Environment

Submitted to:
Bureau of Land Management
Carlsbad, New Mexico

Submitted by:
AECOM
Fort Collins, Colorado
February 2011

Hydrological Assessment and Groundwater Modeling Report for the HB In-Situ Solution Mine Project EIS

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Reviewed By Ellen Dietrich

List of Acronyms and Abbreviations

°F	degrees Fahrenheit
amsl	above mean sea level
ASTM	American Society for Testing and Materials
BLM	Bureau of Land Management
BP	Before Present
CID	Carlsbad Irrigation District
ESI	Environmental Simulations, Inc.
gpm	gallons per minute
IMCC	International Minerals and Chemical Corporation
mg/L	milligrams per liter
NMED	New Mexico Environment Department
PCA	Potash Corporation of America
PEST	parameter estimation code
R	Range
RMS	root-mean-square
SPA	Secretary's Potash Area
T	Township
TDS	Total Dissolved Solids
U.S.	United States
USGS	United States Geological Survey
WIPP	Waste Isolation Pilot Plant
WMC	Water Management Consultants

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1.0 Introduction

1.1 Purpose and Scope

Purpose: The purpose of the hydrologic assessment of the 1986 Secretary's Potash Area (SPA) is twofold. First, the assessment's goal is to summarize the current knowledge concerning the surface water and groundwater hydrology of the SPA. To accomplish this goal a summary presentation was created regarding previous investigations of the area that affects water resources. The second goal for the assessment is to provide the basis for understanding potential impacts to groundwater resources in the area of potash mining that may result from an expansion of solution mining in the SPA. This goal will be addressed by the development of a numerical groundwater flow model that will incorporate the current knowledge of water resources summarized in the assessment. The model will provide predictions of future impacts.

Scope: The hydrologic assessment will be limited to the SPA. The SPA has undergone potash mining in the Salado Formation during the 1930s and continuing to the present. The majority of the mines were active during the 1950s and again during the 1970s. Currently, two mining companies are operating in the SPA. The Waste Isolation Pilot Plant (WIPP) located in the southeastern part of the SPA (Township 22 South [T22S], Range 31 East [R31E]) is a restricted area used for underground storage of nuclear waste. Therefore it is not a part of the SPA. Geologic units and aquifers found throughout the SPA also are found at WIPP site. Important differences exist between the WIPP site and the greater SPA regarding aquifer properties and groundwater flow patterns.

In the southern-most portion of the SPA is an area that was used for an underground nuclear test in the 1950s as part of Project GNOME. To the west and northwest is the Roswell Artesian Basin, an area of extensive groundwater development for agricultural irrigation and municipal consumption of water. The Pecos River forms the eastern boundary of the Roswell Artesian Basin. Groundwater studies for the WIPP project, Project GNOME, and to some extent for the Roswell Artesian Basin provide data and hydrologic evaluations that are applicable to the SPA. The scope of the hydrologic assessment of the SPA will be limited to the area of potash mining (**Figure 1-1**). The report will utilize data and results from the groundwater studies in the surrounding areas to provide a better and more complete understanding of the water resources in the SPA.

1.2 Location

The SPA lies within the northern part of the Delaware Basin (Brokaw et al. 1972). The SPA, as defined by the Order of the Secretary of the Interior, published in the Federal Register on October 28, 1986 (51 Federal Register 39425), is located in Eddy and Lea counties, New Mexico, approximately 10 miles east of Carlsbad, 20 miles southwest of Hobbs, and approximately 15 miles north of the Texas/New Mexico state line (**Figure 1-1**). The SPA is encompassed by T18S through T25S and R28E through R31E. The WIPP site and Project GNOME are both located in the southern portion of the SPA, in T22S, R31E, and T23S, R30E, respectively. The SPA is bordered on the west by the Pecos River and on the east by the High Plains physiographic province (Fenneman 1928). The potash mines straddle the buried segment of the Permian-age Capitan Reef complex that forms the northern border of the Delaware Basin. The SPA encompasses a total of approximately 497,000 acres. Two prominent basins within the SPA are Clayton Basin and Nash Draw (**Figure 1-1**). The mining locations within the SPA as well as other prominent features are shown in **Figure 1-2**.

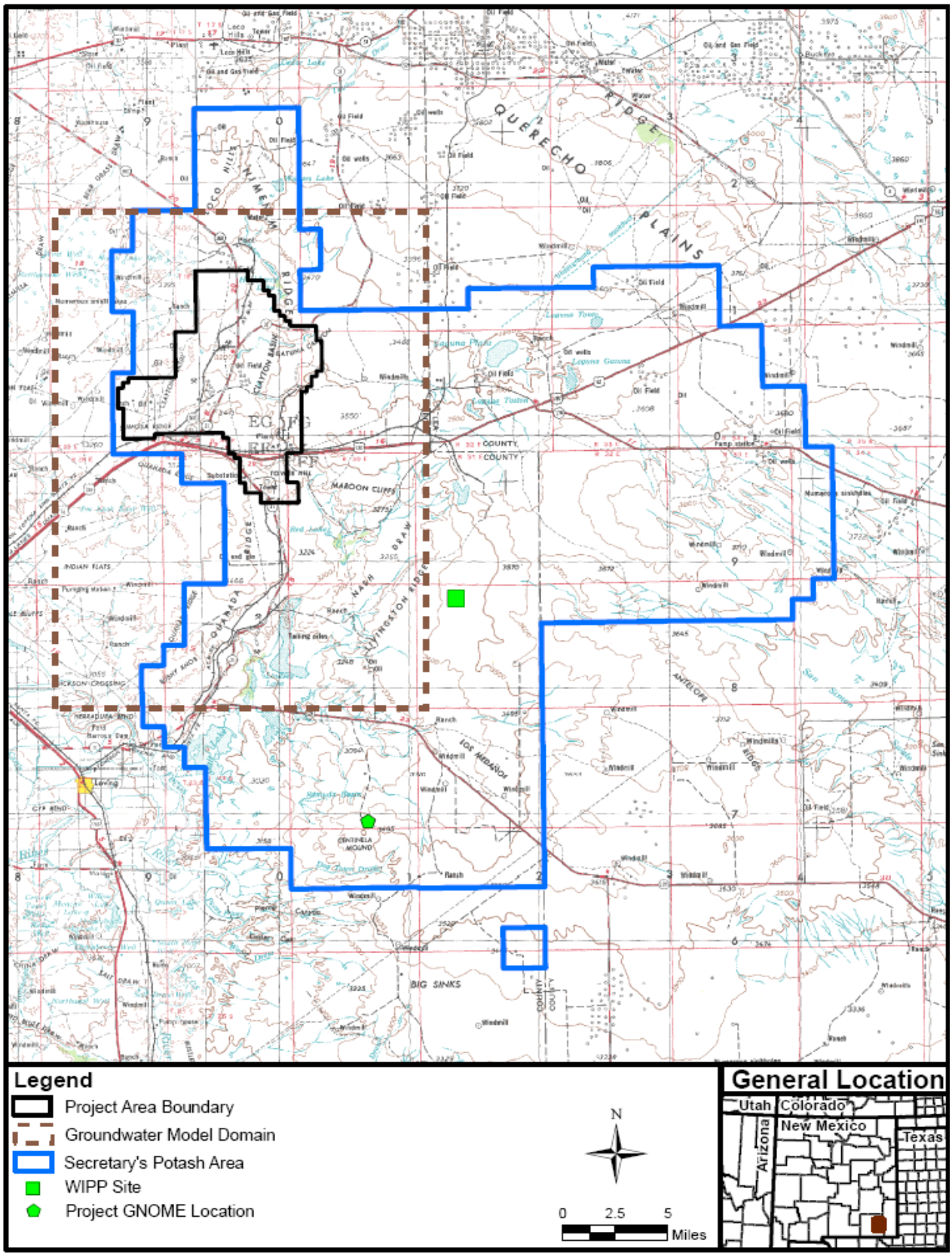


Figure 1-1 Secretary's Potash Area

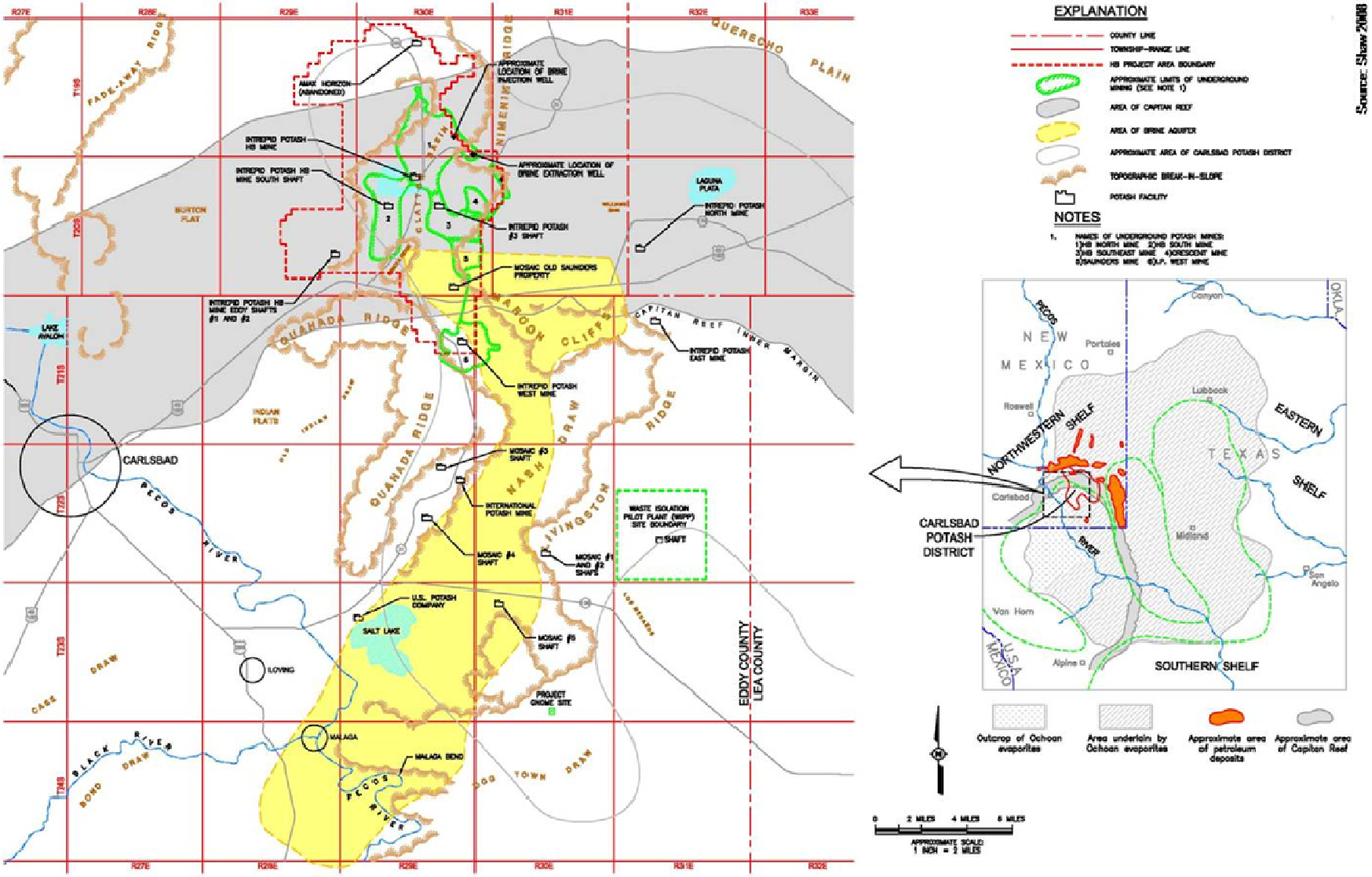


Figure 1-2 Regional Overview Map

1.3 Climate

The climate in the SPA is semiarid and generally warm and dry most of the year, with low rainfall and high evaporation (Powers et al. 1978). Precipitation averages around 13.3 inches per year (World Climate 2009) with lower precipitation along the Pecos River and higher precipitation on the Lea Plateau and the High Plains Physiographic Province to the east. Most of the precipitation comes from intense storms during the summer months or during the winter when cold fronts from the north encounter moisture moving up from the Gulf of Mexico. Precipitation in Carlsbad (elevation 3,120 feet above mean sea level [amsl]) averaged 12.86 inches per year from 1914 to 2009, while precipitation in Hobbs (elevation 3,615 feet amsl) averaged 15.93 inches per year from 1914 to 2009 Western Regional Climate Center [WRCC] 2010). Average monthly temperatures at these two stations range from a low of 27.9 degrees Fahrenheit (°F) in January to a high of 95.7°F in July (WRCC 2010). Approximately 75 percent of the total precipitation falls between April and September (Powers et al. 1978).

Pan evaporation is around 110 inches per year, about 73 inches of evaporation occurs from May to October over the entire area (Powers et al. 1978). At least 90 percent of the rainfall that infiltrates the porous soils of the area estimated to evaporate or evapotranspirate through plants (Powers et al. 1978). Rainfall infiltration to groundwater in many areas is inhibited by caliche layers in the soil. Runoff in the vicinity of the WIPP site is about 0.1 to 0.2 inch per year.

1.4 Previous Investigations

Potash was discovered in southeastern New Mexico in 1925 as a result of drilling for oil (Davis 2009). The first potash mine, developed by the American Potash Company, went into operation in 1931. In 1997, approximately 80 percent of United States (U.S.) potash production came from New Mexico.

Hydrology studies of the SPA have been limited until recent studies were initiated as a result of the proposed WIPP site. Studies of the WIPP site have provided considerable understanding of the hydrology of the stratigraphic units that overly the potash-bearing Salado Formation. All important studies are included in the references of this report and sited throughout the text of this report.

1.5 Methodology

The hydrological assessment of the SPA consists of four components:

1. Summarizing the hydrogeology of the SPA.
2. Estimating a water balance for the SPA.
3. Developing a conceptual hydrologic model for the SPA.
4. Developing a numerical groundwater flow model for the SPA.

The summary of hydrogeology was compiled from published studies regarding the SPA, WIPP, and Project GNOME. The summary discusses geology, hydrogeology, aquifer delineation and aquifer properties, and groundwater chemistry. It also includes a detailed discussion of key areas such as Clayton Basin, Nash Draw, and the proposed area for groundwater pumping for the HB In-Situ Solution Mine Project in Section 2, T21S, R29E (Section 2).

Estimating a water balance for the SPA is difficult because of the lack of current data and the influence of past and present potash refinery discharge into the stratigraphic units and aquifers that overly the Salado Formation. Past water balance estimates within the SPA were documented in the study by Geohydrology Associates (1978b) and the operating potash refineries during the late 1970s. In addition, Hunter (1985) estimated water balances for the WIPP site and surrounding areas including portions of the SPA. Both water balance studies were combined in this assessment to form an overall water balance estimate for the SPA.

Studies performed in the late 1970s were given more weight due to a greater amount of data available during that time period. The data from the 1970s also were used to calibrate the numerical groundwater model.

The hydrogeology and water balance for the SPA was combined to form a proposed conceptual hydrogeological model for the SPA. The model forms the basis for the design of the numerical groundwater flow model. The groundwater flow model serves two roles in the hydrologic assessment of the SPA:

1. To provide a test and method for refining the conceptual hydrogeological model; and
2. To provide a mathematical basis for estimating future impacts to groundwater resources from proposed potash mining operations.

Effectively, the hydrologic assessment combines available data and studies of the SPA and adjacent areas into a groundwater flow model that reasonably represents the groundwater hydrology of the area of potash mining within the SPA.

2.0 Regional Geology

2.1 Geomorphic Features

The SPA lies within the Pecos Valley section of the Great Plains Physiographic Province (Fenneman and Johnson 1946). The SPA and surrounding area are drained by the Pecos River. The Pecos River is bordered on the west by the Guadalupe Mountains. To the east of the SPA are the Lea Plateau and Querecho Plains; both are a part of the High Plains section of the Great Plains Physiographic Province. The Edwards Plateau lies to the south and the Raton Section of the Great Plains Physiographic Province lies to the north of the SPA. **Figure 1-1** provides a regional overview of the SPA and **Figure 1-2** provides a detailed illustration of the key features in the area of potash mining in the SPA.

The Pecos Valley is characterized by rolling hills and mesas that range in elevation from approximately 3,100 feet amsl to 3,600 feet amsl. Two prominent collapse features dominate the SPA: Clayton Basin and Nash Draw. A third collapse feature, the San Simon Swale and Sink, lies to the east of the SPA on the High Plains area and is positioned over the buried eastern limb of the Capitan Reef Complex. These three collapse features were formed by dissolution of underlying evaporites during the end of the last glacial advance (21,000 years Before Present [BP]) and the ensuing wet climatic period following the melting of the continental glaciers. The region has been subject to wetter conditions from anywhere between 10,000 to 20,000 years BP (Corbett and Knupp 1996). Furthermore, the SPA and surrounding areas are dotted with isolated salt lakes and dry salt pans formed by a combination of groundwater seeps, surface water inflow, and locally by past potash processing discharges flowing to Clayton Basin and Nash Draw.

Nash Draw lies to the west of the WIPP site and south of the HB In-Situ Solution Mine Project area. Nash Draw is separated from WIPP site area by the Lea Plateau and from the High Plains province by Livingston Ridge. On the north, Nash Draw is separated from Clayton Basin by the Maroon Cliffs and Mimosa Ridge. On the west, Nash Draw is bordered by Quahada Ridge. Nash Draw is open to the south and drains into Salt Lake (Laguna Grande de la Sal) and possibly into the Pecos River at Malaga Bend (**Figure 1-2**). Conversely, Clayton Basin is a closed basin. It is bordered to the east and separated from the Querecho Plains by Nimenim Ridge. To the north, the Loco Hills form the boundary of the basin. On the west, the Burton Plateau and Fade-Away Ridge limit the basin, and on the south the Quahada Ridge-Mimosa Ridge-Maroon Cliffs arc of low hills separates the basin from Nash Draw.

2.2 Stratigraphic Units in the SPA

The sedimentary stratigraphy of the Delaware Basin is shown in **Table 2-1**. A detailed description of regional geology can be found in the Regional Geology; Geology and Minerals Issues Related to the Proposed HB In-Situ Solution Mine Project report prepared for the Bureau of Land Management (BLM) Carlsbad (AECOM 2010). Rocks in the upper Permian, including the Guadalupian and Ochoan series, are the most important for purposes of this project.

2.2.1 Guadalupian Series

The Guadalupian represents a time of deposition dominated by a reef system that rimmed the basin on the west, north, and east sides. The units of interest in the Guadalupian Series consist of the Capitan Limestone, Bell Canyon Formation, and the upper Artesia Group. These units are time-equivalent: the Capitan Limestone is the basin margin reef-derived unit, the Bell Canyon Formation was deposited in the basin, and the upper Artesia Group consists of back reef and shelf deposits. The reef system provided a distinct break between deep basin and back-reef shallow lagoon shelf deposits (**Figure 2-1**). The major reef former is the Capitan Limestone, which hosts the caves at Carlsbad Caverns National Park. The Capitan Limestone yields water and is considered an aquifer near the Pecos River. Beneath the potash mines, the Capitan Limestone can yield water but yields less water along the Pecos River (Mercer 1983).

Table 2-1 Stratigraphy of the Pecos River Country

			Formations & Members			Thick	Description
Holocene and Pleistocene			Assorted surficial deposits			0-300	Valley alluvium, terrace and pediment gravel, caliche soils, aeolian sand, travertine
Pleistocene-Pliocene			Gatuna Formation			0-200	Sandstone, sand gravel, siltstone, limestone, red, brown, tan, gray, yellowish
Oligocene			Sierra Blanca Volcanics			700-4,000	Andesite breccia and tuff; some flows
Paleocene			Cub Mountain Formation			500-2,000	Sandstone, mudstone, conglomerate, arkose; white, buff, lavender, purple, maroon
Cretaceous			Mesaverde Formation			500-1,500	Sandstone, shale, cool, conglomerate, buff, gray, black
			Mancos Shale			400-700	Shale, siltstone, with local thin sandstone and limestone; black, grayish-black
			Dakota Sandstone			100-150	Sandstone, conglomerate, black shale; gray to tan
Upper Triassic			Chinle Shale			0-300	Mudstone with some claystone and thin sandstone; reddish brown
			Santa Rosa Sandstone			0-300	Sandstone. conglomerate, mudstone; brown, buff, lavender
Permian	Ochoan Series		Dewey Lake Formation			200-250	Sandstone, siltstone; orange-brown; commonly laminated
			Rustler Formation: Upper Member			150-200	Dolomite, gypsum, mudstone, white, red-brown, green, gray, deep orange; Magenta dolomite at base
			Lower Member			100-250	Dolomite, gypsum, mudstone, sandstone; white, red-brown, gray, green; salt in subsurface; Culebra dolomite at base
			Salado Formation			0-2,500	Gypsum, mudstone. thin dolomite; white, red, brown, green, deep orange; breccia residue at surface, thick salt, potash in subsurface
			Castile Formation: Upper Member[1] (surface)			1,000±	Gypsum (anhydrite), salt; white, gray
			Lower Member (surface)			1,000±	Laminated gypsum (anhydrite) and limestone, laminated limestone, laminated gypsum; gray, black, white
	Guadalupian Series	Artesia Group	Tansill Formation	Capitan Ls.[2]	Bell Canyon Fm.[1]	200-300	Dolomite and siltstone (south); dolomite, gypsum, and anhydrile (north); Ocotillo siltstone tongue near exposed top
			Yates Formation			250-350	Siltstone, sandstone, dolomite. limestone and gypsum (south); gypsum, siltstone and thin dolomite (north)
			Seven Rivers Formation			450-600	Dolomite, siltstone (south); gypsum and siltstone (north)
			Queen Formation	Goat Seep Do.[2]	Cherry Canyon Fm.[1]	200-400	Dolomite and sandstone (south); gypsum, red mudstone, dolomite (north); Shattuck member near top
			Grayburg Formation			250-450	Dolomite and sandstone (south); gypsum, mudstone, dolomite (north)
	Leonardian Series		San Andres Formation: Fourmile Draw Member			0-700	Dolomite, gypsum, reddish mudstone; sandstone locally at top; thin-bedded
			Bonney Canyon Member			0-300	Dolomite, local limestone; gray, light-gray, local black; thin-bedded
			Rio Bonito Member			250-350	Dolomite. limestone, sandstone (Glorieta); gray, brownish gray; thick-bedded
			Yeso Formation			0-1,400	Sandstone, siltstone, dolomite, gypsum; tan, red-yellow, gray, white
Precambrian			Syenite, gneiss, and diabase				

[1] Delaware basin facies only.

[2] Reef facies only.

Source: Kelley 1971. Table 1, p. 6.

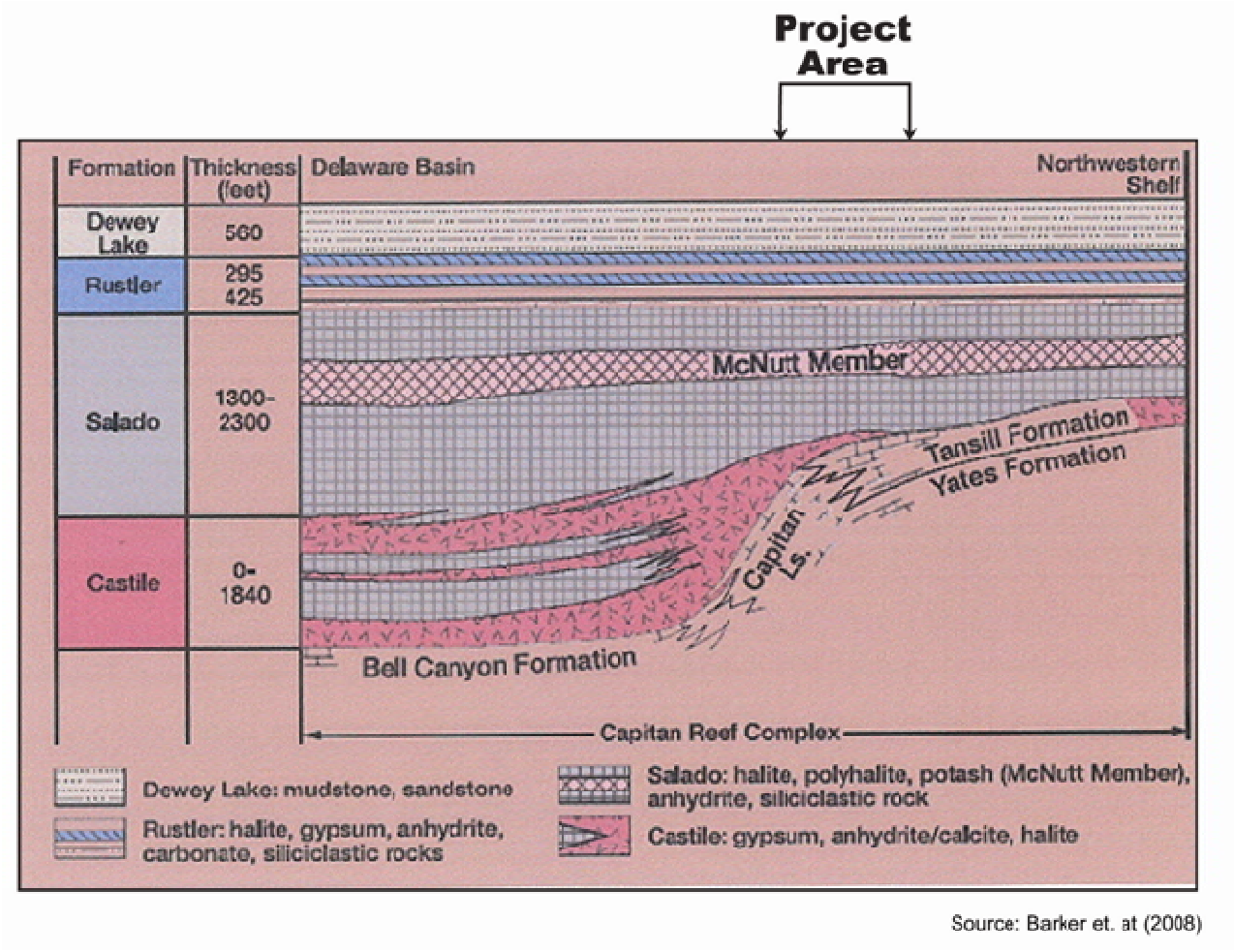


Figure 2-1 Stratigraphic Relationship between Upper Guadalupian-Ochoan Series

2.2.2 Ochoan Series

The Ochoan Series succeeds the Guadalupian Series and is characterized by rocks called evaporites that represent a drastic change of depositional environments from marine basin to a restricted marine and continental setting. The Ochoan Series consists of the Castile, Salado, Rustler formations, and the Dewey Lake Red Beds (Hill 1996) (**Table 2-2**). The Ochoan Series consists of anhydrite, gypsum, halite, soluble potash minerals, dolomite, and minor amounts of siltstone, mudstone, and shale. See Chapter 4.0 of the Regional Geology; Geology and Minerals Issues Related to the Proposed HB In-Situ Solution Mine Project report (AECOM 2010) for a detailed description of the Ochoan Series formations in the project area.

Castile Formation: The Castile is the basal unit of the Ochoan Series and is found basinward (south) of the Capitan reef complex, thinning dramatically above the Capitan (**Figure 2-1**). Within the WIPP site, the Castile is deformed by post-depositional warping and locally contains pressurized brines (Department of Energy 2004).

Table 2-2 Upper Guadalupian-Ochoan Formations in Project Area

System	Series	South	Project Area	North	Approximate Thickness in Project Area (feet)
		Delaware Basin		Northwest Shelf	
		Basin	Basin Margin - Reef	Shelf - Back Reef	
Permian	Ochoan	Dewey Lake Red Beds	Dewey Lake Red Beds	Dewey Lake Red Beds	Up to 250
		Rustler Formation	Rustler Formation	Rustler Formation	Up to 350
		Salado Formation	Salado Formation	Salado Formation	150 to 1,000
		Castile Formation	Castile Formation	No equivalent	10 to 80
	Guadalupian	Bell Canyon Formation	Capitan Limestone	Tansill Formation	1,500
				Yates Formation	
				Seven Rivers	

Sources: Hayes 1964; Hill 1996; Lambert 1983; New Mexico Oil Conservation Division 2009; Wills 1942.

Salado Formation: This is the main halite and potash-bearing unit in the Delaware Basin and the source of the potash in the SPA. It is the first unit deposited across the basin that covers the Capitan reef complex and the backreef Artesia Group (**Figure 2-1**). The formation has been divided into four informal members (**Figure 2-2**):

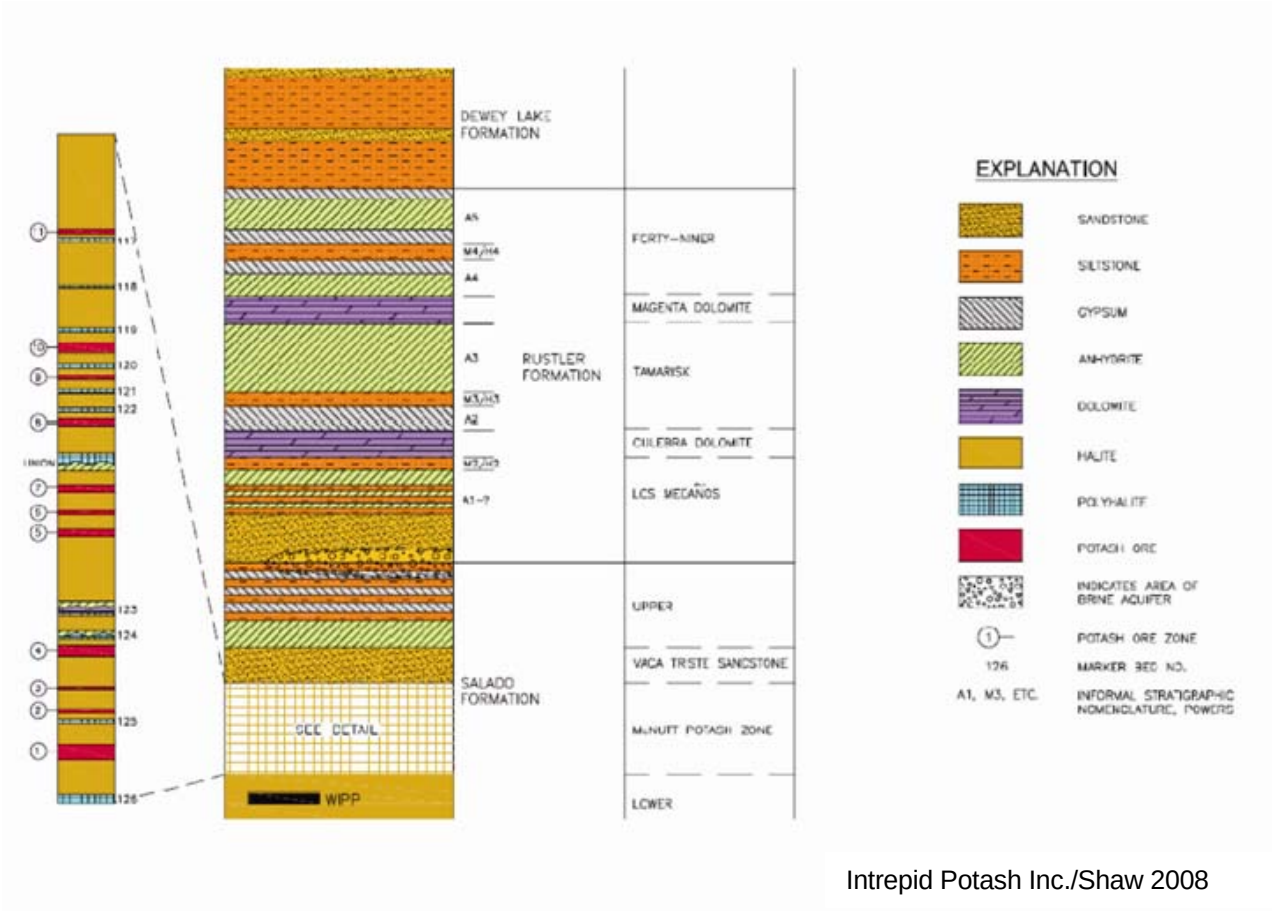
1. A lower unnamed massive halite member;
2. The McNutt Potash Zone;
3. The Vaca Triste Sandstone; and
4. An upper unnamed member with gypsum, siltstone, and anhydrite.

The WIPP underground nuclear waste storage facility is located in the lower massive halite member. The McNutt Potash Zone contains 11 potash zones (Intrepid Postash Inc./Shaw 2008). The Vaca Triste Sandstone is a basal marker unit for the upper unnamed member.

Rustler Formation: The Rustler is the uppermost member of the Ochoan Series and ranges in thickness from 150 feet in Nash Draw to 462 feet in thickness east of WIPP, with a thickness of 310 feet at the WIPP site (Snyder 1985). The formation has been divided into five members (**Figure 2-2**):

1. Los Medanos;
2. Culebra Dolomite;
3. Tamarisk;
4. Magenta Dolomite; and
5. Forty-Niner.

The Los Medanos Member is the basal member of the Rustler and consists of a maximum of 145 feet of bedded, cross-bedded, and brecciated clastic sedimentary rocks showing evidence of bioturbation. The upper part of the member has halite and gypsum interbedded with dark gray to reddish-brown siltstone and sandstone. The Los Medanos is rich in saline brine in areas where the underlying Salado has undergone dissolution and collapse. In the area of Nash Draw, the Los Medanos is the source of brine that flows southwest to Salt Lake (Geohydrolgy 1978a).



Intrepid Potash Inc./Shaw 2008

Figure 2-2 Stratigraphic Column for the Salado and Rustler Formations

The Culebra Dolomite is a brownish gray to gray finely crystalline chemically precipitated dolomite that can be locally rich in clay and siltstone and contains abundant vugs filled with gypsum and anhydrite (Snyder 1985). The unit is 25 to 30 feet thick and is continuous across the SPA and WIPP. This unit carries water and is the first water-bearing unit above the Salado at the WIPP site.

The Tamarisk consists of two anhydrite layers separated by halite and mudstone. The unit is 179 feet thick in the WIPP area, but considerably thinner in Nash Draw where the halite has been removed by dissolution. In the SPA, the unit is mostly mudstone, but at WIPP it is mainly halite. The unit is conformable with the Culebra Dolomite and there is an organic-rich layer separating the two members of the Rustler (Holt and Powers 1990).

The Magenta Dolomite is a gypsiferous dolomite exhibiting cross-bedding and laminae of anhydrite and dolomite. The color ranges from pink to purple depending on the abundance of dolomite versus gypsum. The unit is 20 to 30 feet in thickness and is found in the SPA and at WIPP, although the unit may not be present in the area of Salt Lake. In Nash Draw, removal of halite from the Tamarisk has resulted in collapse of the section and fracturing of the Magenta.

The Forty-Niner is the uppermost unit of the Rustler and consists of two thick medium gray anhydrite beds separated by a reddish-brown silty halite (Snyder 1985). The unit is mostly gypsum in the SPA, due to removal of halite and hydration of anhydrite to gypsum. The unit is up to 150 feet thick and contains the compete section with anhydrite and halite. The unit is 40 to 80 feet in thickness in the SPA.

Dewey Lake Red Beds: The Dewey Lake Red Beds are considered either Triassic or latest Permian/Triassic and represent a major change in the depositional history of the SPA. Siegel et al. (1991) have used stable isotopes to show that fluids within the Dewey Lake have interacted with fluids in the underlying Rustler Formation and that the gypsum in the Dewey Lake is formed from meteoric water. The Dewey Lake is a local source of water for stock wells.

2.3 Dissolution of Evaporites

One of the important geologic features of the SPA and the Pecos Region of southeastern New Mexico is the presence of collapse features that are the result of the dissolution of evaporites and also karst formation in the Capitan Limestone. This dissolution affects both the geologic structure of the area, causing local collapse features and karsts, and the movement of groundwater. Many of the collapse features are thought to have formed during the Pleistocene (Bachman 1984) and may be slowly increasing in size today where surface water is able to penetrate the features and continue the dissolution process. The karst features in the Capitan Limestone and other limestone units are evident in the Carlsbad Caverns, the San Simon Swale, and in some of the breccia pipes formed in the SPA above the Capitan Limestone or backreef units such as the Tansill and the Yates. The breccia pipes can extend through the Rustler and develop as surface collapse features or mounds surrounded by a ring of fractured rock.

The dissolution of evaporites in the Rustler Formation also has resulted in major collapse features in the SPA such as Clayton Basin and Nash Draw and much smaller features such as breccia pipes (Bachman 1984; Snyder and Gard 1982). The dissolution of evaporites in the Rustler appears to be the result of a dissolution front that has migrated eastward and down the stratigraphic dip of the Rustler from the present area of the Pecos River toward WIPP and is currently located along the western side of the WIPP area (Snyder 1985; Snyder and Gard 1982). Near the Pecos River, dissolution in the Rustler is associated with collapse and can be found down to the top of the Salado. At the eastern extent of the dissolution front, the dissolution is limited to the upper member of the Rustler (Forty-Niner member). In Nash Draw, the Gatuna Formation is deposited on collapsed Rustler and the estimated date for collapse was around 600,000 years BP (Bachman 1981). The origin of this dissolution front has been the subject of study related to WIPP (Snyder 1985) and a regional study by Bachman (1984).

Key features needed for dissolution of limestone and evaporites include:

1. Land above sea level;
2. Abundant water in the form of streams and precipitation; and
3. Fractures in the rock to allow for penetration of the water.

Dissolution begins with surface water penetrating fractures. The second stage is the widening of the fractures and the formation of underground solution features and channels for groundwater flow. The late stage is collapse of the system undergoing dissolution due to extensive subsurface brecciation (Bachman 1984). During the dissolution of evaporites, halite is dissolved, resulting in collapse, and anhydrite is converted to gypsum. Anhydrite converted to gypsum results in a 35 percent increase in volume, which leads to buckling that can be followed by collapse.

The model developed for the Pecos Region of southeastern New Mexico by Bachman (1984) involves dissolution during both the Triassic and during the Pleistocene. During the Triassic, southeastern New Mexico underwent uplift and erosion. Streams flowed eastward from the mountains along the western margin of the basin and removed the upper Rustler down to the Culebra and deposited alluvial sediments. Most of the sediments were deposited along the present area of the Pecos River. In some areas, the Salado was removed, allowing collapse of the Culebra to the top of the Castile.

During the Pleistocene, elevated rainfall and drainage from the ancestral Pecos and it tributaries created dissolution in the Rustler and Salado. The dissolution eventually caused many of the present-day collapse features. The ancestral Pecos was a high energy stream that formed east of the present course of the Pecos

(Bachman 1984). By the middle Pleistocene, the ancestral Pecos had formed a karst plain southeast of Malaga (**Figure 2-3**). Ultimately considerable collapse occurred in the Rustler and Salado which allowed for the deposition of stream channel gravels (**Table 2-1**) in the collapse features. The Magenta Dolomite collapsed in this region into a chaotic breccia and a collapse sink developed in the Poker Lake area (Bachman 1984). Underground water flow resulted in the collapsed areas and dissolution of the Rustler and Salado extended to the top of the Castile. The Clayton Basin and Nash Draw collapse features formed and water entering the system as recharge through fractures in the Bear Grass Draw area (T18S, R30E), about 30 miles north of Malaga, found its way to Nash Draw. The current “brine aquifer” located in the Los Medanos member of the Rustler along the Rustler/Salado contact was formed.

The model of Snyder (1985) for dissolution and collapse of the Rustler shows a progressive dissolution front that stair-steps up section in the Rustler from the Nash Draw area through WIPP. **Figure 2-4** shows the location of drill holes used by Snyder (1985) and **Figures 2-5** and **2-6** show the result of lithologic and geophysical evaluation of the boreholes. As shown in **Figure 2-5,** a complete and unaltered section of the Rustler is present east of WIPP in borehole P-18. Moving westward from P-18 toward WIPP, halite is missing (due mainly to dissolution) above the Culebra Dolomite along the eastern section of the WIPP site (**Figure 2-6**). Over most of the WIPP area, halite is missing above the Magenta Dolomite as well as absent above the Culebra Dolomite. Starting with the western section of the WIPP area and including all of Nash Draw, there is no halite in the Rustler. As shown in **Figure 2-5**, the Rustler has collapsed to about 130 feet thick in the eastern part of Nash Draw compared to about 465 feet thick in the complete section at P-18 east of WIPP. According to Snyder (1985), this is due to removal of halite.

The present-day climate of southeastern New Mexico and the SPA is dry compared to the Pleistocene, and the groundwater flow patterns are slowly adjusting to present conditions of much lower recharge and water infiltration through fractures (Corbett 1994). The Nash Draw and Clayton Basin collapse features along with breccia pipes and karst features found in the SPA are the result of dissolution and collapse during the Pleistocene. Some present-day features may be slowly increasing in size due to precipitation entering fractures during heavy rainfall periods, but the main period of dissolution of halite and collapse in the Rustler, as well as karst formation in the Capitan Limestone was most likely the Pleistocene during the glacial and wet interglacial periods (Bachman 1984).

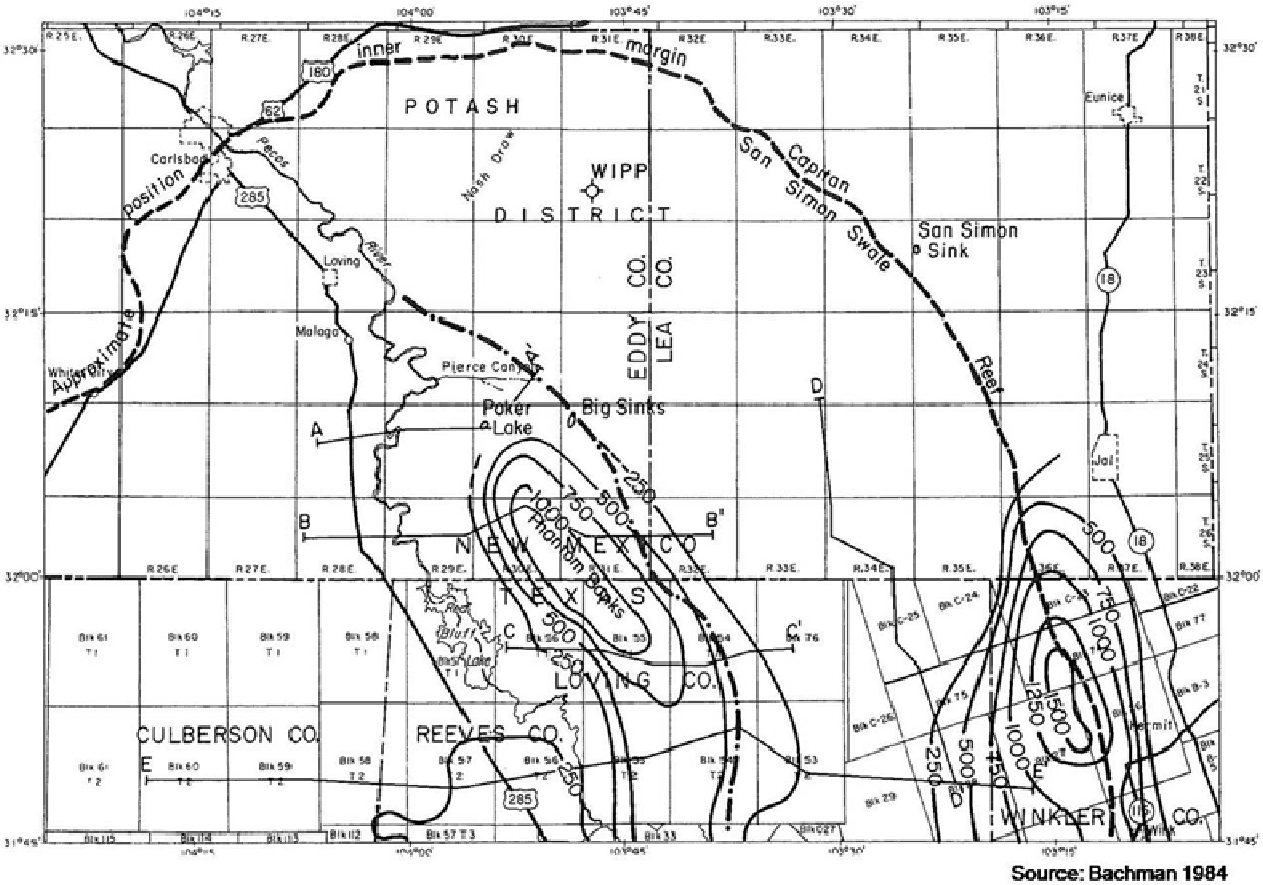


Figure 2-3 Map Depicting a Portion of the Ancestral Pecos River and Isopachs (feet amsl) of Cenozoic Fill

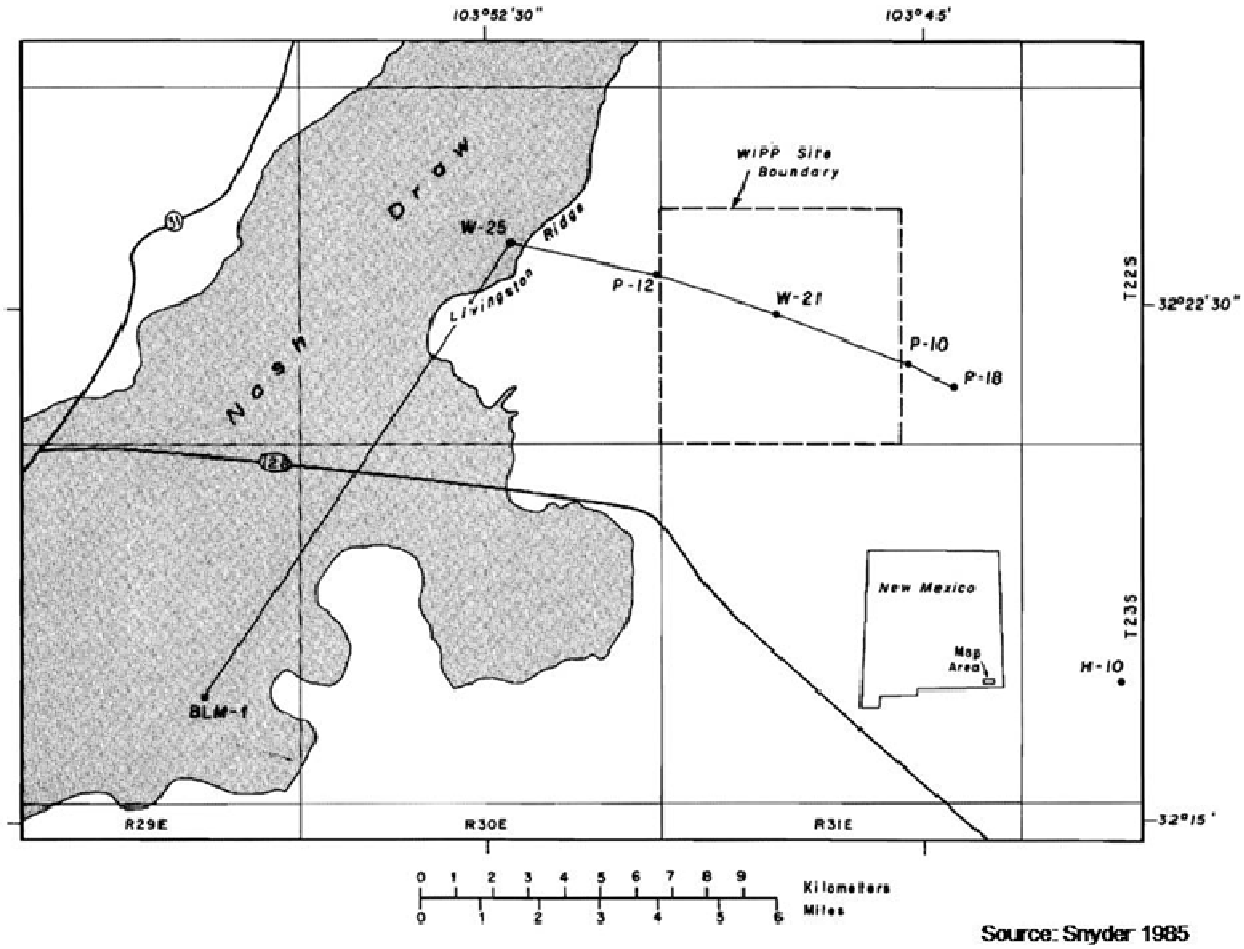


Figure 2-4 Location of Well Bores Referenced for Figure 2-5

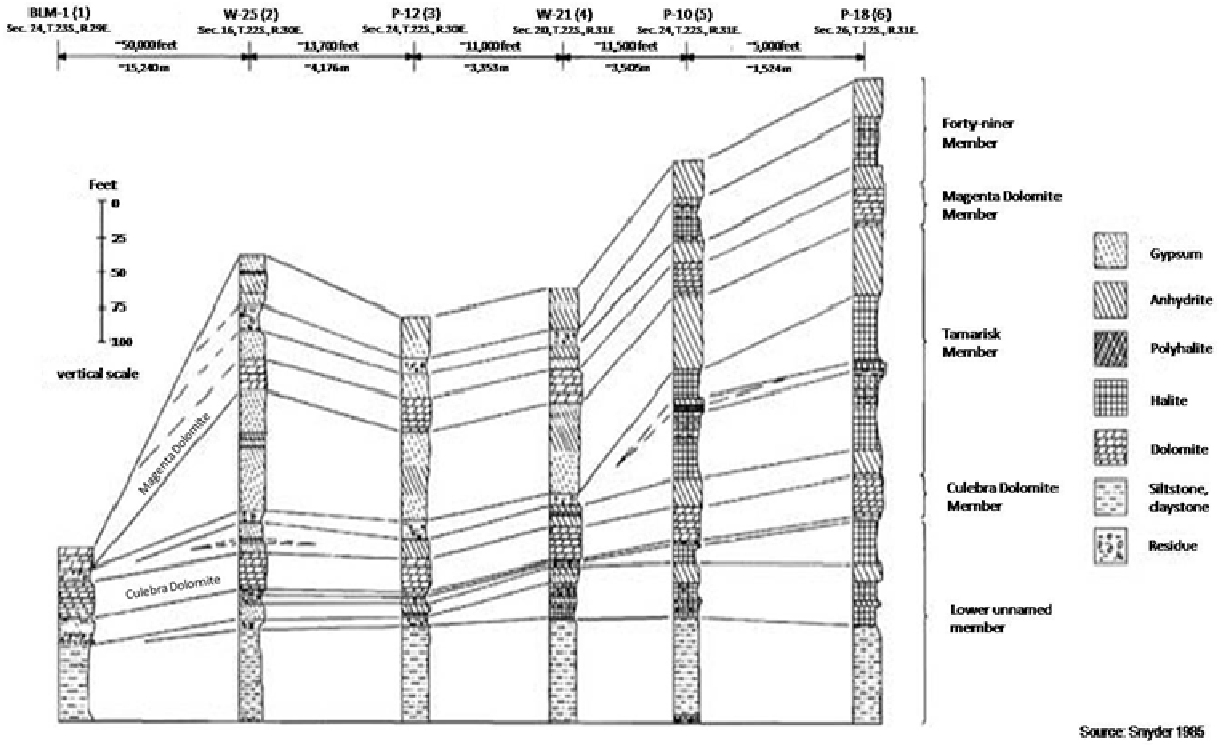


Figure 2-5 Columnar Cross-Section in WIPP Vicinity Showing Lithologic Correlation of Units in the Rustler Formation

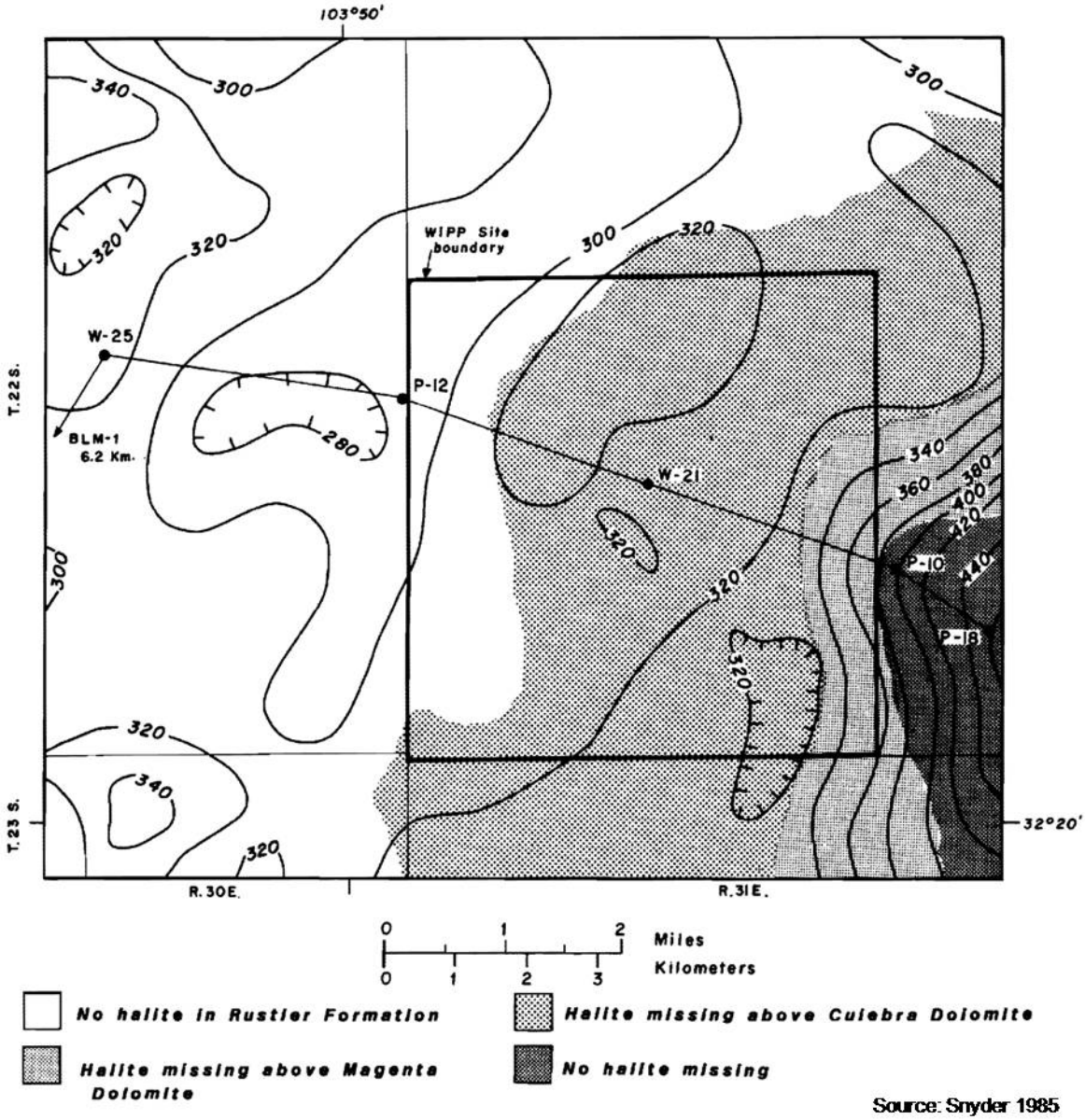


Figure 2-6 Isopach Map of the Rustler Formation Showing Dissolution Zones in the WIPP Vicinity

3.0 Regional Hydrogeology and Groundwater Chemistry

The SPA contains regional aquifers in many of the Permian stratigraphic units, but none are continuous in the Dewey Lake Red Beds or the Santa Rosa Formation. The Salado Formation locally contains brine, as does the Castile Formation, but neither unit acts as an aquifer. The important aquifers that potentially are affected by past, present, and proposed future solution mining and refining activities are those in the Rustler Formation and the Capitan Limestone.

3.1 Groundwater Aquifers in the SPA

There are five main aquifers in the northern part of the Delaware Basin that underlie the SPA:

1. Bell Canyon Aquifer of the Delaware Mountain Group;
2. Capitan Aquifer;
3. Brine Aquifer in the Los Medanos member of the Rustler Formation;
4. Culebra member of the Rustler Formation; and
5. Magenta member of the Rustler Formation.

The Castile and Salado formations lie between the Bell Canyon/Capitan and the Rustler Formation. The Dewey Lake Red Beds and the Santa Rosa Formation locally contain water, but do not act as regional aquifers.

3.1.1 Bell Canyon Aquifer

The Bell Canyon, the deepest aquifer, is the upper member of the Delaware Mountain Group and consists of sinuous channels of sandstone interbedded with black shale and black limestone. The sandstone channels grade laterally into siltstones and shales (Mercer 1983). The Lamar Shale member of the Bell Canyon and the overlying Castile Formation both act as impermeable aquitards that confine the aquifer in the Bell Canyon. The porosity of the sand channels is between 20 to 28 percent, while the siltstones and shales have a lower porosity of about 10 to 20 percent and a low permeability of around 0.1 millidarcy (Mercer 1983). The vertical hydraulic conductivity of the Bell Canyon is low, while the horizontal conductivity from drill-stem tests ranges from 7.0×10^{-3} feet per day to 2.0×10^{-2} feet per day (Mercer 1983). The Lamar Shale has a horizontal hydraulic conductivity of about 2.0×10^{-6} feet per day. Groundwater flows northeast (**Figure 3-1**) with a potentiometric surface of 3,600 feet amsl by Malaga Bend and a potentiometric surface of 3,400 feet amsl beneath WIPP, and a gradient of approximately 25 to 40 feet per mile (Intrepid Postash Inc./Shaw 2008). Water quality is saline and consists of sodium chloride brine with total dissolved solids (TDS) ranging from 180,000 to 270,000 milligrams per liter (mg/L). The density of the brine ranges from 1.06 to 1.13. Calcium ranges from 5,000 to 10,000 mg/L, sodium from 55,000 to 89,000 mg/L, chloride from 110,000 to 150,000 mg/L, sulfate from 1,800 to 2,400 mg/L, and boron from 20 to 76 mg/L. Brine pH is neutral and ranges from 6.3 to 7.7 standard units (Mercer 1983). Well yields are low, less than 5 gallons per minute (gpm), and the aquifer is used for injection of petroleum waste water.

3.1.2 Capitan Aquifer

The Capitan Aquifer consists of the Capitan Limestone, the Goat Seep Formation, and the forereef and backreef facies associated with the Guadalupian Reef Complex (Richey and Wells 1984). The Capitan Aquifer's width at the north end of the Delaware Basin is about 10 to 14 miles and has a maximum thickness of 2,400 feet and an average thickness around 1,500 feet (Mercer 1983). West of the Pecos River, the Capitan Aquifer is unconfined, recharged by precipitation in the Guadalupe Mountains. The Capitan Aquifer discharges into the Pecos River at Carlsbad Springs. Prior to incision of the Pecos River in Pleistocene times, the Capitan Aquifer was probably a continuous aquifer across the northern end of the basin and recharge in the

mountainous areas supplied water for the entire aquifer. East of the Pecos River, the Capitan Aquifer is confined and artesian. The Castile Formation prevents lateral movement of water from the Capitan into the basin. The underlying Delaware Mountain Group has a higher hydraulic head that prevents downward seepage of water from the Capitan. Recharge to the Capitan west of the Pecos ranges from 10,000 to 20,000 acre-feet per year, and discharges around 4,500 acre-feet per year to Carlsbad Springs (Richey and Wells 1984).

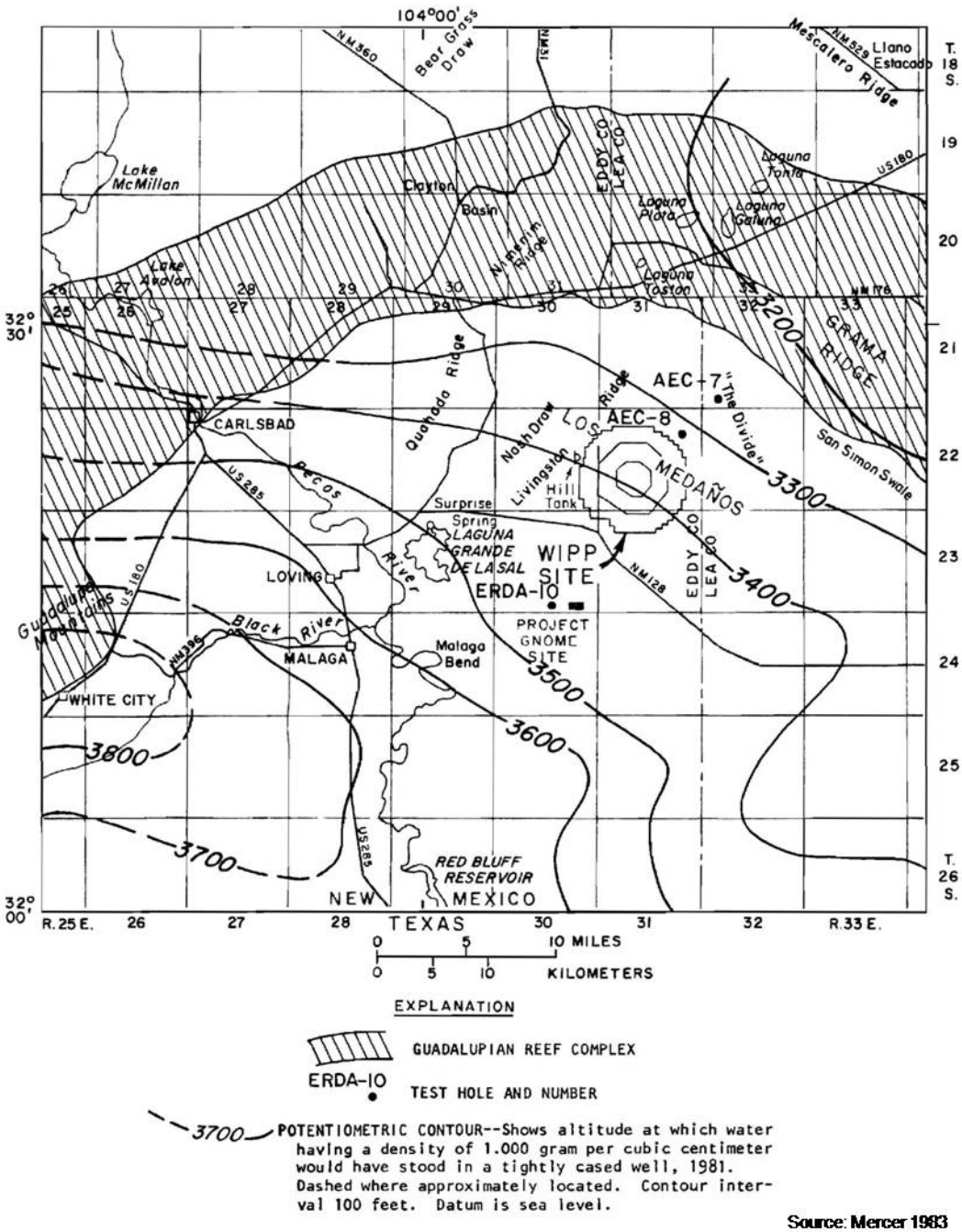


Figure 3-1 Distribution of Lakes near the Bottom of Nash Draw with Potentiometric Surface Contours

The hydraulic conductivity of the Capitan depends on the facies tested. Hydraulic conductivity values range from 1 to 25 feet per day and average around 5 feet per day east of the Pecos along the northern rim of the basin. Transmissivity values range from 5,390 to 16,174 feet squared per day (Mercer 1983).

A transmissivity of about 10,000 feet squared per day is common for the Capitan. In the sand-filled buried submarine channels that cut through the reef complex, lower values of 500 feet squared per day are often recorded. A large submarine channel exists near the east side of the SPA along the Eddy/Lea county line (Mercer 1983; Richey and Wells 1984). Groundwater flow in the Capitan is illustrated by the potentiometric contours in **Figure 3-2**. East of the Pecos and in the western area of the SPA, the groundwater gradient is nearly flat, suggesting limited lateral flow in the Capitan. Ground water flow in the Captain flows east where the Capitan underlies the SPA due to a stronger gradient,

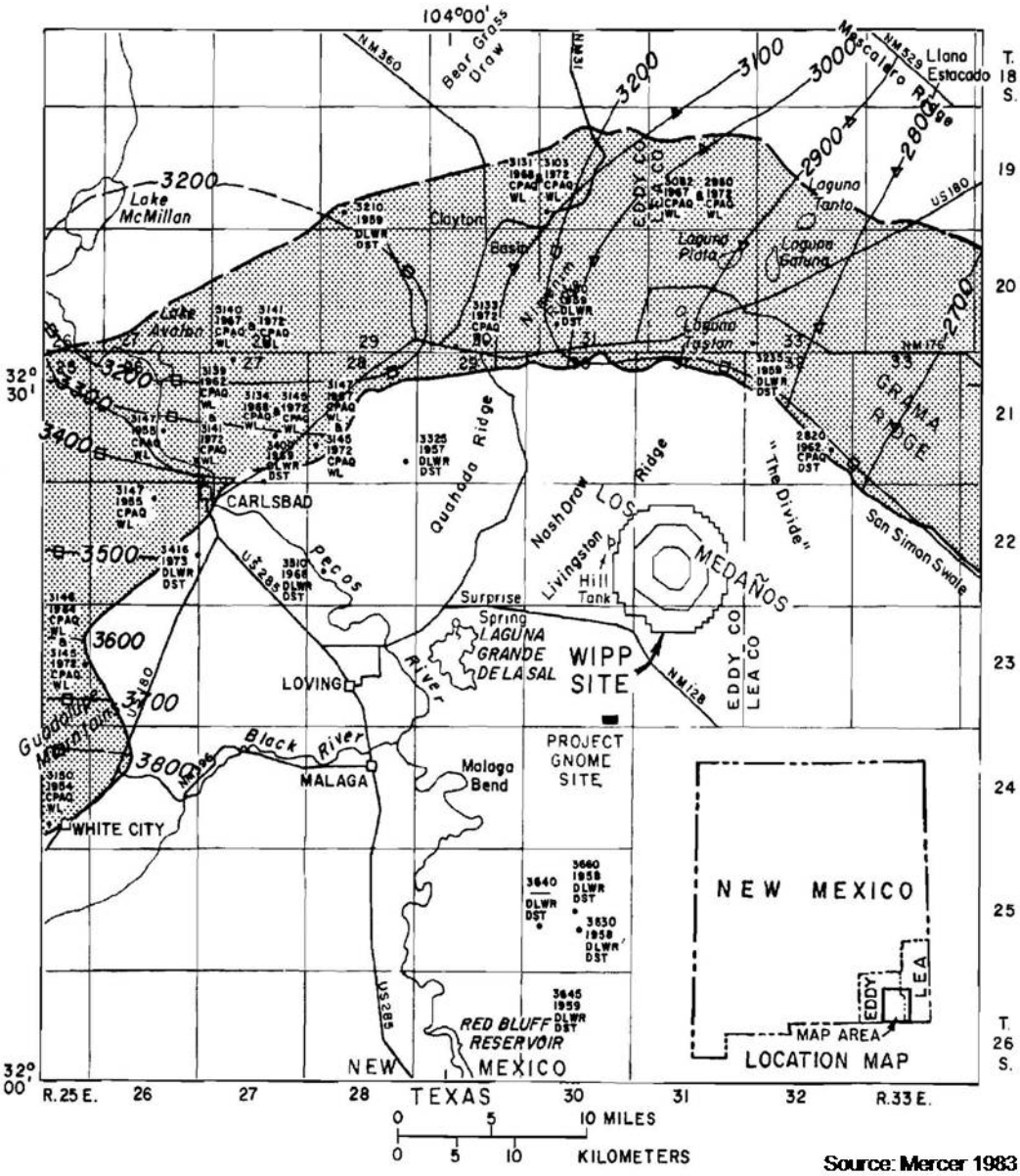


Figure 3-2 Potentiometric Surface of the Capitan Aquifer

Water quality in the Capitan is variable. West of the Pecos, the water quality is considered good. The TDS measurements west of the Pecos range from 300 to 1,700 mg/L (Richey and Wells 1984). East of the Pecos in Eddy County, the water quality can become saline and TDS can range from 10,000 to 30,000 mg/L. Chloride also can be as high as 16,000 to 17,000 mg/L. Water in the Capitan west of the Pecos is used for domestic consumption. East of the Pecos, water in the Capitan is used for agricultural and industrial consumption. The Capitan is a potential source of water in the SPA.

3.1.3 Castile Formation

The Castile Formation consists of thick anhydrite with thin interbedded salt layers. The unit is 1,500 to 1,850 feet thick in the WIPP (Mercer 1983). In south-central Eddy County, the unit is exposed and the anhydrite is converted to gypsum. Water is found in weathered sections of the unit where it is exposed. The water is used locally for stock watering. The unit does not have a regional flow system and is not considered an aquifer. Hydraulic tests conducted at WIPP found the hydraulic conductivity to be too low for field measurement. The hydraulic conductivity is estimated to be approximately 1.0×10^{-8} feet per day (Mercer 1983). The Castile acts as an aquitard, which limits vertical groundwater flow and isolates the Bell Canyon's high hydraulic head from the Salado Formation. The unit is not fractured in the WIPP area. Local brine pockets containing gas have been encountered by oil and gas drilling. The flow of brine in these exploration wells has been as high as 20,000 barrels per day (Powers et al. 1978).

3.1.4 Salado Formation

The Salado is mostly halite with interbedded anhydrite, polyhalite, potash, sandstone, and siltstone layers. The unit is unaltered and 1,700 to 2,300 feet thick in the WIPP area (Mercer 1983). West of WIPP, the Salado exhibits dissolution features in the upper 200 feet that have lead to sinks, karst mounds, and collapse features in the Nash Draw and Clayton Basin areas. Where the Salado is exposed at the surface near the Pecos River, the anhydrite is converted to gypsum. The Salado is not an aquifer and where it is unaltered by dissolution, the porosity is less than 0.001 and the permeability is 12 to 21 microdarcies or less (Mercer 1983).

In places where the top of the Salado has undergone dissolution, a brine aquifer has formed between the Salado and the overlying Rustler Formation. This brine aquifer is quite prominent in the Nash Draw area and its extent is illustrated on **Figure 1-2**. The brine aquifer has an average TDS around 300,000 mg/L and discharges to the Pecos River at Malaga Bend. The transmissivity of the brine aquifer is around 8,000 feet squared per day at Malaga Bend and the discharge rate at Malaga Bend has been estimated at approximately 200 gpm (Mercer 1983). The brine aquifer is considered to be part of the overlying basal member of the Rustler Formation and will be discussed in more detail in the next section.

3.1.5 Rustler Formation Aquifers

The Rustler Formation consists of five members:

1. Los Medanos (basal);
2. Culebra Dolomite;
3. Tamarisk evaporite with anhydrite and halite;
4. Magenta Dolomite; and
5. Forty-Niner evaporite with anhydrite and halite (upper).

The evaporite members are not aquifers at WIPP. In Nash Draw, where dissolution has caused considerable collapse of the Rustler section, the Tamarisk may carry water and act locally as an aquifer, especially in lower Nash Draw near Salt Lake (Mercer 1983). The Los Medanos contains a brine aquifer that is found throughout Nash Draw, and both the Culebra and the Magenta are aquifers.

3.1.5.1 Los Medanos Brine Aquifer

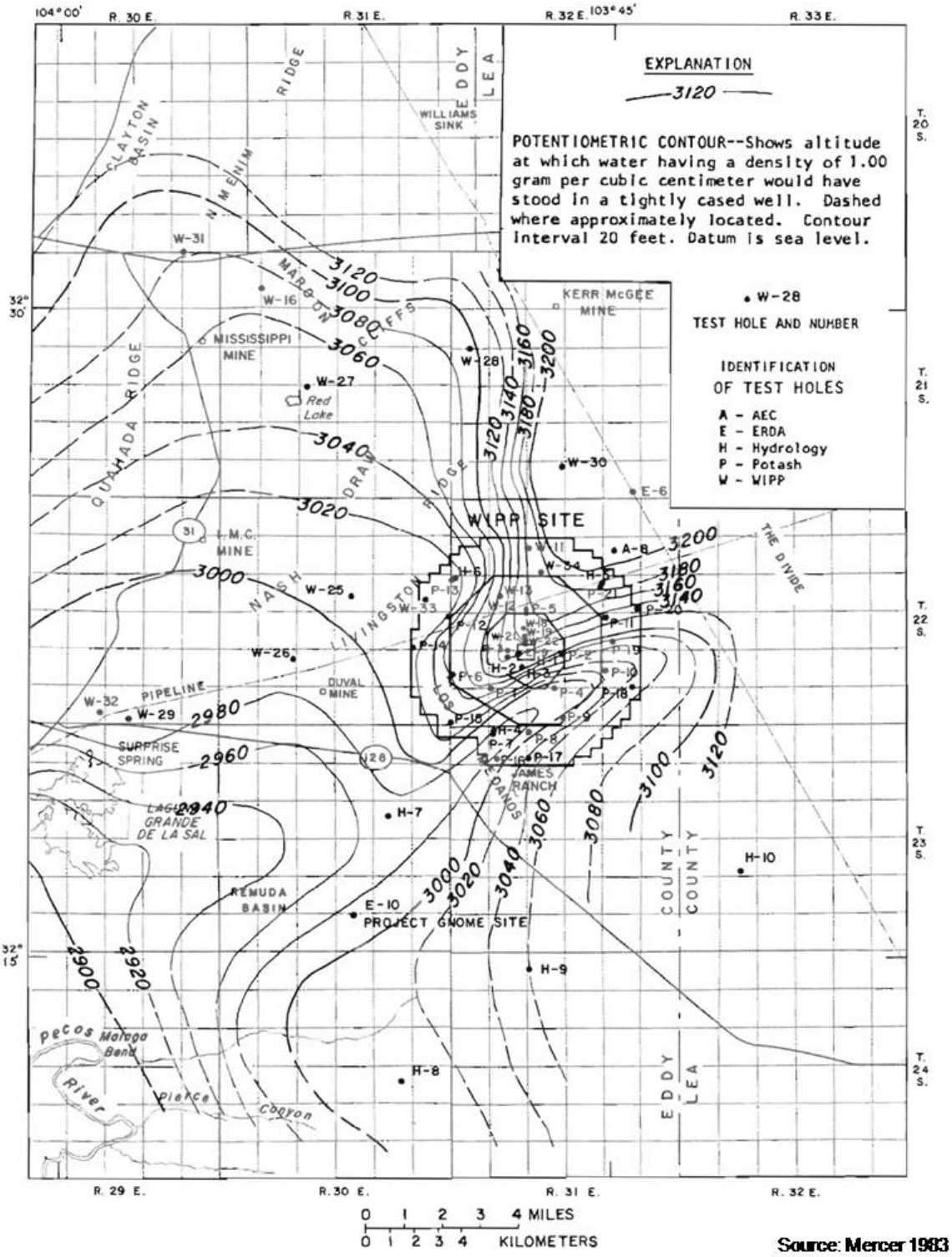
Dissolution of the upper 200 feet of the Salado Formation along the contact with the overlying Rustler has produced a zone of clay residuum containing seams of brecciated gypsum and sandstone. The brecciated seams are 10 to 60 feet in thickness and average around 24 feet in thickness (Mercer 1983). This zone underlies Nash Draw and ranges from 2 to 8 miles in width and has a total length of about 26 miles (**Figure 1-2**). The Brine Aquifer is found in the Los Medanos. It was formed from the dissolution of the upper Salado. This Brine Aquifer discharges to the Pecos River at a rate of approximately 200 gpm (Mercer 1983) and contains brine with a TDS ranging up to 480,000 mg/L and average values of 300,000 mg/L. The Brine Aquifer apparently does not discharge to Salt Lake or Surprise Spring (**Figures 3-1** and **3-2**), based on comparison of water chemistry data and ratios of key constituents (Mercer 1983).The Tamarisk and the Culebra and possibly the Magenta have all collapsed into one another near Salt Lake due to dissolution in the Tamarisk. As a result, the collapse makes them all likely water sources for Surprise Spring and Salt Lake. The water discharges to Surprise Spring and Salt Lake at approximately 115 to 125 gpm (Mercer 1983).

Groundwater flow in the Brine Aquifer of the Los Medanos member of the Rustler is shown in **Figure 3-3**. The hydraulic gradient is around 10 feet per mile in Nash Draw with a flow rate of about 0.002 foot per day (assuming a porosity of 0.2, hydraulic conductivity of 0.15 foot per day, and gradient of 10 feet per mile). Estimates of the transmissivity in the upper part of Nash Draw range from 2.0×10^{-4} feet squared per day at WIPP in well W-27, to 8.0 feet squared per day in WIPP well W-29. The transmissivity measured in the Brine Aquifer near Salt Lake in lower Nash Draw, where the Rustler section has collapsed due to removal of halite and erosion of the Magenta, was 8,000 feet squared per day. At WIPP, the Brine Aquifer is present only in the far western part of the WIPP site and not present in the eastern part of WIPP. Transmissivity measurements for the Los Medanos at WIPP range from 3.0×10^{-5} feet squared per day in well P-18 to 5.0×10^{-2} feet squared per day in well P-14. Recharge for the Los Medanos member of the Rustler may be in Bear Grass Draw (T18S, R30E), similar to other members of the Rustler. Discharges to the Pecos deliver around 342 tons of sodium chloride per day (Mercer 1983). Slow movement of water in the Brine Aquifer within the WIPP area is supported by the high magnesium plus potassium content (Mercer 1983). Magnesium concentrations in the Los Medanos in the eastern part of WIPP range from 21,000 to 82,000 mg/L. In Nash Draw, magnesium values range from 350 to 1,200 mg/L, suggesting a much faster movement of water down Nash Draw than across WIPP toward Nash Draw. **Figure 3-4** shows the water chemistry from wells in Nash Draw and WIPP (Mercer 1983). The 2,000 mg/L magnesium plus potassium line separates high flow from low flow areas in the Brine Aquifer. The low flow is east of the line in the WIPP area, where dissolution of the Salado is limited or absent.

3.1.5.2 Culebra Dolomite Aquifer

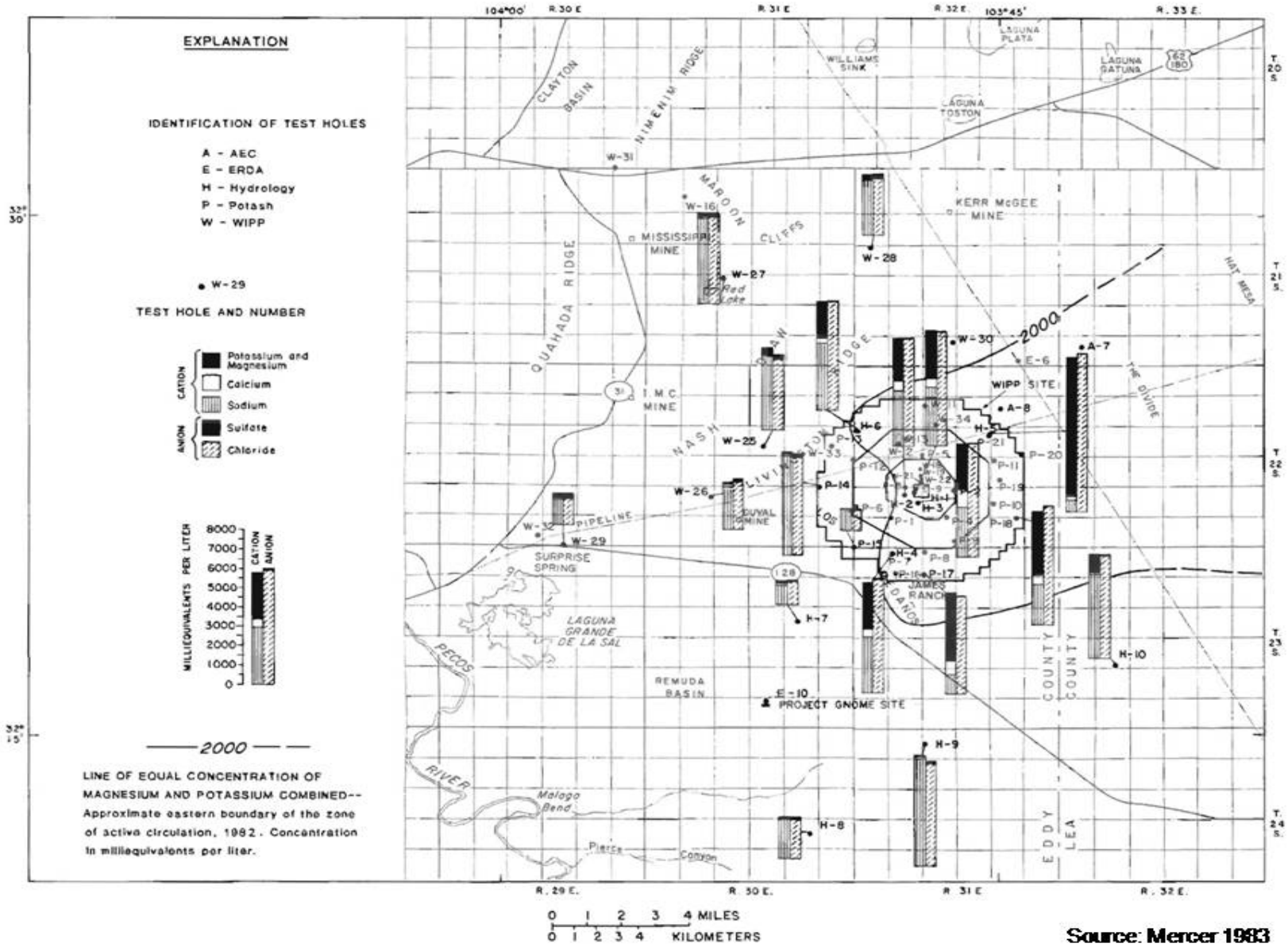
The Culebra Dolomite is a vuggy, crystalline dolomite at WIPP that averages around 25 to 30 feet thick and is located stratigraphically between the basal Los Medanos member and the Tamarisk anhydrite member. At WIPP, the Culebra acts as a confined aquifer and is considered the first aquifer above the Salado, because the Los Medanos at WIPP does not contain the Brine Aquifer. At Nash Draw, the Culebra has collapsed into blocks forming drape structures and karst mounds due to dissolution in the Los Medanos and Salado below and the Tamarisk above (Mercer 1983). The Culebra outcrops at the Pecos River. Fluid flow in the Culebra at WIPP is mainly fracture flow along bedding planes and fractures in the formation (Mercer 1983). In Nash Draw, fluid flow in the Culebra is complex because of the collapse of the unit, formation of blocks, and areas of intense fracturing that allow for hydraulic communication between the Culebra and the Magenta (Mercer 1983).

The potentiometric surface of the Culebra at WIPP and in Nash Draw is shown in **Figure 3-5**. Gradient changes are related to permeability changes and groundwater flow is controlled by fracture orientation. Transmissivity in the Culebra varies considerably from WIPP to Nash Draw and especially within Nash Draw.



Source: Mercer 1983

Figure 3-3 Adjusted Potentiometric Surface of the Brine Aquifer of the Los Medanos



Source: Mercer 1983

Figure 3-4 Water Chemistry in the Brine Aquifer of the Los Medanos

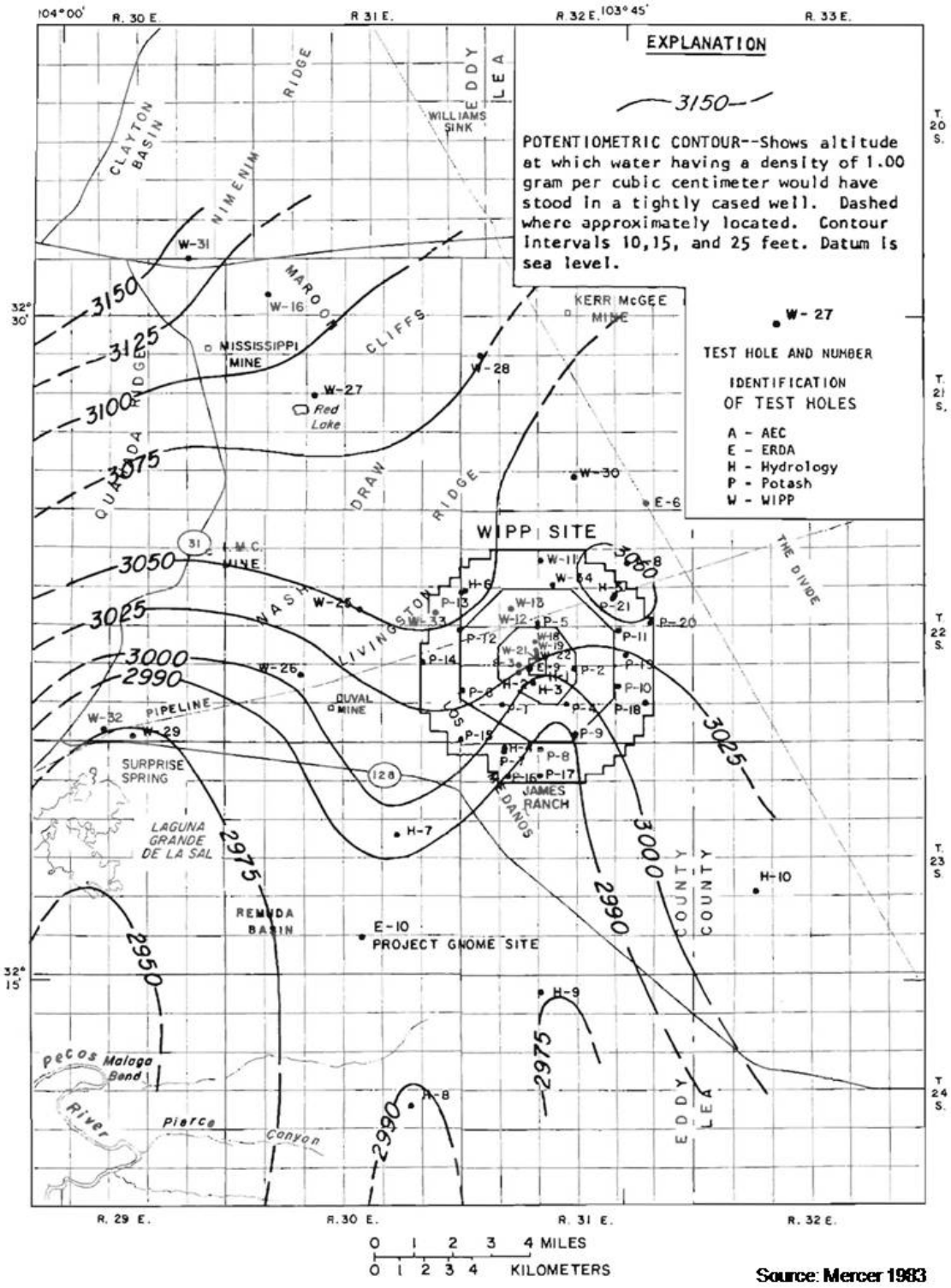


Figure 3-5 Potentiometric Surface of the Culebra Dolomite Aquifer

Table 3-1 presents a summary of measured data given by Mercer (1983). The transmissivity of the Culebra at WIPP ranges from 1.0 x 10^{-3} feet squared per day at P-18 on the east side of WIPP to 140 feet squared per day at P-14 and 73 feet squared per day at H-6B on the west side of WIPP near Nash Draw. Generally, the transmissivity at WIPP is below 1.0 feet squared per day (Mercer 1983). In Nash Draw, transmissivity values range from 18 feet squared per day near the north end at W-28, 270 feet squared per day at W-25, and an unusually high value of 1,250 feet squared per day at W-26. At the GNOME project, transmissivity measured in the Culebra was 535 feet squared per day. Porosity in the Culebra is around 13 to 14 percent, with an effective porosity of 7 to 11 percent (Mercer 1983). At W-25, the Culebra and the Magenta are in hydraulic communication, as suggested by similar transmissivity values (Magenta at 375 feet squared per day), a head difference of only 4 feet, and similar water quality (Mercer 1983). The Culebra is probably recharged at Bear Grass Draw and discharges to Salt Lake.

Table 3-1 Values of Transmissivity and Storage Coefficient for Water-bearing Zones in the Rustler Formation Penetrated by Selected Test Holes at and Near the Proposed Waste Isolation Pilot Plant Site

[Transmissivity is expressed in feet squared per day]

	Magenta Dolomite Member		Culebra Dolomite Member		Rustler-Salado Contact Residuum	
Test Hole	**Transmissivity**	**Storage**	**Transmissivity**	**Storage**	**Transmissivity**	**Storage**
H-1	0.05	-	0.07	1.0E-04	0.0003	-
H-2A	0.01	1.0E-04				
H-2B			0.4	1.0E-09		
H-2C					0.0001	-
H-3	0.1	1.0E-05	19	-	0.0003	1.0E-04
H-4A	0.06	1.0E-06				
H-4B			0.9	1.0E-09		
H-4C					0.0006	1.0E-04
H-5A	0.1	1.0E-05				
H-5B			0.2	1.0E-05		
H-5C					0.00003	1.0E-03
H-6A	0.3	1.0E-05				
H-68			73	-		
H-6C					0.003	1.0E-06
H-7A	Unsaturated	-				
H-7b			1000+	-		
H-7C					0.73	-
H-8A	0.006	1.0E-05				
H-8B			16	-		
H-8C					0.003	-
H-9A	1	1.0E-09				
H-9B			231	-		
H-9C					0.0002	-
H-10A	0.01	1.0E-03				
H-10B			0.07	1.0E-04		
H-IOC					0.00009	-
P-14			140	-	0.05	-
P-15			0.07	1.0E-04	0.0004	-
P-17			1	1.0E-06	0.0002	1.0E-04
P-18			0.001	-	0.00003	1.0E-05
W-25	375	-	270	-	5	1.0E-03

Table 3-1 Values of Transmissivity and Storage Coefficient for Water-bearing Zones in the Rustler Formation Penetrated by Selected Test Holes at and Near the Proposed Waste Isolation Pilot Plant Site

[Transmissivity is expressed in feet squared per day]

	Magenta Dolomite Member		Culebra Dolomite Member		Rustler-Salado Contact Residuum	
Test Hole	**Transmissivity**	**Storage**	**Transmissivity**	**Storage**	**Transmissivity**	**Storage**
W-26	Unsaturated	-	1250	-	0.4	-
W-27	53	-	650	-	0.0002	-
W-28	Unsaturated	-	18	-	0.87	-
W-29	Not	present	1000	-	8	-
W-30	0.004	-	0.3	1.0E-04	0.2	1.0E-04

Source: Mercer 1983. Table 7. P. 105.

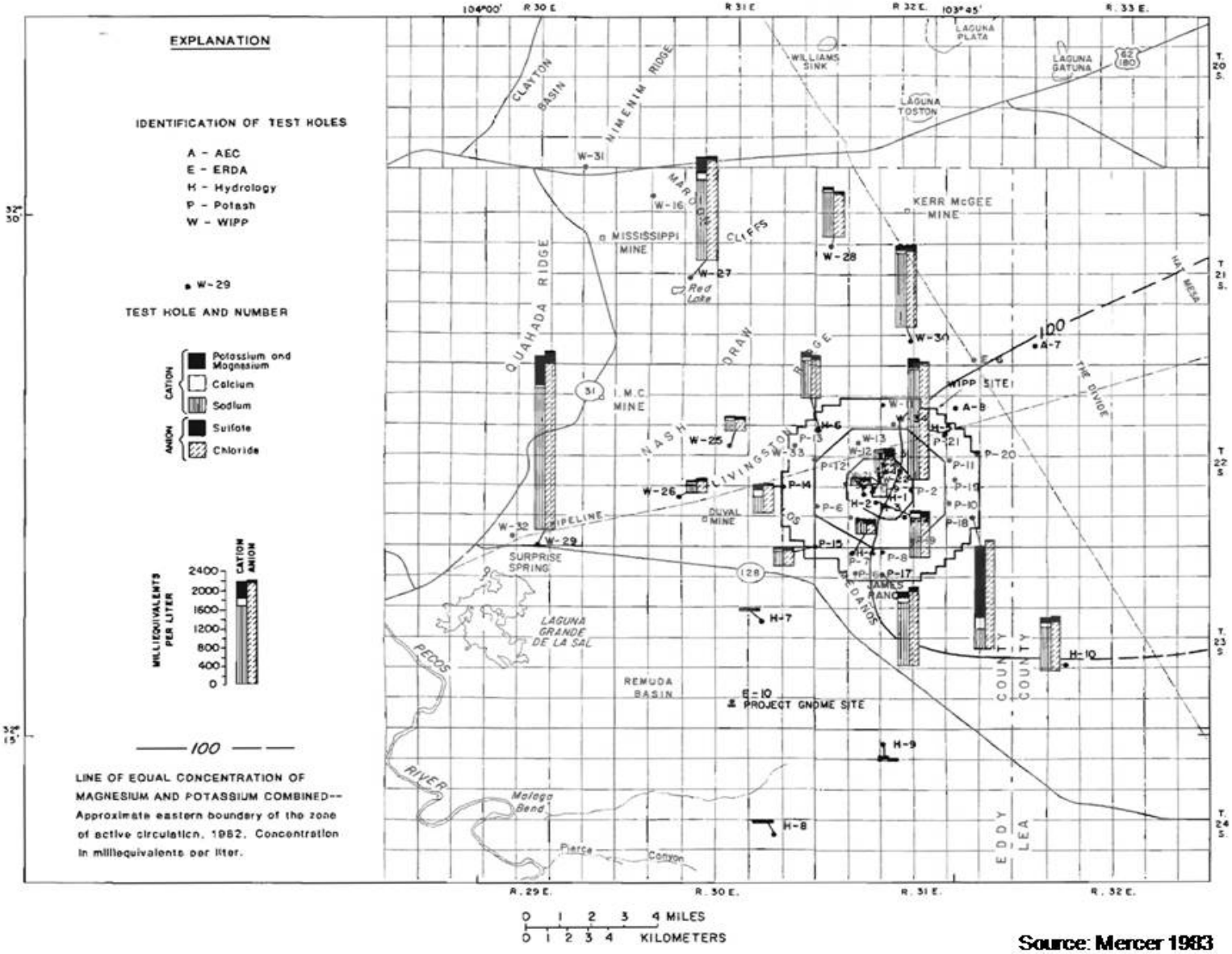
Water quality in the Culebra is highly variable, as shown in **Figure 3-6** and **Appendix A**. TDS can be as low as 3,200 mg/L at well H-8B at WIPP, or as high as 420,000 mg/L at W-29 in Nash Draw. The major constituent of water quality is sodium chloride. The 100 milliequivalent magnesium plus potassium line shown in **Figure 3-6** approximately separates the areas where the Culebra is an intact unit with no halite dissolution above or below at WIPP, and the area of halite dissolution and increasing collapse of the Culebra to the west of the line in Nash Draw (Mercer 1983).

3.1.5.3 Magenta Dolomite Aquifer

The Magenta Dolomite is a clastic carbonate unit with laminae of anhydrite and dolomite. It averages around 20 to 30 feet thick. Water is found in the siltstone and silty dolomite beds and along bedding planes and in fractures. The Magenta Aquifer is confined at WIPP and generally unconfined in Nash Draw where it is extensively fractured. In places in Nash Draw, the Magenta Aquifer can be confined and can even beunsaturated (wells H-7A, W-26, and W-28).

In Nash Draw, the nature of the Magenta depends on dissolution in the Tamarisk and the presence of gypsum in both the Tamarisk and the Forty-Niner members. In the northern, central, and along the eastern boundary of Nash Draw, the Magenta is a relatively continuous bed (Mercer 1983). At well W-29 and in the southern part of Nash Draw near Malaga Bend, the Magenta has been removed by erosion, collapsed into isolated blocks, or forms karst sinks and collapse breccias (Mercer 1983). Breccia mounds are found in Sections 33 and 34 of T22S, R29E (Mercer 1983). Exposures of the Magenta along the west side of Nash Draw near Quahada Ridge are fractured and often dry due to loss of water through the fractures.

Groundwater flow in the Magenta Aquifer depends on the degree of fracturing and collapse. At WIPP, groundwater flow is in the silt beds, silty dolomite, and fractures. At Nash Draw, groundwater flow is fracture flow and very complex because of the collapse and brecciation, especially in the southern part of Nash Draw. The potentiometric surface for the Magenta Aquifer is shown in **Figure 3-7**. The groundwater gradient at WIPP is around 16 to 20 feet per mile, increasing to 32 feet per mile on the west side of WIPP by Nash Draw. The gradient down Nash Draw is 13 feet per mile, due to much higher transmissivity. Transmissivity values are presented in **Table 3-1**. At WIPP, transmissivity values range from 4.0×10^{-3} feet squared per day at W-30 to 1.0 feet squared per day at H-9A. In Nash Draw, transmissivity values as high as 375 feet squared per day have been measured at W-25, with a value of 53 feet squared per day measured at W-27. Static head differences between the Magenta and the Culebra are 8 feet at W-27 and 4 feet at W-25, suggesting hydraulic communication between the two aquifers in these areas (Mercer 1983). At WIPP, static head differences between the Magenta and the Culebra are around 115 to 155 feet. Recharge for the Magenta is probably in Bear Grass Draw. Discharge is through downward flow to other units in Nash Draw, and through contributing flows to either Salt Lake or the Pecos River at Malaga Bend (Mercer 1983).



Source: Mercer 1983

Figure 3-6 Water Chemistry in the Culebra Dolomite Aquifer

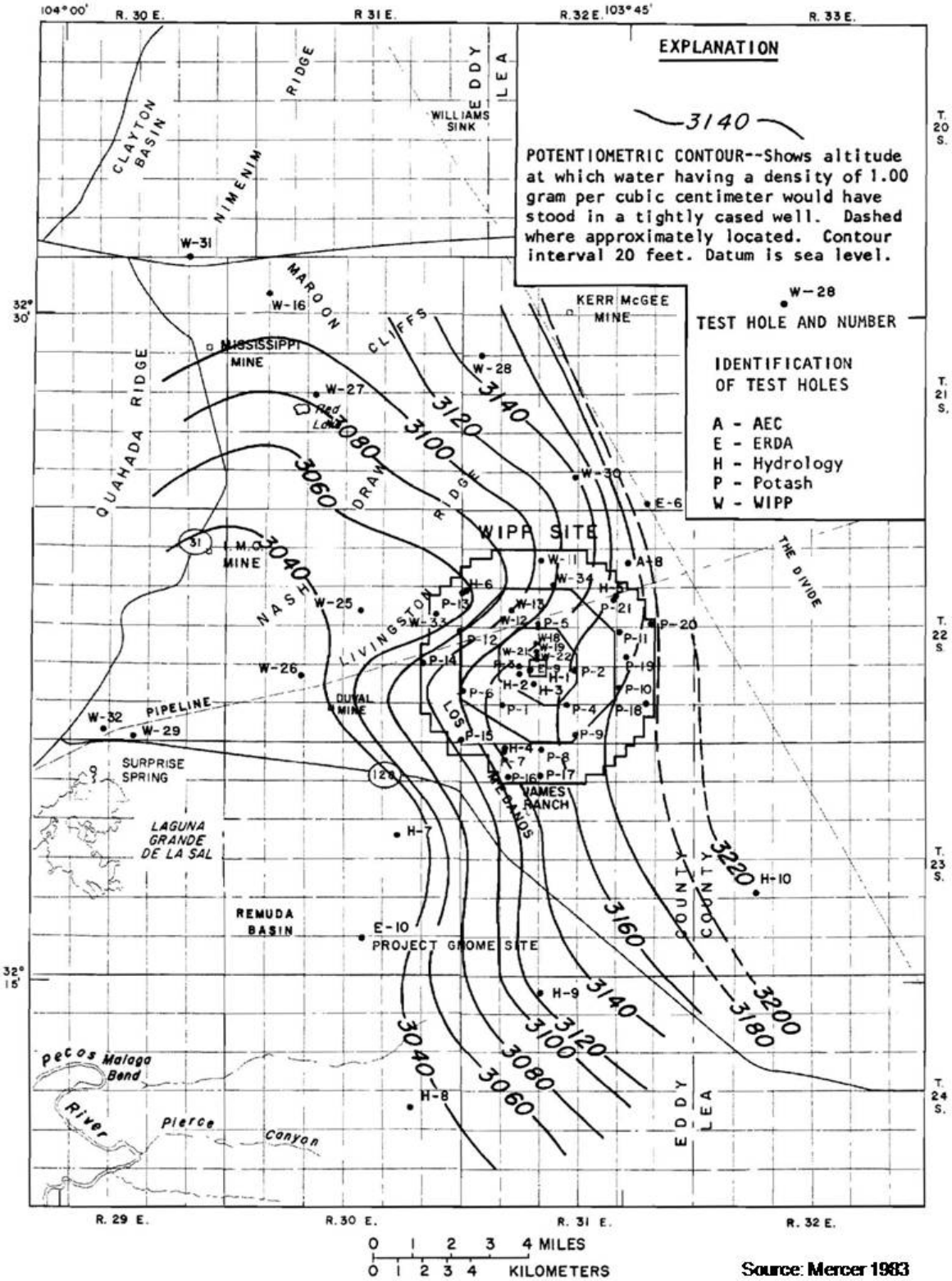


Figure 3-7 Potentiometric Surface of the Magenta Dolomite Aquifer

Water chemistry in the Magenta is highly variable and is summarized in **Figure 3-8** and in **Appendix A**. TDS can range from a low of around 5,400 mg/L to values as high as 270,000 mg/L. The 50 milliequivalent line for magnesium plus potassium in **Figure 3-8** approximately coincides with the presence or absence of halite in the Tamarisk (Mercer 1983).

3.1.6 Formations Above the Rustler

None of the formations above the Rustler in the SPA contain continuous zones of groundwater; therefore, none constitute aquifers. The Dewey Lake Red Beds consist of a deltaic sequence of alternating beds of siltstone, mudstone, and lenticular sandstone deposited after the period of evaporite deposition in the late Permian. These beds of deltaic sands and silts thicken to the southeast and are 350 feet thick in well P-14 on the west side of WIPP and 541 feet thick east of WIPP in well P-18 (Mercer 1983). The Dewey Lake is present only in low bluffs north and east of Nash Draw, having been eroded from most of the Nash Draw area. No water was encountered in drill holes (Mercer 1983). At the James Ranch (Sections 6 and 7, T23S, R31E), saline groundwater used for stock watering has been found at depths of 94 and 212 feet (Mercer 1983). The Dewey Lake is a low permeability unit that protects the underlying Rustler from infiltration of precipitation and removal of halite (Mercer 1983).

The Santa Rosa is an upper Triassic unit that consists of fine to coarse sandstone with siltstone and mudstone. Its thickness ranges from less than a few feet to 176 feet at well H-10 at WIPP. It is found in the low bluffs at the north end of Nash Draw and along the east side of Nash Draw. It serves as the principal aquifer in southern Lea County, but in the SPA it has water only in the lower part of the formation at WIPP. Yields are low.

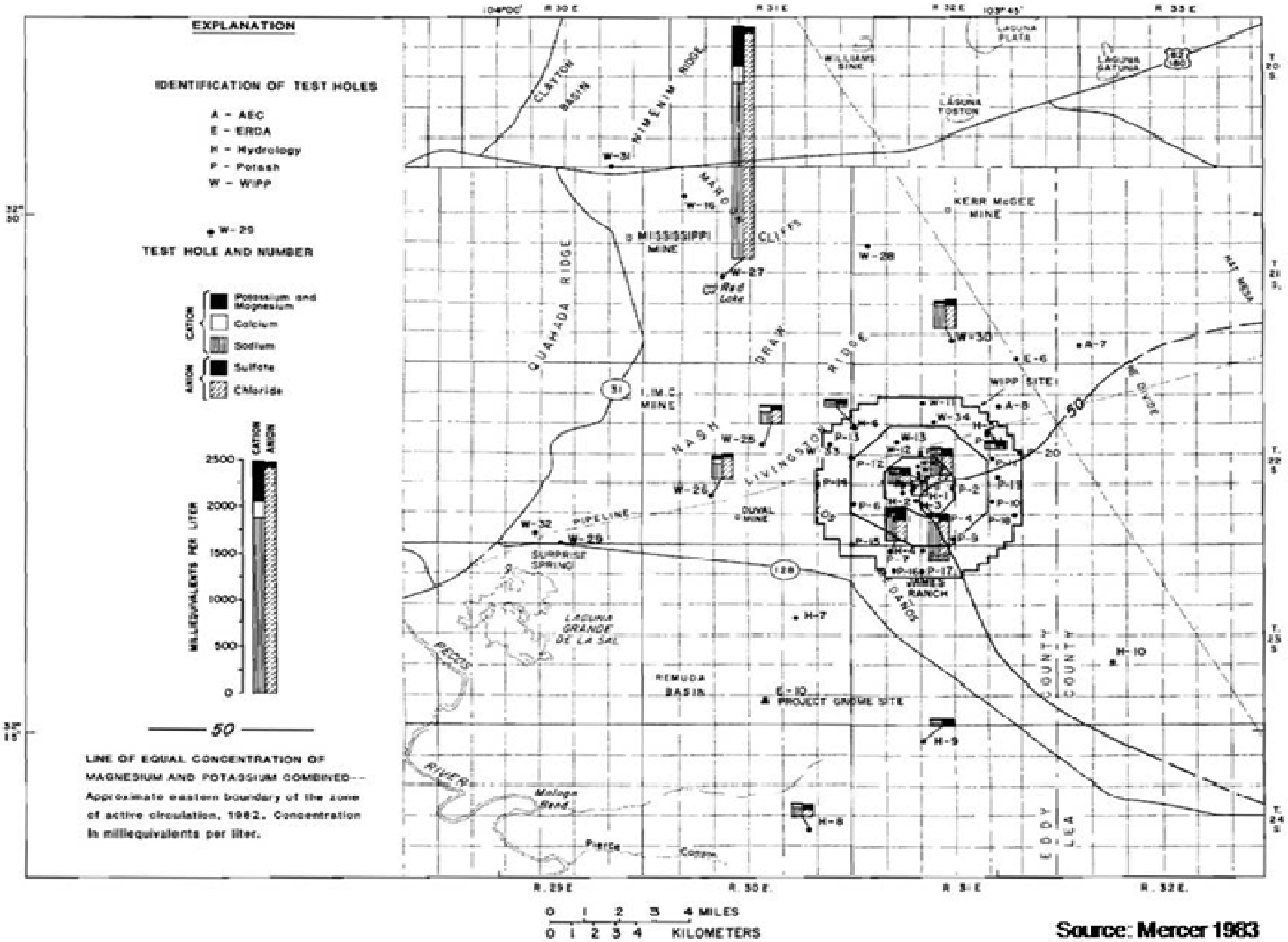
The Gatuna is a discontinuous bolson deposit and is up to 143 feet thick at WIPP, but generally is less than 46 feet thick (Mercer 1983). It has an erratic distribution and no permanent water. Packer tests conducted with injected water at WIPP gave hydraulic conductivity values of 3.0×10^{-3} feet per day to 5.1 feet per day (Mercer 1983). It is not an aquifer.

Alluvium along the Pecos River serves as an aquifer with communication both to the river and possibly to underlying formations. An estimated average transmissivity for the Pecos alluvium is about 13,600 feet squared per day (Mercer 1983). Wind-blown sands and other thin alluvium within the SPA may be wet at times, but do not constitute any type of an aquifer.

3.2 Surface Water Features in the SPA

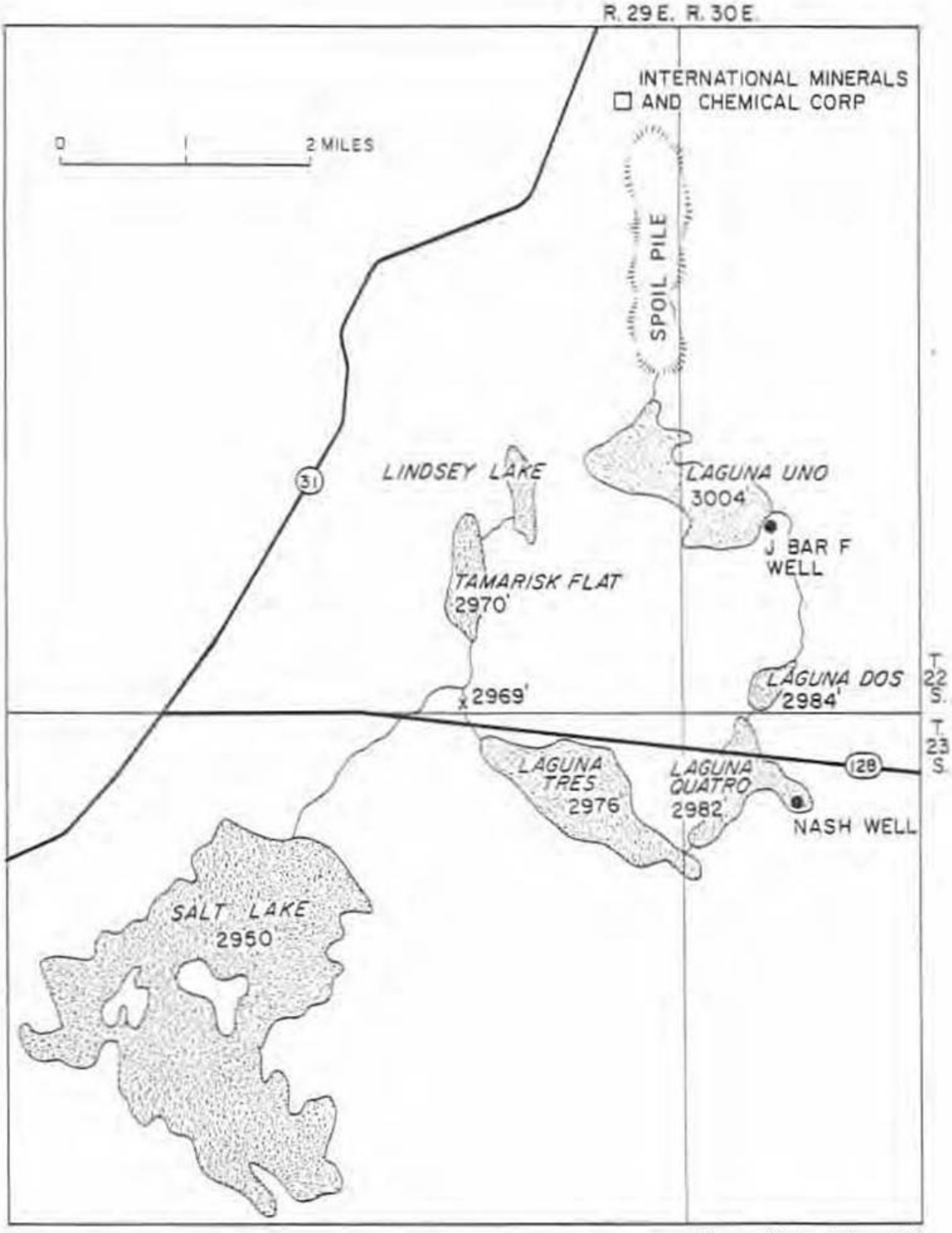
Surface drainage in the SPA is essentially a closed drainage. Ephemeral streams flow to depressions and runoff generated by severe storms collects in local depressions (Geohydrology 1978a). There are many natural brine lakes fed by groundwater within and immediately adjacent to the SPA; some of these natural brine lakes have been used in the past for refinery discharge from the potash mines.

The most notable brine lake used in the past for refinery discharge was Laguna Uno, which lies a few miles northeast of Salt Lake in the lower part of Nash Draw near Malaga, New Mexico (**Figure 3-9**). Laguna Uno and the surrounding natural brine lakes shown in **Figure 3-9** are naturally fed by a brine-rich groundwater that surfaces at the lower (southwest) end of Nash Draw. When it operated in the 1970s, the International Minerals and Chemical Corporation (IMCC) discharged refinery waste directly into Laguna Uno (Geohydrology 1979). Currently, Mosaic owns the former IMCC facility and is continuing the practice of discharging to Laguna Uno. The estimated natural groundwater inflow rate is around 500 gpm. Because Laguna Uno, like most of the natural brine lakes, has no natural outlet, the refinery's waste either evaporated or leaked to groundwater, with leakage rates as high as 3,300 gpm during the winter months (Geohydrology 1979). Salt Lake was also used for disposal of mill tailings from the US Potash Refinery. United Salt has been mining the salt tailings for a number of years. Water in Salt Lake today comes from surface and groundwater inflow discharge by Mosaic Mining Company



Source: Mercer 1983

Figure 3-8 Water Chemistry in the Magenta Dolomite Aquifer



Source: Geohydrology 1979

Figure 3-9 Brine Lakes Near the Bottom of Nash Draw

Clayton Lake is another natural brine lake that has received considerable refinery discharge in the past, in this case from the Potash Company of America (PCA) refinery. Clayton Lake naturally receives both groundwater inflow and surface water runoff. Discharge into Clayton Lake and into man-made holding ponds south and east of PCA during the 1970s resulted in an increase in water levels and brine in Clayton Lake. During the operation of PCA, the leakage rate to groundwater from the PCA siposal pond located near Clayton Lake was around 500 gpm (Geohydrology 1979). The leakage was caused by elevated water levels from refinery discharge. Laguna Toston, a smaller brine lake in the Clayton Basin area, received refinery waste from the Kerr-McGee Chemical Corporation plant during the 1990s.

Other important natural brine lakes are:

1. Williams Sink east of Nimenim Ridge along the Eddy/Lea County line;
2. Laguna Plata, Laguna Gatuna, and Laguna Tonto northeast of Williams Sink on the Querecho Plains; and
3. Hackberry Lake in the northeastern part of Clayton Basin (**Figure 1-1**).

These natural brine lakes receive groundwater through springs and seeps and evaporate the groundwater, thus acting as groundwater sinks for the shallow aquifers. Discharge of refinery waste water to these natural lakes reverses the role of the lakes, and they become sources of groundwater recharge. During the 1970s, many of the natural brine lakes and even the upper part of Nash Draw received considerable refinery discharge. As a result, the groundwater flow patterns within the SPA were locally dominated by refinery discharge. Currently, refinery discharge to upper Nash Draw comes from the Mosaic Mine and the Intrepid West and East mines.

4.0 Project Area Hydrogeology and Groundwater Chemistry

The project area is located in Eddy County, New Mexico, in T19S through T21S, and R28E through R30E, as shown in **Figure 1-1**. The main area of proposed injection and removal of fluids in the McNutt member of the Salado Formation will be in T19S and T20S. However, groundwater pumpage is proposed for Section 2, T21S, R29E (Section 2) from the Magenta member of the Rustler Formation. For this reason, most of the detailed field analyses and data gathering for the proposed project has been in this section. The following discussion of the Project Area, hydrogeology, and groundwater chemistry will focus on Section 2.

4.1 Project Area Stratigraphy

The Capitan Limestone and the Salado formations are found beneath the Rustler Formation in the project area, but are not currently considered sources of water for the proposed HB In-Situ Solution Mine Project. Important geologic units found in borings and on the surface in the Section 2 area include:

1. Rustler Formation;
2. Dewey Lake Red Beds;
3. Santa Rosa Formation; and
4. Gatuna Formation.

Figure 4-1 through **Figure 4-5** present the structure contours for important geologic units in the Section 2 area and **Figures 4-6** and **4-7** demonstrate interpretative geologic and geophysical sections that show the correlation of units in Section 2. **Table 4-1** summarizes the geologic data obtained from seven borings to install wells in the Section 2 area.

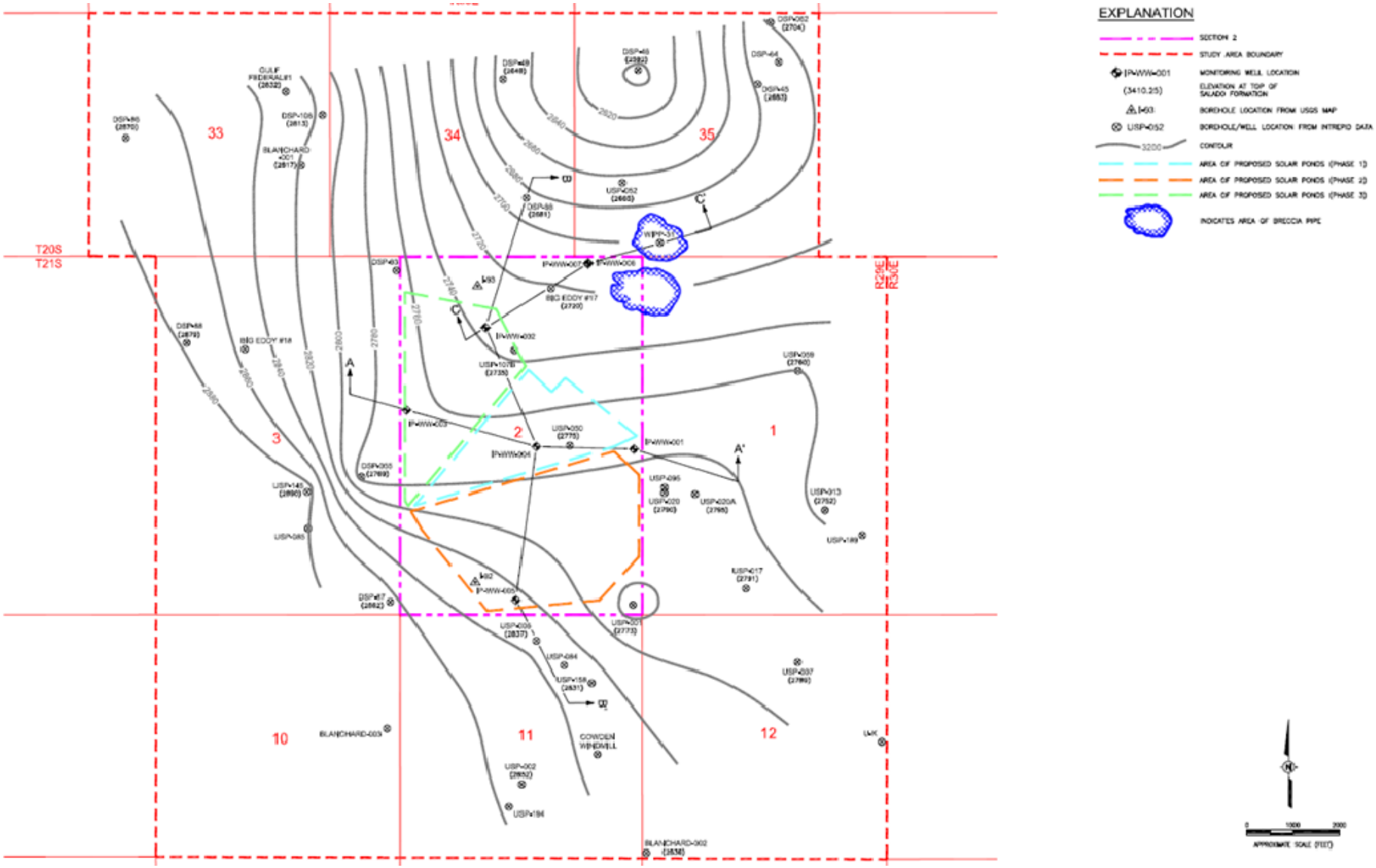
Formation of breccia pipes in Sections 1 and 2, T21S, R29E, and in Section 35, T20S, R30E (WIPP-31 drill hole) due to karst collapse in the Capitan Limestone has affected the geologic units above the Capitan Limestone.

4.1.1 Salado Formation

The top of the Salado was reached in boring IP-WW-002. The IP-WW-002 boring data combined with data from borings in adjacent sections was used by Intrepid Postash Inc./Shaw (2008) to generate the structure contour on the top of the Salado shown in **Figure 4-1**. The Salado dips to the northeast as do the Rustler and the Dewey Lake. The Salado, however, shows the influence of collapse beneath Clayton Basin that lies about 0.5 mile north of the breccia pipes.

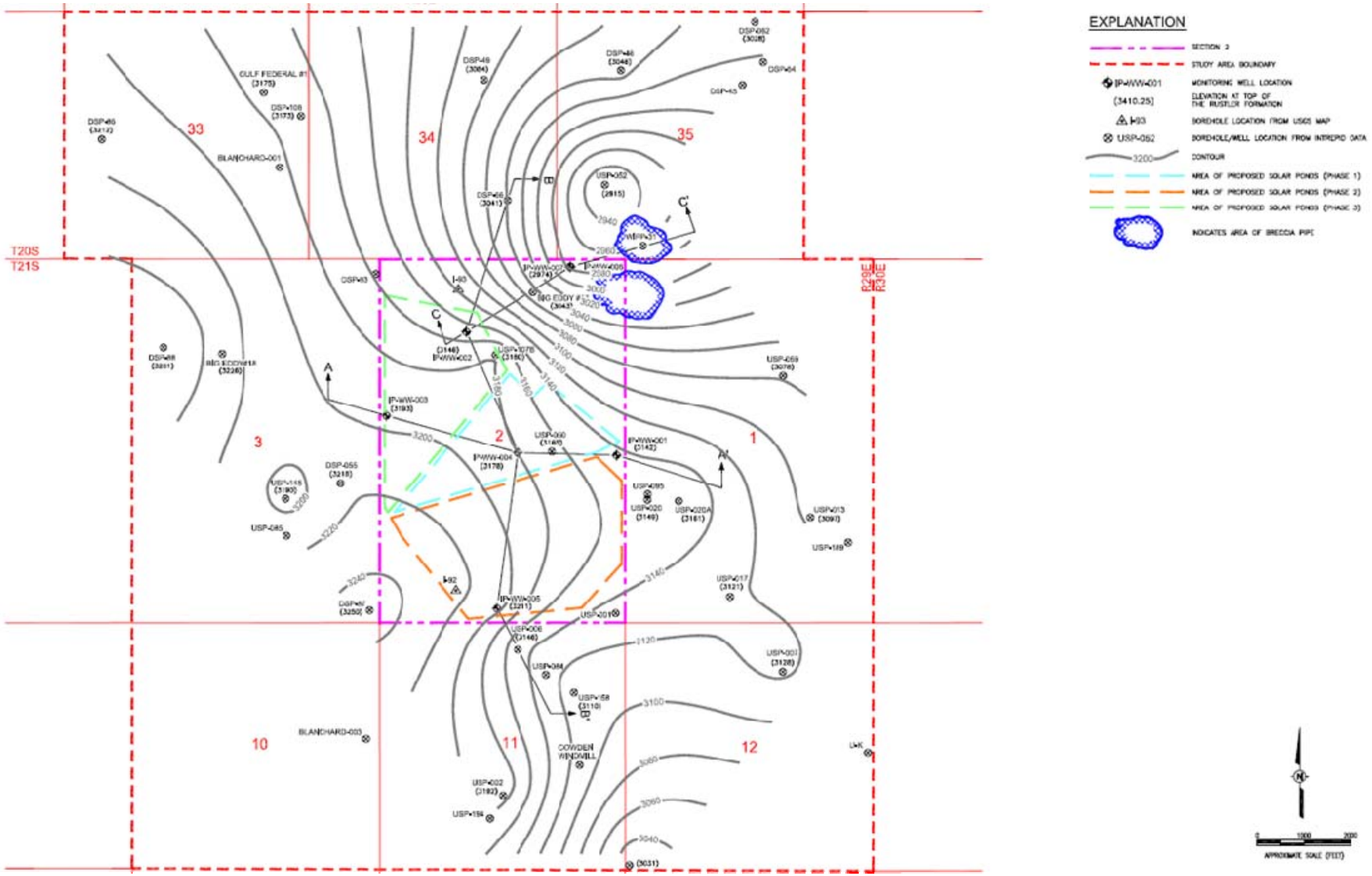
4.1.2 Rustler Formation

All boring holes except IP-WW-007 penetrated the Rustler Formation. Boring IP-WW-002 went through the Rustler all the way to the top of the Salado. The Rustler Formation has a dip to the northeast at about 85 feet per mile (Intrepid Postash Inc./Shaw 2008). As shown in **Figure 4-2**, a structure contour map on the top of the Rustler (Forty-Niner member) shows the influence of the collapse feature associated with the breccia pipes. South of Section 2, the Rustler dips to the southeast.



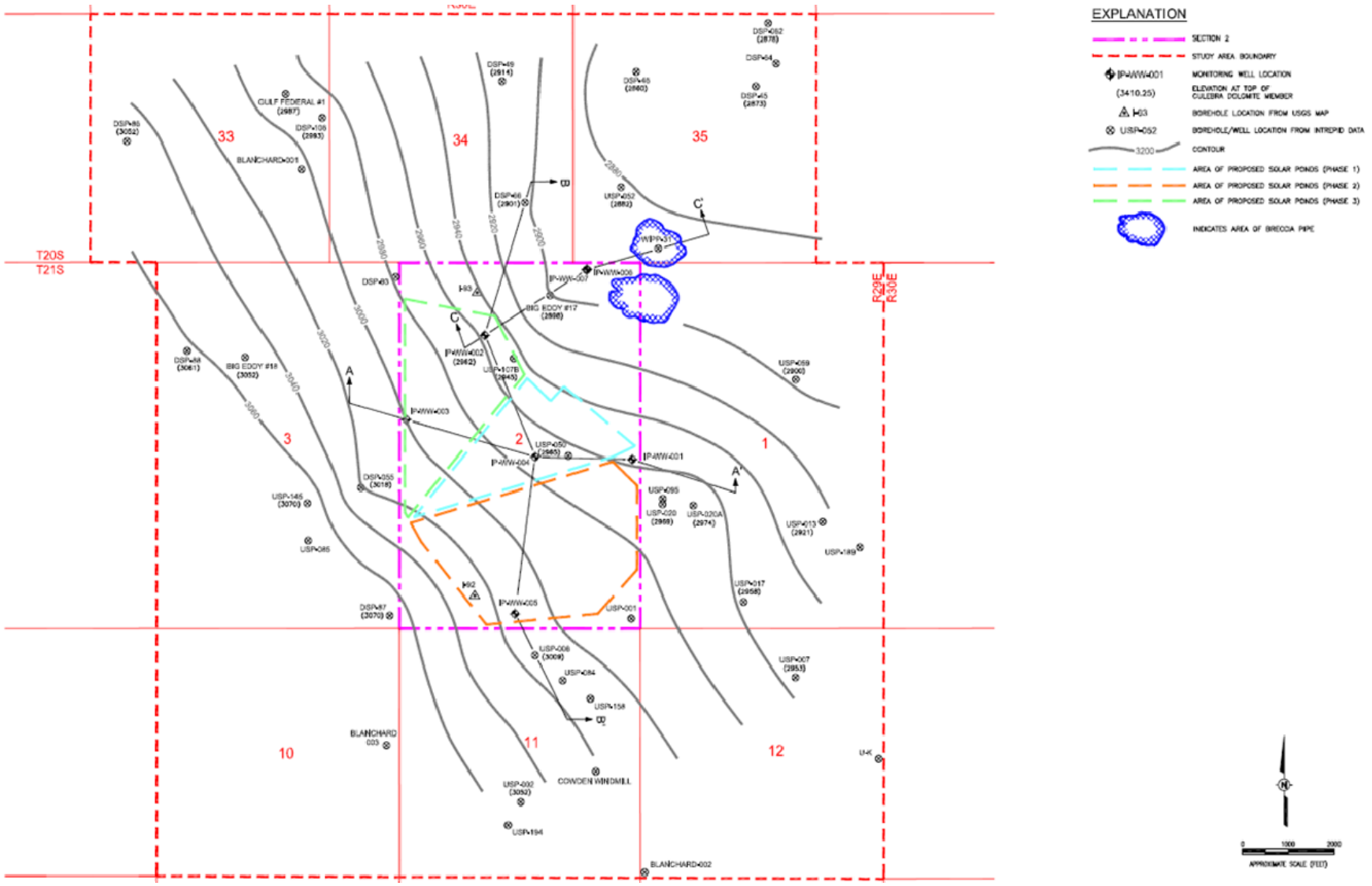
Source: Intrepid Postash Inc./Shaw 2008.

Figure 4-1 Top of the Salado Formation in the Project Area



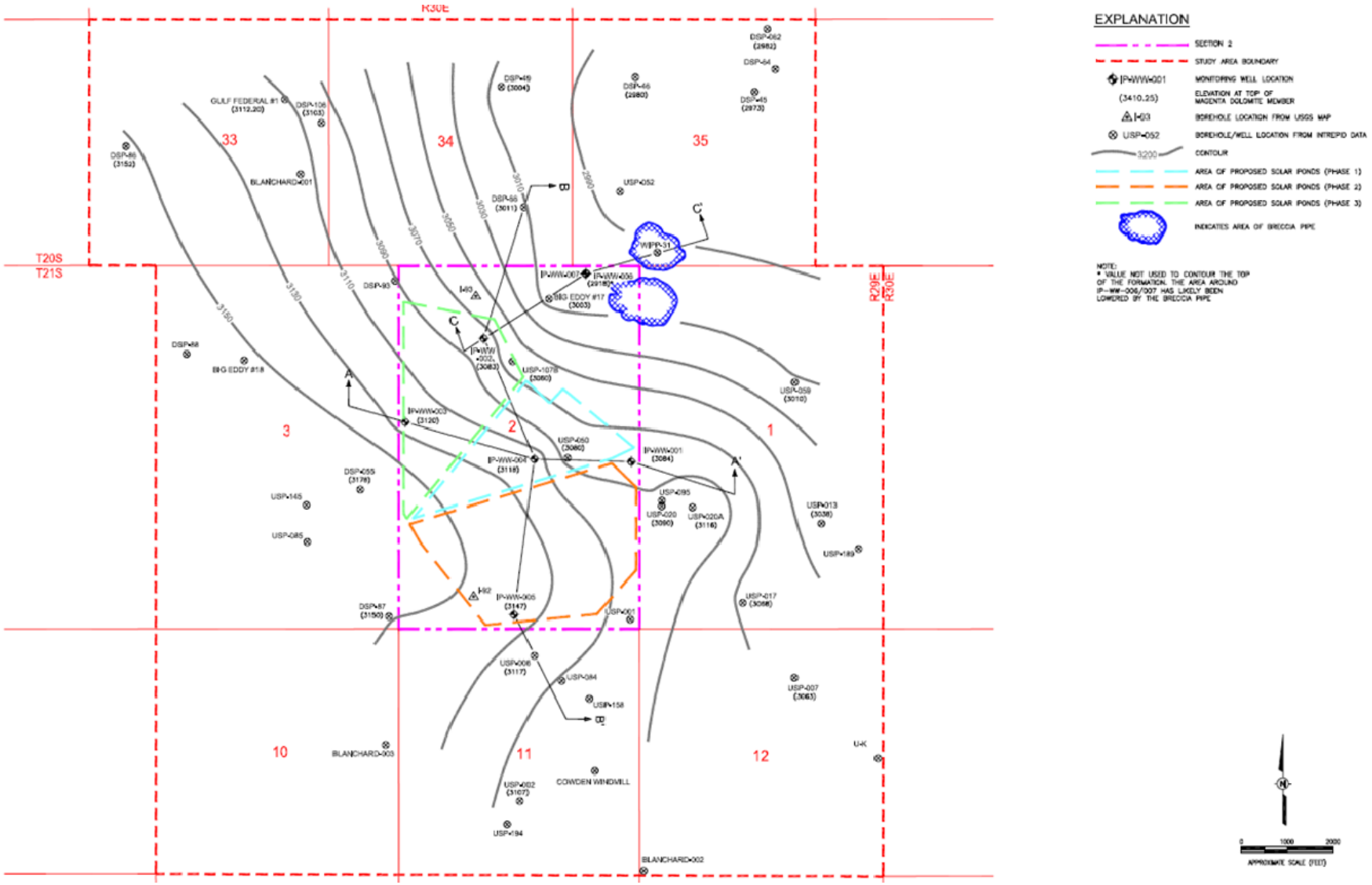
Source: Intrepid Postash Inc./Shaw 2008.

Figure 4-2 Top of the Forty-Niner Member of the Rustler Formation in the Project Area



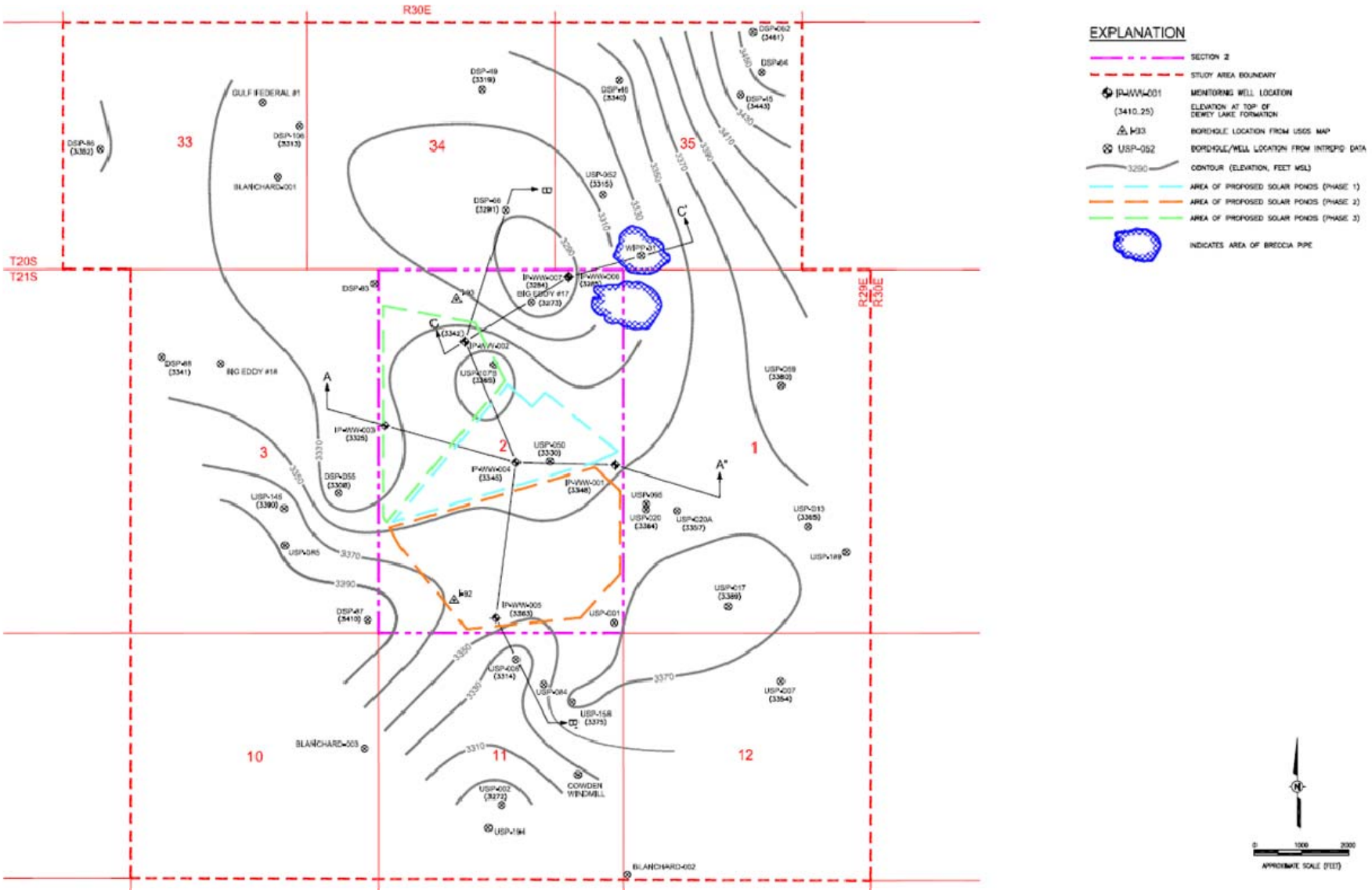
Source: Intrepid Postash Inc./Shaw 2008.

Figure 4-3 Top of the Culebra Dolomite Member of the Rustler Formation in the Project Area



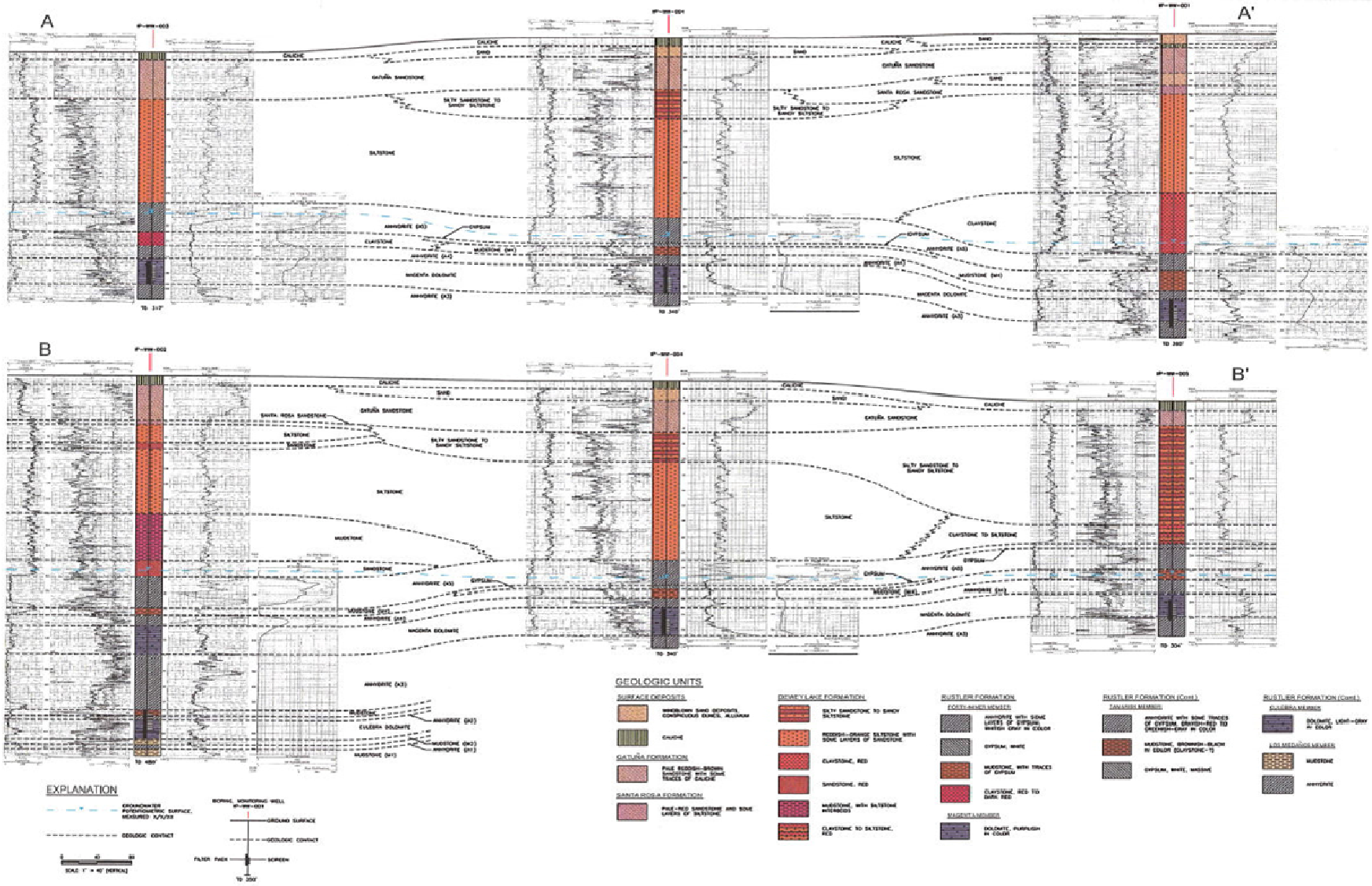
Source: Intrepid Postash Inc./Shaw 2008.

Figure 4-4 Top of the Magenta Dolomite Member of the Rustler Formation in the Project Area



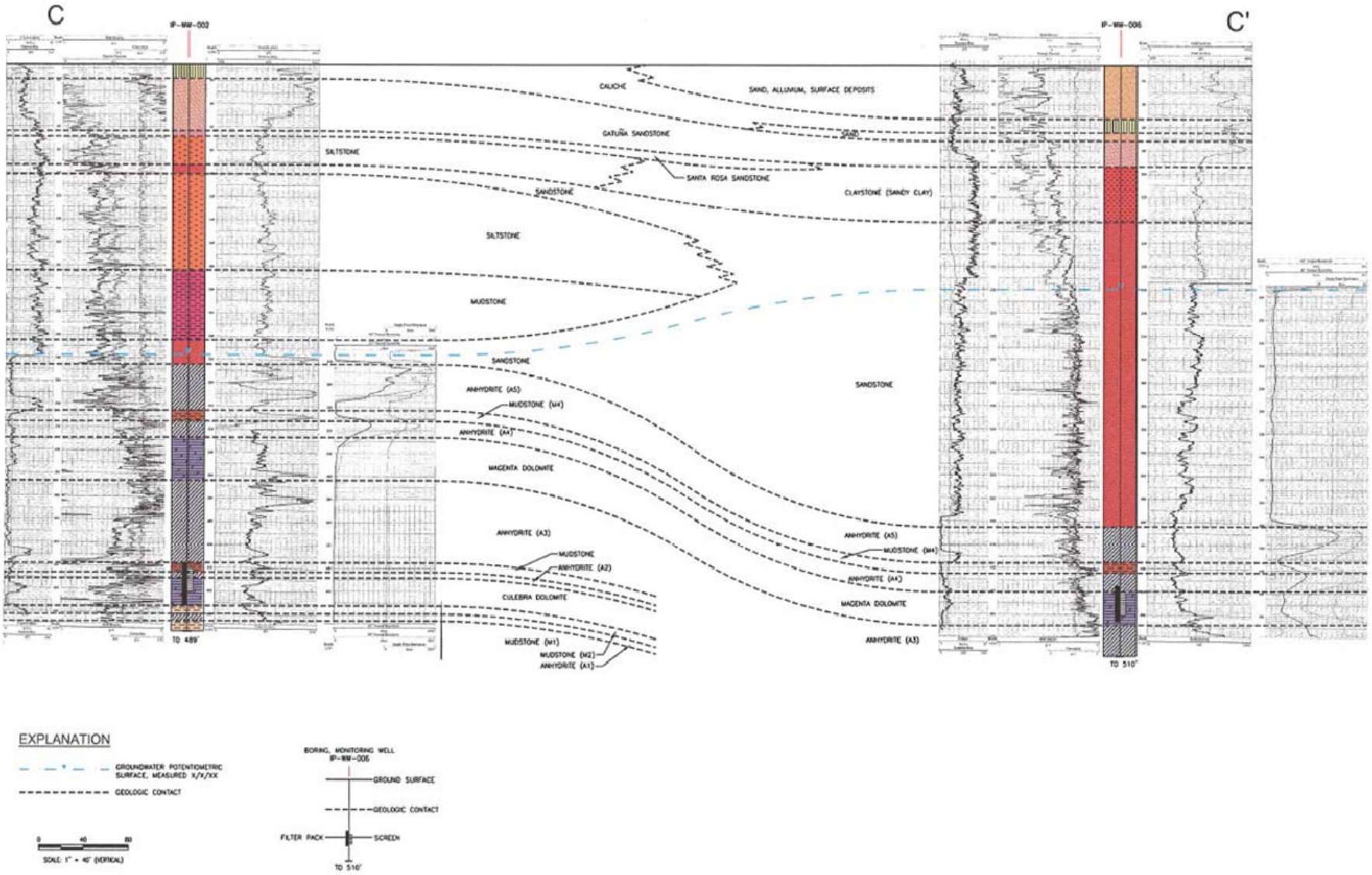
Source: Intrepid Postash Inc./Shaw 2008.

Figure 4-5 Top of the Dewey Lake Formation in the Project Area



Source: Intrepid Postash Inc./Shaw 2008.

Figure 4-6 Borehole Geophysical Cross-Sections A-A[1] and B-B[1]



Source: Intrepid Postash Inc./Shaw 2008.

Figure 4-7 Borehole Geophysical Cross-Sections C-C[1]

Table 4-1 Depth, Elevations, and Thicknesses of Geologic Units Encountered in Section 2 Exploratory Borings

		Well Identification, Relative Location in Section 2, and Unit Screened																					Thickness Summary		
		IP-WW-001 East Well (Magenta)			IP-WW-002 North Well (Culebra)			IP-WW-003 West Well (Magenta)			IP-WW-004 Center Well (Magenta)			IP-WW-005 South Well (Magenta)			IP-WW-006 Northeast Well (Magenta)			IP-WW-007 Northeast Well (Dewey Lake)					
Formation and Members	Subunits Informal Stratigraphy (Powers, 1997)	Depth to Formation Top (ft-bgs)	Elevation ft-msl	Unit Thickness (ft)	Depth to Formation Top (ft-bgs)	Elevation ft-msl	Unit Thickness (ft)	Depth to Formation Top (ft-bgs)	Elevation (ft-msl)	Unit Thickness (ft)	Depth to Formation Top (ft-bgs)	Elevation (ft-msl)	Unit Thickness (ft)	Depth to Formation Top (ft-bgs)	Elevation (ft-msl)	Unit Thickness (ft)	Depth to Formation Top (ft-bgs)	Elevation (ft-msl)	Unit Thickness (ft)	Depth to Formation Top (ft-bgs)	Elevation (ft-msl)	Unit Thickness (ft)	Minimum Thickness (ft)	Maximum Thickness (ft)	Average Thickness (ft)
Ground Surface Elevation, ft msl			3426			3410			3389			3416			3387			3372			3371				
Caliche/Alluvial Sand		0	3426	*18*	0	3410	*13*	0	3389	*8*	0	3416	*24*	0	3387	*12*	0	3372	*65*	0	3371	*65*	*8*	*65*	*29.3*
Gatuna Fm.		18	3408	*59.5*	13	3397	*50*	8	3381	*52*	24	3392	*41*	12	3375	*20*	65	3307	*22*	65	3306	*22*	*20*	*59.5*	*38.1*
Dewey Lake Fm.		77.5	3349	*205.5*	63	3347	*196*	60	3329	*132*	65	3351	*167*	32	3355	*152*	87	3285	*311*	87	3284		*132*	*311*	*193.9*
Rustler Fm.						3410			3389			3416			3387			3372							
Forty-niner Member	*Anhydrite (A5)*	283	3143	*21*	259	3151	*36*	192	3197	*38*	232	3184	*37*	184	3203	*34*	398	2974	*31*				*21*	*38*	*32.8*
	Mudstone (M4)	304	3122	*26*	295	3115	*13*	230	3159	*18*	269	3147	*11*	218	3169	*13*	429	2943	*9*				*9*	*26*	*15.0*
	Anhydrite (A4)	330	3096	*11*	308	3102	*14*	248	3141	*17*	280	3136	*12*	231	3156	*17*	438	2934	*16*				*11*	*17*	*14.5*
Magenta Dolomite Member		341	3085	*29*	322	3088	*37*	265	3124	*32*	292	3124	*33*	248	3139	*30*	454	2918	*29*				*29*	*37*	*31.7*
Tamarisk Member	*Anhydrite (A3)*	370	3056		359	3051	*71*	297	3092		325	3091		278	3109		483	2889					*71*	*71*	*71.0*
	Mudstone (M3)				430	2980	*8*																*8*	*8*	*8.0*
	Anhydrite (A2)				438	2972	*5*																*5*	*5*	*5.0*
Culebra Dolomite Member					443	2967	*24*																*24*	*24*	*24.0*
Los Medanos Member	*Mudstone (M2)*				467	2943	*7*																*7*	*7*	*7.0*
	Anhydrite (A1)				474	2936	*6*																*6*	*6*	*6.0*
	Mudstone (M1)				480	2930																			
		TD =390 ft			TD=489 ft			TD=317 ft			TD=340 ft			TD=304 ft			TD=510 ft			TD=280 ft			TD=280 ft	

Notes:

Fm. = Formation, ft = feet, ft bgs = feet below ground surface, TD = total depth of boring.

Source: Intrepid Postash Inc./Shaw 2008.

The Culebra Dolomite member also was encountered only in boring IP-WW-002 because none of the other borings were deep enough to reach the Culebra. The Culebra was 24 feet thick, dipped to the northeast at 80 to 120 feet per mile, and yielded water at 49 gpm. **Figure 4-3** is a structure contour map drawn on the top of the Culebra and is based on data from outside of Section 2 as well as on boring IP-WW-002. The Culebra dips to the northeast and does not show the influence of the collapse associated with the breccia pipes that is evident for the Dewey Lake Red Beds and the top of the Forty-Niner member of the Rustler.

The Magenta Dolomite member ranges from 29 to 37 feet thick and averages 31.7 feet thick. Fractures in the dolomite contain chlorite and calcite. The unit dips to the northeast at about 85 feet per mile in Section 2. South of Section 2, the dip is to the southeast at 155 feet per mile. There is water in the Magenta and the unit acts as a confined aquifer due to the overlying Forty-Niner member. Protection by the Dewey Lake Red Beds has prevented dissolution of the Forty-Niner and the Tamarisk, so the Magenta has not collapsed or formed blocks of breccia as it has in Nash Draw. Water yields in most of the six borings were less than 3 gpm. Boring IP-WW-001 had a yield of around 100 gpm in a fracture zone at a depth of 371 feet. Well USP-107 south of Section 2 yielded water at a rate of 200 gpm at a depth of 387 feet. **Figure 4-4** shows the structure contour on the top of the Magenta. The Magenta does not show the influence of the collapse associated with the breccia pipes that is evident for the Dewey Lake Red Beds (**Figure 4-5**) and the top of the Forty-Niner member of the Rustler (**Figure 4-2**). As shown in **Figure 4-6**, the Magenta Dolomite member of the Rustler in the Section 2 area appears to be a continuous unit with a reasonably constant thickness.

The Los Medanos basal member of the Rustler was penetrated only in boring IP-WW-002. The upper mudstone M2 and the middle anhydrite A1 were intercepted (**Table 4-1**). The two units together totaled 13 feet. The Tamarisk member consists of anhydrite units (A3 and A2) with an intervening mudstone (M3) (**Table 4-1**). The complete section of the Tamarisk was encountered only in boring IP-WW-002. The total thickness of the unit was 84 feet, the upper anhydrite (A3) was 71 feet thick. No water was encountered in the Tamarisk.

The Forty-Niner member of the Rustler consists of two anhydrite units (A5 and A4), with an intervening mudstone (M4). The upper anhydrite (A5) ranges from 21 to 38 feet thick and averages 32.8 feet thick. The mudstone is 9 to 26 feet thick and averages 15 feet thick. The lower anhydrite is 11 to 17 feet thick and averages 14.5 feet thick. The anhydrite at the top of the Forty-Niner shows alteration to gypsum (Intrepid Postash Inc./Shaw 2008). There is no any water in the Forty-Niner member.

4.1.3 Units Above the Rustler

The units above the Rustler are the Caliche and Alluvial Sand, the Gatuna Formation, the Santa Rosa Formation, and the Dewey Lake Red Beds. The Caliche and Alluvial Sand ranges from 8 feet to 65 feet thick and averages about 29 feet thick. The caliche is the Mescalero Caliche and dates around 500,000 years BP (Intrepid Postash Inc./Shaw 2008). The Gatuna Formation is exposed in arroyos and in collapsed areas. It ranges from 8 to 65 feet thick and averages about 29 feet thick. The unit consists of fine to coarse sandstone that is brown to reddish brown and yellow in color. The Santa Rosa Formation ranges from 20 to 59 feet thick and averages about 38 feet thick. There is not any water in either the Gatuna or the Santa Rosa. The Dewey Lake Red Beds consist of sandy siltstone to fine sandstone and mudstone that have a characteristic reddish-brown color. The unit ranges from 132 to 311 feet thick and averages about 194 feet thick. Water was found only in one boring, IP-WW-07. The Dewey Lake is exposed south of Section 2 and forms the Maroon Cliffs about 2.5 miles east of Section 2.

A structure contour map drawn on the top of the Dewey Lake Red Beds is shown in **Figure 4-5**. The Dewey Lake clearly shows the influence of the collapse features associated with the two breccia pipes. Sections 1 and 2, T21S, R29E, and in Section 35, T20S, R30E. The unit top slopes toward the area of the breccia pipes from all directions. The regional dip to the northeast has been transformed into a dip toward the depression associated with the breccia pipes. **Figure 4-6** and **Figure 4-7** show the different facies of the Dewey Lake encountered in the borings.

4.1.4 Breccia Pipes near Section 2

Snyder and Gard (1982) evaluated many of the breccia pipes within the SPA and WIPP. The breccia pipe in Section 35, T20S, R30E was drilled by Snyder and Gard (1982) in borehole WIPP-31. This boring revealed 1,981 feet of brecciated rock consisting of down-dropped, folded, brecciated Santa Rosa, Dewey Lake Red Beds, Rustler Formation units, and Salado Formation.

The cross-section of the breccia pipe drilled in WIPP-31 showed a zone of brecciated rock surrounded by relatively undisturbed Rustler units. This may explain why the Magenta Dolomite and the Culebra Dolomite do not show influence of the breccia pipe in their structure contour maps. The cross-section does not explain why the Salado and Dewey Lake do show an influence from the breccia pipe. The breccia pipe is relatively impermeable, with an estimated permeability of 0.1 to 0.9 millidarcy based on drill stem tests (Snyder and Gard 1982). The pipe is surrounded by a zone of fractured rock. The breccia pipe was created by cavern collapse in the underlying Capitan Limestone. Water may have moved upward from the Capitan Limestone and caused the dissolution of the evaporite units in the Rustler evident around the pipe (Snyder and Gard 1982).

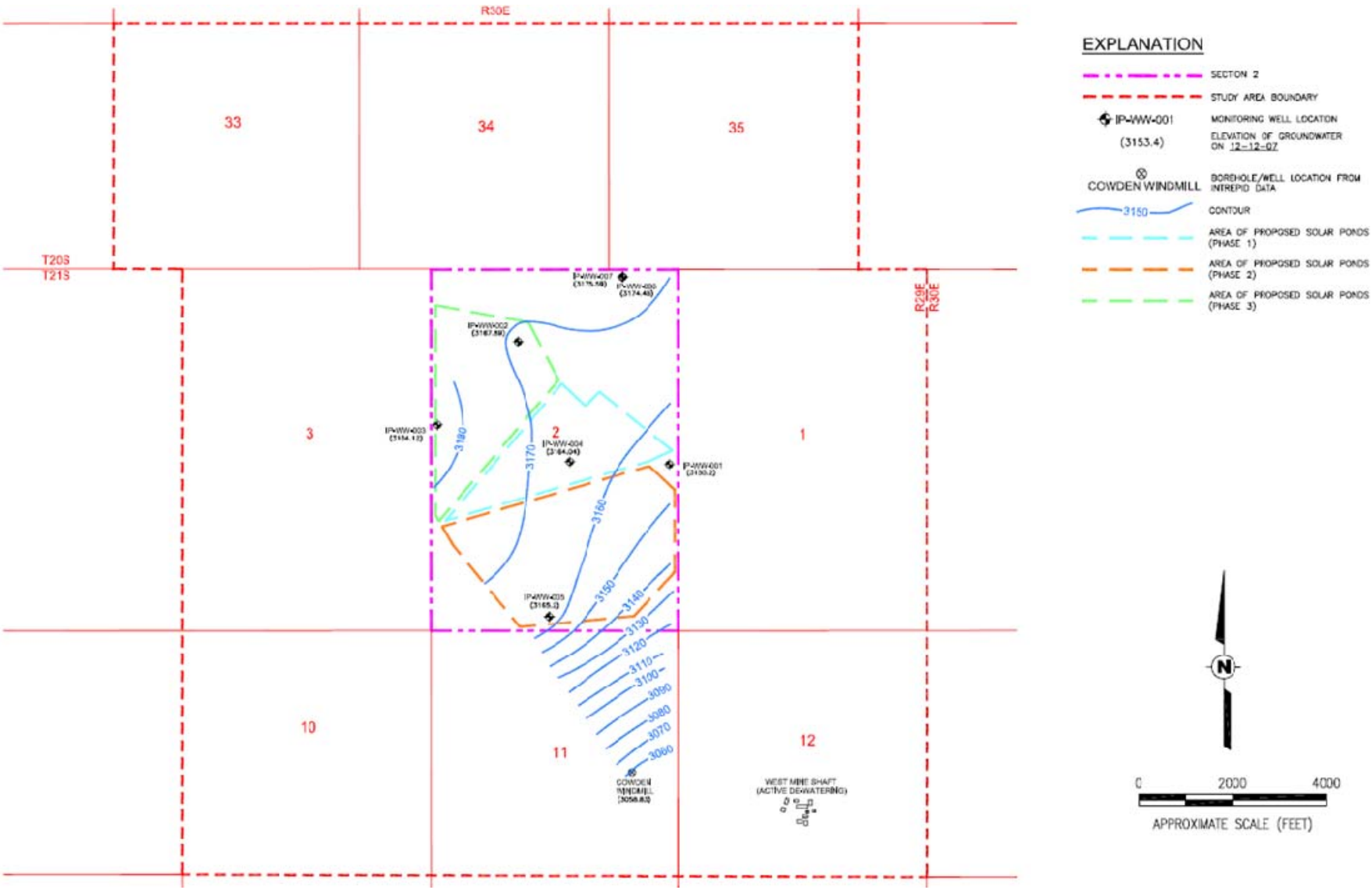
4.2 Hydrogeology

The water levels in the Magenta and Culebra members of the Rustler Formation for December of 2007 are shown in **Figure 4-8**. Well IP-WW-002 is screened in the Culebra and well IP-WW-007 in the northern corner of Section 2 is screened in the Dewey Lake Red Beds. The Cowden Windmill does not have a well installation diagram available, effectively the location of its screen is uncertain. If the water levels in these two wells and the Cowden Windmill water level are not considered, then groundwater in the Magenta flows to the southeast toward Nash Draw. The gradient is approximately 0.005 feet per feet. The aquifer in the Magenta Dolomite is confined and potentiometric levels range from 24 to 70 feet above the top of the unit. One exception is well IP-WW-006, where the potentiometric surface is 255 feet above the top of the Magenta (Intrepid Postash Inc./Shaw 2008).

Short-term single-well aquifer testing completed by Intrepid Postash Inc./Shaw (2008) is summarized in **Table 4-2**. The values colored in blue are preferred by Intrepid Postash Inc./Shaw (2008) as the best estimates from the different aquifer test curve matches. For the Magenta in well IP-WW-001, the transmissivity appears to be around 2600 to 2200 feet squared per day with a hydraulic conductivity of 75 to 92 feet per day. Well IP-WW-001 had a flow rate of 90 gpm from a fracture at 371 feet below ground surface deep. Intrepid Postash Inc./Shaw 's results indicate that the fracture flow is analyzed with analytical methods designed only for porus media flow in an infinite aquifer. Thus, the Cooper-Jacob and Papadopulous-Cooper matches preferred by Intrepid Postash Inc./Shaw (2008) probably are not representative. The Moench method is designed for dual porosity flow. Therefore the MOench method is better suited for fractured dolomite. The Moench fracture flow match transmissivity value of 1,363 feet squared per day with a hydraulic conductivity for the fracture of about 47 feet per day is possibly a more representative analysis of the data. Fractures can produce high flow rates for short periods of time with considerable transmissivity.

For the Culebra in well IP-WW-002, fracture flow also is a possibility (Intrepid Postash Inc./Shaw 2008) and the solution of Moench transmissivity of 13 feet squared per day with an estimated hydraulic conductivity of 0.55 foot per day is possible. The Papadopulous solution gives a similar answer.

The Magenta in wells IP-WW-003 through IP-WW-005 output similar values for transmissivity in each well. The values for transmissivity range from a low value of 1.43 feet squared per day in IP-WW-005 to a high value of 8.42 feet squared per day in IP-WW-003. Hydraulic conductivity estimates range from 0.05 foot per day to 0.26 foot per day. Well IP-WW-006, located near the northeast corner of Section 2, and the breccia pipe have a transmissivity of about 0.03 foot squared per day with a corresponding hydraulic conductivity estimate of 0.001 foot per day. Well IP-WW-007 in the Dewey Lake Red Beds encountered an unconfined water body with an approximate transmissivity of 61 feet squared per day and a corresponding hydraulic conductivity of 0.77 foot per day.



Source: Intrepid Postash Inc./Shaw 2008.

Figure 4-8 Groundwater Potentiometric Elevation Contours in Pumping Area

Table 4-2 Summary of Aquifer Testing Analytical Methods and Results, Section 2 Monitoring Wells

Basic Data							Theis (confined)		Cooper-Jacob (confined)		Papadopulos-Cooper (confined)		Moench w/slab blocks (fractured)		Comments/Selection Rationale
Well / Test	Geologic Formation	Depth to Water (ft btoc)	Saturated Thickness (ft)	Pumping Rate (gpm)	Maximum Drawdown (ft below static)	Specific Capacity (gpm/ft drawdown)	T (ft^2/day)	Hydraulic Conductivity (ft/day)	T (ft^2/day)	Hydraulic Conductivity (ft/day)	T (ft^2/day)	Hydraulic Conductivity (ft/day)	T (ft^2/day)	Hydraulic Conductivity (ft/day)	
IP-WW-001															
Constant Rate Discharge	Magenta	271.58	29	90	17.314	5.20	No Match		2,690	92.7	2,203	75.95	1,363	47.0	The best fit is for either the Cooper-Jacob or the Papadopulos-Cooper methods. Recovery data was not recorded. The relatively higher values of T and K calculated using IP-WW-004 as an observation well indicate that a boundary condition exists between the two wells.
Using IP-WW-004 as Observation Well			29						8,172	281.8	8916	307.4	5,609	193.4	
IP-WW-002															
Constant Rate Discharge	Culebra Dolomite Member	245.2	24	4.0	150.74	0.03	4.66	0.19	7.58	0.32	11.54	0.48	5.35	0.22	Smooth recovery line suggests that recovery results may be more accurate. Best fit is for the double porosity fracture model (Moench). Papadopulos-Cooper results in similar values. Given the fit and anticipated aquifer conditions, the Moench results are considered to be most accurate.
Recovery			24				4.03	0.17	1.26	0.05	13.89	0.58	13.31	0.55	
IP-WW-003															
Constant Rate Discharge	Magenta Dolomite Member	213.36	32	2.4	41.22	0.06	4.51	0.14	3.98	0.12	2.05	0.06	6.14	0.19	Breaks in drawdown could be changes in pumping rates or boundary conditions. Smooth recovery line suggests that recovery results may be more accurate. Late time data are preferred. The Papadopulos-Cooper (confined) appears to have the best fit and is confirmed by the Moench and Theis analyses.
Recovery			32				8.11	0.25	6.41	0.20	8.42	0.26	6.97	0.22	
IP-WW-004															
Constant Rate Discharge	Magenta Dolomite Member	256.35	33	1.0	61.98	0.02	1.41	0.04	1.34	0.04	10.17	0.31	9.53	0.29	Break in drawdown at ~ 200 minutes could be change in pumping rates, well bore storage effect, or boundary conditions. Smooth recovery line suggests that recovery results may be more accurate. Hantush (not shown) is best fit and confirms Papadopulos-Cooper (confined) suggesting the aquitard may be leaky.
Recovery			33				0.87	0.03	1.10	0.03	6.74	0.20	No Match		
IP-WW-005															
Constant Rate Discharge	Magenta Dolomite Member	234.76	30	0.8	48.49	0.02	3.12	0.10	1.63	0.05	0.47	0.02	5.49	0.18	Deflections in drawdown curve in both tests may be the result of boundary conditions.Smooth recovery line suggests that recovery results may be more accurate. The Papadopulos-Cooper (confined) appears to have the best fit.
Recovery			30				1.26	0.04	1.60	0.05	1.43	0.05	7.19	0.24	
IP-WW-006															
Constant Rate Discharge	Magenta Dolomite Member	198	28	variable	221.00	--	0.53	0.02	0.64	0.02	0.03	0.001	No Match		Due to deflection in the borehole the transducer could not be used. Therefore hand measurements were collected. Only early-time data are available. The Papadopulos-Cooper (confined) appears to have the best fit. Storativity results suggest the observation of confined conditions during drilling are correct
Constant Rate Discharge (2)		198	28	variable	221.00	--	0.27	0.01	0.68	0.02	1.18	0.042	No Match		
Recovery			28	3.6	221.00	0.02	2.09	0.07	2.97	0.11	0.03	0.001	No Match		
IP-WW-007															
Constant Rate Discharge	Dewey Lake Formation	198	80	2.4	28.50	0.08	20.25	0.25	54.9	0.69	61.6	0.77	60.6	0.76	Deflections in drawdown curve in both tests may be the result of boundary conditions or pumping variations. Smooth recovery line suggests that recovery results may be more accurate. The Papadopulos-Cooper (confined) appears to have the best fit. The late-time data of the Moench analysis support the Papadopulos-Cooper results
Recovery			80				44.97	0.56	55.7	0.70	65.0	0.81	51.17	0.64	

Notes
Shaded values represent selected tests
Where hydraulic conductivity is calculated from the transmissivity, the saturated thickness is used rather than screen length because the sand pack of the wells fully penetrated the geologic unit.
T = transmissivity

Source: Intrepid Postash Inc./Shaw 2008.

A pumping test of well IP-WW-001 for 111 hours at 90 gpm resulted in 17 feet of drawdown in the well, but no drawdown in any of the nearby monitoring wells. Intrepid Postash Inc./Shaw (2008) hypothesized a boundary between IP-WW-001 and IP-WW-004 based on this test. Apparently, pumping the fracture in well IP-WW-001 did not affect any other wells because these wells are not screened in the same fracture system. Similarly, a vertical pumping test between IP-WW-006 (Magenta) and IP-WW-007 (Dewey Lake) did not show any interaction between the two formations, probably because of the intervening dry Forty-Niner member of the Rustler.

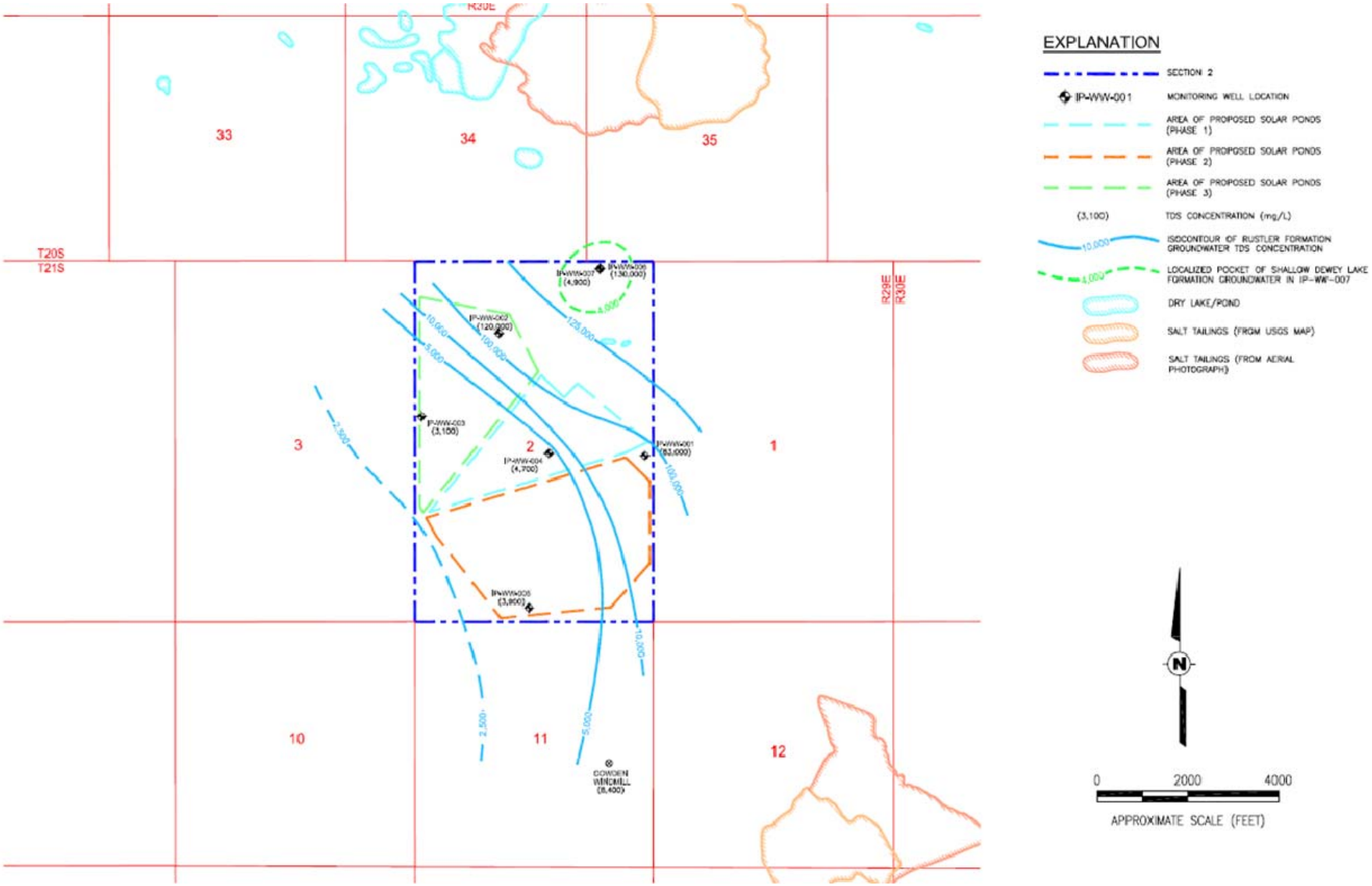
Overall, the aquifer tests conducted by Intrepid Postash Inc./Shaw (2008) suggest that fracture flow is dominant in the Magenta and Culebra members of the Rustler Formation in Section 2. The short-term single well tests also suggest rather low transmissivity, similar to transmissivity found at WIPP. The high values of transmissivity that characterize the Magenta and Culebra in Nash Draw are not present in Section 2 because the Rustler in Section 2 has not undergone the dissolution of halite, conversion of anhydrite to gypsum, and the collapse of the formation that characterizes Nash Draw. The proposed project plans to pump the Magenta for a period of 22 years at an average annual rate of 1,050 gpm.

4.3 Groundwater Chemistry

The seven monitoring wells installed in Section 2 have been sampled by Intrepid Postash Inc./Shaw (2008) for water quality parameters. The results from the sampling are summarized in **Figures 4-9** through **4-13**. **Figure 4-9** presents the TDS values and shows TDS increases to the northeast toward the area of breccia pipes in Section 2. Well IP-WW-007 is in the Dewey Lake Red Beds and its TDS value should not be compared with the other TDS values in the Rustler. Values in the southwest corner of Section 2 are less than 10,000 mg/L and thus below the New Mexico Environment Department (NMED) guidelines for protectable waters. Values in the northeast corner exceed 10,000 mg/L and generally exceed 100,000 mg/L. There is an abrupt increase in TDS starting around the middle of Section 2, northeast of well IP-WW-004.

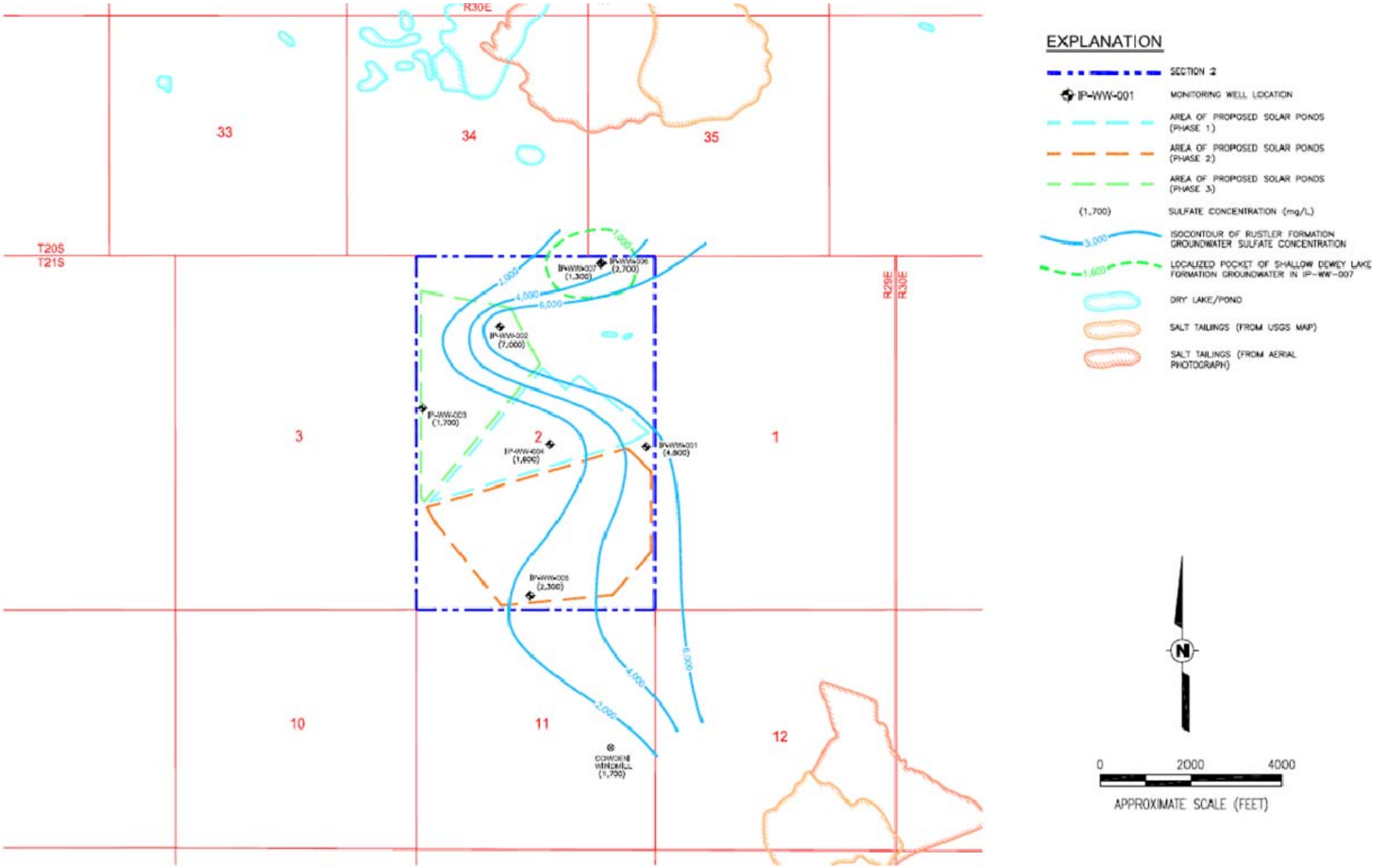
Sulfate shows a similar pattern to TDS (**Figure 4-10**). Values in the southwest corner of Section 2 are below 3,000 mg/L. There is a sharp increase in sulfate starting northeast of well IP-WW-004 and values range from 4,800 to 7,000 mg/L. Well IP-WW-006, located in the far northeast corner of Section 2, and closest to the breccia pipes shows a drop in sulfate values to 2,700 mg/L. Chloride also increases sharply toward the northeast corner of Section 2 (**Figure 4-11**). Values in the southwest part of Section 2 are below 500 mg/L. Starting with well IP-WW-004, values jump to 1,000 mg/L and in the northeast corner of Section 2 values for chloride range from 45,000 to 72,000 mg/L. **Figure 4-12** illustrates a graphical summary of water quality parameters for major ions using Piper and Stiff diagrams (Intrepid Postash Inc./Shaw 2008). As shown in this figure, groundwater in the southwest part of Section 2 falls into the NMED classification of protectable groundwater because the TDS is below 10,000 mg/L. Also, calcium and magnesium are elevated in the groundwater in the Rustler along with sodium and potassium.

Figure 4-13 shows the sodium and potassium ratio for groundwater in Section 2. The ratio of sodium to potassium decreases from southwest to northeast across the section. Ratios in the southwest generally are greater than 10 and up to 100 in well IP-WW-003. Ratios in the northeast corner are around 6. Well IP-WW-007 is in the Dewey Lake Red Beds and should not be compared to the other wells screened in the Magenta and the Culebra (well IP-WW-002). Waters with a high ratio of potassium to sodium, or conversely with a low sodium to potassium ratio, are indicative of potash refinery waste water and tailings water. North of Section 2 in the southern part of Clayton Basin, the Duval Mine operated in the 1950s and 1970s and discharged considerable waste water to holding ponds and tailings (Geohydrology 1979). This may be a possible cause for the sharp increase in chloride, TDS, and the drop in the sodium to potassium ratio in the northeast corner of Section 2. An alternative explanation may be that water from the Salado is moving upward along the ring fractures that surround the breccia pipes (Intrepid Postash Inc./Shaw 2008). This would account for the elevated chloride and TDS, but not the low sodium to potassium ratio in the northeast corner of Section 2 near the breccia pipes.



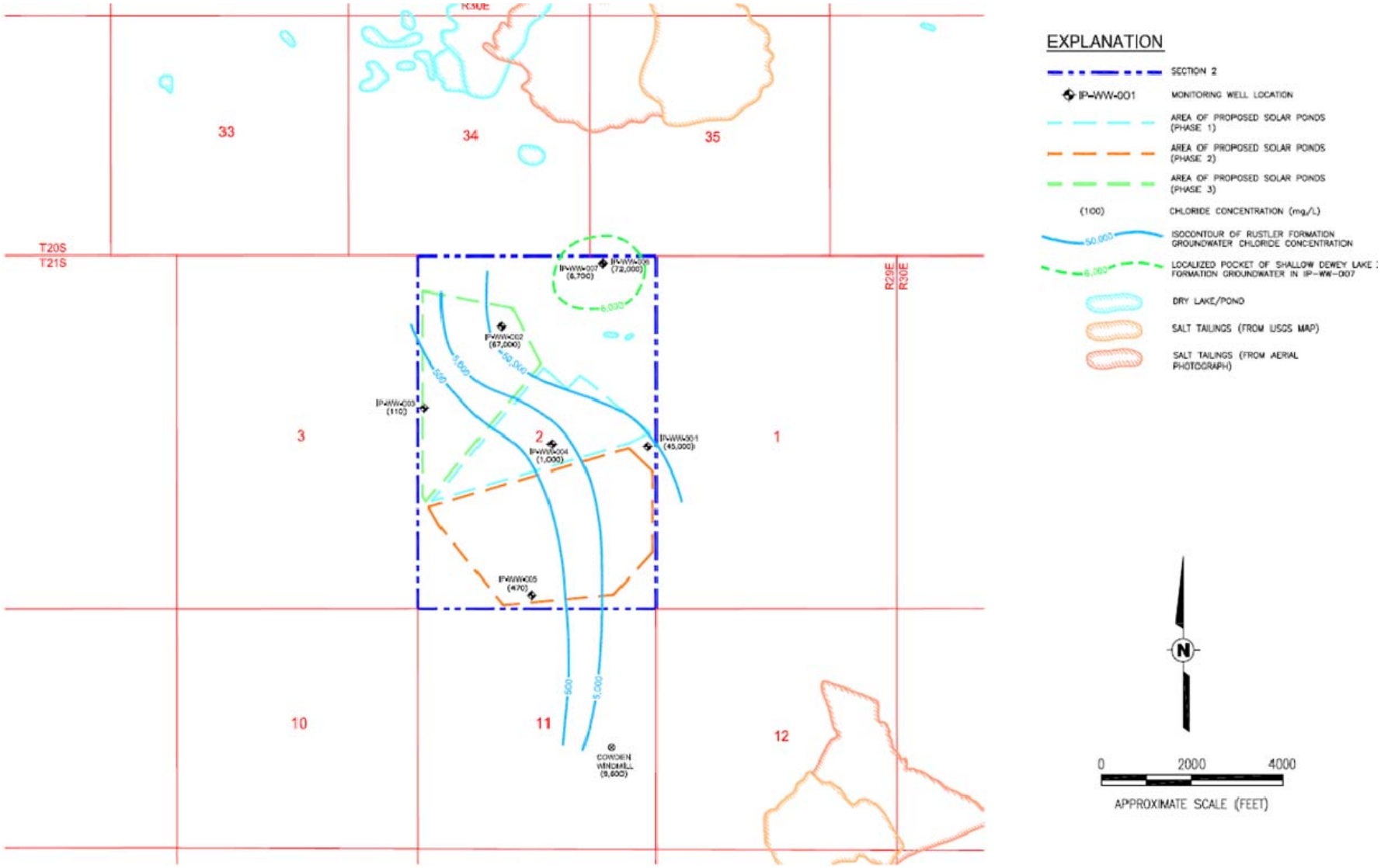
Source: Intrepid Postash Inc./Shaw 2008.

Figure 4-9 Total Dissolved Solids Contours in Groundwater



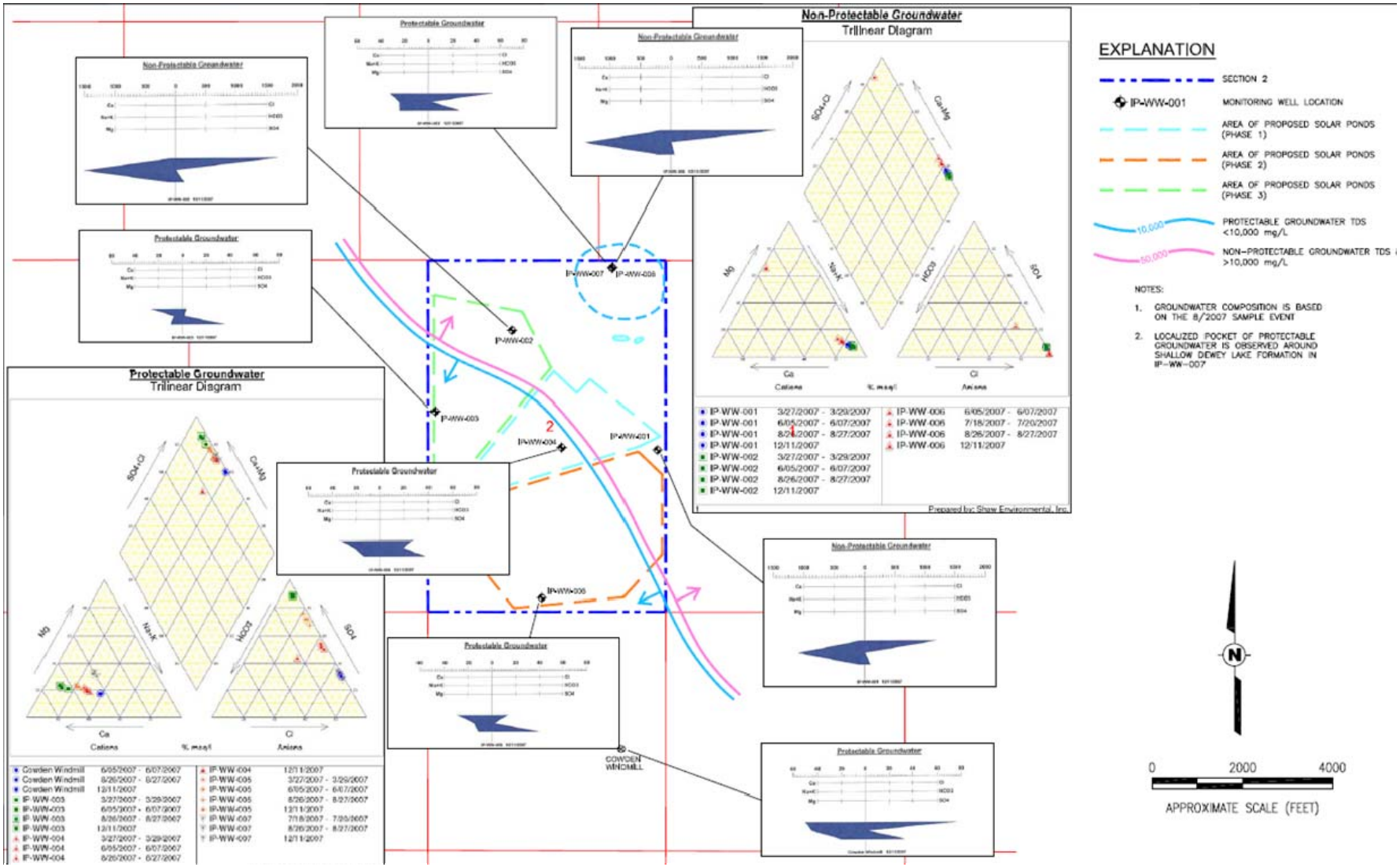
Source: Intrepid Postash Inc./Shaw 2008.

Figure 4-10 Sulfate Contours in Groundwater



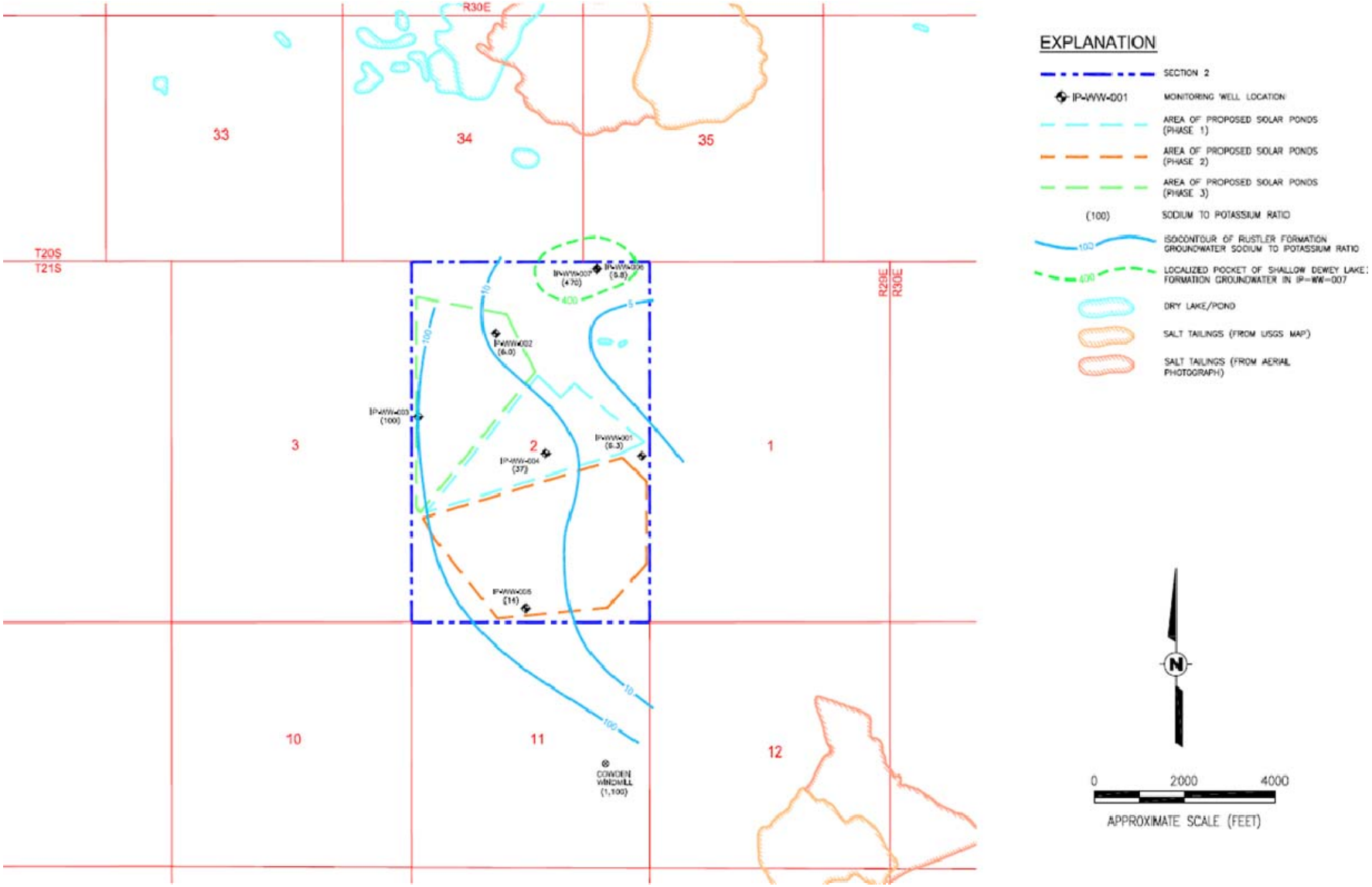
Source: Intrepid Postash Inc./Shaw 2008.

Figure 4-11 Chloride Contours in Groundwater



Source: Intrepid Postash Inc./Shaw 2008.

Figure 4-12 Protectable vs. Non-protectable Groundwater Chemical Composition



Source: Intrepid Postash Inc./Shaw 2008.

Figure 4-13 Sodium to Potassium Ratio Contours in Groundwater

5.0 Water Balance Estimate for the SPA

This section will summarize the key elements of the water balance estimates of Geohydrology (1978b) for the SPA and the regional estimates developed by Hunter (1985). The work of Geohydrology (1978b) was detailed in its estimate of evapotranspiration from plants and evaporation from brine ponds and involved field measurements and data from the operating potash refineries. Geohydrology's studies only focused on Clayton Basin and Nash Draw. Hunter (1985) provides a regional overview water fluxes and is more applicable to a groundwater model that encompasses more than just the SPA.

Developing a water balance for the SPA is difficult to execute due to the movement of water through the two aquifers that lie above the Salado Formation. Geohydrology was the first company to attempt finding a water balance for the SPA (1978b). As part the assessment, Geohydrology developed a water balance for Clayton Basin and Nash Draw that accounted for the influx of refinery discharge into the Rustler Formation, the rise in water levels from 1973 to 1978, and the increase in brine ponds and natural pond surface areas due to refinery discharge and the rise in groundwater levels. The water balance estimate of Geohydrology (1978b) was specifically directed at the western SPA and the discharge of refinery waste water to spoil piles and brine ponds. The work of Geohydrology (1978b) was detailed in its estimate of evapotranspiration from plants and evaporation from brine ponds and involved field measurements and data from the operating potash refineries.

The water balance assessment for the WIPP project was developed for the region from the Pecos River to WIPP and east to the San Simon Swale by Hunter (1985). This water balance estimate relied on the work of Geohydrology (1978b) for the SPA, but included an assessment of the Pecos River and an estimate for the loss of groundwater through the San Simon Swale. Recharge to the Ogallala Formation in the eastern part of the regional domain was not included because the study focused on aquifers between the Salado Formation and the Ogallala. As a result of the larger area studied by Hunter (1985), the water balance estimates differed from Geohydrology's estimates (1978b). Hunter's water balance estimate relied on the work of others and did not involve field studies to estimate important parameters in the water balance equation.

5.1 Clayton Basin and Nash Draw

Geohydrology (1978b) developed a water balance for Clayton Basin and Nash Draw, the major topographic components of the SPA. The water balance was developed for the BLM and was part of a larger study of the hydrology of the SPA.

Geohydrology (1978b) obtained refinery water data for imported and discharged water from operating potash refineries (not all refineries provided data), measured the change in surface area for natural ponds and brine ponds used by the refineries, completed a detailed evaluation of plant evapotranspiration around natural and brine ponds, and used groundwater level measurements from 1973 to 1978 to show the rise in groundwater levels in wells near refinery discharge ponds. The findings from their studies supported their position that refinery discharge ponds leak a substantial amount of water to the underlying Dewey Lake Red Beds and the Rustler Formation. The following is the basic water balance equation used by Geohydrology (1978b):

$$Pi + Swi + Gwi - Eo - Swo - Gwo = \Delta \text{ delta Storage}$$

Where: Pi = Precipitation recharge to groundwater

Swi = Surface water influx, including refinery seepage
Gwi = Groundwater influx
Eo = Evaporation and Evapotranspiration loss within and around ponds
Swo = Surface water loss
Gwo = Groundwater outflow
delta Storage = change in storage for groundwater

Table 5-1 summarizes the water balance for the SPA developed by Geohydrology (1978b).

Table 5-1 Water-budget Parameters for Clayton Basin and Nash Draw

Input	Rate	Area	Amount (acre-ft/yr)
Precipitation recharge	0.42 inch/acre/year		28,300
Potash refinery input			19,100
Petroleum brines			500
		Total Input	**47,900**
Output	**Rate**	**Area**	**Amount (acre-ft/yr)**
Brine-pond evaporation	4.4 feet/acre	1,560 acres	6,850
Spoil-pile evaporation	4.0 feet/acre	1,290 acres	5,100
Mud flat and dense vegetation	3.0 feet/acre	4,804 acres	14,400
Natural ponds and lakes	4.4 feet/acre	655 acres	2,900
Natural salt lakes	4.0 feet/acre	3,671 acres	15,000
Underground outflow (Uo)	200 gallons/min.		323
		Total Output	**44,573**
		Change in Storage	**3,327 (increase)**

Source: Geohydrology 1978b. Table 8. P. 59.

Precipitation recharge was estimated at 0.42 inch per year. This was done by examining studies on the consumptive loss of groundwater by plants in the semi-arid environment around Roswell, New Mexico similar to the SPA. Geohydrology (1978b) concluded that about 96 percent of precipitation is taken up by native plants and transpired. They estimated, based on published studies, that about one percent of precipitation is retained as soil moisture. Therefore, 3 percent of recharge remains for groundwater in the SPA. The average annual precipitation at the Duval Potash Mine, which lies at the south end of Clayton Basin (**Figure 1-2**), is around 14 inches per year (Geohydrology 1978b). Applying this value to the SPA, rather than applying the more regional average of about 13 inches per year, Geohydrology (1978b) estimated recharge to groundwater at 0.42 inch per year (3 percent X 14 inches per year). The recharge estimates were then applied to the area of the SPA that includes Clayton Basin and Nash Draw (800,000 acres) to estimate recharge to groundwater as 28,300 acre-feet per year from precipitation (**Table 5-1**). Precipitation recharge probably reaches groundwater through sink holes, fractures and faults, depressions in the topography, and local flow of surface water to depressions during intense storms.

There is no surface water influx into the SPA because all the streams are ephemeral. Similarly, there is no surface water outflow. Surface water flow has been created by potash refineries that import water from the Ogallala Formation from Caprock Water Company. Approximately 1,652 acre feet a month is imported (**Table 5-2**). A few mines, pump water from the Rustler to supplement the imported water. Approximately 90 percent of the imported or pumped water is discharged to spoil piles and brine ponds. Some of the brine ponds are former natural ponds which are now used for discharge, especially in Clayton Basin. Some refinery brine ponds are man-made and are used to hold the refinery discharge. The existing man-made ponds are unlined, and similar to the natural ponds, interact with groundwater. Thus, the refinery discharge ponds leak high TDS water to shallow aquifers, mainly the Dewey Lake Red Beds and the Rustler Formation.

The estimated annual discharge to brine ponds by the potash refineries from 1973 to 1978 is found in **Table 5-2**. The total discharge estimated by Geohydrology (1978b) was 19,100 acre-feet per year. Sixty-six percent of the estimated total is lost to groundwater as seepage, the rest evaporates. Petroleum operations add about 500 acre-feet per year (Geohydrology 1978b).

Table 5-2 Summary of Water Use by Potash Refineries as Reported in 1978

Company	Imported Water		Consumed	Tailings Discharge	
	gpm	acre-ft/mo		gpm	acre-ft/mo
1. AMAX	1,400	188		1,350 +550	255 +
2. Duval	1,343	181	65	1,278	172
3. IMC	3,605	485		3,244 (est)	436 (est)
4. Kerr-McGee	1,600	215		1,440 (est)	194 (est)
5. MCC	885	119	85 (est)	800 (est)	108 (est)
6. National	700	94	84	616	83
7. PCA	2,750	370	200	2,550	343
		1,652			1,591 acre-ft/mo (approximately 19,100 acre-feet per year)

1. Reported February 13, 1978 , 550 gpm produced from on-site wells.
2. Reported February 1, 1978.
3. F. Henninghausen, OSE Roswell, oral communication, March 1978.
4. Mining Plan Hobbs Potash Facility (Kerr-McGee), February 1977.
5. Reported February 6, 1978; estimates based on reported data.
6. Reported February 2, 1978.
7. Reported February 8, 1978.

Source: Geohydrology 1978b. Table 7. p. 57.

Loss of water from the system that represents the SPA is through groundwater outflow, brine pond evaporation, spoil-pile evaporation, and evaporation/evapotranspiration from mud flats and lakes (Geohydrology 1978b). Water loss is summarized in **Table 5-1**. Loss by evaporation from brine ponds was about 6,850 acre-feet per year, and loss from spoil-piles during the period from 1973 to 1978 was about 5,100 acre-feet per year, for a total of 11,900 acre-feet per year. Groundwater outflow was 323 acre-feet per year (200 gpm), which constitutes the estimated discharge from the Rustler Formation to the Pecos River at Malaga Bend (Geohydrology 1978b). The remaining loss of water from the system was from mud flats and natural ponds, salt lakes, and plants for a total in 1978 of 32,300 acre-feet per year.

Using the same approach as Geohydrology (1978b), the total inflow of water to the system from precipitation, refinery discharge, and petroleum operations was 47,900 acre-feet. The outflow from evaporation and evapotranspiration was 44,573 acre-feet for 1978. This resulted in a positive change in storage (delta Storage) of 3,327 acre-feet, which was consistent with the rise in groundwater levels from 1973 to 1978 observed by Geohydrolgy (1978b) around Salt Lake and its adjacent lakes**,** along with Laguna Uno and the brine ponds and lakes in Clayton Basin. Wells near areas of refinery discharge that had been used for stock watering in the 1950s were inundated with groundwater and not useable in the late 1970s (Geohydrology 1978b).

The analyses of Geohydrology (1978b) suggest that under natural conditions without refinery or petroleum brine discharge, the hydrologic system in Clayton Basin and Nash Draw would recharge the groundwater 28,300 acre-feet per year from precipitation. Precipitation recharge would be balanced by a discharge from natural mud flats, salt pans, natural lakes, and natural salt lakes of about 30,000 to 32,000 acre-feet per year.

The natural system in the SPA likely involves the same natural recharge flux as the Clayton Basin and Nash Draw. A decrease in recharge flux would eventually be balanced by a comparable decrease in water loss to evaporation and evapotranspiration from natural lakes fed by groundwater seepage and local springs, and plants that surround the lakes and springs. Similarly, under natural conditions, a rise in groundwater levels due to precipitation events is offset by increased evaporation from ponds and lakes and increased evapotranspiration by plants. Groundwater outflow remains consistent at a rate around 200 gpm (323 acre-feet per year) at Malaga Bend.

5.2 Regional Water Balance

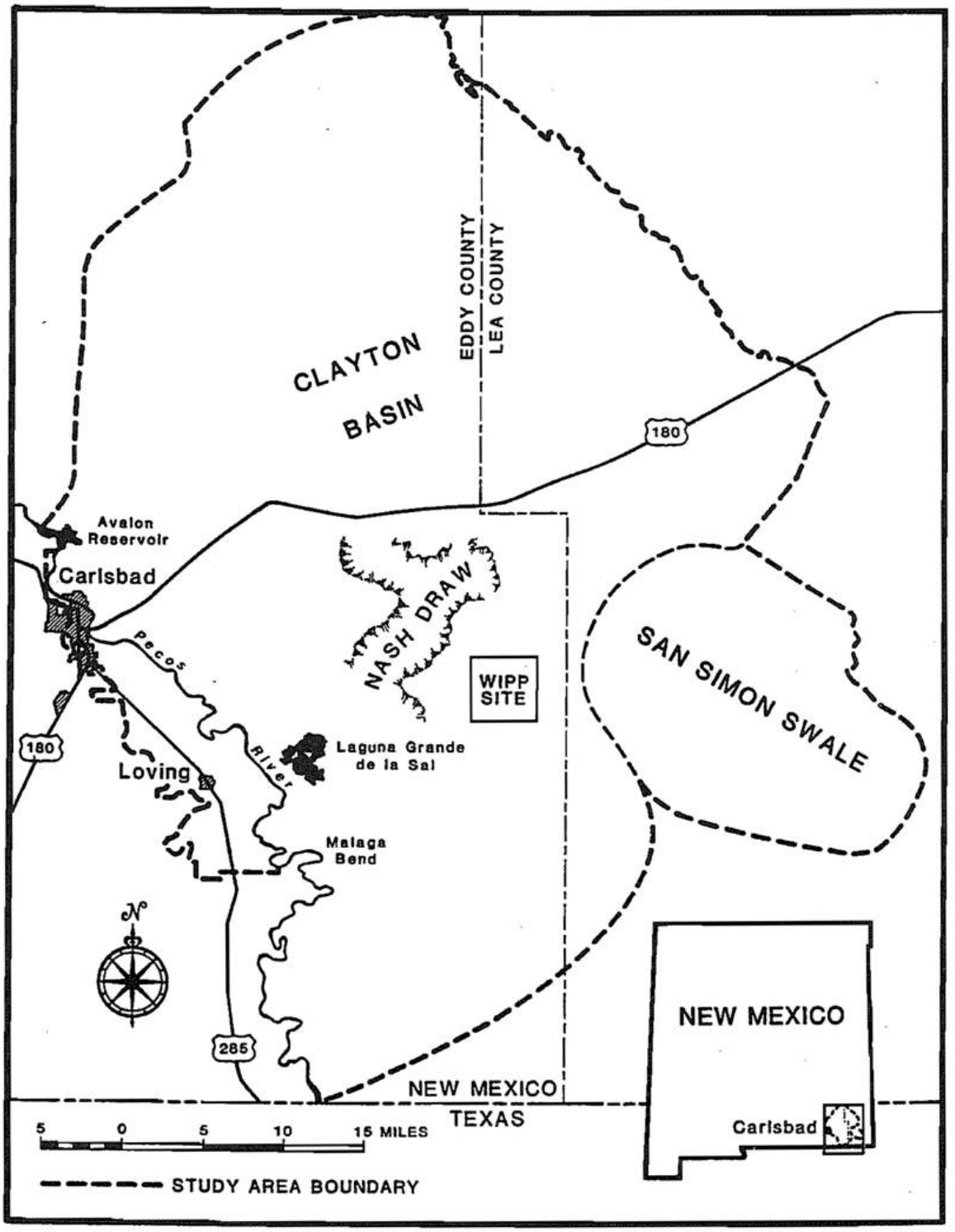
A regional water balance evaluation was completed by Hunter (1985) for the area shown in **Figure 5-1** as part of the hydrologic evaluation of WIPP and adjacent areas west to the Pecos River. The total area encompassed by Hunter's evaluation is about 1.28 million acres (2,000 square miles), of which the San Simon Swale occupies about 143,700 acres (Hunter 1985). The San Simon Swale is unique in that precipitation and groundwater within and around this collapse feature appears to move downward into the Capitan Limestone and then southeast out of the study area (Geohydrology 1978b). The San Simon Swale, therefore, has no effect on WIPP or the SPA. Hunter (1985) approached the water balance estimate for the region from WIPP to the Pecos River by analyzing the following categories of the water balance.

5.2.1 Precipitation

Precipitation over the Hunter (1985) study area was determined by examining precipitation at various stations and then contouring the data to yield a range of possible precipitation values for the study area (**Figure 5-1**). Precipitation at stations considered in the study ranged from 14.21 inches per year at the Duval Potash Mine (1955 to 1982) to 11.25 inches per year at the Carlsbad Federal Aviation Administration weather station (1949 to 1980). Precipitation at WIPP was 13.53 inches per year (1976 to 1979). The lowest value used was 9.67 inches per year at Lakewood in Eddy County (1912 to 1928), and the highest value was 14.36 inches per year for Hobbs in Lea County (1913 to 1982). The final estimated mean precipitation for the study area was 1,466,450 acre-feet per year with a variance of ±6 percent. For the San Simon Swale, the mean was around 137,950 acre-feet per year with a variance of ±20 percent (Hunter 1985). The compilation of this data results in an average precipitation rate for the study area of about 13.7 inches per year.

5.2.2 Irrigation

Irrigation water use for the area along the Pecos River, mainly the Carlsbad Irrigation District (CID), was summarized from data obtained from the CID, the U.S. Bureau of Reclamation, and the New Mexico State Engineer. In Eddy County, 78 percent of surface water and groundwater is used for irrigation along the Pecos River and 80 percent of that irrigation water comes from the Pecos River via the Carlsbad Main Canal from Lake Avalon. The CID comprises about 25,000 acres of irrigated land, with an additional 3,200 acres of irrigated farmland lying outside the CID (Hunter 1985). About one-third of the water used for irrigation is returned to the Pecos River or the alluvial aquifer along the Pecos; the rest is consumed by plants or transpired. The maximum allowed water use in the CID is 3.0 acre-feet per acre (Geohydrology 1978b). About two-thirds of the farms supplement surface water with well water (Hunter 1985). In 1980, the CID used 95,040 acre-feet of surface water and groundwater for irrigation. 55,860 acre-feet was depleted (consumed by plants and evapotranspiration) resulting in a corresponding depletion rate of about 58.8 percent. Effectively, 39,180 acre-feet of water was returned to the Pecos or the alluvial aquifer adjacent to the Pecos.



Source: Hunter 1985

Figure 5-1 Study Area Examined by Hunter (1985) and Used as the Hydrologic Boundary for the SPA

Outside the CID, 3,200 acres of farmland was irrigated in 1980. Approximately 7,965 acre-feet of surface water was diverted via the Harroun Canal to Harroun Farms and 1,800 acre-feet was diverted for Western Farms. In total, about 4,000 acre-feet was returned to the Pecos River (Hunter 1985). Therefore, irrigation water use comes from the Pecos River or alluvium along the Pecos and experiences the depletion rate of about 58.8 percent. The remainder of the water is returned to the Pecos or the alluvium along the Pecos. The SPA is not affected by irrigation water use in the study area of Hunter (1985).

Municipal and Rural Water Use: Municipal water use is mainly by cities along the Pecos River. Carlsbad pumped 8,404 acre-feet from the Capitan Limestone aquifer in 1980 and discharged 3,198 acre-feet of waste water to the Pecos. Total use by Carlsbad in 1980 was 9,545 acre-feet with a depletion of 4,798 acre-feet (Hunter 1985). Happy Valley used 90 acre-feet from the Capitan Limestone with a depletion of 45 acre-feet. Otis and Loving used a total of 658 acre-feet with a depletion of 328 acre-feet. The Mor-West Company, which sells water to Caprock Water Company and other rural water users, pumped 190 acre-feet from the Ogallala in 1980 with a depletion of 95 acre-feet. Overall, total municipal water use in 1980 was 10,343 acre-feet with 50 percent being lost to depletion and the other 50 percent being returned to the Pecos River or its associated alluvial aquifer (Hunter 1985).

Industrial Water Use: Hunter (1985) obtained the water use by the Potash Industry and by the Oil Industry from Geohydrology (1979b). **Table 5-2** summarizes the industrial water use.

Groundwater Discharge to the Pecos River: Stream gauges along the Pecos from Avalon Dam to the southern extent of the study area are shown in **Figure 5-2**. Hunter analyzed stream flux changes, seepage below the Avalon Dam, irrigation diversions and return flow, municipal discharge, and evaporative loss for the reaches shown in **Figure 5-2**. Due to the large changes in stream flux compared to the possible additions of groundwater to the Pecos from both the west and east sides of the river reaches in **Figure 5-2**, this approach gave a maximum estimate of groundwater discharge to the Pecos for each reach segment. To estimate groundwater discharge to the Pecos from only the east side of the river, Hunter (1985) assumed that the increase in TDS for each of the reach segments was due to saturated brine entering the Pecos as groundwater flow from the east side only. This approach gave a “minimum” estimate for groundwater flow to the Pecos.

The results of the analysis by Hunter (1985) demonstrated that from gauging station 4052 to gauging station 4065, over the course of 1 year the river receives groundwater flow from Nash Draw and Salt Lake and gains 168,300 tons in TDS, resulting in an estimate of 397.6 acre-feet of groundwater flow from the southern end of Nash Draw (Hunter 1985; Table 10). The estimated maximum groundwater flow for this reach, which includes groundwater entering from the west side of the river, was 6,100 acre-feet. For reach 4065 to 4070, the groundwater flow from the east side was estimated at 233.9 acre-feet with a maximum estimate for total groundwater inflow of 3,100 acre-feet. The reach from 4070 to 4075 had the largest influx of brine from the east side of the Pecos with an estimated change in TDS of 330,000 tons and a groundwater inflow from the east of 779.7 acre-feet. The maximum estimated groundwater inflow was 7,000 acre-feet (Hunter 1985; Table 10). The estimate for groundwater flow from Nash Draw (reach segment 4065 to 4070) of 397.6 acre-feet is consistent with the assumed approximate flow of groundwater from the Rustler Los Medanos member of 200 gpm (323 acre-feet) by Geohydrology (1978b).

Rangeland and Brine Lake Evapotranspiration: Hunter (1985) combined evaporation and plant transpiration into the term evapotranspiration for the purpose of estimating water loss from the study area. Unirrigated rangeland comprises about 98 percent of the study area (Hunter 1985), and rangeland evapotranspiration about 96 percent of precipitation, according to the literature review and summary presented by Geohydrology (1978b). Four percent remains for groundwater recharge, resulting in groundwater recharge over 98 percent of the study area of about 62,000 acre-feet per year. If soil moisture takes up 1 percent of precipitation (Geohydrology 1978b), then the recharge to groundwater would be around 44,000 acre-feet per year. A small error in the estimated 96 percent for rangeland evapotranspiration leads to a large error in recharge. For example, an error of ±1 percent in the percentage of precipitation that becomes evapotranspiration leads to a ±25 percent error in recharge to groundwater (Hunter 1985).

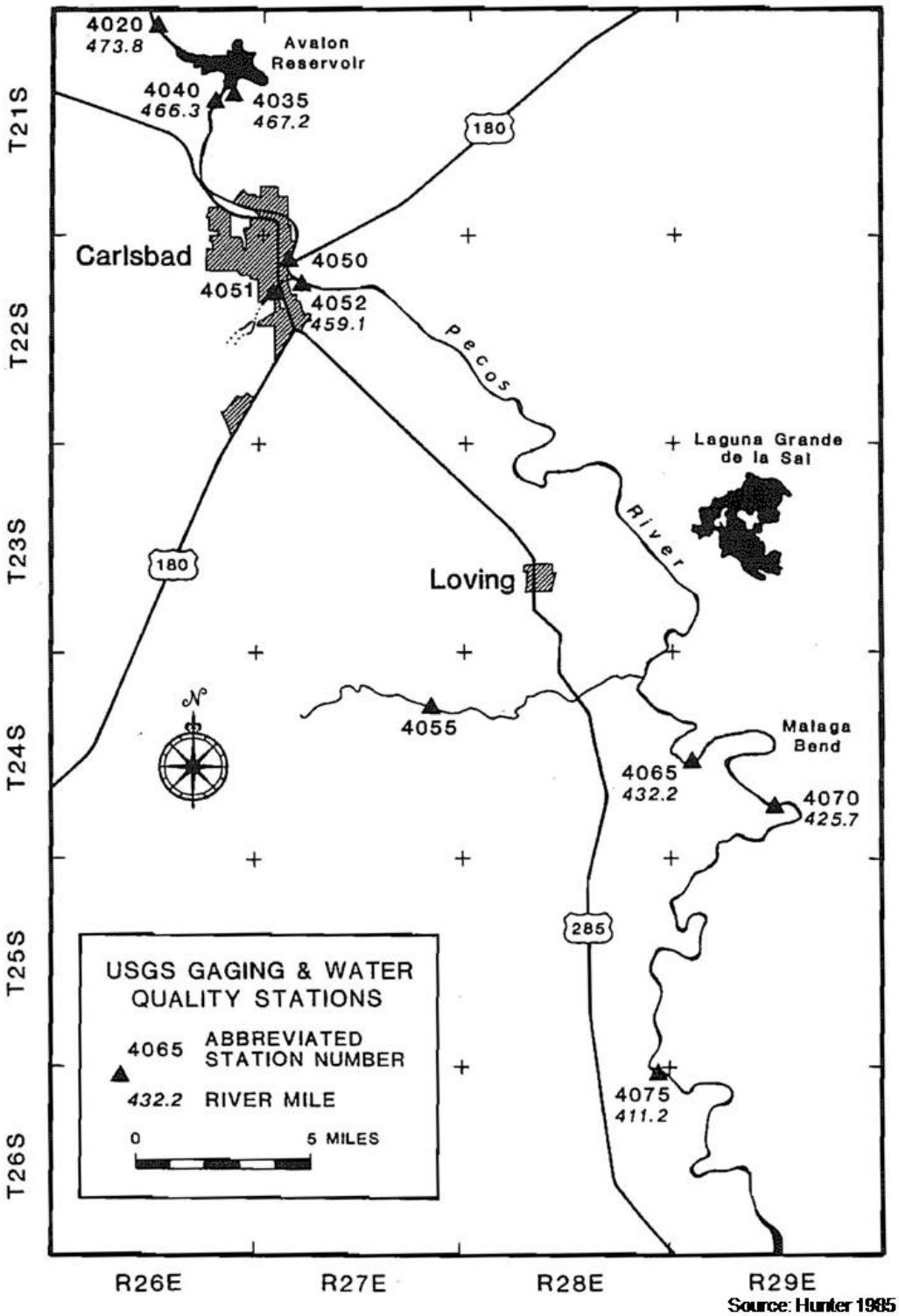


Figure 5-2 Pecos River Gaging and Water Quality Stations Used by Hunter (1985)

Brine lake evaporation and evapotranspiration by plants within and near the lakes data was acquired from Geohydrology (1978b). **Table 5-3** summarizes the calculations and estimates of Hunter (1985). Natural brine lake water loss accounts for about 17,200 acre-feet of water in 1980. Laguna Uno is grouped with the refinery discharge ponds because it was used for refinery discharge in 1980. Hunter (1985) also looked at Salt Lake (Laguna Grande de la Sal) under natural conditions circa 1942. At that time, Salt Lake had an area of 1,970 acres and an estimated water loss from evaporation of about 5,780 acre-feet. Groundwater flow to Salt Lake in 1942 was about 924 acre-feet per year. Flow from Surprise Spring to Salt Lake in 1942 was around 194 acre-feet per year (Hunter 1985).

Table 5-3 Evapotranspiration in the Hunter Study Area

		Water Committed or Acreage	Rate of Evapotranspiration	Total Evapotranspiration (ac-ft/yr)
Municipalities		10,533 ac-ft	50 percent	5,266
Potash-Related[1]				**26,350**
Spoil ponds (including Laguna Uno)		1,560 acres	4.4 ft/yr	6,850
Spoil piles		1,290 acres	4.0 ft/yr	5,100
Mud flats and dense vegetation		4,804 acres	3.0 ft/yr	14,400
Brine Lakes				
Laguna Grande de la Sal		2,880 acres	4.4 ft/yr	17,200
Other (excluding Laguna Uno)		1,035 acres		
Fresh-Water Bodies				
Lake Avalon		470 acres	6.1 ft/yr	10,900
Pecos River (station 4040 to station 4075)		1,320 acres		
Irrigated Acreage (applied water)		27,700 acres	58.8 percent	48,900
Unirrigated Acreage[2]				
Main Part of Study Area	high	1,317,000	98 percent	1,291,000
	low	1,241,000	89 percent	1,104,000
	best	1,290,500	96 percent	1,239,000
San Simon Swale	high	192,000	98 percent	188,000
	low	155,700	89 percent	139,000
	best	175,950	96 percent	169,000

5.3 Groundwater Flow Patterns

Groundwater is found in the Rustler Formation, the Dewey Lake Red Beds, and the Santa Rosa Formation (Dockum group) within and near the SPA. East of the SPA in Lea County, groundwater is found in the Ogallala Formation. In Clayton Basin and Nash Draw, groundwater is found mainly in the Rustler Formation. South of Nash Draw, the Santa Rosa is the uppermost water-bearing unit. Between Nash Draw and Clayton Basin, the Dewey Lake Red Beds are the uppermost water-bearing unit, although groundwater is found mainly in sand channels rather than throughout the formation. In northern Eddy County, the uppermost water-bearing units

are the Artesia Group and the Santa Rosa Formation (Hunter 1985). West of the Pecos River, groundwater is pumped from the Capitan Limestone.

Most aquifers in the regional area studied by Hunter (1985) have similar water levels or potentiometric surfaces, leading to the conclusion that there is a reasonable amount of hydraulic interconnection between aquifers above the Salado Formation (Hunter 1985; Geohydrology 1978b). The exceptions are the WIPP area, the high plateaus east of the SPA in Lea County, and Section 2, T21S, R29E in the Project Area part of the SPA (see Chapter 4.0). Both Hunter (1985) and Geohydrology (1978b) have contoured the uppermost aquifer water levels to produce a regional map of groundwater flow in the SPA and the regional study area. **Figure 5-3** taken from Geohydrology (1979) shows the general pattern of groundwater flow. Two key features that will be discussed below are:

1. The closed nature of groundwater flow in Clayton Basin; and
2. The convergence of flow on Nash Draw and the flow of groundwater through the Rustler Formation down Nash Draw to the Pecos River.

5.3.1 Groundwater Flow in Clayton Basin

Clayton Basin appears to be a closed basin for groundwater flow in the Rustler Formation and units above the Rustler (Hunter 1985). **Figure 5-4** shows contours for groundwater levels in the Rustler and units above the Rustler in the Clayton Basin area for 1978-1980. Depth to groundwater in 1978 generally was less than 50 feet over most of Clayton Basin (Geohydrology 1978b). There is an east-west groundwater divide along Mimosa Ridge in 1978 that separates Clayton Basin from Nash Draw. Recharge to Clayton Basin comes probably from the Burton Flat area west of Clayton Basin, the Loco Hills of northern Eddy County, possibly as far north as the Rustler outcrops in Bear Grass Draw, and from east of Clayton Basin in the units that overly the Rustler in the Querecho Plains (Hunter 1985). Discharge originates from numerous natural ponds and lakes that are found in an area of about 14 square miles that has depths to groundwater of less than 25 feet (Geohydrology 1978b; Hunter 1985). In 1978, this discharge amounted to 26,000 acre-feet per year, of which about 10,000 acre-feet was refinery discharge. This leaves about 16,000 acre-feet per year of loss of natural groundwater through evaporation and evapotranspiration related to the natural ponds and lakes (Hunter 1985).

The groundwater divide at Mimosa Ridge may be a temporary divide separating Clayton Basin and Nash Draw. In 1978, the volume of water in this divide was estimated at 9,600 acre-feet by Hunter (1985) using a groundwater divide height of 25 feet, an area of about 6 square miles, and an assumed porosity of 10 percent. Seepage from the Duval Potash brine ponds in 1978 was around 1,326 acre-feet per year (Geohydrology 1978b), although Duval claimed the seepage was only 418 acre-feet per year. Duval had operated since 1951 and anywhere from 14,000 to 45,000 acre-feet of refinery waste brine could have entered the Mimosa Ridge area (Hunter 1985). This could account for the groundwater divide. If this is the source of water in the divide, then the groundwater divide should be subsiding by spreading of the brine water. An alternative possibility is that the elevated precipitation in the Duval Potash Mine area of southern Clayton Basin may account for the groundwater divide. Precipitation averages 14.2 inches per year versus an average of around 13 inches per year for most of the basin. In this case, the divide is a permanent feature separating groundwater flow between Clayton Basin and Nash Draw. Geohydrology (1978b) assumed that Clayton Basin and Nash Draw were hydraulically connected in their evaluation of groundwater flow and water balance for Clayton Basin and Nash Draw.

5.3.2 Groundwater Flow in Nash Draw and WIPP

Groundwater flow patterns for the WIPP-Nash Draw area (**Figure 5-5**) were contoured by Hunter (1985) from data available in various WIPP project reports and studies. Nash Draw is a major collapse feature that acts as a groundwater sink with groundwater flowing into the Draw from both the east and the west and then flowing down the draw to the Pecos River. In the WIPP area, the Magenta and Culebra members of the Rustler Formation act as confined aquifers with very distinct potentiometric surfaces and little hydraulic communication. Groundwater in the Rustler at WIPP flows westward into Nash Draw.

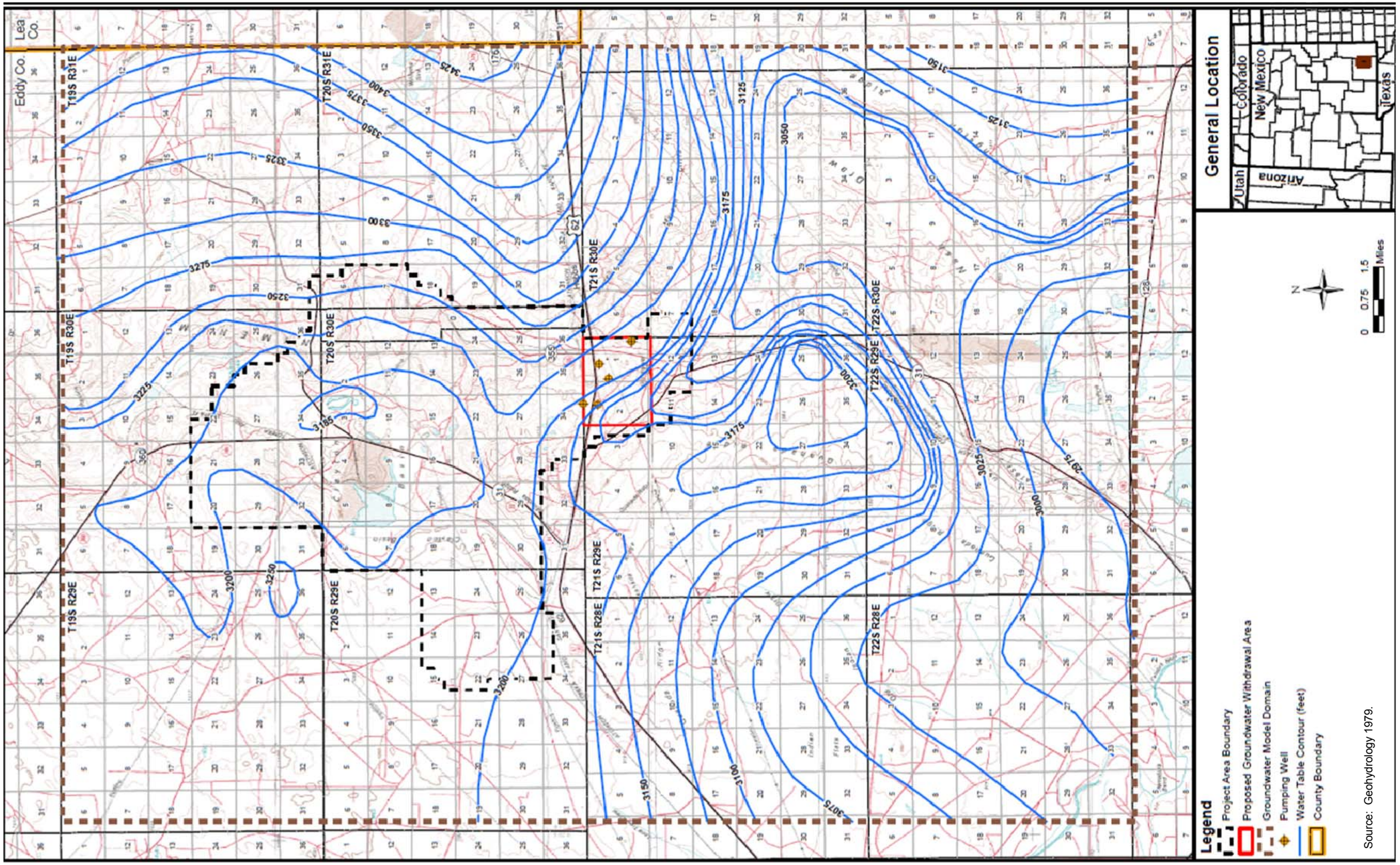
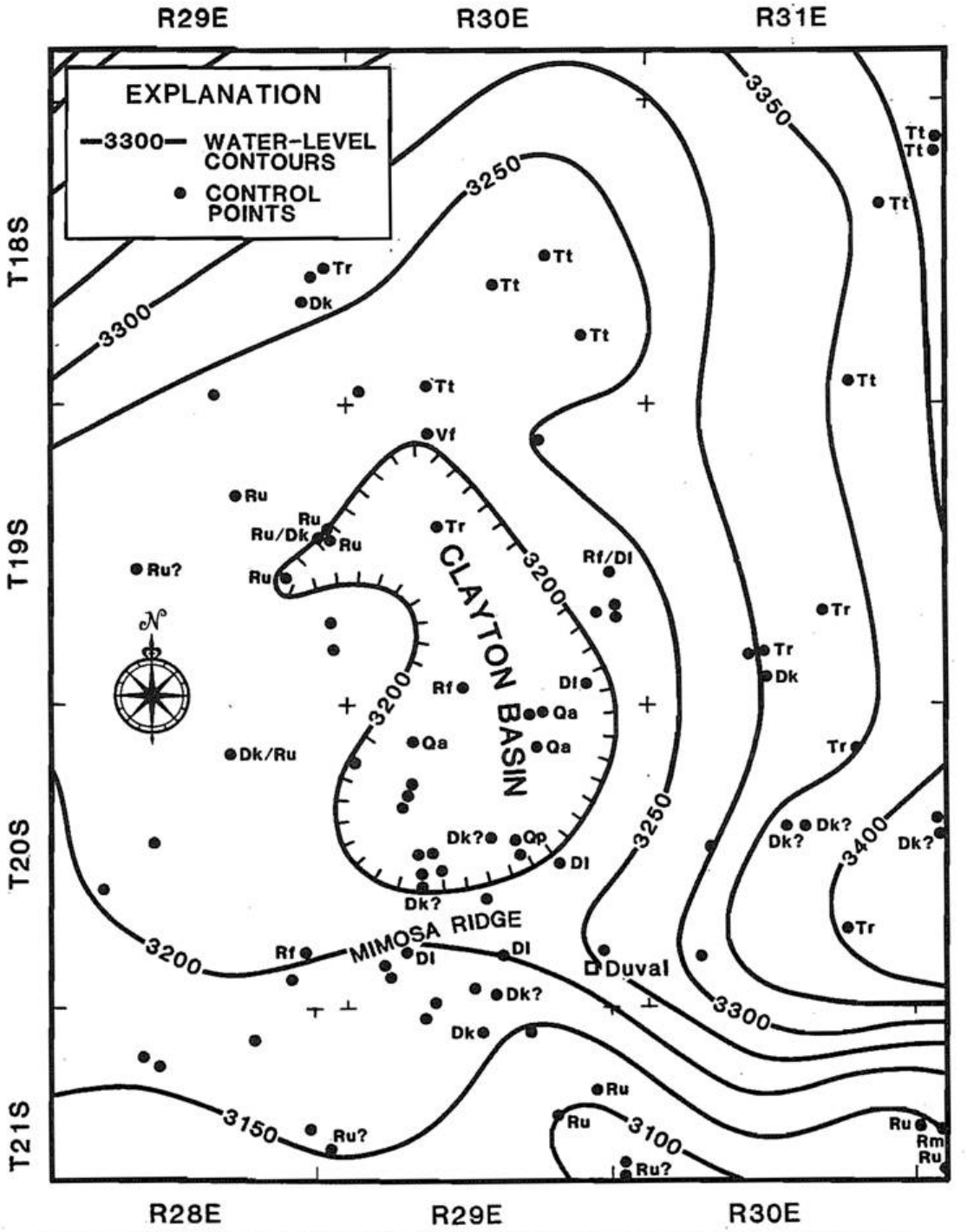


Figure 5-3 Water Table Contours (feet amsl) in the Model Domain



(Aquifers: Qa, Quaternary alluvium; Vf, Valley fill; Tt, Tertiary rocks, undivided; Dk, Dockum Group; Tr, Triassic rocks, undivided; Dl, Dewey Lake Redbeds; Ru, Rustler Fm., undivided; Rf, Rustler Fm., Forty-niner Member; Rm, Rustler Fm., Magenta Member)

Source: Hunter 1985

Figure 5-4 Potentiometric Surface of Rustler and Units Above in the Clayton Basin Area

In Nash Draw, because of the dissolution of halite and the collapse of the Rustler Formation, the Magenta and the Culebra aquifers are in hydraulic communication and the Rustler is in hydraulic communication with overlying units (Hunter 1985). The water levels in wells screened at different depths and in different aquifers are similar. In WIPP-27, unit tops are 116 feet apart, but water levels vary by only 3 feet. For WIPP-25, the unit tops are 145 feet apart and water levels vary by only 6 feet. Mercer (1983) concluded from an examination of WIPP well data in Nash Draw that hydraulic communication existed between all units in the WIPP wells except for WIPP-28. Chemical data from the Magenta and the Culebra in Nash Draw are similar, supporting the conclusion that these two Rustler aquifers are in hydraulic communication in Nash Draw (Hunter 1985). The Los Medanos brine aquifer, however, is distinct chemically from both the Magenta and the Culebra.

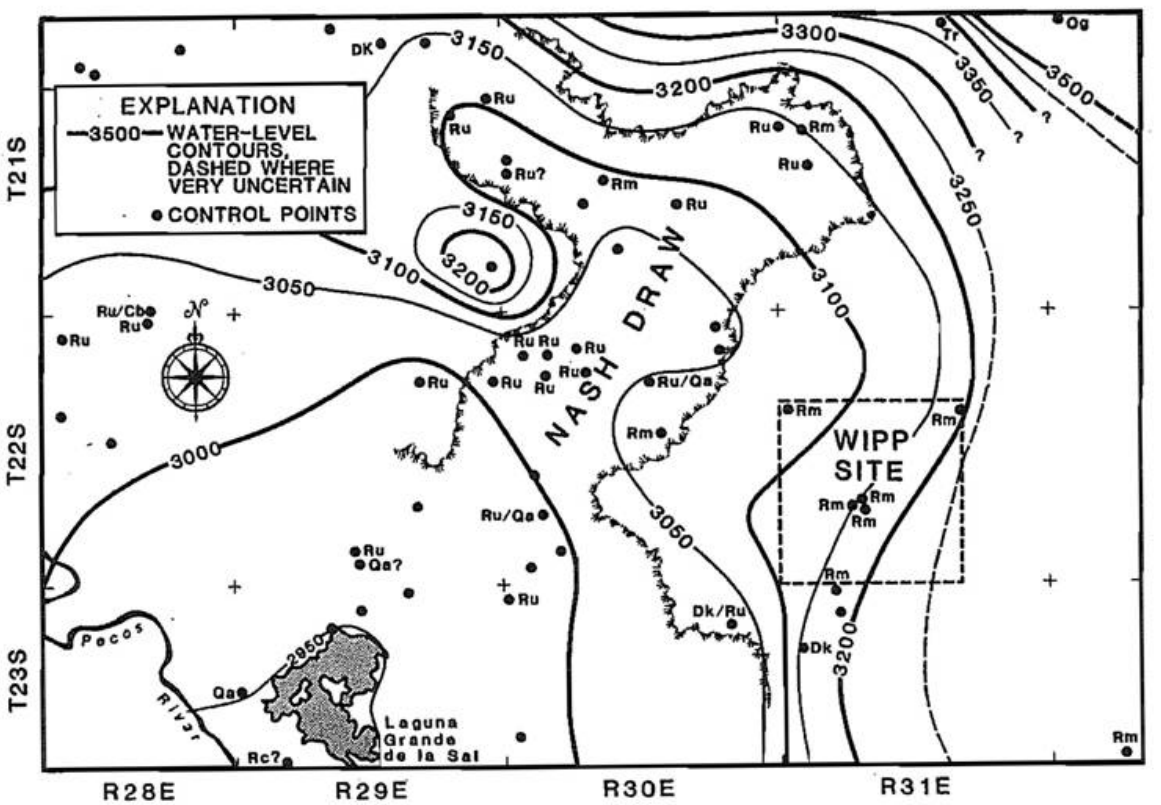
The only source for groundwater recharge in the Nash Draw – WIPP Project Area is precipitation and refinery discharges (Hunter 1985). Groundwater flowing from the east to Nash Draw is bounded on the east by The Divide, Bootleg Ridge, and Antelope Ridge, which are located east of WIPP and west of the San Simon Swale (Hunter 1985). The estimated precipitation for the Nash Draw – WIPP area is 256,000 to 277,000 acre-feet per year (Hunter 1985). Using 96 percent as the evapotranspiration loss from rangeland vegetation and 1 percent for soil moisture retention, a recharge rate of 3 percent leaves 7,680 to 8,310 acre-feet per year for recharge to groundwater in the Nash Draw – WIPP area. Refinery discharge from the Mississippi Chemical refinery would have added about 1,300 acre-feet per year of water to the system in 1980. Assuming the current operations at Intrepid Potash (current owners of the former Mississippi Chemical refinery) are comparable, the current refinery discharge to the Rustler in the Nash Draw area would be about 1,300 acre-feet per year.

5.4 Summary

The hydrology of the SPA and the surrounding area is complex and varied. Clayton Basin and Nash Draw are both collapse features, but they have different hydraulic characteristics. Clayton Basin is a closed hydrologic system and Nash Draw is a major groundwater sink drawing water from the Quahada Ridge area to the west and the WIPP area to the east. Nash Draw is an open system with discharge to the Pecos River. The Pecos River and its associated alluvial aquifer are in hydraulic communication and both provide the major source of water for irrigation in Eddy County. The Rustler Formation at WIPP contains confined aquifers in the Magenta and Culebra members that are probably not in hydraulic communication. This also appears true for Section 2, T21S, R29E (Section 2) in the project area where Intrepid Potash is proposing to pump approximately 1,100 to 2,000 gpm of water from the Magenta for 22 years. In Nash Draw and Clayton Basin, dissolution of halite in the Rustler Formation caused the overlying formations to collapse, resulting in the entire Rustler Formation acting as a single aquifer. Also, there is considerable evidence in Clayton Basin and Nash Draw that there is hydraulic communication between the members of the Rustler and between all aquifers overlying the Salado (Mercer 1983; Geohydrology 1978b). Some key points relative to the water balance of the SPA and adjacent areas are:

- Precipitation recharge to groundwater is about 3 percent of precipitation (Geohydrology 1978b).
- Precipitation recharge for Clayton Basin and Nash Draw is about 28,000 acre-feet per year; precipitation recharge for a larger area from the Pecos River to the San Simon Swale is about 44,000 acre-feet per year.
- Clayton Basin is a closed basin receiving about 16,000 acre-feet of groundwater recharge per year. This is evapotranspired from natural ponds, lakes, and their associated plants.
- Nash Draw is a groundwater sink open to the south with groundwater flow to the Pecos River. Flow to the Pecos is around 200 to 385 acre-feet per year based on estimates by Geohydrology (1978b) and Hunter (1985).
- Precipitation recharge to Nash Draw is around 7,600 to 8,300 acre-feet per year. This recharge to groundwater must find its way to the Pecos River, suggesting that flow to the Pecos may be greater than previously estimated.
- The Pecos River is the major source of irrigation water. Irrigation return to the Pecos is about one-third of water withdrawn for irrigation. Consumptive loss of water is around 50 to 58 percent.

- The WIPP area has a distinct hydrologic system that is not found in either Nash Draw or Clayton Basin. The Rustler is intact and the Magenta and Culebra members are separate confined aquifers with distinctly different potentiometric surfaces. Groundwater flow is west to Nash Draw (see **Figure 5-5**). The WIPP hydrologic system is bound on the east by The Divide, Bootleg Ridge, and Antelope Ridge.
- Potash refinery discharge ponds leak and seep about 60 to 70 percent of the discharge to groundwater. This leads to a rise in groundwater levels near the ponds and an increase in the surface area of nearby natural ponds. Discharge by refineries directly to natural ponds, like in Clayton Basin and at Salt Lake from the 1950s to present, results in increased evaporation from the ponds due to the larger surface area. Water balance estimates by Hunter (1985) and Geohydrology (1978b) suggest that refinery discharge to ponds is either lost by evapotranspiration or results in a rise in groundwater levels.
- Under natural conditions, where there is no potash refinery discharge, rangeland plants take up 96 percent of precipitation and 1 percent is held as soil moisture (Geohydrology 1978b). The 3 percent that becomes groundwater recharge is either lost by increased evapotranspiration in closed basins (Clayton Basin) due to a rise in water levels or natural pond surface area, or it flows out of the system to the Pecos River (via Nash Draw).



(Aquifers: Qa, Quaternary alluvium; Og, Ogallala Fm.; Tr, Triassic rocks, undivided; Dk, Dockum Group; Ru, Rustler Fm., undivided; Rm, Rustler Fm., Magenta Dolomite Member; Rc, Rustler Fm., Culebra Dolomite k, Chalk Bluff Fm.)

Source: Hunter 1985

Figure 5-5 Potentiometric Surface of Rustler and Units Above in the Nash Draw Area

6.0 Conceptual Hydrologic Model

The purpose of this section is twofold:

1. Summarize the important hydrologic features and formulate a conceptual hydrologic model for the area of potash mining within the SPA.
2. Present basic groundwater model design considerations to guide the development of a groundwater model for the potash mining within the SPA.

The SPA and the surrounding area from WIPP to the Pecos River encompass a complex hydrologic system. Groundwater flow exists in all Permian stratigraphic units except the Salado Formation. Groundwater flow in the Capitan Aquifer may interact with flow in Permian units below the Salado, but probably does not interact with the Rustler Formation or units above the Rustler. This section will be limited to the Rustler and younger units that are potential aquifers in the SPA since the emphasis of this report and groundwater model is on the Rustler and units above the Rustler. Concepts presented in this section are a synthesis of ideas and data presented in previous sections of this report, and therefore represent the opinions of the author of this report.

The Rustler is a stratigraphic unit consisting of five members, as shown in **Figure 2-2**. Where the Rustler has not undergone dissolution of halite, as is the case at WIPP, the five members are intact and groundwater flow is limited mainly to the Magenta Dolomite and the Culebra Dolomite members. At WIPP, these two members of the Rustler are separate confined aquifers with slightly different flow patterns and somewhat different aquifer hydraulic characteristics due to differences in lithologic and structural properties. Both aquifers, however, have groundwater flow to the west across WIPP that eventually enters Nash Draw. Flow in the Rustler is bounded to the east of WIPP by The Divide (Hunter 1985). The only area within the SPA shown through drilling and aquifer testing to have the five members of the Rustler intact is Section 2 at the north end of Quahada Ridge (**Figure 1-2**), as discussed in Chapter 4.0, Project Area Hydrogeology and Groundwater Chemistry. The extent of this area of the Rustler within the SPA that has not undergone dissolution is unknown.

Most of the SPA consists of Clayton Basin and Nash Draw. Both Clayton Basin and Nash Draw are collapse features generated by the dissolution of halite in the Rustler Formation and also along the top of the Salado Formation near the contact with the Rustler. In addition, karst formation in the underlying Capitan Limestone and subsequent collapse above the karsts to form breccia pipes is common in the southern part of Clayton Basin and in the Nash Draw area.

The dissolution of halite in the Rustler and the dissolution of carbonate material in the Capitan Limestone probably developed over many thousands of years during periods of wetter climate in southeastern New Mexico (Bachman 1984). Possibly, most of the dissolution and collapse took place during the Pleistocene glacial period from about 2.5 million years BP to about 20,000 years BP. Over the past 10,000 years, the climate in southeastern New Mexico has become more arid and although collapse features may be enlarging along fractures and faults, no new major collapse features are forming naturally (Bachman 1984). In areas where industrial activity has resulted in the injection of water into the Rustler, the Salado, or the Capitan Limestone, new collapse features may be developing. In the areas of major collapse, such as Clayton Basin and Nash Draw, the five members of the Rustler have collapsed due to salt dissolution and are in hydraulic communication. The brecciation along with the pervasive fracturing led to vertical hydraulic communication within the Rustler so that water levels and water chemistry in the Culebra and Magenta members are similar.

Key components of a conceptual hydrologic model for the SPA therefore involve:

1. Clayton Basin as a closed basin that resulted from collapse;
2. Nash Draw as a major collapse feature that drains to the Pecos River;

3. The WIPP area as a source of groundwater flow into Nash Draw from the Magenta and Culebra members of the Rustler;
4. The Section 2 area and Quahada Ridge where the Rustler is still intact, but over a limited area;
5. The possible groundwater divide between Clayton Basin and Nash Draw along Mimosa Ridge;
6. The limited recharge to aquifers due to the semi-arid climate where 97 percent of precipitation is consumed by rangeland plants and soil moisture retention; and
7. The discharge of refinery waste water into unlined ponds or natural ponds that led to substantial water level increases during the 1970s and local changes in groundwater chemistry.

6.1 Conceptual Hydrologic Framework of the SPA

Key components of the hydrology of the SPA and surrounding areas are summarized below:

1. Recharge is from precipitation. There are no perennial streams in the SPA. The Pecos River is not part of the SPA. About 3 percent of precipitation recharges groundwater, but only in areas where there are fractures, collapse features such as sinkholes, and topographic depressions to collect local runoff during intense storms. During periods of low rainfall, it is possible that there is no recharge to groundwater in the SPA.
2. Discharge of groundwater from the SPA is through evaporation and evapotranspiration related to natural ponds fed by groundwater or groundwater springs, and by discharge to the Pecos River through Nash Draw of about 323 to 387 acre-feet per year. The discharge could be greater than this estimate, as indicated by the water balance estimates of Hunter (1985).
3. Groundwater and surface water interaction is limited to natural ponds, springs, and seeps and man-made refinery waste discharge ponds that seep about 60 to 70 percent of the discharge to shallow groundwater.
4. Refinery waste water discharge results in seepage of about 60 to 70 percent of the discharge to shallow groundwater. This causes a rise in groundwater levels near the discharge ponds can flood local wells. The water table may increase to a level that causes increased surface area of natural ponds in the vicinity and increased evaporation and evapotranspiration. Eventually, all refinery waste water discharged to natural or man-made ponds is lost from the system through increased evaporation or evapotranspiration.
5. Aquifer interaction through vertical flow of groundwater is apparently limited to areas where the Rustler Formation has collapsed due to dissolution of halite. At WIPP and in the Section 2 area of Quahada Ridge, the Rustler has not undergone dissolution of halite and the Magenta and Culebra members are distinct confined aquifers with little hydraulic communication. In areas where collapse has occurred, such as Nash Draw and Clayton Basin, similar water levels and water chemistry suggest that the Magenta and the Culebra interact and function as one hydrostratigraphic unit.
6. The Dewey Lake Red Beds and the Santa Rosa Formation overly the Rustler in the SPA and adjacent areas. Within the SPA, these two units can contain water, but do not appear to be continuous aquifers over the area of the SPA. East of Clayton Basin, these units are aquifers and south of the SPA the Santa Rosa acts as an aquifer. Hydraulic communication between these two units and the Rustler is limited to areas of fracturing and where substantial collapse has occurred, such as Clayton Basin and Nash Draw.
7. Quahada Ridge may be a groundwater divide, based on contouring of water level data by Geohydrology (1978b), Hunter (1985), and other authors discussed in previous sections of this report. There are limited data to support this groundwater divide, but contoured water level data by various authors suggest that this possibility needs to be considered.
8. Mimosa Ridge, at the southern end of Clayton Basin, separates Clayton Basin from Nash Draw and was a groundwater divide separating the two areas in the late 1970s and early 1980s. The origin of

9. The groundwater budget for the SPA allows for about 28,000 acre-feet of recharge to groundwater annually. This recharge is offset by evaporation and evapotranspiration from natural ponds and discharge to the Pecos River through Nash Draw. Perturbations to this natural system by refinery waste water discharge are offset by evaporation, increased evapotranspiration due to increased surface area of natural ponds and elevated groundwater levels, and possibly through increased discharge to the Pecos River.
10. Natural hydrologic boundaries for the SPA are those shown by the outline of the area considered for water balance estimates by Hunter (1985) in **Figure 5-1**. The Pecos River is a groundwater sink along the western boundary. The Divide, Bootleg Ridge, and Antelope Ridge act as groundwater divides along the east (Hunter 1985). The northern boundary groundwater divide is the outcrop of the Rustler in Bear Grass Draw (Geohydrogeology 1978b). The flow of groundwater to Nash Draw from WIPP acts as a southern boundary. Nash Draw is a major groundwater sink that allows for groundwater flow to the Pecos River and Clayton Basin is a closed collapse basin. Within the SPA, there are possible local groundwater divides at Quahada Ridge, Mimosa Ridge, and west of Burton Flat along Fade-Away Ridge (Hunter 1985). The San Simon Swale is distinct from the SPA and does not affect groundwater flow within the SPA.
11. The Magenta and Culebra members of the Rustler Formation generally have rather low permeability, with transmissivity limited mainly to fractures, as is the case at WIPP. At WIPP these members are intact and have not been affected by dissolution of halite or collapse of the Rustler (Geohydrology 1978b; Mercer 1983). In areas where collapse has occurred, such as Nash Draw, the transmissivity of both units can be high due to fracturing and brecciation, and hydraulic interconnection between the units.

Groundwater enters the SPA by flow from areas outside the SPA, as shown in **Figure 5-3** (Geohydrology 1979) and leaves the SPA through evaporation and evapotranspiration or by flow down Nash Draw to the Pecos River. Precipitation adds about 28,000 acre-feet per year as groundwater recharge in areas of fractures, topographic depressions, and collapse features such as sinks. Refinery waste water discharge to natural ponds adds water to the system because refinery water is imported from outside the SPA. About 60 to 70 percent of discharge to man-made ponds seeps to the groundwater. This additional water is lost through evaporation and evapotranspiration or flow to the Pecos River. In areas where the Rustler has not undergone halite dissolution and collapse, the Magenta and Culebra members are distinct and separate confined aquifers with permeability limited mainly to fractured areas. In areas where collapse has occurred, these two members interact hydraulically and have high transmissivity. There is limited pumpage of groundwater in the SPA. Presently, most pumpage is from the Dewey Lake Red Beds or the Santa Rosa Formation for stock water.

6.2 Groundwater Model Design Considerations

To develop and calibrate a groundwater model for the SPA, sufficient data on water levels and water fluxes during a specific time period was needed. The most available data for the SPA is from 1978, obtained from the Geohydrology reports (1979, 1978a,b), Hunter (1985), Mercer (1983), Beauheim and Ruskauff (1988), and Richey (1989). Data for the HB In-Situ Solution Mine Project area, mainly Section 2, was retrieved from Intrepid Postash Inc./Shaw (2008). The synthesis of groundwater flow in Geohydrology (1979) sets the stage for calibrating the model of the SPA.

To adjust the model to the present (circa 2005–2009), a transient calibration was applied and assumptions were made about the decreased waste water discharge and subsequent decrease in evaporation and evapotranspiration related to natural and man-made brine ponds.

The second challenge faced in developing the groundwater model was to account for the highly variable nature of transmissivity in the Rustler Formation. In areas where the Rustler members are intact, the transmissivity of the Culebra and Magenta members is relatively low and related to fracturing. In areas of halite dissolution and collapse of the Rustler, as in Nash Draw and Clayton Basin, the transmissivity of both the Magenta and the Culebra can be high; both members can interact with other members of the Rustler hydraulically due to brecciation and extensive fracturing. Clayton Basin is a hydraulically closed basin and may be separated from Nash Draw by a groundwater divide along Mimosa Ridge. Nash Draw is a major collapse feature and acts as a groundwater sink drawing groundwater from WIPP on the east, Quahada Ridge on the west, and Mimosa Ridge on the north, and draining to the Pecos River on the south. The Pecos River is a major groundwater sink west of the SPA.

Groundwater usage within the SPA is currently limited to stock wells that derive water from units above the Rustler and possibly from the Rustler in limited areas. Presently, the impact of pumpage on groundwater is minimal. Water used by the operating potash mines and refineries comes from the Ogallalla Formation (Intrepid Potash, Caprock wells) or from an aquifer near Carlsbad Spring (Mosaic Mine). About 90 percent of the imported water is discharged as refinery waste water and about 60 to 70 percent of that discharge seeps to groundwater through unlined brine ponds (Geohydrology 1978b). Any serious long-term pumpage of groundwater from the SPA would be expected to result in substantial changes in the groundwater flow patterns because recharge from precipitation is very low (about 28,000 acre-feet per year) and may not exist during years with low rainfall. In order to model the potential impacts from proposed pumping, assumptions were made as to how groundwater flows between the areas of collapse in the Rustler and the areas where collapse has not occurred.

7.0 Groundwater Model Design

A numerical groundwater flow model (Groundwater Model) was developed for the SPA to better understand the hydrologic relationships between the stratigraphic members of the Rustler Formation, potential hydrologic interactions between the Rustler Formation and Dewey Lake Red Beds, and the potential impact of pumping groundwater from the Rustler Formation. Examples of surface water features include salt ponds, springs, seeps, and playas.

The groundwater model focuses on the Rustler Formation, primarily the Magenta and Culebra members, because these members act as aquifers in the SPA. The Salado Formation forms the base of the model; therefore, the hydrologic features of the Salado are not part of the model.

The model has two primary goals:

1. To assess the potential impacts of pumping groundwater from the Magenta and Culebra members of the Rustler Formation proposed for the HB In-Situ Solution Mine Project; and
2. To provide a quantitative synthesis of hydrologic studies completed in the Rustler Formation in the SPA over the past 40 years.

7.1 Modeling Code

The numerical code utilized in the Groundwater Model is MODFLOW 2000 (Harbaugh et al. 2000) running within Groundwater Vistas model processing software, developed by Environmental Simulations, Inc. (GFLOW 2007). MODFLOW is part of a family of public-domain numerical flow codes that have been developed by the USGS starting in 1988 (MODFLOW 88, MODFLOW 96, MODFLOW 2000, and MODFLOW 2005). MODFLOW was selected because it is capable of simulating steady-state or transient groundwater flow in one, two, or three dimensions, allowing it to simulate a wide variety of boundary conditions. The MODFLOW modeling codes have been thoroughly documented (McDonald and Harbaugh, 1988; Harbaugh et al. 2000) and extensively tested (Andersen 1993). The MODFLOW modeling codes are porous media codes designed for modeling groundwater flow in sedimentary formations, such as the Rustler Formation. Fractured areas in the model domain are treated as equivalent porous media. This approach is satisfactory because, at the scale of the model grid blocks, the combined flow of a fracture and the surrounding matrix can be simulated as an equivalent porous media.

7.2 Model Domain

The model domain, shown in **Figure 7-1** and **Figure 1-1**, covers most of the SPA and includes current and past potash mining areas and the proposed Intrepid HB In-Situ Solution Mine Project area. The model domain encompasses Clayton Basin, the upper half of Nash Draw, Livingston Ridge, and all of Quahada Ridge, extending west almost to Fade-Away Ridge and east to the Williams Sink area. La Grande de la Sal (Salt Lake) lies outside the southern model boundary and the WIPP site is just east of the eastern boundary of the model domain. The model domain extends across T19S through T22S and R29E through R31E. The Groundwater Model domain encompasses 429 square miles, measuring 17.6 miles from west to east and 24.4 miles from north to south. The southwest corner of the model grid is located at Easting 1,912,038 feet and Northing 11,740,890 feet (UTM Zone 13N, NAD 1983). The model grid cells are uniform, 1,000 square feet each. The model grid, shown in **Figure 7-2**, contains 129 rows, 83 columns, and 6 layers for a total of 71,982 cells.

The area of proposed groundwater pumping from the Rustler Formation for the HB In-Situ Solution Mine Project is shown on **Figure 7-1**.

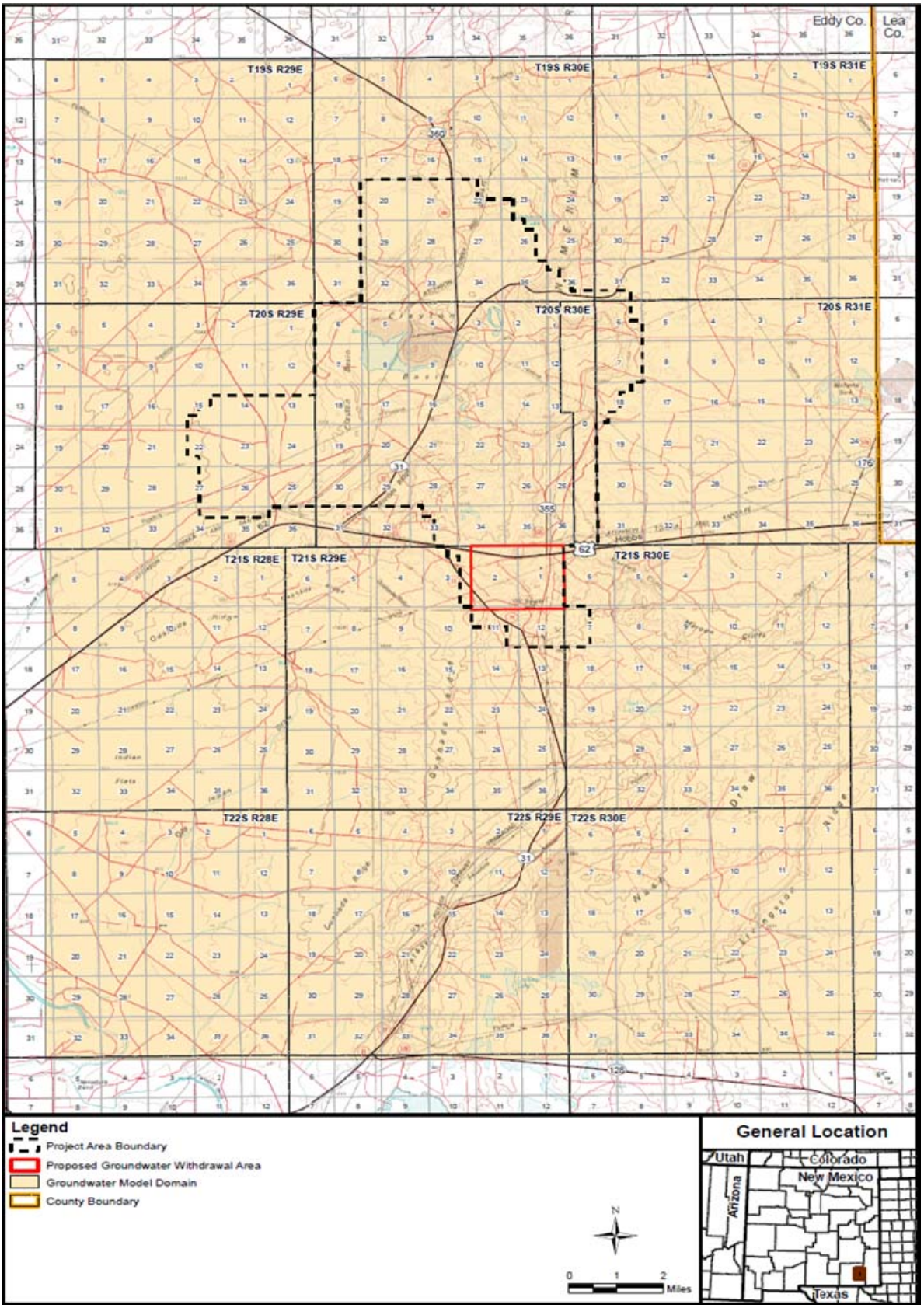


Figure 7-1 Groundwater Model Domain

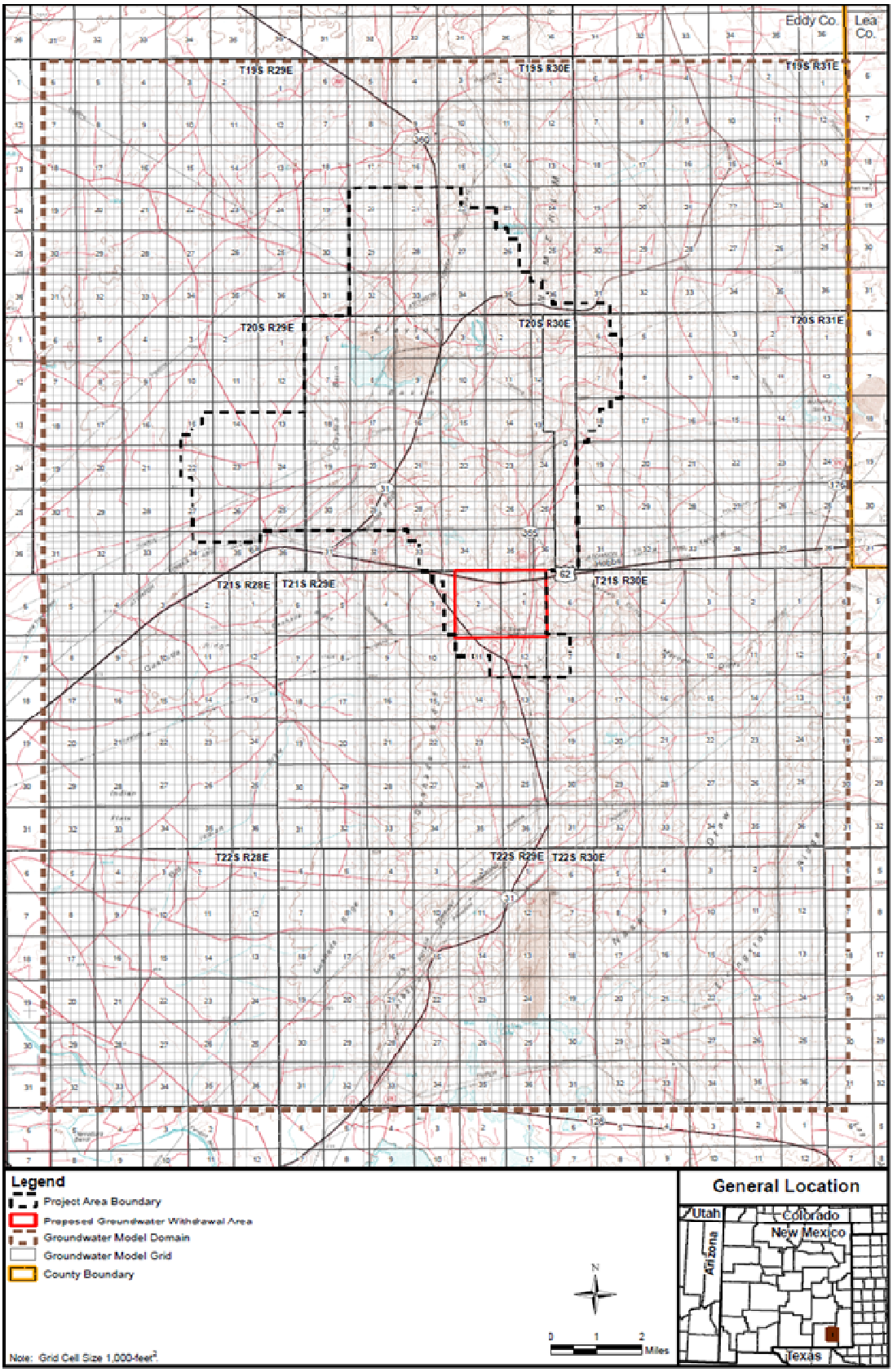


Figure 7-2 Groundwater Model Grid

7.3 Model Grid

The MODFLOW numerical flow models use a finite-difference grid. Groundwater flow can be described by complex partial differential equations (mathematical equations) that cannot be solved exactly unless assumptions are made to reduce the equations to linear equations. Analytical groundwater models employ assumptions such as a homogenous, isotropic, infinite aquifer, in order to linearize the complex equations. For the complex regional aquifer systems found in the Rustler Formation of southeastern New Mexico, analytical solutions are not adequate for modeling groundwater flow and subsequent impacts from long-term pumping.

Numerical flow models, such as MODFLOW, solve the complex partial differential equations by numerical approximation. MODFLOW utilizes a grid with a node in the center of each grid cell and calculates a hydraulic head (i.e., water level) for each grid node. When the mathematical solutions for each grid cell all correspond for the model domain, the model is said to “converge.” The finite-difference technique used by MODFLOW models requires that the aquifer system be divided into a set of discrete rectangular blocks or grid cells that form the model grid. The process of creating the model grid is called discretization. The spacing and design of the model grid depends on the purpose of the model. Tighter grids are used for pumping areas; water levels for each grid cell represent the average water level across the grid cell.

7.4 Model Layers

The model was divided into six layers to represent the Dewey Lake Red Beds and the five members of the Rustler Formation. Layer 1 represents the Dewey Lake Red Beds and overlying alluvial deposits. Layers 2 through 6 represent the members of the Rustler Formation, including (in order from top to bottom), the Forty-Niner Member, the Magenta Dolomite, the Tamarisk Member, the Culebra Dolomite, and the Unnamed Lower Member (sometimes referred to as the Los Medanos Member). The two main aquifers of the Rustler Formation are represented in layer 3 (Magenta Dolomite) and layer 5 (Culebra Dolomite).

In areas where units have thinned due to collapse and fracturing, such as the Magenta and Culebra Dolomites in Clayton Basin and especially in Nash Draw, a default thickness of 10 feet was used where there is no geologic borehole data to establish the thickness for the unit in that area. In areas where well logs are available, the thickness of each layer was based on the data provided by the well logs. Because layers cannot “pinch out” in MODFLOW, areas where a geologic unit (i.e., layer) is absent were modeled with an assumed constant thickness of 10 feet.

7.5 Boundary Conditions

Groundwater models seldom incorporate an entire hydrologic basin. Ideally, the boundary of a model should be set at the natural hydrologic boundaries of a basin (Franke et al. 1984). This is often not practical, as is the case with the Groundwater Model.

When the model boundaries are inside the natural hydrologic divides that define a basin, the model must account for areas where groundwater enters and leaves the model domain as part of the natural flow within and through the basin. This is done with the use of boundary conditions in MODFLOW.

The boundary conditions of the Groundwater Model were set so that key hydrologic features of the district are incorporated in the model. They also were set far enough from the area of expected groundwater pumping in the Section 2 area (Sections 1 and 2, T21S, R29E) so that drawdown created by the proposed pumping would not impinge on the model boundaries. Water levels (heads) and approximate flow rates (fluxes) for the model boundaries were based on a regional compilation of groundwater flow and water levels in the Rustler Formation compiled by Geohydrology Associates (1979).

Numerical models such as MODFLOW use three types of boundary conditions to model groundwater entering or leaving the model domain. These three types of boundary conditions are the specified-head, specified-flux, and head-dependent flux boundaries. The specified-head boundary was used to set the water levels along the boundaries of the model domain where the compilation of Geohydrology Associates (1979) showed

groundwater either entering or leaving the model domain. Specified-head boundaries (also called constant head boundaries) were set along the model boundaries for layers 1, 3, and 5. The specified-head boundaries for layer 1 (Dewey Lake Red Beds) are shown in **Figure 7-3**. The specified-head boundaries for layer 3 (Magenta Dolomite) and for layer 5 (Culebra Dolomite) are shown in **Figure 7-4**. Based on the work of Geohydrology Associates (1979), groundwater enters the model domain to the north and east and flows out of the model domain through the southern boundary, which simulates flow down Nash Draw and out of upper Nash Draw towards Salt Lake and the Pecos River (Hunter 1985).

Specified-flux boundaries are used in MODFLOW to represent wells, recharge, or no-flow zones (flux equals zero). Recharge from precipitation was incorporated into the model using the recharge package of MODFLOW, which is a specified-flux boundary condition. Recharge to groundwater was set at 0.48 inch per year and was applied to layer 1 of the model. This recharge rate is based on the studies summarized in Chapter 3.0 of this report.

No-flow boundaries are placed in a model where groundwater is not present, where leakage of water into the model is negligible, or where groundwater flow is parallel to the model boundary. Along the western edge of the model, groundwater flow is mainly north-south and parallel to the model boundary. The base of the model is the top of the Salado Formation, which was set as a no-flow boundary.

Head-dependent flux boundaries are a hybrid between the specified-head and specified-flux boundary. In this type of boundary, the flow of water (flux) into or out of a grid cell is computed based on the head calculated for the cell, the head specified for the boundary, and the conductance (ability to transmit water) applied to the boundary. In MODFLOW, head-dependent flux boundaries are established using the drain, river, stream, general-head, and evapotranspiration packages. Only the drain package was used in the Groundwater Model, applied to layer 1 to allow for groundwater to leave the model domain when groundwater levels rise above the land surface. This simulated the loss of water through springs, seeps, playas, and salt ponds. When the water table was below the base of the drain, no water was lost from the model domain.

7.6 Aquifer Parameters

Model parameters required by MODFLOW 2000 include the horizontal and vertical hydraulic conductivity values for each grid cell in the model domain, as well as storage parameters for transient simulations. The aquifer parameters used in the model were derived from the measured values discussed in detail in Chapters 3.0 and 4.0 of this report.

The main sources of aquifer test data are the studies of the WIPP site by the U.S. Geological Survey (USGS) and Sandia National Laboratories (see Chapter 3.0), the evaluation of Clayton Basin (Water Management Consultants [WMC] 1999), and the aquifer tests conducted in Section 2 by Intrepid Postash Inc./Shaw (2008) as part of the proposed groundwater withdrawal for the HB In-Situ Solution Mine Project. Brinster (1989) suggests a range in hydraulic conductivity values for the Culebra Dolomite from 6.0×10^{-5} feet per day to 56.7 feet per day with a log mean value of about 0.1 feet per day. For the Magenta Dolomite, the range in hydraulic conductivity values at WIPP ranges from 3.0×10^{-5} feet per day to 2.8 feet per day with a log mean value of about 0.0028 foot per day. At WIPP, the Magenta and Culebra dolomites are intact and separate from each other, forming confined aquifers, similar to that found in Quahada Ridge.

In Clayton Basin, the Dewey Lake Red Beds were found to have hydraulic conductivity values ranging from 0.02 to 1.2 feet per day and the Rustler Formation (undifferentiated) had values ranging from 0.003 to 25 feet per day (WMC 1999).

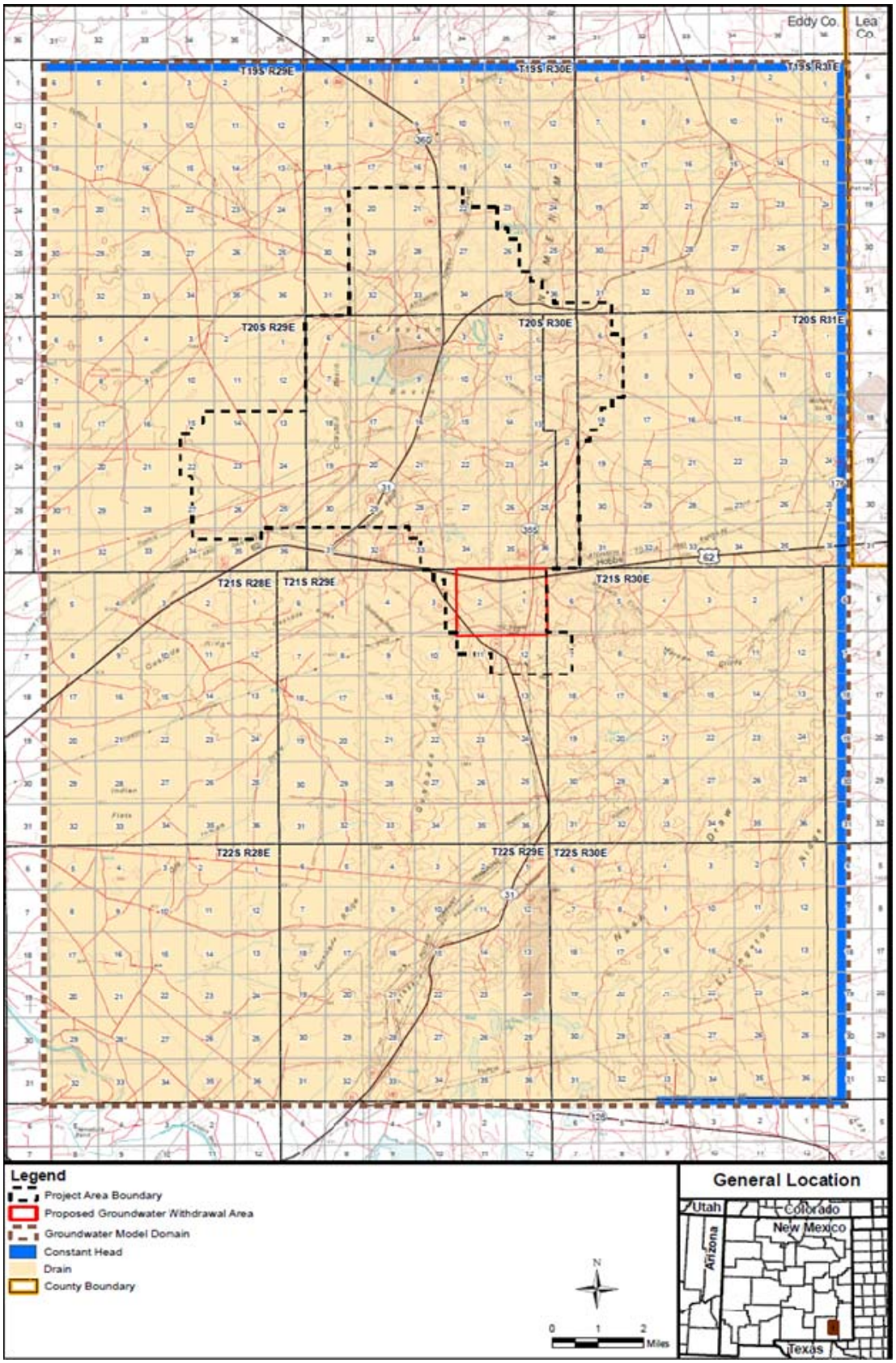


Figure 7-3 Model Layer 1 (Dewey Lake Red Beds) Boundary Conditions

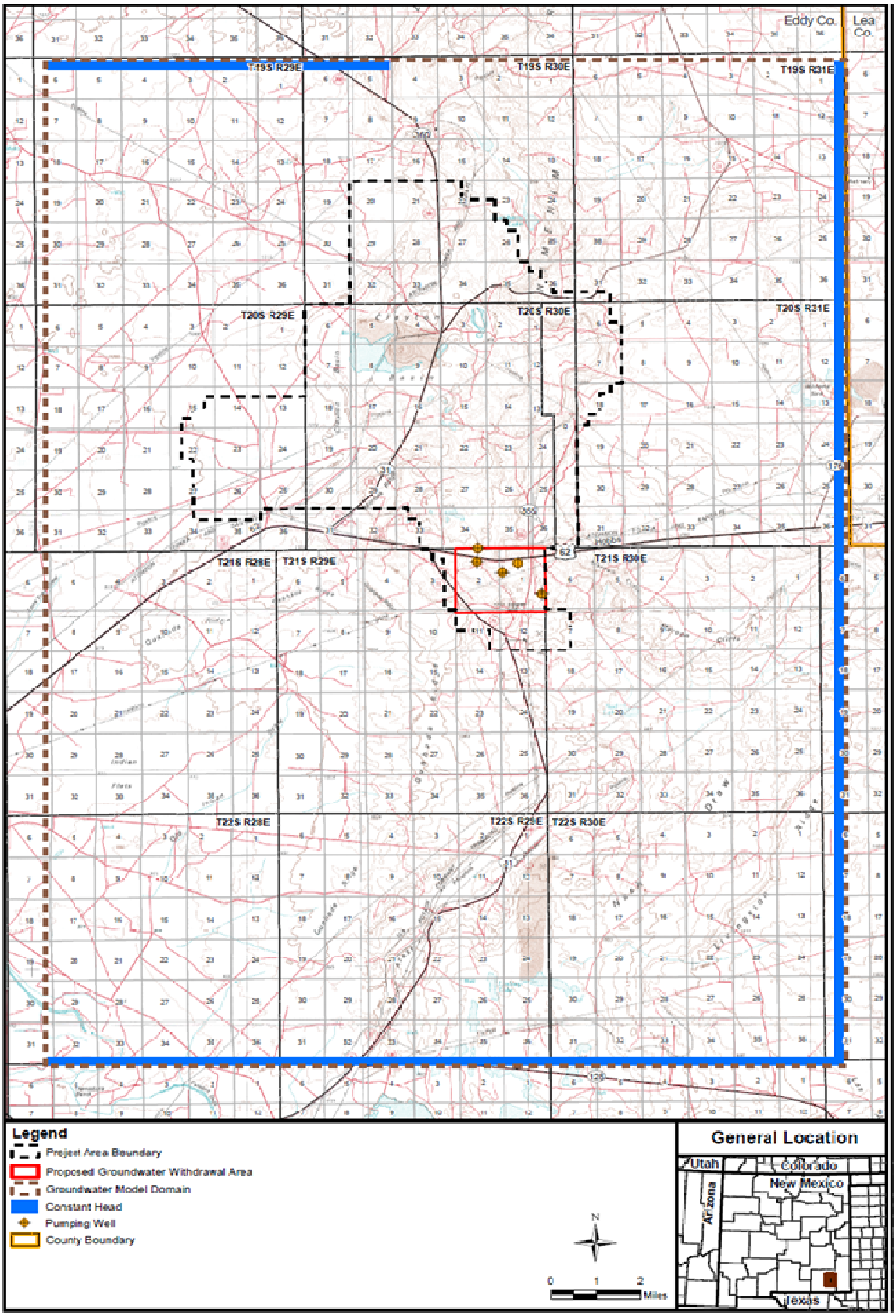


Figure 7-4 Model Layer 3 (Magenta Dolomite) and Layer 5 (Culebra Dolomite)) Boundary Conditions

In Section 2, the aquifer testing by Intrepid Postash Inc./Shaw (2008) was limited mostly to the Magenta Dolomite and produced values ranging from 0.001 to 92.7 feet per day for hydraulic conductivity estimates. The geometric mean of all the hydraulic conductivity estimates was 0.19 foot per day. The value of 92.7 feet per day was from well IP-WW-001 and was based on a short-term pumping test in a fracture or fault zone. The other values were obtained from wells in the Magenta and were all less than 1.0 foot per day. One aquifer test in the Culebra Dolomite yielded an estimated hydraulic conductivity of 0.6 foot per day. One test in the Dewey Lake Red Beds resulted in an estimated hydraulic conductivity of 0.77 foot per day.

7.7 Calibration Target Wells

Calibration targets were taken from available water level data published in reports by Geohydrology Associates (1978a,b), Water Management Consultants (WMC 1999), Cooper and Glanzman (1971), Intrepid Postash Inc./Shaw (2008), and the various reports prepared for the WIPP site that included wells in Nash Draw (see Chapter 3.0). The wells used for calibration are shown in **Figure 7-5** and listed in **Table 7-1**. Water level measurement dates ranged from the 1950s to 2008, with the most water levels measured during the 1970s by Geohydrology Associates (1978a,b) for the BLM when most of the mines in the SPA were active. Groundwater in the Rustler Formation is saline, as discussed in Chapter 3.0. The salinity varies from area to area and from aquifer to aquifer. The highest salinity water is in the Los Medanos member (layer 6 of the Groundwater Model). The model was not calibrated to layer 6 due to the lack of reliable target well data. For the Magenta and the Culebra dolomites, the variation in salinity is not sufficient to warrant correction of water levels for salinity differences. Consequently, calibration of the Groundwater Model did not correct for salinity differences.

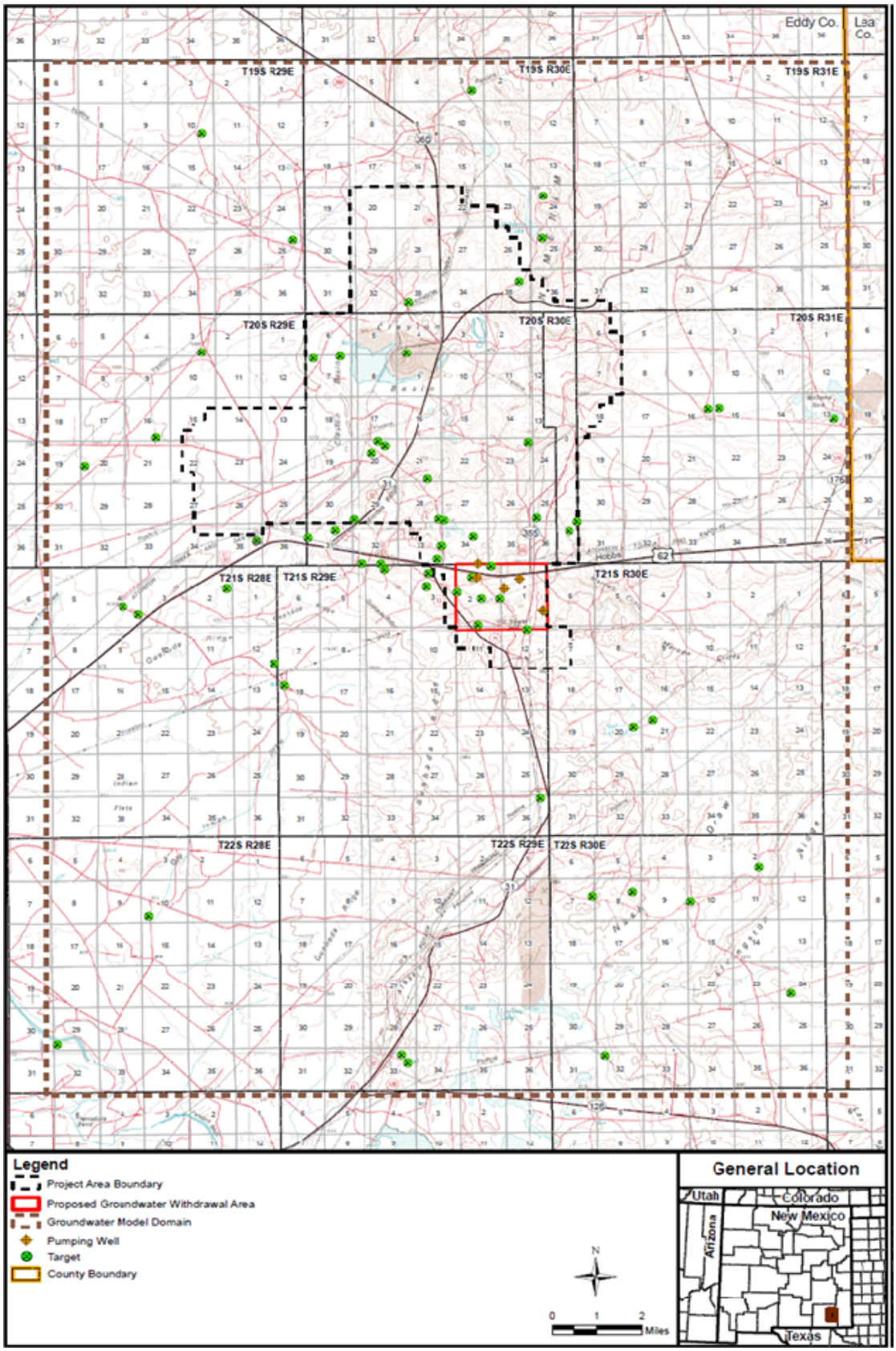


Figure 7-5 Calibration Target Wells

Table 7-1 Calibration Well Data

Well #	UTM Coordinates[1]		Model Layer	Observed Water Level (feet amsl)	Well Name	Date Measured	Source
	X (feet)	Y (feet)					
27	1,924,698	11,823,150	3	3206.72	20.29.16.434	1977	Geohydrology 1978a
28	1,916,289	11,819,590	3	3202.24	20.29.20.311	1977	Geohydrology 1978a
31	1,929,974	11,833,825	3	3211.66	20.29.3.434	1977	Geohydrology 1978a
32	1,936,378	11,810,194	5	3173.00	20.29.35.24	1967	Geohydrology 1978a
40	1,949,820	11,821,217	1	3194.52	20.30.20.142	1977	Geohydrology 1978a
41	1,956,453	11,818,071	3	3185.00	20.30.21.434	1974	Geohydrology 1978a
46	1,945,614	11,811,470	3	3197.05	20.30.31.214	1977	Geohydrology 1978a
50	1,957,582	11,807,897	3	3176.20	20.30.33.440	1948	Geohydrology 1978a
53	1,943,114	11,833,051	3	3199.76	20.30.7.112	1977	Geohydrology 1978a
54	2,003,824	11,825,499	1	3425.90	20.31.13.42	1977	Geohydrology 1978a
58	1,990,574	11,826,808	1	3386.90	20.31.15.130	1948	Geohydrology 1978a
60	1,989,127	11,826,706	1	3398.80	20.31.16.240	1948	Cooper & Glanzman 1971
61	1,938,504	11,794,859	5	3153.00	21.28.12.444	1973	Geohydrology 1978a
64	1,932,904	11,804,216	5	3157.00	21.28.2.24	1966	Geohydrology 1978a
67	1,920,817	11,801,988	3	3183.76	21.28.4.413	1977	Geohydrology 1978a
68	1,922,641	11,801,033	5	3154.80	21.28.4.442	1977	Geohydrology 1978a
70	1,967,989	11,799,094	3	3205.12	21.29.12.211	1978	Geohydrology 1978a
73	1,939,724	11,792,011	3	3154.90	21.29.18.130	1948	Geohydrology 1978a
77	1,956,555	11,806,093	3	3170.00	21.29.3.120	1948	Geohydrology 1978a
78	1,956,362	11,804,488	5	3170.50	21.29.3.141	1967	Geohydrology 1978a
79	1,951,319	11,806,581	3	3197.73	21.29.4.121	1977	Geohydrology 1978a
84	1,980,495	11,786,841	5	3110.00	21.30.20.243	1963	Geohydrology 1978a
92	1,923,894	11,763,186	3	3068.00	22.28.10.33	1957	Geohydrology 1978a

Table 7-1 Calibration Well Data

Well #	UTM Coordinates[1]		Model Layer	Observed Water Level (feet amsl)	Well Name	Date Measured	Source
	X (feet)	Y (feet)					
99	1,913,164	11,747,067	5	3026.00	22.28.30.44	1965	Geohydrology 1978a
111	1,953,307	11,745,771	5	2964.25	22.29.33.214	1977	Geohydrology 1978a
115	1,954,049	11,744,826	3	2967.00	22.29.33.241a	1959	Cooper & Glanzman 1971
118	1,987,044	11,764,987	1	3074.30	22.30.10.311	1959	Cooper & Glanzman 1971
120	1,995,187	11,769,288	3	3044.15	22.30.2.431	1976	Geohydrology 1978a
125	1,977,205	11,745,669	3	3001.57	22.30.32.114	1977	Geohydrology 1978a
140	1,975,715	11,765,659	3	3034.30	22.30.7.244	1949	Geohydrology 1978a
143	1,980,367	11,766,188	3	3050.20	22.30.8.241	1959	Cooper & Glanzman 1971
154	1,969,541	11,778,045	3	3110.00	C 02223	1991	NMOSE 2010
663	1,964,842	11,802,965	3	3154.01	IP-WW-001	2007	Intrepid Postash Inc./Shaw 2008
668	1,961,604	11,805,591	5	3167.59	IP-WW-002	2007	Intrepid Postash Inc./Shaw 2008
673	1,959,903	11,803,784	3	3181.21	IP-WW-003	2007	Intrepid Postash Inc./Shaw 2008
678	1,962,724	11,803,006	3	3163.21	IP-WW-004	2007	Intrepid Postash Inc./Shaw 2008
683	1,962,302	11,799,663	3	3154.27	IP-WW-005	2007	Intrepid Postash Inc./Shaw 2008
688	1,963,833	11,807,005	3	3174.01	IP-WW-006	2007	Intrepid Postash Inc./Shaw 2008
691	1,963,815	11,806,996	1	3176.25	IP-WW-007	2007	Intrepid Postash Inc./Shaw 2008
800	1,950,571	11,822,680	1	3196.80	20.30.20.12213	1965	WMC 1999
803	1,951,417	11,822,100	1	3194.60	20.30.20.12441	1976	WMC 1999
804	1,968,127	11,822,533	1	3202.40	20.30.23.11	1979	WMC 1999
805	1,969,108	11,813,031	1	3275.30	20.30.25.33	1979	WMC 1999
806	1,958,386	11,812,717	1	3248.50	20.30.27.333	1992	WMC 1999
808	1,947,815	11,812,841	3	3196.30	20.30.29.33	1979	WMC 1999
809	1,948,691	11,807,346	3	3198.60	20.30.32.34312	1970	WMC 1999

Table 7-1 Calibration Well Data

Well #	UTM Coordinates[1]		Model Layer	Observed Water Level (feet amsl)	Well Name	Date Measured	Source
	X (feet)	Y (feet)					
811	1,950,899	11,807,293	3	3193.70	20.30.32.43334	1968	WMC 1999
813	1,958,091	11,809,544	3	3171.70	20.30.33.42144	1948	WMC 1999
814	1,958,091	11,809,544	1	3195.60	20.30.33.42144	1971	WMC 1999
815	1,961,755	11,810,709	1	3233.25	20.30.34.131	1992	WMC 1999
818	1,953,885	11,833,711	5	3178.15	20.30.4.34312	1981	WMC 1999
820	1,946,220	11,833,307	3	3211.65	20.30.7.11221	1965	WMC 1999
822	1,957,779	11,812,907	3	3207.60	20.30.28.44	1979	WMC 1999
824	1,942,487	11,810,564	3	3195.25	20.30.31.23224	1966	WMC 1999
826	1,973,944	11,812,536	5	3187.00	20.30.36.111	1993	WMC 1999
827	1,972,986	11,811,385	5	3175.00	20.30.36.132	1993	WMC 1999
t19_8	1,930,024	11,861,281	1	3224.20	19.29.10.43	1971	WMC 1999
t19_11	1,940,717	11,847,867	1	3291.00	19.29.25.232	1977	WMC 1999
t19_16	1,969,849	11,853,431	1	3210.00	19.30.24.133	1979	WMC 1999
t19_17	1,969,764	11,848,119	1	3218.40	19.30.25.12	1983	WMC 1999
t19_18	1,954,123	11,840,151	1	3198.50	19.30.33.31	1993	WMC 1999
t19_14	1,961,585	11,866,627	1	3255.90	19.30.3.44	1979	WMC 1999
t19_15	1,967,066	11,842,681	1	3184.60	19.30.35.23	1979	WMC 1999
P-14	1,998,869	11,753,483	5	3039.00	P-14	1983	Davies 1988
WIPP-28m	1,982,715	11,787,715	3	3149.00	WIPP-28	1983	Richey 1987a,b

[1] UTM Zone 13N, NAD 1983 in units of feet.

8.0 Groundwater Model Calibration

8.1 Calibration Concepts

Calibration is the process of adjusting parameters in the model so that the model-computed water levels match water levels measured in target wells. Calibrating a groundwater model is difficult when relatively little information is available on subsurface conditions. Most of the parameters in a model, such as hydraulic conductivity, are only known at a few locations where past measurements have been taken. Even at “known” locations, the measurement of subsurface properties is an inexact science. Therefore, calibration of groundwater modeling is necessary to adjust aquifer properties to ensure that water level elevations reasonably match the target well water levels in the model domain.

During calibration, the model-computed water levels are compared to water levels measured in the known wells. These measured water levels are called calibration targets or targets. The targets represent water levels or changes in water level measured at a particular time during the simulation or during steady-state conditions. In the case of the Groundwater Model prepared for the HB In-Situ Solution Mine Project, steady-state conditions represent water levels measured over the time period from 1950 to 2008.

The model assumes that equilibrium conditions exist over the model domain because there has been relatively little groundwater pumpage in the area of the model since the 1970s. This assumption is limited because target well water elevations taken in the 1970s occurred when there was minimal groundwater pumping in Clayton Basin by potash mining operations. The pumpage by the potash mines in the 1970s was mostly offset for changes in groundwater levels by the discharge of waste water and seepage from tailings facilities (Geohydrology Associates 1979, 1978b). As discussed in Chapter 5.0, in Clayton Basin, discharge during the 1970s by the potash refineries exceeded the amount of groundwater pumped due to importation of water (Geohydrology Associates 1978b).

After each simulation, the target water levels are compared to model-computed water levels, which are subtracted from the field measurements to produce a residual. Positive residuals represent computed water levels that are lower than those measured in the field; negative residuals represent areas where the model is computing water levels higher than the measured ones.

A statistical analysis is then performed on the collection of residuals from all targets used in the model (Konikow 1978). Simple statistics such as the mean, standard deviation, root-mean-square error, and absolute mean are commonly used. The mean residual should be close to zero, indicating that the positive and negative residuals are balanced. The absolute mean is computed by making all residuals positive and thus represents the average error in the calibration. These statistical measures are used to determine the quality of the calibration, as discussed under Section 8.3, Calibration Results.

In addition to statistics computed for residuals, the distribution of residuals should be analyzed during calibration. It is desirable to have positive and negative residuals randomly scattered throughout the model and clustering of positive or negative residuals over large areas is called spatial bias. One goal of calibration is to minimize spatial bias. It is virtually impossible, however, to eliminate spatial bias due to the lack of adequate amounts of subsurface data.

8.2 Calibration Approach

In traditional calibration techniques, a relatively small number of zones are used to calibrate the model. Each zone covers many cells in the model, and within each zone, properties such as hydraulic conductivity are constant. The result is a piece-wise homogeneous aquifer configuration in which large areas of each aquifer have homogeneous properties.

In contrast, the pilot point method of calibration that was used to calibrate the Groundwater Model produces a nearly continuous hydraulic conductivity field that has a unique value in each model cell. The calibration process estimates a value of hydraulic conductivity at each pilot point and the group of pilot points is interpolated to obtain a property value for each cell, typically using a technique called kriging. The pilot point technique was first used in the U.S. by Lavenue et al. (1988) in the WIPP groundwater model of the Culebra Dolomite.

Doherty (2003) introduced a new technique called regularization that attempts to keep the hydraulic conductivity values as homogeneous as possible or at specified values, while still matching the water level data. In regularization, additional prior observations are added to the set of calibration targets. The additional observations are not field measurements but are mathematical equations that require that the hydraulic conductivity at adjacent pilot points be no more heterogeneous than necessary to match observed water levels. In some cases, the pilot points maintain their initial values unless it becomes necessary to adjust them during calibration.

Each pilot point has an initial estimate of hydraulic conductivity and an upper and lower bound to constrain the estimated value used to start the calibration process. The initial estimate of hydraulic conductivity at each pilot point comes from the range of hydraulic conductivity values published for the area or from specific aquifer test results where available. The upper and lower limits of hydraulic conductivity also are based on published values from the literature.

8.3 Calibration Results

There are many ways to assess the quality of calibration. The Groundwater Model calibration was assessed by comparing the calibration statistics to the goals established prior to calibration based on a visual comparison of observed versus simulated values and through analysis of spatial bias in the model. What constitutes an acceptable calibration is subjective. Woessner and Anderson (1992) suggest that goals should be established before the calibration starts. However, no standards have been put forth by the American Society for Testing and Materials (ASTM) or in the scientific literature that describes what the calibration goals should be. ASTM (1993) provides guidelines for model construction and calibration but not standards. Goals were established for the SPA Groundwater Model by the project team. The goals are based on those used by ESI in all models that have undergone peer review by the U.S. Environmental Protection Agency and many state government agencies. These goals are summarized as follows.

- Residual standard deviation divided by the range in head values (water levels) for all targets should be less than 0.10 (10 percent).
- Absolute residual mean divided by the range in head values for all targets should be less than 0.10 (10 percent).
- Residual mean divided by the range in head values for all targets should be less than 0.05 (5 percent).
- There will be limited spatial bias in the distribution of residuals.
- Total groundwater flow leaving the model to the south should be approximately 200 to 400 gpm based on the water balance estimates of Hunter (1985).

The statistics for the Groundwater Model calibration meet the calibration goals described above. The statistical analysis of the Groundwater Model calibration is provided in **Table 8-1**, which shows the residual mean, residual standard deviation, and absolute residual mean for all data from all times, and specifically for steady-state, 1990, and 2008 data. The goal for the residual mean divided by the range in head values (461.65 feet) is a maximum of 0.05 (5 percent). The residual mean divided by the range in head values is -1.1 percent. The standard deviation divided by the range in head values is 3.6 percent. The absolute residual mean divided by the range in head values is 3.0 percent. The goal for both absolute residual mean and residual standard deviation divided by the range in head values is 10 percent. Therefore, all of these statistical measures are substantially better than the established goals.

Table 8-1 Calibration Statistics and Residuals for the Groundwater Model

Well Number	X (feet)[1]	Y (feet)[1]	Layer	Observed	Computed	Residual
27	1,924,698	11,823,150	3	3206.72	3195.93	10.79
28	1,916,289	11,819,590	3	3202.24	3195.36	6.88
31	1,929,974	11,833,825	3	3211.66	3218.79	-7.13
32	1,936,378	11,810,194	5	3173.00	3177.67	-4.67
40	1,949,820	11,821,217	1	3194.52	3198.46	-3.94
41	1,956,453	11,818,071	3	3185.00	3203.65	-18.65
46	1,945,614	11,811,470	3	3197.05	3196.93	0.12
50	1,957,582	11,807,897	3	3176.20	3181.54	-5.34
53	1,943,114	11,833,051	3	3199.76	3203.20	-3.44
54	2,003,824	11,825,499	1	3425.90	3432.06	-6.16
58	1,990,574	11,826,808	1	3386.90	3402.74	-15.84
60	1,989,127	11,826,706	1	3398.80	3382.20	16.60
61	1,938,504	11,794,859	5	3153.00	3143.47	9.53
64	1,932,904	11,804,216	5	3157.00	3162.67	-5.67
67	1,920,817	11,801,988	3	3183.76	3161.55	22.21
68	1,922,641	11,801,033	5	3154.80	3159.28	-4.48
70	1,967,989	11,799,094	3	3205.12	3172.70	32.42
73	1,939,724	11,792,011	3	3154.90	3138.69	16.21
77	1,956,555	11,806,093	3	3170.00	3178.00	-8.00
78	1,956,362	11,804,488	5	3170.50	3171.68	-1.18
79	1,951,319	11,806,581	3	3197.73	3178.91	18.82
84	1,980,495	11,786,841	5	3110.00	3124.55	-14.55
92	1,923,894	11,763,186	3	3068.00	3081.99	-13.99
99	1,913,164	11,747,067	5	3026.00	3024.09	1.91
111	1,953,307	11,745,771	5	2964.25	2977.37	-13.12
115	1,954,049	11,744,826	3	2967.00	2970.89	-3.89
118	1,987,044	11,764,987	1	3074.30	3094.09	-19.79
120	1,995,187	11,769,288	3	3044.15	3073.02	-28.87
125	1,977,205	11,745,669	3	3001.57	3004.32	-2.75
140	1,975,715	11,765,659	3	3034.30	3067.69	-33.39
143	1,980,367	11,766,188	3	3050.20	3067.52	-17.32
154	1,969,541	11,778,045	3	3110.00	3117.26	-7.26

Table 8-1 Calibration Statistics and Residuals for the Groundwater Model

Well Number	X (feet)[1]	Y (feet)[1]	Layer	Observed	Computed	Residual
663	1,964,842	11,802,965	3	3154.01	3172.96	-18.95
668	1,961,604	11,805,591	5	3167.59	3176.86	-9.27
673	1,959,903	11,803,784	3	3181.21	3174.20	7.01
678	1,962,724	11,803,006	3	3163.21	3173.34	-10.13
683	1,962,302	11,799,663	3	3154.27	3168.07	-13.79
688	1,963,833	11,807,005	3	3174.01	3184.08	-10.08
691	1,963,815	11,806,996	1	3176.25	3230.76	-54.51
800	1,950,571	11,822,680	1	3196.80	3199.22	-2.42
803	1,951,417	11,822,100	1	3194.60	3200.22	-5.62
804	1,968,127	11,822,533	1	3202.40	3242.22	-39.82
805	1,969,108	11,813,031	1	3275.30	3262.81	12.49
806	1,958,386	11,812,717	1	3248.50	3223.45	25.05
808	1,947,815	11,812,841	3	3196.30	3198.69	-2.39
809	1,948,691	11,807,346	3	3198.60	3185.43	13.17
811	1,950,899	11,807,293	3	3193.70	3182.97	10.73
813	1,958,091	11,809,544	3	3171.70	3188.18	-16.48
814	1,958,091	11,809,544	1	3195.60	3227.85	-32.25
815	1,961,755	11,810,709	1	3233.25	3229.83	3.42
818	1,953,885	11,833,711	5	3178.15	3191.03	-12.88
820	1,946,220	11,833,307	3	3211.65	3192.28	19.37
822	1,957,779	11,812,907	3	3207.60	3202.36	5.24
824	1,942,487	11,810,564	3	3195.25	3189.30	5.95
826	1,973,944	11,812,536	5	3187.00	3190.64	-3.64
827	1,972,986	11,811,385	5	3175.00	3188.61	-13.61
t19_8	1,930,024	11,861,281	1	3224.20	3262.57	-38.37
t19_11	1,940,717	11,847,867	1	3291.00	3282.37	8.63
t19_16	1,969,849	11,853,431	1	3210.00	3232.96	-22.96
t19_17	1,969,764	11,848,119	1	3218.40	3224.93	-6.53
t19_18	1,954,123	11,840,151	1	3198.50	3202.05	-3.55
t19_14	1,961,585	11,866,627	1	3255.90	3251.19	4.71
t19_15	1,967,066	11,842,681	1	3184.60	3216.16	-31.56

Table 8-1 Calibration Statistics and Residuals for the Groundwater Model

Well Number	X (feet)[1]	Y (feet)[1]	Layer	Observed	Computed	Residual
P-14	1,998,869	11,753,483	5	3039.00	3065.64	-26.64
WIPP-28m	1,982,715	11,787,715	3	3149.00	3126.35	22.65
Residual Mean						**-5.25**
Absolute Residual Mean						**13.67**
Residual Standard Deviation						**16.71**
RMS Error						**17.51**
Min. Residual						**-54.51**
Max. Residual						**32.42**
Number of Observations						**65**
Range in Observations						**461.65**
Scaled Std. Dev.						**3.62%**
Scaled Abs. Mean						**2.96%**
Scaled RMS						**3.79%**

[1] UTM Zone 13N, NAD 1983 in units of feet.

Note: Well Number refers to **Table 7-1**.

In addition to statistics, another standard method of judging calibration quality is to plot the measured water levels versus the computed water levels. In a perfect calibration, the points would lie along a straight line at a 45-degree angle indicating that the computed water levels match the observed water levels exactly. In reality, the spread of data points about the perfect line is an overall indication of spatial bias in the model. The higher water levels in the model represent the northern portion of the model domain, while the lower water levels are found in the southern portions of the model. **Figure 8-1** shows the plot of observed versus simulated water levels for the model calibration. The plot shows that there is no large-scale bias in the calibration with each broad area having the same degree of scatter about the 45-degree line.

Assessing spatial bias at a more local scale is accomplished by plotting residual circles on maps. A residual circle is a circle drawn with the target well at its center. The size of the circle is proportional to the magnitude of the residual at the target, and the color indicates positive or negative residual. Blue circles are positive residuals and red circles are negative residuals. **Figures 8-2**, **8-3**, and **8-4** show residual circles for the Dewey Lake Red Beds (layer 1), the Magenta Dolomite (layer 3), and the Culebra Dolomite (layer 5), respectively.

In general, the residuals should be distributed in each model layer so that there is a mix of positive and negative residuals. There are some small areas of spatial bias and there is a clustering of negative residuals (red circles where model-computed water levels are too high) in layer 5 (Culebra Dolomite) in the southeastern corner of the model domain. All residuals but two in the Culebra are negative. However, the errors are all low, indicating that the spatial bias is not a significant problem. The Magenta Dolomite, the focus of the calibration, has a more uniform distribution of residuals with some spatial bias at the southern edge of the model similar to the Culebra.

The final check on the model calibration is the groundwater discharge rate leaving the model to the south. The conceptual model (see Chapter 5.0) suggests that this value should be between 200 and 400 gpm and around

300 gpm. The model predicts a flow rate of groundwater leaving the model to the south of 306 gpm. This is close to the conceptual model's projected value and indicates that the constant head boundaries are not causing an unrealistic amount of groundwater to flow through the model.

8.4 Calibrated Parameter Values

Calibration of the Groundwater Model started with homogeneous properties in each aquifer, then added heterogeneity where necessary to achieve the calibration goals. The final hydraulic conductivity distributions are shown in **Figures 8-5**, **8-6**, and **8-7** for the Dewey Lake Red Beds (layer 1), the Magenta Dolomite (layer 3), and the Culebra Dolomite (layer 5), respectively. Blue areas in these figures are the lowest hydraulic conductivity values while red represents the highest values.

The pilot point calibration technique results in a heterogeneous distribution of hydraulic conductivity values as shown in **Figures 8-5** through **8-7**. Hydraulic conductivity in the Dewey Lake Red Beds (layer 1) ranges from 0.0017 to 20.7 feet per day with a mean of 4.7 feet per day and a log-mean of 1.89 feet per day. Hydraulic conductivity in the Magenta Dolomite (layer 3) ranges from 0.00084 to 177 feet per day with a mean of 4.8 feet per day and a log-mean of 1.33 feet per day. Hydraulic conductivity in the Culebra Dolomite (layer 5) ranges from 0.000008 to 21.8 feet per day with a mean of 4.6 feet per day and a log-mean of 1.18 feet per day.

The hydraulic conductivity values for the aquifer layers are within the range of values reported for the area. In addition, specific pilot points were added to the model in the HB In-Situ Solution Mine Project area to represent the Magenta Dolomite aquifer test results performed by Shaw for Intrepid Potash. These points were not allowed to vary so that the model is assured of honoring the aquifer test results for the project wells evaluated. **Figure 8-6** shows the highest yielding Magenta test at Well IP-WW-001 as a red area of high hydraulic conductivity in the center of the figure, which is the highest hydraulic conductivity value for the Magenta Dolomite.

8.5 Calibration Summary

The calibration to target water levels in the Groundwater Model is reasonable considering the area covered by the model domain, the complexity of the geology in the Rustler Formation, and the extended time period over which available water level data was gathered. The flux out of the southern part of the model domain of 306 gpm is consistent with estimates of flow down Nash Draw to the Pecos River (Hunter 1985). The Rustler Formation has undergone salt dissolution in Clayton Basin and Nash Draw, resulting in the collapse and fracturing of the Magenta and Culebra dolomites. This has resulted in hydraulic communication between the two Rustler aquifers that is not present in Quahada Ridge, the WIPP site area, or other parts of the SPA. In addition, many older well logs simply state that they are screened in the Rustler, and this requires the modeling team to determine based on depth which member of the Rustler is screened.

The calibration for the Dewey Lake Red Beds is good considering that the Dewey Lake is not a regional aquifer, but rather a sedimentary unit that locally contains water in more permeable units. Thus, the residuals for the Dewey Lake are high in some areas and the calibration to the Dewey Lake should be considered only approximate.

The calibration to the Magenta Dolomite shows low residuals except for upper Nash Draw and just south of Section 2 in the Intrepid HB In-situ Solution Mining Project area. In upper Nash Draw, collapse of the Magenta creates problems for a precise calibration. The screened interval for the target well just south of Section 2 was uncertain. Calibration to the Culebra Dolomite had low residuals, except for the east side of upper Nash Draw. Therefore, there were only a few reliable targets for calibration in the Culebra Dolomite.

As shown in **Figure 8-5**, there is a high conductivity zone in the Dewey Lake Red Beds trending approximately north-south through the model domain. This zone may be an artifact of calibration because the Dewey Lake is not a regional aquifer. In **Figure 8-6**, the Magenta Dolomite has a uniformly low hydraulic conductivity except for Clayton Basin and upper Nash Draw. This is consistent with the findings of the USGS and Sandia for the WIPP area and upper Nash Draw (see Chapter 3.0), and the study completed by Water Management

Consultants (WMC 1999). In the Section 2 area of the HB In-Situ Solution Mine Project area, the Groundwater Model honored the measured hydraulic conductivity values for the Magenta Dolomite. As a result, a localized area of high conductivity in the Magenta was created due to the single aquifer test performed in a fault or fracture zone in Section 2 by Intrepid Postash Inc./Shaw . In **Figure 8-7**, the Culebra Dolomite shows high hydraulic conductivity in Clayton Basin and upper Nash Draw due to the collapse of the Rustler Formation in these areas. Quahada Ridge and the WIPP area have uniformly low conductivity values, consistent with the intact nature of the Culebra and the confined nature of the aquifer in the Culebra. Overall, the model calibration presents a reasonable approximation to the current understanding of the hydrology of the SPA.

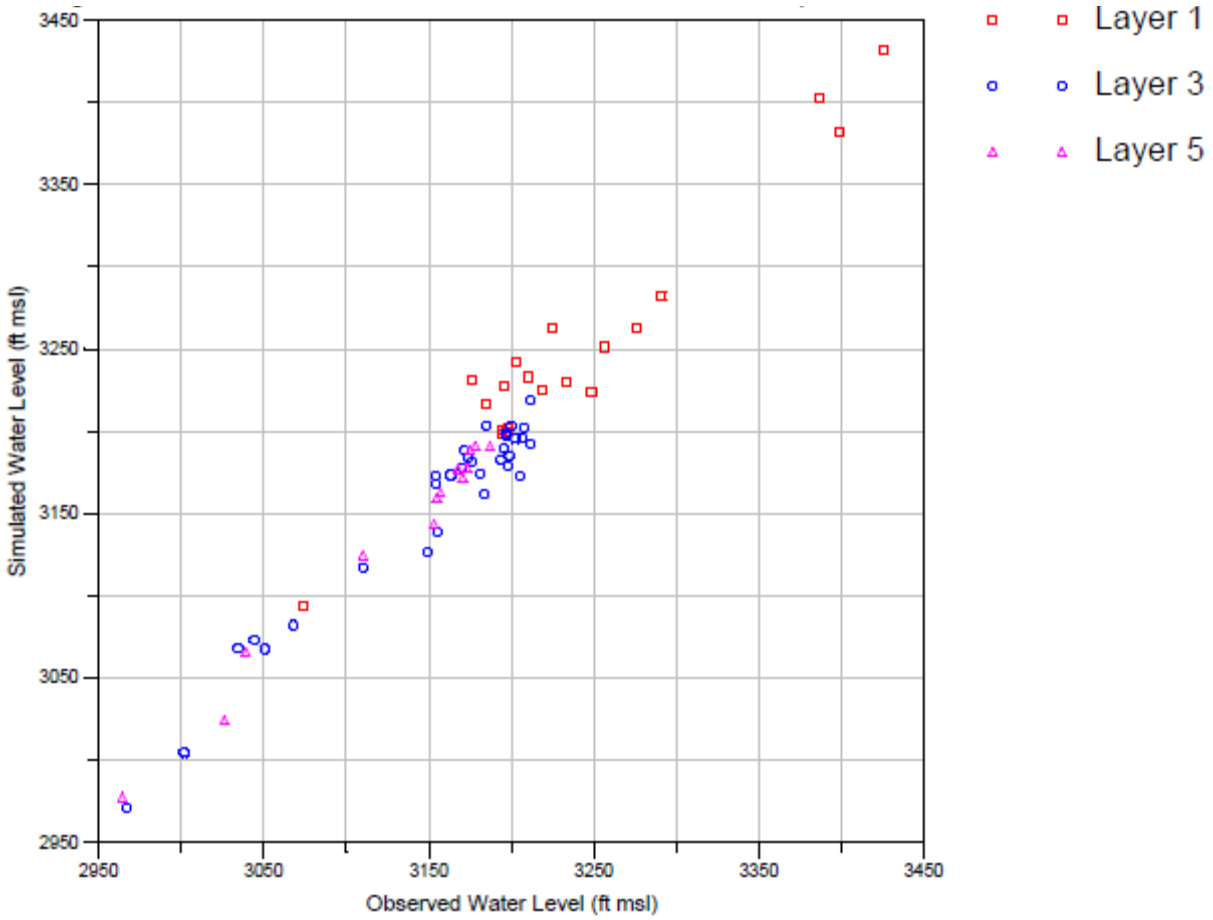


Figure 8-1 Observed Versus Simulated Water Levels in the Groundwater Model Calibration

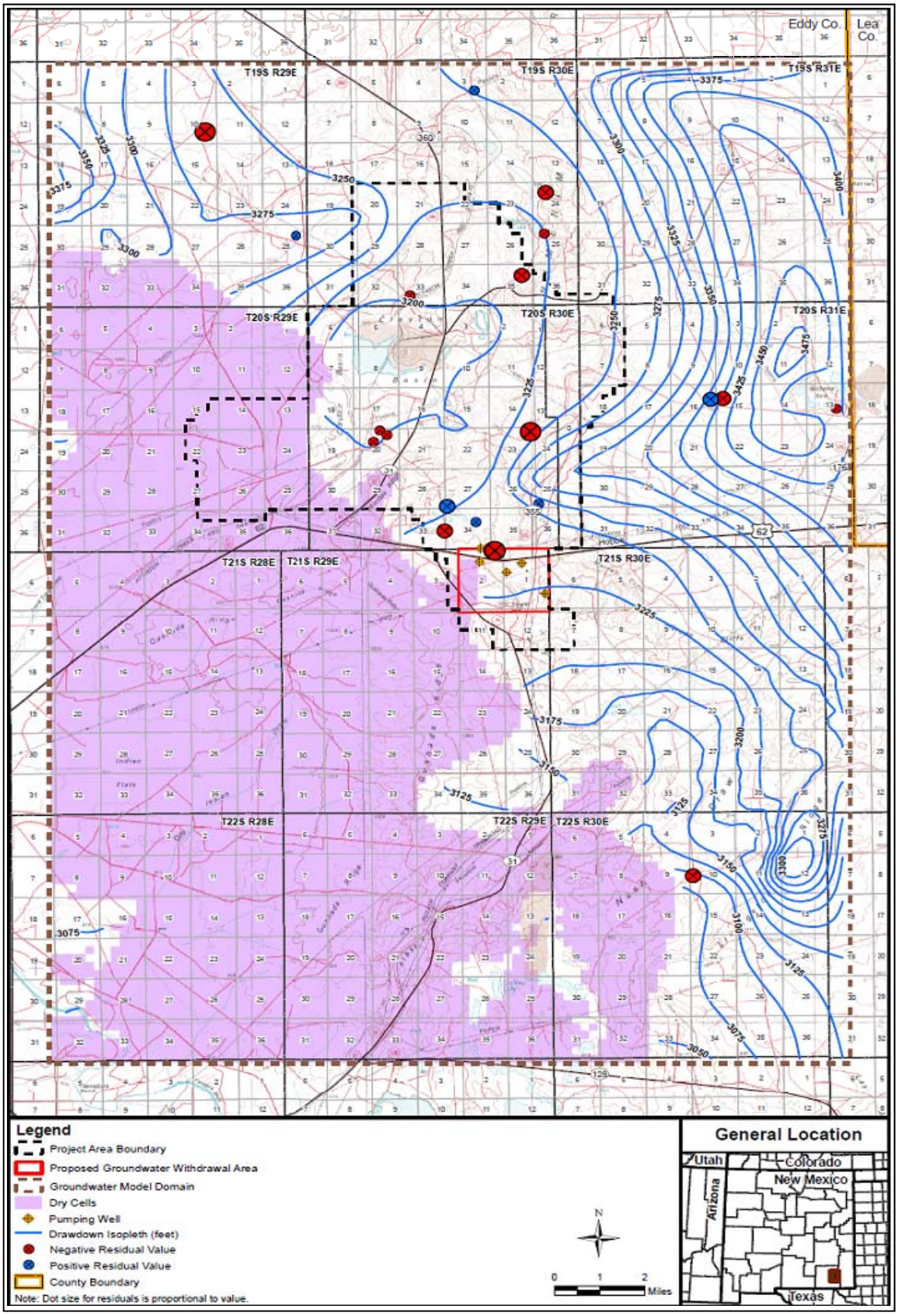


Figure 8-2 Calibration Residuals – Dewey Lake Red Beds

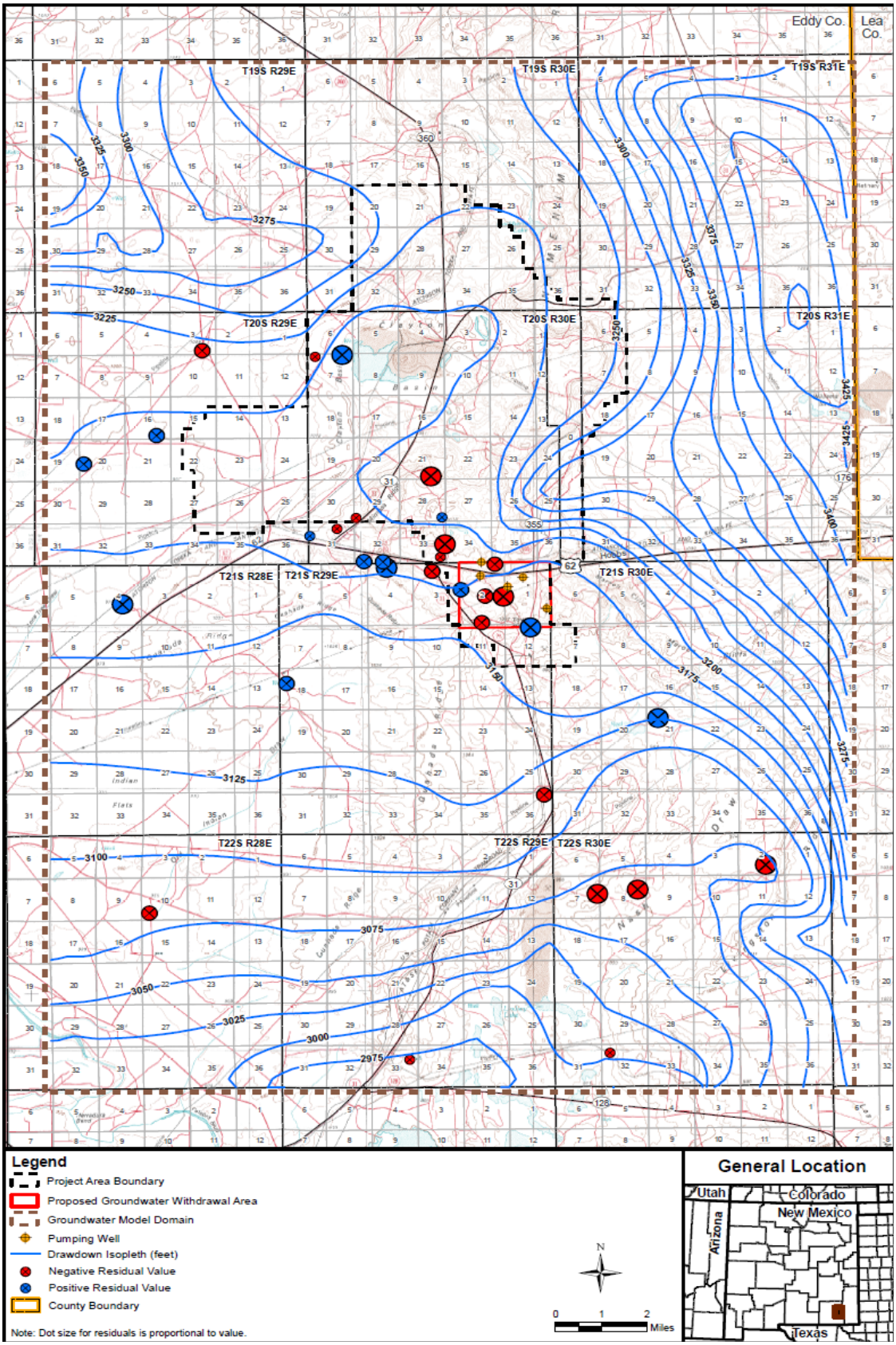


Figure 8-3 Calibration Residuals – Magenta Dolomite

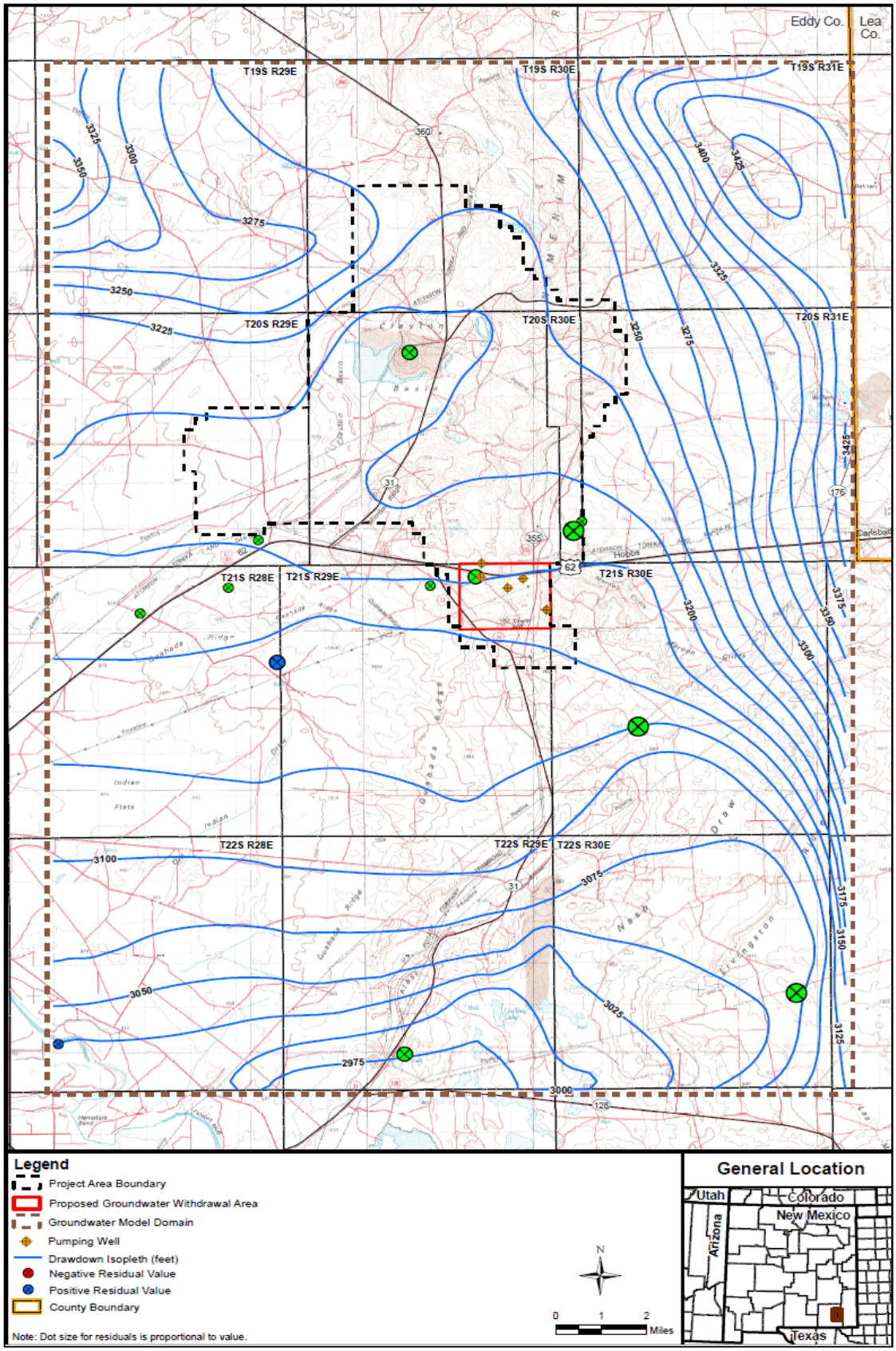


Figure 8-4 Calibration Residuals – Culebra Dolomite

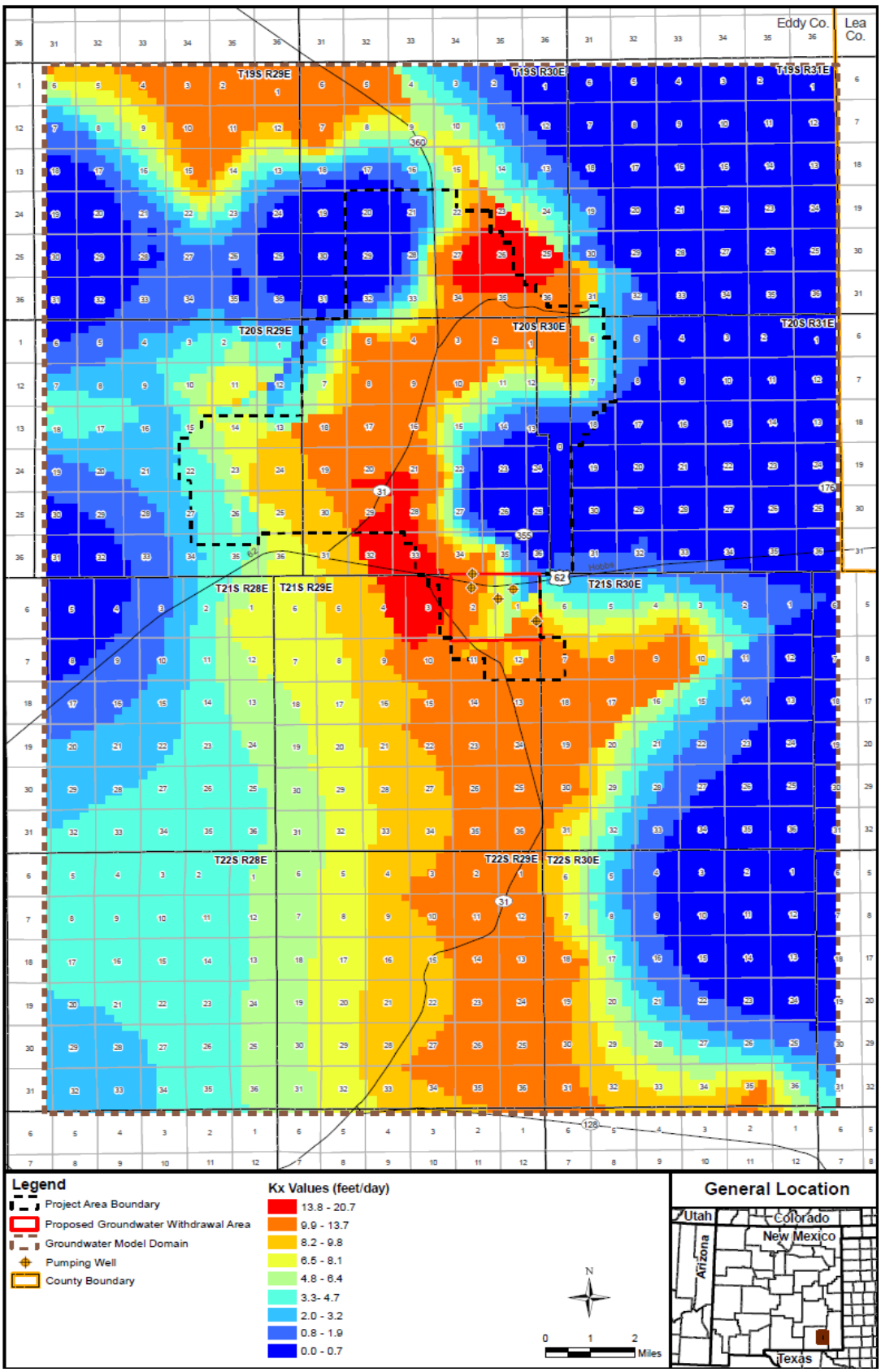


Figure 8-5 Hydraulic Conductivity Array – Dewey Lake Red Beds

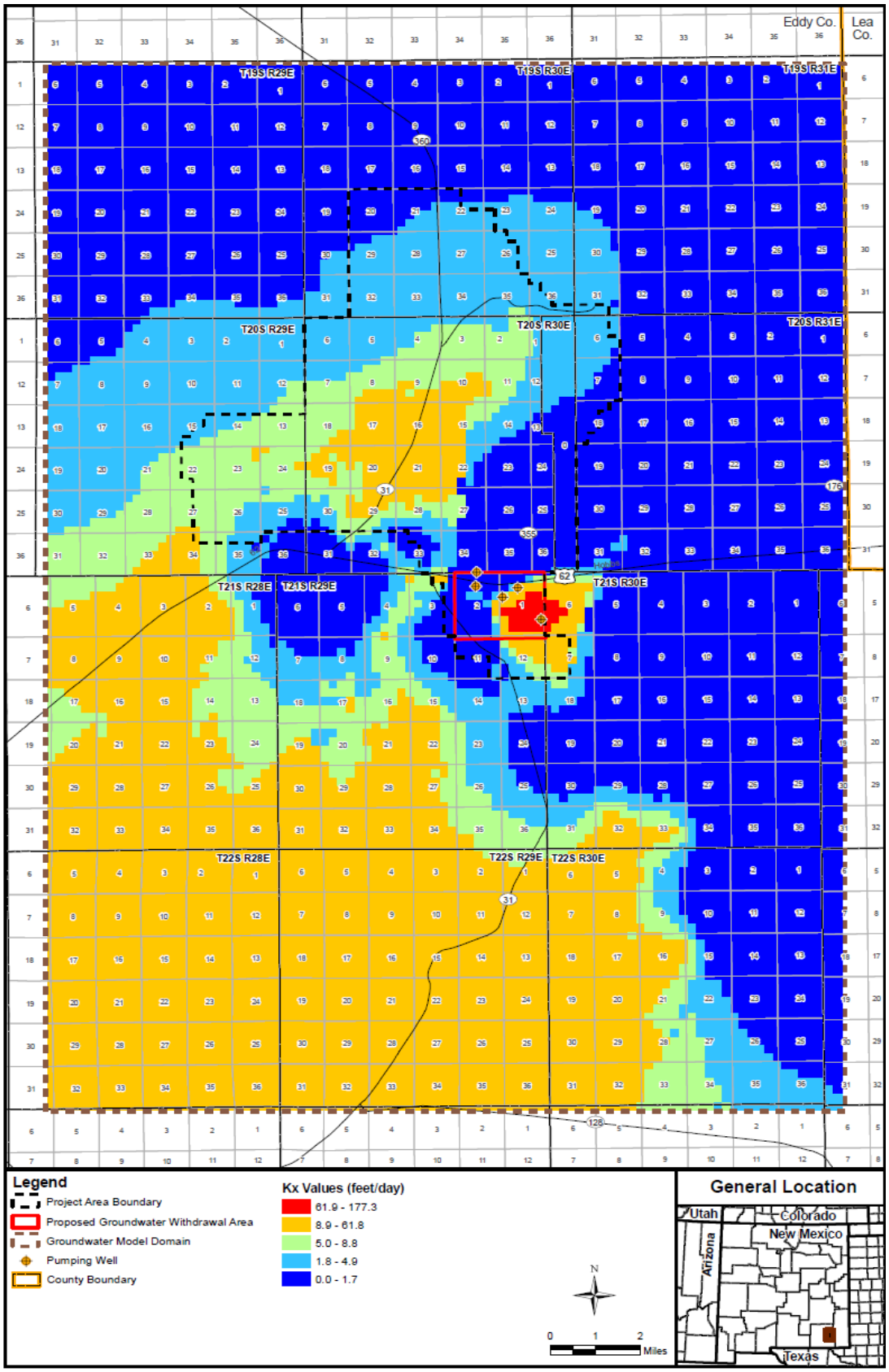


Figure 8-6 Hydraulic Conductivity Array – Magenta Dolomite

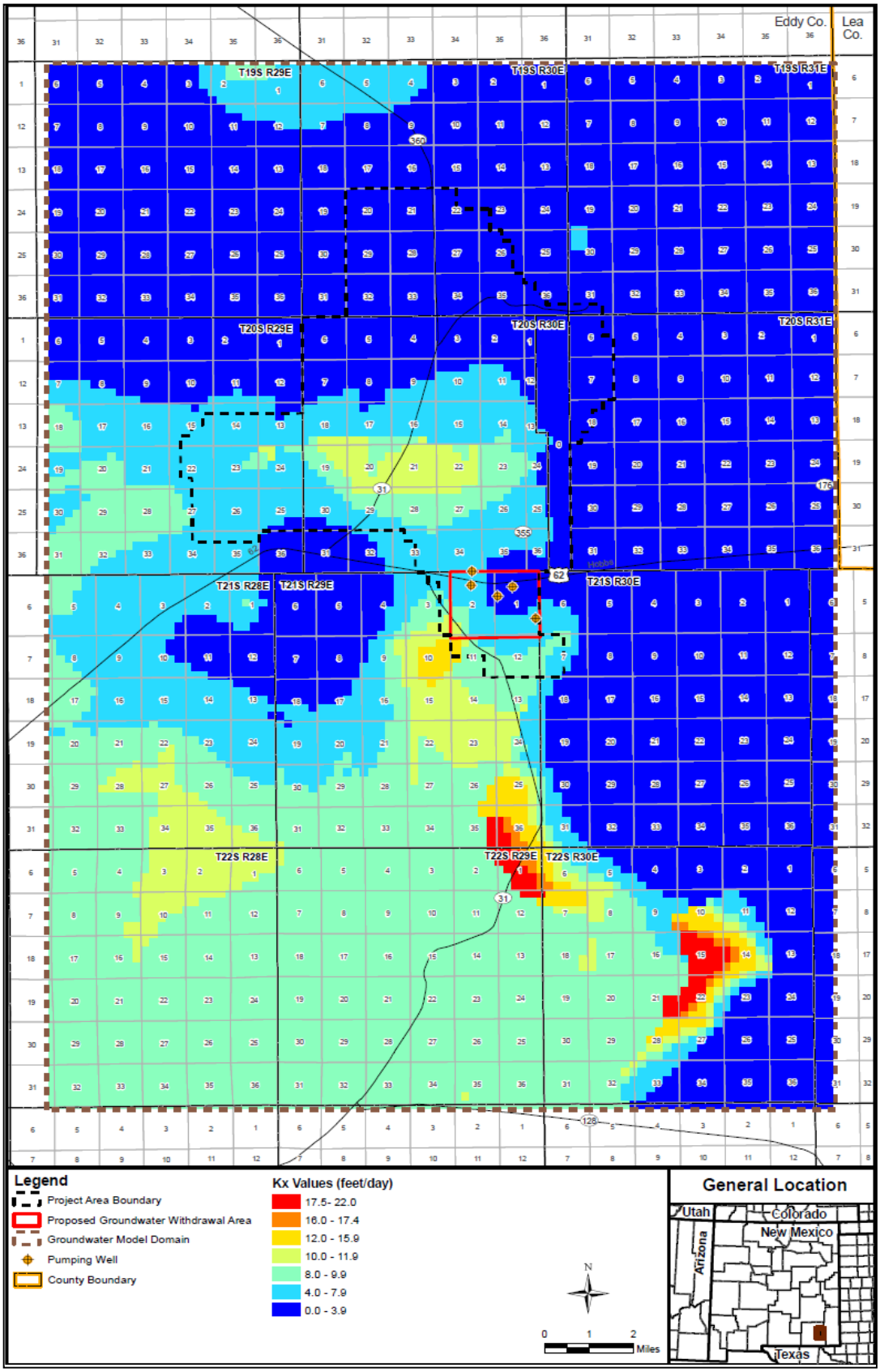


Figure 8-7 Hydraulic Conductivity Array – Culebra Dolomite

9.0 Groundwater Model Predictive Scenarios

One goal of the Groundwater Model is to provide a tool for testing proposed withdrawal of groundwater from the Rustler Formation. Four approaches were evaluated to consider the proposed withdrawal of 1,050 gpm for 22 years by the proposed HB In-Situ Solution Mine Project.

1. Modeling the 1,050 gpm with the calibrated model in a steady-state mode (1,050 gpm Model).
2. Estimation of the maximum sustainable pumping rate with the calibrated model.
3. Enhancing the calibrated model by increasing the hydraulic conductivity in the area of proposed pumpage by the HB In-Situ Solution Mine Project to the maximum defensible values, then recalibrating the model, and estimating the maximum sustainable pumping rate.
4. Using the parameter estimation code (PEST) (Doherty 2001) to determine the model parameters needed to sustain the proposed pumping of 1,050 gpm for 22 years (i.e., under steady-state conditions).

The following discussion will review these four scenarios and will show that under no conditions can the Magenta Dolomite sustain 1,050 gpm for 22 years. It should be noted that the project proposes to pump up to a maximum of 2,000 gpm during the first 7 years, then 1,054 gpm for the next 15 years. However, this higher rate was not evaluated at this stage because the results determined that the lower pumping rate could not be achieved.

9.1 Calibrated Model with 1,050 gpm in Section 2 Area

All five proposed Rustler wells located in Section 2 and the adjacent Section 1 in T21S, R29E, were run in the Groundwater Model at a total of 1,050 gpm under steady-state conditions. Because the Magenta Dolomite is currently proposed as the source of groundwater for the HB In-Situ Solution Mine Project, these wells were located in the Magenta for the model runs. When this total pumping rate was applied to the calibrated model, the water level in the Magenta Dolomite dropped below the base of the formation, indicating that the rate of 1,050 gpm is not sustainable.

9.2 Maximum Sustainable Pumping Rate in Section 2 Area Using the Calibrated Model

The next step was to use the calibrated model to determine the maximum sustainable pumping rate for the Section 2 area, (the Section 2 area is comprised of both Sections 1 and 2). This was done by setting the head in each of the five proposed pumping wells at 10 feet above the base of the Magenta Dolomite. The steady-state equilibrium pumping rate obtained was 177 gpm. The drawdown within the model domain created by pumpage at this rate is shown in **Figure 9-1**. At this pumping rate, the flow out of the southern boundary of the model is reduced by 36 gpm from current conditions, which is about 11 percent of the calibrated value of 306 gpm. Flow to the drains in layer 1 changes from 13.35 acre-feet per year to 12.26 acre-feet per year, indicating a potential reduction in spring and seep flow of about 8.1 percent. As shown in **Figure 9-1**, drawdown in the Magenta Dolomite is in excess of 100 feet in the Section 2 area and about 10 feet in the southern part of Clayton Basin. Upper Nash Draw would experience a drawdown in the Magenta of about 10 to 25 feet. A potential reduction in spring and seep flow to natural salt ponds and playas would be about 8.1 percent, probably within natural statistical variation. A decrease in flow down Nash Draw of about 11 percent is probably within the natural variation between wet and dry years.

9.3 Maximum Sustainable Pumping Rate in Section 2 Area Using the Enhanced Model

To determine what might be the maximum defensible pumping rate in the Section 2 area, the calibrated model was enhanced by raising the hydraulic conductivity of the model in the Section 2 area. The chosen values were the highest defensible values, based on previous studies and recent pumping tests performed by Intrepid

Postash Inc./Shaw for the HB In-Situ Solution Mine Project. As shown in **Figure 9-2**, a large area of hydraulic conductivity equal to 100 feet per day was added northwest of well IP-WW-001 and a large area with hydraulic conductivity of 10 feet per day was added to the Section 2 area. The value of 10 feet per day is at least 10 times what has been measured in the Magenta Dolomite in the Section 2 area. The value of 100 feet per day over a large area assumes that the fracture tested in well IP-WW-001 is part of an extensive interconnected fracture system. Both of these assumptions are not supported by field data, but to determine the maximum sustainable pumping rate, these assumptions were applied to the calibrated model.

The Enhanced Model was then calibrated. The calibration statistics for the Enhanced Model are shown in **Table 9-1**. Site wells had increased errors of 5 to 15 feet over the calibrated model. The overall residual mean increased by 2 feet and the calibration goals for the project were still met. The maximum sustainable pumping rate was 730 gpm and the drawdown created by pumping at this rate under steady-state conditions is shown in **Figure 9-3**. Flow out of the southern model domain decreased to 224 gpm, a drop of 27 percent from the original 306 gpm under the current conditions used in the calibrated model. Drawdown in the Section 2 area was 200 feet or more. Drawdown in the Magenta Dolomite in Clayton Basin was 10 feet near the center of the basin and 75 to 100 feet in the southern part of the basin. Drawdown in upper Nash Draw was 25 to 100 feet in the Magenta Dolomite. Flow to drains in layer 1 decreased from 13.35 acre-feet per year in the calibrated model to 9.28 acre-feet per year in the Enhanced Model, indicating a potential drop in flow to springs and seeps of about 30.5 percent. The decrease in flow down Nash Draw of 27 percent and the potential decrease in flow to springs, seeps, natural salt ponds, and playas of about 30.5 percent are both probably outside the expected natural statistical variation from wet to dry years.

9.4 PEST Estimation of Model Parameters needed for 1,050 gpm Pumping Rate

A final test of the calibrated model was attempted by allowing the PEST (Doherty 2001) to adjust model parameters in an attempt to calibrate to a pumping rate of 1,050 gpm at steady-state in the Section 2 area. Under this scenario, an additional calibration target was added to the model, which was the sum of the pumping rates from the five constant head cells used to simulate pumping from the Magenta Dolomite. These constant head cells maintained a head 10 feet above the base of the Magenta. The result of this test was that PEST was not able to calibrate the model with 1,050 gpm being pumped from the five wells in the Section 2 area while keeping the model calibrated to observed water levels in the target wells.

9.5 Summary

In summary, the Groundwater Model developed for the SPA demonstrates that a pumping rate of 1,050 gpm is not possible from the Magenta Dolomite member of the Rustler Formation in the Section 2 area. Even under enhanced conditions where the maximum hydraulic conductivity values that can be defended were assigned to the Section 2 area, the maximum sustainable pumping rate from the Magenta Dolomite in the Section 2 area is 730 gpm. This high pumping rate results in a reduced flow out of the southern part of the model domain of 27 percent, which may affect groundwater flow to the Pecos River. This maximum rate also may reduce flow to seeps and springs by 30 percent. Based on these model results, it may be necessary to investigate areas in or near the HB In-Situ Solution Mine Project area where the Rustler Formation has collapsed due to salt dissolution in order to obtain a sustainable pumping rate of 1,050 gpm. Areas to investigate would include Clayton Basin and Nash Draw, especially lower Nash Draw where the highest transmissivity in the Rustler Formation have been measured.

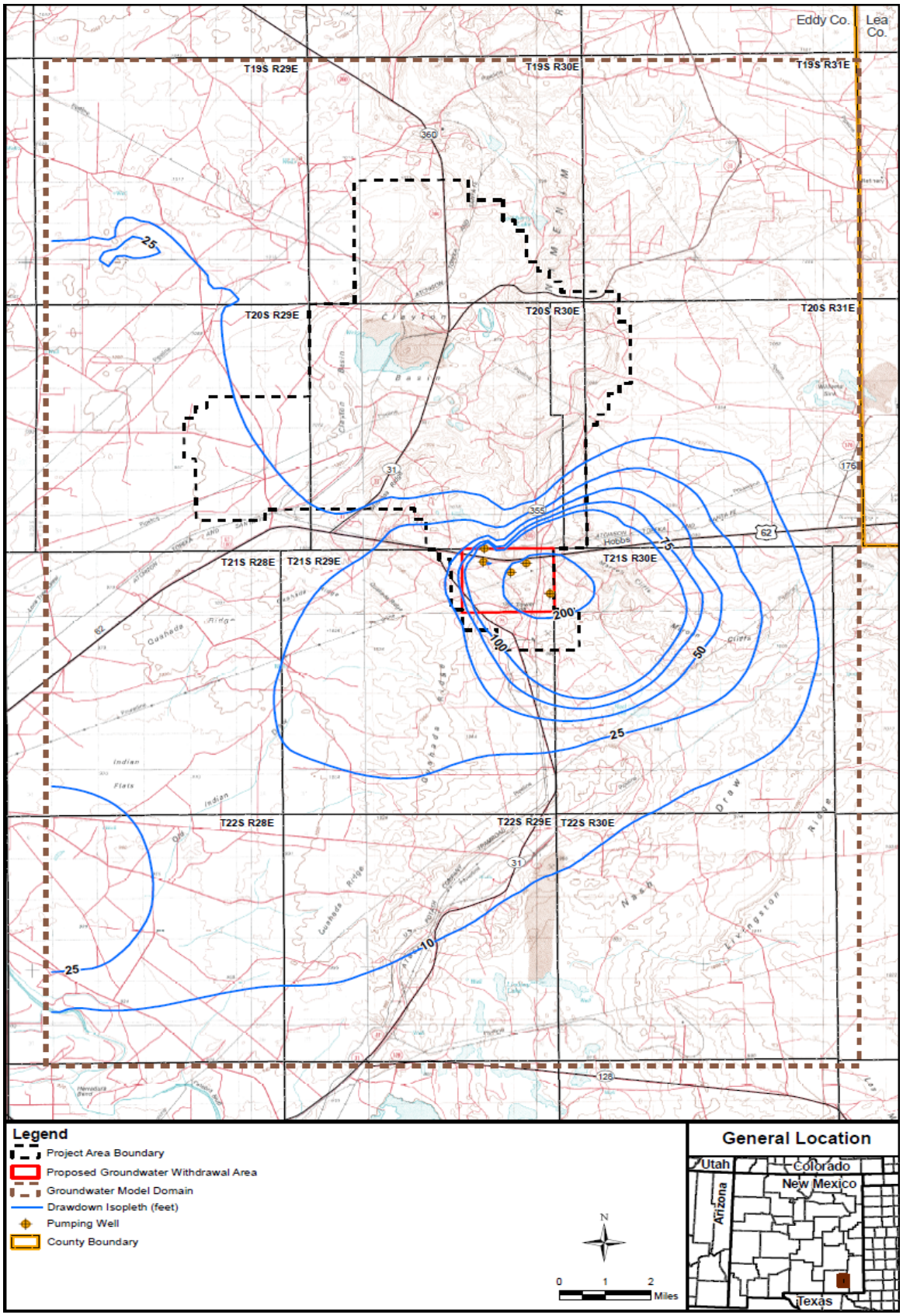


Figure 9-1 Drawdown Isopleths for Magenta in the Calibrated Model

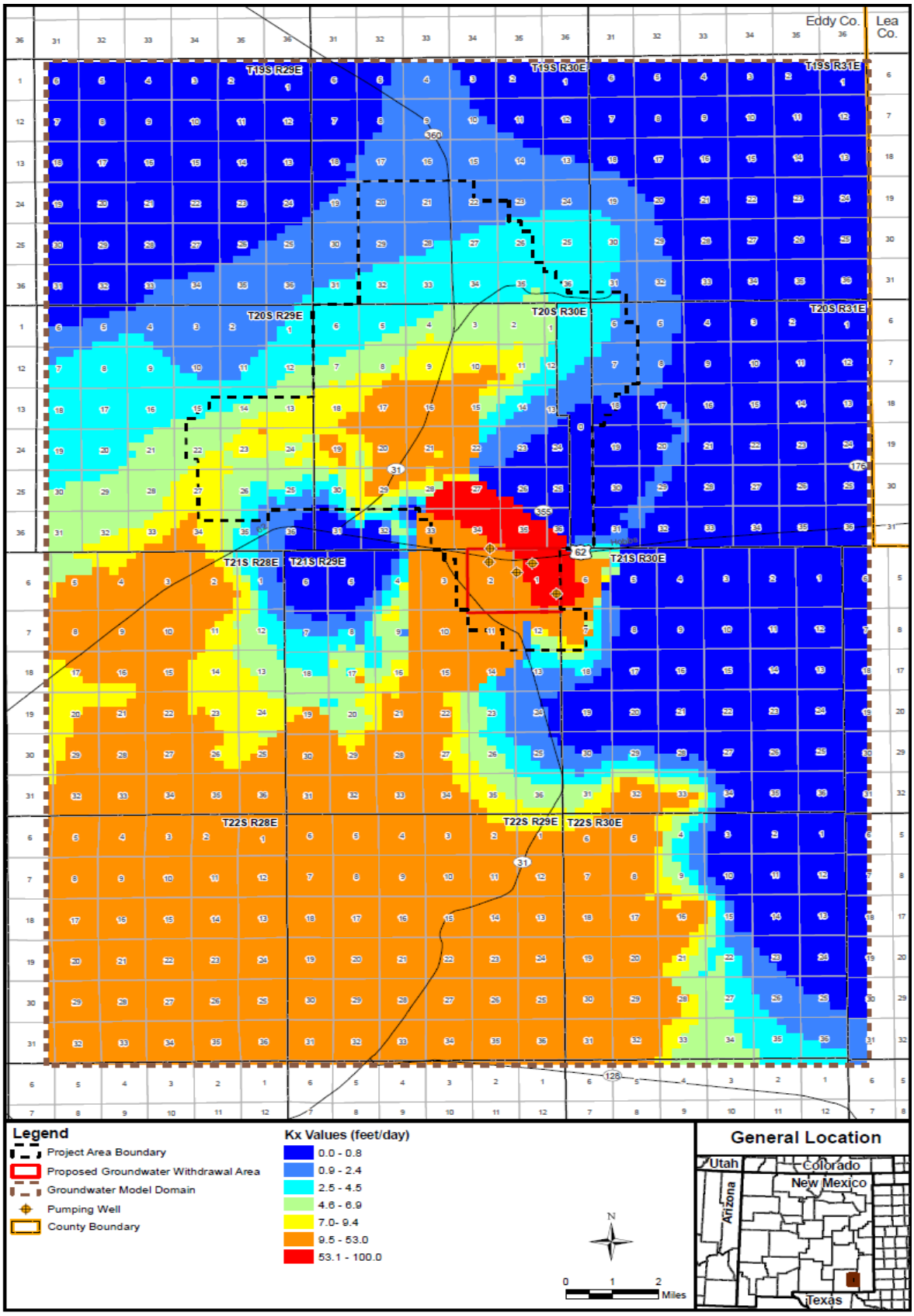


Figure 9-2 Hydraulic Conductivity Array in Enhanced Model

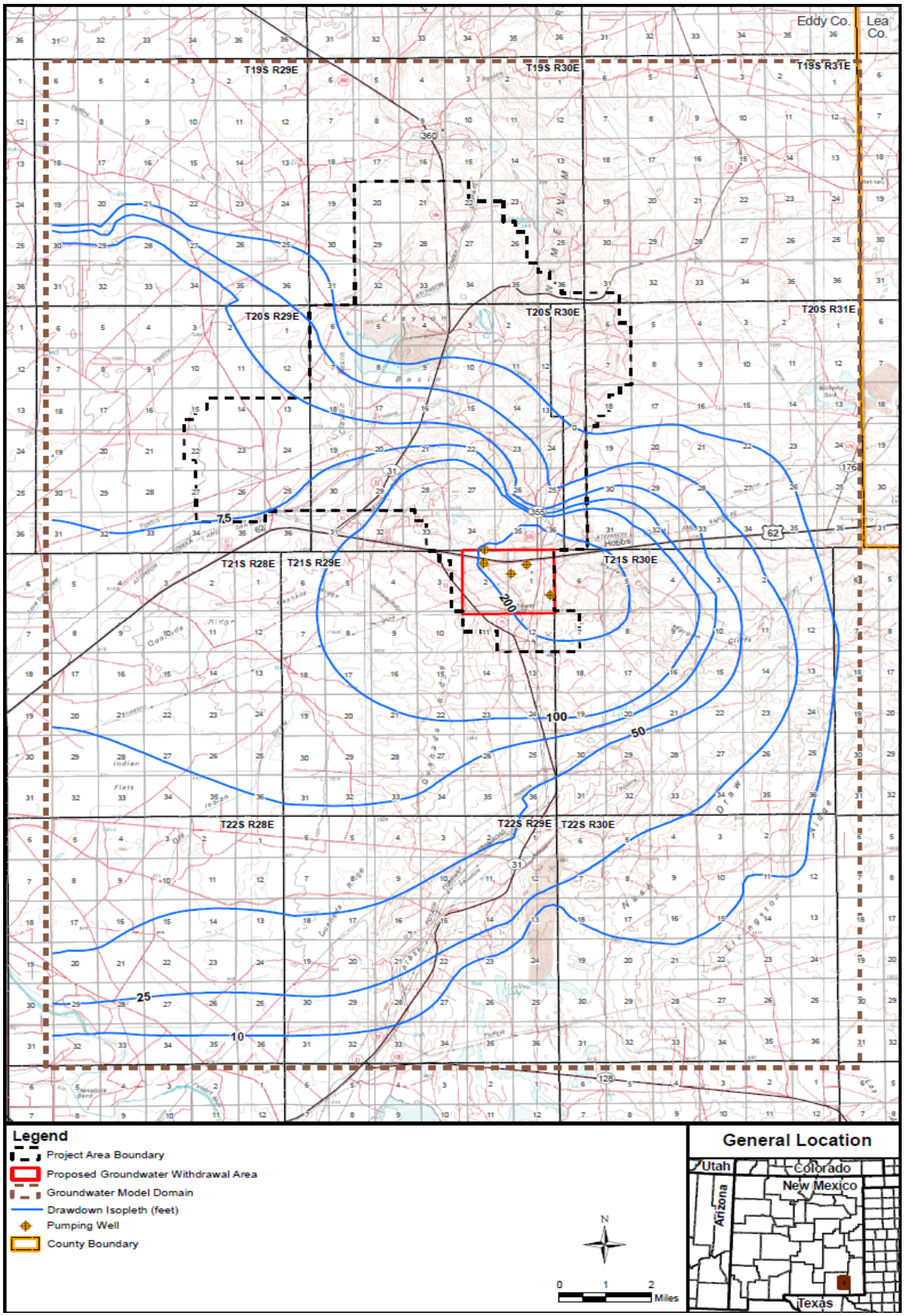


Figure 9-3 Drawdown Isopleths for Magenta in Enhanced Model

Table 9-1 Calibration Statistics and Residuals for the Enhanced Groundwater Model

Well Number	X (feet)[1]	Y (feet)[1]	Layer	Observed	Computed	Residual
27	1,924,698	11,823,150	3	3206.72	3199.04	7.68
28	1,916,289	11,819,590	3	3202.24	3199.04	3.20
31	1,929,974	11,833,825	3	3211.66	3220.85	-9.19
32	1,936,378	11,810,194	5	3173.00	3181.51	-8.51
40	1,949,820	11,821,217	1	3194.52	3198.18	-3.66
41	1,956,453	11,818,071	3	3185.00	3198.47	-13.47
46	1,945,614	11,811,470	3	3197.05	3196.42	0.63
50	1,957,582	11,807,897	3	3176.20	3186.50	-10.30
53	1,943,114	11,833,051	3	3199.76	3203.57	-3.81
54	2,003,824	11,825,499	1	3425.90	3432.06	-6.16
58	1,990,574	11,826,808	1	3386.90	3402.78	-15.88
60	1,989,127	11,826,706	1	3398.80	3382.25	16.55
61	1,938,504	11,794,859	5	3153.00	3152.10	0.90
64	1,932,904	11,804,216	5	3157.00	3168.56	-11.56
67	1,920,817	11,801,988	3	3183.76	3167.72	16.04
68	1,922,641	11,801,033	5	3154.80	3165.55	-10.75
70	1,967,989	11,799,094	3	3205.12	3186.16	18.96
73	1,939,724	11,792,011	3	3154.90	3148.04	6.86
77	1,956,555	11,806,093	3	3170.00	3183.83	-13.83
78	1,956,362	11,804,488	5	3170.50	3178.61	-8.11
79	1,951,319	11,806,581	3	3197.73	3184.39	13.34
84	1,980,495	11,786,841	5	3110.00	3131.23	-21.23
92	1,923,894	11,763,186	3	3068.00	3084.92	-16.92
99	1,913,164	11,747,067	5	3026.00	3024.20	1.80
111	1,953,307	11,745,771	5	2964.25	2978.17	-13.92
115	1,954,049	11,744,826	3	2967.00	2971.47	-4.47
118	1,987,044	11,764,987	1	3074.30	3095.28	-20.98
120	1,995,187	11,769,288	3	3044.15	3074.20	-30.05
125	1,977,205	11,745,669	3	3001.57	3004.45	-2.88
140	1,975,715	11,765,659	3	3034.30	3069.94	-35.64
143	1,980,367	11,766,188	3	3050.20	3069.50	-19.30
154	1,969,541	11,778,045	3	3110.00	3122.89	-12.89

Table 9-1 Calibration Statistics and Residuals for the Enhanced Groundwater Model

Well Number	X (feet)[1]	Y (feet)[1]	Layer	Observed	Computed	Residual
663	1,964,842	11,802,965	3	3154.01	3185.09	-31.08
668	1,961,604	11,805,591	5	3167.59	3181.19	-13.60
673	1,959,903	11,803,784	3	3181.21	3181.89	-0.68
678	1,962,724	11,803,006	3	3163.21	3183.25	-20.05
683	1,962,302	11,799,663	3	3154.27	3179.16	-24.89
688	1,963,833	11,807,005	3	3174.01	3187.69	-13.68
691	1,963,815	11,806,996	1	3176.25	3229.41	-53.16
800	1,950,571	11,822,680	1	3196.80	3198.57	-1.77
803	1,951,417	11,822,100	1	3194.60	3199.38	-4.78
804	1,968,127	11,822,533	1	3202.40	3241.69	-39.29
805	1,969,108	11,813,031	1	3275.30	3261.58	13.72
806	1,958,386	11,812,717	1	3248.50	3221.12	27.38
808	1,947,815	11,812,841	3	3196.30	3197.59	-1.29
809	1,948,691	11,807,346	3	3198.60	3188.32	10.28
811	1,950,899	11,807,293	3	3193.70	3187.00	6.70
813	1,958,091	11,809,544	3	3171.70	3189.27	-17.57
814	1,958,091	11,809,544	1	3195.60	3226.02	-30.42
815	1,961,755	11,810,709	1	3233.25	3227.98	5.27
818	1,953,885	11,833,711	5	3178.15	3190.98	-12.83
820	1,946,220	11,833,307	3	3211.65	3192.36	19.29
822	1,957,779	11,812,907	3	3207.60	3192.57	15.03
824	1,942,487	11,810,564	3	3195.25	3190.69	4.56
826	1,973,944	11,812,536	5	3187.00	3191.87	-4.87
827	1,972,986	11,811,385	5	3175.00	3190.06	-15.06
t19_8	1,930,024	11,861,281	1	3224.20	3262.58	-38.38
t19_11	1,940,717	11,847,867	1	3291.00	3282.60	8.40
t19_16	1,969,849	11,853,431	1	3210.00	3232.96	-22.96
t19_17	1,969,764	11,848,119	1	3218.40	3224.92	-6.52
t19_18	1,954,123	11,840,151	1	3198.50	3202.04	-3.54
t19_14	1,961,585	11,866,627	1	3255.90	3251.19	4.71
t19_15	1,967,066	11,842,681	1	3184.60	3216.15	-31.55
P-14	1,998,869	11,753,483	5	3039.00	3066.48	-27.48

Table 9-1 Calibration Statistics and Residuals for the Enhanced Groundwater Model

Well Number	X (feet)[1]	Y (feet)[1]	Layer	Observed	Computed	Residual
WIPP-28m	1,982,715	11,787,715	3	3149.00	3132.35	16.65
Residual Mean						**-7.55**
Absolute Residual Mean						**14.26**
Residual Standard Deviation						**16.26**
RMS Error						**17.93**
Min. Residual						**-53.16**
Max. Residual						**27.38**
Number of Observations						**65**
Range in Observations						**461.65**
Scaled Std. Dev.						**3.52%**
Scaled Abs. Mean						**3.09%**
Scaled RMS						**3.88%**

[1] UTM Zone 13N, NAD 1983 in units of feet.

Note: Well Number refers to **Table 7-1**.

10.0 Caprock Model Design and Calibration

GFLOW, version 2.1.2 (GFLOW 2007), is the analytic element model selected to evaluate the projected aquifer drawdown due to pumping on the Intrepid Caprock well field (T17S, R33-35E), Lea County, New Mexico. This chapter summarizes the resources used in establishing the baseline parameters for the calibration model, the assumed parameters, the results of recharge sensitivity, and the head calibration statistics.

10.1 Modeling Code

Models are conceptual descriptions or approximations that describe physical systems using mathematical equations; they are not exact descriptions of physical systems or processes. By mathematically representing a simplified version of a hydrogeological system, reasonable alternative scenarios can be predicted, tested, and compared. The applicability or usefulness of a model depends on how closely the mathematical equations approximate the physical system being modeled.

GFLOW is an efficient stepwise groundwater flow modeling system based on the analytic element method and operating in the Windows 95/98/NT environment. It models steady-state flow in a single heterogeneous aquifer using the Dupuit-Forchheimer assumption. While GFLOW supports some local transient and three-dimensional flow modeling, it is particularly suitable for modeling regional horizontal flow. To facilitate detailed local flow modeling, it supports a MODFLOW extract option to automatically generate MODFLOW files in a user-defined area with aquifer properties and boundary conditions provided by the GFLOW analytic element model. GFLOW also supports conjunctive surface water and groundwater modeling using stream networks with calculated baseflow. GFLOW is well documented software and readily available for use.

10.2 Model Design

The Intrepid Caprock well field model domain encompasses an area within a 10-mile radius of T17S, R34E near Buckeye, New Mexico (Caprock area). The model is two dimensional with a single layer, the Ogallala Formation. The steady-state model boundary conditions are based on USGS SIM 3044 by Anne Tillery (2008) as well as the contour calibration. Thirty-five points, also called observations, were chosen to calibrate the model area to the contours.

The model parameters were provided by the New Mexico Office of the State Engineer and literature including McAda (1984) and Musharrafieh and Chudnoff (1999). **Table 10-1** summarizes the baseline aquifer parameters.

Table 10-1 Baseline Model Constant Aquifer Parameters

PARAMETER	VALUE
Saturated Thickness	120-180 feet
Hydraulic Conductivity	15-32 feet/day
Transmissivity	3000-3200 ft^2/day
Porosity	0.2
Aquifer Recharge rate	0.49 inches/year

For steady state conditions, the aquifer storativity is not determined because hydraulic head does not change with time; therefore storativity was not included in this analysis. The aquifer bottom used in Musharrafieh and

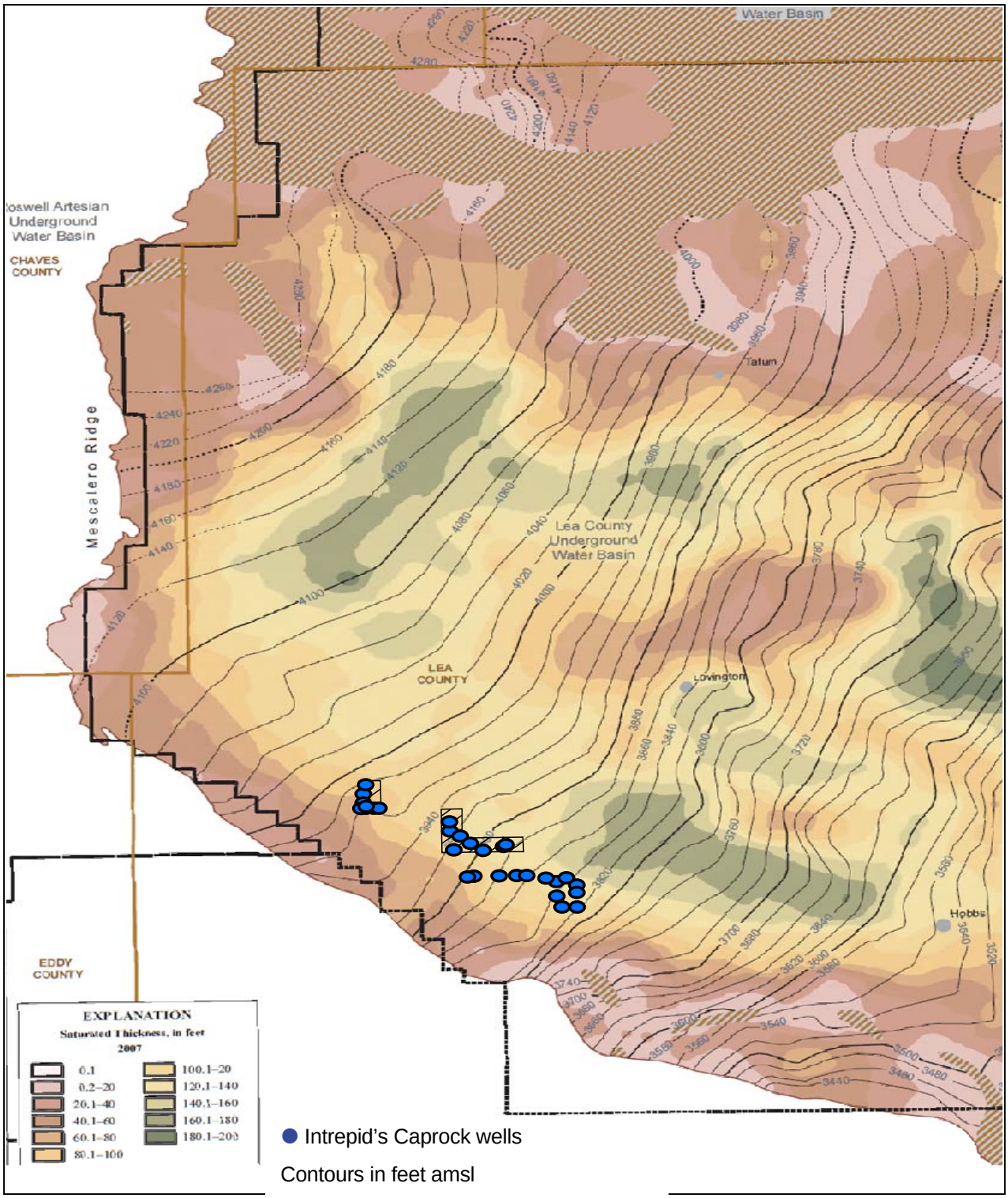
Chudnoff (1999) was discussed generally. Therefore, to generate an accurate model inhomogeneities were created for the average aquifer bottom between the contours to reflect changes in transmissivity and water levels. The inhomogeneities are depicted in Figure 10-2 by wavy lines located in the near the modeled wells. The hydraulic conductivity values generally ranged from 15 – 32 feet per day. Exceptions to this value occurred in inhomogeneity 4050 feet and 4200 feet in elevation. The hydraulic conductivity values ranged from 85 feet per day to 95 feet per day, respectively. The higher transmissivity values were included to reflect Tillery's studies (2008) and thereby create a more representative hydraulic model.

10.3 Model Calibration

The two USGS SIM 3044 figures (Tillery 2008) are shown below. **Figure 10-1** illustrates the steady state water table contours used in the model calibration. **Figure 10-2** shows the aquifer bottom contours. All the Intrepid wells are shown on the figures, however for the predictive scenario modeling, only the East Caprock and HB Well Fields (shown within the rectangular boundaries) were used (Intrepid Potash, Inc. 2010).

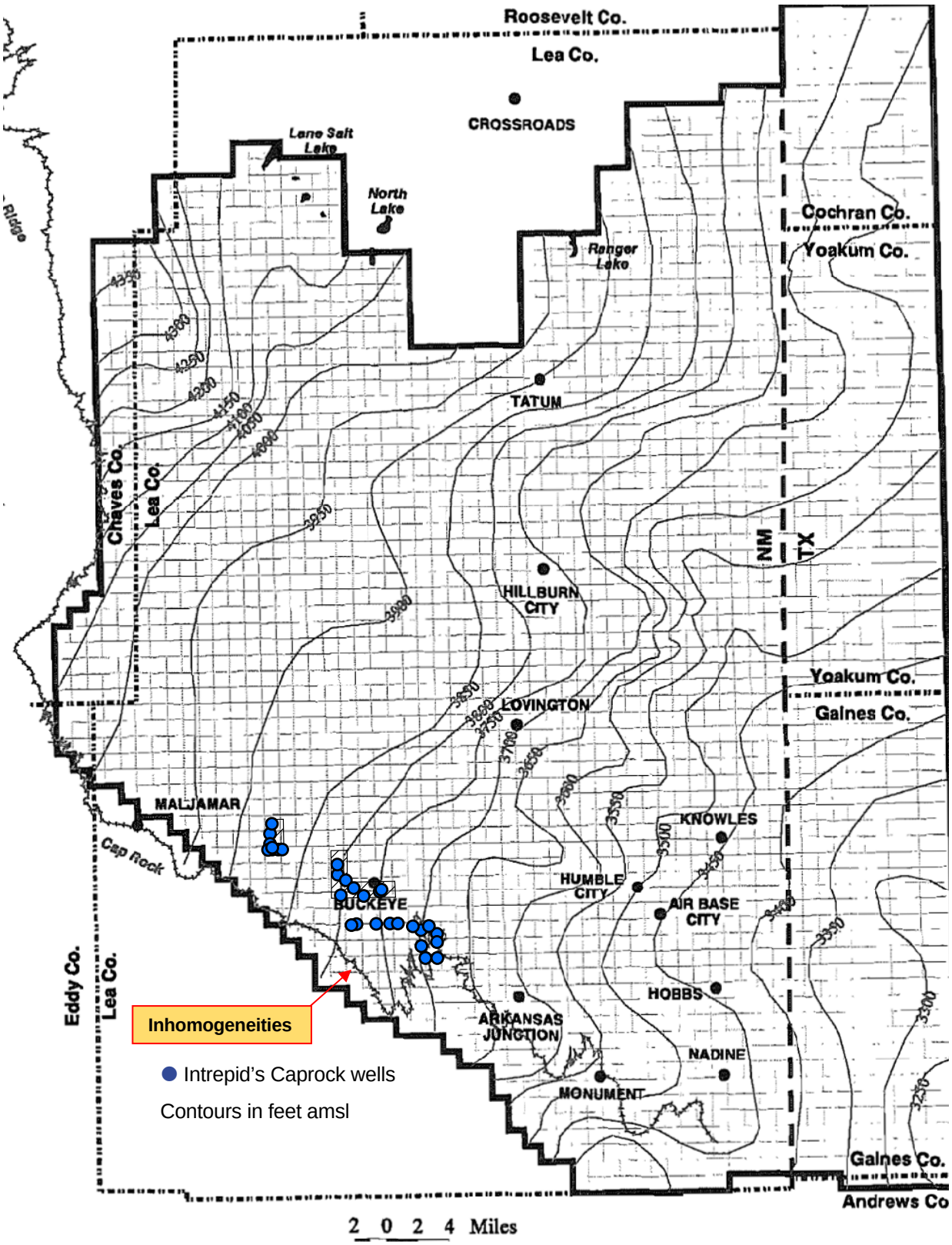
Thirty-five test points were chosen to calibrate the water table contours for the model. The no flow boundary was included from Tillery 2008. **Figure 10-3** illustrates these features.

Figure 10-4 illustrates how well the contours taken from Musharrafieh and Chudnoff (1999) match the modeled inhomogeneities.



Source: McAda 1984, Tillery 2008

Figure 10-1 Water Table Contours



Source: Musharrafieh and Chudnoff 1999

Figure 10-2 Aquifer Bottom Contours

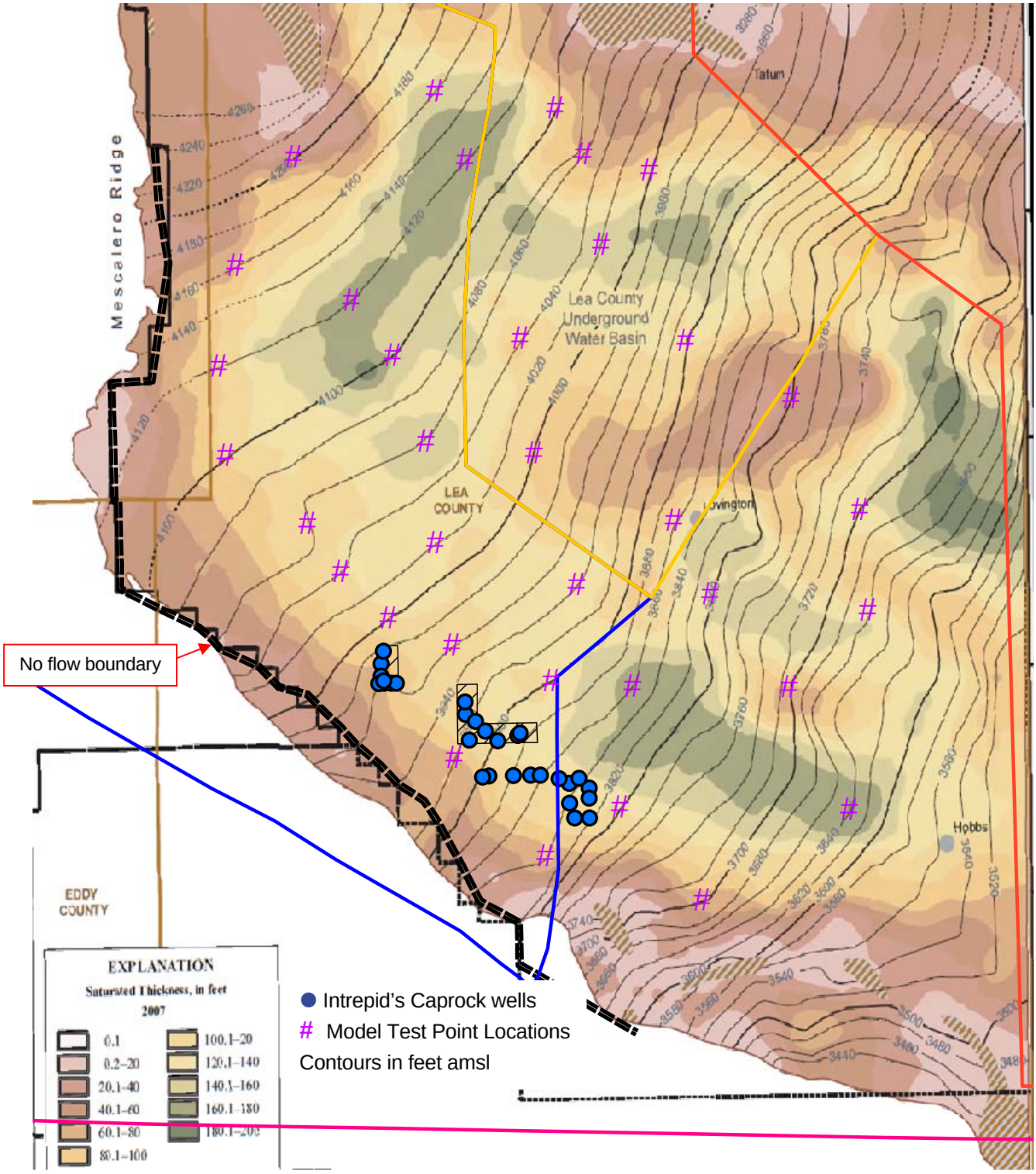


Figure 10-3 No Flow Boundary and Test Point Locations

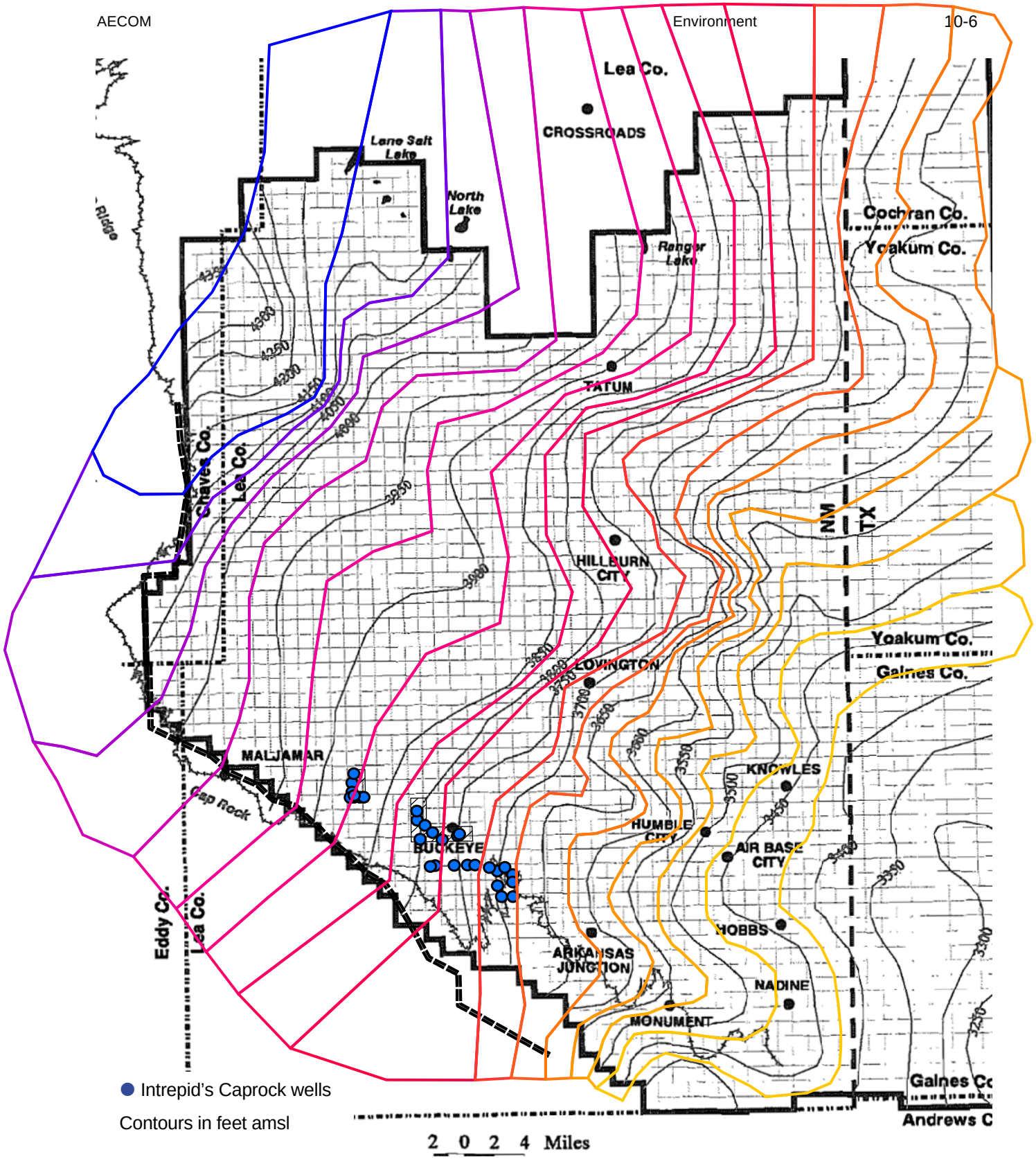


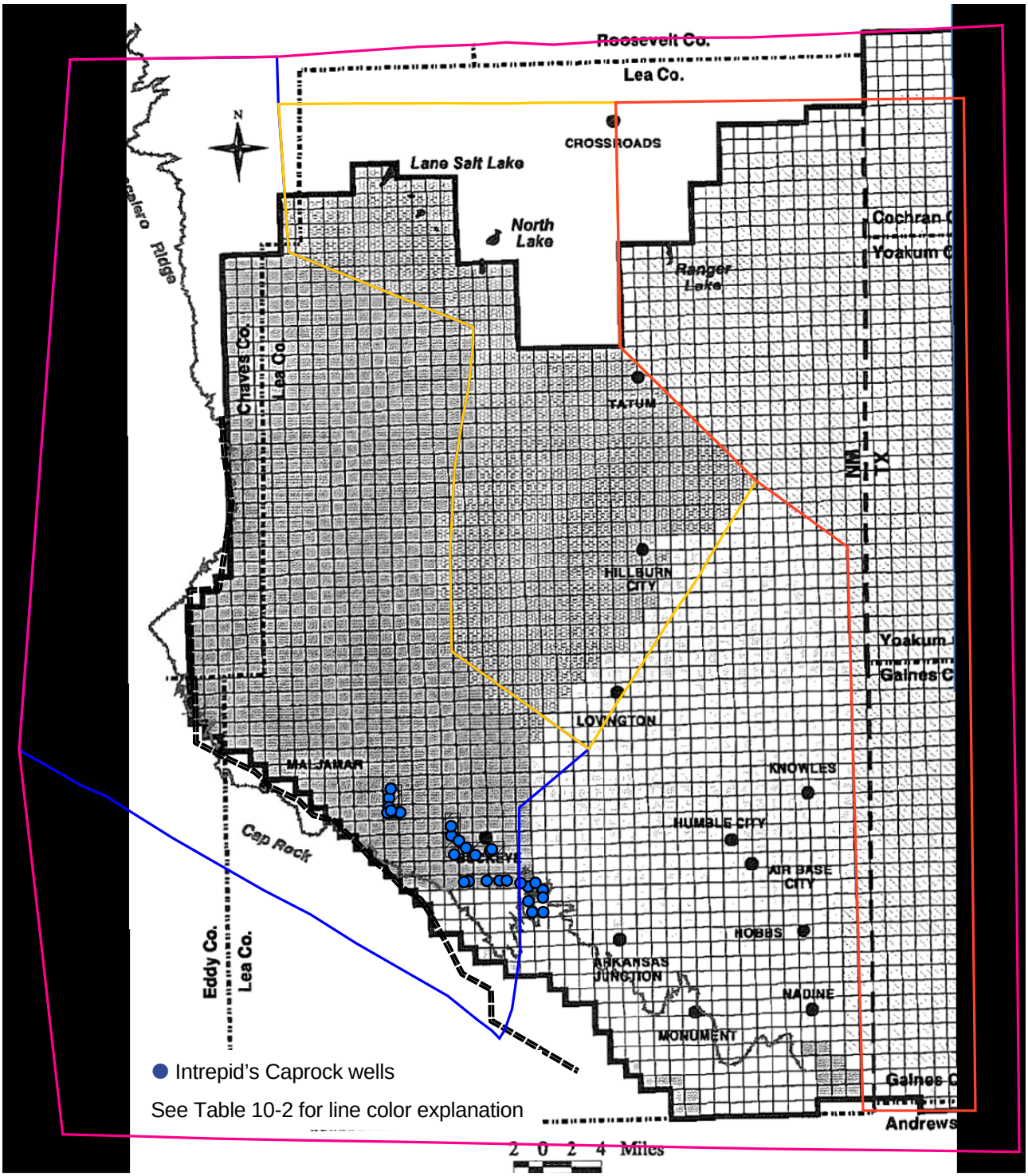
Figure 10-4 Modeled Inhomogeneities Overlaid with Aquifer Bottom Contours from Musharrafieh and Chudnoff (1999) Report

Aquifer recharge rates were compared between the values provided in Musharrafieh and Chudnoff (1999) to the modeled values. **Table 10-2** provides a comparison of these values. Higher values could be justified by studies that show aquifer recharge rates from the bottom formations to the Ogallala in areas that are not paleo-valleys. **Figure 10-5** presents the modeled aquifer recharge rates.

Table 10-2 Aquifer Recharge Rate Comparison in (ft^3/day)

Aquifer Recharge Rates	Modeled Aquifer Recharge Rate	Contour Line Color in Figure 10-5
0.000114	0.0001995	Blue
0.0001004	0.000175683	Yellow
0.0000867	0.000151725	Orange
0.0000661	0.000115675	Pink

Source: Musharrafieh and Chudnoff 1999



Source: Musharrafieh and Chudnoff 1999

Figure 10-5 Aquifer Recharge Rates

Modeled values are within the range of the New Mexico Office of the State Engineer's Musharrafieh and Chudnoff (1999) groundwater model results and fit within the accepted model calibration guideline. The model screen shot in **Figure 10-6** shows an acceptable calibration given an average difference of 17 feet and a maximum difference of 20 feet. Additionally, a calculation confirms this acceptable calibration by:

$$\frac{Mean\ Absolute\ Difference}{Head\ Difference} = 19.7 * \frac{100}{4200-3600} = 3.28\%$$

A calibration varying less than 5% is acceptable for this type of model. Additionally, the analytic element model provides its own calibration statistics.

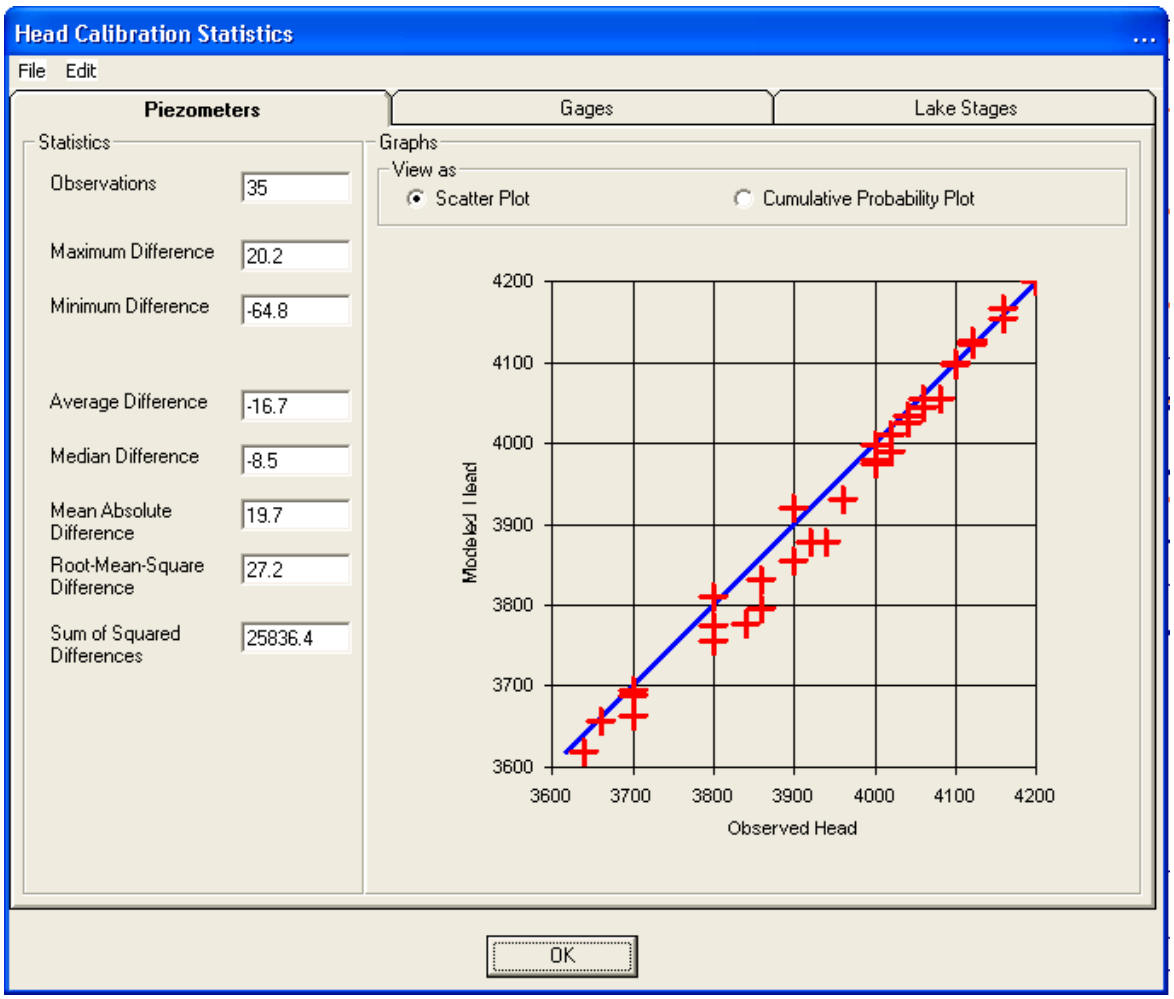
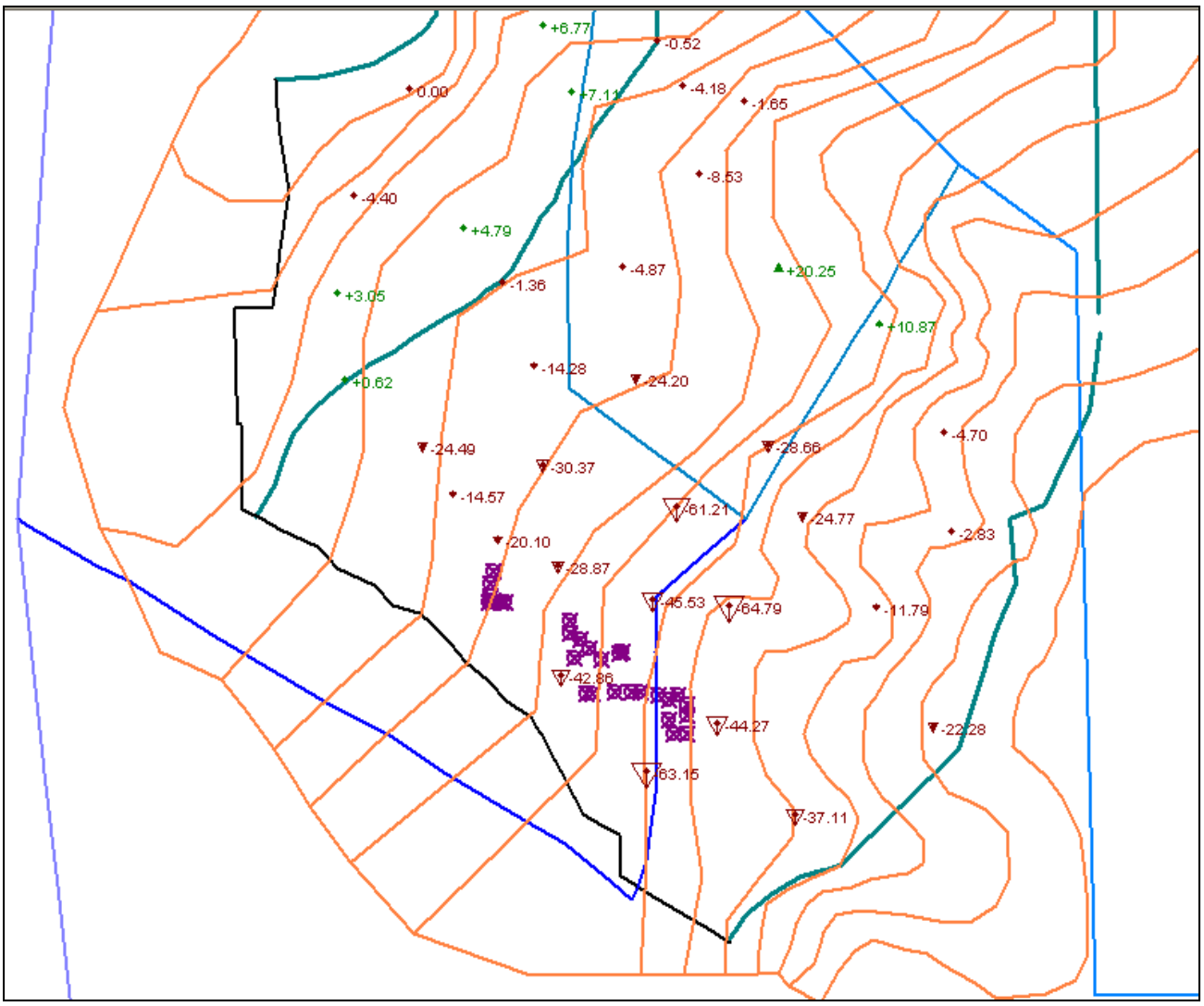


Figure 10-6 Calibration Statistics from GFLOW Model Results

The saturated thickness and transmissivity values are within an acceptable range for the Caprock East and HB Well Fields after an iterative process of refining the aquifer bottom and adjusting the hydraulic conductivity. The final calibrated model results are graphically presented in **Figure 10-7**.



Note: Purple X points are Intrepid's Caprock wells.

Figure 10-7 Calibrated Model Results

11.0 Groundwater Model Results—Proposed Action

The Proposed Action would consist of obtaining groundwater for the project from the Rustler Formation in the Section 2 area (T21S, R29E, Sections 1 and 2) and from the former Potash Corporation of America mine (PCA) area of Clayton Basin (T 20S, R 30E, Section 4) . Groundwater would be obtained in three phases:

1. Phase I (0-7 years) at maximum rate of 2,000 gpm
2. Phase II (8-21 years) at an average annual rate of 1,054 gpm
3. Phase III (22-28 years) at a rate of zero gpm from the Rustler Formation.

In addition to Phases I–III, water would be pumped from the Intrepid Caprock wells screened in the Caprock area Ogallala Formation near Buckeye in Lea County, New Mexico for use in the refinery. During Phase I, the maximum pumping rate for Ogallala Formation water would be 267 gpm. For Phase II and Phase III, the maximum pumping rate from the Ogallala would be 208 gpm.

11.1 Caprock Water

Under the Proposed Action, Caprock water would only be used for refinery operations. In Phase I, the maximum pumping rate from the Caprock wells would be 267 gpm. Phase II and Phase III would pump water at a maximum rate of 208 gpm.

An analytic element model was calibrated to water levels in Tillery (2008) and utilized data provided by the New Mexico Office of the State Engineer (Meyers 2010) and data recorded by Musharrafieh and Mustafa (1999). The water levels used for calibration from Tillery (2008) reflect pumping in the Caprock Area from existing operating wells, including Intrepid wells. Because GFLOW cannot model time-sequenced pumping from a single well, modeling of drawdown where the pumping rate changes with time requires either modeling the maximum drawdown case, or use of a time-weighted average pumping over the life of the well. For the Proposed Action, a time-weighted average of 28 years was used because the pumping rates vary from 208 to 267 gpm.

The results of pumping water from the Intrepid wells in the Ogallala Formation in the Caprock area at a time-weighted average rate of 223 gpm for 28 years are shown in **Figure 11-1.** The additional drawdown in the Caprock Area southwest of Lovington is 6-8 feet and is limited to the well field areas.

11.2 Preferred Calibrated Groundwater Model Results

The preferred calibrated groundwater model was run to obtain the maximum sustainable pumpage from both the Section 2 area and the former PCA area simultaneously. Maximum sustainable pumpage means the maximum steady state pumpage rate that can be sustained without drawing the potentiometric surface below the level of the pump in the wells. Steady-state conditions were used to estimate maximum pumpage because of the long period of projected pumping required for the project. In the Section 2 area, the maximum sustainable pumpage was 177 gpm.

Groundwater in the Section 2 area would come from the Magenta member of the Rustler Formation. The Magenta in the Section 2 area is locally fractured. The extent of the fracturing and the role of fracturing in groundwater availability are uncertain. In the preferred calibrated groundwater model for the project area**,** the Magenta has a hydraulic conductivity ranging from 0.05 feet/day to a maximum of 180 feet/day (**Figure 8-6**). The average for the Section 2 area is about 10 feet/day. The value of 180 feet/day was applied to the fractured area in the Magenta along the eastern side of the Section 2 area. Pumping in the groundwater model from the Section 2 area was distributed over 5 wells in Sections 1 and 2.

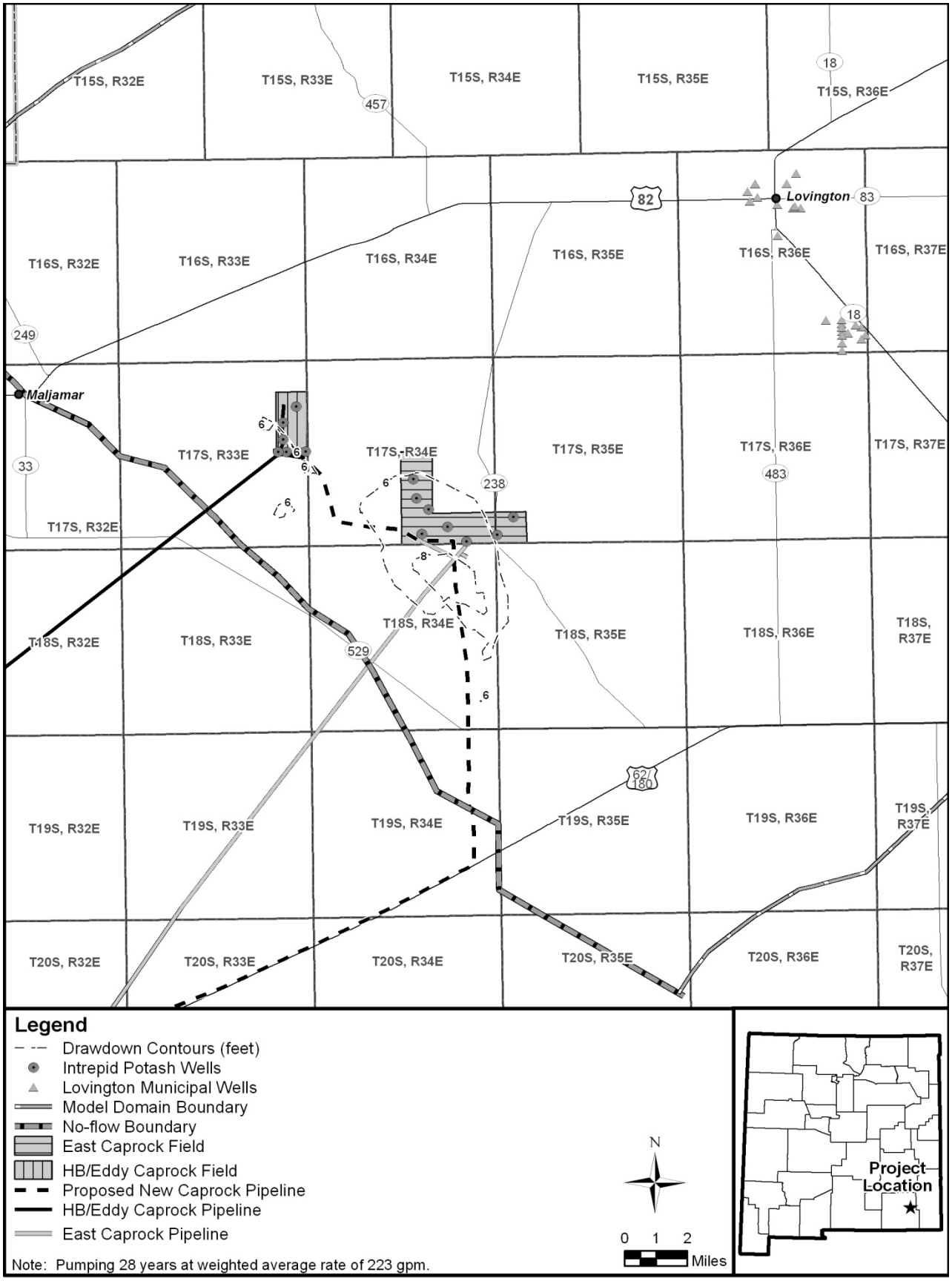


Figure 11-1 Time-weighted Average Drawdown—Proposed Action

The maximum drawdown in the Section 2 area, shown in **Figure 11-2**, was 200 feet. Drawdown of this magnitude in the Section 2 area would affect groundwater from the Magenta member of the Rustler that has a TDS of less than 10,000 mg/L, as well as the higher TDS groundwater (water quality in the Magenta is highly variable). The drawdown in the adjacent Nash Draw ranged from 75 feet on the west side to 10 feet on the east side along Livingston Ridge. The maximum sustainable pumping rate from the Section 2 area using the enhanced model is 177 gpm. For the PCA area, the maximum sustainable rate is 1,440 gpm, giving a total for both areas of the Rustler Formation of 1,617 gpm.

The former PCA area in Clayton Basin located north of the Section 2 area was assigned a transmissivity of 2,000 feet squared/day based on specific capacity tests conducted in the PCA wells during operation in the 1970's (Schowengerdt 2010). The transmissivity was the composite transmissivity over a 400-foot depth from the surface to the base of the Culebra member of the Rustler Formation. This transmissivity was assigned over a two-mile radius in the groundwater model. For the Magenta and Culebra members, the transmissivity value resulted in hydraulic conductivity values around 100 feet/day. Pumping in the groundwater model was assigned to one well screened over the entire 400 feet. In actual practice, Intrepid would probably use 2 to 3 wells screened mainly in the Magenta and Culebra members of the Rustler Formation. Because the total amount of water pumped would be the same, just distributed across two or three wells that are close together, the pumping effects would be the same as that modeled for the one well. The drawdown in Clayton Basin ranged from 75 to 150 feet. The 10-foot drawdown isopleth along the eastern boundary of the model domain near Clayton Basin reached the western edge of Williams Sink.

Flow down Nash Draw and out of the south boundary of the model domain was reduced from the calibrated value of 306 gpm to 228 gpm, a reduction of 25 percent. Flow to layer 1 in the groundwater model, which simulates flow to springs and seeps, was reduced from 3,014 gpm to 1,170 gpm, a reduction of 61 percent.

11.3 Enhanced Calibrated Groundwater Model Results

The enhanced calibrated groundwater model differs from the preferred model only in the Section 2 area and adjacent sections to the north in southern Clayton Basin. Because the role of fractures is not well understood, the enhanced model was developed to allow for the maximum possible flow of groundwater from an integrated fracture system that covers the eastern half of the Section 2 area, plus adjacent sections in southern Clayton Basin. A hydraulic conductivity value of 100 feet/day was set in the Magenta in a broad northwest-trending zone that encompasses about three square miles (see **Figure 9-2**). Surrounding this zone of high conductivity was a broad zone of conductivity averaging 10 feet/day. In all other respects, including the PCA area of Clayton Basin, the enhanced model is the same as the preferred model.

The maximum sustainable pumping rate from the Section 2 area using the enhanced model is 670 gpm. For the PCA area, the maximum sustainable rate is still 1,440 gpm, giving a total for both areas of the Rustler Formation of 2,110 gpm. Drawdown created by pumping at these rates under steady-state conditions is shown in **Figure 11-3**. The drawdown in the Section 2 area is 200 feet; drawdown in the PCA area is 100 to 150 feet. Drawdown in the Section 2 like the preferred model would include high TDS water from the Magenta and groundwater with a TDS less than 10,000 mg/L. Clayton Basin drawdown ranges from 75 to 150 feet. In Nash Draw, drawdown ranges from 100 feet on the west side to 25 feet on the east side. The 10-foot drawdown isopleth crosses Nash Draw and intersects Livingston Ridge, the eastern boundary of the model domain. In Clayton Basin, the 10-foot drawdown isopleth intersects the western part of Williams Sink. Flow down Nash Draw and out of the southern model boundary is reduced 35 percent from the calibrated value of 306 gpm to 200 gpm. Flow to springs and seeps would be reduced from 3,014 gpm to 1,085 gpm, a reduction of 64 percent.

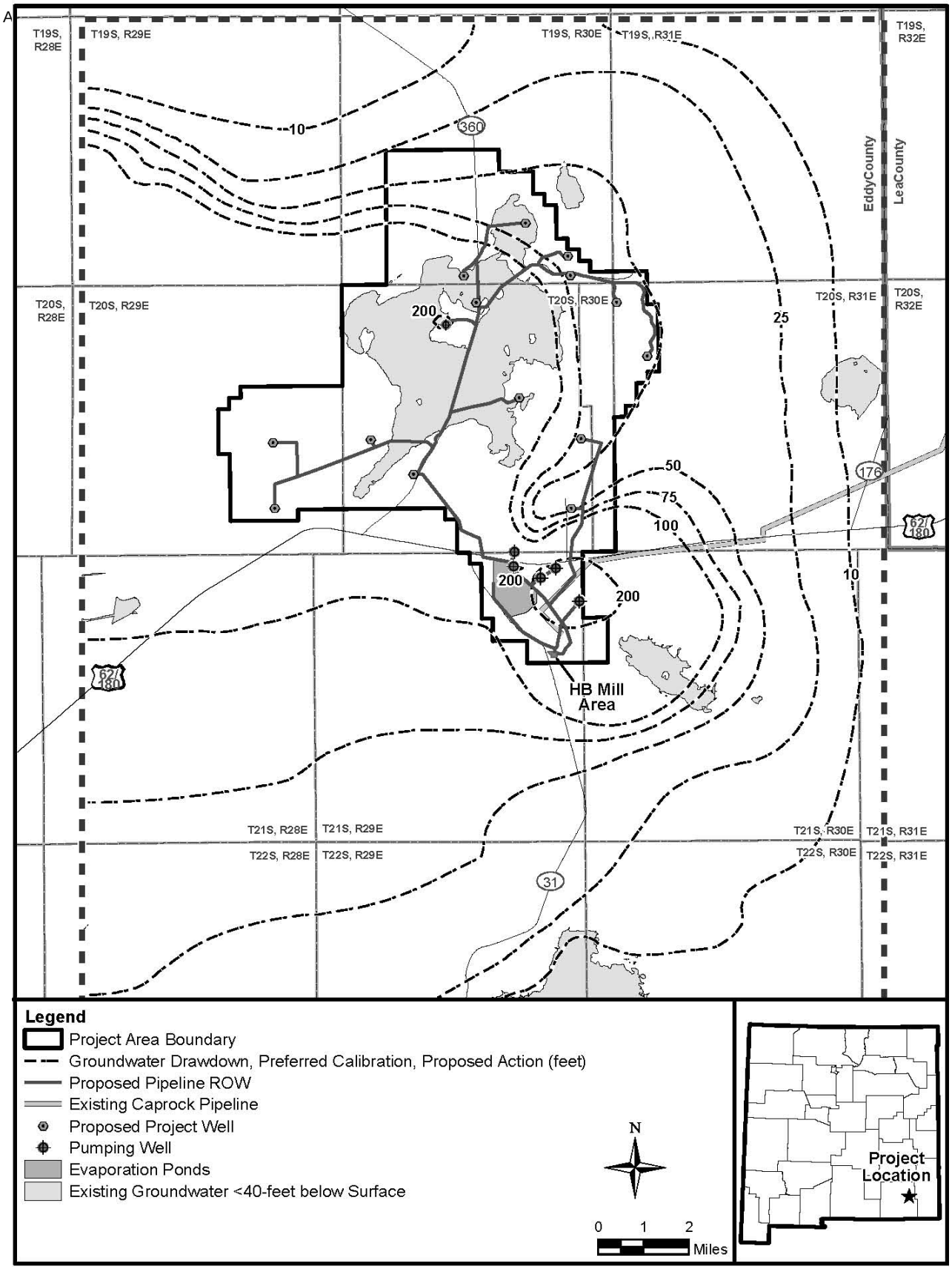


Figure 11-2 Drawdown in Preferred Model (Low Kx): Rustler Wells in Section 2 Area and PCA—Proposed Action

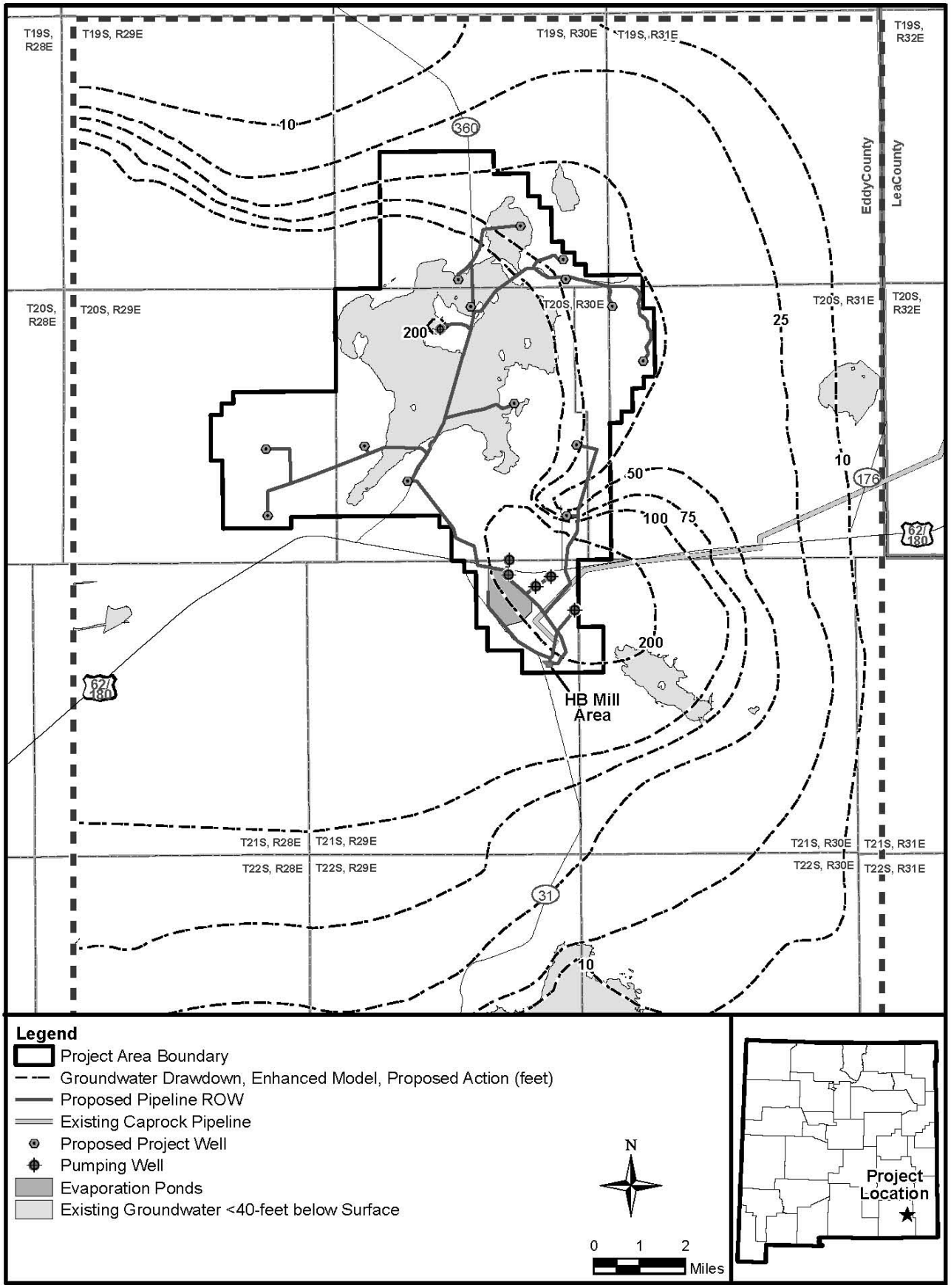


Figure 11-3 Drawdown in Enhanced Model (High Kx): Rustler Wells in Section 2 Area only—Proposed Action

11.4 Summary

The Proposed Action would permit Intrepid to obtain all water needed for injectate by pumping the Magenta and Culebra members of the Rustler Formation. Water pumped from the Rustler includes both high and low TDS water. Two areas would be used for pumping the Rustler the Section 2 area near Intrepid's current operating facilities and planned evaporation ponds, and the former PCA mine area in Clayton Basin. Using the preferred calibrated groundwater model, the estimated maximum sustainable pumpage from both areas simultaneously is around 1,600 gpm. Pumping the Rustler would lower the flow down Nash Draw towards the Pecos River and would lower flow rates to springs and seeps, mainly in the Clayton Basin area. Pumpage of the Ogallala Aquifer in the Caprock area would only be used by the refinery. The Proposed Action pumping would be in addition to Intrepid's current permitted pumping in the Caprock area.

The enhanced groundwater model allows for the maximum amount of Rustler groundwater to be pumped from the integrated fracture system in the Section 2 area. The total amount of water that could be obtained would be 2,100 gpm. Intrepid would only pump 208 to 267 gpm from its Caprock wells over the life of the mine. A greater reduction in Flow down Nash Draw towards the Pecos River would occur in the preferred model case, and flow to springs and seeps in the Clayton Basin area would also exhibit a greater reduction in flow than in the preferred model case.

Under the Proposed Action, Intrepid would obtain all water needed as injectate water from the Rustler Formation. Most of this Rustler water would come from the former PCA area in Clayton Basin. In order for Intrepid to obtain 2,000 gpm, the fracture system in the Section 2 area would have to be well integrated and capable of yielding 670 gpm for at least 7 years. If this is not the case, then Intrepid would have only around 1,500 to 1,600 gpm for injectate water during the first 7 years of mine life (Phase I). **Table 11-1** summarizes the model results for the Proposed Action.

Table 11-1 Summary of Results from Groundwater Models for the Proposed Action

	Rustler Preferred		Rustler Enhanced		Caprock	
Proposed Action	**North**	**South**	**North**	**South**	**Maximum**	**Time-Weighted**
Pumping Rate (gpm)	1,440	177	1,440	670	N/A	223
Drawdown (ft)	200	200	200	200	N/A	8

12.0 Groundwater Model Results—Alternative B

Alternative B proposes to obtain water for use as injectate water from the Rustler Formation in the Section 2 area (T 21S, R 29E, Sections 1 and 2), and from the Ogallala Formation in the Caprock area. Rustler water from the former PCA area in Clayton Basin would not be used. Recent water tests of the former PCA wells that are currently unused indicate that there are relatively high levels of lead (approximately 0.3 mg/L) in these wells (American West Analytical Laboratories 2010). As a means of comparison, the EPA identifies an action level for lead in drinking water to be 0.015 mg/L. If drinking water exceeds the action level, steps must be taken to treat the water or the system to protect human health. As under the Proposed Action, groundwater would be obtained in three phases:

1. Phase I (0-7 years) at maximum rate of 2,000 gpm
2. Phase II (8-21 years) at an average annual rate of 1,054 gpm
3. Phase III (22-28 years) at a rate of zero gpm from the Rustler Formation

In addition to Phases I – III, water would be pumped from the Intrepid Caprock wells at rates ranging from 208 to 267 gpm for use in the refinery.

12.1 Preferred Rustler Model

12.1.1 Caprock Water Model Results

The project requires 2,000 gpm for injectate water during Phase I. To supplement the 177 gpm from the Section 2 area, Intrepid would need to pump 1,823 gpm from the Ogallala Formation in the Caprock area. Water from the Ogallala Formation in the Caprock area would be in addition to the 267 gpm needed from the Ogallala for refinery water. The net pumpage from the Ogallala from the Caprock area would be 2,090 gpm For Phase II, Intrepid would need 1,054 gpm for injectate water, thus requiring pumpage of the Ogallala at a rate of 877 gpm for Phase II. In addition, Intrepid would need 208 gpm from the Ogallala for refinery water, resulting in a total pumpage from the Ogallala during Phase II of 1,085 gpm. For Phase III, only the 208 gpm would be needed from the Caprock area for refinery.

The resulting drawdown is shown in **Figure 12-1** for the case of maximum pumpage during Phase I and in **Figure 12-2** (for the time-weighted average pumping over 28 years)**.** The pumpage of 2,090 gpm for Phase I results in an additional 30-50 feet of drawdown in the Caprock area. The 10-foot drawdown isopleth extends northeast to Lovington. The time-weighted average drawdown in the Intrepid well field area is around 20 to 25 feet after 28 years. The 10-foot drawdown isopleth extends about 7 to 8 miles northeast of the well field. Time-weighted average pumping demonstrates the drawdown after 28 years of pumping and accounts for the decrease in drawdown that will occur as the pumping rate declines during Phase II and Phase III. Therefore, time-weighted average pumping (**Figure 12-2**) represents the overall impact of proposed Intrepid pumping for the duration of the mine life (28 years).

12.1.2 Preferred Rustler Calibrated Model Results

The preferred calibrated model indicates the maximum sustainable yield from the Section 2 area would be 177 gpm. The distribution of hydraulic conductivity in the Section 2 area was discussed under the Proposed Action and is shown in **Figure 8-6**. Drawdown in the Section 2 area would range from 100 feet to a maximum of 200 feet. Drawdown of this magnitude in the Magenta in the Section 2 area would be expected to include both the high TDS water and the groundwater with less than 10,000 mg/L in the Magenta. Drawdown in Nash Draw would range from 75 feet on the west side to 10 feet on the east side **Figure 12-3.** The southern part of Clayton Basin would experience about 10 feet of drawdown. Flow down Nash Draw and out of the south boundary of the model domain would be reduced to 272 gpm from the calibrated value of 306 gpm, a reduction of 11 percent. Flow to springs and seeps would be reduced from 3,014 gpm to 2,790 gpm, a reduction of 7.4 percent. Both of these flow reductions are within the statistical fluctuation of flows and thus would not be measurable.

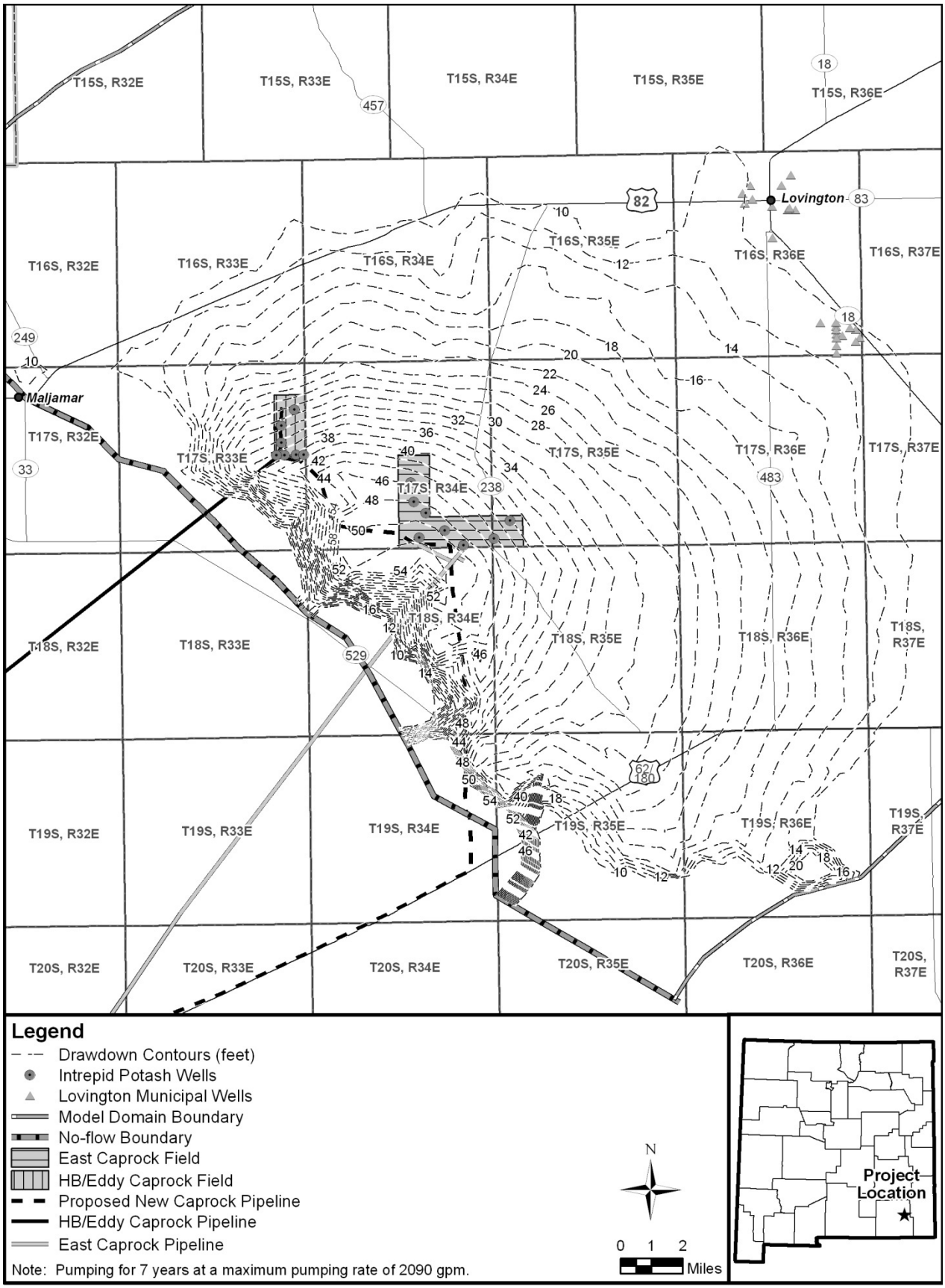


Figure 12-1 Maximum Drawdown in Preferred Model: Caprock Wells, Years 0 – 7—Alternative B

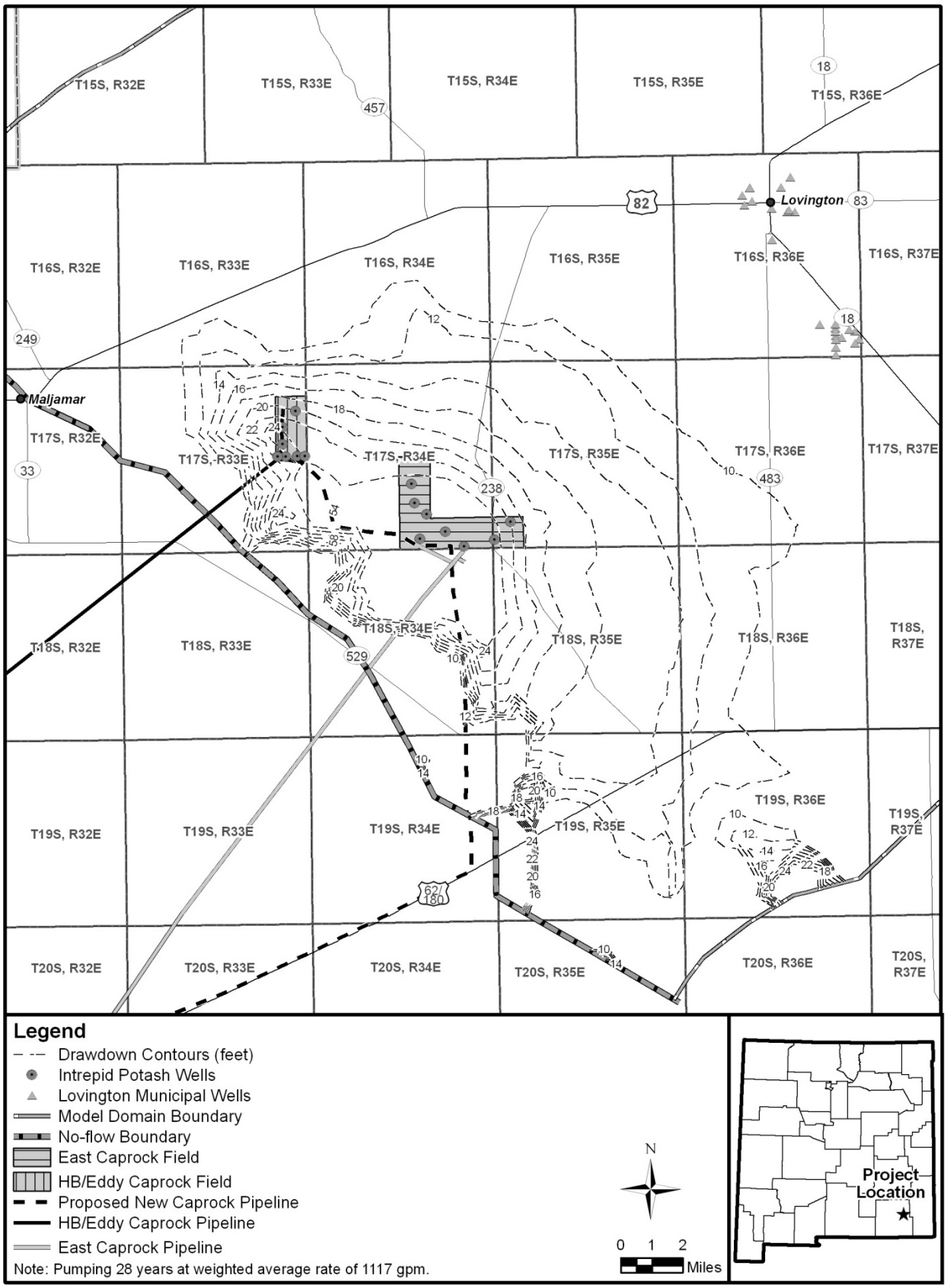


Figure 12-2 Drawdown in Preferred Model: Caprock Wells Time-Weighted Average Pumping Case—Alternative B

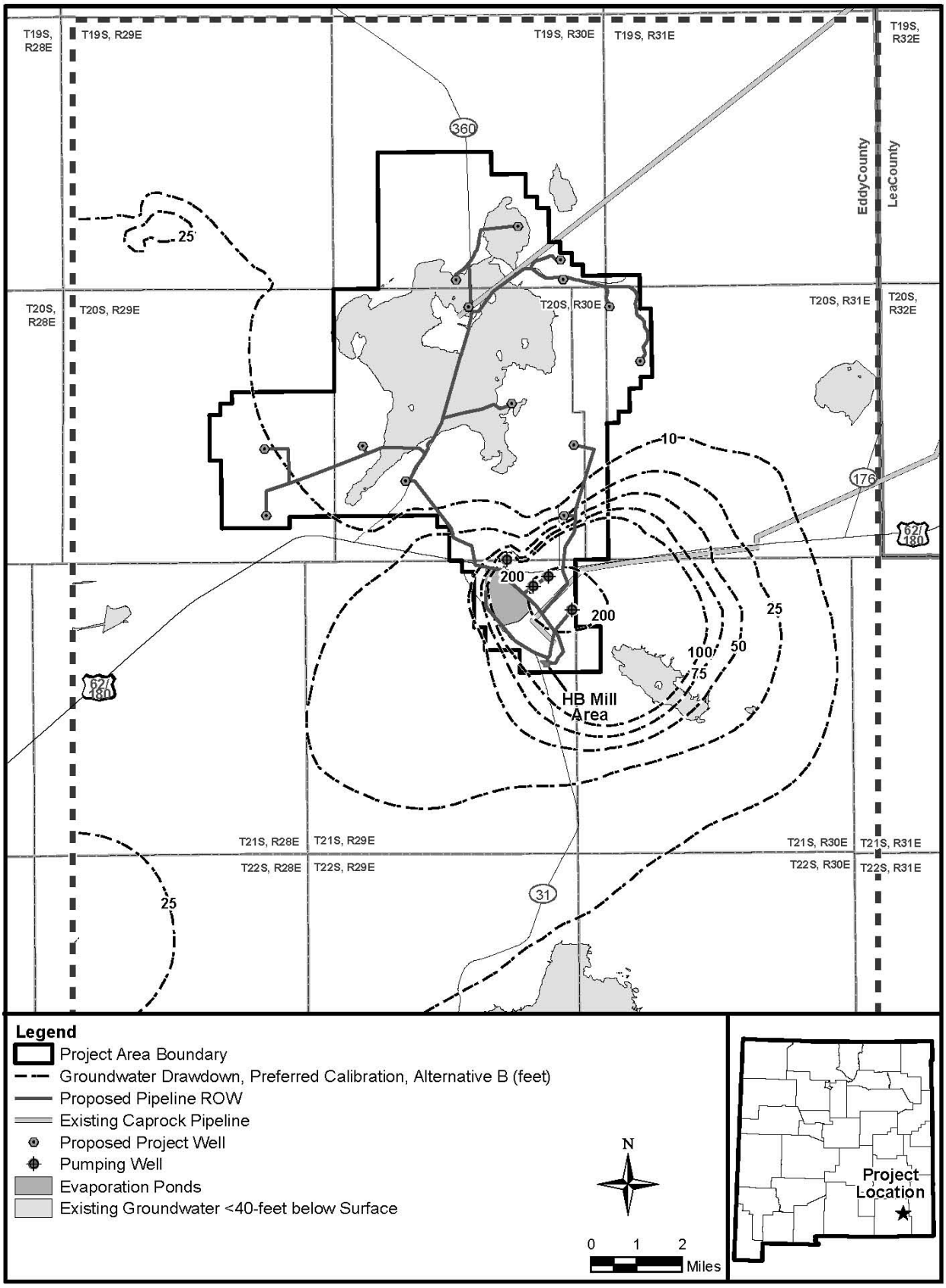


Figure 12-3 Drawdown in Preferred Model (Low Kx): Rustler Wells in Section 2 Area only—Alternative B

12.2 Enhanced Rustler Model

12.2.1 Caprock Water Model Results

The project requires 2,000 gpm for injectate water during Phase I. To supplement the 670 gpm from the Section 2 area, Intrepid would need to pump 1,330 gpm from the Ogallala Formation in the Caprock area. This would be in addition to the 267 gpm needed from the Ogallala for refinery water, resulting in a net pumpage from the Ogallala at Caprock of 1,579 gpm during Phase I. For Phase II, Intrepid would need 1,054 gpm for injectate water, thus requiring pumpage of the Ogallala at a rate of 384 gpm for Phase II. In addition, Intrepid would need 208 gpm from the Ogallala for refinery water, resulting in a total pumpage from the Ogallala during Phase II of 592 gpm. For Phase III, only the 208 gpm for refinery water would be needed from the Caprock area.

Pumpage of the Ogallala at Caprock at a rate of 1,597 gpm for Phase I, then at a rate of 592 gpm for Phase II, and finally at a rate of 208 gpm for Phase III was modeled using the analytic element model discussed under the Proposed Action. The resulting maximum drawdown at the end of Phase I is shown in **Figure 12-4.** The time-weighted average pumping case drawdown after 28 years is shown in **Figure 12-5**. For the pumping of 1,579 gpm for 7 years, the additional drawdown in the Caprock area is 30 to 36 feet. The 10-foot drawdown isopleths extends almost to the town of Lovington. Time-weighted average demonstrates the additional drawdown is a maximum of 15 to 20 feet and the 10-foot drawdown isopleth extends about 5 miles to the northeast of the Caprock well fields.

12.2.2 Enhanced Rustler Calibrated Model Results

Using the enhanced model, the maximum sustainable pumpage rate for the Section 2 area would be 670 gpm. The enhanced model is discussed under the Proposed Action. The hydraulic conductivity distribution for the enhanced model is shown in **Figure 9-2**. Drawdown in the Section 2 area would be 200 feet, as shown in **Figure 12-6**. Both the high TDS groundwater and groundwater with less than 10,000 mg/L in the Magenta would be affected by this drawdown. Nash Draw would experience 100 feet of drawdown along the west side and 25 feet of drawdown along the east side. The 10-foot drawdown isopleth would extend into Livingston Ridge. Flow down Nash Draw and out of the southern model boundary would be reduced from 306 gpm to 228 gpm, a reduction of 25 percent. Flow to springs and seeps, would be reduced from 3,014 gpm to 2,070 gpm, a reduction of 31 percent.

12.3 Caprock Only Water Pumping Scenario

The Rustler Formation in the Section 2 area and in the former PCA area may not be able to provide all or even most of the injectate water needed by Intrepid for its proposed solution mining. The degree of fracturing in the Section 2 area is uncertain and the present capacity of wells in the former PCA area has not been evaluated. Thus, Intrepid may find that the only reliable long-term source of water would be from their permitted wells in the Ogallala Formation in the Caprock area.

If Intrepid decides to obtain all injectate water from the Caprock area, they would need to pump 2,000 gpm for Phase I, 1054 gpm for Phase II, and 208 gpm for (Phase III. In addition, during Phase I, Intrepid would need an additional 267 gpm for refinery water. The additional refinery water would increase total pumpage to 2,267 gpm. During Phase II, Intrepid would need 208 gpm for refinery water, resulting in a total pumpage of 1,262 gpm. Phase III would only require the 208 gpm for refinery water.

Two cases were modeled for the Caprock Only Water Scenario: maximum pumping impacts which occur at year 7 during Phase I with a pumping rate of 2,267 gpm for 7 years and time-weighted average pumping over 28 years, which provides an estimate of the impact to the Ogallala Formation at year 28 with a time-weighted average pumping rate of 1,249 gpm. The corresponding results are shown in **Figure 12-7** and **Figure 12-8**, respectively. For the first scenario, the additional drawdown in the Caprock area is a maximum of 50 to 60 feet and the 10-foot drawdown isopleth reaches into the northern part of Lovington. For the time-weighted average scenario, the additional maximum drawdown is 30 to 34 feet and the 10-foot drawdown isopleth extends about 10 miles northeast toward Lovington.

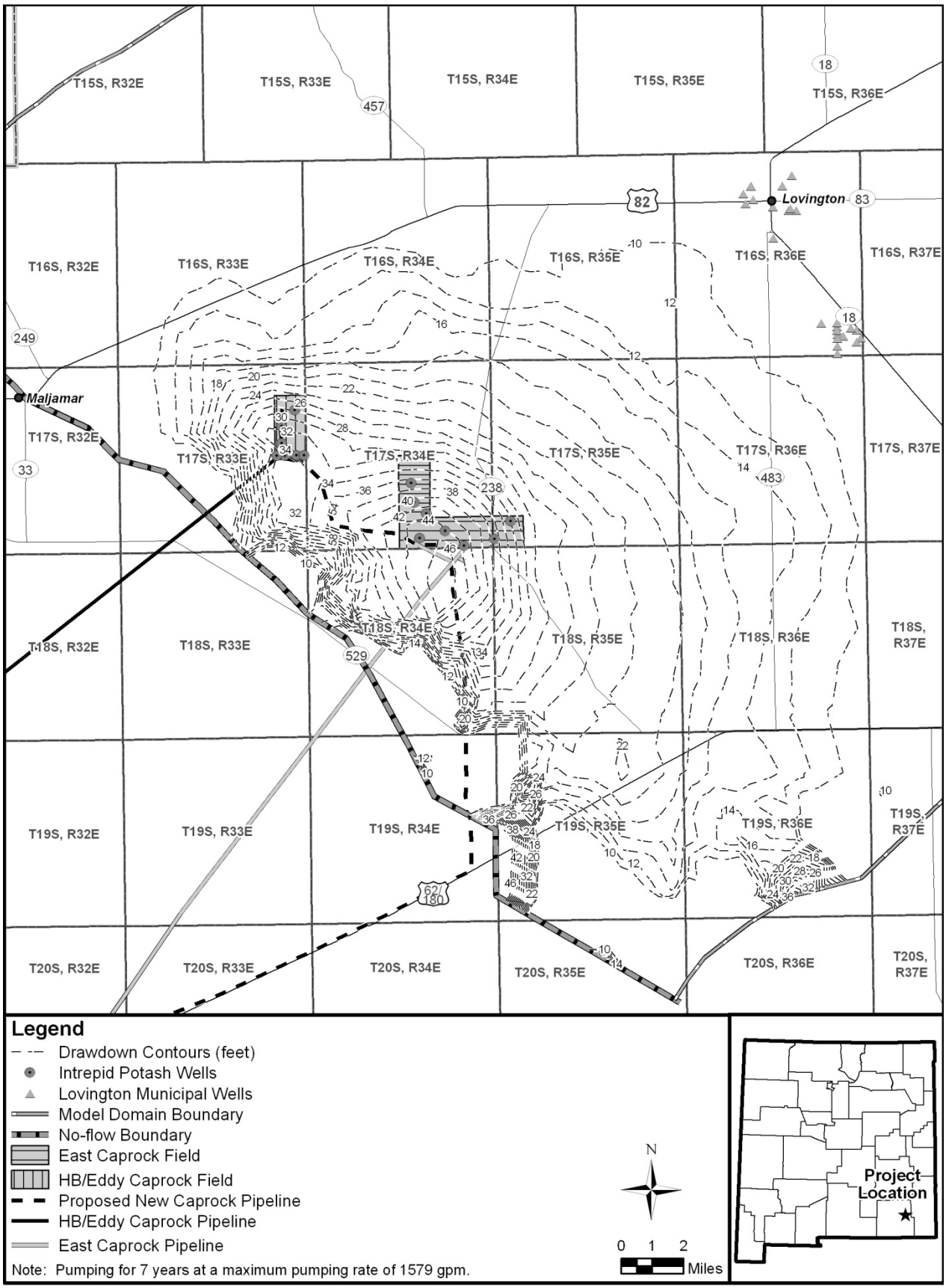


Figure 12-4 Maximum Drawdown in Enhanced Model: Caprock Wells, Years 0–7—Alternative B

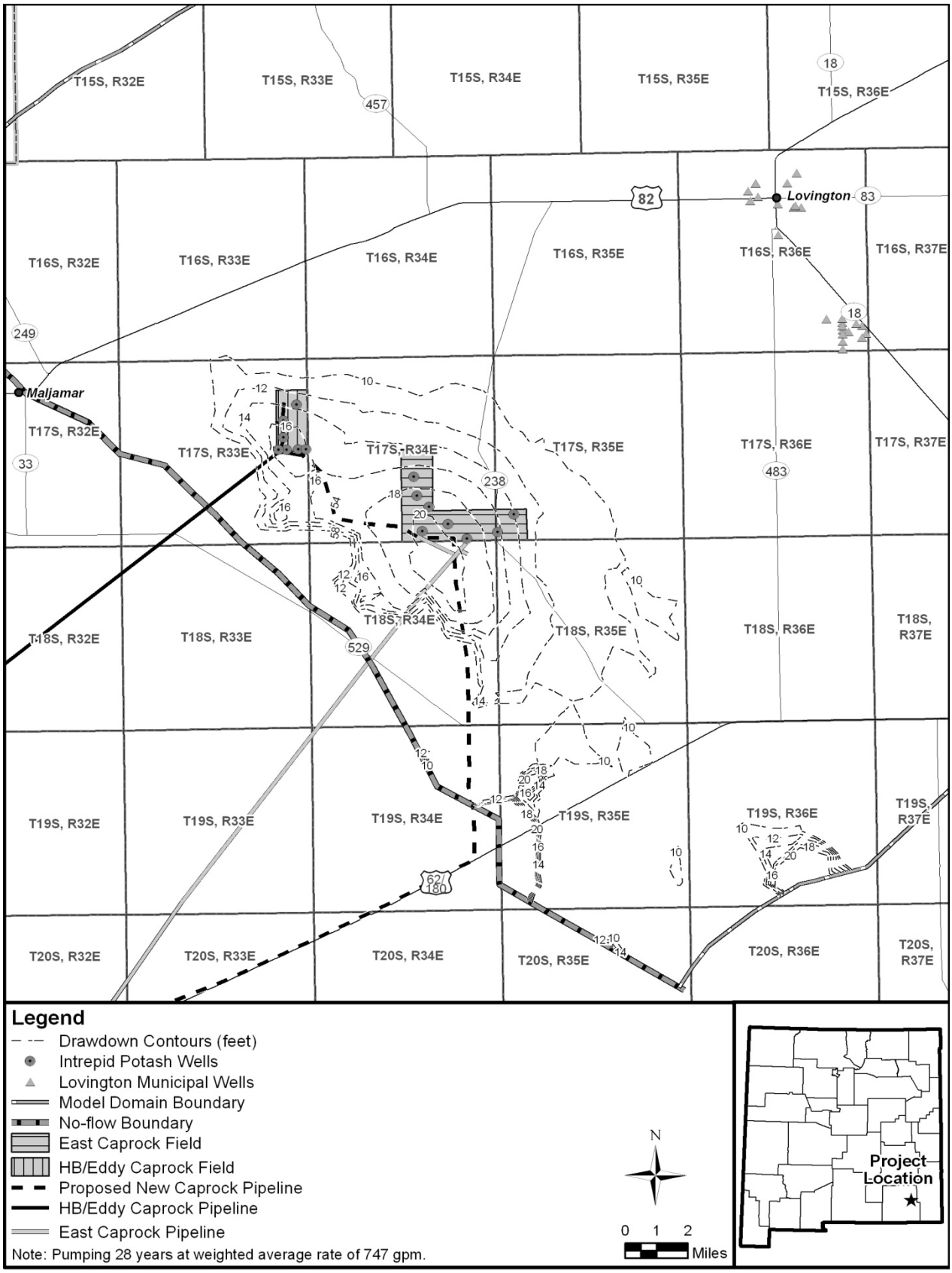


Figure 12-5 Figure 12-5 Drawdown in Enhanced Model: Caprock Wells, Time-Weighted Average Pumping—Alternative B

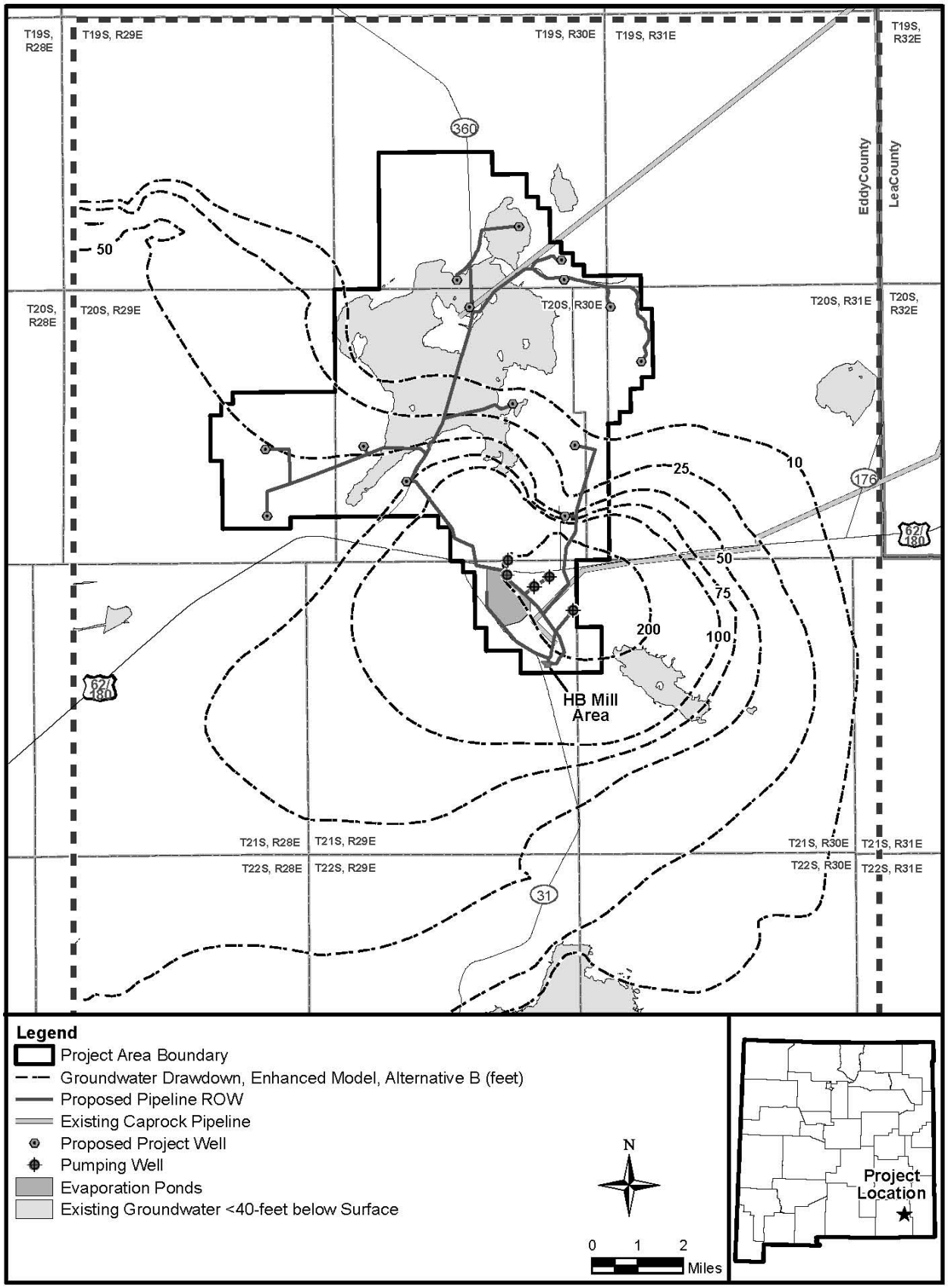


Figure 12-6 Drawdown in Enhanced Model (High Kx): Rustler Wells in Section 2 Area only—Alternative B

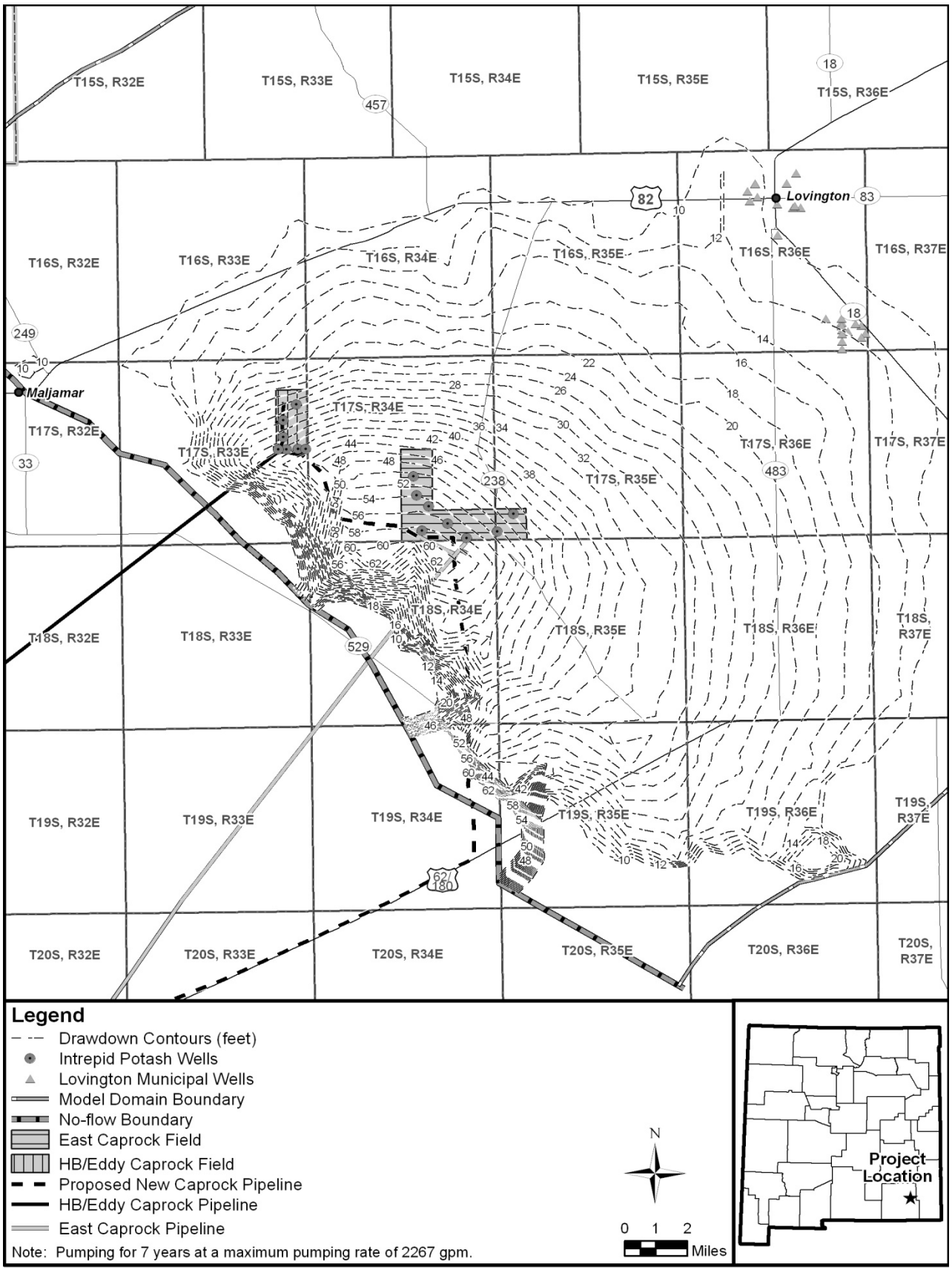


Figure 12-7 Maximum Drawdown from Pumping Only Caprock Wells, Years 0–7—Alternative B

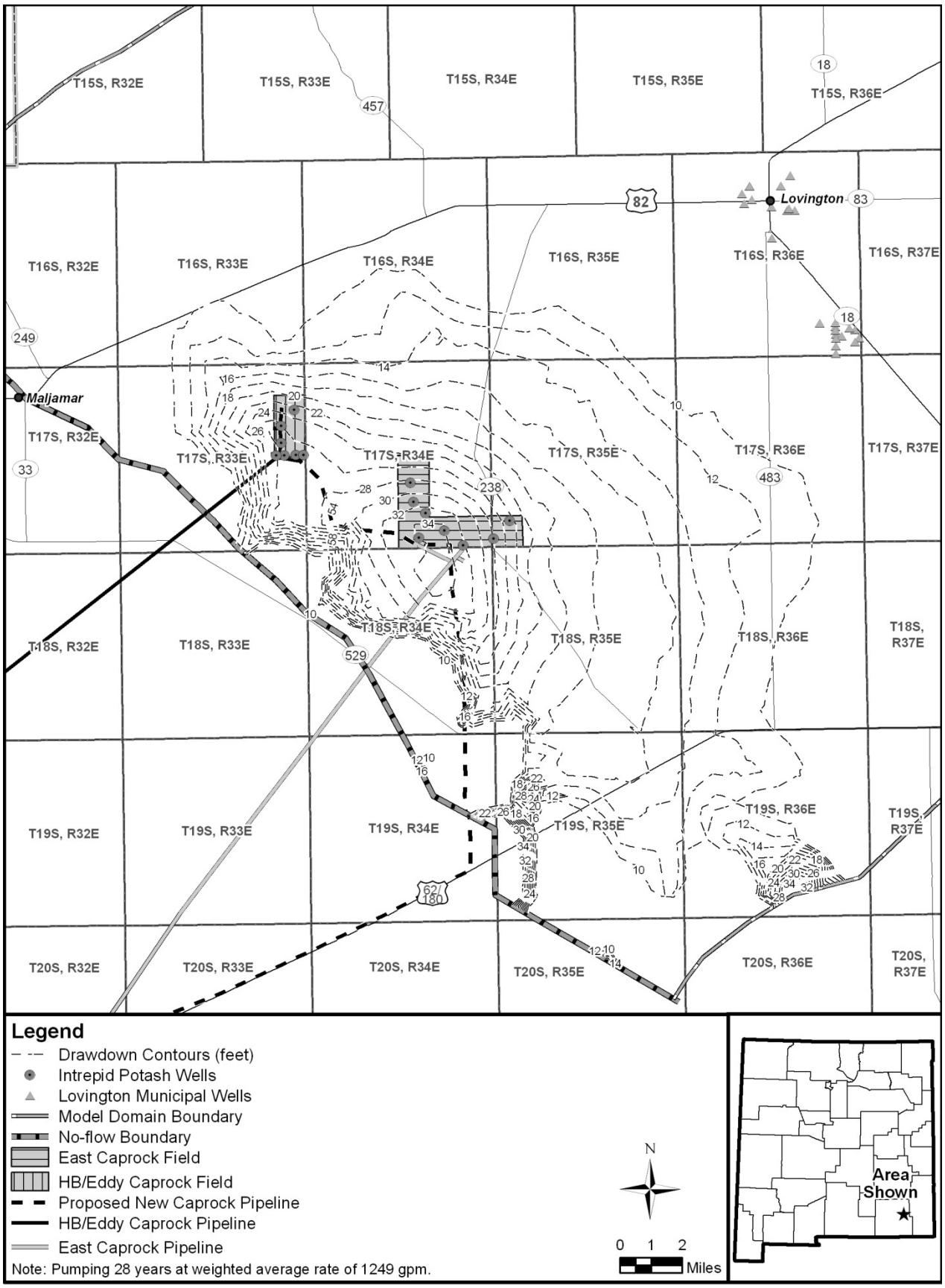


Figure 12-8 Drawdown from Pumping Only Caprock Wells, Time-Weighted Average—Alternative B

In both scenarios, use of Caprock only water with a maximum pumping rate of 2,267 gpm for the first 7 years and then a time-weighted average pumping rate of 1,249 gpm over 28 years results in substantial additional drawdown in the Caprock area.

12.4 Summary

Alternative B would require most of the injectate water from its wells from the Ogallala Formation in the Caprock area. Pumpage required for Phase I would be between 1,597 gpm and 2,090 gpm. For Phase II, most of the injectate water would come from the Caprock area and pumpage would be between 592 gpm and 1,085 gpm. For Phase III, pumpage from Caprock would be 208 gpm to supply refinery water. Impacts to the Section 2 area would be drawdown in the range of 100 to 200 feet, with drawdown in Nash Draw ranging from 10 feet on the east side to 100 feet on the west side. Flow down Nash Draw would be reduced from 11 to 25 percent, and flow to springs and seeps would be reduced between 7.4 and 31 percent. The Section 2 area would supply only 177 to 670 gpm of injectate water. **Table 12-1** summarizes the model results for Alternative B.

Table 12-1 Summary of Results from Groundwater Models for Alternative B

	Rustler Preferred		Rustler Enhanced		Caprock	
	Northern	Southern	Northern	Southern	Maximum	Time-Weighted
Alternative B - Rustler South Preferred & Caprock						
Max. Pumping Rate (gpm)	—	177	—	—	2,090	1,117
Max. Drawdown (ft)	—	200	—	—	54	24
Alternative B - Rustler South Enhanced & Caprock						
Pumping Rate (gpm)	—	—	—	670	1,579	747
Drawdown (ft)	—	—	—	200	46	20
Alternative B - Caprock Only						
Pumping Rate (gpm)	—	—	—	—	2,267	1,249
Drawdown (ft)	—	—	—	—	62	34

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Appendix A

Chemical and Radiochemical Analyses of Water from Test Holes at and near the Proposed Waste Isolation Pilot Plant Site

Derived from Mercer 1983, Table 2

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site

[GEOLOGIC UNIT: 231SNRS, Santa Rosa Sandstone; 313BLCN, Bell Canyon Formation; 312RSLRL, Rustler-Salado residuum; 312CLBR, Culebra Dolomite Member; 310MGNT, Magenta Dolomite Member. GM/ML AT 20 C: Grams per milliliter at 20 degrees Celsius; MG/L: milligrams per liter; UG/L: micrograms per liter; PCI/L: picocuries per liter.]

WELL	DATE OF SAMPLE	GEO-LOGIC UNIT	DENSITY (GM/ML AT 20 C)	PH (UNITS)	ALKA-LINITY FIELD (MG/L AS CACO3)	BICAR-BONATE FET-FLD (MG/L AS HCO3)	CAR-BONATE FET-FLD (MG/L AS CO3)	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	SULFIDE TOTAL (MG/L AS S)	HARD-NESS (MG/L AS CACO3)
H-5C	78-05-24	231SNRS	--	--	200	240	--	.36	--	150
AEC-7	79-04-28	313BLCN	1.130	--	43	--	--	--	--	35000
AEC-8	77-09-27	313BLCN	1.060	6.3	--	--	--	--	--	--
ERDA-10	77-09-29	313BLCN	1.165	7.7	90	110	0	3.1	.2	19000

WELL	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SILICA, DIS-SOLVED (MG/L AS SIO2)	BORON, DIS-SOLVED (UG/L AS B)	SOLIDS, RESIDUE AT 105 DEG. C, DIS-SOLVED (MG/L)
H-5C	150	56	51	280	25	120	530	1.2	11.0	890	1200
AEC-7	35000	9700	2600	55000	970	110000	1800	1.4	14.0	76000	180000
AEC-8	--	--	--	--	--	--	--	--	--	--	230000
ERDA-10	19000	5300	1300	89000	720	150000	2400	0.3	3.4	20000	270000

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site - Continued

WELL	DATE OF SAMPLE	GEO-LOGIC UNIT	DENSITY (GM/ML AT 20 C)	PH (UNITS)	ALKA-LINITY FIELD (MG/L AS CACO3)	BICAR-BONATE FET-FLD (MG/L AS HCO3)	CAR-BONATE FET-FLD (MG/L AS CO3)	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	SULFIDE TOTAL (MG/L AS S)	HARD-NESS (MG/L AS CACO3)
H-1	77-02-23	312RSLRL	--	7.9	554	675	0	.29	--	160000
H-2C	77-02-23	312RSLRL	--	5.9	163	199	0	1.1	--	130000
H-3	77-02-23	312RSLRL	--	7.6	383	467	0	.77	--	150000
H-4C	79-03-16	312RSLRL	--	--	1	1	0	.27	--	130000
H-5C	79-05-16	312RSLRL	--	--	180	300	--	--	--	340000
H-6C	79-04-09	312RSLRL	--	--	1	--	--	--	--	97000
H-7C	80-03-20	312RSLRL	1.048	6.8	35	--	--	.03	--	10000
H-8C	80-09-06	312RSLRL	--	7.6	21	--	--	.00	.6	4800
H-9C	80-05-20	312RSLRL	1.202	7.0	24	--	--	1.1	--	6800
H-10C	80-05-19	312RSLRL	1.198	6.3	53	--	--	.84	--	49000
P-14	77-02-24	312RSLRL	--	7.2	182	222	0	.34	--	6400
P-15	79-04-03	312RSLRL	--	--	45	--	--	--	--	3400
P-17	79-05-11	312RSLRL	--	--	650	--	--	.04	--	200000
P-18	79-05-11	312RSLRL	1.266	5.35	400	--	--	.06	.0	--
WIPP-25	80-03-19	312RSLRL	1.173	7.2	80	--	--	.04	--	15000
WIPP-26	80-03-18	312RSLRL	1.078	8.5	160	--	--	.05	--	12000
WIPP-27	80-05-21	312RSLR	1.205	7.8	--	--	--	--	--	--
WIPP-28	80-03-20	312RSLRL	1.140	7.0	--	--	--	--	--	--
WIPP-29	80-03-18	312RSLRL	1.068	7.3	130	--	--	.23	--	10000
WIPP-30	80-03-19	312RSLRL	1.201	7.0	320	--	--	.04	--	12000

WELL	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SILICA, DIS-SOLVED (MG/L AS SIO2)	BORON, DIS-SOLVED (UG/L AS B)	SOLIDS, RESIDUE AT 105 DEG. C, DIS-SOLVED (MG/L)
H-1	160000	13000	30000	56000	17000	210000	520	--	<.1	110000	480000
H-2C	130000	9200	25000	66000	9100	200000	1300	--	2.0	150000	450000
H-3	150000	18000	25000	59000	14000	210000	370	--	1.0	1900	327000
H-4C	130000	8300	27000	66000	8600	210000	1400	1.7	1.3	360000	322000
H-5C	340000	2100	82000	14000	21000	290000	2000	<.1	1.6	67000	412000
H-6C	97000	4200	21000	80000	8000	200000	2000	1.0	1.4	200000	316000
H-7C	10000	2600	910	22000	210	41000	2900	.8	7.2	3100	79800
H-8C	4700	1200	430	46000	660	70000	5300	.4	.8	1300	130000
H-9C	6800	1300	870	130000	1200	190000	2600	.1	3.8	19000	326000
H-10C	49000	1500	11000	100000	4000	190000	3300	.7	3.2	120000	323000
P-14	6200	570	1200	120000	1300	180000	10000	--	2.0	1700	350000
P-15	3300	770	350	24000	1400	38000	2800	1.3	1.3	3700	--
P-17	200000	15000	40000	23000	8800	180000	1200	3.8	15	880	--
P-18	--	10000	37000	48000	12000	220000	480	2.3	.4	160000	--
WIPP-25	15000	650	3200	90000	2400	130000	12000	.0	2.6	35000	252000
WIPP-26	12000	2700	1300	52000	1000	88000	7600	.0	2.5	30000	153000
WIPP-27	4700	1160	1040	102000	2570	154000	5190	.2	.1	1300	363000
WIPP-28	13000	615	2070	65000	2070	102000	11000	.2	6.0	54000	--
WIPP-29	10000	850	2000	32000	1000	49000	12000	.9	3.5	21000	129000
WIPP-30	11000	850	2300	120000	1500	170000	7000	.0	3.5	77000	302000

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site - Continued

WELL	DATE OF SAMPLE	GEO-LOGIC UNIT	SELE-NIUM, TOTAL (UG/L AS SE)	GROSS ALPHA, DIS-SOLVED (PCI/L AS U-NAT)	GROSS ALPHA, SUSP. TOTAL (PCI/L AS U-NAT)	GROSS BETA, DIS-SOLVED (PCI/L AS CS-137)	GROSS BETA, SUSP. TOTAL (PCI/L AS CS-137)	RADIUM 226, DIS-SOLVED, RADON METHOD (PCI/L)	URANIUM DIS-SOLVED, EXTRAC-TION (UG/L)	GROSS ALPHA, DIS-SOLVED (UG/L AS U-NAT)
H-1	77-02-23	312RSLRL	<1	--	--	16000	160	64	.02	<6300
H-2C	77-02-23	312RSLRL	<1	--	--	8400	91	4.8	2.4	<5000
H-3	77-02-23	312RSLRL	1	--	--	12000	26	51	.06	<6000
H-4C	79-03-16	312RSLRL	<1	<7500	3.3	8900	<.4	340	1.2	<11000
H-5C	79-05-16	312RSLRL	1	<13000	.7	15000	.6	310	<.04	<19000
H-6C	79-04-09	312RSLRL	1	<7500	.9	6800	<.7	280	<.04	<11000
H-7C	80-03-20	312RSLRL	--	<950	--	<580	--	65	1.9	<1400
H-8C	80-09-06	312RSLRL	--	<1800	--	<1100	--	18	.04	<2600
H-9C	80-05-20	312RSLRL	--	<5400	--	7600	--	.31	.45	<8000
H-10C	80-05-19	312RSLRL	--	<5600	--	7200	--	10	.37	<8200
P-14	77-02-24	312RSLRL	1	--	--	<2000	2.3	15	1.3	<3700
P-15	79-04-03	312RSLRL	<1	<1000	<.3	1300	<.4	.59	.08	<1500
P-17	79-05-11	312RSLRL	<1	<7500	6.8	13000	2.8	340	<.02	<11000
P-18	79-05-11	312RSLRL	<1	<8800	<.3	9800	<.4	11	.05	<13000
WIPP-25	80-03-19	312RSLRL	--	<5200	--	<3600	--	2.7	.29	<7700
WIPP-26	80-03-18	312RSLRL	--	<3200	--	<1700	--	12	5.2	<4700
WIPP-27	80-05-21	312RSLR	--	<1200	--	<7100	--	2.4	.07	<1800
WIPP-28	80-03-20	312RSLRL	--	<4100	--	<2700	--	3.6	2.7	<6000
WIPP-29	80-03-18	312RSLRL	--	<1100	--	740	--	1.2	2.0	<1600
WIPP-30	80-03-19	312RSLRL	--	<7500	--	<4500	--	98	<.01	<11000

WELL	GROSS ALPHA, SUSP. TOTAL (UG/L AS U-NAT)	GROSS BETA, DIS-SOLVED (PCI/L AS SR/YT-90)	GROSS BETA, SUSP. TOTAL (PCI/L AS SR/YT-90)
H-1	290	12000	120
H-2C	190	6700	76
H-3	68	9600	21
H-4C	4.9	8100	<.4
H-5C	1.1	14000	.6
H-6C	1.3	6200	<.7
H-7C	--	<590	--
H-8C	--	<1100	--
H-9C	--	<7200	--
H-10C	--	<6900	--
P-14	6.3	<1600	1.9
P-15	<.4	1200	<.4
P-17	10	12000	2.5
P-18	<.4	8800	<.4
WIPP-25	--	<3800	--
WIPP-26	--	<1800	--
WIPP-27	--	<15000	--
WIPP-28	--	<2800	--
WIPP-29	--	730	--
WIPP-30	--	<4500	--

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site - Continued

WELL	DATE OF SAMPLE	GEO-LOGIC UNIT	DENSITY (GM/ML AT 20 C)	PH (UNITS)	ALKA-LINITY FIELD (MG/L AS CACO3)	BICAR-BONATE FET-FLD (MG/L AS HCO3)	CAR-BONATE FET-FLD (MG/L AS CO3)	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	SULFIDE TOTAL (MG/L AS S)	HARD-NESS (MG/L AS CACO3)
H-1	76-06-02	312CLBR	--	7.6	86	105	0	--	.0	3100
H-2B	77-02-22	312CLBR	--	8.4	57	59	5	.01	--	2400
H-3	77-03-17	312CLBR	--	7.4	94	115	0	.07	--	6500
H-4B	78-12-14	312CLBR	--	7.6	48	59	--	.02	--	2200
H-5B	78-12-19	312CLBR	--	6.8	34	41	--	.01	--	8700
H-6B	78-12-20	312CLBR	--	7.3	85	--	--	.02	--	7000
H-7B	80-03-20	312CLBR	1.001	7.0	100	--	--	.40	--	2000
H-8B	80-02-11	312CLBR	1.000	7.3	61	--	--	.95	--	2100
H-9B	80-02-05	312CLBR	--	7.3	90	--	--	.13	--	2100
H-10B	80-03-21	312CLBR	1.045	8.3	37	--	--	.01	--	8100
P-14	77-03-14	312CLBR	--	6.0	290	357	0	.01	--	11000
P-15	77-05-10	312CLBR	--	--	92	63	24	.04	--	2200
P-17	77-05-10	312CLBR	--	7.4	63	77	0	.06	--	11000
P-18	77-05-10	312CLBR	--	7.2	254	310	0	.81	--	80000
WIPP-25	80-08-14	312CLBR	1.014	7.3	370	--	--	.67	.8	3300
WIPP-26	80-08-18	312CLBR	1.013	6.9	130	--	--	3.5	.0	4400
WIPP-27	80-08-22	312CLBR	1.094	6.4	150	--	--	4.0	.0	16000
WIPP-28	80-08-21	312CLBR	1.044	6.4	670	--	--	.09	10	4900
WIPP-29	80-08-20	312CLBR	1.178	6.1	210	--	--	.02	.0	26000
WIPP-30	80-08-13	312CLBR	1.072	6.8	74	--	--	1.2	.0	6300

WELL	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SILICA, DIS-SOLVED (MG/L AS SIO2)	BORON, DIS-SOLVED (UG/L AS B)	SOLIDS, RESIDUE AT 105 DEG. C, DIS-SOLVED (MG/L)
H-1	3000	780	280	9400	190	12000	7400	5.1	2.7	2400	30100
H-2B	2300	690	160	2100	91	2800	3000	2.0	1.7	9500	9700
H-3	6400	1500	670	19000	630	29600	5700	.5	1.2	20000	62000
H-4B	2200	180	430	5800	180	7500	4000	1.9	5.2	19000	18100
H-5B	8700	360	1900	53000	1400	86000	810	1.4	2.1	36000	144000
H-6B	6900	1200	970	18000	500	28000	3800	1.5	8.5	9500	52600
H-7B	1900	590	130	210	1.4	350	1900	1.4	39	780	3610
H-8B	2100	570	170	82	4.7	57	2000	2.4	19	580	3200
H-9B	2000	580	150	210	1400	320	2000	3.0	26	780	3590
H-10B	8100	1600	1000	21000	520	36000	5600	1.3	1.5	13000	69200
P-14	11000	3100	760	7600	600	20000	1400	.9	33	700	38000
P-15	2100	770	63	6900	1700	11000	3200	1.2	1.6	4700	24000
P-17	11000	1700	1600	30000	120	54000	5000	1.5	1.0	1700	97000
P-18	80000	5600	16000	9200	6200	80000	980	1.2	1.0	100000	420000
WIPP-25	3000	920	250	5100	.9	8300	2400	1.4	29	1900	22100
WIPP-26	4300	1200	340	3600	2.0	8200	2300	1.5	20	1800	23800
WIPP-27	16000	3100	2000	39000	714	77000	3900	.5	13	1900	186000
WIPP-28	4300	1200	470	21000	4.0	30000	3200	1.1	28	5400	74000
WIPP-29	25000	810	5700	79000	150	140000	13000	.7	11	45000	239000
WIPP-30	6300	1100	870	37000	888	64000	5050	.5	2.9	64000	110000

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site - Continued

WELL	DATE OF SAMPLE	GEO-LOGIC UNIT	SELE-NIUM, TOTAL (UG/L AS SE)	GROSS ALPHA, DIS-SOLVED (PCI/L AS U-NAT)	GROSS ALPHA, SUSP. TOTAL (PCI/L AS U-NAT)	GROSS BETA, DIS-SOLVED (PCI/L AS CS-137)	GROSS BETA, SUSP. TOTAL (PCI/L AS CS-137)	RADIUM 226, DIS-SOLVED, RADON METHOD (PCI/L)	URANIUM DIS-SOLVED, EXTRAC-TION (UG/L)	GROSS ALPHA, DIS-SOLVED (UG/L AS U-NAT)
H-1	79-03-13	312CLBR	<1	<200	<.3	410	<.4	1.7	.16	<290
H-2B	77-02-22	312CLBR	2	--	--	120	110	4.6	--	330
H-3	77-03-17	312CLBR	2	--	--	850	<.4	57	.09	<880
H-4B	78-12-14	312CLBR	<1	--	--	310	--	67	2.9	720
H-5A	78-12-19	312CLBR	<1	2700	--	1100	--	290	1.0	4000
H-6B	78-12-20	312CLBR	5	--	--	<420	--	6.6	4.3	<1200
H-7B	80-03-20	312CLBR	--	<38	--	19	--	.98	9.7	<56
H-8B	80-02-11	312CLBR	--	62	<.3	<19	<.4	3.4	7.4	91
H-9B	80-02-05	312CLBR	--	--	--	<25	--	7.3	34	<100
H-10B	80-03-21	312CLBR	--	<1100	--	<590	--	29	.08	<1600
P-14	77-03-14	312CLBR	1	--	--	790	<.4	68	<.01	<390
P-15	79-04-11	312CLBR	4	<1300	<.3	4700	<.4	11	2.2	<1900
P-17	77-05-10	312CLBR	1	--	--	1300	<.4	84	.10	2900
P-18	77-05-10	312CLBR	<1	--	--	7700	.5	190	.33	<4800
WIPP-25	80-08-14	312CLBR	--	<200	--	<170	--	17	6.1	<290
WIPP-26	80-08-18	312CLBR	--	<260	--	<220	--	18	12	<380
WIPP-27	80-08-22	312CLBR	--	<1800	--	6300	--	79	4.9	<2600
WIPP-28	80-08-21	312CLBR	--	<1100	--	<1100	--	40	1.3	<1600
WIPP-29	80-08-20	312CLBR	--	<7500	--	18000	--	17	18	<11000
WIPP-30	80-08-13	312CLBR	--	<880	--	<660	--	64	.29	<1300

WELL	GROSS ALPHA, SUSP. TOTAL (UG/L AS U-NAT)	GROSS BETA, DIS-SOLVED (PCI/L AS SR/YT-90)	GROSS BETA, SUSP. TOTAL (PCI/L AS SR/YT-90)
H-1	<.4	390	<.4
H-2B	380	97	88
H-3	<.4	710	<.4
H-4B	--	290	--
H-5B	--	1000	--
H-6B	--	<390	--
H-7B	--	19	--
H-8B	<.4	<18	<.4
H-9B	--	<23	--
H-10B	--	<610	--
P-14	<.4	620	<.4
P-15	<.4	4300	<.4
P-17	<.4	1000	<.4
P-18	<.4	6100	.5
WIPP-25	--	<160	--
WIPP-26	--	<210	--
WIPP-27	--	6100	--
WIPP-28	--	<1000	--
WIPP-29	--	17000	--
WIPP-30	--	<600	--

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site - Continued

WELL	DATE OF SAMPLE	GEO-LOGIC UNIT	DENSITY (GM/ML AT 20 C)	PH (UNITS)	ALKA-LINITY FIELD (MG/L AS CACO3)	BICAR-BONATE FET-FLD (MG/L AS HCO3)	CAR-BONATE FET-FLD (MG/L AS CO3)	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	SULFIDE TOTAL (MG/L AS S)	HARD-NESS (MG/L AS CACO3)
H-1	76-06-04	310MGNT	--	7.4	75	92	0	--	.0	3300
H-2A	77-02-22	310MGNT	--	8.6	61	74	0	.04	--	2700
H-3	77-05-10	310MGNT	--	8.0	42	51	0	.08	--	5000
H-4A	78-12-14	310MGNT	--	8.0	52	63	--	.01	--	2200
H-5A	78-12-14	310MGNT	--	7.8	41	50	--	.01	--	1300
H-6A	78-12-20	310MGNT	--	7.3	42	51	--	.03	--	2000
H-8A	80-02-12	310MGNT	1.006	9.3	26	--	--	.06	--	2200
H-9A	80-02-05	310MGNT	1.003	8.5	35	--	--	.02	--	2100
H-10A	80-03-21	310MGNT	1.175	7.1	0	--	--	.03	--	17000
WIPP-25	80-09-04	310MGNT	1.010	7.5	150	--	--	.64	1.2	3300
WIPP-27	80-07-24	310MGNT	1.080	6.8	57	--	--	.32	--	11000
	80-09-20	310MGNT	--	6.5	180	--	--	.40	1.8	17000
WIPP-30	80-09-24	310MGNT	--	8.8	62	--	--	.00	.0	2400

WELL	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SILICA, DIS-SOLVED (MG/L AS SIO2)	BORON, DIS-SOLVED (UG/L AS B)	SOLIDS, RESIDUE AT 105 DEG. C, DIS-SOLVED (MG/L)
H-1	3300	890	270	5700	70	8000	3900	2.8	1.3	2200	18900
H-2A	2700	820	170	2700	81	4100	2400	--	6.0	220	12000
H-3	4900	1200	480	9300	250	15000	3400	1.8	6.4	13000	32000
H-4A	2100	210	410	7000	130	7500	7000	2.5	6.4	13000	22300
H-5A	1300	240	170	1500	53	880	3200	2.8	9.0	11000	--
H-6A	2000	520	160	1100	46	1200	2700	1.4	7.7	2500	--
H-8A	2200	870	17	2400	84	3500	2100	.7	.9	3100	9410
H-9A	2000	550	170	800	28	750	2700	1.8	3.3	2600	5460
H-10A	17000	2500	2600	93000	510	160000	2700	1.3	1.9	3900	270000
WIPP-25	3100	910	240	3100	.8	5600	1900	1.5	25	1900	18700
WIPP-27	11000	1100	1900	34000	1800	61000	9400	.0	1.7	26000	106000
	17000	3600	2000	43000	10000	85000	2900	.4	13	230	173000
WIPP-30	2400	690	170	5500	190	8700	3200	1.9	.7	12000	19000

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site - Concluded

WELL	DATE OF SAMPLE	GEO-LOGIC UNIT	SELE-NIUM, TOTAL (UG/L AS SE)	GROSS ALPHA, DIS-SOLVED (PCI/L AS U-NAT)	GROSS ALPHA, SUSP. TOTAL (PCI/L AS U-NAT)	GROSS BETA, DIS-SOLVED (PCI/L AS CS-137)	GROSS BETA, SUSP. TOTAL (PCI/L AS CS-137)	RADIUM 226, DIS-SOLVED, RADON METHOD (PCI/L)	URANIUM DIS-SOLVED, EXTRAC-TION (UG/L)	GROSS ALPHA, DIS-SOLVED (UG/L AS U-NAT)
H-1	77-05-10	310MGNT	1	--	--	940	<.4	170	.60	<400
H-2A	77-02-22	310MGNT	1	--	--	69	2.6	6.1	.80	<160
H-3	77-05-10	310MGNT	7	--	--	330	<.4	44	--	550
	79-05-10	310MGNT	1	<420	.3	1300	.4	10	.24	<620
H-4A	78-12-14	310MGNT	<1	--	--	<100	--	9.3	.08	<320
H-5A	78-12-14	310MGNT	<1	--	--	53	--	17	1.0	160
H-6A	78-12-20	310MGNT	1	--	--	43	--	11	6.7	110
H-8A	80-02-12	310MGNT	--	<140	<.3	130	<.4	1.9	.08	<200
H-9A	80-02-05	310MGNT	--	--	--	<38	--	9.4	.15	<150
H-10A	80-03-21	310MGNT	--	<5300	--	<3500	--	480	<.10	<7800
WIPP-25	80-09-04	310MGNT	--	<160	--	<140	--	12	8.4	<230
WIPP-27	80-07-24	310MGNT	--	--	--	1900	--	12	--	--
	80-09-20	310MGNT	--	<2000	--	6000	--	24	5.8	<2900
WIPP-30	80-09-24	310MGNT	--	<300	--	<200	--	26	.02	<440

WELL	GROSS ALPHA, SUSP. TOTAL (UG/L AS U-NAT)	GROSS BETA, DIS-SOLVED (PCI/L AS SR/YT-90)	GROSS BETA, SUSP. TOTAL (PCI/L AS SR/YT-90)
H-1	<.4	790	<.4
H-2A	12	55	2.0
H-3	<.4	260	<.4
	.4	1200	.4
H-4A	--	<92	--
H-5A	--	48	--
H-6A	--	39	--
H-8A	<.4	130	<.4
H-9A	--	<35	--
H-10A	--	<3600	--
WIPP-25	--	<130	--
WIPP-27	--	1800	--
	--	5800	--
WIPP-30	--	<190	--