and Clebsch (1961) indicate that downward flow into the Dewey Lake is evident only in areas where collapse features have created significant fracturing, which is not the case at the WIPP site.

The *Gatuña Formation* (hereafter referred to as *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 Formation is water-bearing in some areas, with saturation occurring in discontinuous perched zones. However, because of its erratic distribution, the Gatuña Formation 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.

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 Formation (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).

2.3.1 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.

2.3.2 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 the SSW water budget. However, site development at the WIPP has altered the recharge conditions by focusing storm water in retention ponds and removing vegetation over large areas, thereby increasing recharge in comparison to natural conditions.

2.4 Previous On-Site Hydrogeologic and Soils Investigations

While many hydrogeologic investigations have been conducted at the WIPP site, this section describes only the more recent 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). The locations of monitor wells installed to investigate the SSW and shaft seepage are shown in Figure 2, and copies of well logs (Intera, 1996, 1997a) are provided in Appendix A. The investigations and ongoing monitoring of these wells provide the basis for our current understanding of the SSW conditions.

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

- 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.*)

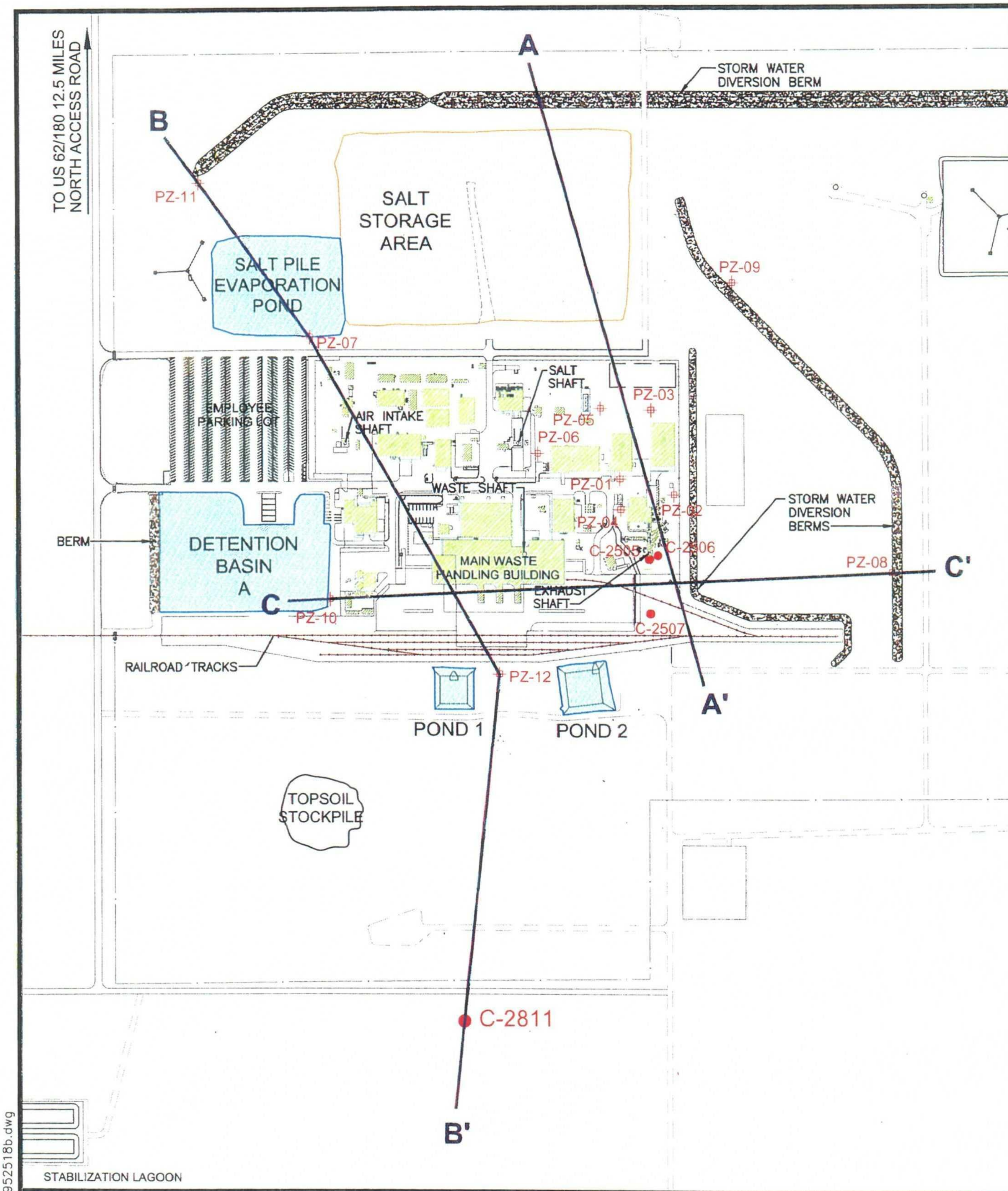
During the investigation, a saturated zone ranging from 12 to 32 feet thick was encountered in the Santa Rosa in wells completed at depths ranging from 54 to 75 feet bgs. The well screens are predominantly in the saturated interval in the lower portion of the Santa Rosa, and the wells typically penetrate approximately 5 to 10 feet into the Dewey Lake. The Dewey Lake Formation 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 easternmost piezometer, PZ-08, which is located approximately 0.25 mile east of the facilities area, did not intersect SSW, suggesting a limit on the saturated zone in this area; however, the full extent of the SSW was not determined.

Water quality analysis of samples from the monitor wells and piezometers indicated total dissolved solids (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 sandstone of 2.42×10^{-6} to 5.48×10^{-3} centimeters per second (cm/s) (Intera, 1996, 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.

Continued water quality monitoring and water level measurements have been carried out by WIPP personnel from 1997 to present. The monitoring data used in the water budget include monthly water level and TDS measurements from the 12 PZ-series piezometers and the 3 C-series monitor wells.

Water recently 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 5), 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



N

0 500 ft

Explanation

+	Piezometer
●	Monitor well

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WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER

Monitor Well C-2811 and Cross Section Location Map

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Figure 5

drilling of earlier wells nearby. The thin zone of Santa Rosa, encountered from 35 to 45 feet bgs at the 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 the SSW wells, but follows the trend of decreasing TDS concentration toward the south.

Figures 6 to 8 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 7) 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 saturated zone at C-2811 is also 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 (Section 2.4.3).

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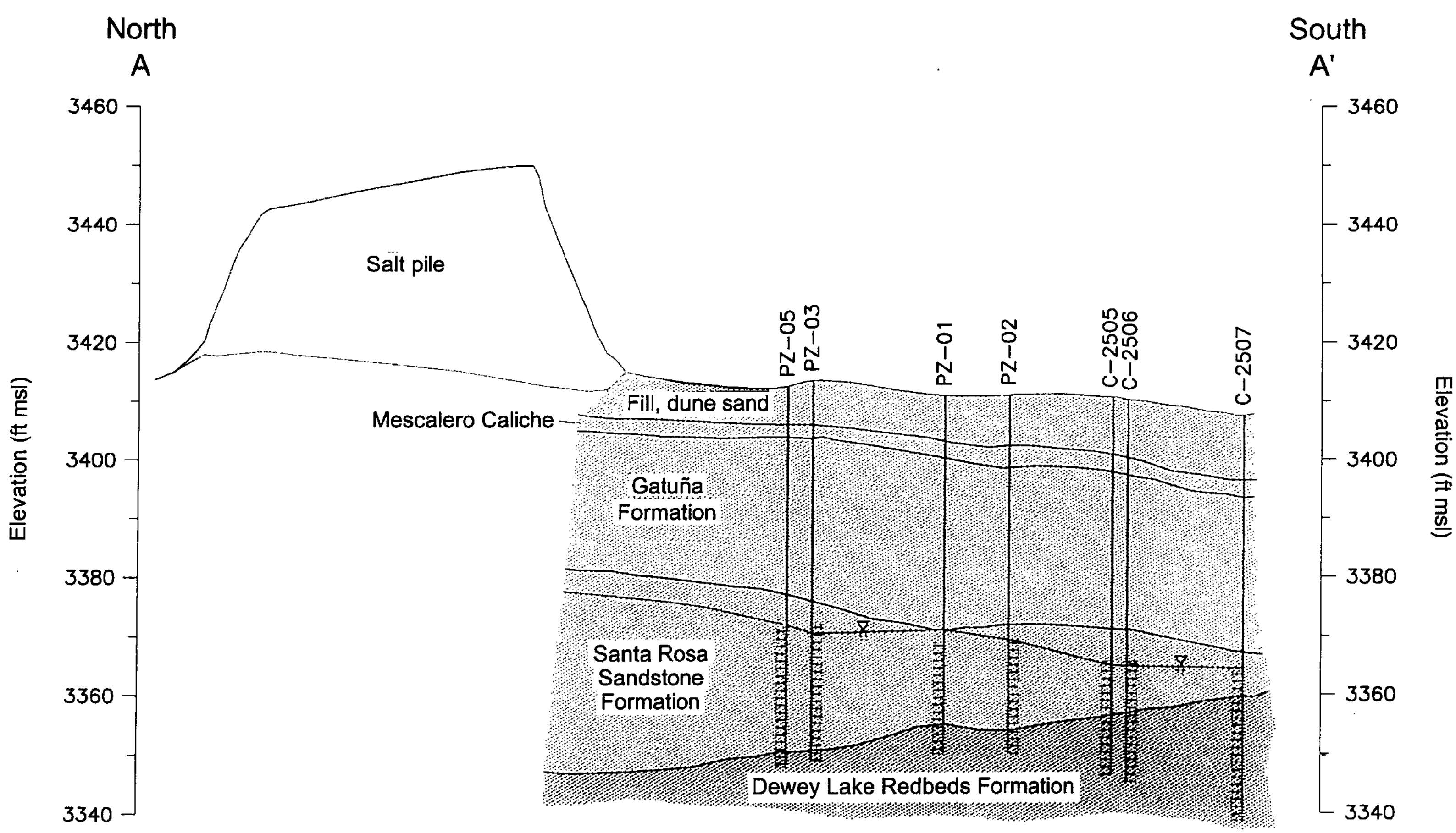

Vertical exaggeration = 10x

0 300 ft

Explanation

Water level (phreatic) surface measured November 6, 2002

Note: Monitor well and water level elevations are projected to the cross section line in Figure 5.

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Cross Section A-A'

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Figure 6

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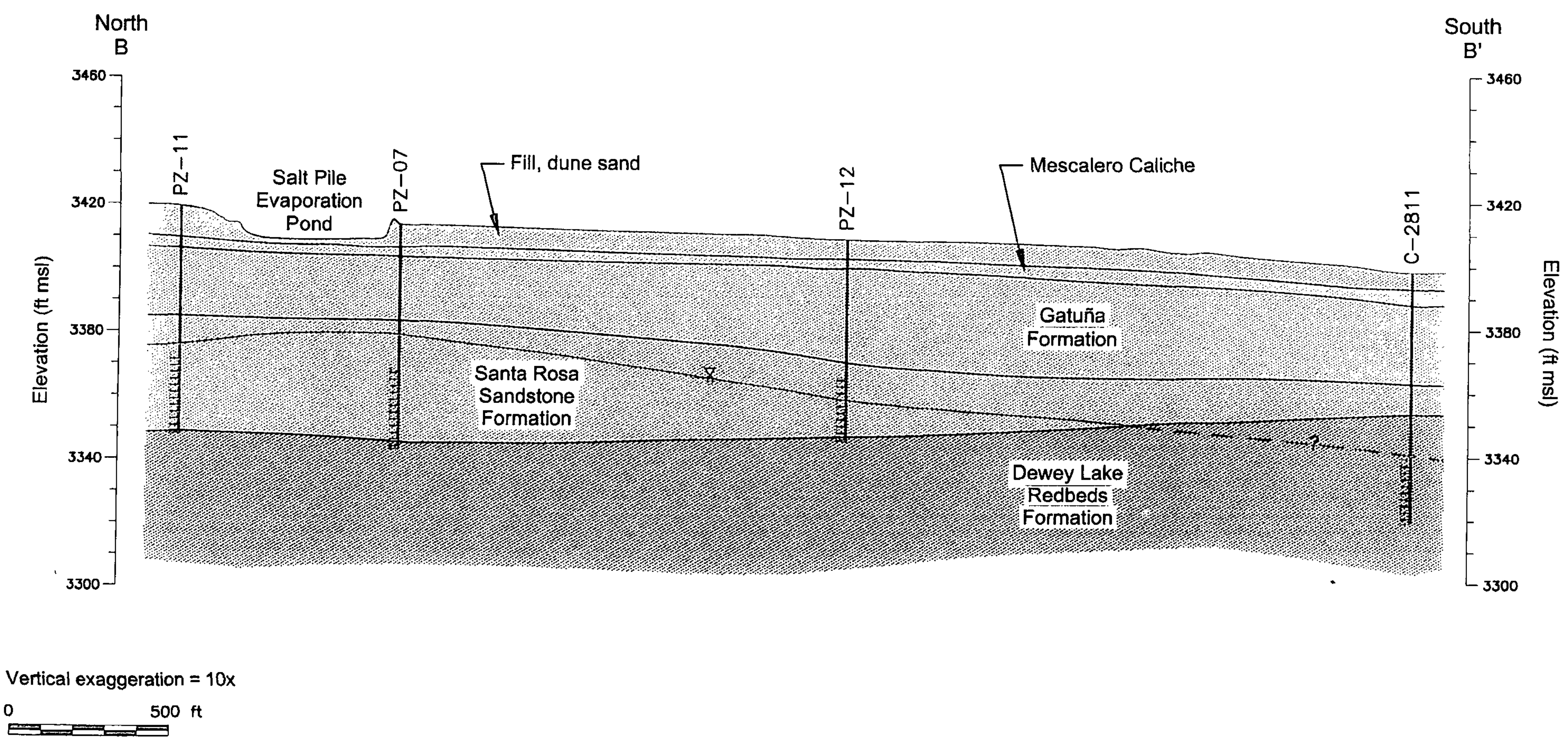

Note: Monitor well and water level elevations are projected to the cross section line in Figure 5.

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Cross Section B-B'

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Figure 7

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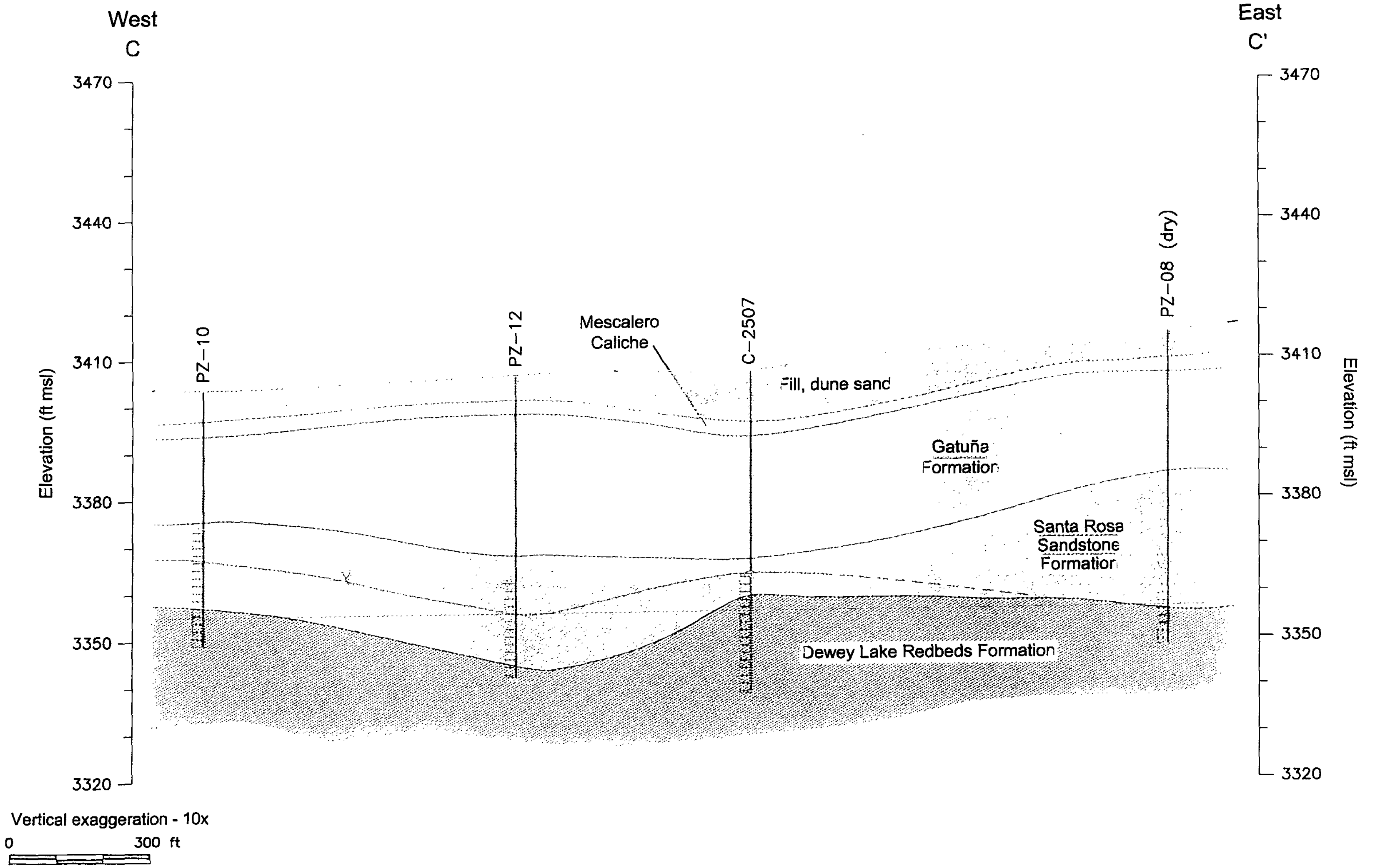

Note: Monitor well and water level elevations are projected to the cross section line in Figure 5.

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Cross Section C-C'

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Figure 8

3. Characteristics of Shallow Subsurface Water

To estimate the quantity and source of recharge to the SSW, it was first necessary to determine the amount and characteristics of the water in the SSW lens. This section describes the initial assessment of water quantity and quality in the saturated lens, which provides the basis for the water budget analyses that follow.

3.1 Estimated Volume

The volume of SSW was estimated from the Santa Rosa saturated thickness measured in the on-site monitor wells (Figure 9). Water columns in the SSW monitor wells range from 4 to 34 feet thick in the Santa Rosa. The saturated thickness has been relatively constant since 1998.

The volume of SSW was calculated by estimating the area, average saturated thickness, porosity, and initial moisture conditions of the Santa Rosa Sandstone.

- The areal extent of the SSW (Figure 10) was estimated to be approximately 150 acres considering (1) the saturated thickness in the monitor wells, (2) the predominant direction of flow, and (3) the slope of the Santa Rosa/Dewey Lake contact.

- For the purpose of calculating the saturated volume, it was assumed that the Dewey Lake Redbeds Formation effectively represents an impermeable boundary beneath the Santa Rosa, giving an average saturated thickness of 16.6 feet, based on measurements made during October 1998 and October 2001.

- The only test data on the porosity of the Santa Rosa sandstone in the vicinity of the WIPP site are from a pumping test of a supply well in the Santa Rosa (Nicholson and Clebsch, 1961), which indicated an average 13 percent porosity. No test data on the Santa Rosa initial moisture content at the WIPP are available. Assuming this average 13 percent porosity and a residual moisture content of 3 percent, saturation in the SSW zone would be achieved when the remaining porosity of 10 percent is filled by additional water.

Thus, the calculated average volume of water needed to saturate the observed SSW is 83 million gallons. This amount represents only the addition of water to the SSW; adding the initial moisture content in the Santa Rosa Formation gives a total estimated SSW volume of 108 million gallons. This SSW volume estimate is based on information from on-site monitor wells and includes limited extrapolation beyond the perimeter of the monitor well network. A second estimate of the SSW volume based on MODFLOW saturated flow modeling is presented in Section 6.2.3.3.

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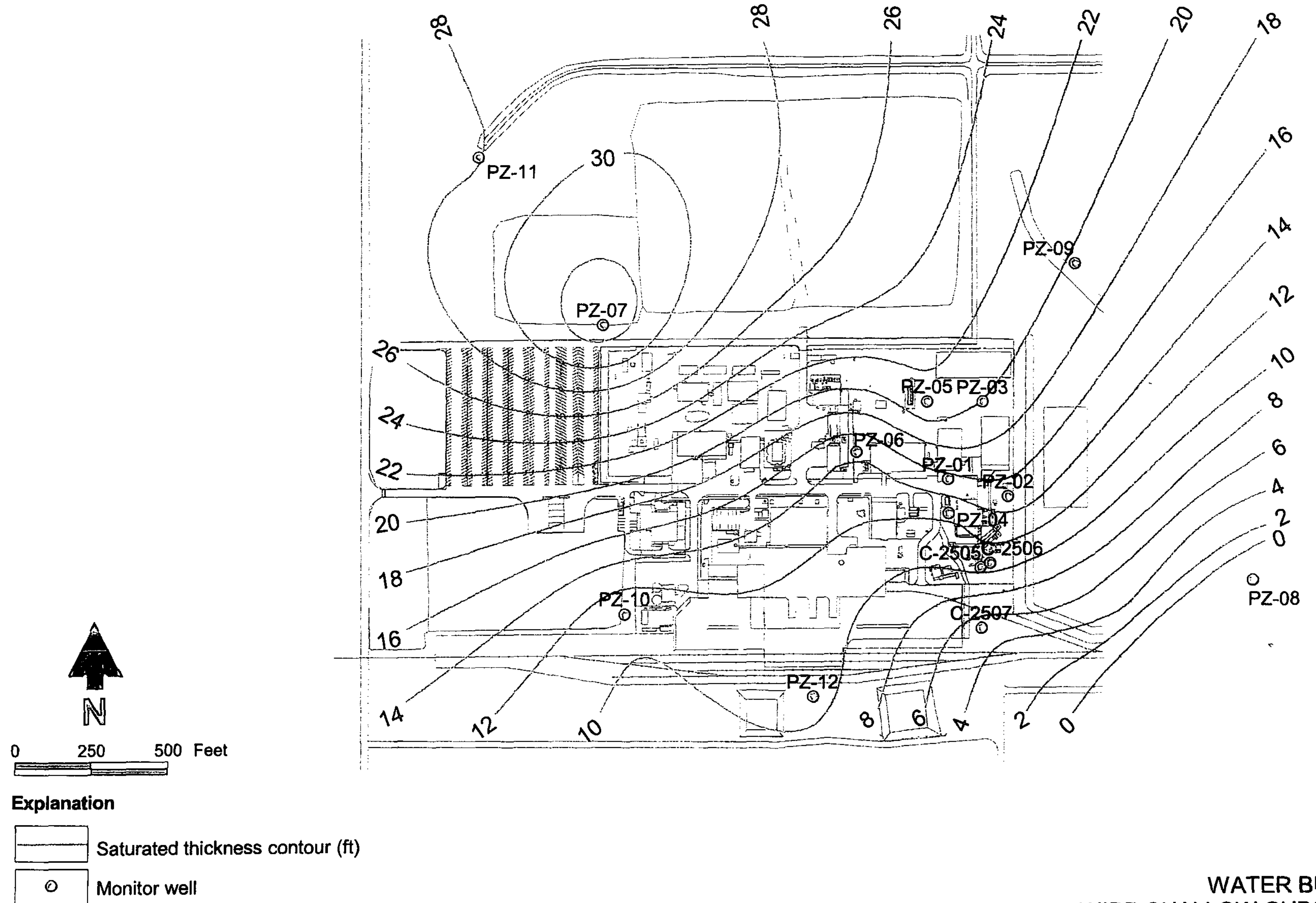

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Saturated Thickness in the Santa Rosa
November 6, 2002

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Figure 9

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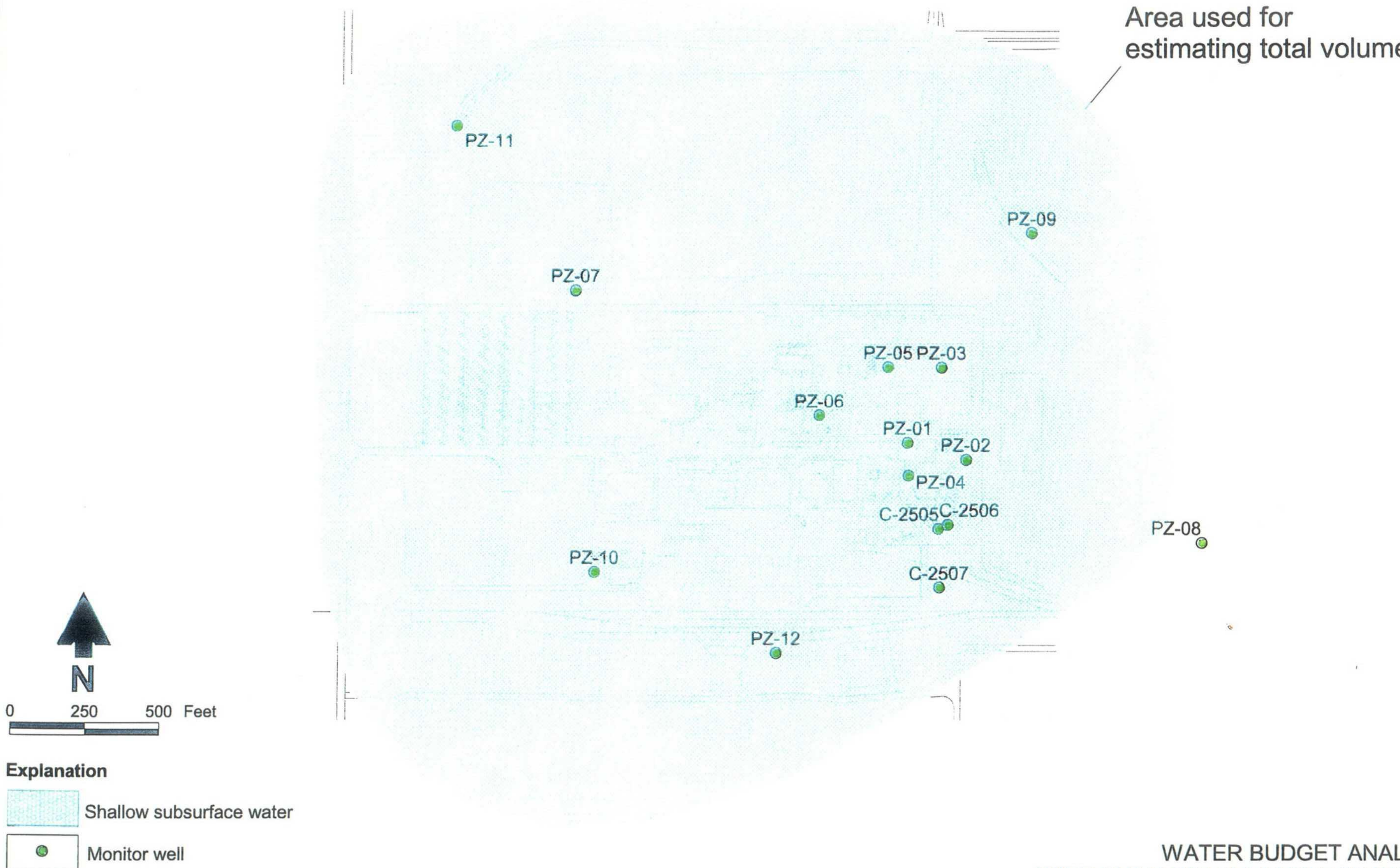

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Estimated Areal Extent of Shallow Subsurface Water

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Figure 10

3.2 Water Level Correction

Because of contrasting TDS values observed in the SSW, the measured water levels were corrected to account for water density differences. In cases where TDS concentrations were not measured during the same timeframe that water levels were measured, the first TDS concentration measured after the water level measurement was used in the correction.

3.3 Direction and Rate of Flow

A potentiometric surface contour map from October 2001 is presented in Figure 11. The contours are hand-drawn based on SSW monitor well water level measurements that have been corrected for density differences. In the northern portion of the site, limited well locations required interpretation to establish reasonable contours that consider the likely sources of significant recharge. In addition, monitor well PZ-04 was omitted from the potentiometric surface contours because measured water levels at this well have been anomalously low in relation to surrounding wells after dropping dramatically, by over 4 feet, during a one-week monitoring interval in 1997 (U.S. DOE, 2000). Omitting PZ-04 affects the water level contouring in only a localized area near the well.

The available water level data indicate that a water table mound exists near the Salt Pile Evaporation Pond and Salt Storage Area. The general SSW flow pattern suggests radial flow outward from the high point at PZ-07, with a predominantly eastward flow in the northern portion of the site and a predominantly southward flow in the southern portion. In the WIPP administrative 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 of the water table mound.

The hydraulic gradient is variable, depending on the flow direction. Using the October 2001 contours (Figure 11) as a representative example, the typical hydraulic gradient beneath the WIPP administrative area is approximately 0.016 ft/ft toward the south. A typical SSW seepage velocity can then be calculated using an effective porosity of 10 percent and the geometric mean hydraulic conductivity (Intera, 1997a) of 1.5 feet per day (ft/d) for wells PZ-06, PZ-07, PZ-10, and PZ-12 (located in the central portion of the site where a relatively uniform southerly gradient is observed). The resulting seepage velocity is 0.24 ft/d, which represents a typical SSW flow velocity for current conditions.

3.4 Water Level Fluctuations

Water levels were observed to rise significantly in the SSW monitor wells during the first years of record, from 1996 to 1998. Since 1998, the water levels have remained fairly constant. A

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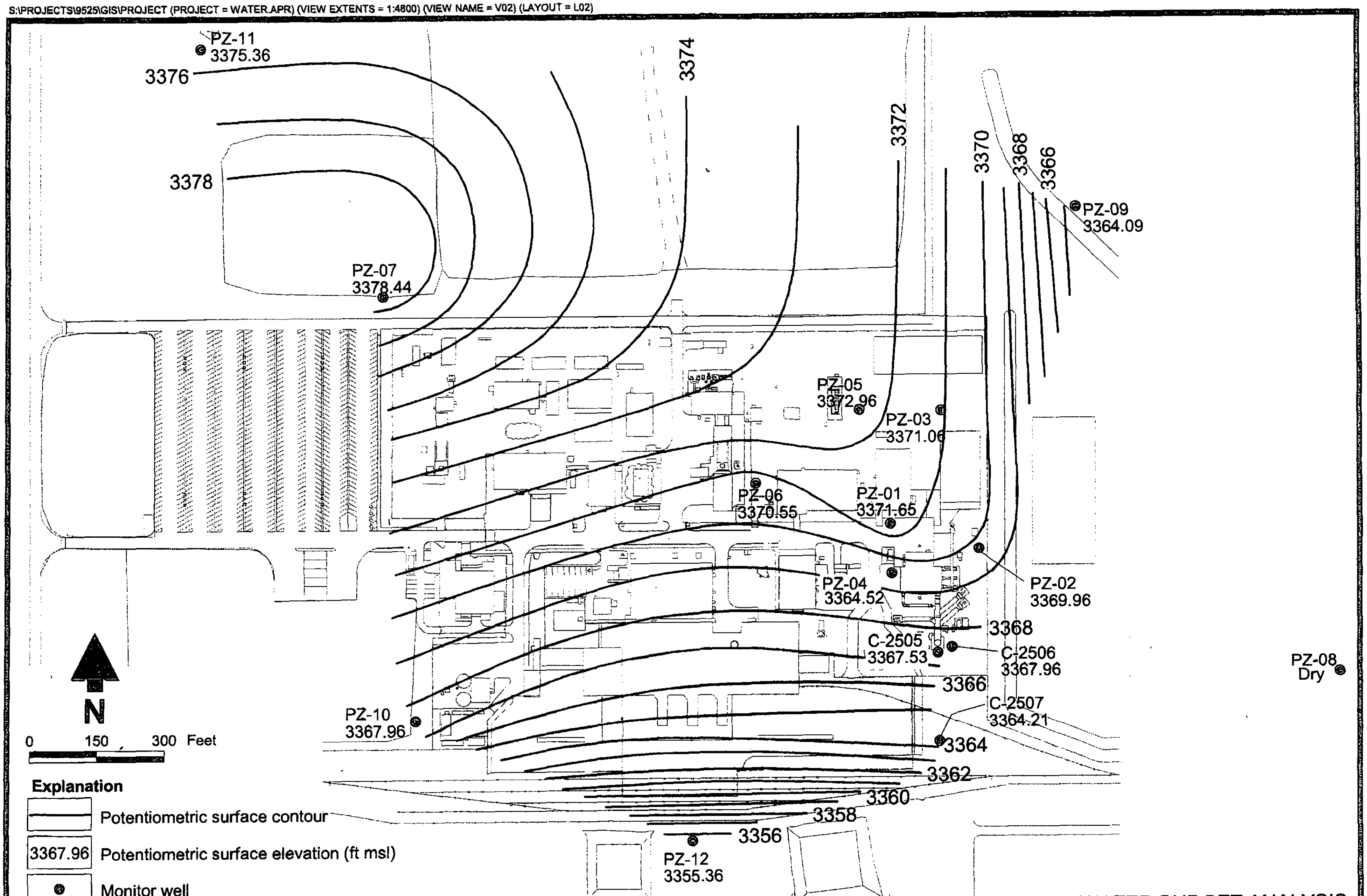

Notes:
1. Elevation from PZ-04 was omitted from contouring
2. Freshwater equivalent elevation used for contouring

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Potentiometric Surface Contours, October 2001

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Figure 11

time series analysis to examine water level trends for each of the SSW monitor wells was completed by plotting water level hydrographs along with precipitation records.

The SSW water levels appear to correlate with precipitation rates over the six-year period of record. The SSW monitor wells were installed in 1996, following a period of above average precipitation since 1984 (Figure 4). In the first year after installation of the wells (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 (1998 to 2001), when the total annual precipitation was below the WIPP station average (Figure 4), observed water levels declined. These correlations are demonstrated in well PZ-07, located close to the Salt Pile Evaporation Pond, where the water level trends appear to be a result of high recharge rates during periods of high precipitation (Figure 12).

3.5 Water Quality

For the water budget analysis, DOE provided DBS&A up-to-date water quality monitoring data and TDS concentration contour maps for the years 1997 and 2000 (Figures 13 and 14, respectively). The highest TDS concentrations are found throughout the northern portion of the WIPP site, where much of the water encountered in the wells is classified as brine (TDS greater than 35,000 mg/L). Concentrations are much lower in the southern half of the site, but appear to be increasing over time. For example, the TDS concentration of PZ-12 was 3,140 mg/L in 1997, but increased to above 9,000 mg/L by 2000.

Time-series plots for each of the SSW monitor wells show distinct trends in the distribution of high TDS concentrations. In the vicinity of the Salt Storage Area, where TDS concentrations are most elevated, concentrations are steady or declining, consistent with the conceptual model for the SSW hydrologic characteristics. 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 TDS plume spreading radially and increasing the TDS in wells at the periphery.

The 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; thus the SSW is likely derived, at least in part, from anthropogenic saline sources. Two potential sources of the saline zone within the SSW, the Salt Storage Area and Salt Pile Evaporation Pond, are close to the monitor wells with the highest TDS concentrations. In contrast, monitor wells near the storm water retention ponds, which are sources of fresh water recharge, exhibit the lowest TDS concentrations.

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

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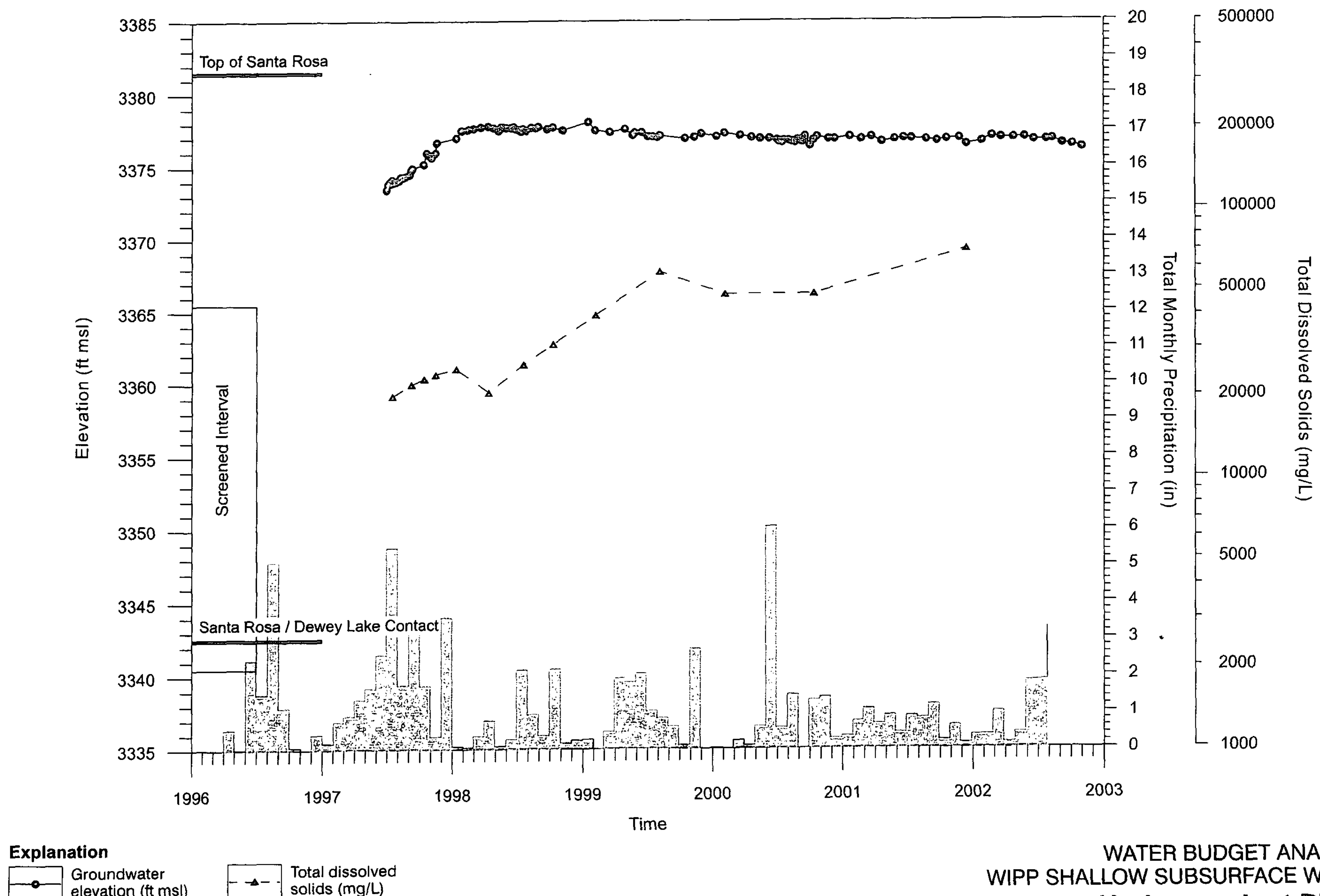

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER

Hydrograph at PZ-07
Monthly Precipitation and Total Dissolved Solids

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Figure 12

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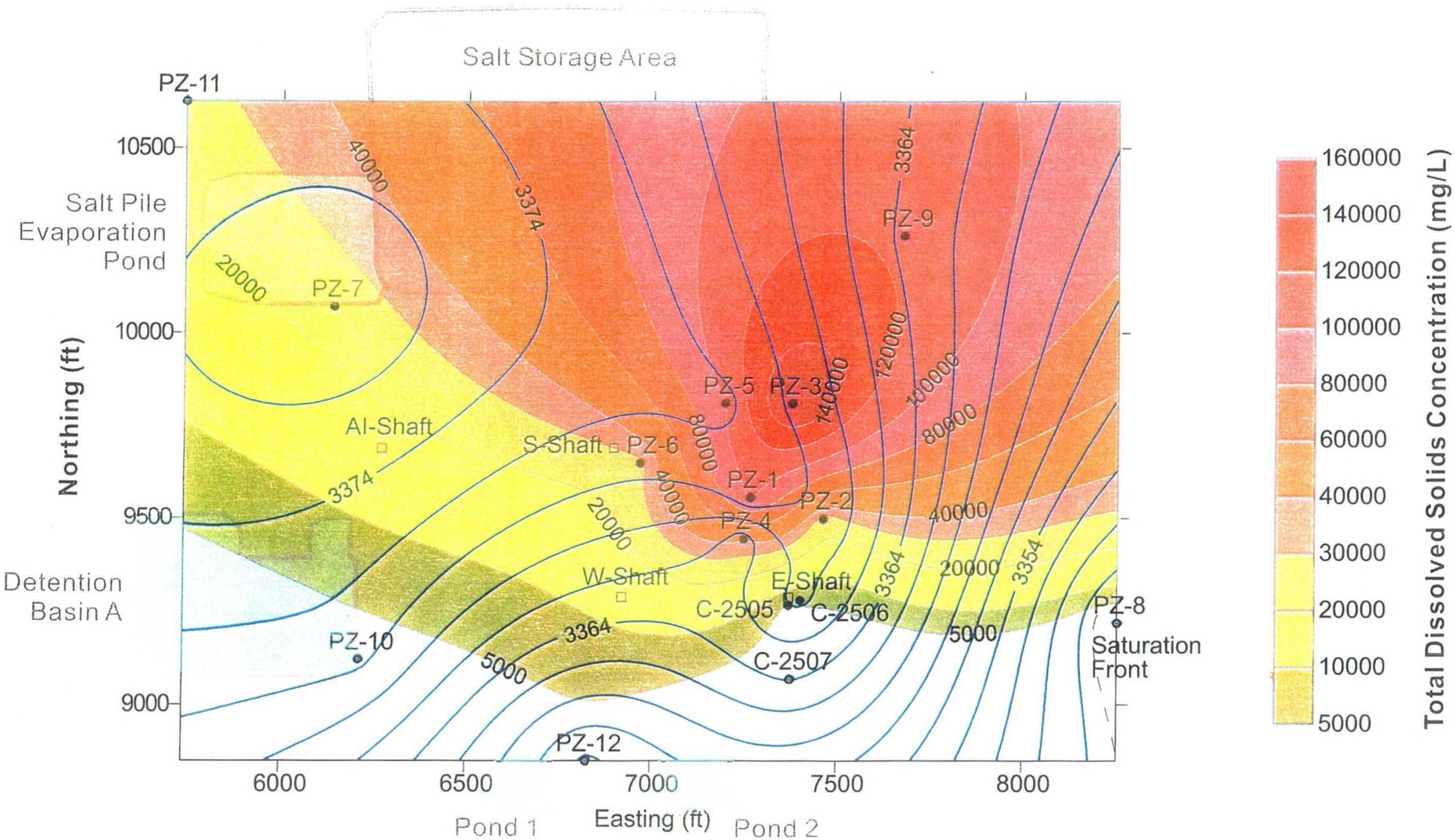

Source of drawing:
Adapted from contours provided in
Geotechnical Analysis Report for July 2000-June 2001
Volume 1, DOE/WIPP 02-3177, September 2002

Not to Scale

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WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Water Level Elevation and
Water Quality (Total Dissolved Solids)
Contour Map, February 1997

Figure 13

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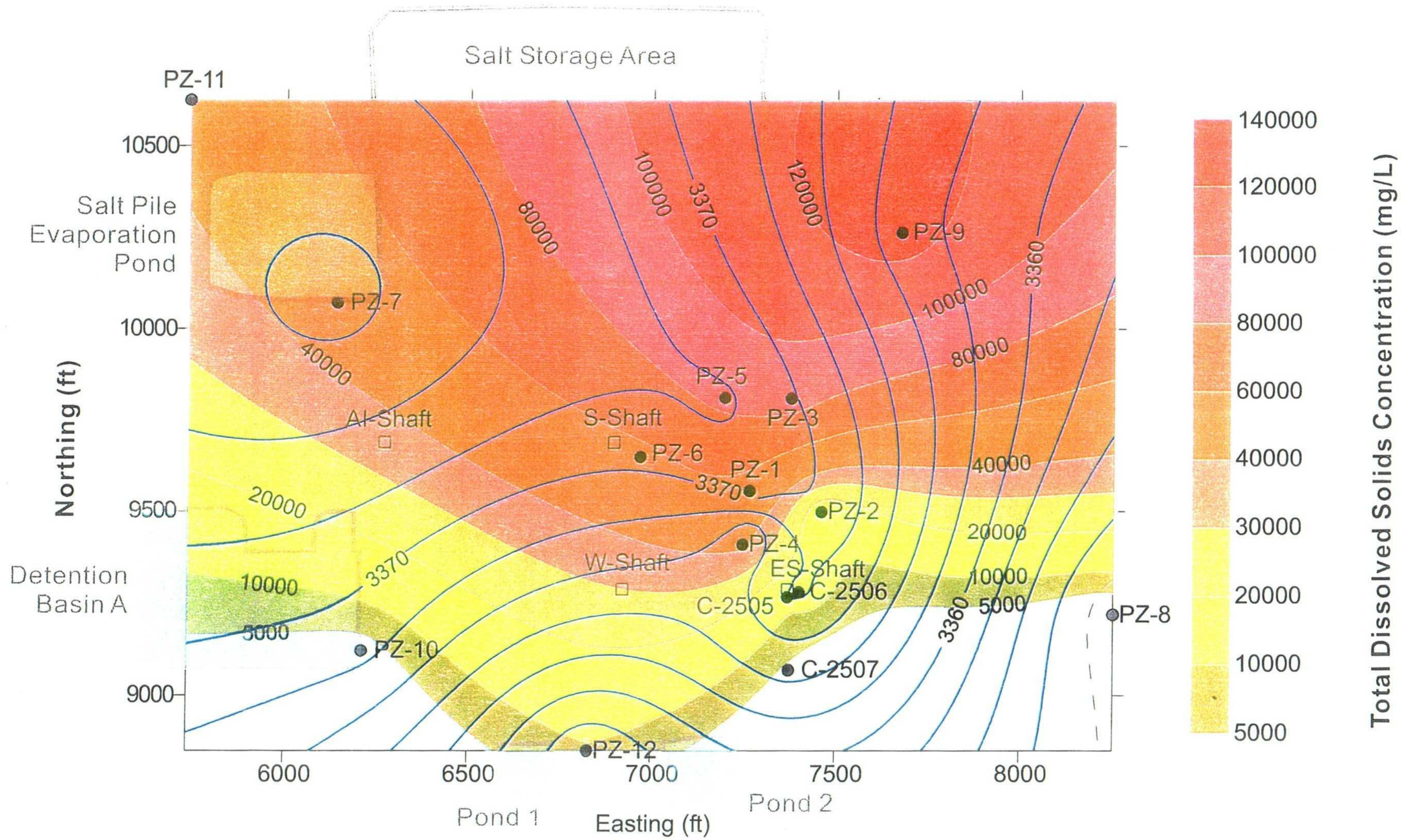

Source of drawing:
Adapted from contours provided in
Geotechnical Analysis Report for July 2000-June 2001
Volume 1, DOE/WIPP 02-3177, September 2002

Not to Scale

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Water Level Elevation and
Water Quality (Total Dissolved Solids)
Contour Map, October 2000

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Figure 14

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 SSW. Thus, seepage from the Salt Storage Area provides a potential mechanism to generate the TDS concentrations observed in the monitor wells.

4. Operational Discharges and Losses

Numerous reports and documents describe the known and suspected water discharges and losses at the WIPP site. DBS&A compiled reported discharge rates, quantities, and sources, beginning with WIPP construction and continuing until the present. The operational discharges and water system leakage that may have contributed to the currently observed SSW are described in Sections 4.1 and 4.2, respectively. Operational-related losses from the SSW due to seepage into the Exhaust Shaft are described in Section 4.3.

4.1 Compilation of Historical Discharges

The record of historical water discharges at the WIPP site provides information on past flows of drilling fluids, fluids from shaft dewatering and water line purging, treated sewage effluent, and other discharges that occurred at various locations across the facility. Most historical discharges were not closely metered or measured, and for the water budget, discharge periods were estimated from available records to calculate total volumes. The sources, locations, and quantities of on-site discharges are summarized in Table 2.

The most significant historical discharges at the site occurred from the early to mid-1980s during drilling of the WIPP shafts, with the two largest sources of discharge being mine dewatering (1,300,000 gallons) and drilling of the Air Intake Shaft (770,000 gallons). Records from that time estimated the quantity of brine to be used during other drilling activities at more than 3 million gallons (U.S. DOE, 1980). This drilling fluid was discharged to a synthetically lined holding pond, and the amount of any release to the subsurface is uncertain. Other sources of operational discharges include flushing of the water supply pipeline (D'Appolonia Consulting Engineers, 1983), temporary showers for subsurface workers (U.S. DOE, 1980), and construction water from the Waste Handling Shaft (U.S. DOE, 1985).

The total volume of recorded on-site discharges to the ground surface is approximately 6 million gallons. Much of this was discharged into the Salt Pile Evaporation Pond, and a portion of the discharge was lost to evaporation. In comparison to the 108 million gallons of water estimated to be in the SSW saturated zone (Section 3.1), the volume of construction and operational discharges appears to provide only a minor contribution.

4.2 Estimate of Water Line Leakage

Leakage from water and sewer lines is a likely component of the overall water budget at the WIPP. Intera (1997b) indicates that several water line leaks were reported over a period of several months in 1996 and 1997. In addition to these identified leaks, a certain amount of leakage typically occurs in the underground piping network of most water systems.

Leakage rates from water systems are commonly estimated as a percentage of total use. A single water meter on the water system serving the WIPP facilities was put into service in

Table 2. Compilation of Historical Water Discharges

Source	Timeframe	Discharge: Location	Discharge: Rate[a] (gpd)	Discharge: Total Quantity[a] (gallons)	Reference
Mine dewatering[b]	August 1991 – December 1993	Salt pile evaporation pond	1,500[c]	1,280,000	U.S. DOE, 1991 NMED, 1993
Air intake shaft	December 1987 – February 1988; April 1988 – July 1988; August 1988[d]	Salt pile evaporation pond	5,000[c]	765,000	Westinghouse, 1987a, 1987b; Holt and Powers, 1990
Drilling fluid	---	---	---	2,400,000	U.S. DOE, 1980
	---	---	---	600,000	U.S. DOE, 1980
Pipeline flushing, 24-inch	September 1983 – January 1985	On-site	---	558,130	D'Appolonia, 1983
Pipeline flushing, 10-inch	September 1983 – January 1985	On-site	---	96,873	D'Appolonia, 1983
Temporary showers	October 1983 – February 1984	0.4-acre evaporation pond	1,000[c]	123,000	U.S. DOE, 1980
Waste handling shaft construction and aquifer inflow	June 1981 – March 1982	Salt pile evaporation pond	17,000 – 20,000	250,000[e]	U.S. DOE, 1985

--- = Not available gpd = Gallons per day

[a] Except as noted below, rates or quantities were obtained from references cited in last column.

[b] The timeframe for mine dewatering was taken from the DOE 1991 request for emergency permit and from a subsequent approval by New Mexico Environment Department (NMED) for a 60-day extension dated September 16, 1993.

[c] Only rates were given for these discharges; total volumes were calculated using the rates and the timeframe.

[d] Timeframe from *Geologic mapping of the air intake shaft at the Waste Isolation Pilot Plant* (Holt and Powers, 1990).

[e] Total quantity for waste handling shaft construction and aquifer inflow was reported; this figure was not based on rates.

October 2000. Since that time, flow meter readings show an average water use of 6,240,000 gallons per year for 2001 and 2002. Because the WIPP water system is relatively new, leakage was estimated based on a low leakage rate of 5 percent. Since this water leaks into shallow soils, it was assumed that approximately 50 percent is evaporated at ground surface and the remainder seeps downward to the SSW zone. Leakage for a separate fire-water system at the WIPP site was determined to be 15 gallons per hour in September 2002, based on pumping of the system makeup pump (Hedin, 2002).

Estimated water line leakage to the SSW is summarized in Table 3. An estimated seepage of 222,000 gallons per year from the combined systems provides a reasonable input volume to the SSW from this source. Thus, seepage from water lines since the WIPP facilities opened in 1984 is estimated to total approximately 4 million gallons.

Table 3. Estimate of Water Line Leakage Input to Shallow Subsurface Water

Source	Annual Flow (gallons)	Leakage Rate			
		Percent of System	Hourly (gallons)	Daily (gallons)	Annual (gallons)
Water supply system	6,240,000	5	36	855	312,000
Fire-water system	NA	NA	15	360	131,000
Total annual leakage					443,000
Annual seepage to SSW [a]					222,000

[a] Calculated as 50 percent of total leakage NA = Not available

4.3 Exhaust Shaft Seepage

Seepage into the Exhaust Shaft (Figure 2) from the SSW saturated zone was first detected in May 1995 (U.S. DOE, 2002), when a scheduled inspection found water emerging from small cracks in the concrete shaft liner. Video inspections of the shaft liner show that seepage through these cracks occurs principally at depths of approximately 50 and 80 feet bgs (U.S. DOE, 2002). Measurement of the seepage rate is complicated by the fact that much of the seepage into the shaft is lost to evaporation because of air flow of up to 425,000 cubic feet per minute in the Exhaust Shaft (U.S. DOE, 2002). Although the flow has not been directly measured, DOE (2002) estimates, based on visual observations and periodic measurements of water collected at the base of the Exhaust Shaft during times of low air flow, that seepage into the shaft is about 1 to 3 gallons per minute (gpm). A flow rate of this magnitude could represent a significant loss from the SSW in the range of 0.5 to 1.6 million gallons per year.

The rate of seepage into the Exhaust Shaft is uncertain, and seepage through cracks in the shaft liner may be increasing over time. Assuming that the Exhaust Shaft seepage has occurred at a rate of 1 gpm (0.5 million gallons per year) from 1995 to 2002, the estimated loss from SSW storage amounts to approximately 4 million gallons since the time seepage was first observed.

5. Storm Water Runoff

Storm water runoff, generated by on-site precipitation, is a major component of the water budget. Much of the precipitation within the WIPP surface facilities falls on impervious areas and is routed to shallow, unlined storm water retention ponds. This section examines total storm water flows, flow paths, and fate of storm water runoff to determine the contributions of storm water to the SSW system, using the storm water runoff as input to the seepage modeling analyses (Section 6).

The runoff calculations are based in part on the original site grading and drainage plans and engineering calculations completed for the WIPP facilities design in the early 1980s. This information was supplemented with new runoff calculations completed for the water budget that reflect the most recent topographic surveys and incorporate new infrastructure that has been added since the original design calculations.

5.1 On-Site Water Retention Facilities

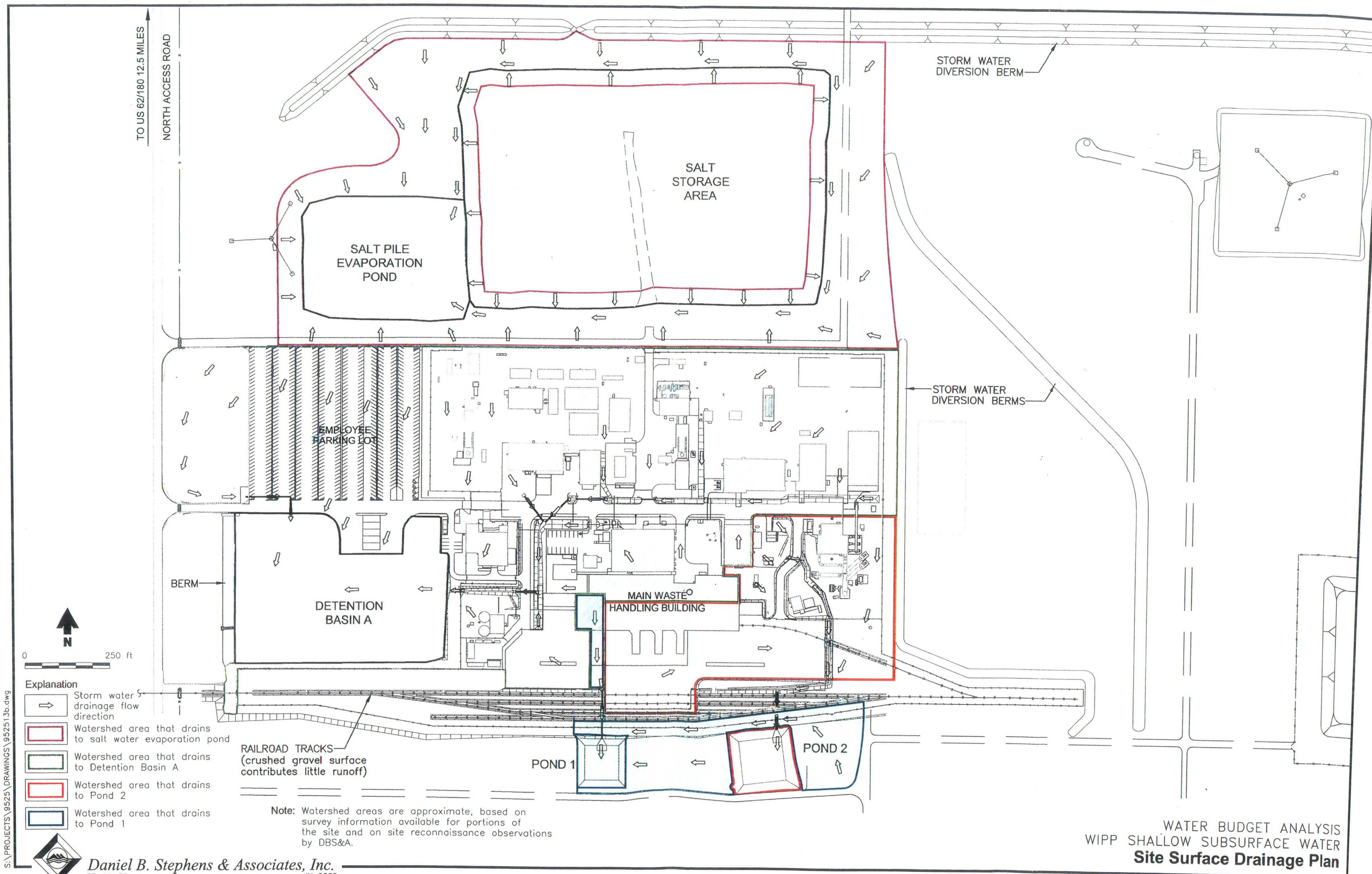
Surface water drainage at the WIPP site consists of four distinct watersheds that drain to four on-site, storm water retention ponds through a network of swales and culverts (Figure 15). The four ponds are:

- Salt Pile Evaporation Pond
- Detention Basin A
- Storm water retention Pond 1
- Storm water retention Pond 2

The areas of the ponds and watersheds, including the pervious and impervious areas, are summarized in Table 4. Figure 15 shows the ponds and their contributing watersheds. Three of the ponds receive relatively clean storm water from the surface facilities, while the Salt Pile Evaporation Pond receives runoff containing dissolved salt from the outer slopes of the Salt Storage Area. The largest watershed, located in the central portion of the facilities area, which includes the administrative area and parking area, drains to Detention Basin A. The southeast portion of the site drains to storm water retention Pond 2, while storm water retention Pond 1 collects a small amount of runoff from areas surrounding both Ponds 1 and 2.

The surface conditions of the watersheds range from relatively permeable bare ground to impermeable pavement and rooftops. Vegetation in the ponds is variable:

- Salt Pile Evaporation Pond: Sparse vegetation mainly in western half of pond
- Detention Basin A: Dense, well established vegetation
- Pond 1: No vegetation on caliche pond bottom
- Pond 2: No vegetation on caliche pond bottom



TO US 62/180 12.5 MILES
NORTH ACCESS ROAD
STORM WATER DIVERSION BERM
SALT STORAGE AREA
SALT PILE EVAPORATION POND
STORM WATER DIVERSION BERMS
EMPLOYEE PARKING LOT
BERM
DETENTION BASIN A
MAIN WASTE HANDLING BUILDING
POND 1
POND 2
N
0
250 ft
Explanation
Storm water drainage flow direction
Watershed area that drains to salt water evaporation pond
Watershed area that drains to Detention Basin A
Watershed area that drains to Pond 2
Watershed area that drains to Pond 1
RAILROAD TRACKS (crushed gravel surface contributes little runoff)
Note: Watershed areas are approximate, based on survey information available for portions of the site and on site reconnaissance observations by DBS&A.
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WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Site Surface Drainage Plan

Figure 15

Constructed berms to the north and east of the site prevent off-site surface water from running onto the WIPP site (Figure 15). Therefore, all of the storm water collected in the retention ponds is from on-site runoff.

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 storm water retention (Westinghouse, 1992).

Table 4. Summary of Watershed and Pond Areas

Pond	Pervious [a] Watershed Area		Impervious [b] Watershed Area		Entire Pond Area		Total Watershed Area	
	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
Storm water retention Pond 1	119,793	2.75	16,615	0.38	21,818	0.50	158,226	3.63
Storm water 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.

5.2 Storm Water Runoff Calculations

For the water budget, runoff was estimated using the rational formula; a standard method that was also used for the original WIPP facility engineering design. Inasmuch as the purpose of the analysis was not to estimate peak discharge rates, but rather to estimate total runoff on a daily basis, a modified version of the rational formula was used (Wanielista et al., 1997).

Runoff was calculated using WIPP daily precipitation records from 1997 through 2002. Drainage flow paths for each watershed were determined from site topography, previous storm water calculations, and observations made during site visits. The irregular pond bottom grades were taken into account in the storm water calculations by determining the submerged area for average-size storms. Table 5 summarizes pond infiltration areas, total watershed areas, and rational method weighted average runoff coefficients used to calculate storm water runoff volumes.

Table 5. Summary of Runoff Calculation Input

Location	Pond Infiltration Area (ft^2)	Total Watershed Area (ft^2)	Total Watershed Area (acres)	Weighted Average Runoff Coefficient
Salt Pile Evaporation Pond	79,012	882,417	20.3	0.7507
Detention Basin A	70,222	1,642,906	37.7	0.8458
Pond 1	10,000	158,226	3.63	0.7954
Pond 2	15,624	353,387	8.11	0.9232

5.3 Discharges to Storm Water Ponds

Table 6 summarizes the total annual precipitation, runoff, and cumulative inches of storm water in each pond for the period of record from January 1997 through August 2002. The average annual precipitation rate for 1997 to 2001 is 12.7 in/yr, which translates to an average annual precipitation volume of approximately 29.2 million gallons over the 84.6-acre watershed, including the four storm water pond watersheds (24.0 million gallons of annual precipitation) and the 15-acre Salt Storage Area top deck (5.1 million gallons of annual precipitation).

The total combined runoff volume received at all four ponds for the period of record was 113.6 million gallons, and the average annual storm water runoff for 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

Detention Basin A and the Salt Pile Evaporation Pond together capture more than 80 percent of storm water runoff. Detention Basin A alone captures more than half of the storm water runoff and therefore appears to be a primary source of seepage.

Table 6. Summary of Runoff Volumes

Year	Annual Precipitation (inches)	Volume of Runoff (gallons)					Cumulative Runoff Depth (inches)			
		Salt Water Evaporation Pond	Detention Basin A	Pond 1	Pond 2	Total	Salt Pile Evaporation Pond	Detention Basin A	Pond 1	Pond 2
1997	23.9	9,874,445	20,713,467	1,876,013	4,863,162	37,327,088	200	473	301	499
1998	7.7	3,188,120	6,687,669	605,700	1,570,149	12,051,639	65	153	97	161
1999	11.9	4,906,168	10,291,592	932,107	2,416,287	18,546,155	100	235	150	248
2000	12.0	4,959,757	10,404,004	942,288	2,442,679	18,748,728	101	238	151	251
2001	8.0	3,295,167	6,912,220	626,038	1,622,869	12,456,294	67	158	100	167
2002[a]	9.3	3,820,125	8,013,416	725,773	1,881,411	14,440,726	78	183	116	193
Total	72.8	30,043,782	63,022,368	5,707,919	14,796,557	113,570,630	611	1,440	915	1,519
Annual Average[b]	12.7	5,244,731	11,001,790	996,429	2,583,029	19,825,981	107	251	160	265

[a] Data for 2002 covers only through August.
[b] Average over the years 1997 through 2001.

6. Storm Water Pond and Salt Pile Seepage

Local recharge to the SSW from potential sources of on-site seepage was analyzed using multiple calculation methods. Because impermeable surfaces cover much of the WIPP facilities area, seepage is expected to occur predominantly from the following five pervious areas, as shown on Figure 15:

- Salt Storage Area
- Salt Pile Evaporation Pond
- Detention Basin A
- Pond 1
- Pond 2

Using the calculated quantities of storm water runoff, the seepage rate was calculated for these five primary seepage sources. The calculation methods used for estimating local, focused recharge in these areas are independent approaches that can be cross-referenced to evaluate the reliability of the results. These methods include:

- *Surface infiltration model:* Calculates downward seepage based on hydraulic loading of precipitation and variably saturated flow processes in the soil/salt profile using UNSAT-H.

- *Saturated flow model:* Calculates seepage based on SSW hydrologic conditions and potentiometric surface of the saturated zone. Two types of saturated flow models were applied: (1) steady state (MODFLOW) and (2) transient flow (MODFLOW-SURFACT).

Multiple methods were used to evaluate seepage rates to provide a range of estimated results and corroboration of the general magnitude of seepage. Although the analyses were performed independently, they used many of the same input parameters to maintain consistency among the methods and ensure general reasonableness of results. The models were run with a range of input values during development, and sensitivity analyses were performed on input variables. The seepage rate estimates determined by these models were then used as input to a SSW flow model to examine long-term migration potential (Section 7). Details of the seepage analysis methods and results are described in Sections 6.1 and 6.2.

6.1 Surface Infiltration Modeling

Modeling of surface infiltration, the movement of precipitation from the ground surface to deep percolation, was conducted to estimate the volume of water contributing to SSW recharge from each of the five primary seepage sources. The UNSAT-H model (Fayer, 2000) was selected because it can consider variably saturated/unsaturated infiltration. The model accounts for the water budget losses of evaporation and transpiration and the seepage that contributes to the SSW. The UNSAT-H model can also determine the evapotranspiration losses and seepage inputs from sources with very different characteristics, such as those at the WIPP site.

Conceptually, surface infiltration occurs in cycles following storm events. Precipitation that falls on the Salt Storage Area can infiltrate below the salt pile surface through extensive fractures and dissolution channels (i.e., macropores) observed on the salt pile surface. In the storm water retention ponds, water collects to depths of a few inches to a few 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 will completely infiltrate and/or evaporate, and the soil in the basin will dry out as evapotranspiration and gravity drainage continue.

6.1.1 UNSAT-H Model

The UNSAT-H model uses a one-dimensional finite element version of Richard's equation to simulate infiltration in variably saturated media as a function of environmental conditions such as climate, soil type, and vegetation. The model was developed at Pacific Northwest National Laboratory (PNNL) and has been verified against analytical solutions and validated against lysimeter data by Fayer et al. (1992). More information about UNSAT-H is available from the DOE's PNNL (2002) web site.

Evapotranspiration losses from the soil profile are an important component of the water budget, and UNSAT-H provides a robust consideration of evapotranspiration. The model accounts for both downward and upward redistribution of moisture in the soil profile and changes in soil moisture storage. The model determines the seepage exiting the base of the model domain, which is assumed to migrate vertically downward and become recharge to the SSW.

6.1.2 Ponded Water Calculations

Storm water inputs to the retention ponds from the much larger watersheds result in accumulation of ponded water when storm water inflow exceeds the infiltration capacity of the ponds. To model seepage from the ponds, it was necessary to determine the depth of water (hydraulic head) in each pond after each precipitation event (the ponded water calculations did not apply to the Salt Storage Area, which receives only direct precipitation). Using the runoff volume and pond infiltration area, the depth of water in each pond was calculated for each day's runoff volume within the period of record. The ponding depth following precipitation events was calculated using the following input:

- Infiltration capacity of the soil in the pond bottom
- Weather data records from the WIPP weather station (1997 through September 2002)
- Storm water runoff calculated as described in Section 5

UNSAT-H simulated the evapotranspiration losses and infiltration of ponded water over a period of days. Calculations included daily time increments to ensure that evaporative losses were based on the actual climatic data for that day. This application of UNSAT-H produced negligible amounts of surface runoff from the ponds (3 percent of infiltration), which UNSAT-H shows as a minor mass-balance loss from the system.

6.1.3 UNSAT-H Input Data

UNSAT-H modeling was conducted for unconsolidated near-surface materials, including the Salt Storage Area and the first bedrock unit encountered, the Gatuña Formation. These materials were of four distinct types: crushed rock salt, unconsolidated sand, caliche, and the Gatuña Formation. The thickness of each unit and the four model profiles analyzed are depicted in Figures 16 and 17.

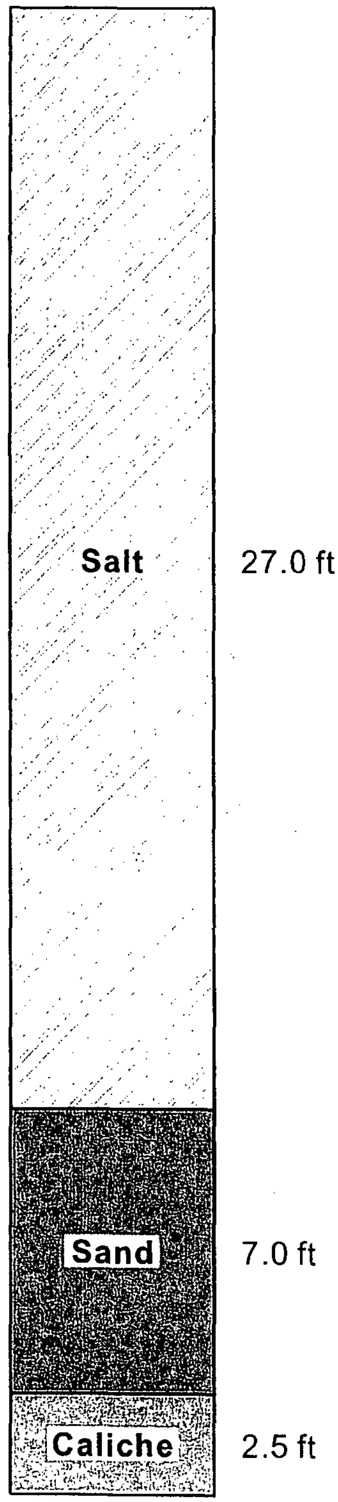
Inputs to the UNSAT-H model include climatological, soils, and vegetation data. Table 7 indicates the sources for these data, while Tables 8 and 9 indicate the data used for soil and vegetation parameters. No laboratory data are available for unsaturated flow parameters for WIPP soils or the crushed rock salt; therefore, the selected values in Table 8 are based on typical values for the general lithology of the materials.

Table 7. Sources of UNSAT-H Climatological, Vegetation, and Soil Parameters

Input Parameter	Source
Climatological data	
Precipitation	WIPP weather station
Temperature	
Solar radiation	
Relative humidity	
Wind speed	
Plant data	
Leaf area index	Neitsch et al., 2002
Rooting depth	Neitsch et al., 2002 www.wa.gov/agr/weedboard/weed_info/kochia.html http://csd.unl.edu/csd/illustrations/ra5a/plants.html
Rooting density	Ayers and Westcot, 1989 http://csd.unl.edu/csd/illustrations/ra5a/plants.html
Soil data	
Hydrologic characteristics	U.S. SCS, 1971; Carsel and Parrish (1988)
Unit thicknesses	Sergent, Hauskins & Beckwith (1979); Intera (1997a)

Prior to each simulation, the weather data for 2000 were repeated for four years in UNSAT-H runs to allow the initial soil-water conditions in the model domain to attain a steady state with respect to typical climatic conditions. The model was then run for a five-year timeframe (1997 to 2001) to determine infiltration rates and evaporative losses.

Salt Storage Area



WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER

Salt Storage Area UNSAT-H Model Profile

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Figure 16

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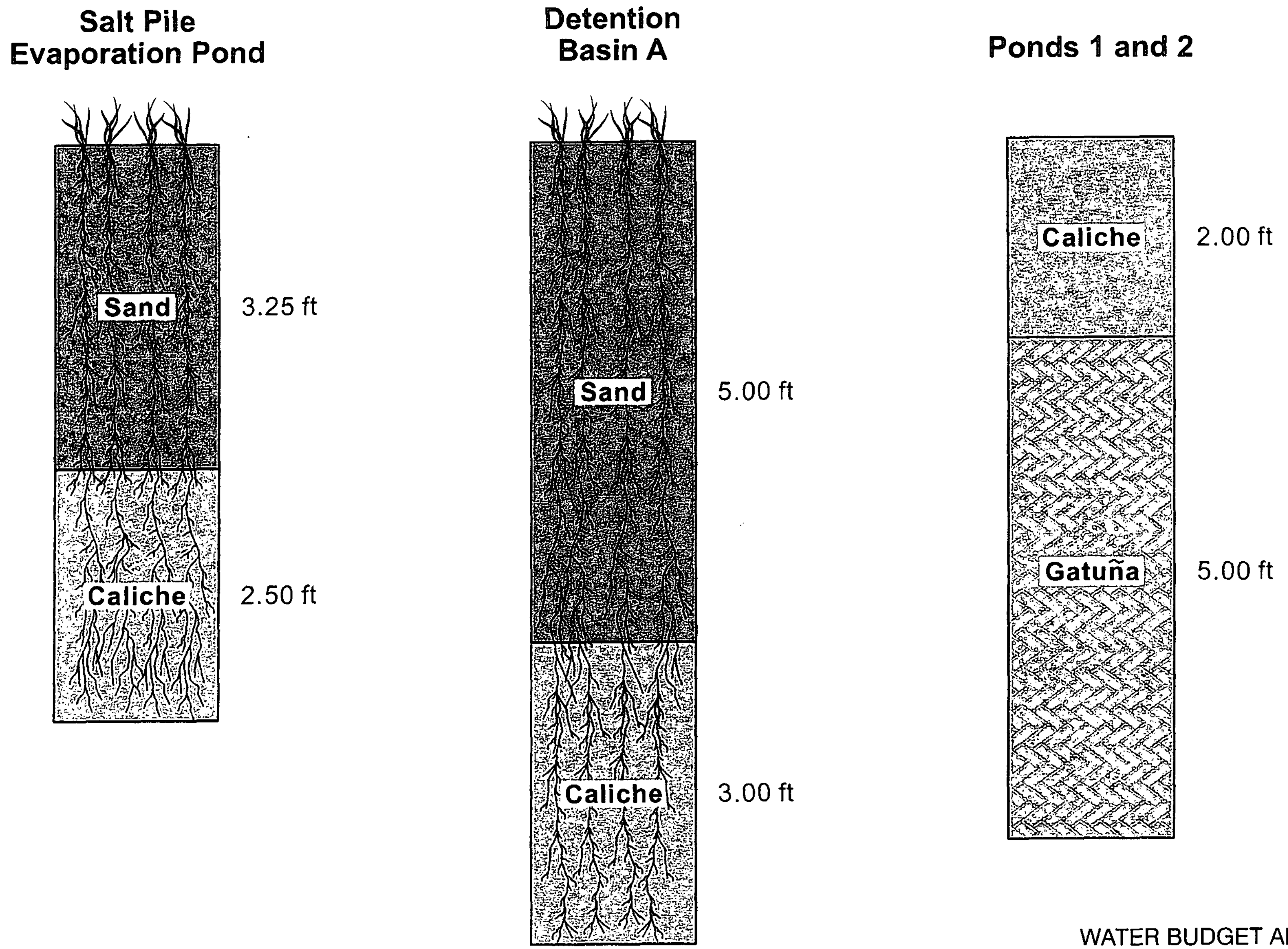

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER

Storm Water Retention Ponds UNSAT-H Model Profiles

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Figure 17

Table 8. Unsaturated Flow Parameters Used in UNSAT-H

Unit Parameters	Crushed Rock Salt	Sand	Caliche	Gatuña Formation
K_{sat} (cm/s)	4.30×10^{-2}	1.36×10^{-4}	6.53×10^{-4}	3.63×10^{-4}
α	0.126	0.020	0.059	0.059
N	2.27	1.41	1.48	1.48
θ_s (v/v)	0.41	0.45	0.39	0.39
θ_r (v/v)	0.057	0.067	0.100	0.100

Note: Data source references are provided in Table 7.
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

Table 9. Vegetation Parameters Used in UNSAT-H Modeling

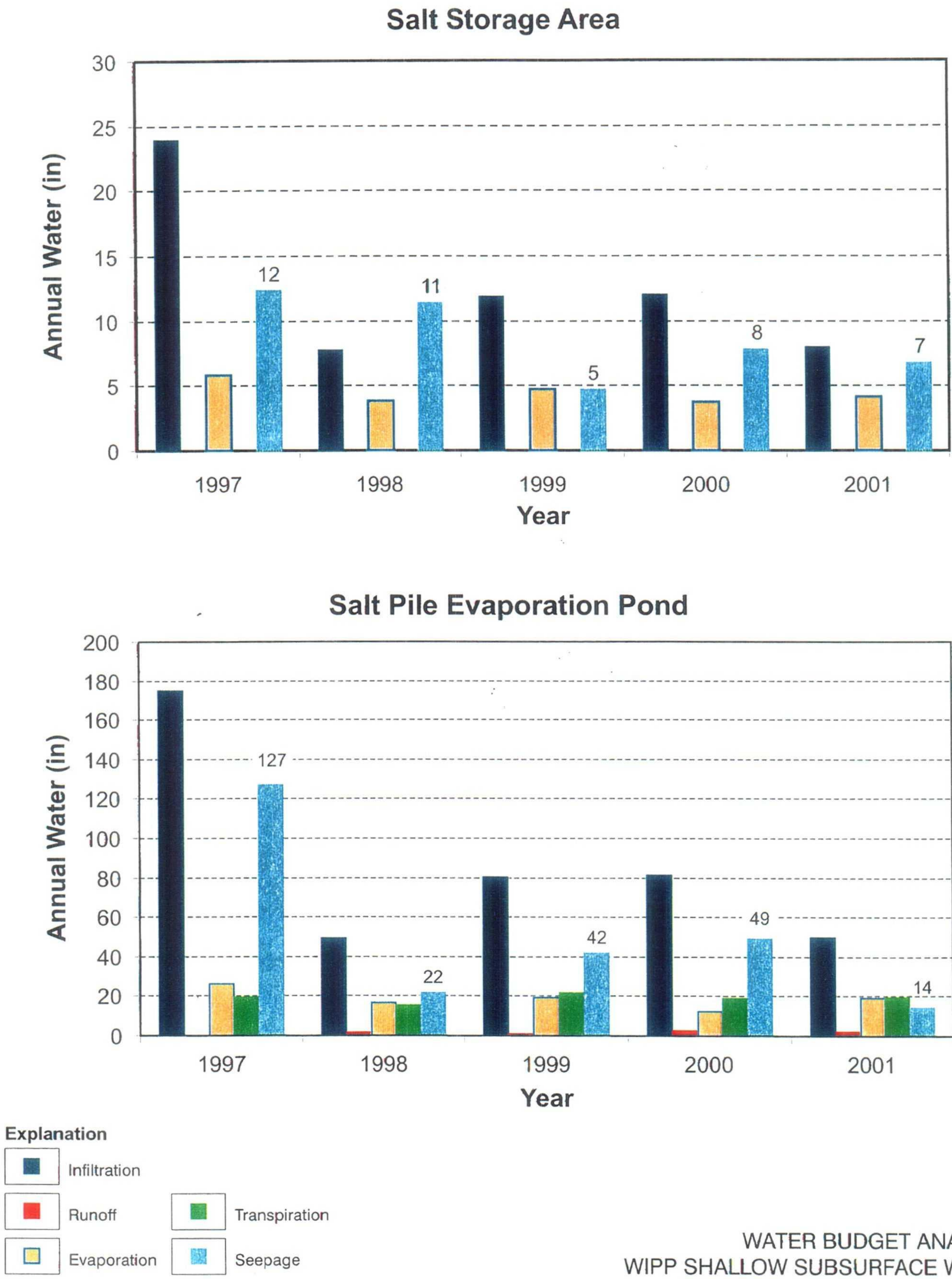
Location	LAI	HW		HD		HN		Coefficients			% Vegetation
		cm	v/v	cm	v/v	cm	v/v	a	b	c	
Salt Storage Area	---	---	---	---	---	---	---	---	---	---	0
Salt Pile Evaporation Pond	2.5	20,000	0.13	3,000	0.23	1	0.43	0.25	0.03	0.001	65
Basin A	2.5	20,000	0.13	3,000	0.23	1	0.43	0.25	0.03	0.001	95
Pond 1	---	---	---	---	---	---	---	---	---	---	0
Pond 2	---	---	---	---	---	---	---	---	---	---	0

Note: Data source references are provided in Table 7.
HW = Water content below which plants wilt and stop transpiring
HD = Water content below which plant transpiration starts to decrease
HN = Water content above which plants do not transpire because of anaerobic conditions
LAI = Leaf area index
cm = Centimeters
v/v = Volume per volume

6.1.4 UNSAT-H Modeling Results

In the UNSAT-H modeling results, infiltration represents the flux into the top surface of the model domain, and seepage represents the flux from the bottom of the model domain contributing recharge to the SSW. Bar graphs summarizing the complete water budget for each simulated profile are provided in Figures 18 and 19. UNSAT-H seepage results are summarized in Table 10 and shown in Figure 20 for the five years simulated (1997 to 2001).

The model results vary from year to year, depending on the amount of precipitation received, with seepage rates in 1997 (annual precipitation 23.91 inches) far exceeding subsequent years (Figures 18 and 19). Conversely, the amounts of water lost to evaporation and transpiration tend to change only modestly from year to year.



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WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER

UNSAT-H Water Budget for Salt Storage Area and Salt Pile Evaporation Pond

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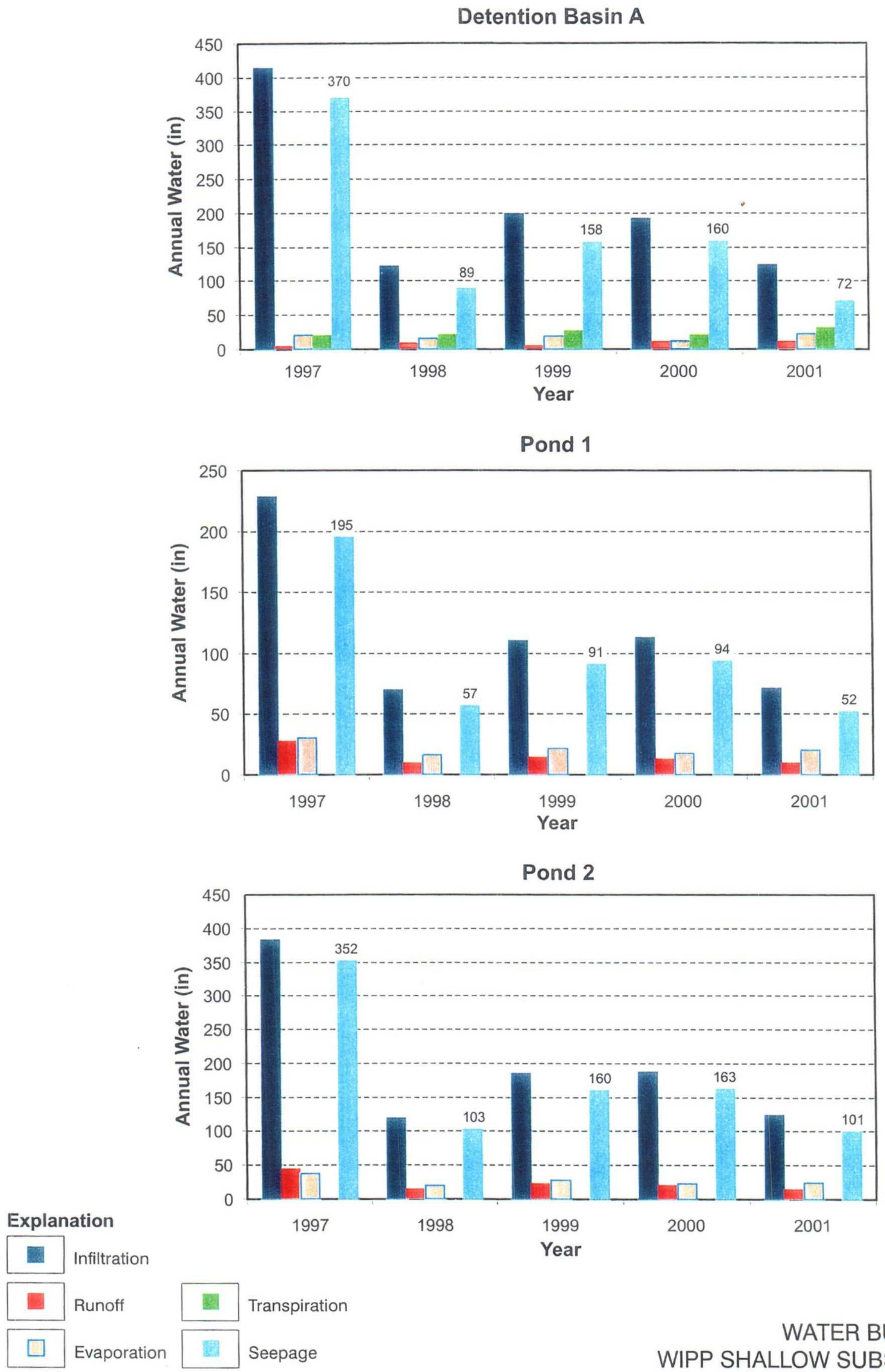
Figure 18

Table 10. UNSAT Modeling Results

Location	Year	Seepage (inches)	Total Annual Seepage (gal/yr)
Salt Storage Area	1997	12.38	6,725,103
	1998	11.42	6,203,741
	1999	4.74	2,574,971
	2000	7.81	4,238,928
	2001	6.78	3,680,342
Five-year average		8.63	4,684,617
Salt Pile Evaporation Pond	1997	127.10	6,260,879
	1998	21.66	1,067,126
	1999	41.88	2,063,154
	2000	49.39	2,432,993
	2001	14.35	706,859
Five-year average		50.88	2,506,202
Detention Basin A	1997	369.65	16,180,626
	1998	89.40	3,913,153
	1999	157.51	6,894,663
	2000	159.75	6,992,550
	2001	72.20	3,160,353
Five-year average		169.70	7,428,269
Pond 1	1997	195.28	1,219,601
	1998	56.74	354,354
	1999	91.00	568,324
	2000	93.90	586,458
	2001	51.67	322,714
Five-year average		97.72	610,291
Pond 2	1997	352.05	3,431,927
	1998	102.54	999,640
	1999	160.04	1,560,157
	2000	163.22	1,591,092
	2001	100.88	983,404
Five-year average		175.75	1,713,244

gal/yr = Gallons per year



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WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER

UNSAT-H Water Budget for Detention Basin A, Pond 1, and Pond 2

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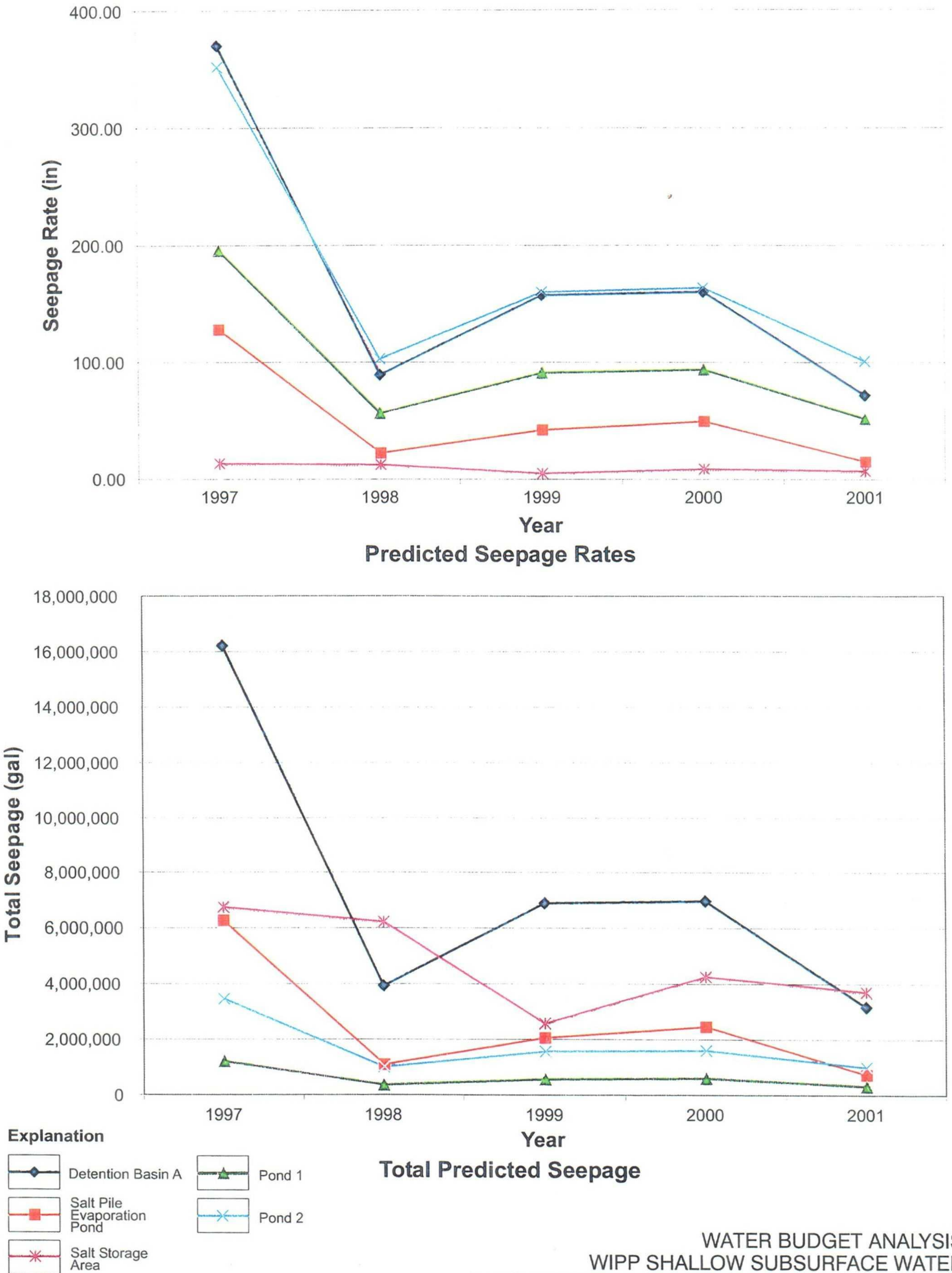
Figure 19



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WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
UNSAT-H Predicted Seepage Rates and Total Predicted Seepage

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Figure 20

Table 10 presents seepage in terms of inches of water that seep vertically downward and the total seepage volume from each source. The greatest amount of seepage is from Detention Basin A, which receives the most storm water. The Salt Storage Area is the next largest seepage source, due more to its large seepage area than its seepage rate.

The model predicts seepage rates to be relatively high, with seepage generally exceeding 50 percent of the water applied. The rates are high for two reasons: (1) the storm water retention ponds receive large inflows of water, which greatly exceed rates of evapotranspiration, and (2) areas without vegetation, such as Ponds 1 and 2 and the Salt Storage Area, have no loss to transpiration, and evaporative losses remove only a small percentage of the precipitation and ponded water. Seepage rates range from a low of approximately 5 to 12 in/yr for the Salt Storage Area to a high of approximately 70 to 370 in/yr for both Detention Basin A and Pond 2.

The total seepage volumes predicted by the UNSAT-H model show substantial annual inputs to the SSW. Average annual seepage rates range from 610,000 gallons per year for Pond 1 to 7,400,000 gallons per year for Detention Basin A. The seepage rates are estimated to average approximately 70 percent of the total water applied to the ponds and basins, after other losses that occur during storm water runoff.

6.2 Saturated Flow Modeling

Saturated flow modeling of the SSW was used to estimate areally distributed seepage rates that account for the water level elevations observed at the site. This approach determines seepage based on fundamental saturated flow principles. The seepage rates are estimated by determining the recharge to the SSW necessary to sustain the observed water table mound. The model focused on a limited area centered on the primary seepage sources and the portion of the SSW lens where hydrologic conditions have been most thoroughly characterized.

The code used to model SSW flow and seepage inputs was MODFLOW (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996), a U.S. Geological Survey (USGS) quasi-three-dimensional finite-difference groundwater flow model that has been used previously for modeling of the SSW (Duke Engineering & Services, Inc., 1999). MODFLOW can simulate a wide variety of hydrologic features and processes, and is widely accepted by regulators.

For the water budget, steady-state and transient simulations were run to determine rates and distribution of seepage that contribute to the SSW. To better simulate fluctuating water table conditions, a MODFLOW variation, MODFLOW-SURFACT (Hydrogeologic, Inc., 1999) was used for the transient analyses. This variation is more adept at handling the complete drying and re-wetting of grid cells to simulate wetting front migration.

6.2.1 Conceptual Model and Model Domain

The model simulated SSW water table conditions under the influence of variable seepage inputs from the surface. Iterative model runs were conducted to determine seepage rates that match actual water levels observed in the SSW monitor wells.

6.2.1.1 Conceptual Model

The SSW was depicted as an unconfined perched zone with superimposed seepage contributing recharge to the water table. The only sources of recharge to the model are the Salt Storage Area, Salt Pile Evaporation Pond, Detention Basin A, and storm water retention Ponds 1 and 2. The model did not consider operational discharges from drilling and construction activities, water line leakage, or the SSW losses from seepage into the Exhaust Shaft, since these are apparently relatively small contributors in the SSW water budget (Section 4). In general, the inputs and losses omitted from the model are expected to be offsetting and thus are not likely to significantly impact the simulation of recharge from the primary seepage sources.

6.2.1.2 Model Domain

This analysis used a one-layer model simulating the saturated Santa Rosa perched zone above an impermeable Dewey Lake contact at the base of the model. Contours of the Santa Rosa/Dewey Lake contact were generated based on the reported contact elevation in boring logs from piezometers and monitor wells installed on-site (Figure 21). A no-flow boundary was assumed at the top of the Dewey Lake, because within the area where the SSW monitor wells were drilled, the Dewey Lake was found to be dry within 5 feet below the contact and little downward leakage appears to occur. The Santa Rosa pinchout to the west was also assumed to represent a no-flow boundary in the model. This boundary is based on boring logs (Sergent, Hauskins & Beckwith, 1979) that show the Santa Rosa to be absent approximately 1,500 feet southwest of the known limits of the SSW.

6.2.2 Steady-State Analysis

The objective of the steady-state MODFLOW simulation was to estimate the average recharge rate that sustains the water table mound in a near steady-state condition, based on monitor well hydrographs, which show relatively uniform water levels over the past five years.

6.2.2.1 Steady State Model Approach and Calibration

The recharge rate and its spatial distribution were varied in the steady-state MODFLOW model to simulate recharge that most closely replicated the observed shape of the SSW potentiometric surface. Recharge was applied to the Salt Pile Evaporation Pond, Salt Storage Area, Detention Basin A, and Ponds 1 and 2 (Figure 22). Based on the storm water runoff calculations (Section 5.1), recharge in Detention Basin A and the Salt Pile Evaporation Pond was applied to a portion of the ponds where the predominant seepage appears to occur. Recharge rates were varied during the calibration using iterative adjustments. To maintain the expected steady outflow near

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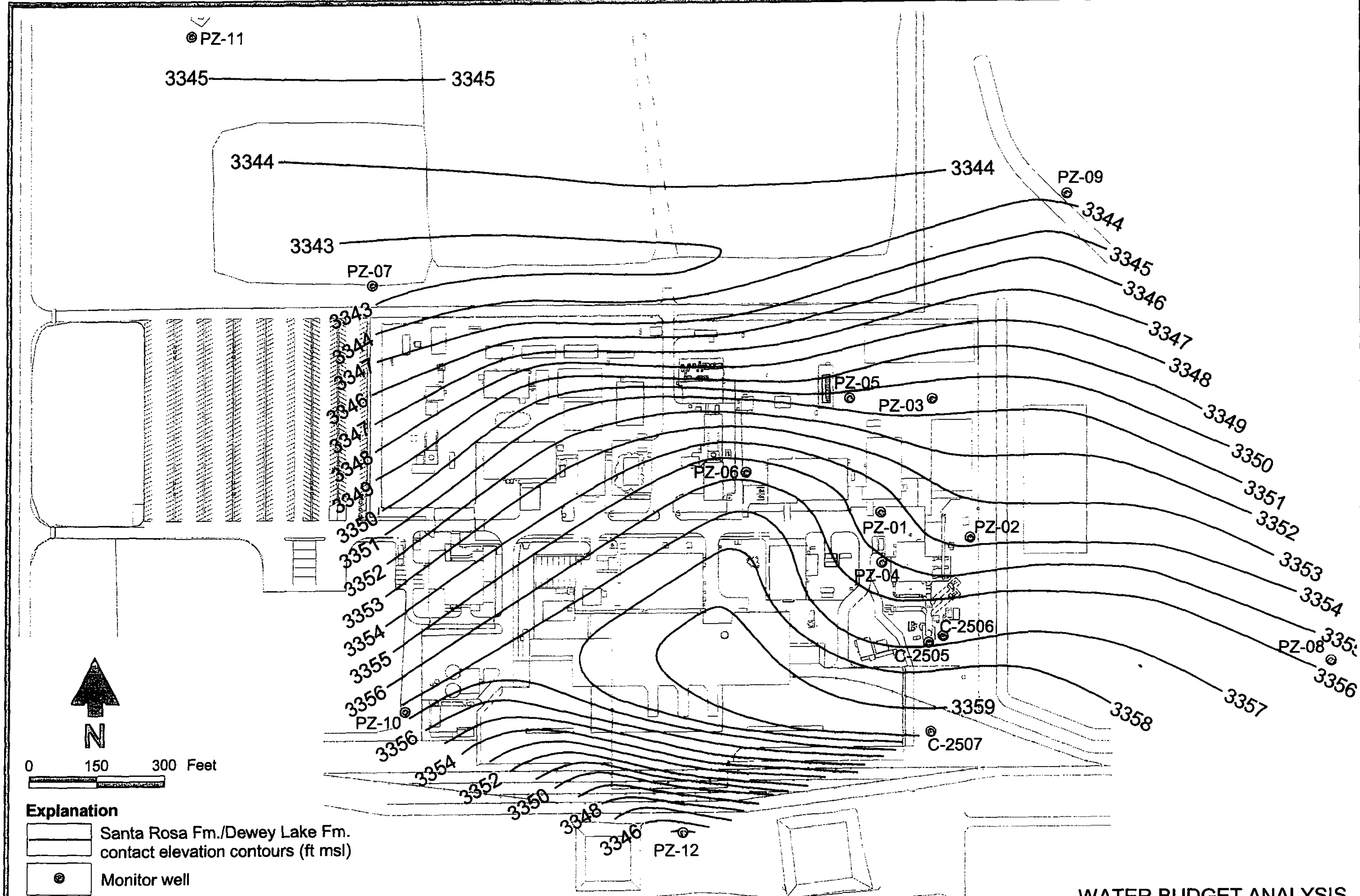

Note:
Elevation from PZ-04 was omitted from contouring

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Contours of Santa Rosa/Dewey Lake Contact

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Figure 21

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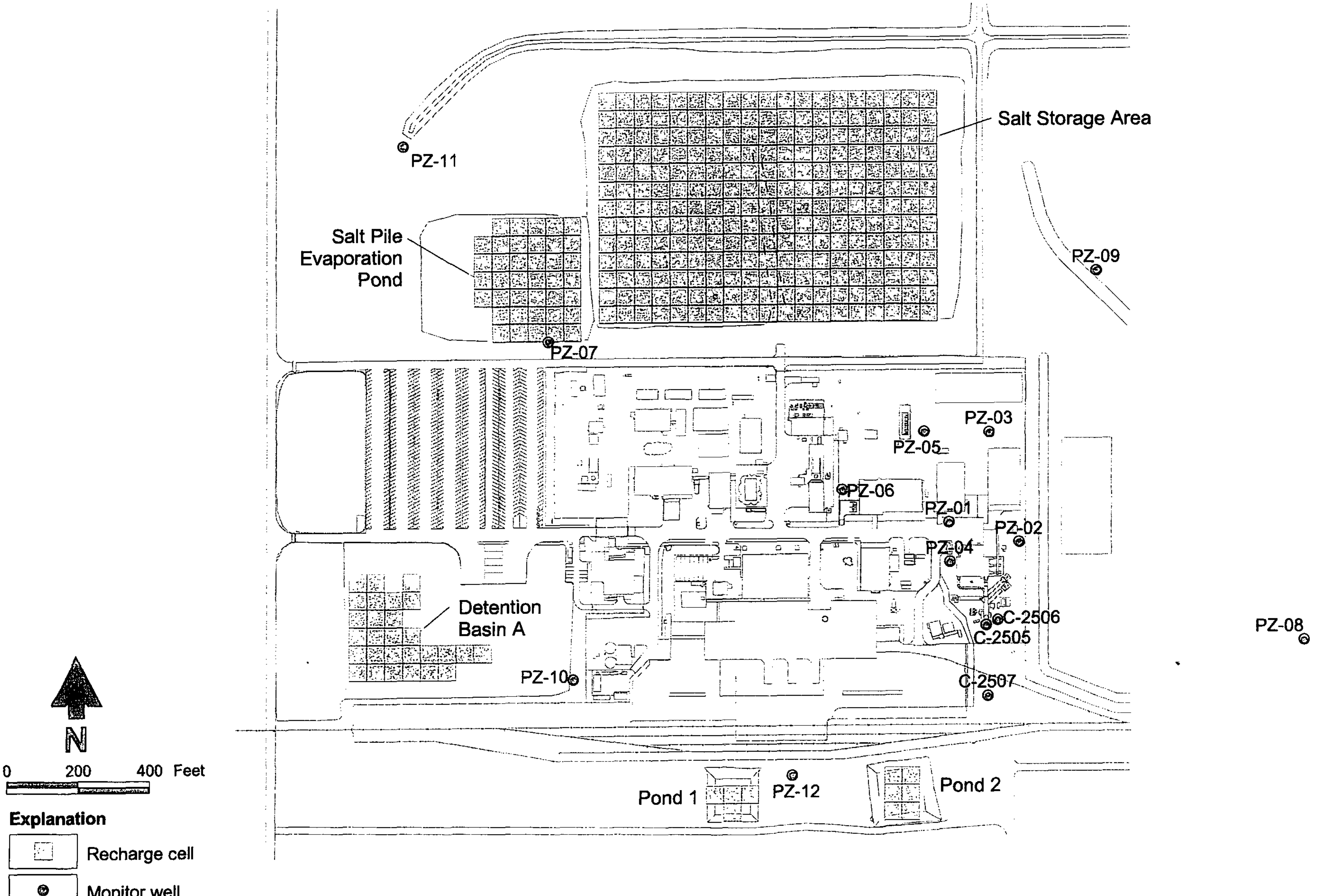

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Recharge Areas in MODFLOW Models

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Figure 22

the boundaries of the site, constant-head boundaries were placed at the estimated extent of the saturated area (Figure 23), based on the results of the calibrated transient model described in Section 6.2.3.

The spatial distribution of hydraulic conductivity of the Santa Rosa was estimated from several slug tests and pumping tests. As shown in Table 11, hydraulic conductivity values ranged from 0.007 to 15.5 ft/d. Several simulations were run using the two hydraulic conductivity zones shown in Table 11. However, the simulation that best represented observed water levels was a homogeneous hydraulic conductivity distribution using a calibrated value of 1 ft/d, which is close to the geometric mean of all the measurements (0.72 ft/d). While the calibrated hydraulic conductivity value differs significantly from some measurements at individual wells, it provides a good representation of the overall SSW flow field and observed water levels.

6.2.2.2 Steady-State Model Results

Figure 23 shows the simulated steady-state water level elevations in the Santa Rosa, and Table 12 presents the final calibrated recharge rates. The model reasonably predicts general flow directions and the steepening of the gradient to the east and south and provides reasonable estimates of recharge rates from the various seepage sources. However, the results do not represent a unique solution; simulation of other combinations of recharge rates may yield similar water level results.

The steady-state model predicts that seepage rates from the Salt Storage Area and Salt Pile Evaporation Pond dominate the seepage inputs to the SSW. This is due to the proximity of these seepage sources to the apex of the water table mound near monitor well PZ-7, in the northern portion of the observed SSW lens. At the southern edge of the site near monitor well PZ-12, the model tended to predict water levels higher than actual values, leading to relatively low predicted seepage rates for Detention Basin A and Ponds 1 and 2. A probable cause for this difference is that the field-measured hydraulic conductivity (5.98 ft/d) exceeds the values assigned to the model near this well, and the Santa Rosa/Dewey Lake contact slopes steeply southward at this location.

6.2.3 Transient Analysis

The objective of the transient analysis was to simulate the progressive saturation of the SSW due to increased recharge from the five primary seepage sources, beginning with the WIPP facilities development in 1981. The transient analysis considered variable recharge rates needed to simulate the observed water level hydrographs at the SSW monitor wells for the record available from 1996 to 2002. The results include seepage estimates for each source and estimates of the extent of the SSW saturated lens and volume in storage.

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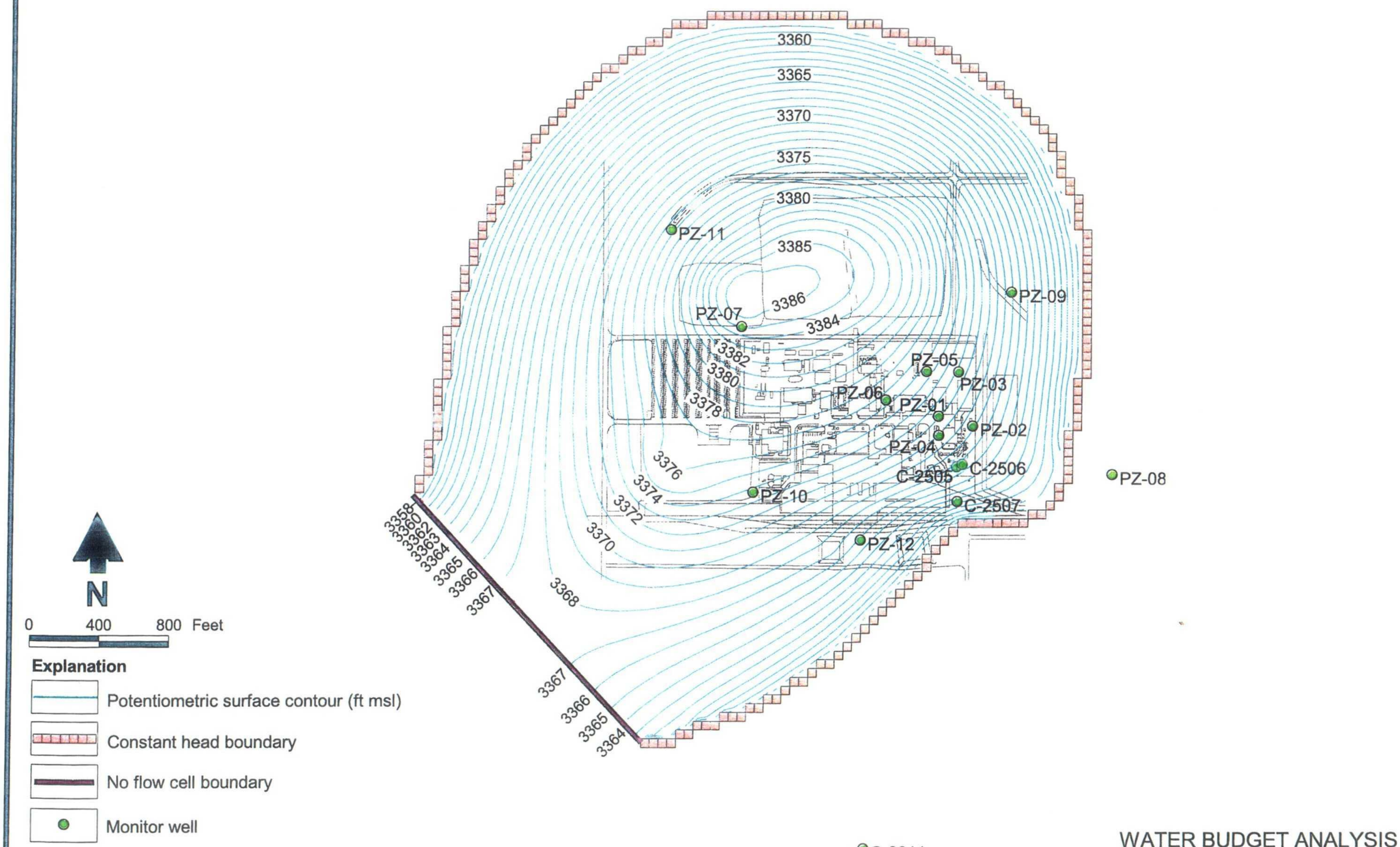

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Simulated Potentiometric Surface
Contours for Steady-State MODFLOW Model

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Figure 23

Table 11. Hydraulic Conductivities

Well	Zone	Test Date	Hydraulic Conductivity (ft/day)	Arithmetic Average of Hydraulic Conductivity at Well (ft/day)
C-2505	1	10/17/96[a]	15.5	8.87
		03/06/97[b]	2.21	
C-2506		02/25-28/96[b]	5.64	4.92
		10/17/96[a]	4.20	
C-2507		10/17/96[a]	0.442	1.05
		09/05/97[c]	1.67	
PZ-04		09/05/97[c]	0.686	0.686
PZ-06		08/21/97[c]	1.06	1.06
PZ-07		09/07/97[c]	0.490	0.490
PZ-10		09/12/97[c]	1.47	1.47
PZ-11		09/12/97[c]	0.930	0.930
PZ-12		09/06/97[c]	5.98	5.98
Geometric Mean for Zone 1				1.723
PZ-01	2	09/05/97[c]	0.0162	0.0162
PZ-02		09/06/97[c]	0.00748	0.00748
PZ-05		08/22/97[c]	0.0394	0.0394
Geometric Mean for Zone 2				0.017
Geometric Mean for All Wells				0.72

Notes: Hydraulic testing has not been performed on PZ-03 and PZ-09.
Monitor well PZ-08 is dry.
ft/day = Feet per day

References:
[a] Intera (1996)
[b] Intera (1997b)
[c] Intera (1997a)

Table 12. Final Calibrated Recharge Rates, Steady State Model

Location	Calibrated Recharge Rate (inches per year)	Recharge Volume (gallons per year)
Salt Storage Area	9	3,500,000
Salt Pile Evaporation Pond	29	1,400,000
Detention Basin A	9	390,000
Pond 1	9	60,000
Pond 2	9	80,000

6.2.3.1 Transient Model Approach and Calibration

The transient analysis used MODFLOW-SURFACT to simulate saturated/unsaturated flow using the model's capabilities for re-wetting of dry cells to progressively saturate the SSW lens from initially unsaturated conditions. The transient model used a constant head boundary of 0.1 foot above the Santa Rosa/Dewey Lake contact on the north, east, and south borders of the model, with a "no-flow" boundary to the southwest, where the Santa Rosa pinches out. Recharge was applied at variable annual rates from 1981 to 2002 (Figure 24), beginning between 1981 and 1984 from the various seepage sources, based on records of construction of the various ponds and the Salt Storage Area.

The recharge rates at the four storm water ponds were established using a linear regression calculated between the annual precipitation rate and the recharge rate estimated from the unsaturated flow modeling (Section 6.1) and storm water runoff calculations (Section 5). Using the precipitation record from the WIPP weather station for 1991 through 2002 and from the Carlsbad FAA weather station for 1981 through 1990, the recharge to the SSW was estimated from the linear regressions. The recharge rates for the Salt Storage Area were initially set as a given percentage of precipitation and then adjusted until simulated hydrographs were in agreement with observed hydrographs during the 1996 to 2002 record.

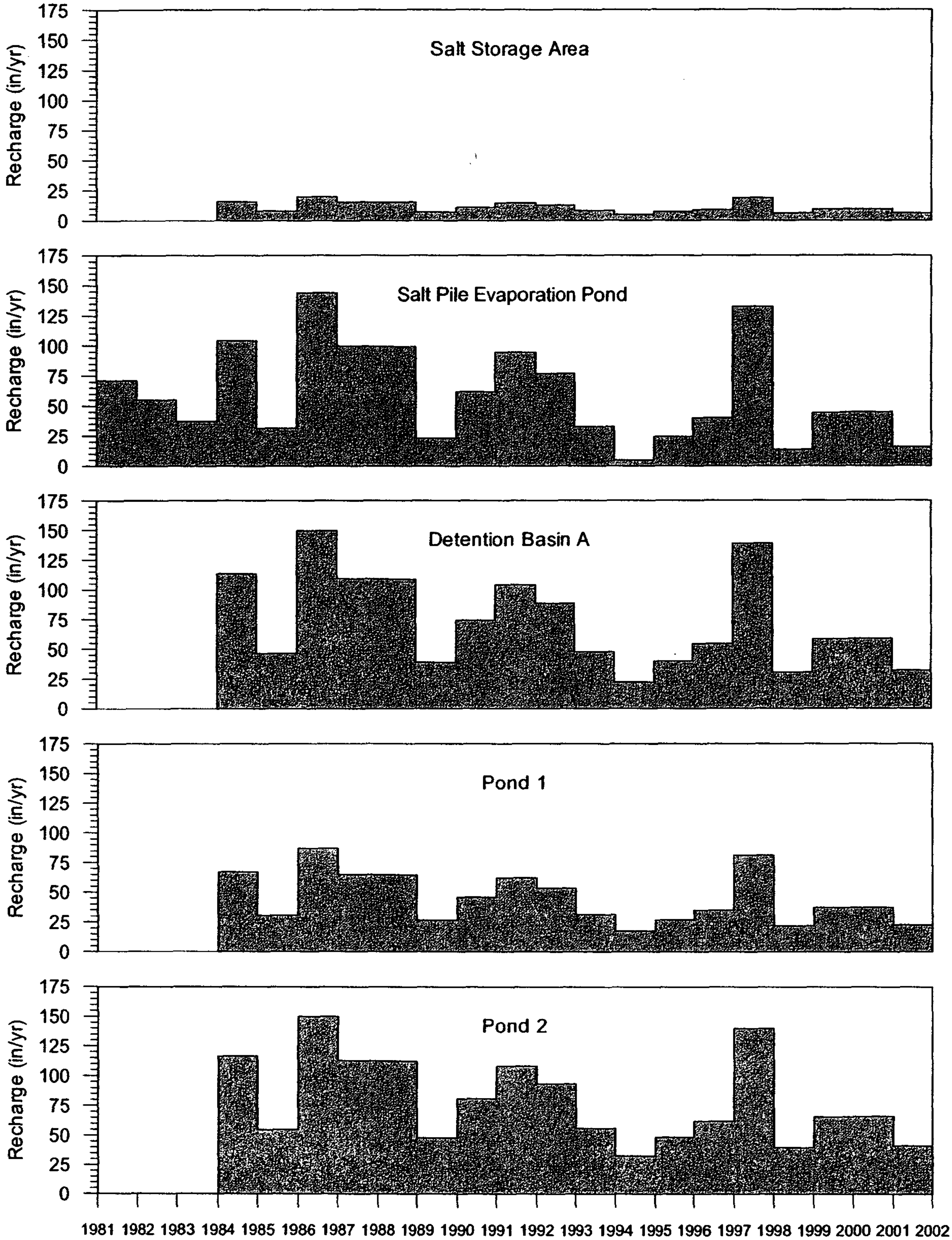
The transient model used two hydraulic conductivity zones set at 1.7 ft/d for Zone 1 and 0.017 ft/d for Zone 2 (Table 11, Figure 25). The lower hydraulic conductivity zone (Zone 2) surrounds PZ-01, PZ-02, and PZ-05 (Table 11) and was also extended around PZ-08 because the dry condition in this well may be due to a lower hydraulic conductivity that inhibits the wetting front advance.

The transient model requires the storage parameter specific yield, defined as the ratio of the volume of water that drains from saturated rock due to gravity to the total volume of rock (Fetter, 1993). A uniform specific yield of 0.1 was assigned to the entire model, based on an estimated 0.13 porosity (Nicholson and Clebsch, 1961) and an assumed 0.03 residual water content.

6.2.3.2 Transient Model Results

Results of the MODFLOW transient analysis are illustrated in Figures 26 and 27, which show the simulated potentiometric surface contours and saturated thickness contours, respectively. Comparison of the simulated water level fluctuations with the observed hydrographs for each SSW monitor well shows that the simulation tracked the observed conditions favorably at most wells, with the more significant differences occurring primarily at wells with particularly high or low hydraulic conductivities based on field test results.

The recharge rates for the retention ponds were constrained by the storm water flow calculations (Section 5), which specify relative amounts of flow to each pond. Recharge rates are variable from year to year, based on long-term precipitation records, with seepage of storm water partitioned among the primary seepage sources.



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WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER

Recharge Rates Applied in Transient Model

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Figure 24

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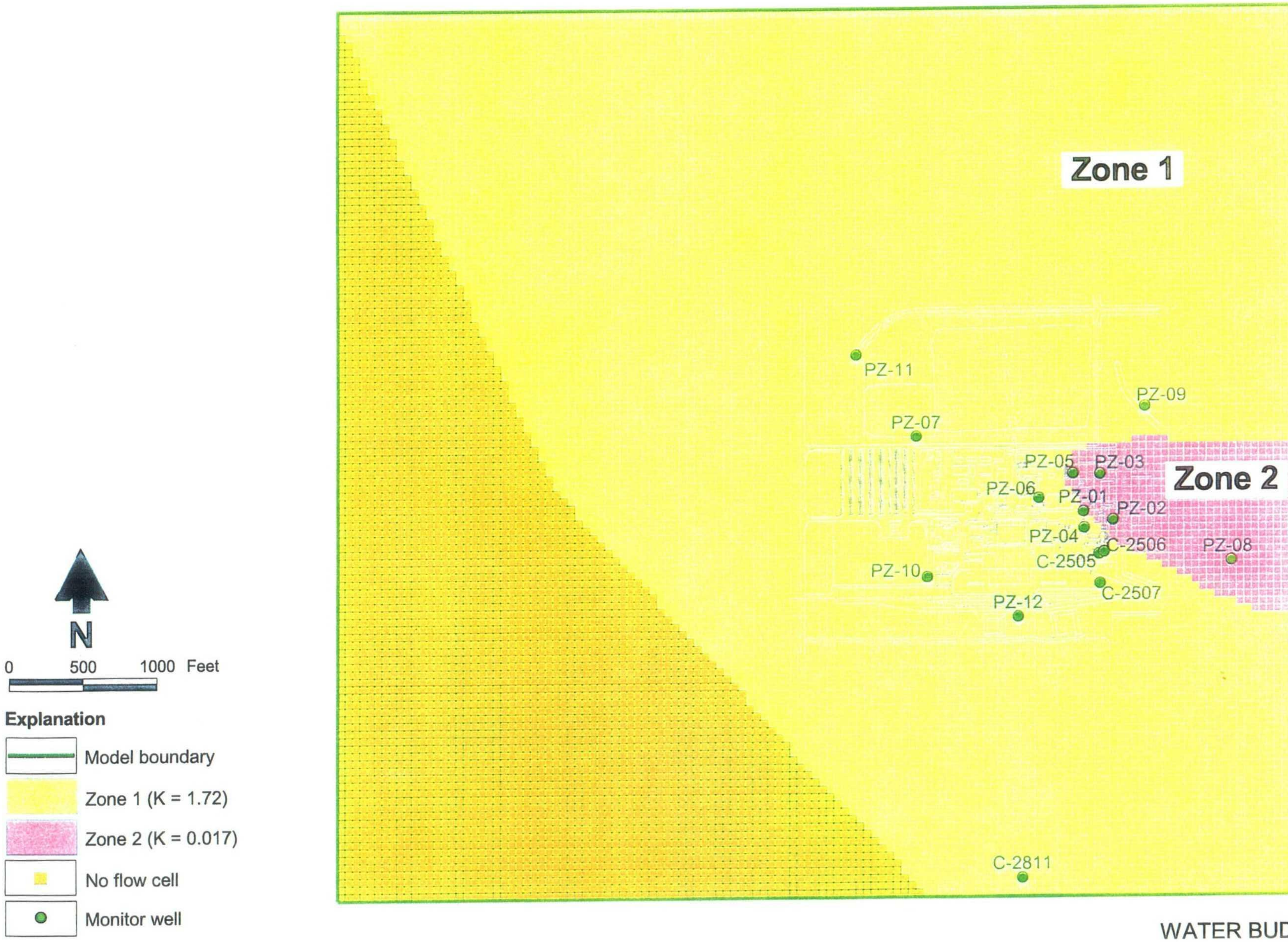

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER

Spatial Distribution of Hydraulic Conductivity for Transient Analysis

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Figure 25

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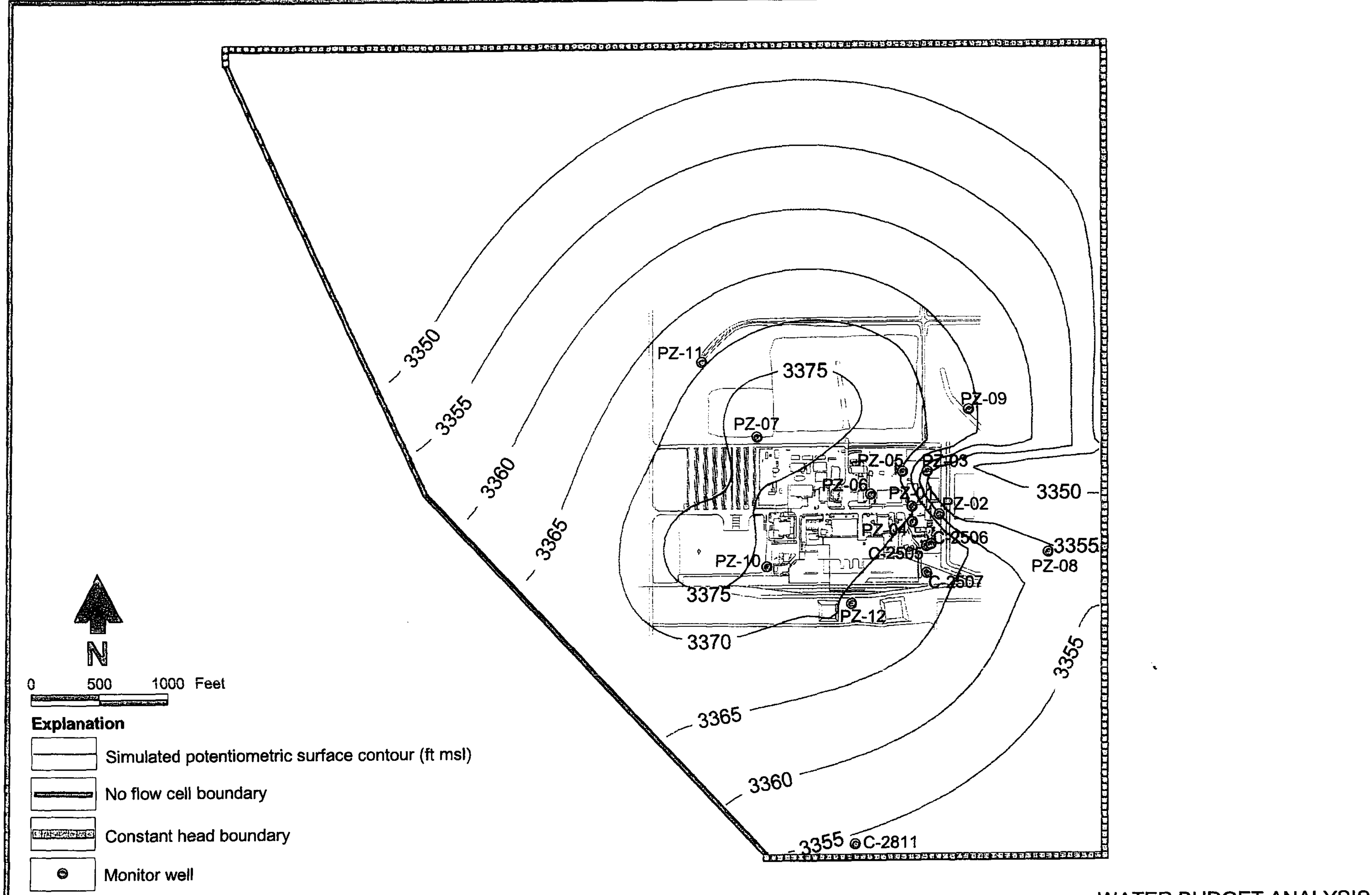

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Simulated Potentiometric Surface Contours, December 2002

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Figure 26

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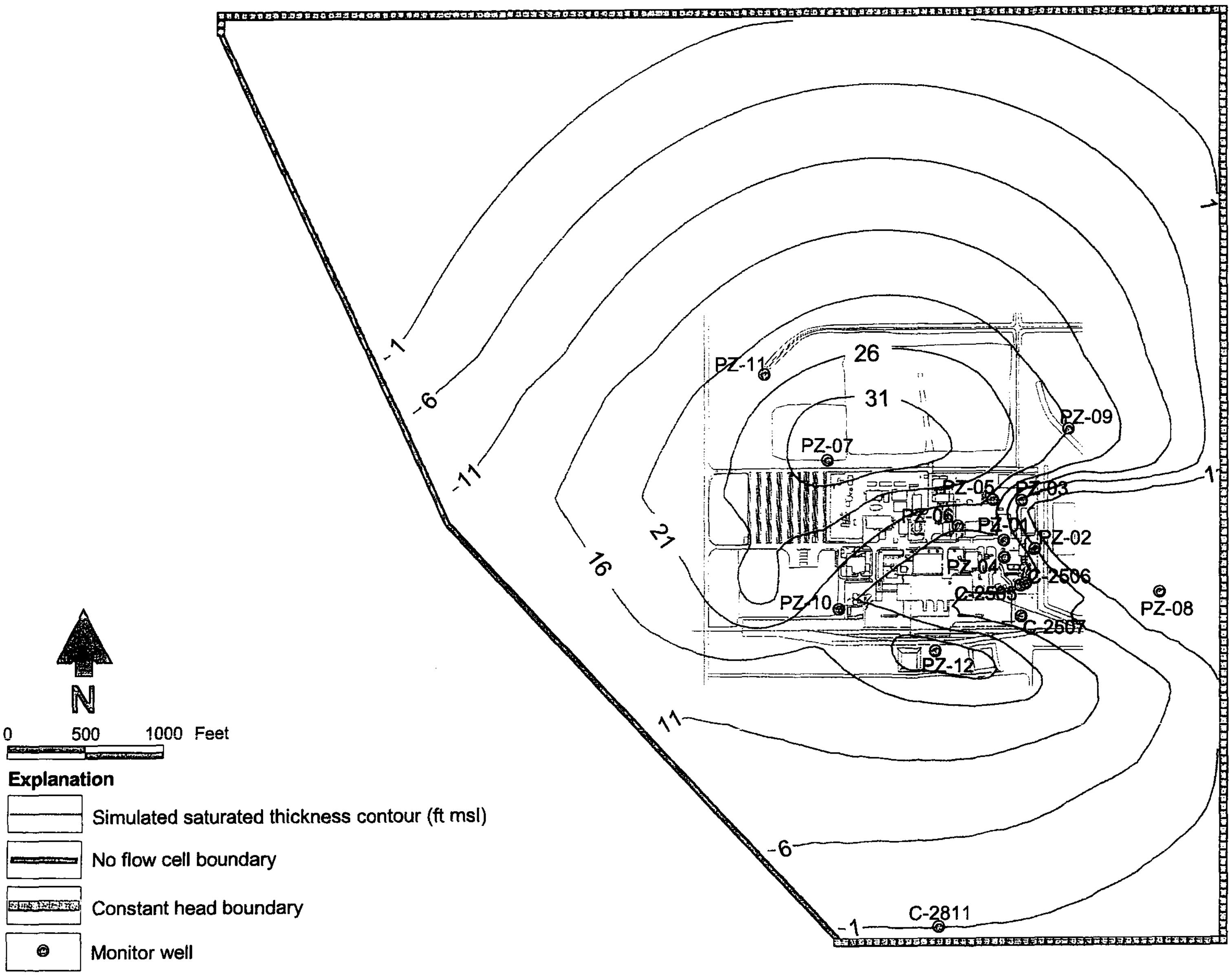

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Simulated Saturated Thickness Contours, December 2002

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Figure 27

Table 13 shows the estimated recharge rates from the transient model calibration. The transient model demonstrates that, using reasonable recharge rates, combined recharge from the five primary sources could have created the observed SSW saturated zone in the timeframe since the WIPP site was first developed. The model shows that the saturated zone is areally extensive and provides a reasonable simulation of the increasing SSW water levels over time. The seepage rates predicted by the transient model are not necessarily a unique solution, and it is possible that other combinations of parameters would provide similar results.

Table 13. Final Calibrated Recharge Rates, Transient Model

Location	Calibrated Recharge Rate[a] (in/yr)			Average Volume (gal/yr)
	Average	Minimum Annual	Maximum Annual	
Salt Storage Area	11.0	5.1	19.9	4,200,000
Salt Pile Evaporation Pond	59.4	4.7	143.8	3,000,000
Detention Basin A	73.0	22.2	149.6	3,200,000
Pond 1	44.9	17.2	86.7	280,000
Pond 2	79.3	32.6	149.7	740,000

[a] Recharge rate statistics calculated for years when recharge was applied (1981 through 2002 for Salt Pile Evaporation Pond; 1984 through 2002 for all others).

in/yr = Inches per year
gal/yr = Gallons per year

6.2.3.3 SSW Volume Estimate

The simulated saturated thickness contours presented in Figure 27 provide a basis to estimate the total volume of the SSW saturated zone. The MODFLOW-SURFACT transient analysis predicts a seepage input to the SSW of 242 million gallons from 1981 to 2002. Since this input represents only seepage and does not include the initial moisture content in the Santa Rosa Formation, which is assumed to be 0.03 (based on a porosity of 0.13), the total SSW volume is estimated to be 315 million gallons.

The transient analysis projects saturation over a broad 520-acre area extending beyond the SSW monitor wells, and the estimated SSW volume is thus far higher than the estimate of 108 million gallons presented in Section 3.1, which is based more directly on the SSW saturated zone observed in on-site monitor wells. The higher SSW volume estimate from the transient analysis, however, is dependent on projecting information on the Santa Rosa's hydraulic properties considerably beyond the area where data are available, leading to added uncertainty with this estimate.

7. Long-Term Migration Modeling

The potential extent of long-term SSW migration was examined using the transient MODFLOW-SURFACT model over a model domain extended to the WIPP land withdrawal boundary. The potential for migration was examined both with and without the engineered controls that are being planned by DOE to prevent seepage from the primary seepage sources and reduce SSW migration.

The long-term migration model added features to the MODFLOW-SURFACT model to provide predictive simulations for a 100-year timeframe and more detailed consideration of:

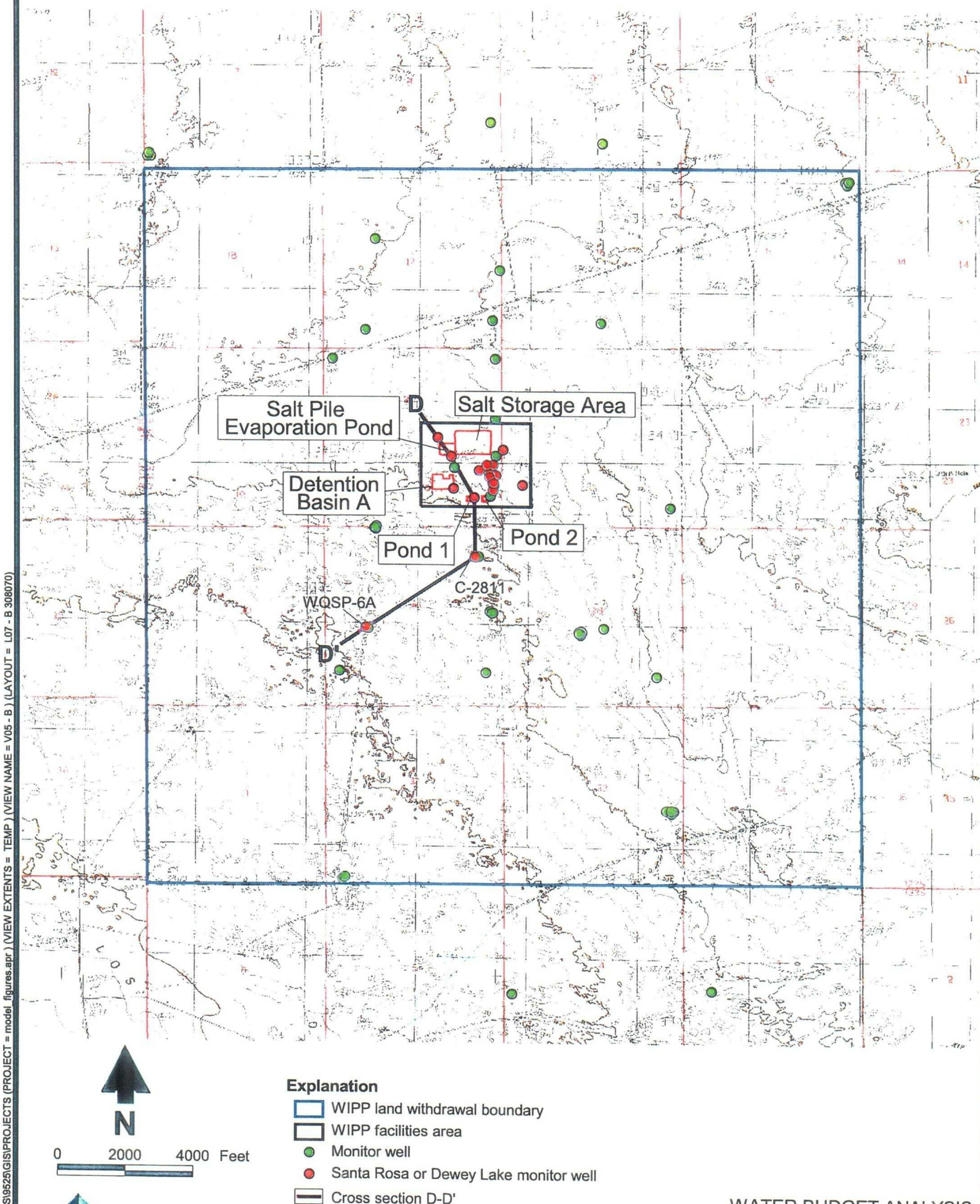
- Hydrogeologic characteristics of the Gatuña, Santa Rosa, and Dewey Lake Formations over the larger modeling domain
- Locations of potential groundwater resources that could be affected by SSW migration
- Potential for top down SSW migration from the Santa Rosa through the unsaturated zone and into lower horizons in the Dewey Lake Formation

Previous investigation activities at the WIPP have provided considerable information on the hydrogeologic regime, which was used to create a model domain that reasonably simulates expected SSW conditions in the future. The long-term migration modeling establishes a reasonable scenario of SSW distribution between the Santa Rosa and Dewey Lake Formations, as the SSW lens expands laterally and leaks downward into the Dewey Lake Formation. To provide confidence in the validity of the predictive simulations, the model was first calibrated to represent the SSW conditions currently observed.

This section describes the scenarios modeled to predict the potential long-term SSW migration conditions and the effects of engineered seepage controls. The simulations follow the expected timeline for WIPP operations and final decommissioning, although the schedule is subject to variability. The timelines for various model scenarios are presented in Section 7.1.1. The conceptual model and model domain are described in Sections 7.1.1 and 7.1.2, and model calibration is described in Section 7.2. Results of the long-term migration modeling are presented in Section 7.3.

7.1 Conceptual Model and Model Domain

The model simulated long-term SSW migration in the Santa Rosa, Dewey Lake, and Gatuña Formations within the 16-square-mile WIPP land withdrawal boundary (Figure 28). Seepage inputs to the SSW are focused near the center of model domain at the WIPP facilities area, and migration is controlled by the hydrogeologic characteristics of the formations. The model uses the seepage estimates from Section 6 as input for transient simulations that depict lateral migration and downward flow in a two-layer system.



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WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER

Long-Term Migration Model Domain Base Map

Figure 28

7.1.1 Conceptual Model

The conceptual model depicts potential migration of the SSW perched lens that has been identified in the Santa Rosa by previous site investigations. An upper Layer 1 includes the Santa Rosa and, where the Santa Rosa pinches out, the Gatuña, with lateral flow of the perched lens above the Dewey Lake contact. The deeper Dewey Lake is modeled as Layer 2, with downward vertical leakage providing recharge that creates a second saturated lens in the Dewey Lake. The potential migration of SSW is a top-down process, with 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 saturated horizon in the middle Dewey Lake is the shallowest groundwater depth interval used for water supply near the WIPP boundary, with wells south of the boundary producing from depths of 100 to 200 feet bgs.

Downward flow from the Santa Rosa to the Dewey Lake depends on the low-permeability siliceous layer at the contact and the sulfate cementation change in the lower Dewey Lake. Downward leakage in the upper Dewey Lake is modeled using a uniform vertical hydraulic conductivity, although the downward leakage is likely to occur in a complex system of fractures and permeable zones that create a heterogeneous flow field. The conceptual model represents a conservative approach in that it routes all of the Dewey Lake recharge to accumulate in a single layer as a saturated lens in the middle Dewey Lake, 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 predictive simulations follow a timeline for WIPP operations that is based on input provided by DOE (2003a, 2003b). DOE is pursuing implementation by 2004 of engineered seepage controls, which will include covering the Salt Storage Area and lining the storm water ponds, to virtually eliminate the sources of increased seepage, including the apparent sources of saline seepage. The WIPP operating period is planned to extend until 2035. The water budget assumes that after site decommissioning, the site will be restored in a way that eliminates the sources of enhanced seepage. The long-term model was run for an initial calibration stage from 1981 to 2002 and a 100-year migration stage from 2003 through 2102, well beyond facility closure.

7.1.2 Model Domain

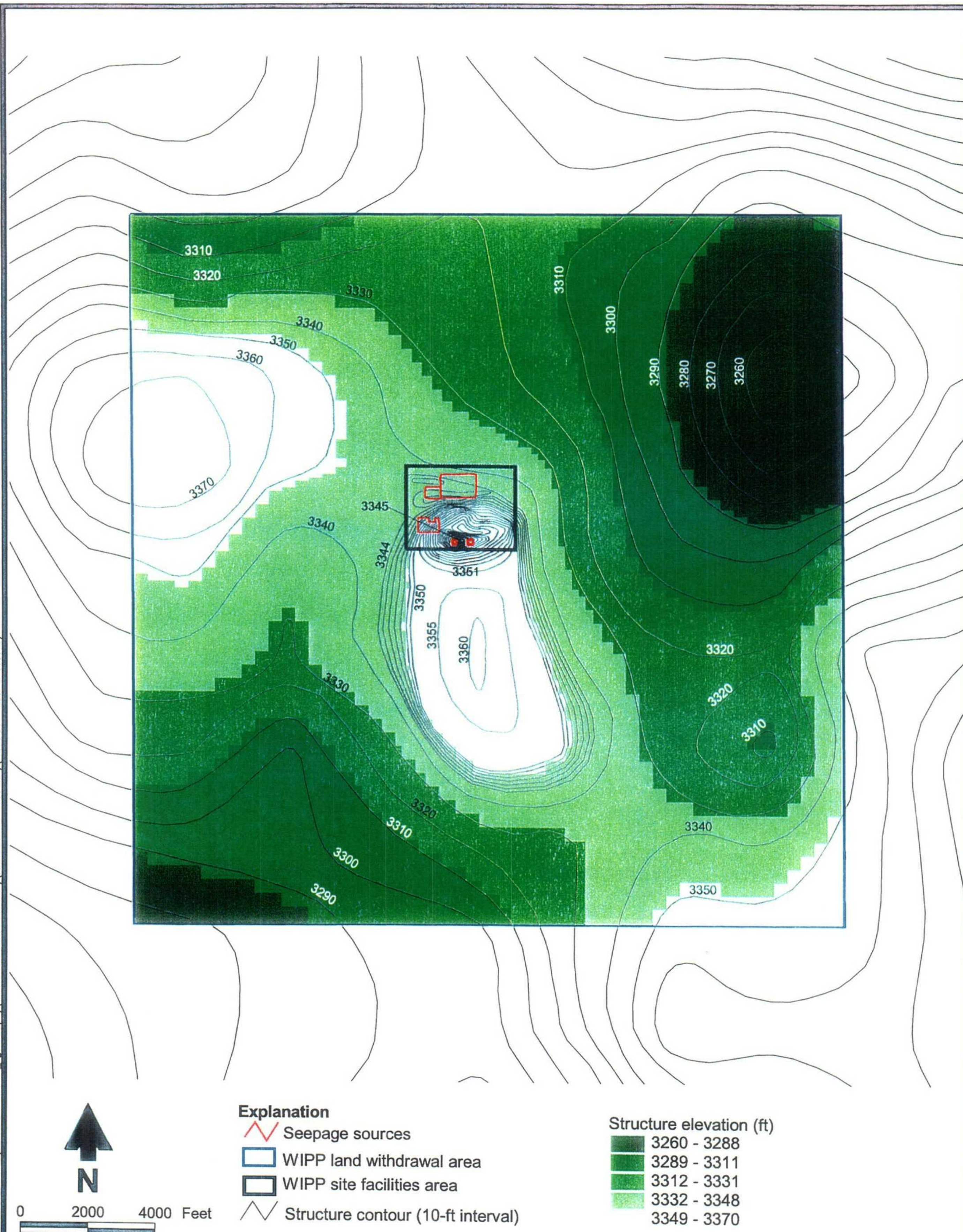
The model domain encompasses the formations where SSW has been identified and where it may potentially migrate. The domain includes the one-layer MODFLOW-SURFACT saturated flow model described in Section 6.2, which includes formation contacts developed from results of drilling near the primary seepage sources. The domain is expanded for the long-term migration model based on the structural contours and reported hydrologic characteristics of the Santa Rosa, Gatuña, and Dewey Lake Formations.

The top of Layer 1 is at ground surface, and the bottom is defined by structural contours of the top of the Dewey Lake from the WIPP Compliance Certification Application (U.S. DOE, 1996), merged with the updated contours from the PZ- and C-series wells (Figure 29). The bottom of Layer 2 was defined by the transition from carbonate to sulfate cementation in the Dewey Lake, where gypsum fracture infilling is reported to reduce porosity and permeability (Powers, 2003a). Saturated conditions are found above the cementation change in the middle Dewey Lake in the southwest corner of the WIPP site, near monitor well WQSP-6A. The conceptual model assumes the accumulation and migration of a saturated lens above the cementation change, as a conservative approach to examine the potential for SSW migration to reach naturally occurring groundwater. The elevation contours of the uppermost reported sulfate cementation are based on Powers (1997) (Figure 30), although this report suggests some uncertainty with regard to interpretation of the contours. At the boundary of the model domain, no-flow boundary conditions were set at the perimeters of Layers 1 and 2, and a no-flow boundary condition was set at the base of Layer 2. Figure 31 illustrates a cross-section of the stratigraphic boundaries that control SSW migration within the model domain.

Downward leakage from Layer 1 to Layer 2 is limited by a siliceous layer at the Santa Rosa/Dewey Lake contact, identified during drilling of the PZ- and C-series wells (Intera, 1997a; Powers, 2003b). The SSW is perched above the siliceous layer, but the layer's extent and continuity are uncertain. The model domain includes a 1-foot-thick low-permeability layer over the entire Santa Rosa/Dewey Lake contact. The vertical hydraulic conductivity of the siliceous layer is a key model calibration parameter; derived from the seepage rates estimated in Section 6 and the observed thickness of the SSW saturated lens. The low-permeability layer is absent where the Gatuña overlies the Dewey Lake.

Seepage into the Exhaust Shaft is simulated in the model as a well, where water is lost from the SSW system. The model allows seepage to continue at a constant rate until facility closure in 2035. Based on estimates reported by DOE (2002), the seepage rate was set at 1 gpm, which is conservative in retaining the most SSW storage.

The long-term migration model domain and boundary conditions are illustrated in Figure 32. This figure uses an extreme vertical exaggeration as a conceptual illustration of the model components. The actual thickness of the two-layer model is highly variable, ranging from 70 to 500 feet thick across the site. This variability is primarily a result of the irregular surface of the uppermost reported sulfate cementation change contours (Figure 30), which varies by more than 400 feet in elevation at the base of Layer 2. Layer 2 generally thins toward the northeast corner of the site and thickens in the northwest and southwest corners of the site. Layer 1, consisting of the Santa Rosa and Gatuña, is up to 270 feet thick in the eastern portion of the site, but is absent in the western portion of the site, where these formations have been removed by erosion and the Dewey Lake is covered only by thin, surficial soils.



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WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER

Structure Contours on Top of Dewey Lake

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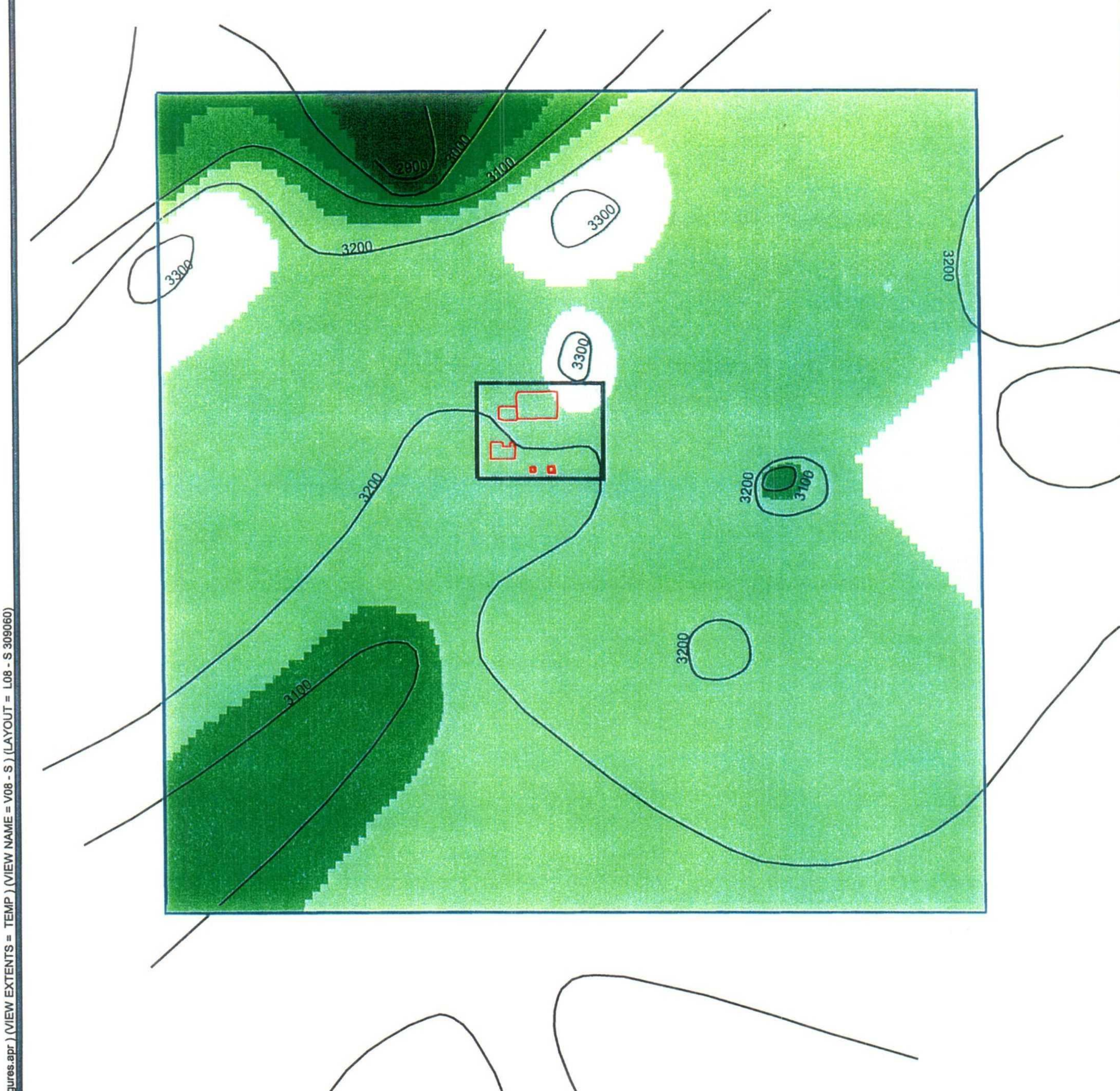
Figure 29



N

0 2000 4000 Feet

Explanation
- Seepage sources
- WIPP land withdrawal area
- WIPP facilities area
- Uppermost sulfate contour (100-ft interval)

Uppermost sulfate elevation (ft)
- 2900 - 2979
- 2980 - 3059
- 3060 - 3139
- 3140 - 3219
- 3220 - 3300

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Uppermost Reported Sulfate Elevation

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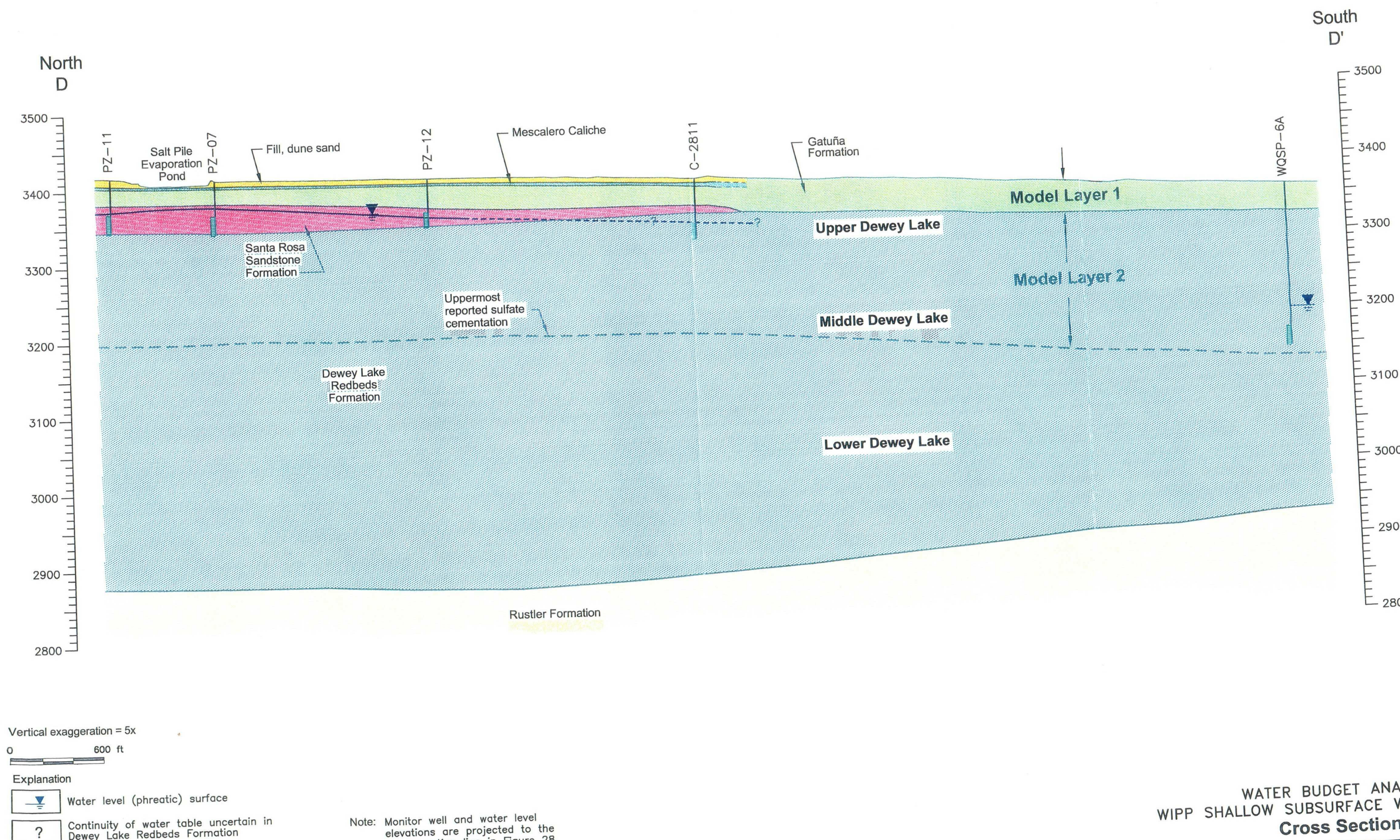
Figure 30



Note: Monitor well and water level elevations are projected to the cross section line in Figure 28.

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Cross Section D-D'

Figure 31

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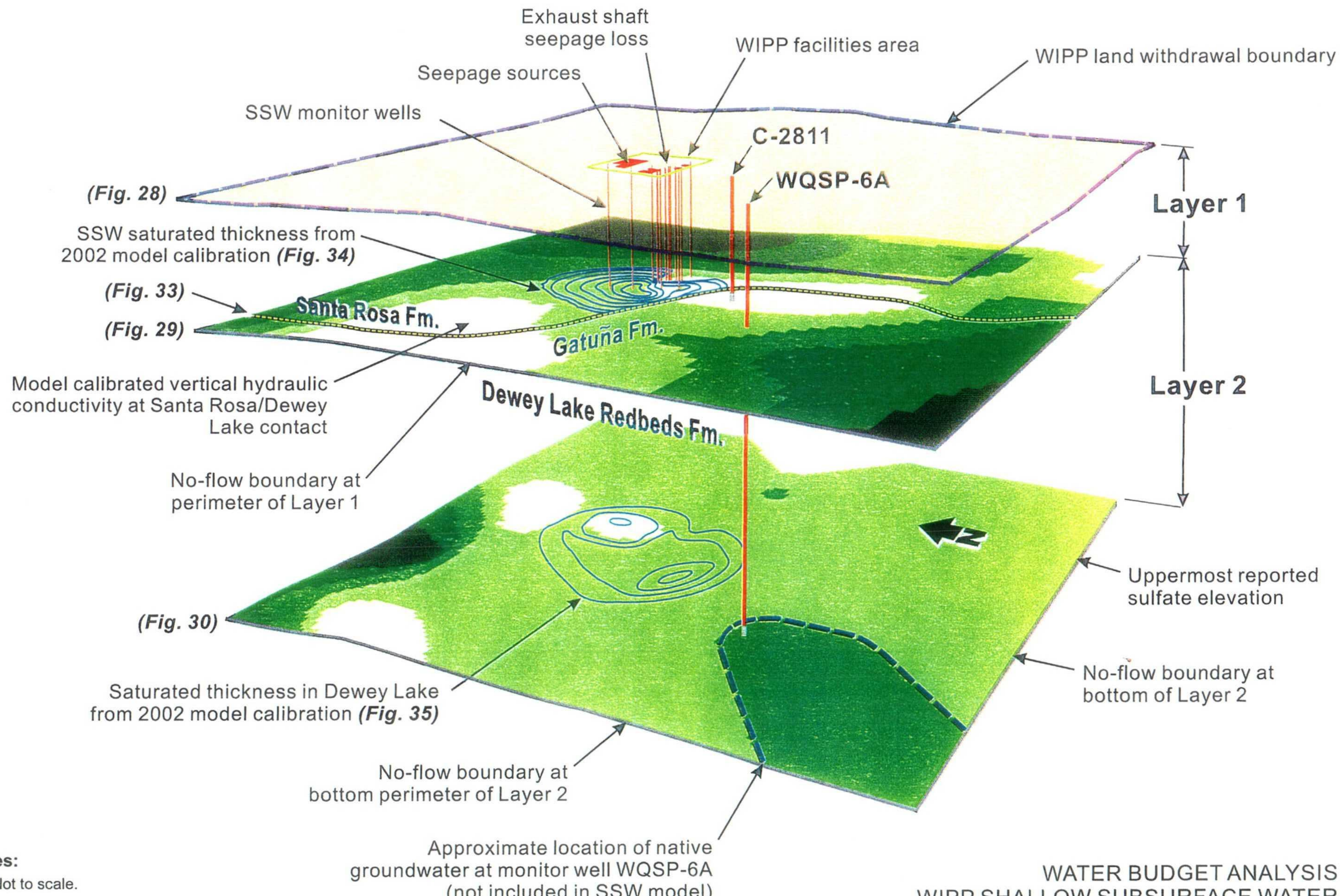

Notes:

1. Not to scale.
2. Vertical exaggeration greatly expanded for illustration.

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER

Long-Term Migration Model Domain and Boundary Conditions

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Figure 32

7.2 Long-Term Migration Model Approach and Calibration

The long-term migration model was used to simulate a variety of scenarios using transient MODFLOW-SURFACT simulations. The model was run for a calibration phase (1981 to 2002) and a predictive phase (2003 through 2102). Model calibration involved a series of iterative input parameter adjustments until a close match was obtained between simulated and observed water levels.

7.2.1 Input Parameters

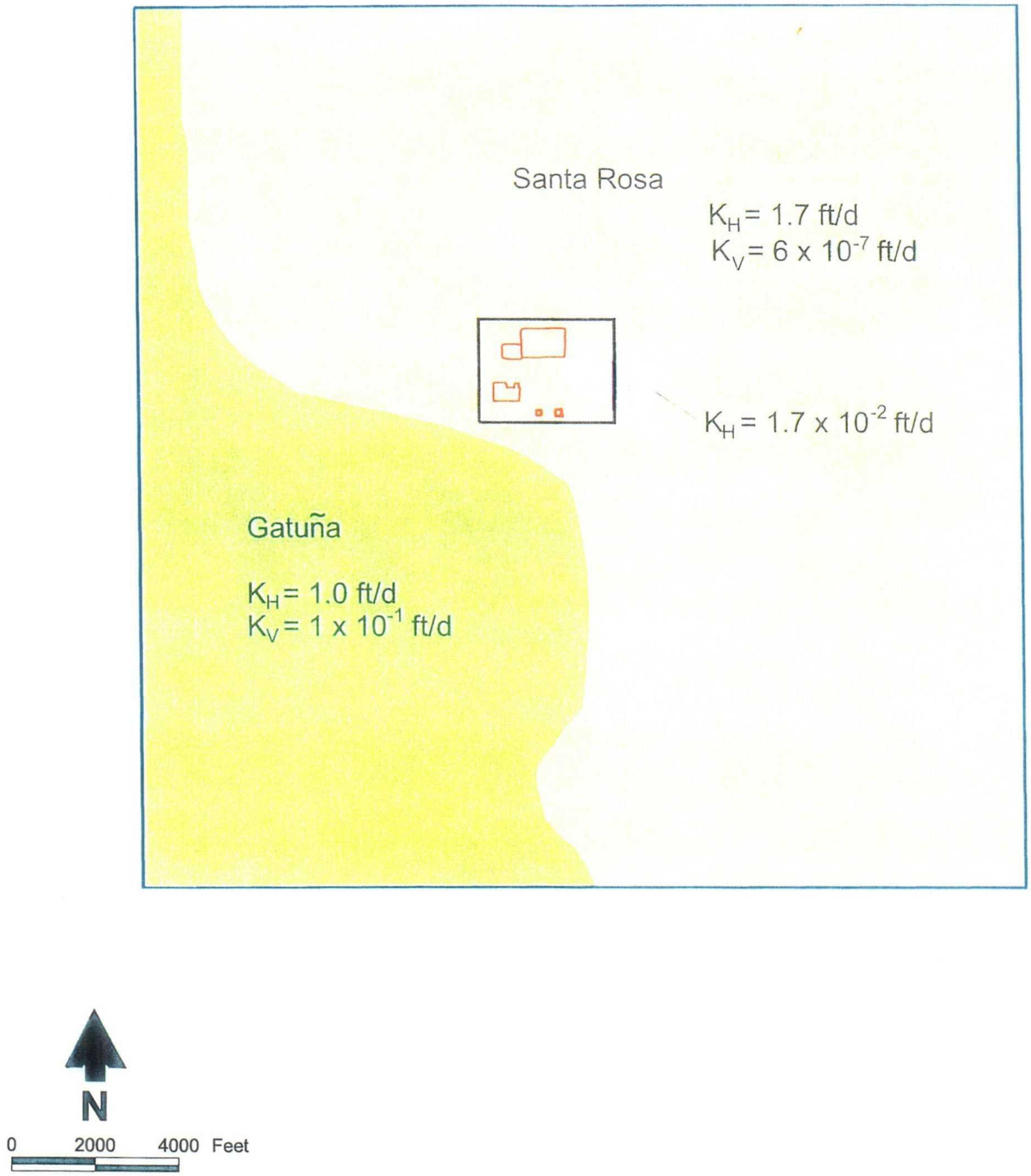
Recharge to the SSW was applied from the Salt Storage Area, Salt Pile Evaporation Pond, Detention Basin A, and Ponds 1 and 2. The very low recharge rate from desert soils across the WIPP site (Section 2.3.2) was not included in the model.

A range of seepage rates was estimated by surface infiltration unsaturated flow modeling using UNSAT-H and saturated flow modeling using MODFLOW (Section 6). The highest seepage rates were predicted by UNSAT-H; therefore, to take the most conservative approach for long-term migration modeling, seepage rates were based on the UNSAT-H model results presented in Section 6.1. The UNSAT-H results gave a linear regression relating seepage to precipitation, and the recharge to the MODFLOW-SURFACT long-term migration model was calculated based on the recorded precipitation for 1981 through 2002. The predictive scenarios calculated seepage based on the average annual precipitation of 13.24 inches from the NOAA WIPP weather station record for 1986 through 2002.

Hydrologic parameters representative of the Santa Rosa, Dewey Lake, and Gatuña Formations were reviewed and compiled from available data and reports for the WIPP site, as well as from other regional literature. Geometric mean hydraulic conductivities were calculated for the Dewey Lake (0.68 ft/d) and Gatuña Formations (1.0 ft/d), and the Santa Rosa is modeled with two hydraulic conductivity zones (1.7 and 0.017 ft/d [Figure 33), consistent with the transient saturated flow model presented in Section 6.2.3.

The vertical hydraulic conductivity must restrict downward seepage sufficiently to simulate SSW accumulation. The siliceous layer at the Santa Rosa/Dewey Lake contact has a vertical hydraulic conductivity several orders of magnitude lower than the horizontal hydraulic conductivities of either formation. The vertical hydraulic conductivity for this contact was established in the model calibration stage, based on seepage rate estimates for 1981 to 2002 (Section 6) and observed hydrographs during the 1996 to 2002 record. The calibration gave a vertical hydraulic conductivity for the siliceous layer of 4×10^{-7} ft/d to provide a close match with the observed hydrographs in the PZ- and C-series wells.

The vertical hydraulic conductivities of the Gatuña and Dewey Lake Formations were estimated as 10 percent of the horizontal hydraulic conductivity based on Domenico and Schwarz (1998), who provide representative values for horizontal and vertical hydraulic conductivities in different



Explanation

- Ponds
- WIPP land withdrawal area
- WIPP facilities area

Notes:

K_H = Horizontal hydraulic conductivity

K_V = Vertical hydraulic conductivity

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER

Model Layer 1
Hydraulic Conductivity Spatial Distribution

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7.2.2 Predictive Simulations

The long-term migration model was used in two predictive simulations to evaluate the effects of engineered seepage controls to limit SSW migration over a 100-year timeframe. This evaluation assumes that the engineered seepage controls, including lining of storm water ponds and channels and covering the Salt Storage Area, will be effective in eliminating seepage from fresh and saline sources that exceeds the very low seepage rates that occur under natural conditions. The following timelines were established for the two predictive simulations.

- *Simulation 1:* SSW migration without seepage controls
  - Seepage continues for the WIPP operating period to 2035.
  - Seepage stops in 2036 and thereafter.
  - SSW migration is simulated through 2102.

- *Simulation 2:* SSW migration with engineered seepage controls
  - Engineered seepage controls are implemented by the end of 2004.
  - Transient drainage continues in 2005, providing continued seepage at constant rates.
  - Seepage stops in 2006 and thereafter.
  - SSW migration is simulated through 2102.

Under each simulation, seepage and SSW accumulation begins in 1981, with seepage rates varying annually based on actual precipitation records. The model is calibrated to match observed conditions in 2002, after which the predictive simulations project SSW migration over 100 years. Both simulations allow seepage into the Exhaust Shaft beginning in 1995 and continuing at a constant rate until final closure is completed in 2035 or until the region around the Exhaust Shaft can no longer sustain the specified 1-gpm flow.

7.3 Long-Term Migration Model Results

The results of the long-term migration model predictive simulations are presented in a series of figures (Figure 34 through 37) that show the extent of the SSW in the Santa Rosa and Gatuña (Layer 1) and the Dewey Lake (Layer 2). These figures illustrate the saturated thickness in each of the two layers in saturated lenses at the bottom of each layer, overlying the low-permeability cementation zones that define the bottom of each layer in the model domain.

Figures 34 and 35 show the saturated thickness in each of the two layers for 2002, at the start of the predictive simulations. These figures illustrate the calibrated model condition that simulates the observed SSW water levels, with a saturated thickness of up to 30 feet in the

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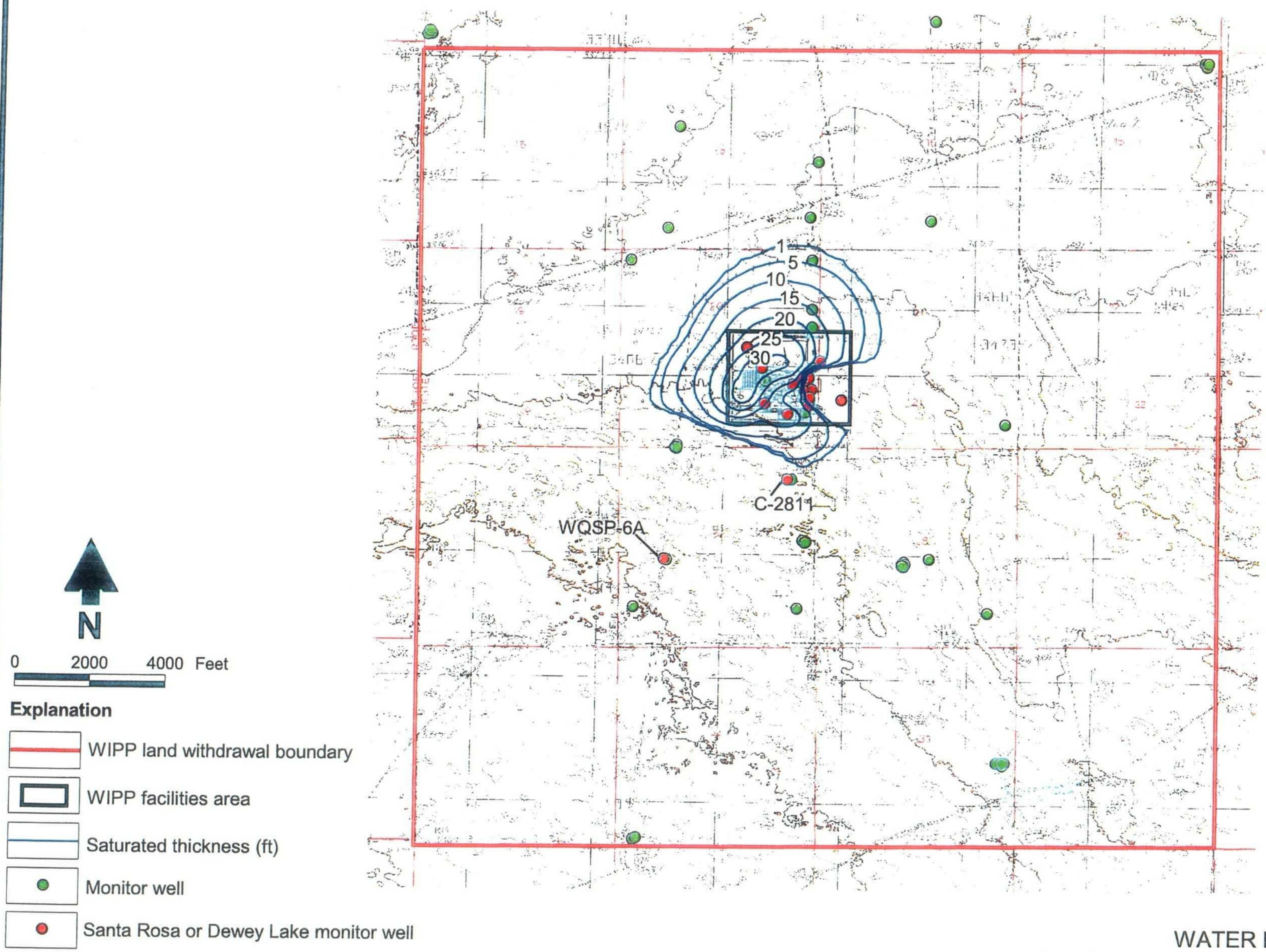

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Long-Term Migration Model Calibration Phase
Santa Rosa/Gatuña Saturated Thickness in 2002

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Figure 34

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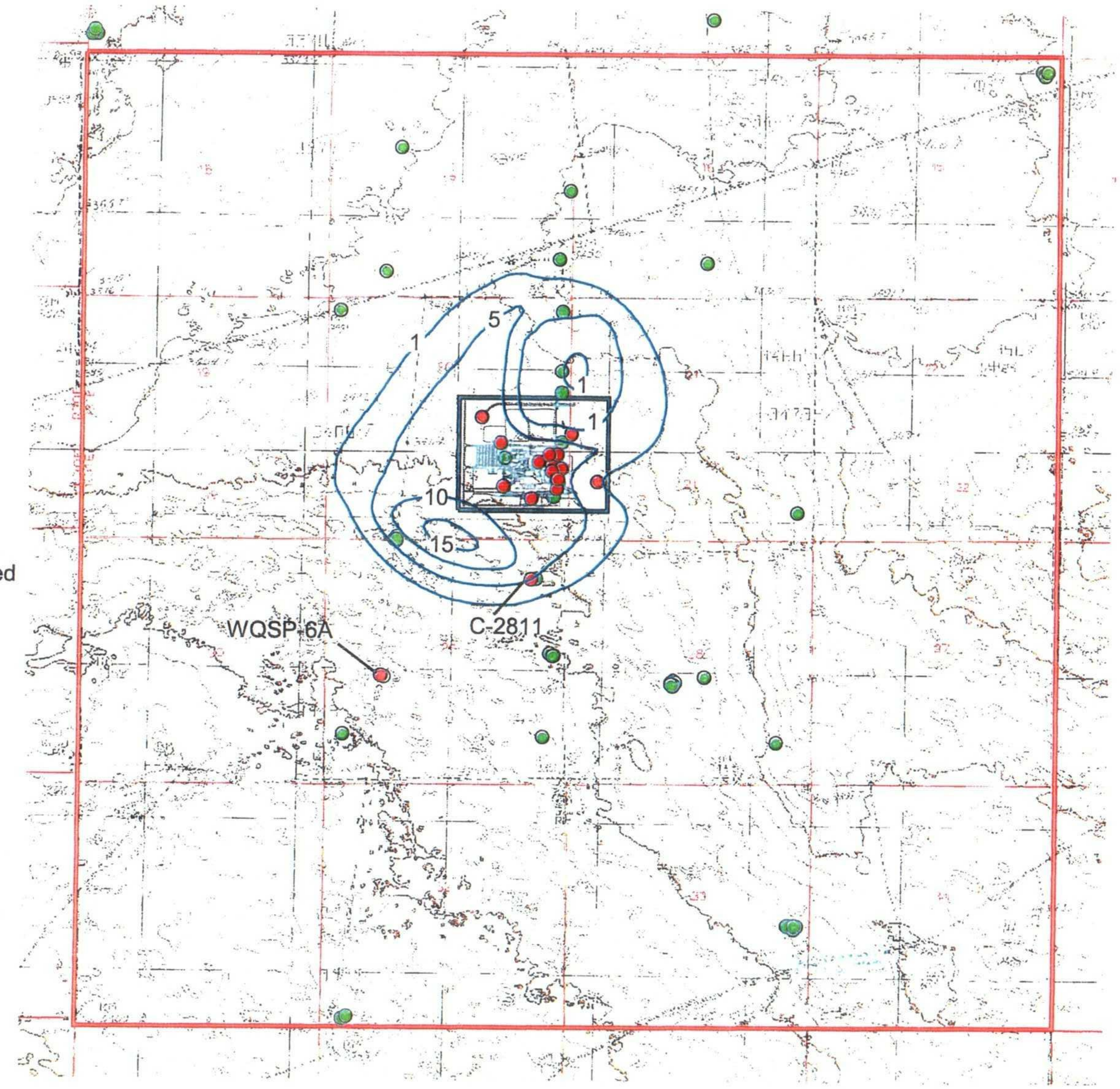
Note:
The model simulates the saturated thickness above the Dewey Lake sulfate cementation change at the base of Layer 2. Monitor well C-2811 is screened approximately 100 feet above the simulated saturation at the base of Layer 2.



N

0 2000 4000 Feet

Explanation

- WIPP land withdrawal boundary
- WIPP facilities area
- Saturated thickness (ft)
- Monitor well
- Santa Rosa or Dewey Lake monitor well

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WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Long-Term Migration Model Calibration Phase
Dewey Lake Saturated Thickness in 2002

Figure 35

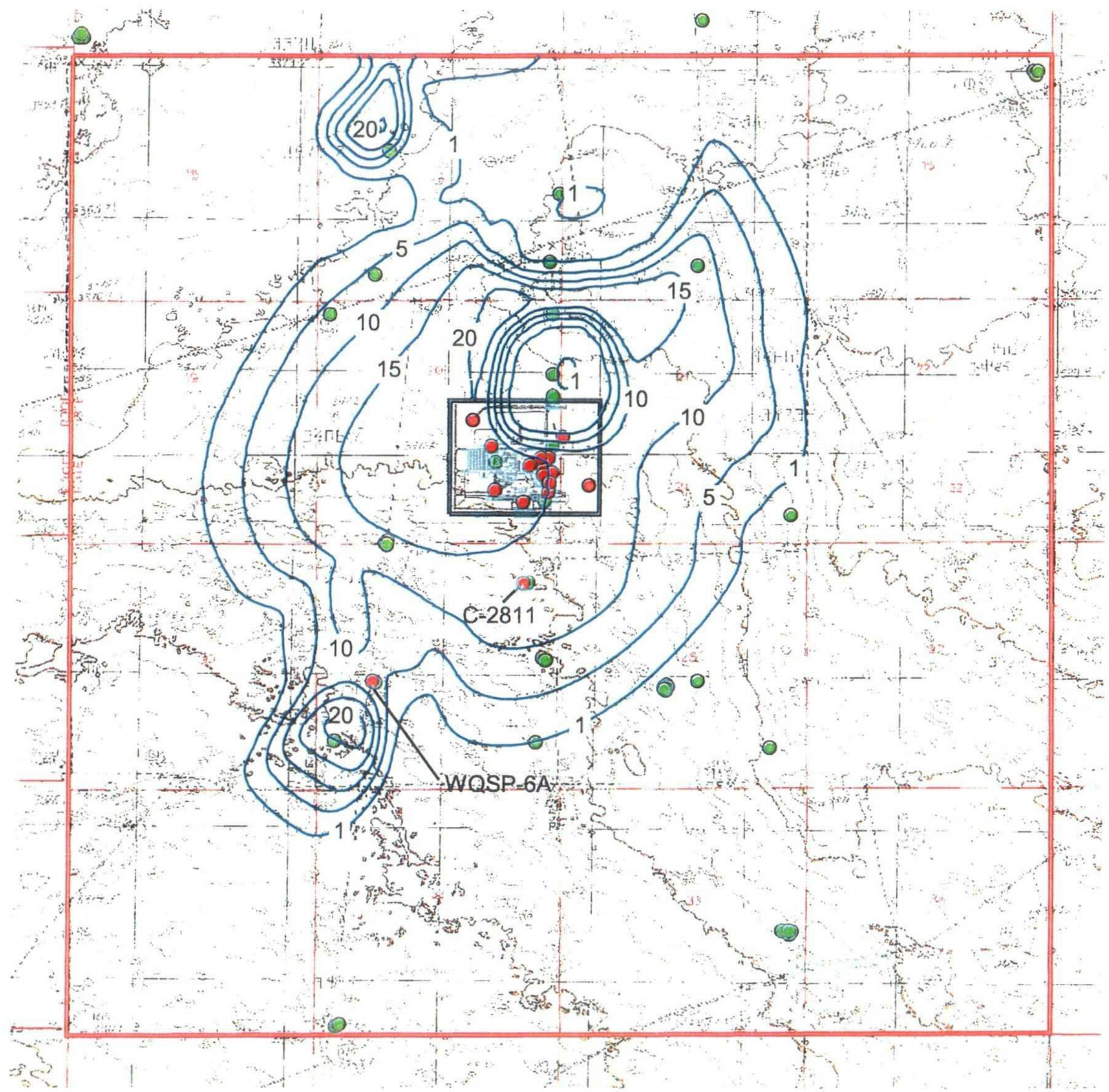
Santa Rosa. The model predicts that downward leakage to the Dewey Lake has begun to develop a saturated lens in the middle Dewey Lake. Although the two-layer model simulates saturation at the base of Layer 2 in the middle Dewey Lake, the results suggest a potential for the SSW to extend to monitor well C-2811, where saturation occurs in the upper Dewey Lake.

Figure 36 shows the potential extent of SSW migration without seepage controls (Simulation 1). After 100 years, the model predicts that Layer 1 will drain downward to the Dewey Lake, and the saturated lens in the Santa Rosa will not be sustained. The SSW is predicted to migrate in the middle Dewey Lake in a general radial pattern, with flow strongly influenced by the formation contours used to set up the model domain (Figures 29, 30, and 33). If seepage from the surface continues, the saturated zone in the Dewey Lake is predicted to cover an area of approximately 4.4 square miles, with a saturated thickness above the sulfate cementation change surface exceeding 20 feet. The saturated lens contributed by the surface seepage is projected to migrate as far as monitor well WQSP-6A to the south, where naturally occurring saturated conditions exist, and to just reach the WIPP land withdrawal boundary to the north.

Figure 37 shows the potential extent of the SSW with implementation of engineered seepage controls (Simulation 2). After 100 years, the model predicts that Layer 1 will again become unsaturated, with downward drainage forming a saturated lens in the Dewey Lake. With the engineered seepage controls stopping recharge, however, the extent of the SSW lens in the Dewey Lake is significantly less than in Simulation 1. The saturated zone still covers approximately 3.5 square miles, but the saturated thickness is reduced by about half, to just over 10 feet. The northern extent of migration is maintained within the WIPP land withdrawal boundary. The southern extent of migration continues to reach monitor well WQSP-6A, but the saturated thickness of the SSW reaching the naturally occurring saturated zone is diminished by about half.

The predictive simulations show that seepage losses into the Exhaust Shaft are reduced when engineered seepage controls are implemented to prevent SSW recharge from the surface. Simulation 1, with continued recharge, shows seepage to the Exhaust Shaft continuing at a steady rate of 1 gpm up to 2035. Simulation 2, with the engineered seepage controls to prevent SSW recharge, shows that seepage to the Exhaust Shaft is not sustained at 1 gpm after 2008, and in the model, seepage is stopped for the remaining years of the simulation. The reduced seepage into the Exhaust Shaft is a result of declining water levels in the SSW lens in the Santa Rosa as the lens spreads laterally and leaks downward into the Dewey Lake. This large-scale model domain does not provide the detailed analysis of Exhaust Shaft seepage necessary to reach definitive conclusions about seepage improvements; however, the modeling results suggest that the engineered seepage controls will reduce seepage into the Exhaust Shaft.

Figure 38 shows the expected reduction in the Dewey Lake saturated lens that is created by the engineered seepage controls. The saturated thickness is reduced by as much as 12 feet, and a substantial improvement in the extent of migration is expected near the northern WIPP land withdrawal boundary.



Explanation

- WIPP land withdrawal boundary
- WIPP facilities area
- Saturated thickness (ft)
- Monitor well
- Santa Rosa or Dewey Lake monitor well

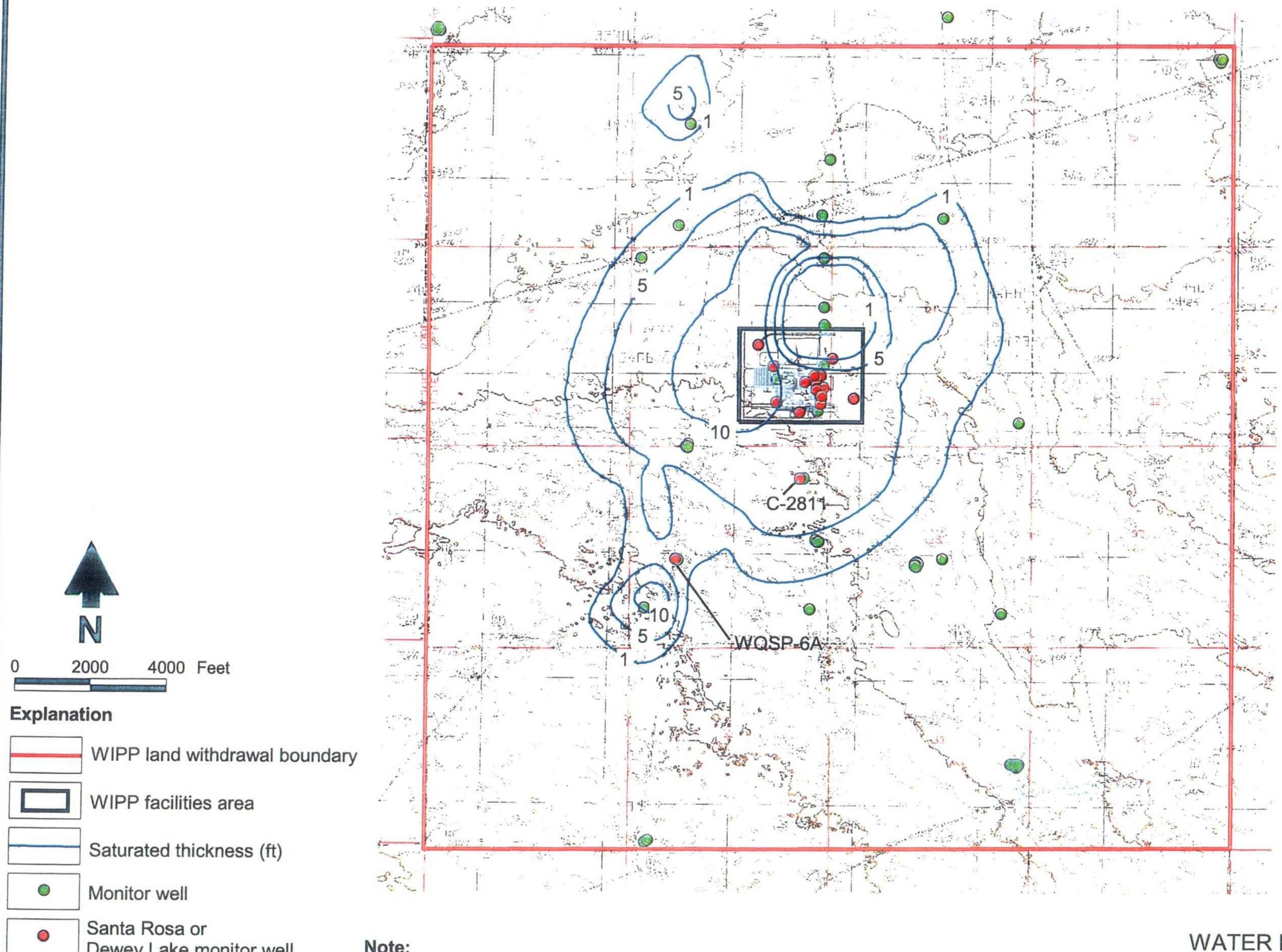
Note:
Santa Rosa/Gatuña layer is dry in 2102.

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Predictive Simulation 1: Continued Seepage to 2035
Dewey Lake Saturated Thickness in 2102

Daniel B. Stephens & Associates, Inc.
8-27-03 JN 9525

Figure 36

S:\PROJECTS\9525\GIS\PROJECT (PROJECT = WATER.APR) (VIEW EXTENTS = 1:48000) (VIEW NAME = V26 (LAYOUT = L26)



Note:
Santa Rosa/Gatuña layer is dry in 2102.

WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER
Predictive Simulation 2: Seepage Stopped in 2006
Dewey Lake Saturated Thickness in 2102

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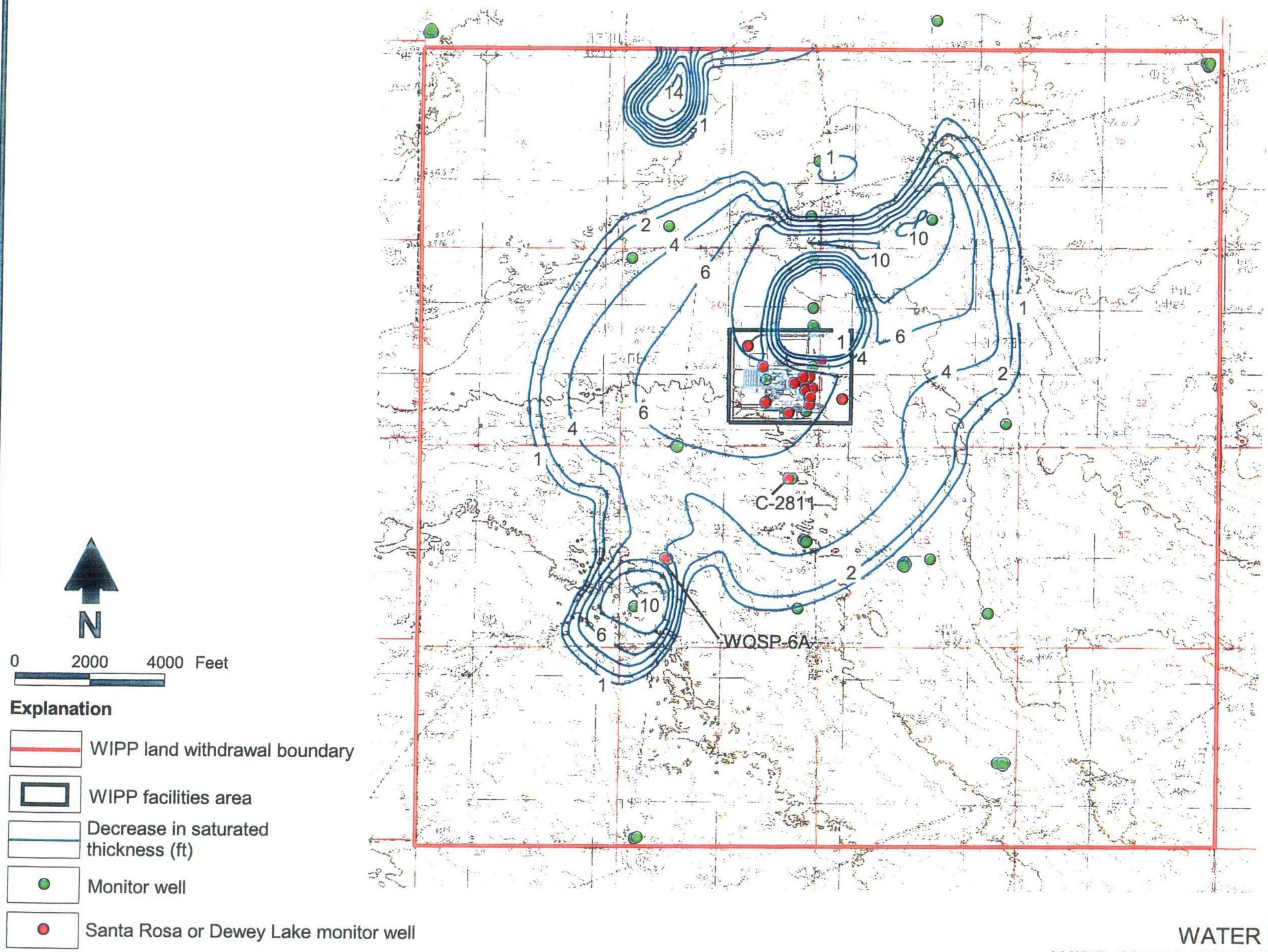
7-11-03
JN 9525

S:\PROJECTS\9525\GIS\PROJECT (PROJECT = WATER.APR) (VIEW EXTENTS = 1:48000) (VIEW NAME = V24 (LAYOUT = L24)



WATER BUDGET ANALYSIS
WIPP SHALLOW SUBSURFACE WATER

Engineered Controls Stop Seepage in 2006
Decrease in Dewey Lake Saturated Thickness in 2102

Daniel B. Stephens & Associates, Inc.
8-27-03
JN 9525

Figure 38

The long-term migration model results are summarized in Table 14.

Table 14. Summary of Long-Term Migration Model Predictive Simulations

Simulation Result	Total Seepage Volume (millions of gallons) Simulation 1 Continued Seepage	Simulation 2 Engineered Seepage Controls	Net Improvement [a]
Calibration Stage (1981-2002)			
Seepage volume	328	328	---
Volume lost to Exhaust Shaft	4	4	---
Volume in SSW storage	323	323	---
Predictive Stage (1981-2102)			
Seepage volume	882	392	490
Volume lost to Exhaust Shaft	22	7	15
Volume in SSW storage	861	385	475

[a] Simulation 1 volume minus Simulation 2 volume

The long-term migration model predicts that downward leakage to the Dewey Lake will continue, and the SSW saturated zone will continue to spread laterally. However, the predictive simulations indicate that implementation of engineered seepage controls will reduce the volume in storage by approximately 55 percent and significantly reduce the extent of saturation over the 100-year timeframe considered.

8. Summary and Conclusions

The SSW water budget for the WIPP provides information on the occurrence of shallow saturated conditions beneath the WIPP facilities area and the effects of site development on subsurface recharge. Through a quantitative analysis of the primary inputs to and losses of on-site water, the water budget examines each input and loss on a local scale and considers the potential for SSW migration in the context of the regional hydrogeologic setting.

The water budget was completed to support DOE regulatory compliance at the WIPP. Existing data and information were compiled and analyzed, but no new field data were gathered as part of the project. Certain data limitations were identified; however, existing data are sufficient to assemble a reasonable representation of the SSW water budget.

8.1 Principal Findings

The water budget used multiple analysis approaches to obtain a range of independent results that enhance the reliability of the overall analysis. The analyses focused on estimates of seepage from five principal seepage sources within the WIPP surface facilities area: the Salt Storage Area, Salt Pile Evaporation Pond, Detention Basin A, and storm water retention Ponds 1 and 2.

Since 1981, when construction of the WIPP surface facilities began, recharge of precipitation to the subsurface has increased, largely because approximately 26 acres developed for the WIPP surface facilities have been covered with impervious surfaces. Under pre-development conditions, precipitation falling on rangeland was predominantly lost to evaporation and plant uptake and transpiration, with only a small fraction (less than 1 percent) contributing to deep recharge. However, due to site development, storm water runoff is now routed to retention ponds, where focused runoff infiltrates over an area of approximately 10 acres. Another recharge source is the Salt Storage Area, where precipitation falling on the salt pile infiltrates through the highly fractured surface.

The greatest component of the water budget is precipitation that falls on-site, and based on the average annual precipitation rate, precipitation on the 85-acre watershed surrounding the WIPP facilities area amounts to approximately 29.2 million gallons per year. The resulting average annual storm water flow to the retention ponds, plus precipitation falling on the Salt Storage Area, amounts to approximately 25.0 million gallons per year. Since 1984, when the WIPP facilities were constructed, precipitation rates have exceeded the long-term average by 19 percent, with precipitation on the 85-acre watershed amounting to approximately 33 million gallons per year. Less than a year after the SSW monitor wells were installed in 1996, higher-than-normal precipitation in 1997 exceeded the long-term annual average by 98 percent, and a corresponding water level rise was observed in the SSW monitor wells. The relatively high precipitation experienced since 1984, along with the focusing of runoff in retention ponds, has resulted in significant recharge to the Santa Rosa.

On a regional basis, shallow water at depths less than 100 to 200 feet bgs is a common occurrence, and to the east of the WIPP site, the Santa Rosa Sandstone is an important aquifer. The Dewey Lake Redbeds Formation is also an aquifer that provides water supply locally from limited saturated horizons. At the time that the WIPP shafts were drilled, the Santa Rosa and Dewey Lake were unsaturated in the WIPP facilities area. Although the initial moisture content in the Santa Rosa and Dewey Lake prior to WIPP development is unknown, the increased seepage from WIPP development has contributed sufficient recharge to reach saturation and create a perched water lens 40 to 60 feet bgs in the Santa Rosa.

8.1.1 Shallow Subsurface Water Volume Estimate

The total volume of water in the SSW zone was estimated by two methods, providing a likely range of the SSW volume added to the saturated portion of the Santa Rosa. The first, based on the saturated zone observed in on-site monitor wells, yields an estimated SSW volume of 108 million gallons, covering approximately 150 acres at an average saturated thickness of 16.6 feet. The second, based on the MODFLOW transient analysis, yields an estimated SSW volume of 315 million gallons, covering approximately 520 acres with a saturated thickness from 1 to 31 feet. However, the SSW characteristics available for the estimations are limited. Certain aspects of the SSW volume estimate are reasonably well understood, including the (1) water table surface, (2) base configuration of the Santa Rosa, and (3) area where water is present in 14 of the 15 SSW monitor wells. Key uncertainties include the porosity and initial moisture content of the Santa Rosa Sandstone and the undefined limits of the SSW.

8.1.2 Operational Shallow Subsurface Water Inputs and Losses

Inputs to the SSW from on-site operational discharges were estimated from available records. Discrete discharges from drilling and construction activities since WIPP construction began in 1981 amount to approximately 6 million gallons, with evaporative losses further reducing the volume these discharges may have contributed to the SSW. The estimated leakage from water lines is approximately 0.22 million gallons per year, a total of approximately 4 million gallons since the WIPP facilities opened in 1984. These operational discharges represent a relatively small contribution to the total SSW volume.

Seepage into the Exhaust Shaft, first observed in 1995, represents a loss from the SSW; however, the seepage rate has not been directly measured. Current seepage rates may constitute a significant loss, having been estimated at rates of 0.5 to 1.6 million gallons per year (U.S. DOE, 2002). The Exhaust Shaft seepage is affected by the condition of the concrete shaft liner and the SSW hydraulic head, which suggests that seepage rates may have been lower in the past.

8.1.3 Shallow Subsurface Water Recharge Modeling

For the water budget, seepage providing recharge to the SSW was modeled using three independent methods to produce a range of seepage estimates for cross-comparison. The results are summarized in Table 15.

Table 15. Summary of Seepage Modeling Results

Location	Total Precipitation [a] (M gal/yr)	Total Storm Water [a] (M gal/yr)	Seepage Volume (M gal/yr)		
			UNSAT-H Simulation [b]	Steady-State MODFLOW Simulation	Transient MODFLOW Simulation [c]
Salt Storage Area	5.1	5.1	4.7	3.5	4.2
Salt Pile Evaporation Pond	7.0	5.2	2.5	1.4	3.0
Detention Basin A	13.0	11.0	7.4	0.39	3.2
Pond 1	1.3	1.0	0.61	0.06	0.28
Pond 2	2.8	2.6	1.7	0.08	0.74
Total	29.2	25.0	16.9	5.4	11.4
Estimated total seepage for 1984 to 2002			320	100	220

M gal/yr = Million gallons per year

[a] Volume represents the average over the years 1997 through 2002. For the Salt Storage Area, it includes direct precipitation onto the top deck. For the storm water ponds, it includes storm water runoff from the watershed and direct precipitation to the pond.

[b] Volume represents the average over the years 1997 through 2001.

[c] Volume represents the average over the years 1981 through 2002.

The UNSAT-H model, which uses a physically based approach to consider near-surface infiltration processes, predicts the highest seepage rates. The steady-state MODFLOW simulation predicts the lowest seepage rates, and the transient MODFLOW simulation predicts intermediate seepage rates. The MODFLOW simulations use SSW water levels and hydraulic testing data to determine the seepage inputs that would create the observed water levels. The MODFLOW simulations provide a reasonable, but non-unique solution; other combinations of seepage inputs may yield similar water level results.

The seepage modeling results are reasonably consistent, considering the uncertainties of each approach. All the models showed total annual seepage rates of several million gallons per year. Recharge to the SSW is estimated to be between 18 and 58 percent of the on-site precipitation. Together, the seepage volumes from the five primary seepage sources are sufficient to have contributed the volume of water necessary to create the SSW saturated zone. Although uncertainties exist in the SSW volume and seepage rates estimated for the five primary sources, it is clear that increased seepage resulting from the WIPP site development contributes significant recharge to the SSW.

8.2 Predictive Simulations

Predictive modeling simulations were used to evaluate the potential extent of long-term SSW migration and the effects of engineered controls to prevent discharges from the primary seepage sources, including the apparent sources of saline seepage. The predictive simulations used a transient saturated/unsaturated flow model that was first calibrated to match observed SSW conditions. Following calibration, the model was run in a predictive mode to evaluate (1) the potential long-term SSW migration for a 100-year timeframe and (2) the effectiveness of engineered seepage control measures in reducing SSW migration. The potential migration of SSW is a top-down process, with 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 predictive simulations represent a complex hydrogeologic system as a two-layer model, which is conservative in considering the potential extent of long-term SSW migration, because all recharge to the Dewey Lake is routed to a single layer, whereas the actual heterogeneous flow field in the unsaturated upper Dewey Lake may disperse the flow and lead to less migration.

The predictive simulations examined the downward leakage from the Santa Rosa to the Dewey Lake across the low-permeability siliceous layer observed at the contact. The vertical hydraulic conductivity was established by calibrating the model to a vertical hydraulic conductivity that limits downward flow, such that SSW accumulates in the Santa Rosa perched lens as a result of seepage inputs and water level hydrographs are matched in the SSW monitor wells. The calibration was based on the highest seepage rate estimates for 1981 to 2002 and observed water level hydrographs for the 1996 to 2002 period of record. Given the calibrated vertical hydraulic conductivity, current seepage rates cause an increase in the SSW volume and water levels; however, with a cessation of anthropogenic seepage, either after engineered seepage controls are implemented (2004) or after the WIPP operating period ends (2035), downward leakage is predicted to drain the SSW from the Santa Rosa to the Dewey Lake. The 100-year predictive simulations suggest that the Santa Rosa will become unsaturated and the saturated lens in the Dewey Lake will expand laterally.

The long-term migration model, although preliminary, predicts that over a 100-year timeframe, the SSW has the potential to migrate as far as the northern boundary of the WIPP land withdrawal area. The results also show that within 100 years, SSW migration has the potential to reach monitor well WQSP-6A, where naturally occurring groundwater may be encountered. The model predicts sufficient potential for SSW migration, such that water currently present at monitor well C-2811 may be interconnected with the SSW lens.

The long-term migration model indicates that the engineered seepage controls being planned by DOE will substantially reduce the extent of SSW migration. The predictive simulations show that implementation of engineered seepage controls will reduce the volume of water in the SSW by more than half, from approximately 860 million gallons to 385 million gallons, and reduce migration to prevent the SSW from reaching the northern facility boundary, maintaining the saturated lens within the site.

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Appendix A

Well Logs

Sources of well logs included in this appendix:

PZ-series wells:

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.

C-series wells:

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

Well C-2811:

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.

Well WQSP-6A:

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.

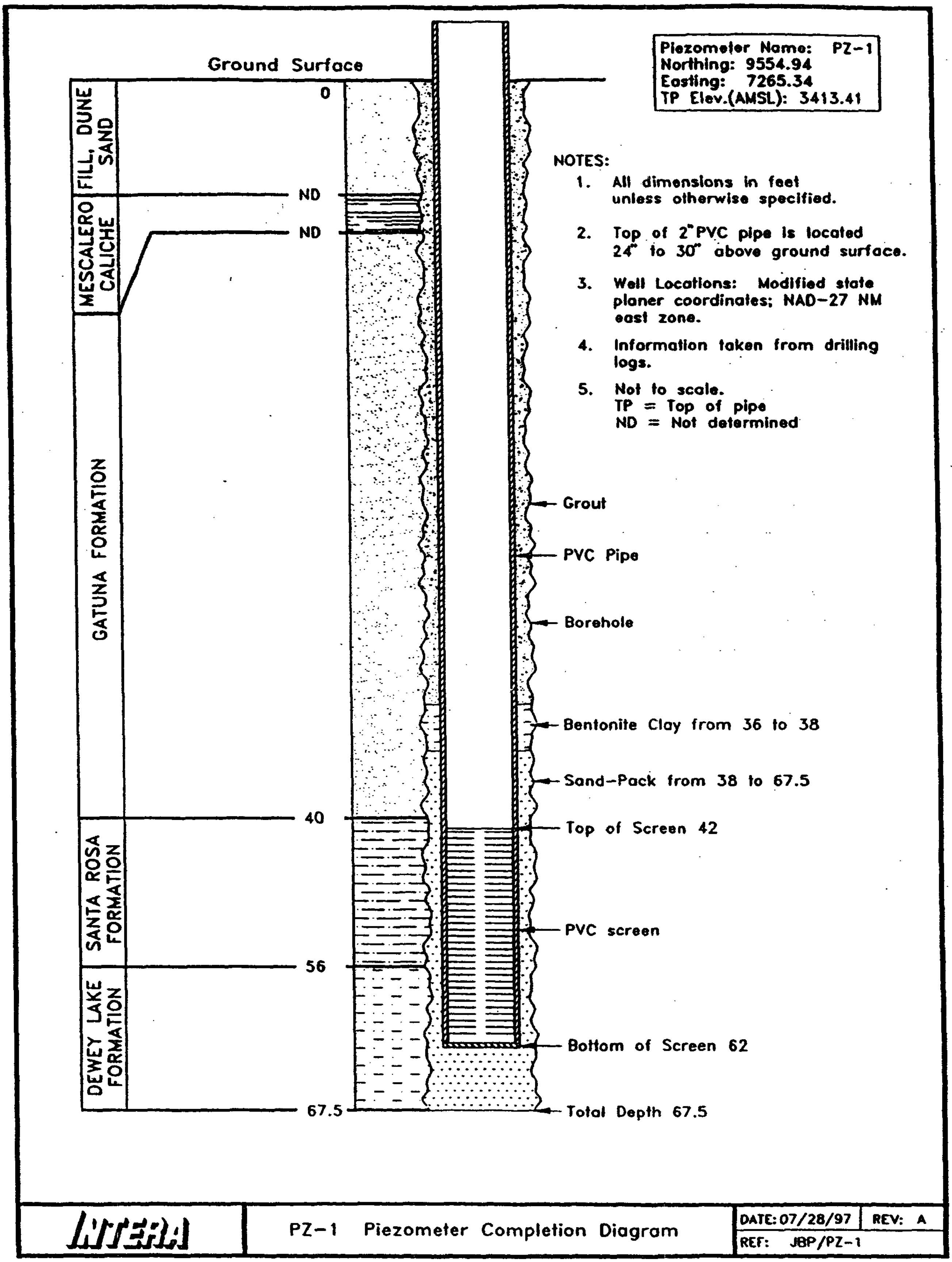


Figure 2.3 PZ-1 piezometer completion diagram

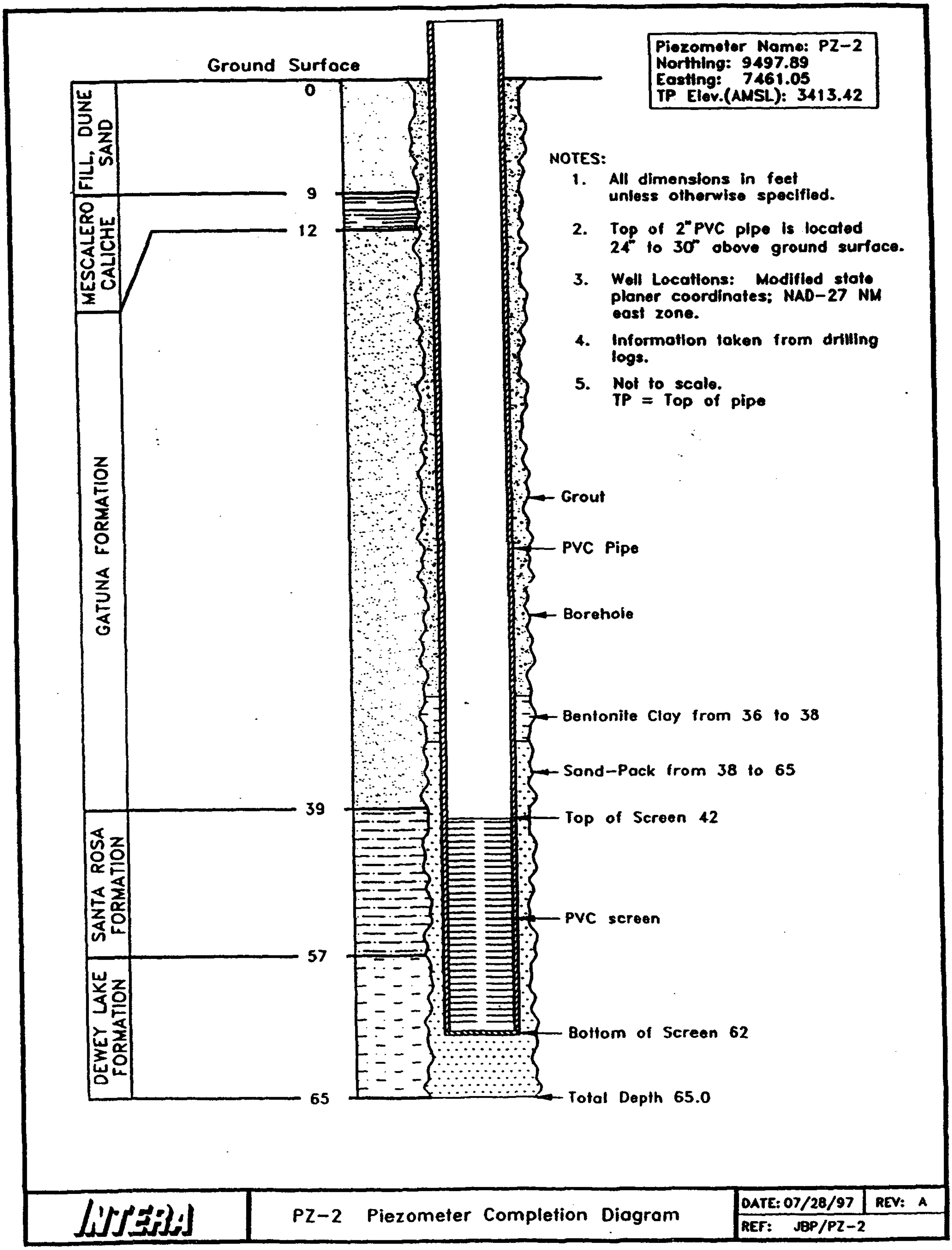


Figure 2.4 PZ-2 piezometer completion diagram

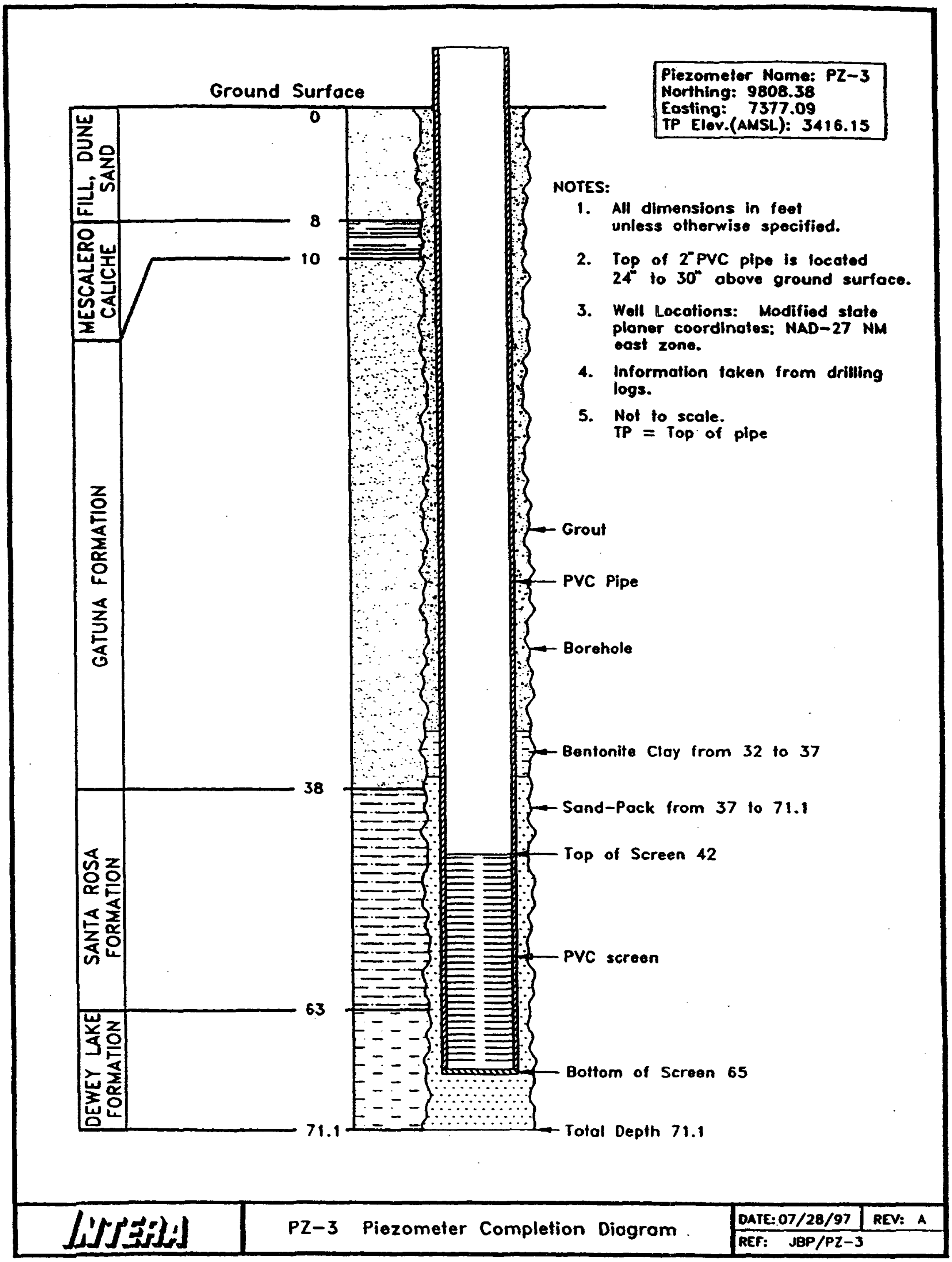


Figure 2.5 PZ-3 piezometer completion diagram

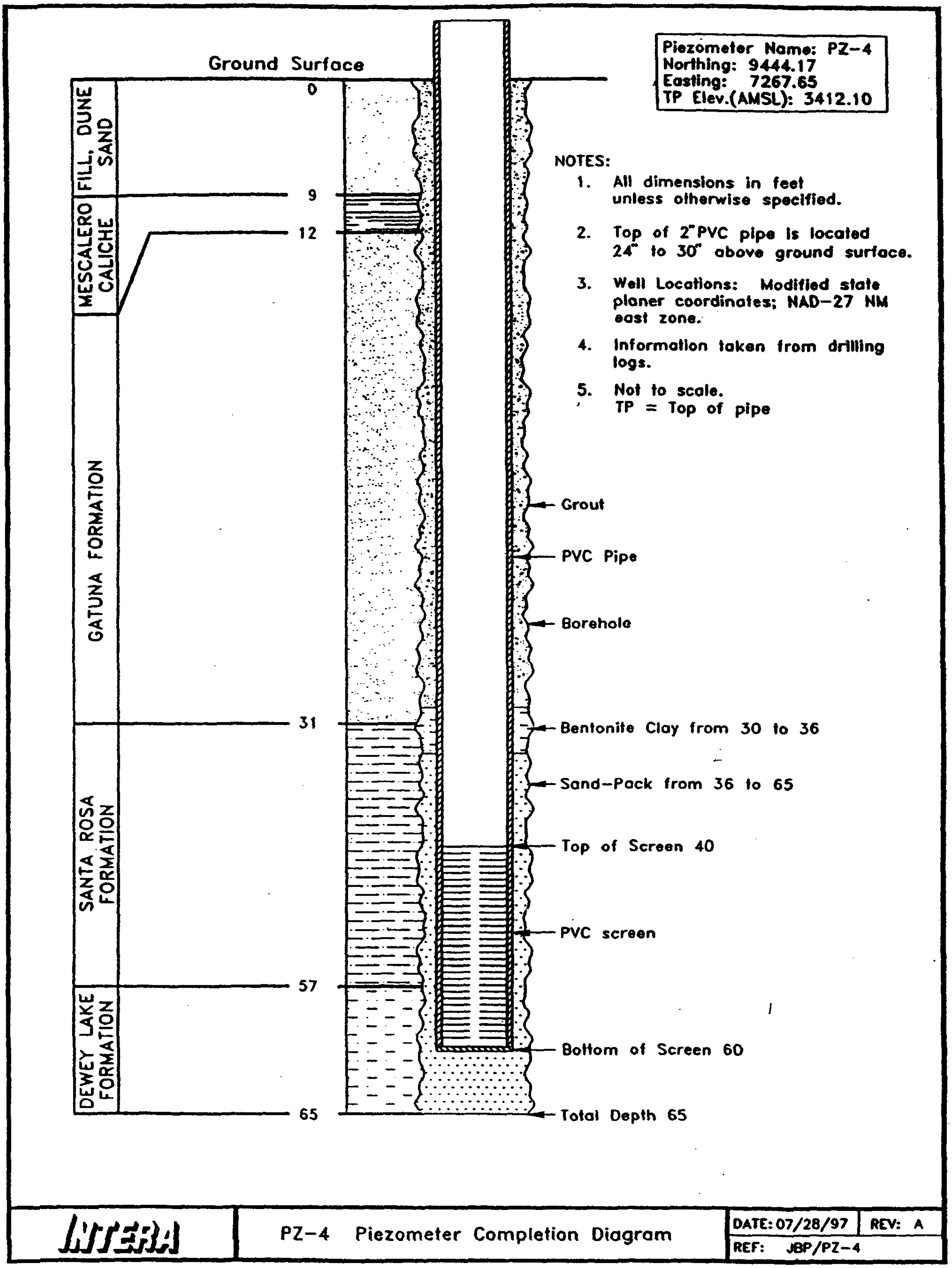


Figure 2.6 PZ-4 piezometer completion diagram

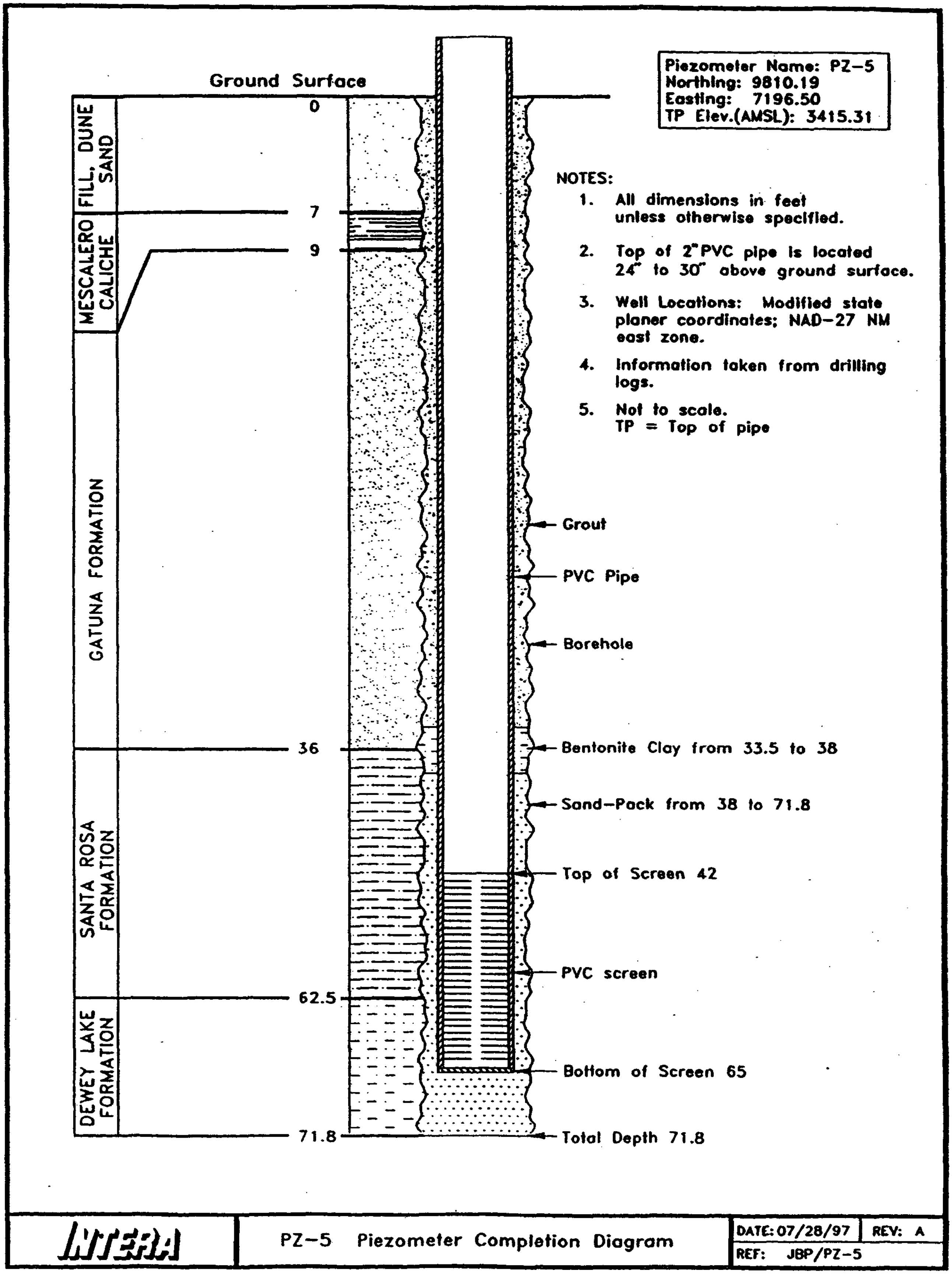


Figure 2.7 PZ-5 piezometer completion diagram

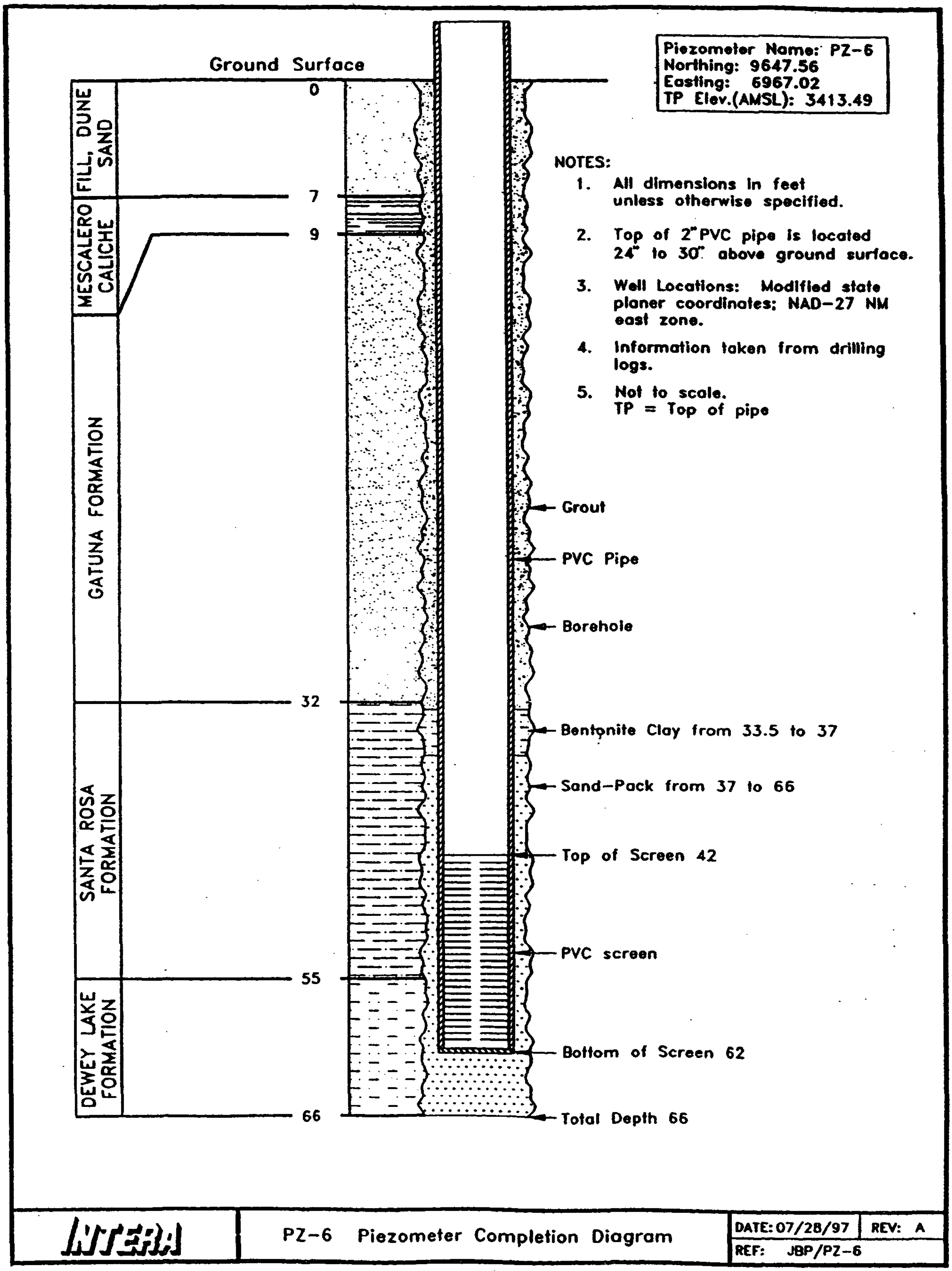


Figure 2.8 PZ-6 piezometer completiondiagram

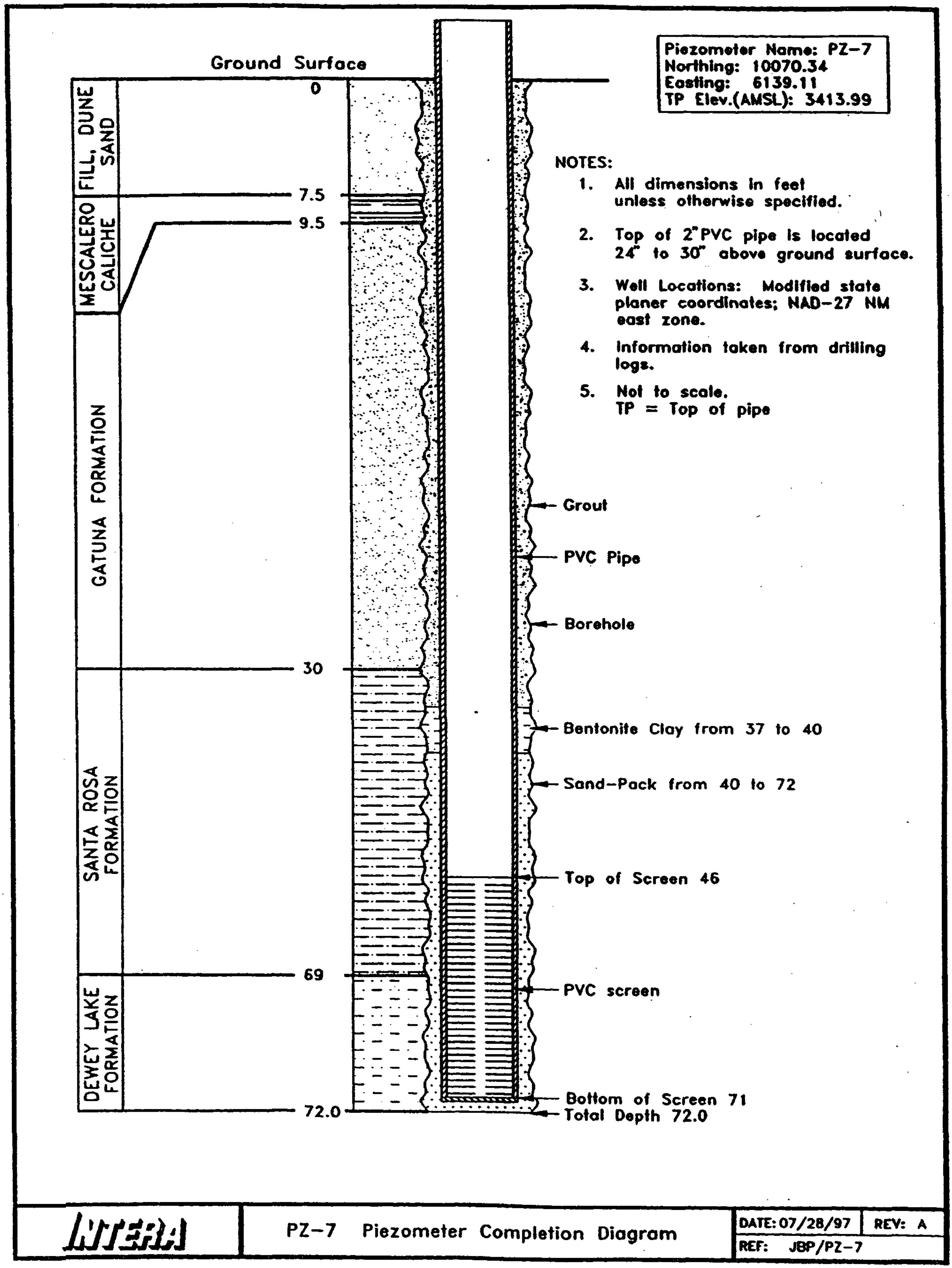


Figure 2.9 PZ-7 piezometer completion diagram

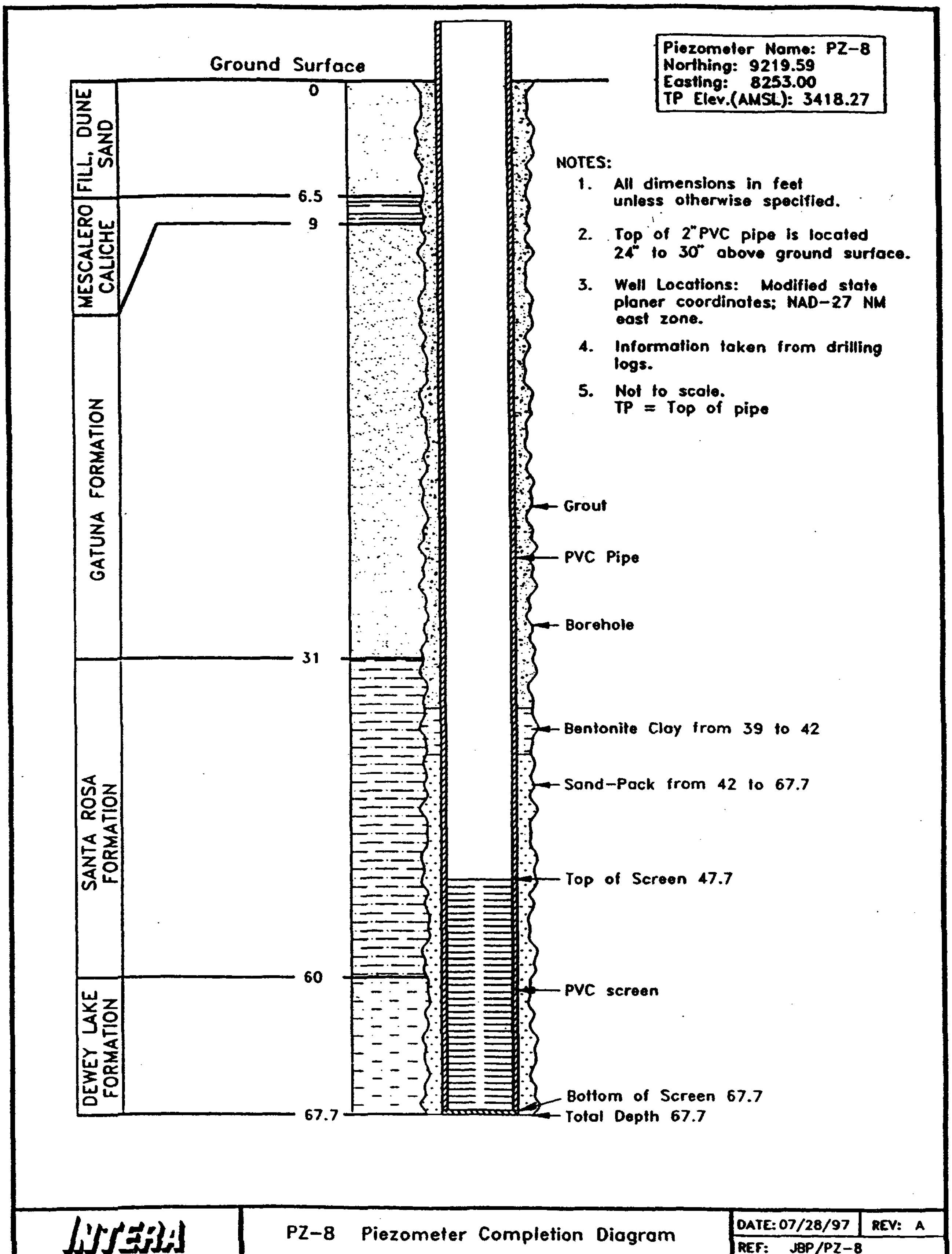


Figure 2.10 PZ-8 piezometer completion diagram

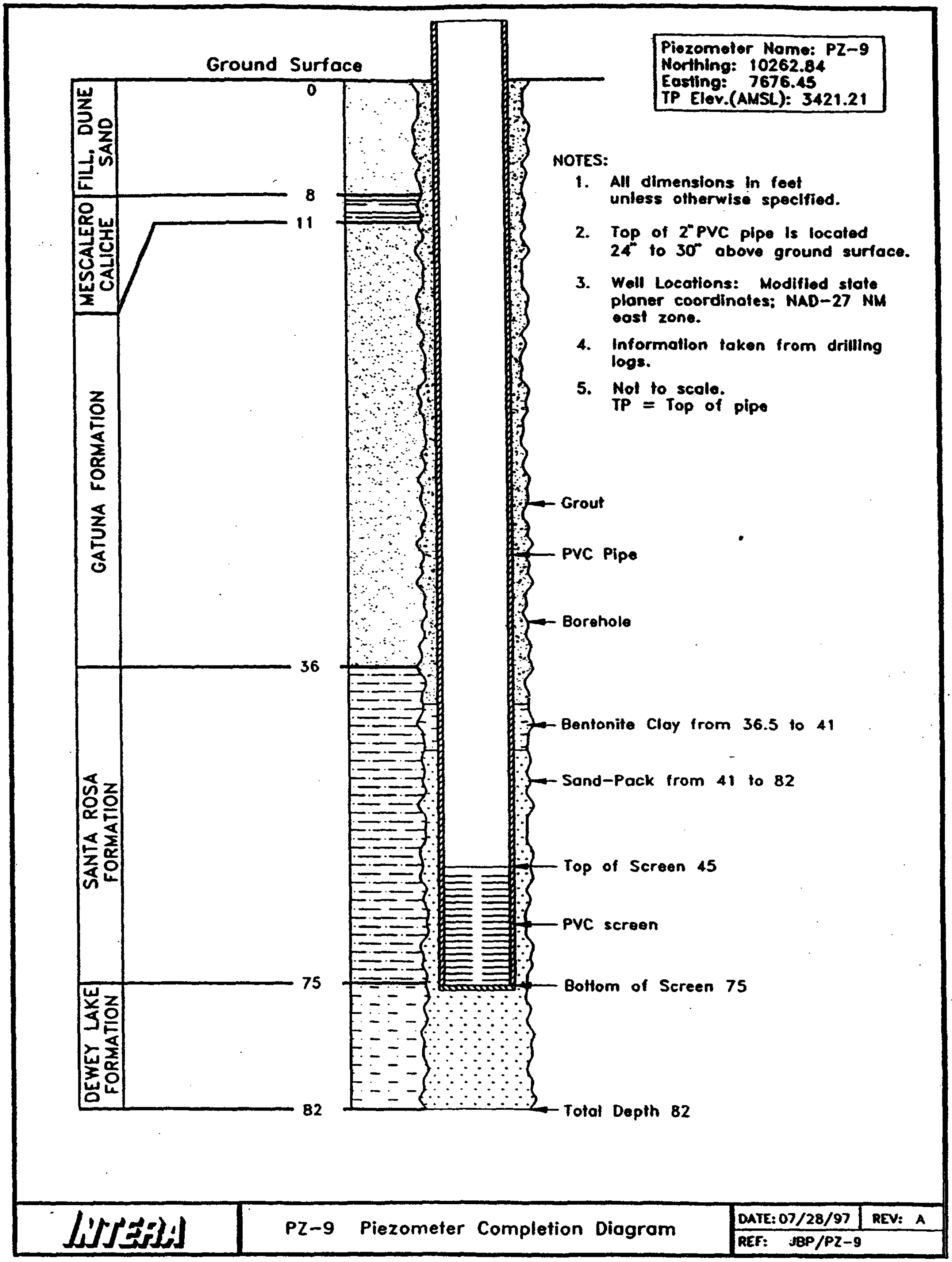


Figure 2.11 PZ-9 piezometer completion diagram

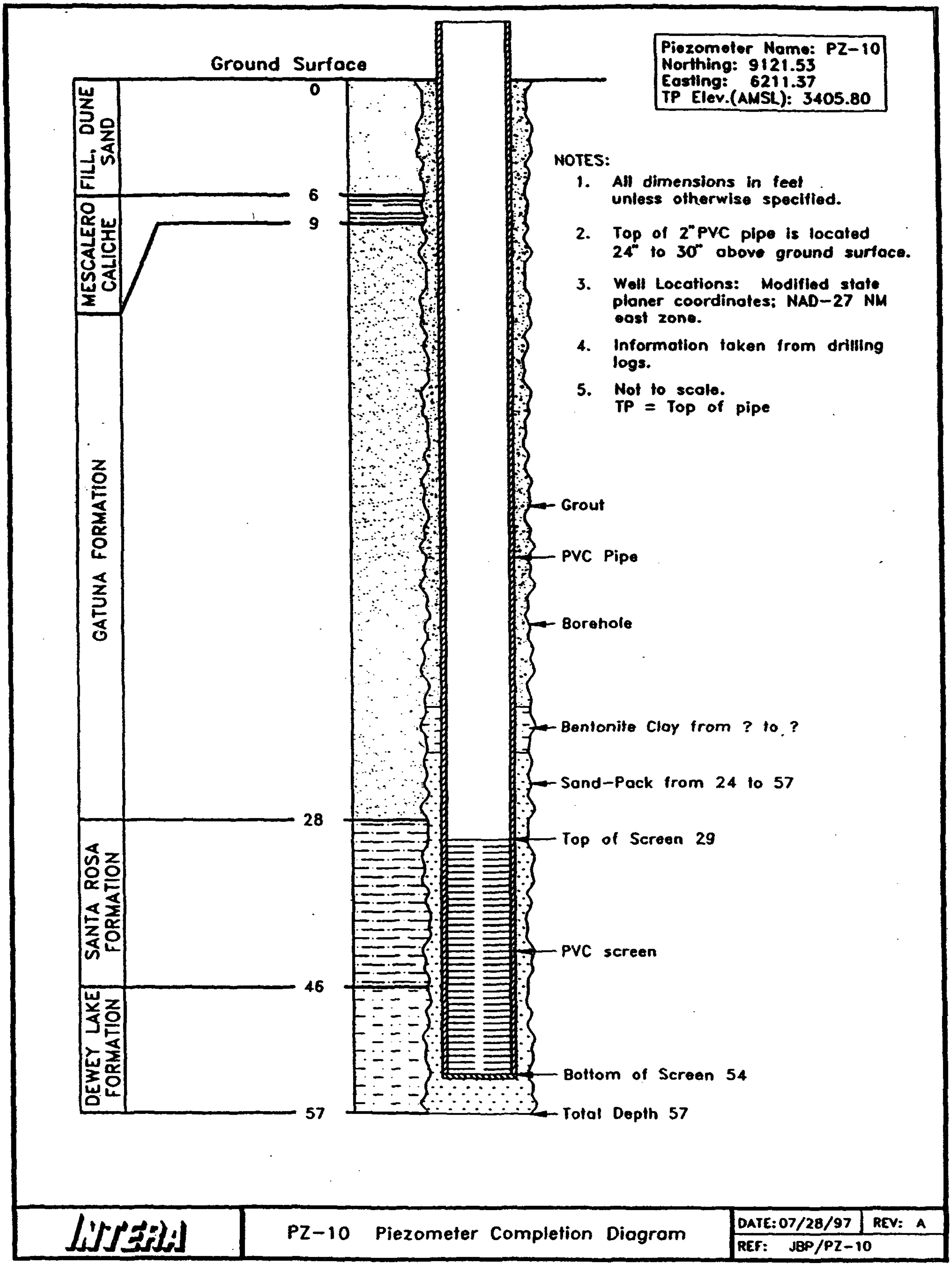


Figure 2.12 PZ-10 piezometer completion diagram

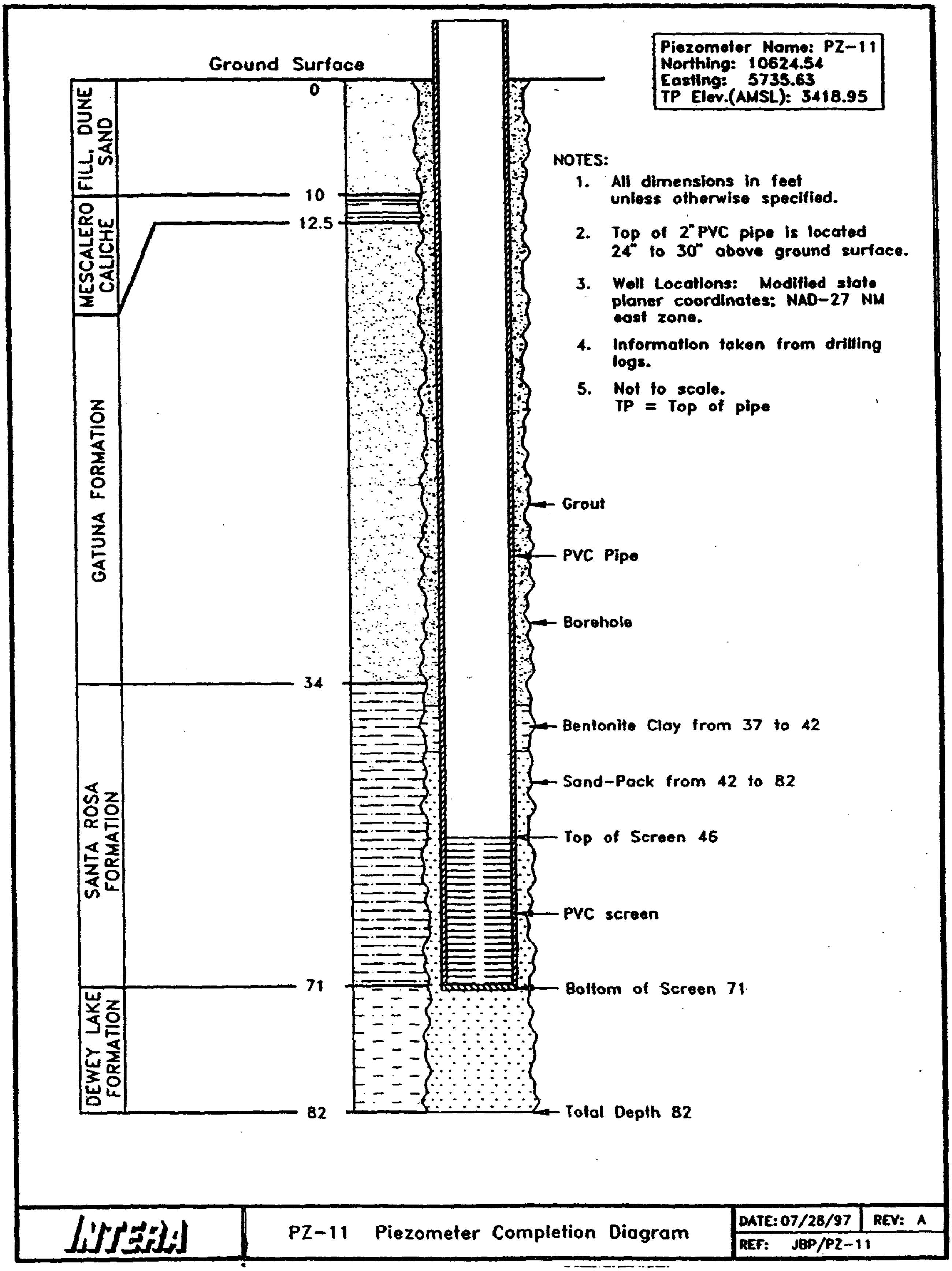


Figure 2.13. PZ-11 piezometer completion diagram

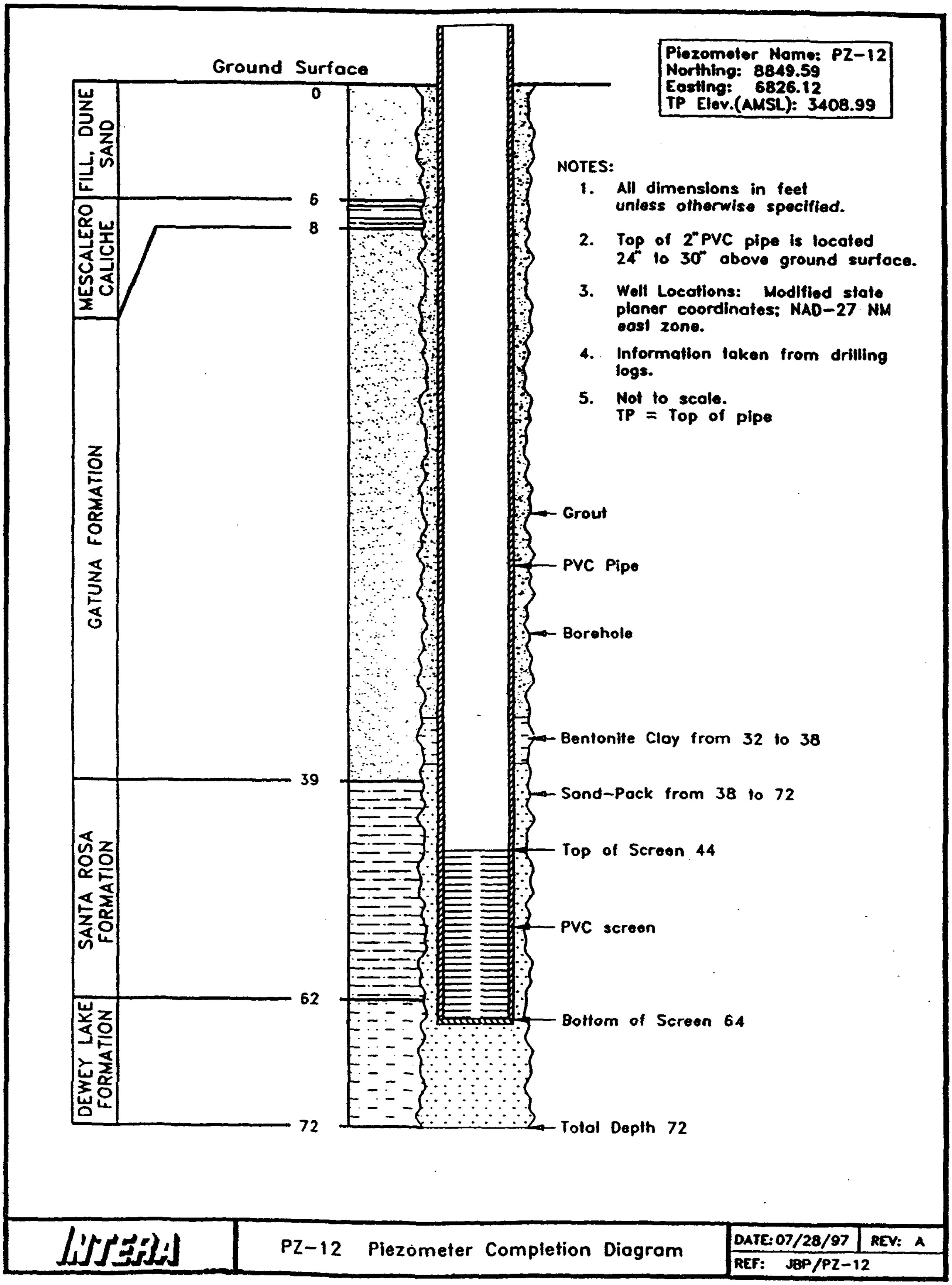


Figure 2.14 PZ-12 piezometer completion diagram

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

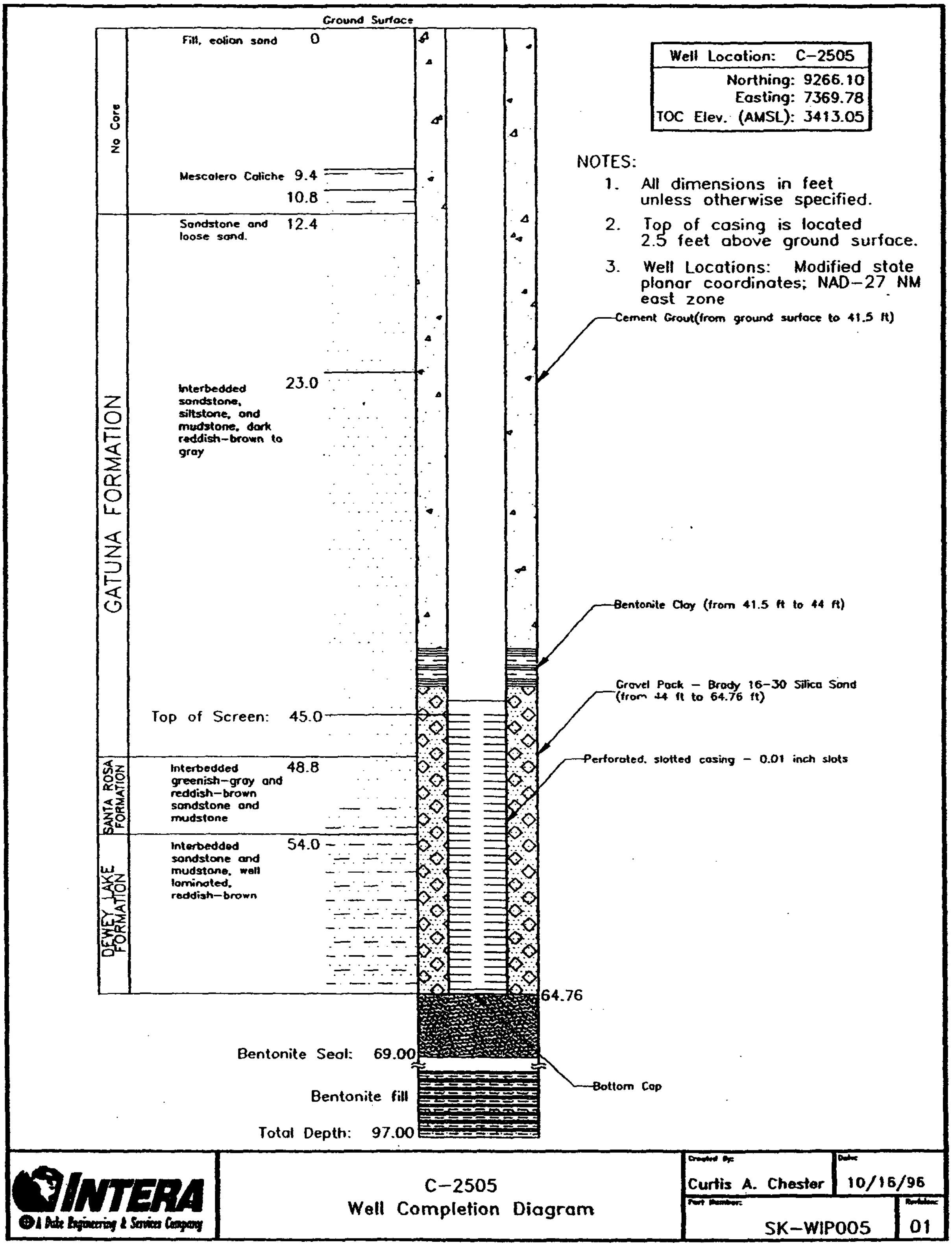


Figure 3.1 Well completion diagram - C-2505

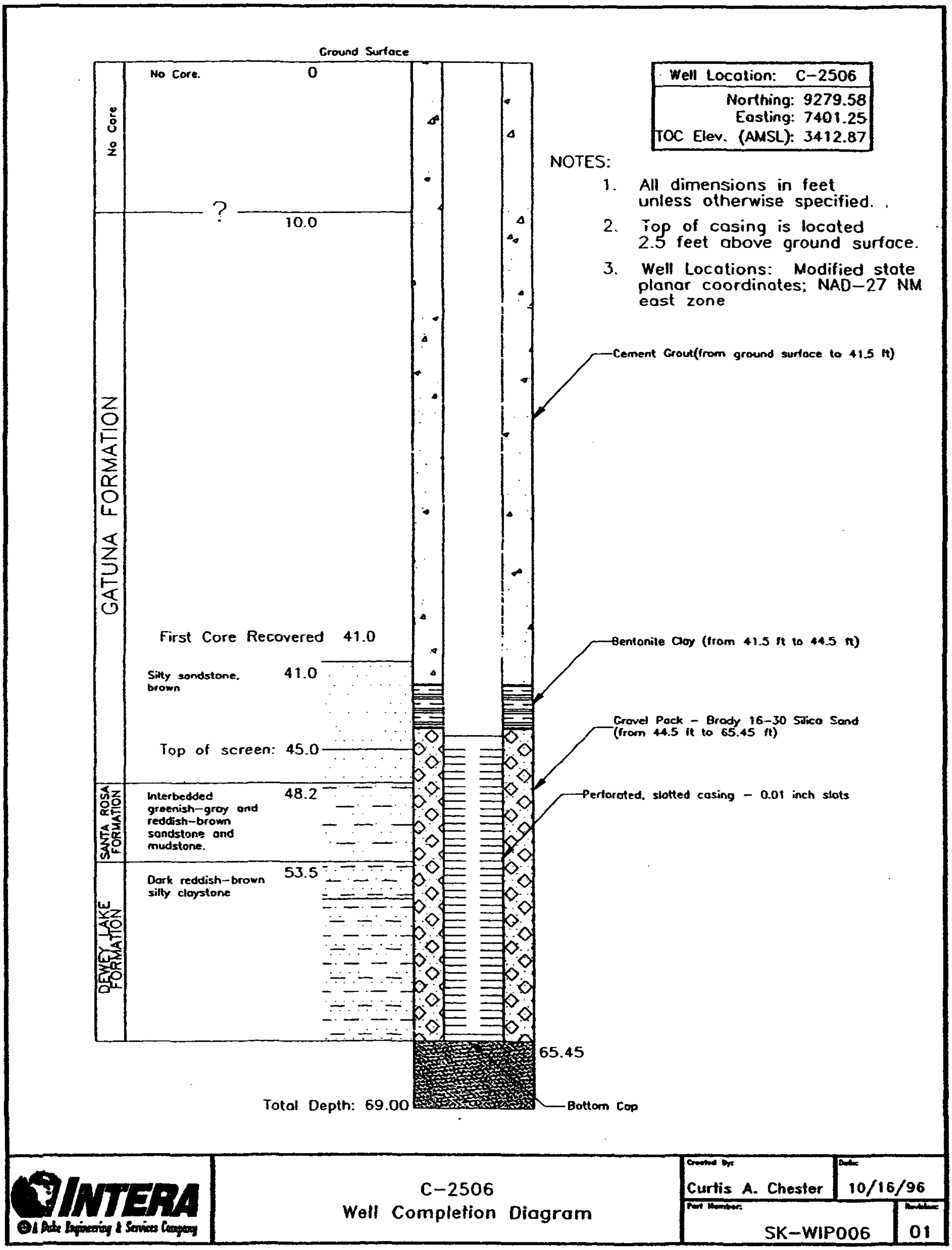
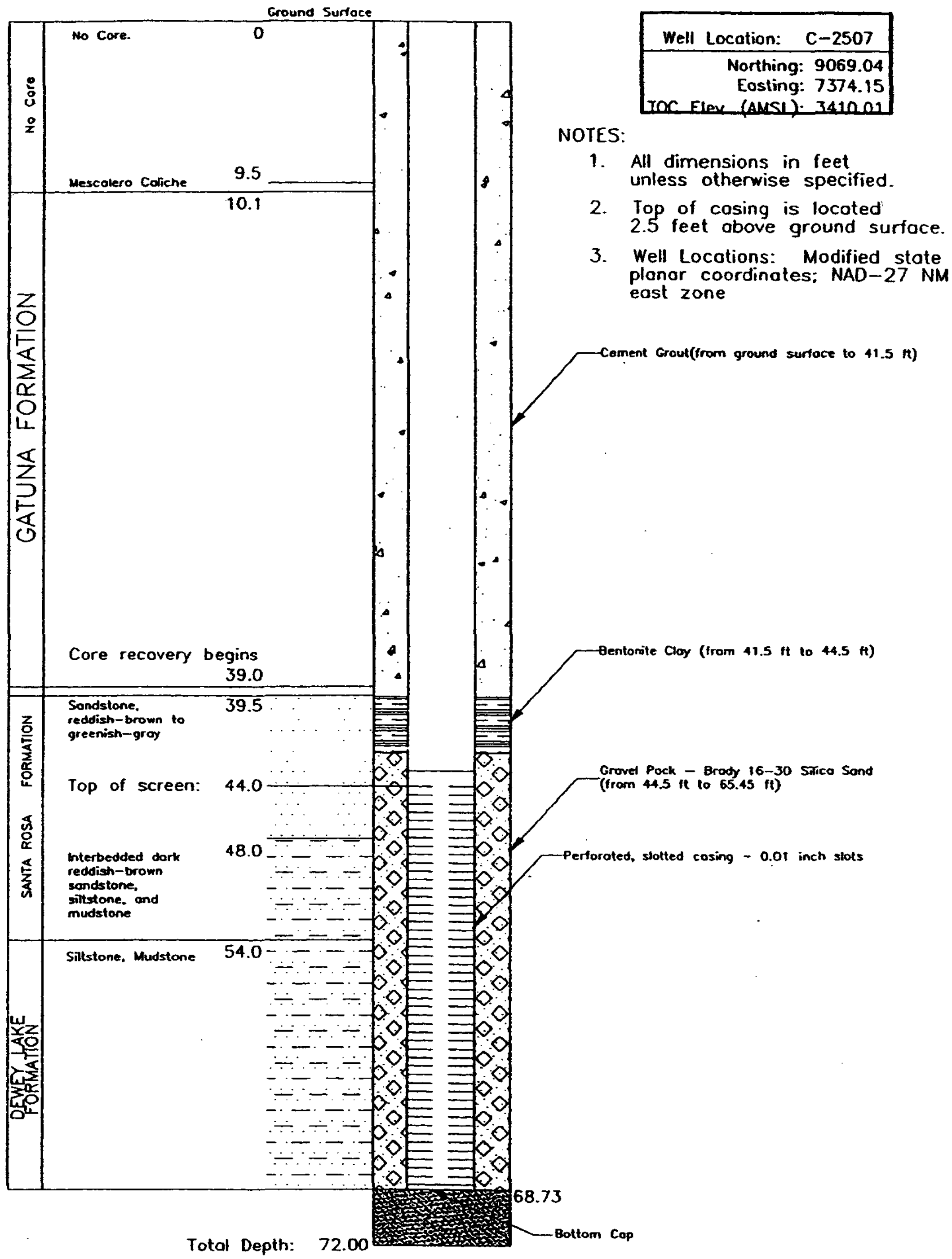


Figure 3.2 Well completion diagram – C-2506



INTERA A Duke Engineering & Services Company	C-2507 Well Completion Diagram	Created By: Curtis A. Chester	Date: 10/16/96
		Part Number: SK-WIP007	Revision: 01

Figure 3.3 Well completion diagram – C-2507

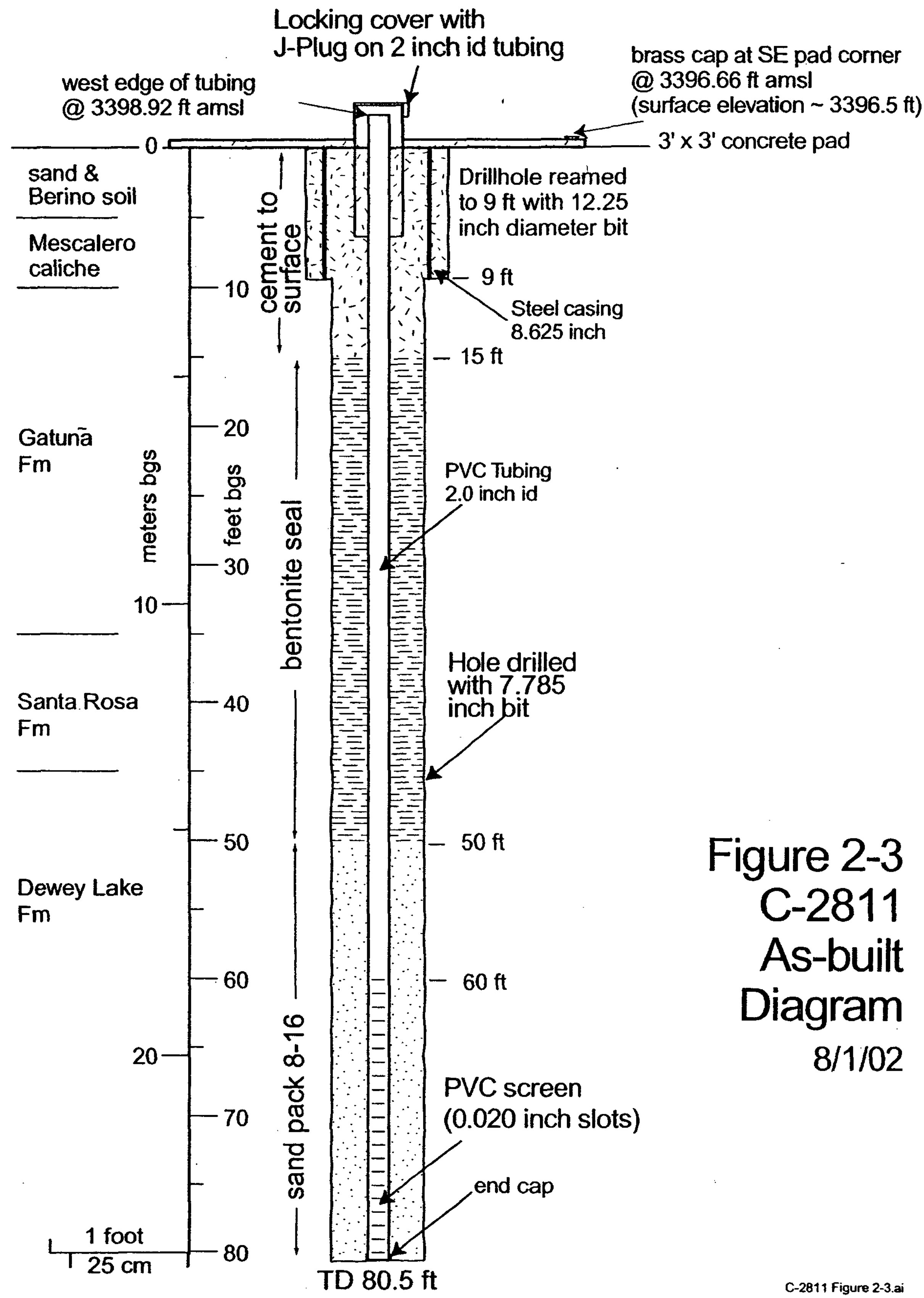


Figure 2-3
C-2811
As-built
Diagram
8/1/02

C-2811 Figure 2-3.ai

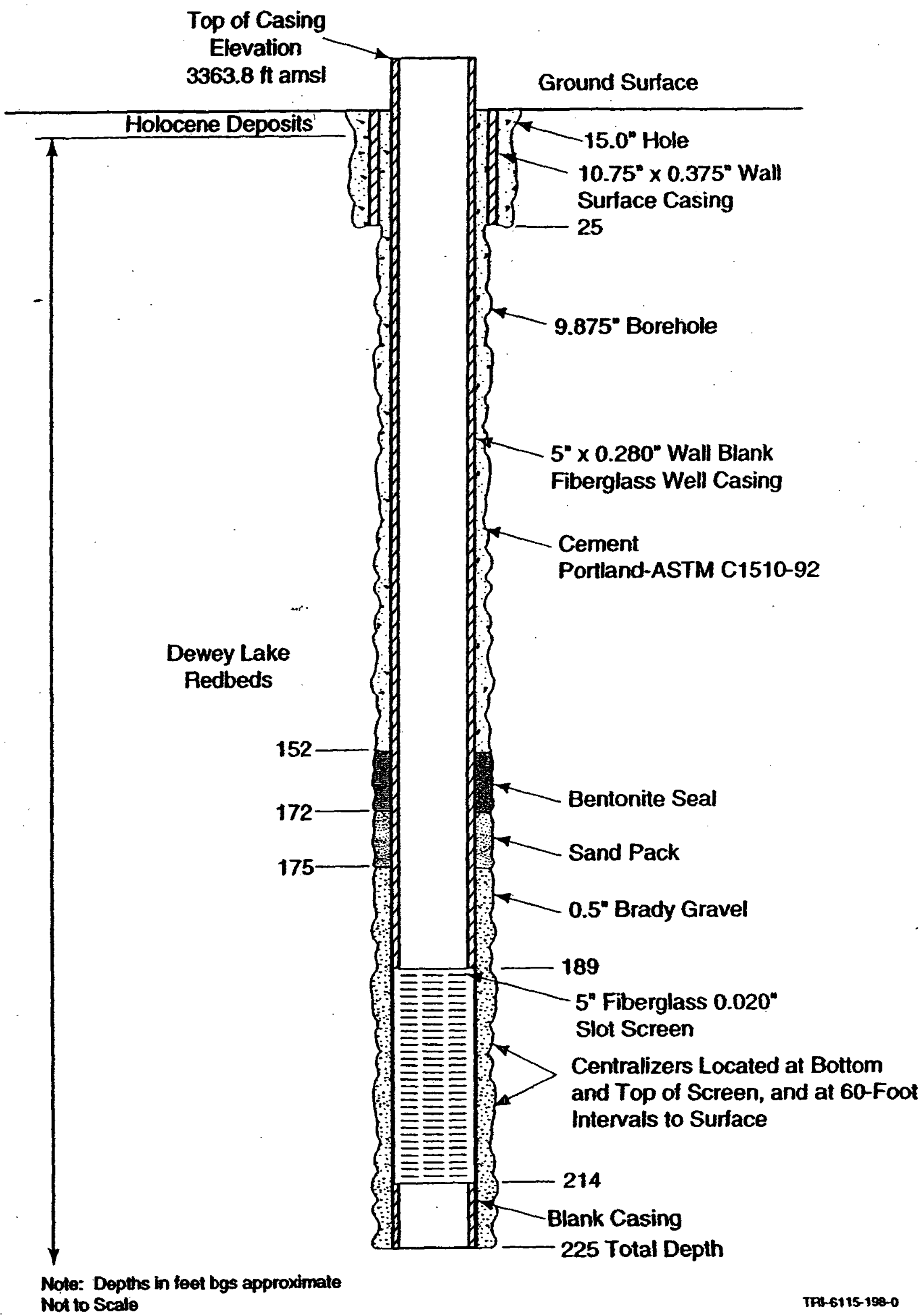


Figure 5-7. As-built configuration of well WQSP-6A.