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A Regional Water Balance for the Waste Isolation Pilot Plant (WIPP) Site and Surrounding Area

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Regina L. Hunter
Waste Management Systems Division
Sandia National Laboratories
Albuquerque, NM 87185

Abstract

The WIPP water-balance study area defined here comprises ~2000 mi^2 in Eddy and Lea Counties, southeastern New Mexico. Inflows to the study area are precipitation (roughly 1.47×10^6 ac-ft/yr), surface water (roughly 1.1×10^5 ac-ft/yr), water imported by municipalities and industries (roughly 3×10^4 ac-ft/yr), and ground water (volume not estimated). Outflows from the area are evapotranspiration (roughly 1.5×10^6 ac-ft/yr), surface water (roughly 1.2×10^5 ac-ft/yr), and possibly some ground water. The volume of surface and ground water in storage in Nash Draw has increased since the beginning of potash refining. Regional ground-water flow in aquifers above the Salado Formation is from the northeast to the southwest, although this pattern is interrupted by Clayton Basin, Nash Draw, and San Simon Swale. The Pecos River is the only important perennial stream. Most of the area has no integrated surface-water drainage.

The available data suggest that ~1600 mi^2 of the study area are hydrologically separate from Nash Draw and the WIPP site. Ground water north of Highway 180 apparently discharges into Clayton Basin and evaporates. Water in San Simon Swale apparently percolates downward and flows to the southeast. Data are inadequate to create a water budget for the Nash Draw—WIPP site hydrologic system alone, although an attempt to do so can provide guidance for further study.

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Much of the information contained in this report has not been previously published: personal communications have been invaluable. I thank all those persons cited in the text for their time and cooperation and for permission to use the information they have provided.

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A Regional Water Balance for the Waste Isolation Pilot Plant (WIPP) Site and Surrounding Area

Introduction

The Waste Isolation Pilot Plant (WIPP) will serve as a research and development facility to demonstrate safe disposal of defense-generated transuranic (TRU) wastes that the US Department of Energy (DOE) may designate as requiring deep geologic disposal. The WIPP will also provide a separate underground facility in which in situ experiments with various waste forms, including defense high-level waste, may be conducted. All the wastes placed into the WIPP for intended disposal would be retrievable for the periods required to demonstrate the safety of the disposal concept. These periods are not expected to exceed 5 yr for TRU waste. Wastes used in the experimental program will be removed at the conclusion of the experiments.

The DOE is conducting site investigations to address issues on which the State of New Mexico has asked for further information and to refine existing knowledge of geologic and hydrologic processes at and near the WIPP site. Sandia National Laboratories in Albuquerque (SNLA) supports the DOE in WIPP development in two major areas, Geotechnical Site Evaluation and Experimental Programs. The Geotechnical Site Evaluation consists of programs that will develop a more comprehensive understanding of geologic and hydrologic processes that may affect the WIPP area now and in the near geologic future. On completion of site characterization, the geotechnical program will focus on issues and technology development of generic value to characterization of sites for waste disposal in salt.

This water balance for the area surrounding the WIPP site is part of the Geotechnical Site Evaluation. The water balance meets two specific objectives. First, it satisfies the recommendation of the New Mexico Environmental Evaluation Group to conduct such a water balance (Neill and others, 1983). Second, it reveals and illuminates some inadequacies in the available hydrologic data pertaining to a water balance. In addition, the water balance enhances our understanding of the hydrology of the WIPP site and of the site's future integrity. The results of the study can be used to guide future data collection and modeling.

Water-Balance Concept

Water balances or budgets (the terms are interchangeable) have been used for many purposes. Eakin (1966) used a water budget to determine the extent of a regional ground-water flow system by finding recharge areas large enough to account for known discharge. Water budgets have been used to determine ground-water recharge and use of ground water by phreatophytes (Bouwer, 1978, pp 267, 305). A regional water balance for the San Juan Basin in northwestern New Mexico described all inflow, outflow, and water usage in the Basin (Geohydrology Associates, 1978c). In the WIPP study area, water-budget techniques have been used to compute leakage from Lake Avalon (National Resources Planning Board, 1942, p 60) and from potash refinery spoil ponds (Geohydrology Associates, 1978b). The WIPP water budget is similar in scope to the San Juan Basin water budget.

Each water balance or budget was developed as an accounting of the hydrologic components of a closed hydrologic system. In principle, any hydrologic system can be described by a water budget that accounts for the disposition of inputs to and outputs from the system and for changes in storage. Although many variations of the water-budget equation can be written, a general expression is

$$\sum_{1}^{n} I_i + \sum_{1}^{n} O_i + \Delta S = 0 \qquad (1)$$

where

I_i = a given inflow volume,
O_i = a given outflow volume, and
ΔS = change in storage within the region.

The simplicity of this equation tends to be misleading, however, for two reasons. First, the components—inflow, outflow, and change in storage—may not be easily or adequately quantified. Second, in a developed area like the WIPP region, the water budget must include many usage factors, such as municipal or industrial pumpage. In the WIPP water-budget study area, inflows are precipitation, surface-water inflow, ground-water inflow, and the artificial addition of surface and ground water (such as water piped in from locations outside the region for use in the potash industry). The outflows are surface runoff, evaporation and transpiration, and ground-water outflow. Changes in storage in the WIPP region have also been documented.

Determining the volumes of water in these three basic components of the water-balance equation requires determining or calculating such items as the volumes of water devoted to agricultural, municipal, industrial, and domestic use. Quantifying these components helps to clarify the interaction between surface- and ground-water flow within the system and to identify the quantity of water gained by or lost from the system. Determining actual values for the components of the water budget can be difficult. Both areal variation and time dependency of the components are hidden when the study is performed for a particular year. Data are usually available only on an annual basis, however. Furthermore, the volumes of water in some components of the water budget strongly depend on one another. For example, in a year of above-normal precipitation, runoff is also above normal. Use of surface water for irrigation increases; use of ground water decreases. Clearly, a water budget cannot be based on precipitation data from one year and runoff data from another. Two possible means of avoiding the introduction of errors that can arise from time-dependency of the data are first, to use long-term averages and second, to use data from only one year. The most recent year for which many kinds of data are available is 1980. The WIPP water balance described here is based on a combination of both long-term averages and figures for 1980.

Boundaries of the Study Area

The study area for the water budget encompasses roughly 2000 mi^2 in Eddy and Lea Counties, New Mexico, mostly east of the Pecos River (Figure 1). The study area has been chosen to approximate a closed hydrologic system. It is substantially larger than the WIPP site itself because the site alone does not constitute a closed hydrologic system.

It is convenient to choose the boundaries of any water-balance study area so that the number and volumes of inflows and outflows are minimized. This can sometimes be done by choosing coinciding surface- and ground-water divides as boundaries, effectively eliminating any horizontal component of inflow along those portions of the boundary. Unfortunately, surface- and ground-water divides do not strictly correspond in the WIPP area. The northwestern portion of the WIPP water-balance study area approximates this type of boundary.

Perennial streams can also be useful boundaries, for two reasons. First, streams are commonly gaged, so that hydrologic data are available; second, a perennial stream forms a constant-head boundary for computer modeling of ground-water flow, making the water balance more useful to modelers. On the other hand, flow to or from a stream can be both horizontal and vertical, and the Pecos River undoubtedly receives ground-water inflow from both the study area and from the Pecos River Valley to the west of the river. Nevertheless, portions of the study-area boundary follow the Pecos River.

Much of the acreage of the Carlsbad Irrigation District is irrigated with water from the Pecos River. Some of the irrigation water returns to the Pecos by shallow ground-water flow. Because the Pecos River is a highly regulated stream whose flow is affected by the Carlsbad Irrigation District, the District has been included in the study area. The western boundary of the District forms a portion of the boundary of the study area.

There is no conveniently located ground- or surface-water divide in the southeastern portion of the study area. San Simon Swale is a topographic sink that seems to be a ground-water recharge area, from which water flows to the southeast. The Swale has been included as a separate subarea of the study area. The topography of the Swale provides a convenient boundary. Southwest of San Simon Swale, the study-area boundary follows a flow line in the topmost aquifer. A flow line provides a no-flow boundary.

Consideration of any impact the Ogallala aquifer might have on the hydrology of the study area is beyond the scope of this study. For this reason, the northeastern boundary follows the escarpment of the High Plains. Unfortunately, the escarpment is sub-parallel to contour lines for the potentiometric surface of the topmost aquifer in the study area; that is, ground water flows into the study area along this boundary. The escarpment does form a surface-water divide, however.

Only the rocks and aquifers above the Salado Formation (Fm.) and below the Ogallala Fm. are discussed in detail in this report, although some wells completed in outliers of the Ogallala Fm. are included in Plate 1.

Hydrology

Developing a water balance begins with a detailed examination of the component inflows to, outflows from, and changes in storage inside the study area. Some of these components must be calculated using

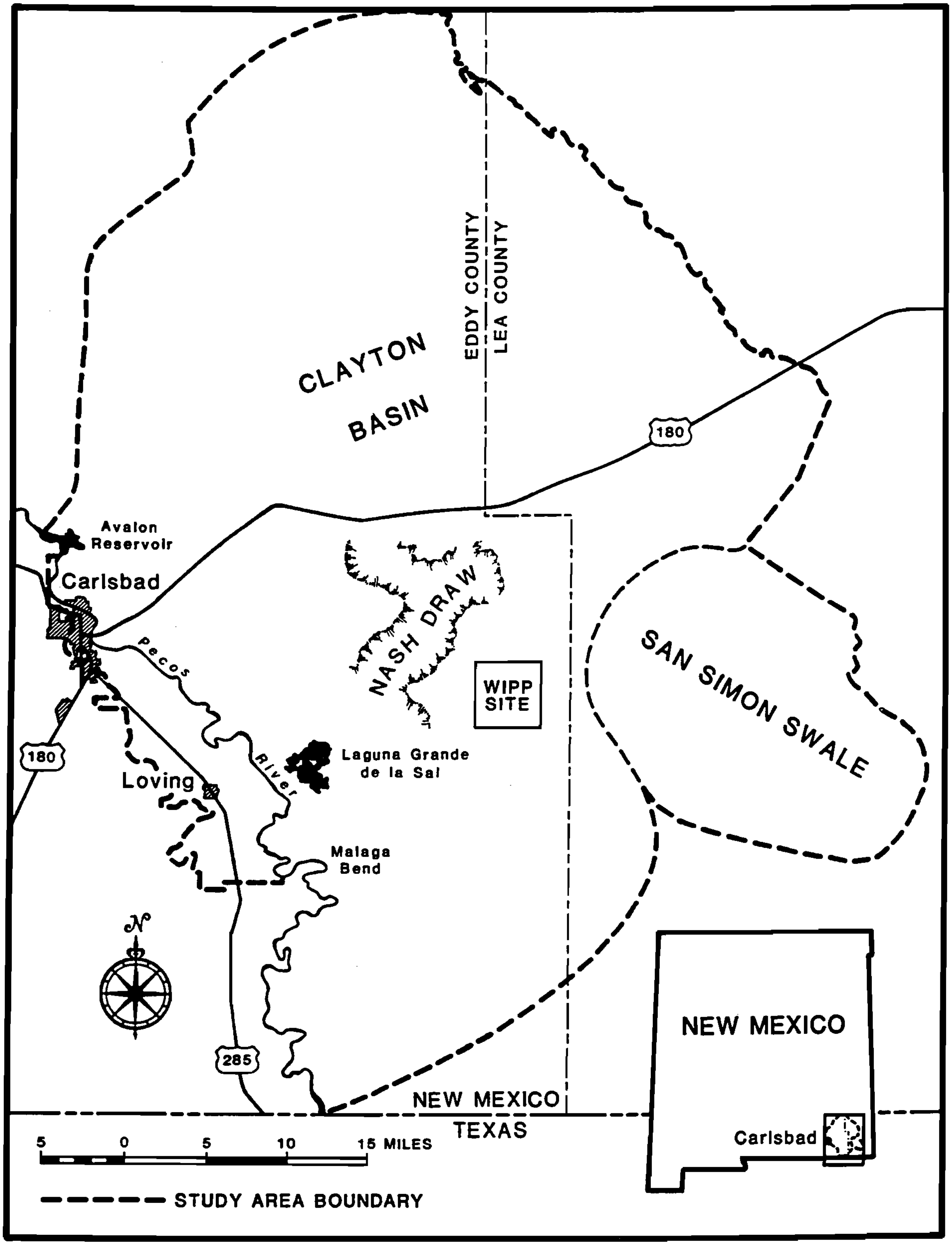


Figure 1. Study Area for the WIPP Water Balance

data on use of water inside the study area by various agencies. This section examines the data available on precipitation; agricultural, municipal, and industrial water usage; stream flow; evapotranspiration; ground-water flow; and change in storage.

Precipitation

Southeastern New Mexico is an arid-to-semiarid fringe of the Chihuahuan Desert that receives little more than 12 in. of precipitation annually. Even so, precipitation is the second largest item in the water budget, easily dwarfing surface-water inflow, ground-water pumpage, and all forms of water use in the study area. The volume of precipitation is so great that the uncertainty in it is larger than many other items in the water budget. Only evapotranspiration is larger than precipitation in volume.

Some of the precipitation that falls in the study area runs off. Runoff is discussed in the section on Surface-Water Inflow and Outflow. Most of the precipitation evaporates again fairly rapidly. Evaporation is discussed in the section on Evapotranspiration from Rangeland and Brine Lakes. A small part of the precipitation recharges the ground-water system, as discussed under Ground-Water Flow.

Precipitation at weather stations in and near the study area varies greatly from year to year (Figure 2). For example, Roswell's record low annual precipitation is only 4.35 in. The record annual high is 32.92 in. Most years are either "wet" or "dry"; few are "average." An average precipitation for a station with few years of record is only an approximation of the long-term mean. Precipitation data are available for 16 stations in and near the study area (National Oceanic and Atmospheric Administration (NOAA); Geohydrology Associates, 1978b; Gabin and Lesperance, 1977). Six stations are inside the study area, although four are near its edges. The interior of the study area is poorly documented: in an area of ~1700 mi^2, only the station at Duval Potash Mine has a lengthy record. Data are not currently being collected at the Otis, Lake Avalon, Lakewood, Loving, WIPP, or Eunice stations. The period of record varies from <4 yr for the WIPP site to 107 yr for Roswell. Table 1 gives the mean annual precipitation and enumerates the years of record for each station. Appendix A tabulates the monthly and annual precipitation for 11 stations at which data were collected between 1977 and 1982.

Only three complete years of record (1977 through 1979) are available for the WIPP site; records are also available for parts of 1976 and 1980 (Table 2). Although precipitation in the vicinity of the study area in 1977 and 1979 was near normal, 1978 was a very wet year. (The National Weather Service defines "normal precipitation" as the mean value for 1941 to 1970.) The seven stations for which normal precipitations are available had excess precipitations of 4.15 to 15.11 in. during 1978 (Table 3a). The mean departure from normal for the seven stations was 8.87 in. The 1978 precipitation of 19.47 in. at the WIPP site is 5.94 in. greater than the mean for the site for 1977, 1978, and 1979. Therefore, the mean precipitation for 1977 through 1979 at the WIPP site of 13.53 in. is probably not representative of the long-term mean.

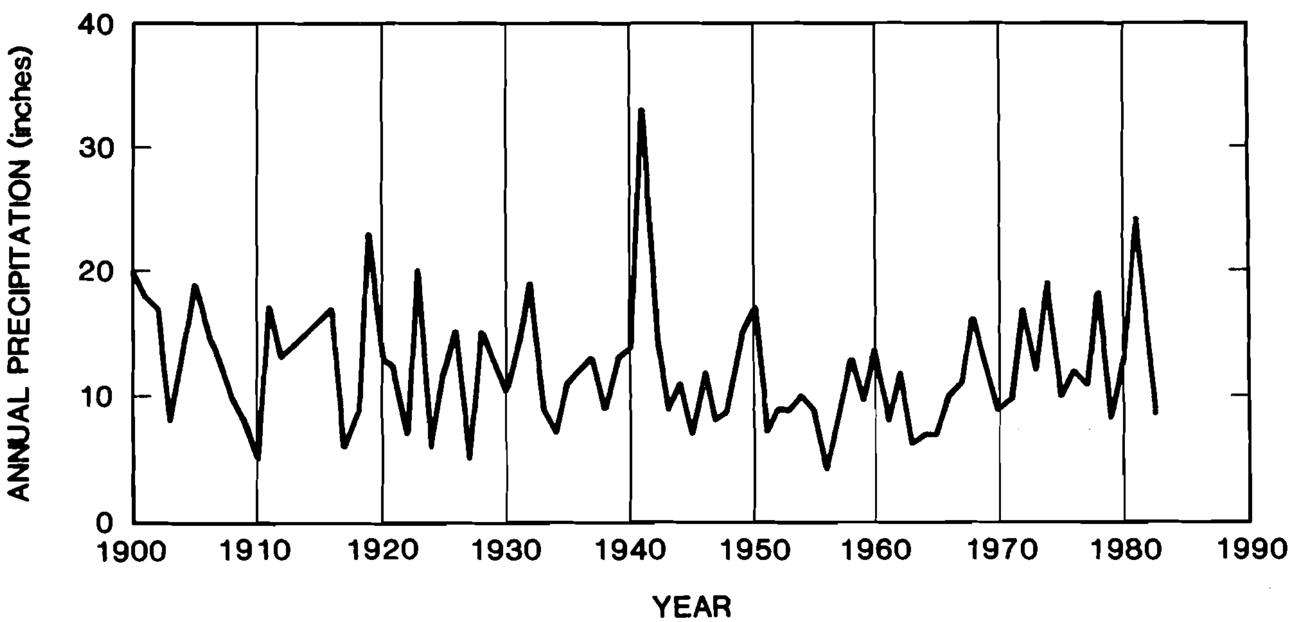


Figure 2. Precipitation at Roswell, New Mexico, 1900 to 1982 (after Geohydrology Associates, 1978b)

Table 1. Precipitation In and Near the Study Area (compiled from Geohydrology Associates, 1978b; National Resources Planning Board, 1942; and NOAA)

Station	Mean Annual Precipitation (in.)	Years of Record Through 1982
Chaves County		
Roswell	10.61 (N)	1878 through 1982
Eddy County		
Artesia	10.44 (N)	1905 through 1907, 1910 through 1982
Carlsbad	11.91 (N)	1889, 1891, 1894 through 1948, 1951, 1953 through 1982
Carlsbad FAA	11.25 (M)	1949 through 1982 (1955 through 1980)
Duval Potash	14.21 (M)	1955 through 1967, 1969 through 1982 (1955 through 1982)
Lake Avalon	11.01 (N)	1914 through 1978
Lakewood	9.67 (M)	1912 through 1928
Loving	11.88 (M)	1918 through 1939, 1945
Otis	11.84 (M)	1909 through 1913
WIPP	13.53 (M)	1976 through 1980 (1977 through 1979)
Lea County		
Eunice	12.42 (M)	1929 through 1935 (1931 through 1933)
Hobbs	14.36 (N)	1913 through 1930, 1932 through 1935, 1938 through 1982
Jal	11.67 (N)	1919 through 1921, 1923 through 1927, 1932 through 1933, 1941 through 1982
Maljamar	14.51 (M)	1947 through 1982 (1955 through 1982)
Ochoa	11.17 (N)	1943 through 1946, 1949 through 1950, 1953 through 1982
Pearl	13.32 (N)	1906 through 1908, 1917, 1919 through 1922, 1927, 1930, 1932 through 1948, 1950, 1952 through 1982

N = Normal precipitation (i.e., mean of years 1941 through 1970, given by NOAA)
M = Mean precipitation for the years indicated in parentheses or for total years of record

Table 2. Monthly and Annual Precipitation Summary for the WIPP Site
[Matejka, 1977; Pocalujka, Babij, and Church, 1979a, b, c; and Pocalujka, Babij, Catizone, and Church, 1980a, b; 1981a, b. Monthly data are given in centimeters; annual totals are given in centimeters and inches (in parentheses).]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1976	—	—	—	—	3.83	0.56	4.83	2.92	8.36	1.70	0.28	0.00	—
1977	0.62	0.18	0.97	1.39	3.65	2.78	1.76	1.45	5.32	5.13	0.49	0.01	23.75 (9.35)
1978	0.19	1.10	0.19	0.50	4.13	9.50	1.60	5.10	13.18	3.38	8.92	1.66	49.45 (19.47)
1979	0.33	1.49	0.10	0.38	5.64	4.42	8.05	5.18	1.30	0.00	0.43	2.57	29.89 (11.77)
1980	1.93	0.48	—	—	—	—	—	—	—	—	—	—	—

An attempt has been made to approximate the long-term mean precipitation at the WIPP site in the following way. First, the mean departure from normal for the seven stations for which normals are available was calculated for each year of WIPP record (Table 3a). The mean departure was subtracted from the WIPP precipitation for each year, to give an adjusted precipitation. The mean of these three adjusted precipitations is called here the "mean adjusted precipitation." The mean adjusted precipitation for the years 1977 through 1979 also was calculated for each of the seven stations (Table 3b). In six cases, the mean adjusted precipitation was nearer the normal precipitation than was the mean for 1977 through 1979. Presumably, the mean adjusted precipitation for the WIPP site, 10.91 in., is also nearer the long-term mean precipitation than is the mean for 1977 through 1979.

Because precipitation data are so sparse in the interior of the study area, the data could be contoured in many ways. Figures 3a, 3b, and 3c show three possible interpretations of the data. Figure 3a displays contours based on the two assumptions that the WIPP mean is representative of the long-term mean and that all points between Duval Nash Draw Mine and Maljamar 4SE have more than 14 in. of average annual precipitation. Figure 3b assumes that the mean adjusted WIPP precipitation is more representative of the long-term mean than the 3-yr mean and that the precipitation at Duval Potash Mine is high because of a localized orographic effect: the Duval station is on Nimenim Ridge, overlooking the southeast portion of Clayton Basin. Figure 3c, taken from Tuan and others (1973), has a large contour interval. The US Department of Commerce (1968, p 51) gives 225 million gallons of water per square mile (12.95 in.) as the mean annual precipitation in the study area.

Calculating the volumes of precipitation falling on the study area that would be indicated by each of the contour maps and by the Department of Commerce number may provide an indication of the uncertainty associated with available precipitation data. The volume indicated by Figure 3a is 1,292,000 acre-feet per year (ac-ft/yr) for the main part of the study area and 187,600 ac-ft/yr for San Simon Swale. The volume indicated by Figure 3b is 1,241,000 ac-ft/yr for the main part and 168,500 ac-ft/yr for San Simon Swale. The volume indicated by Figure 3c is 1,317,000 ac-ft/yr for the main part and 155,700 ac-ft/yr for San Simon Swale, assuming 13 in. of precipitation annually. The Department of Commerce number gives 1,312,000 ac-ft/yr for the main part and 192,000 ac-ft/yr for San Simon Swale. The mean value for the total study area is 1,466,450 ac-ft/yr.

The uncertainty in long-term average total precipitation is thus at least 76,000 ac-ft/yr, or ~6%, for the main part of the study area, and 36,300 ac-ft/yr, or ~20%, for San Simon Swale. This uncertainty is not caused by errors in the data, but rather by sparsity of and resulting ambiguities in the data. Annual precipitation is measured at most stations to the nearest 0.01 in. Many of the stations have many years of record, so that the mean or normal precipitation is probably representative of the true long-term average. However, the sparsity of the data allows great leeway in interpreting the amount of precipitation falling at points away from the stations, and thus gives rise to considerable uncertainty.

Table 3. Data Used to Calculate the WIPP Mean Adjusted Precipitation

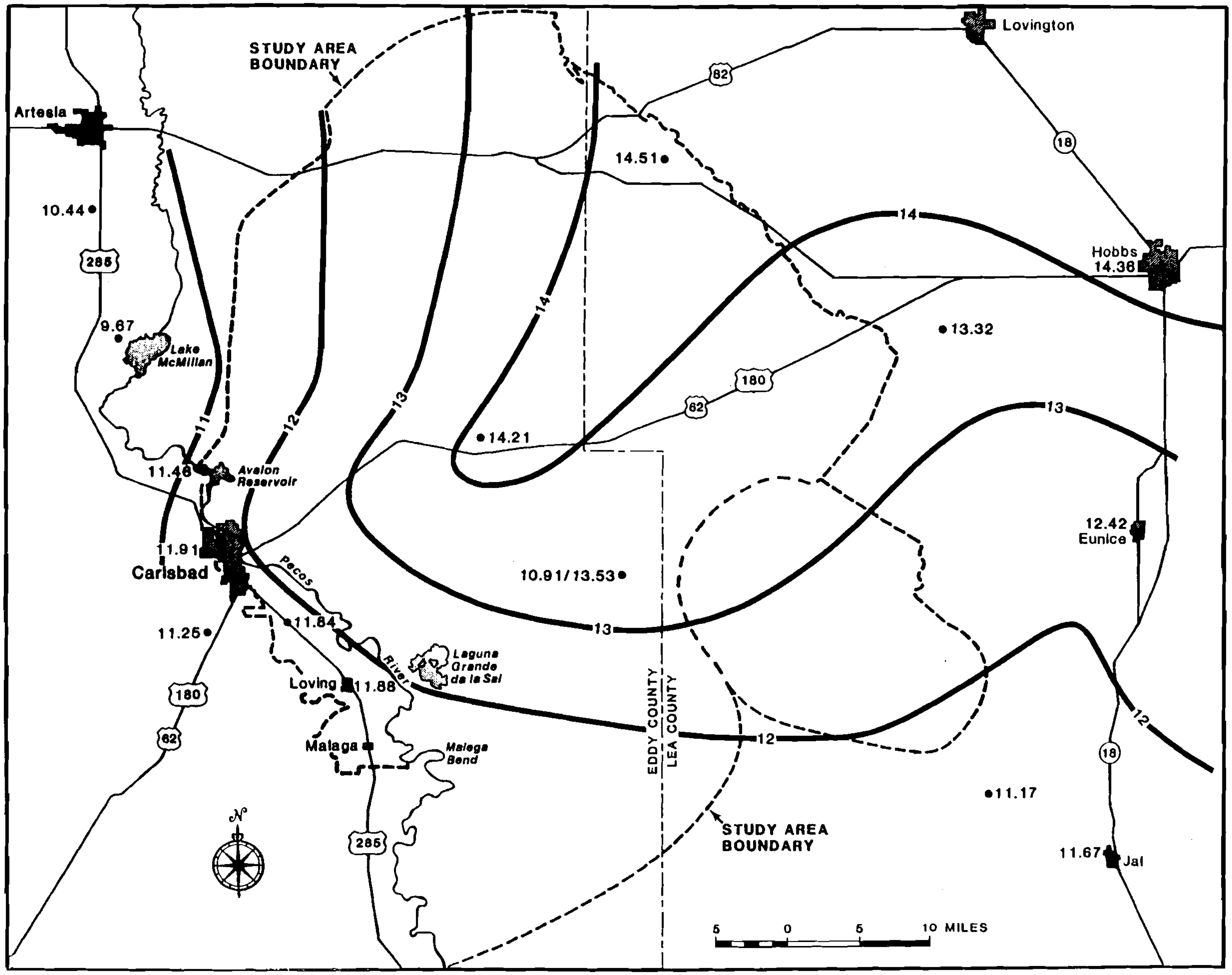
a. Departures from normal, in inches, at seven nearby stations, 1977 through 1980 (NOAA)

	Year			
	1977	1978	1979	1980
Hobbs	−2.10	6.37	0.47	5.33
Jal	−2.93	5.53	—	3.56
Ochoa	−4.43	11.72	1.01	2.51
Pearl	−3.90	4.15	−0.63	1.64
Roswell WSO	0.34	7.64	−2.08	2.59
Artesia 6S	3.29	15.11	2.17	5.63
Carlsbad	0.88	11.59	0.58	7.51
Mean of Departures	−1.26	8.87	0.25	4.11
Adjusted WIPP Precipitation	10.61	10.60	11.52	—

b. Mean adjusted precipitation, in inches, at seven nearby stations, 1977 through 1979

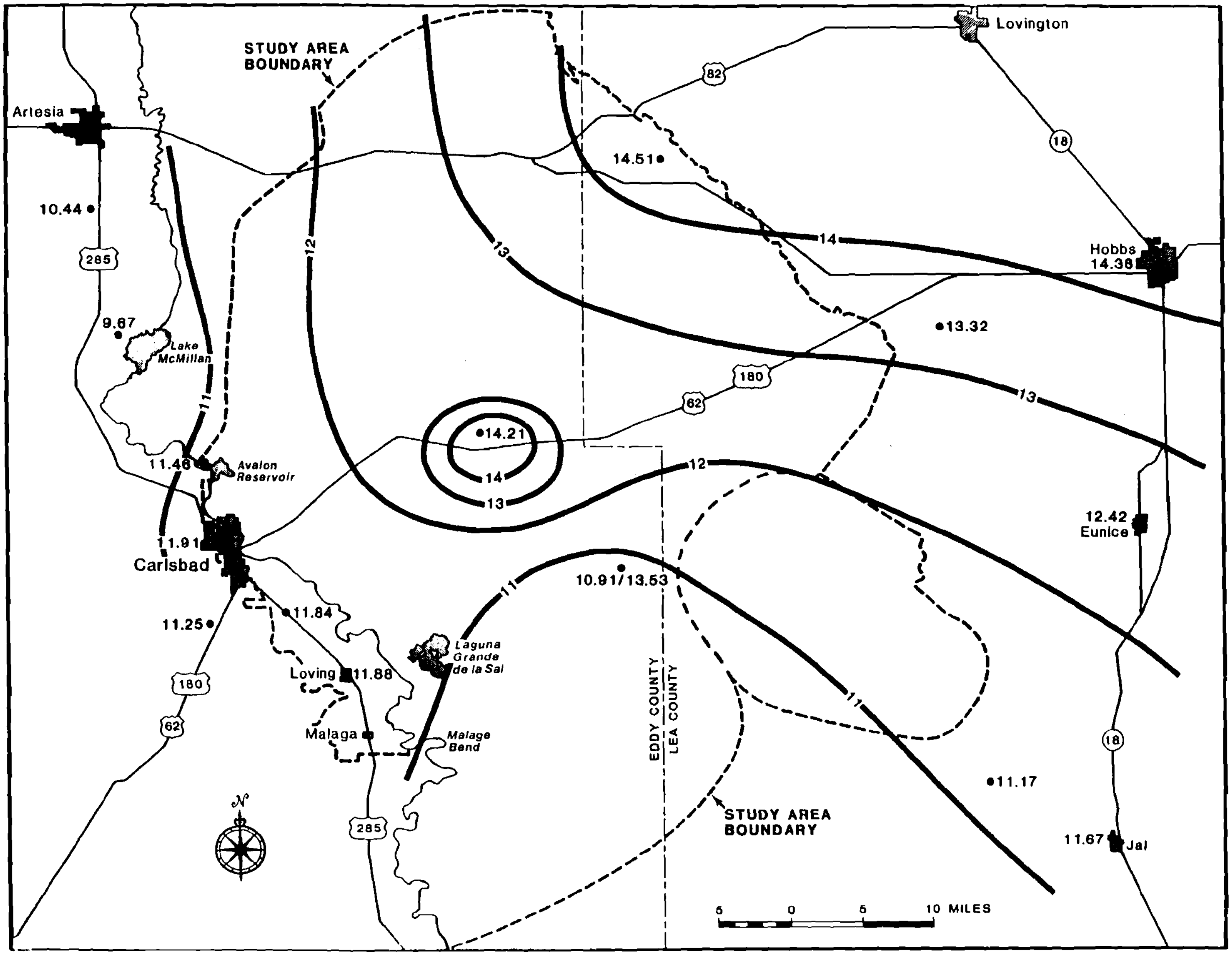
	Precipitation			% Adjusted Precipitation Varies From Normal	% Mean Precipitation Varies From Normal
	Normal	Mean	Adjusted		
Hobbs	14.36	15.94	13.32	−7.2	+11.0
Jal*	11.67	13.72	9.82	−15.9	+17.6
Ochoa	11.17	13.94	11.31	+1.3	+24.8
Pearl	13.32	13.19	10.57	−20.6	−1.0
Roswell WSO	10.61	12.57	9.95	−6.2	+18.5
Artesia 6S	10.44	17.30	14.68	+40.6	+65.7
Carlsbad	11.91	16.26	13.64	+14.5	+36.5

*Based on the years 1977, 1978, and 1980



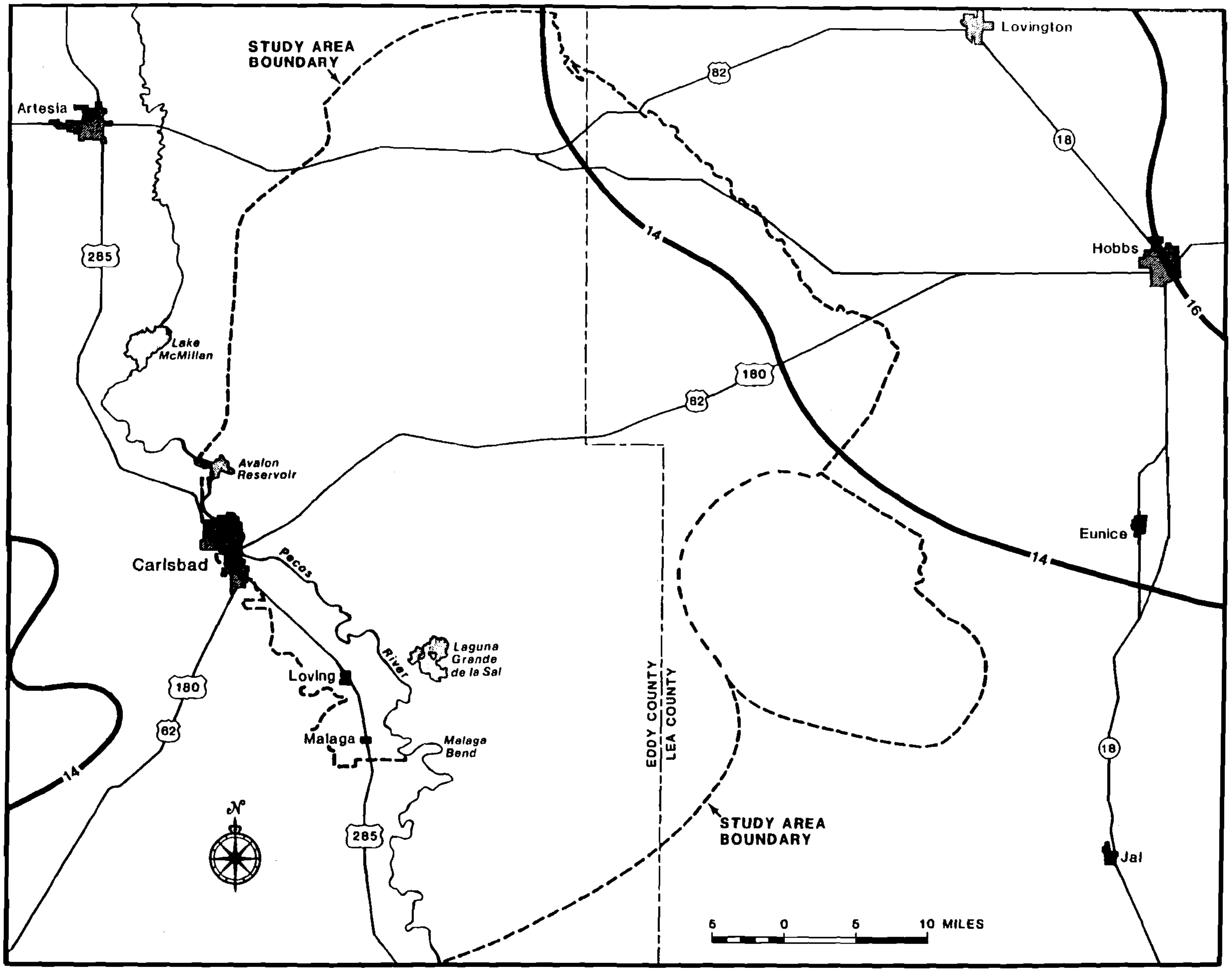
(a) Contours Reflecting the WIPP Mean Precipitation

Figure 3. Precipitation Contours In and Near the Study Area



(b) Contours Reflecting the WIPP Mean Adjusted Precipitation and Assuming Localized Orographic Effects Near Duval Nash Draw Mine

Figure 3. (Continued)



(c) Contours Published by the New Mexico State Planning Office (Tuan and others, 1973)

Figure 3. (Concluded)

Irrigation

Irrigated agriculture used 78% of the surface and ground water withdrawn in 1980 in Eddy County (Sorensen, 1982, p 21). About 80% of the water used for irrigation in the study area comes from surface water; in consequence, all irrigated acreage is near the Pecos River. Water is withdrawn from the Pecos or Black Rivers or from aquifers and applied to crops. Much of the water evaporates or is transpired by the crops. Some is incorporated into the crops. About one-third of all water withdrawn returns to the Pecos River or to the alluvial aquifer. Although only about 2% of the study area is irrigated, irrigation profoundly affects the flow of the Pecos River and thus the water budget as a whole.

About 27,700 acres of the study area are irrigated (Figure 4). Of this acreage, ~25,000 acres are included in the Carlsbad Irrigation District (CID). Mr. Oral Nichols, Manager of the Carlsbad Irrigation District, has described the flow of water into and within the District (pers. comm., 12/7/83 and 1/17/84). Most of the water for the Irrigation District is diverted from Lake Avalon and transported to the cropland through the Carlsbad Main Canal. The remainder of the surface water delivered to the District comes from a small entitlement of 2800 ac-ft/yr out of the Black River. Some water from the Pecos River is channeled through the Main Canal and the Black River Supply Ditch into a small artificial pool in the Black River. From the pool, it is channeled out of the Black River through the Black River Ditch, on the south side of the river. In addition to the 2800 ac-ft delivered to the CID, the District diverts 100 ac-ft/yr through the Black River Ditch for delivery to the Larremore Lands and also delivers Black River water to Willow Lake (not a part of CID) during flood flows, following completion of CID's diversion entitlement.

Mr. Nichols also explained the column headings in the Bureau of Reclamation reports that include data on the Carlsbad Irrigation District (Table 4). Net supply includes flow from Lake Avalon through the Carlsbad Main Canal and the diversion from the Black River. Operational spills normally return directly to the Pecos or Black Rivers. Transportation losses include seepage from canals and laterals before delivery to the farms and evaporation. Mr. Nichols reports that "Miscellaneous" accounts for the Larremore Lands and Willow Lake deliveries.

Table 4. Water Distribution in the Carlsbad Irrigation District

		Acre-Feet						
						Delivered to Farms		
Year	Irrigated Acres	Net Supply	Operational Spills	Transportation Losses	Misc.	Total	Per Acre	Source
1969	22,216	79,433	267	26,746	—	52,420	2.36	US Bur. Rec., 1970
1970	22,190	73,580	135	25,193	—	48,252	2.17	US Bur. Rec., 1971
1973	21,529	101,868*	1710*	25,086	2867	72,205	3.35	US Bur. Rec., 1974
1974	21,850	57,521	1014	14,727	2274	39,506	1.81	US Bur. Rec., 1975
1975	21,453	70,556	984	21,299	1624	46,649	2.17	US Bur. Rec., 1976
1976	21,490	38,800	5	12,795	329	25,671	1.19	US Bur. Rec., 1977
1977	20,999	41,426	27	15,837	689	24,873	1.18	US Bur. Rec., 1978; CID records
1978	20,705	60,683	69	18,782	2303	39,529	1.91	CID records
1979	21,854	77,381	44	21,397	3476	52,464	2.40	US Water & Power Resources, 1982
1980	21,354	80,254	43	22,235	1906	56,070	2.36	US Bur. Rec., 1981; CID records
1981	20,545	47,669	—	12,848	2215	32,606	1.59	US Bur. Rec., 1982a; CID records

*Estimated

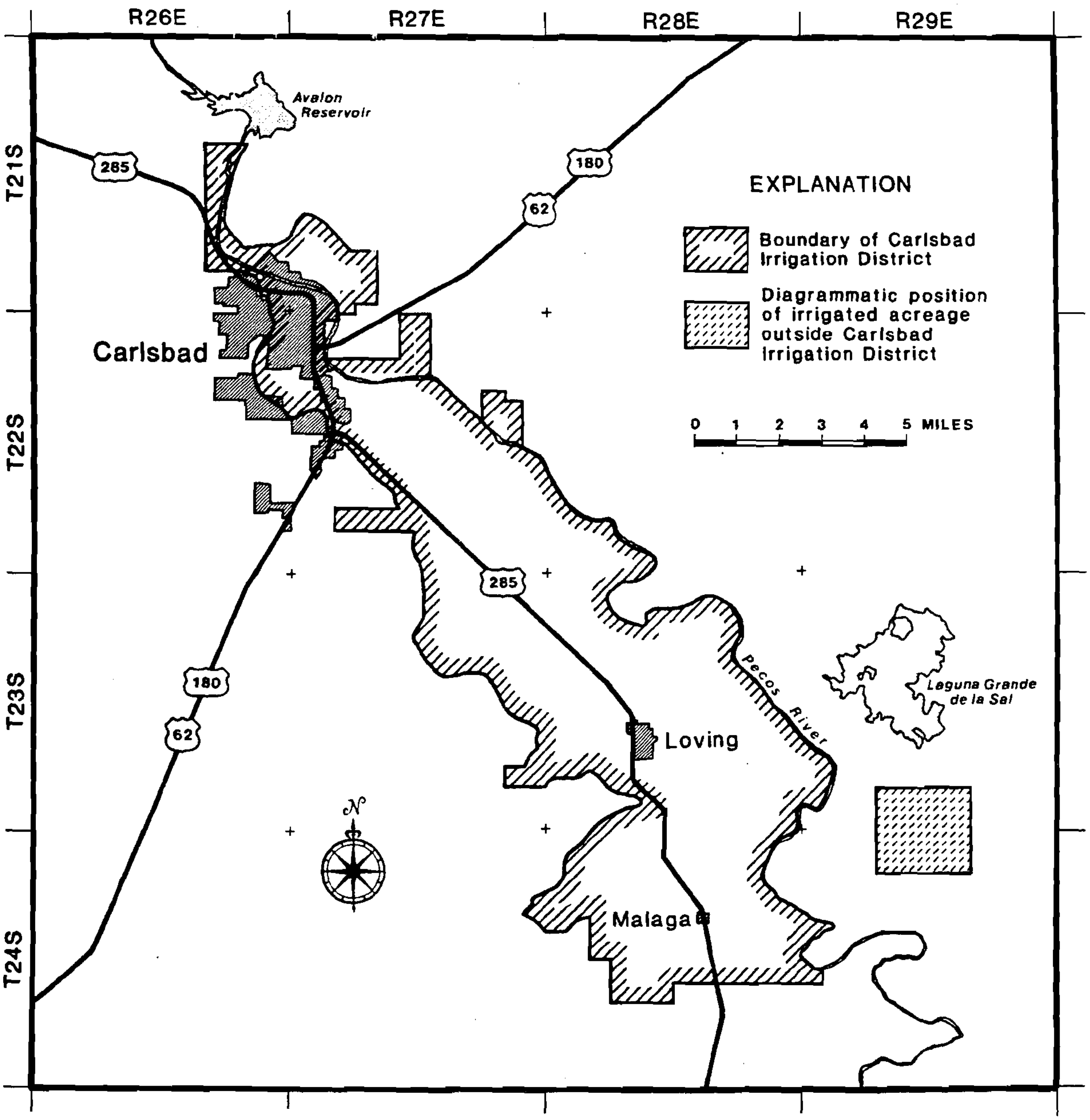


Figure 4. Irrigation in the Study Area

According to Mr. Nichols, about two-thirds of the farmers in the District have supplemental wells. Their water rights are limited to 3 ac-ft/ac/yr from all sources. In years during which the CID delivers 3 ac-ft/ac to the fields, the farmers are not permitted to use their wells. In most years the CID does not deliver 3 ac-ft/ac. Mr. Nichols believes that most farmers use their wells every year, but as little as possible. According to D. W. Nelson (Assistant District Supervisor, SEO, Roswell, pers. comm., 1/18/84), almost all these supplemental wells are in the alluvial aquifer. In 1980, the CID delivered 2.36 ac-ft/ac to 21,354 acres (US Bureau of Reclamation, 1981). If the acreage was also irrigated from wells for a total of 3 ac-ft/ac, then 13,670 ac-ft of well water was used. A 58.8% depletion (see below) would have been 8000 ac-ft.

According to Mr. Nichols, the fields in the CID are flood-irrigated, but there is no tail-water system to return excess water to the river by means of canals or ditches. Return flow to the Pecos River is by direct infiltration to the shallow ground water and then by ground-water flow into the river.

Much of the water delivered to irrigated crops is lost from the local hydrologic system by evaporation from the ground surface or surface water, transpiration by the crop, and incorporation into plant material. The State Engineer Office (Sorensen, 1982, Table 9) estimated that in 1980 the total water withdrawal for irrigated agriculture in the CID was 95,040 ac-ft, and the depletion was 55,860 ac-ft, or 58.8%. In that case, 39,180 ac-ft returned to the Pecos River or to its associated alluvial aquifer.

Outside the Carlsbad Irrigation District, only ~3200 acres, located in Townships (Ts.) 22, 23, and 24 S., Ranges (Rs.) 28, 29, and 30 E., are currently irrigated in the study area, according to Mr. Dan Liesner, the Eddy County Extension Agent (pers. comm., 1/4/84). The Harroun farm and three others have ~2000 acres of alfalfa under cultivation. Another 1200 acres are also irrigated near the Harroun Farm. The Harroun Canal diverted 7965 ac-ft for the irrigation of Harroun Farm in 1980, and ~1800 ac-ft for Western Farms (D. W. Nelson, pers. comm., 1/18/84). Of this total, ~890 ac-ft were considered to be transportation losses. Total return flow to the Pecos River was ~4000 ac-ft. There is no unirrigated farming in Eddy County, according to Mr. Liesner.

As discussed above, ~27,700 acres of the study area are irrigated, all in Eddy County. The total amount of water applied to the acreage is assumed to be 3 ac-ft/yr/ac, because this is the amount farmers in the Carlsbad Irrigation District usually have rights for (Oral Nichols, Manager of the Carlsbad Irrigation District, pers. comm., 1/17/84). The depletion for irrigated acreage in the CID was 58.8% of the total withdrawal (Sorensen, 1982). Thus evapotranspiration from irrigated lands was ~48,900 ac-ft in 1980. None of the study area in Lea County is irrigated (Wallace Cox, Lea County Extension Agent, pers. comm., 1/4/84).

Municipal and Rural Water Usage

Municipalities and water users' cooperatives in the study area use ground water to supply the needs of their citizens. Much water comes from the Capitan Limestone (Ls.) or the Ogallala Fm., and thus is imported into the study area. Some water comes from the alluvial aquifer along the Pecos River. Half of the water pumped is used consumptively. Most of the remainder returns to the alluvial aquifer and the Pecos River.

The only large municipality in the study area is Carlsbad. Most of the city's water comes from the Capitan Ls. According to Mr. Claude Tabor, the City Administrator (pers. comm., 1/13/84), the city pumped 2,738,770,000 gal (~8404 ac-ft) from the Capitan Ls. in 1980. In the same year, the effluent discharged into the Pecos River from the sewage treatment plant was 1,041,910,000 gal (~3198 ac-ft). The City of Carlsbad also has water rights for the evaporation from a recreational lake and for irrigation of the golf course from sources other than the Capitan. In 1980, the city diverted 393.9 ac-ft of water either from a shallow aquifer or from the Pecos river for the golf course (D. W. Nelson, pers. comm., 1/18/84). Carlsbad's total 1980 withdrawal from all sources was 9595 ac-ft, and the depletion was 4798 ac-ft (Sorensen, 1982, p 43).

Mr. Bill Sherrell, Manager of the Happy Valley Water Cooperative, has supplied information about water usage by the co-op (pers. comm., 1/19/84). The co-op serves an area immediately west of Carlsbad, abutting the Carlsbad city limits. The water comes from a deep well in the Capitan Ls. Most or all of the water users have septic tanks. Happy Valley's 1980 withdrawal was 90 ac-ft, and the depletion 45 ac-ft (Sorensen, 1982, p 43).

Mr. Bill Bunten, President of the Otis Water Users Cooperative, stated that the co-op's water comes from shallow alluvial wells (pers. comm., 1/19/84). Most or all of the users have septic tanks. The Otis withdrawal in 1980 was 441 ac-ft, and the depletion 220 ac-ft (Sorensen, 1982, p 43). According to Mr. Bunten, the 1983 usage was 798.58 ac-ft, out of a total water right of 852.39 ac-ft. Carlsbad has recently annexed part of the area served by the co-op. The co-op is planning to sell that part of the system serving the annexed area to the City of Carlsbad. The co-op will purchase water from the City of Carlsbad to serve about 90 users when the sale is made. The co-op expects to be supplying the same amount that they are currently pumping over the next few years.

Mr. Pat Darcy, Manager of the Loving Water Department, stated that Loving is currently supplying ~498 water meters in Loving, ~500 meters in Malaga, and ~30 meters for farmers outside Loving (pers. comm., 1/19/84). Loving is pumping ~430 ac-ft of water, out of a total water right of ~860 ac-ft. Most of the people in Loving are on a sewage system. According to Shirley Talbot, Office Manager of the Malaga Water Users Cooperative (pers. comm., 1/19/84), most of the people in Malaga use septic tanks. The Loving withdrawal was 217 ac-ft in 1980, and the depletion 108 ac-ft (Sorensen, 1982, p 43).

Mor-West Company is a private corporation that pumps water from the Ogallala Fm. and sells water to Caprock Water Company, a public utility; to the City of Carlsbad; and to Mescalero Ridge Water Cooperative (Jim Morgan, pers. comm., 1/19/84). Water is supplied to Loco Hills by Caprock. According to Mr. Morgan, Manager of Caprock, the company supplies a total of ~4000 bbl/day (188 ac-ft/yr) to Loco Hills and other rural domestic users and a maximum of ~50 bbl/day (2.4 ac-ft/yr) for stock water. Mor-West sells a maximum of ~500 bbl/day (240 ac-ft/yr) to Mescalero Ridge Water Co-op for use in Maljamar. The water sold to Carlsbad is used in water-flooding operations by the oil industry (described in the section on Water Usage by the Oil Industry). Sorensen's (1982) values for rural withdrawal and depletion for Eddy and Lea Counties give depletion rates of 50%. Thus, of the 190 ac-ft/yr of Ogallala water imported by Caprock, 95 ac-ft can be considered depletion and 95 ac-ft recharge.

Most of the stock tanks at permanent water supplies in the study area have a concrete bottom and steel sides (Mr. Dan Liesner, pers. comm., 1/20/84). Stock water in these tanks is presumed here to be used 100% consumptively rather than to provide any recharge. The many earthen structures designed to catch rainwater and other runoff for temporary livestock water in the area do provide some recharge.

Fifty percent of the total municipal withdrawal of 10,343 ac-ft for Carlsbad, Happy Valley, Otis, and Loving was depleted in 1980 (Sorensen, 1982). Total evapotranspiration in 1980 was 5171 ac-ft. The remaining 5171 returned to the alluvial aquifer and the Pecos River. Including the water imported by Mor-West Company, the total municipal evapotranspiration was 5266 ac-ft in 1980.

Water Usage by the Potash Industry

Potash refineries are major users of water in the study area. Potash-industry usage and its impact on the hydrology of Clayton Basin, Nash Draw, and the Pecos River was recently studied in detail for the Bureau of Land Management (Geohydrology Associates, 1978b, 1979). In 1978, the potash industry imported 19,768 ac-ft of water into the area (Geohydrology Associates, 1978b). In addition, 887 ac-ft/yr is pumped from the Rustler by Amax (Geohydrology Associates, 1978b). The water, after use in refining operations, is dumped onto large spoil piles, where some of it evaporates. Below the spoil piles are large unlined spoil ponds, where more water evaporates. Water seeps from some of the ponds, recharging the water table locally. The relative amount of water that evaporates, versus the amount that seeps from the ponds and joins the water table, is highly sensitive to local geology and hydrology. The ponds investigated allow 43% to 87% of the plant discharge to seep into the water table. For three companies, the data available to Geohydrology Associates were inadequate to estimate relative evaporation and seepage.

Some of the brine that seeps from the ponds reappears at the surface elsewhere, in either natural or newly created ponds, allowing further evaporation. It is difficult to separate the natural discharge of ground water in Clayton Basin and Nash Draw from the secondary appearance of industrial brine at the surface. This section treats only evaporation from the spoil piles and spoil ponds proper; evaporation from other wetlands and lakes, whether natural or industrial in origin, is discussed in the section on Evapotranspiration from Rangeland and Brine Lakes. Table 5 describes the use of water by the potash industry in 1978.

Mr. Eddie Lyon of the Carlsbad Department of Development (pers. comm., 1/3/84) has supplied the following current information on the potash industry in the study area. Five of the potash companies are using about the same amount of water that they were using in 1978, although Duval Potash Company has cut back its operation slightly over the last few years. In 1980, all the companies were still operating. National Potash Company discontinued operation in February 1982, and Mississippi Chemical Company discontinued operation in January 1983. Both companies retain their water rights, and Mississippi Chemical still has good ore reserves. Kerr-McGee has a lease with option to buy the facilities, water rights, and

Table 5. Water Usage by the Potash Industry (Geohydrology Associates, 1978b)

a. Volumes of water imported and discharged

Company	Volume Imported (gpm)	Volume Discharged (gpm)
Amax	1400	1900* (net 1350)
Duval	1343	1278
Kerr-McGee	1600	1440
PCA	2750	2550
IMC	3605	3244
National	700	616
Mississippi	855	1700† (net 800)

b. Volumes of water seeping from ponds

	Geohydrology Estimate		
Company	Seepage as % of Plant Discharge	Seepage (gpm/ac-ft/yr)	Company Estimate of Seepage (gpm)
Amax	87	1109/2675.8	1012
Duval	64	822/1325.2	259
Kerr-McGee	54	778/1264.0	—
PCA	43	—/1780.2	—

*Amax pumps 550 gpm from the Rustler Fm. on the site
†MCC recycles 900 gpm from the ponds.

mines of National. In January 1984, Kerr-McGee was using some of the National facilities, but not using National water for refining. During 1983, Amax and Potash Company of America shut down their operations for ~2 or 3 months, but began operations again after these limited periods. According to Mr. Lyon, ore reserves are still ample in the region.

Geohydrology Associates (1978b, p 59) calculated the total 1978 evaporation from the potash spoil piles and ponds (taking Laguna Uno as the IMC pond) to be 11,950 ac-ft. The remainder of the imported water, 7818 ac-ft, seeped from the ponds. These figures are somewhat uncertain because data were inadequate to calculate the evaporation and seepage from three of the seven potash refineries. None of the four refineries for which data are available is located in Nash Draw; the percentage of water seeping from ponds in Nash Draw may be significantly different from the percentage in Clayton Basin or on the ridges. In addition, brine is known to leave Laguna Uno (the IMC pond) by surface-water flow (Geohydrology Associates, 1978b, p 73).

Water Usage by the Oil Industry

The oil industry produces large volumes of brine and consumes large volumes of fresh water in the study area. However, apparently very little of this production and consumption affects the aquifers above the Salado Fm.

Most of the oil- and gas-producing formations below the Salado Fm. also contain brine. As the oil, gas, and brine are removed from the formation, water is reinjected into the formations. These water-flooding operations accomplish two purposes. First, they allow the extraction of more oil and gas than could be produced without the maintenance of hydraulic pressure in the formation. Second, they provide a convenient disposal mechanism for the produced brine, which cannot legally be disposed of on the surface except under certain circumstances. Some water must be added to the system, of course, to replace the oil and gas. This water is called "makeup water." Apparently none of the oil and gas companies are currently obtaining makeup water from the aquifers above the Salado in the study area. Conversations with several oil company representatives indicated that all of the makeup water seems to come from the Ogallala or Capitan aquifers, either directly or in the form of effluent from the Hobbs municipal sewage treatment plant. One company, Maralo, has rights to some shallow water near Jal, which they use occasionally when their other supply wells are down (Cecil Evans, Maralo Inc., pers. comm., 12/22/83).

Both the New Mexico Oil Conservation Division (OCD) and the oil companies (e.g., Joe Ramey, OCD, pers. comm., 12/21/83) maintain that the boreholes do not allow leakage of water or oil into or out of the formations above the Salado. The wells are monitored annually by OCD and, at least in the case of Shell (the operator for the North Hobbs Water Flooding Unit), quarterly by the company itself (Mr. Welton Moore, Shell, pers. comm., 12/21/83).

In Clayton Basin and Nash Draw, there is little or no potable ground water above the Salado Fm. The New Mexico Oil Conservation Commission (OCC) has thus found (OCC, 1968a) that the protections ordinarily provided to near-surface ground water would not be advanced by prohibiting the disposal of salt water from oil and gas wells in pits or lakes in this area. For this reason, oil and gas wells in the area described in Table 6 are exempt from the provisions of Order No. R-3221, which prohibits disposing of oil brines on the ground surface in Lea, Eddy, Chaves, and Roosevelt Counties (OCC, 1967a, b). The Monthly Statistical Report (OCC, published monthly) records the monthly and cumulative total volumes of salt water disposed of by the oil industry; however, no disposal wells or pits are listed for the area described in Order No. R-3221-B.

Table 6. Portions of the Study Area in Which Disposal of Oil-Field Brines in Unlined Pits is Permitted (OCC, 1968a, b, c)

T. 19 S., R. 30 E.,	Sections 8 through 36
T. 20 S., R. 30 E.,	Sections 1 through 36
T. 20 S., R. 31 E.,	Sections 1 through 36
T. 20 S., R. 32 E.,	Sections 4 through 9,
	Sections 16 through 21,
	Sections 28 through 33
T. 21 S., R. 29 E.,	Sections 1 through 36
T. 21 S., R. 30 E.,	Sections 1 through 36
T. 21 S., R. 31 E.,	Sections 1 through 36
T. 22 S., R. 29 E.,	Sections 1 through 36
T. 22 S., R. 30 E.,	Sections 1 through 36
T. 23 S., R. 29 E.,	Sections 1 through 3,
	Sections 10 through 15,
	Sections 22 through 27,
	Sections 34 through 36
T. 23 S., R. 30 E.,	Sections 1 through 19

There are a few authorized disposal pits in the study area outside Clayton Basin and Nash Draw. For example, Pollution Control, Inc., accepts oil-industry brines for disposal in Laguna Gatuña, in T. 20 S., R. 33 E. In 1980, 976,604 bbl (126 ac-ft) of salt water were disposed of in Laguna Gatuña (OCC, 1980, 1981). By June 1983, the cumulative volume had reached 5,271,225 bbl (680 ac-ft) (OCC, 1983). The Laguna Gatuña area had no potable surface water before the disposal operation (Larry Brooks, District Geologist, Oil Conservation Division (OCD), Artesia, pers. comm., 1/13/84). Ray Westall operates a salt-water disposal operation at Loco Hills, Sec. 16, T. 17 S., R. 30 E., where there was no shallow ground water before the operation began (Larry Brooks, pers. comm., 1/13/84).

Oil-field brines are also disposed of into Laguna Tres and Laguna Quatro in Nash Draw (Figure 5) (Larry Brooks, pers. comm., 1/16/84). B & E, Inc. had disposed of a cumulative volume of oil-field brines of 610,149 bbl (78.65 ac-ft) into Laguna Tres and Laguna Quatro as of November 1983. B & E operates the Tuz Lu Kopeks disposal system. Unichem International, Inc. had disposed of a cumulative volume of 440,683 bbl (56.80 ac-ft) of oil-field brines into Laguna Tres as of November 1983. Unichem operates the Rattlesnake disposal system at Laguna Tres.

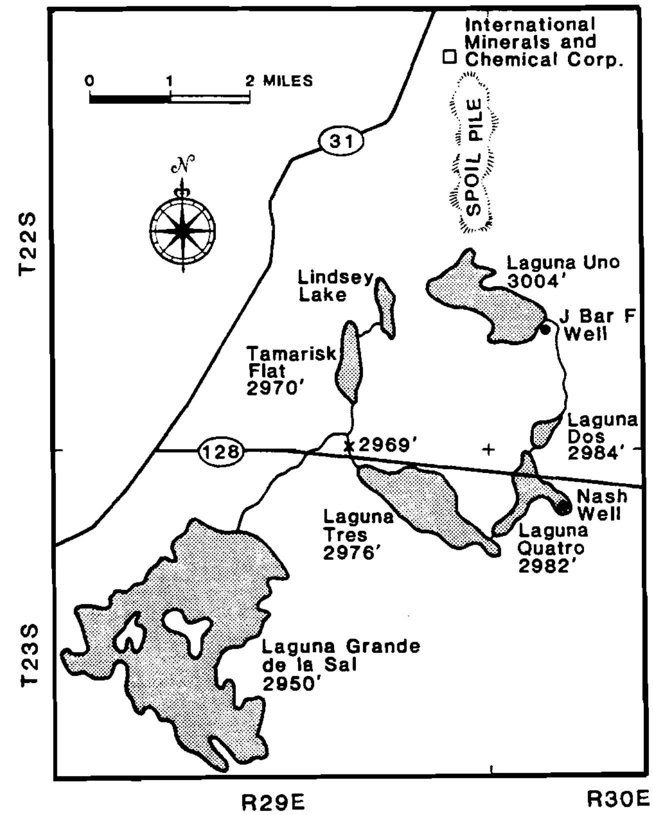


Figure 5. Brine Lakes in Southeastern Nash Draw, With Selected Water-Surface Altitudes (after Geohydrology Associates, 1979)

Thus it seems that the primary effect of the oil industry on the water budget for the study area is one of importing relatively small volumes of water. The imported water may be ultimately derived either from the rocks underlying the Salado Fm. or from the Ogallala Fm. In the latter case, Ogallala water is first pumped into the underlying rock as makeup water and then out of the oil fields as part of the produced water. The total cumulative volume of oil-field brines disposed of in the study area since records have been kept seems to be <1000 ac-ft.

Surface-Water Inflow and Outflow

Man's impact on the natural hydrologic system began almost simultaneously with the first settlement of the study area. The earliest recorded diversion of water from the Pecos River in the study area began in the 1870s (Myers, 1974). The old Nash Ditch diverted water from the Pecos River at a point near the present-day crossing of Highway 128 for irrigation of lands near the Harroun farm. In 1887, a small ditch diverted water from the Pecos River ~3 mi north of the present Avalon Dam for delivery to the La Huerta area. Construction of Avalon Dam and its associated canals and laterals began in 1889. Irrigated acreage in the Carlsbad Irrigation District reached current levels in 1918 (National Resources Planning Board, 1942, p 143). Most of the surface-water gaging stations in the area were established in the late 1930s (US Geological Survey, 1982), 50 years after the construction of Avalon Dam. Some earlier records are available for the Pecos River below Avalon Dam (15 months in 1906 and 1907) and for the Pecos River near Malaga (from 1920 to date).

The configuration of the undisturbed hydrologic system in the study area is unknown, because no technical records of surface-water flow or ground-water levels predate the substantial perturbations imposed on the natural hydrologic system by dam construction, diversions for irrigation and industry, additions by municipalities, or lowering of artesian head in the aquifers by pumpage. The current, perturbed configuration may be inadequate for modeling the flow of water between the WIPP site and the accessible environment, however, because it depends on such ephemeral human activities as potash refining and storage of water for irrigation. It may also be inadequate to construct a water balance, if the hydrologic system is very far out of equilibrium. Some attempt must be made to reconstruct the natural hydrologic system and to assess how much the current and natural systems differ.

The amount of water that flows through any section, or "reach," of a stream is a function of several variables (Figure 6). Gaging stations, which measure the flow past a given point, are convenient control points for the upstream and downstream ends of a reach. A reach gains surface water from its tributaries, which may or may not be gaged, and from direct runoff of rainfall along the banks. Some rainfall, of course, falls directly into the river. Rainfall and runoff from tributaries can vary greatly from year to year in arid environments. In addition, many streams gain water in a reach by ground-water discharge into the stream. (Streams in arid areas often lose water to the water table, but the Pecos River seems to gain ground water steadily all along its length.) Losses from a reach of a gaining stream such as the Pecos River result from evaporation from the water surface and from diversions for irrigation. The State Engineer Office estimates that in Eddy County about one-third of the diversions for irrigation ultimately return to streams by shallow ground-water flow. Evaporation from freshwater lakes or streams in the study area is estimated to be 6.1 ft/yr (Geohydrology Associates, 1978b, p 51). Combining this evaporation with precipitation slightly greater than 1 ft/yr results in net evaporative losses from lakes and streams of about 5 ft/yr. It is usually assumed that ground-water discharge to a reach is the least variable of these factors, and that low flows are a measure of ground-water discharge to a stream. The Pecos River is so highly regulated, however, that these two assumptions may be invalid. The primary aim of the following discussion is to determine bounds for the normal ground-water discharge to the Pecos River in the study area.

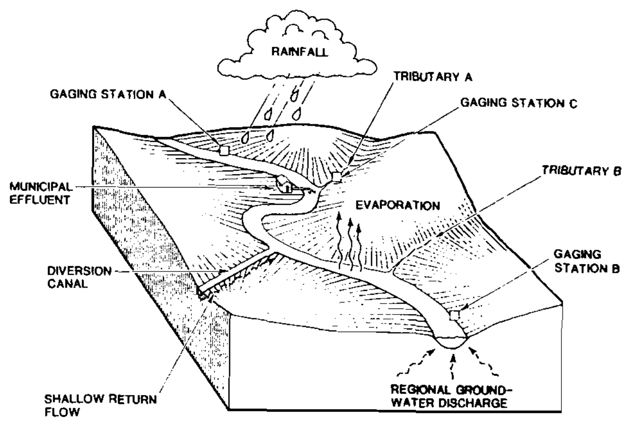


Figure 6. Inflow and Outflow to a Reach of a Stream

Ground-water discharge into a reach of the Pecos River in the study area can be calculated as

$$Q_g = \Delta Q_s + E + I - R - M - S \qquad (2)$$

where

Q_g = the ground-water discharge to the reach
ΔQ_s = the change in flux in the river between gages at the ends of the reach
E = the net evaporative loss
I = the diversion for irrigation
R = the return flow from irrigation
M = the return flow or direct addition of municipal effluent
S = surface runoff.

It appears impossible to determine the ground-water discharge to the Pecos River in the study area using the currently available data. Of the terms in Eq (2), ΔQ_s and I are known reasonably accurately, but both are large relative to Q_g. Evaporation, E, can be estimated reasonably well. The other terms, R, M, and S, can only be roughly estimated. The ground-water discharge can be bounded, however. Eq (2) gives an upper bound, assuming that the surface runoff is greater than the gaged runoff (almost certainly correct) and that R and M are not too inaccurate. A more certain, but much larger, upper bound can be obtained by neglecting R and M. Because some ground-water discharge to the Pecos River is known to be very high in dissolved solids, a reasonable lower bound can be obtained by assuming that the increase in dissolved solids in any reach results entirely from the discharge of saturated brine into the river.

Because the Pecos River probably also receives ground-water discharge from the aquifers to the west of the study area, both lower and upper bounds are probably higher than the volumes discharged to the river from the study area alone.

Pecos River Flow, 1980 (Table 7, Figure 7)

In 1980, 90,060 ac-ft of surface water flowed into the study area past station 4020, 1 mi upstream from Lake Avalon. Water flowing out of Lake Avalon amounted to 76,820 ac-ft through the Carlsbad Main Canal. Twenty-six ac-ft also flowed past station 4040 in the Pecos River below Avalon Dam. The difference, 13,214 ac-ft, is attributable to evaporation and seepage from Lake Avalon. The area of Lake Avalon ranges from ~40 to 900 acres (US Bureau of Reclamation, 1982b, p III-17). Estimated net lake evaporation is 5 ft, or 2350 ac-ft/yr, leaving an estimated seepage of

Table 7. Stream Discharge (US Geological Survey, 1982)

Abbreviated Station Number (river mile)	Location	Average Discharge (ac-ft/yr) (cfs)	1980 Discharge (ac-ft)	Extremes (maximum/ minimum) (cfs)
4020 (473.8)	1 mi upstream from flow line of Lake Avalon	113,700 (157)	90,060	~69,000/4.3
4035 (467.2)	Carlsbad Main Canal at head, 220 ft downstream from headgates of Avalon Dam	74,620 (103)	76,820	526/0
4040 (466.3)	4800 ft below Avalon Dam (station bypassed by station 4035)	23,110 (31.9)	26	~90,000/0
4051	Dark Canyon Draw, 0.6 mi upstream from mouth	6,660 (9.19)	19,680	66,000/0
4052 (459.1)	700 ft downstream from Dark Canyon Draw	36,800 (50.8)	36,910	>28,200/0
4055	Black River, 7.1 mi upstream from mouth	9,560 (13.2)	7,200	~74,600/0.73
4065 (432.2)	4.3 mi downstream from Black River, near Malaga	127,500 (176)	56,400	120,000/3.7
4070 (425.7)	550 ft upstream from Pierce Canyon Crossing	99,260 (137)	58,980	65,000/0.54
4075 (411.2)	0.2 mi downstream from Red Bluff Draw	122,400 (169)	65,060	111,000/0.19

Stations are on the Pecos River unless otherwise noted.

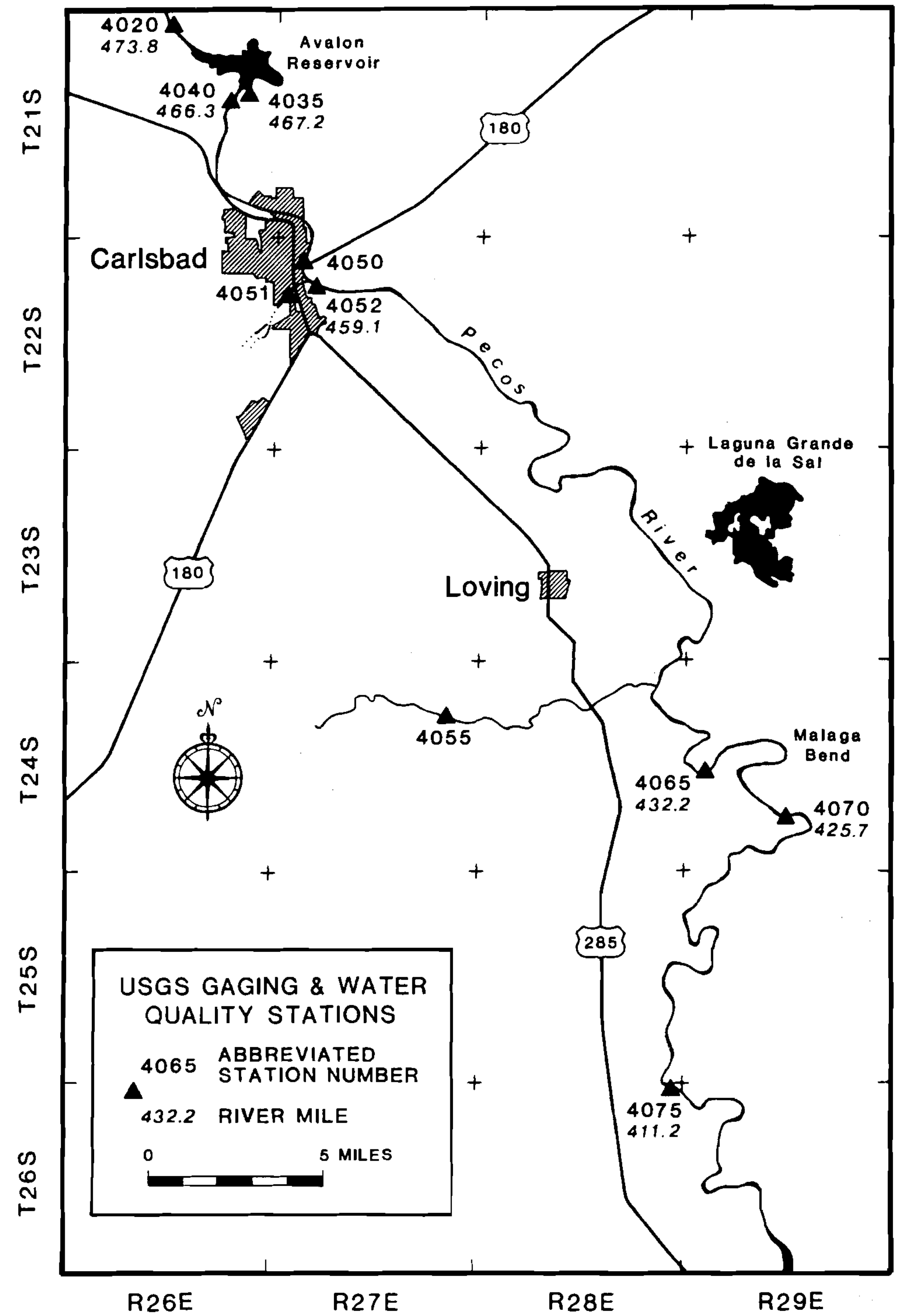


Figure 7. US Geological Survey Gaging Stations in the Study Area

10,864 ac-ft/yr. The National Resources Planning Board (1942, pp 61-62) estimated that ~26 cfs, or 18,800 ac-ft/yr, seeped under the dam in 1938-1940 and rejoined the Pecos near Carlsbad Spring, although it was thought at the time that the estimate might have been too high. The 1942 and current estimates are in good agreement.

In 1980, 19,680 ac-ft entered the Pecos River from Dark Canyon Draw. Seven hundred feet downstream from the Draw, the flow in the Pecos River was 36,910 ac-ft. Thus, disregarding evaporative losses, the 7.2-mi reach of the Pecos between station 4040 below Avalon Dam and station 4052 below Dark Canyon Draw gained 17,204 ac-ft in 1980 from "normal" ground-water discharge, from seepage from Lake Avalon that rejoins the Pecos below the dam, from return flow from irrigation, and, possibly, from direct ungaged surface runoff. The latter two contributors are probably minor. In this reach, the Pecos River is ~250 ft wide; the surface area of the reach is ~220 ac. Net evaporative losses were therefore ~1100 ac-ft. The total gain in this reach was ~18,300 ac-ft in 1980. Assuming seepage from Lake Avalon to be 10,900 ac-ft, ground-water discharge to this reach was 7400 ac-ft.

The 1980 flow at station 4065, 4.3 mi downstream from Black River, was 56,400 ac-ft. The net gain in the 26.9-mi reach of the Pecos between stations 4052 and 4065 was 19,490 ac-ft in 1980. Discharge from the Carlsbad sewage treatment plant—3198 ac-ft in 1980—enters this reach. The 1980 Harroun Farm and Western Farms diversion of ~9765 ac-ft came out of this reach. Much of the return flow from irrigation of the CID, say 20,000 ac-ft annually, enters this reach, as does municipal return flow from Otis, Loving, and Malaga (328 ac-ft in 1980). If water from Salt Lake and the potash spoil ponds enters the Pecos River, it enters this reach. The 1980 flow in the Black River above the Carlsbad Irrigation District diversion was 7200 ac-ft. The CID apparently diverted 1528 ac-ft (see Tables 4 and 7). The Willow Lake diversion was 1911.6 ac-ft (Irene Schuler, Roswell SEO, pers. comm., 5/18/84). The flow of the Black River into the Pecos thus may have been as high as 3760 ac-ft in 1980. In this reach, the Pecos River is ~250 ft wide; the surface area of the reach is ~820 acres. Net evaporative losses were therefore ~4100 ac-ft. The gain that might be attributable to ground-water inflow in this reach was therefore ~6100 ac-ft in 1980.

The 1980 flow at station 4070, upstream from the Pierce Canyon Crossing, was 58,980 ac-ft. The River gained 2580 ac-ft in the 6.5-mi reach between stations 4065 and 4070, exclusive of evaporative losses. In this reach, the Pecos River is ~125 ft wide; the surface area of the reach is ~100 ac. Net evaporative losses were therefore ~500 ac-ft. This reach may receive some irrigation return flow from the southernmost portion of the CID and from Harroun Farms, but there is little or no surface runoff or municipal return flow. The total gain in this reach was ~3100 ac-ft in 1980.

The 1980 flow at station 4075, near Red Bluff Draw, was 65,060 ac-ft. The River gained 6080 ac-ft in the 14.5-mi reach between stations 4070 and 4075, exclusive of evaporative losses. In this reach, the Pecos River is ~100 ft wide; the surface area of the reach is ~180 ac. Net evaporative losses were therefore ~900 ac-ft. Several ungaged ephemeral streams, but little or no irrigation or municipal return flow, enter the Pecos River in this reach. The total gain in this reach was ~7000 ac-ft in 1980.

The total gain of the Pecos River in 1980 that might be attributable to ground-water inflow between Avalon Dam and station 4075, near Red Bluff Draw, was 23,600 ac-ft. This quantity should provide an upper bound on ground-water discharge to the River in the study area.

Increase in Dissolved Solids

Additions to the flow of the Pecos River come from ground-water discharge, from irrigation and municipal return flow, and from surface-water inflow. Ground-water discharge to the Pecos River tends to be high in dissolved solids and in some places may be nearly saturated in sodium chloride. Irrigation and municipal return flow and surface-water inflow tend to be low in dissolved solids. A determination of the increase in the amount of dissolved solids in a reach will provide a lower bound on the ground-water discharge, assuming that the increase comes entirely from the addition of saturated brine. This assumption becomes poorer as the amount of dissolved solids from the other sources becomes greater.

The dissolved-solid load for each station has been estimated using the data in Table 8 and the formula

$$L = \sum_{1}^{12}(F_i \times C \times TDS_i \times 10^{-6})$$

where

L = the total annual load in kilograms

F_i = the instantaneous flow for month i, in cfs

C = a conversion factor to convert cfs to L/month

TDS_i = total dissolved solids in mg/L for month i. For most stations, TDS has been estimated as 105% of the sum of constituent dissolved solids, based on those stations for which both residue and sum-of-constituent values are available.

The results are presented in Table 9 and Figure 8. Errors in L arise from at least three sources. First, the instantaneous flow rate must be used as the flow rate for the entire month, and in some cases for several months. Table 9 shows both calculated and measured annual flow as an indication of the uncertainty in this calculation. It would not be wise to use these figures for a correction factor, because increased flow usually means decreased concentration of dissolved solids. Second, the sum of constituent dissolved solids is less than the total dissolved solids. Although a correction, based on samples for which both measurements are given, has been applied, the figure used may not be accurate. Third, not all the dissolved solids are sodium chloride, as assumed.

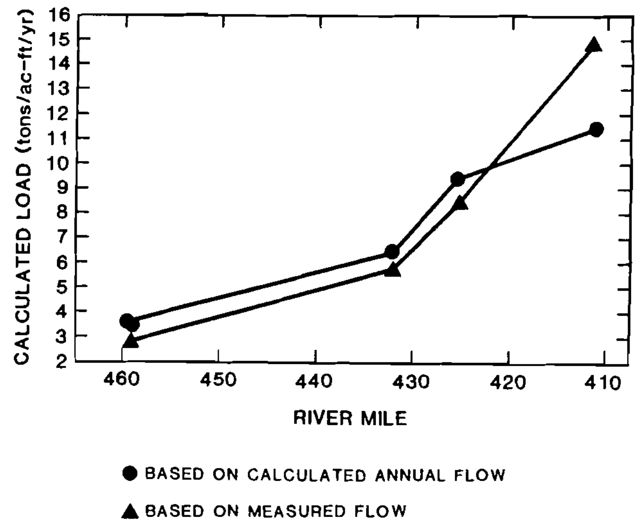


Figure 8. Increase in Dissolved Solids in the Pecos River

A saturated-water solution of sodium chloride contains ~423.25 tons of salt per acre-foot of water. The gains in dissolved solids in the Pecos River are equivalent to a minimum of ~400 ac-ft of saturated brine discharging to the River between Dark Canyon Draw and Malaga, ~240 ac-ft between Malaga and Pierce Canyon Crossing, and ~800 ac-ft between Pierce Canyon Crossing and Red Bluff Draw in water-year 1981 (Table 10). These estimates are in excellent agreement with that of Havens (1972), who found that 200 gpm (323 ac-ft/yr) of brine are discharged into the River near Malaga Bend. No dissolved-solids data are available for stations near Avalon Dam. The minimum discharge of ground water to the Pecos River between stations 4040 and 4052 is estimated to be 10% of the maximum discharge, or 740 ac-ft/yr.

Table 8. Dissolved Solids at Pecos River Stations, Water Year 1981 (US Geological Survey, 1982)

	Station									
	4050		4052		4065		4070		4075	
	Flow	TDS	Flow	TDS	Flow	TDS	Flow	TDS	Flow	TDS*
Oct 24	—	—	—	—	69	—	—	3970	67	—
Nov 19	—	—	35	2700*	78	4550*				
20							75	6370*	81	8320
Dec 16	26	2350	26	—						
17					85	4040	78	5820	81	6920
Jan 20	31	2250	31	—						
26					72	4240	72	6230	75	7250
Feb 23	25	2350	25	—						
24									45	8710
25					47	4390	43	6890		
Mar 17					68	3770	73	5990	86	6160
23	56	3020	56	—						
Apr 21	25	2060	25	—						
23					42	4560	43	7890	45	9150
May 27	30	2420								
28					21	6140*	19	11200*	17	12200
29			17	2660*						
Jun 24					19	6290	16	12400	22	12700
29	11	2790	11	—						
Jul 10	—	—	24	1300						
28					13	5940	16	11000	323	9740
Aug 20					53	3040	68	5360	80	5230
24	16	2280	17	—						
Sep 17	22	2360	—	—	28	5190	31	8200	30	8630

"Flow" is instantaneous flow in cfs.
"TDS" is dissolved solids, in mg/L, as the sum of constituents, unless otherwise noted.
*Dissolved solids, residue.

Table 9. Annual Flow and Load of Dissolved Solids for Stations Listed in Table 8, Water Year 1981

	Station				
	4050*	4052	4065	4070	4075
Calculated Load					
(kg)	5.9×10^7	5.7×10^7	2.1×10^8	3.0×10^8	6.0×10^8
(tons)	64,900	62,700	231,000	330,000	660,000
Calculated Load (tons/ac-ft/yr)	3.6	3.3	6.4	9.4	11.4
Calculated Flow (ac-ft/yr)	18,000	19,000	36,000	35,000	58,000
Measured Flow (ac-ft/yr)	—	22,160	39,310	39,530	44,610

*River mile 459.4

Table 10. Minimum and Maximum Annual Ground-Water Discharge to the Pecos River

Pairs of Stations	Gain in TDS (tons)	Minimum Discharge (ac-ft)	Maximum Discharge (ac-ft)
4040 - 4052	—	—	7400
4052 - 4065	168,300	397.6	6100
4065 - 4070	99,000	233.9	3100
4070 - 4075	330,000	779.7	7000

Uncertainty

The maximum ground-water gain to the Pecos River in the study area is 23,600 ac-ft/yr. The minimum gain is estimated to be 2200 ac-ft/yr. The uncertainty is roughly an order of magnitude. Some of the ground-water gain comes from aquifers west of the Pecos River. The relative contributions of the study area and the region to the west are unknown, but are assumed in this report to be equal. T. E. Kelly of Geohydrology Associates, Inc., believes that more ground water enters from the west side of the Pecos River than from the east, because of higher altitudes and greater precipitation to the west (pers. comm., 11/21/84). The assumption in this report of equal flow from each side of the river probably tends to overestimate ground-water flow through the study area.

Evapotranspiration from Rangeland and Brine Lakes

Evapotranspiration is a general term referring to all processes by which ground water, surface water, and water used by plants and animals return to the atmosphere. It is the largest item in this water budget, because most of the precipitation that falls in the study area returns almost immediately to the atmosphere without ever becoming incorporated into the ground- or surface-water systems, and because much of the imported water also evaporates. On unirrigated rangeland, which makes up most of the study area, much of the precipitation that does not evaporate immediately is taken up fairly rapidly by plants and transpired. Roughly half of the water used by municipalities and the potash industry and for irrigation undergoes evapotranspiration. For convenience of discussion, evapotranspiration associated with irrigation, municipal and industrial usage, and freshwater lakes and streams is not treated here. Rather, evapotranspiration has been discussed in each of those sections. Other types of evapotranspiration, such as evapotranspiration from brine lakes and unirrigated land, are discussed here in this section. Table 11 summarizes evapotranspiration from all processes.

Evapotranspiration from Rangeland

Unirrigated rangeland makes up ~98% of the main part of the study area. None of San Simon Swale is irrigated. Geohydrology Associates (1978b, p 48) reviewed the literature on evapotranspiration and found that most papers pertain to irrigated lands. Three papers (Rich, 1951; Tuan and others, 1973; Thornthwaite and Mather, 1957) were found to be useful for the Eastside Roswell Range, which includes the WIPP study area. Evapotranspiration values that seemed applicable ranged from 89% to 98%; the best value was found to be 96%. The average total evapotranspiration from unirrigated range land in the study area is thus likely to be between 1,243,000 and 1,479,000 ac-ft/yr; the best estimate is 1,408,000 ac-ft/yr.

The evapotranspiration rate of 96% applies to the region as a whole. Serious errors of calculation could arise from using 96% as an evapotranspiration rate for a small or especially uniform part of the water-balance study area. The evapotranspiration rate may be much lower, even close to zero, for parts of the study area like the point recharge sinks in western Clayton Basin (see Ground-Water Flow Near Clayton Basin). The rate is probably close to 100% in areas of ground-water discharge, such as central Clayton Basin or the area near Laguna Grande de la Sal. In addition to the uncertainty caused by the spatial variability in the evapotranspiration rate, small percentage errors in evapotranspiration clearly give rise to large percentage errors in calculated ground-water recharge. For example, if evapotranspiration is $96 \pm 1\%$ of rainfall, and recharge is $4 \pm 1\%$, then the uncertainty in evapotranspiration is only 1.04%, while the uncertainty in recharge is 25%.

Evaporation from Brine Lakes

Laguna Grande de la Sal is a natural salt lake located between Nash Draw and the Pecos River. In 1942, after some potash refinery waste had already been dumped into the lake, the total area of the lake was 1970 ac. Only the northern part of the lake, however, was perennial. The southern part of the lake contained water only when water levels became high enough to pass through the narrow constriction separating the northern and southern sections (National Resources Planning Board, 1942, p 69). In addition to rising and falling seasonally in response to changes in evaporation, the lake level responded sharply to rainfall and local runoff. Apparently the playa and salt deposits in the southern portion of the lake became completely dry to depths of 8 to 10 ft, at which depth an artesian brine aquifer with heads several inches above the land surface existed at the base of the Rustler Fm. (National Resources Planning Board, 1942, pp 70-71).

By 1979, the total area of the lake had increased to 2880 ac. According to Mr. Wayne Williamson (Plant Manager, United Salt Corp., pers. comm., 10/3/84), the amount of water in the southern portion of the lake depends strongly on precipitation. He estimates that for every 1 in. of rainfall, precipitation on and

Table 11. Evapotranspiration in the Study Area

		Water Committed or Acreage	Rate of Evapotranspiration	Total Evapotranspiration (ac-ft/yr)
Municipalities		10,533 ac-ft	50%	5,266
Potash-Related*				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%	48,900
Unirrigated Acreage†				
Main Part of Study Area	high	1,317,000	98%	1,291,000
	low	1,241,000	89%	1,104,000
	best	1,290,500	96%	1,239,000
San Simon Swale	high	192,000	98%	188,000
	low	155,700	89%	139,000
	best	175,950	96%	169,000

*Geohydrology Associates, 1978b, p 59
†Including precipitation on irrigated acreage

Note: For clarity most references or discussions justifying the tabular entries are contained in the text, rather than in the table.

runoff into the lake raise the lake level 3 in. The southern part of the lake was dry from 1979, when he first arrived, until late 1981, when high rainfall (see Appendix A) put ~3 ft of water into the lake. The lake did not dry up again until the winter of 1983-1984. In Mr. Williamson's experience, the water level never gets more than ~6 in. below the top of the salt. The salt crust is porous: even when the lake is dry, a saturated brine poured on the crust readily flows down to the water level. The lake is fed by several springs of unsaturated water in the center, but when the lake is dry, the springs often crust over and cannot be seen. When the lake level is above the springs, they are observed to dissolve the salt crust locally. The current lake characteristics, described by Mr. Williamson, are similar to those described earlier by the National Resources Planning Board (1942).

Several new brine lakes formed northeast of Laguna Grande de la Sal between 1942 and 1979, apparently as a result of potash refining and oil brine disposal in Nash Draw. The total area of the new lakes is 1745 acres.

Several factors affect an estimate of evaporation from the brine lakes. Evaporation from brine lakes is less than evaporation from a freshwater body, which in turn is substantially less than evaporation from a Class A evaporation pan (Havens, 1972). Usually only freshwater pan data on evaporation are available. Based on a review of the literature, including the work of Havens at Malaga Bend, Geohydrology Associates (1978b, p 51) concluded that a brine-lake evaporation rate of 4.4 ft/yr of brine is appropriate for use in the Nash Draw and Clayton Basin area, compared with a freshwater pan evaporation of more than 9 ft.

If 4.4 ft/yr of water evaporates from the total current acreage of brine lakes in Nash Draw (exclusive of Laguna Uno), then 17,200 ac-ft of water is discharged annually from Nash Draw by evaporation. Under natural conditions, much less water would be discharged, primarily for two reasons. First, the natural acreage of brine lakes was much less, no more than the 1970 acres of Laguna Grande de la Sal in 1942. Second, ground water in at least the southern portion of the lake was confined, so that when the lake was dry, little or no evaporation occurred. In contrast, the depth to water is now rarely more than 6 in., and evaporation is probably continuous. If the northern third of a smaller Laguna Grande de la Sal was perennial, and the southern two-thirds was covered half the time, then the total annual evaporation would have been 5780 ac-ft. Not all of this total was ground water. If no ground water evaporates from the southern two-thirds (other than precipitation that falls locally and seeps into the lake through the ground), and if 12 in. of rain is equivalent to 3 ft of evaporation from the lake (using Mr. Williamson's estimate), then 1.4 ft/acre of ground water evaporates from 660 acres of the lake. This rough calculation results in an estimate of 924 ac-ft/yr of natural ground-water discharge from Laguna Grande de la Sal. Surprise Spring is the largest of the springs discharging into the lake, and therefore its known discharge provides a check on the estimate of total ground-water discharge from the lake. In 1942, Surprise Spring discharged 120 gpm (194 ac-ft/yr) (National Resources Planning Board 1942, p 69). The estimate of 924 ac-ft/yr total ground-water discharge does not seem unreasonable. No correction for the volume of dissolved solids, which would further reduce the estimate of ground-water discharge, has been made in this report.

Ground-Water Flow

The volumetric rate and direction of ground-water flow between two points in a flow path is determined, in essence, by the difference in hydraulic head between the two points and the permeability and cross-sectional area of the path connecting them. Differences in hydraulic head are most frequently mapped with "water-level" or "potentiometric" contours, each of which shows the altitude at which water in a cased well would stand. Hydraulic head is easily measured if wells have been drilled and allowed to come to equilibrium. A potentiometric-surface map is a necessary component of the calculation to determine the volume of ground water entering a study area and can also be used in determining boundary conditions.

Water will always move from points of greater to lesser hydraulic head, providing that a path exists between the two points. Thus, the gross direction of ground-water flow can be determined by examining a potentiometric-surface map: water flows perpendicular to lines of equal head, toward lines of lesser head, in an isotropic system. On a finer scale, water may take a more tortuous path, and in an anisotropic system the lines of flow may be at an acute angle to the contour lines. Closed contours that are higher in altitude than the surrounding contours usually indicate recharge of the contoured aquifer. Similarly, closed contours that are lower in altitude indicate ground-water discharge. Recharge and discharge to an aquifer tend to occur near or at the land surface, although water can also flow from one aquifer to another. Such interaquifer flow is most commonly confirmed by changes in ground-water chemistry in the aquifer receiving the flow. Usually, two aquifers present at the same place on a map have separate flow regimes, by definition, and do not exchange much water. Over the periods of time of interest to the WIPP project, however, two aquifers may exchange enough water to be of concern.

There are many aquifers of importance in the WIPP water-balance study area; however, potentiometric-surface maps are available, for the most part, only for the portion of each aquifer that is near the land surface and that produces water at least suitable for stock. Geohydrology Associates (1978a), in a study prepared for the Bureau of Land Management, tabulated old data and collected new data on aquifer productivity, water chemistry, water levels, and depth to water for the entire Eastside Roswell Range, which includes the present study area. Most of the available data apply only to the uppermost aquifer at a given location. Mercer (1983) provided detailed information on all the aquifers for a much smaller area in the immediate vicinity of the WIPP site. Both Geohydrology Associates and Mercer reviewed earlier hydrologic studies that had been done in the area.

These are the chief formations and other geologic deposits of importance in the study area, from youngest to oldest:

Quaternary	Alluvium Playa lake deposits Valley fill
Tertiary	Tertiary rocks, undivided Ogallala Fm.
Triassic	Triassic rocks, undivided Dockum Group
Permian	Dewey Lake Redbeds Rustler Fm., undivided Rustler Fm., Tamarisk Member Rustler Fm., Magenta Member Rustler Fm., Forty-niner Member Rustler Fm., Culebra Dolomite Member Chalk Bluff Fm. Tansill Fm. Carlsbad (term no longer used—included Artesia Group, Capitan Ls., and other units)

In Lea County and in Eddy County east of Clayton Basin, Triassic rocks and outliers of the Ogallala Fm. are the chief aquifers. South of Nash Draw in Eddy County, rocks of the Dockum Group are the chief aquifer. Rocks of the Rustler Fm. yield water from Clayton Basin and Nash Draw west to the Pecos River valley. In the Carlsbad Irrigation District, most wells are finished in alluvium or in the Capitan Ls. The Chalk Bluff facies of the Artesia Group and the Dockum Group are the chief aquifers in northern Eddy County. The Dewey Lake Redbeds are important between Clayton Basin and Nash Draw.

Plate 1 is a potentiometric-surface map showing water levels in the uppermost aquifers in the water-balance study area. Ideally, a regional map such as this one should be prepared for each aquifer in a manner similar to, but much more extensive than, that of Mercer (1983). Each map should be based only on data from wells completed in only one aquifer. Existing data are inadequate to prepare such maps, and the necessary data for the important aquifers are unlikely to become available on a regional scale in the near future. Plate 1 is a compromise between the demands for rigorous hydrologic accuracy and for a useful compilation of the available data; because regional-scale data are not available for any aquifer, it assumes that all the aquifers above the Salado Fm. are connected to some extent. This assumption is strongly supported by completion and water-level data shown on the map. Except in the immediate vicinity of the WIPP site and in Lea County east of Clayton Basin, wells within a few miles of each other have similar water levels, no matter what aquifer they are completed in. Differences in water levels in wells near each other but completed in different aquifers are usually smaller than expected errors in land-surface altitudes. Near the WIPP site and in Lea County east of Clayton Basin, aquifers seem to be more or less "normal," that is, separate. The contours on Plate 1 probably represent an upper bound on water levels in lower aquifers in these two areas.

Because data are presented on Plate 1 itself, as well as in Appendix B, areas of greater and lesser certainty in the contours are readily apparent. Contours may reflect either confined or water-table conditions, depending on the aquifer. Only in the immediate vicinity of the WIPP site have the aquifers above the Salado Fm. been contoured individually in the past (Mercer, 1983). Plate 1 uses data for the Magenta Member of the Rustler Fm. near the WIPP site. Detailed modeling of the WIPP site should use potentiometric-surface maps of the individual units of the Rustler Fm., not Plate 1. Plate 1 contains no data for aquifers below the Salado Fm.; such aquifers seem to be isolated from those above the Salado and are outside the scope of this study. For convenience, portions of Plate 1 have been included here in the text as Figures 9, 11, and 13.

Plate 1 can be used to determine the general direction of ground-water flow in the near-surface aquifers in the region and in rough calculations of the volumes of ground water entering and leaving the area. All water levels on Plate 1 are observed heads; none have been corrected for density. The gross direction of ground-water flow in the study area is from northeast to southwest; water levels are highest along Mescalero Ridge and lowest along the Pecos River.

This regional flow is interrupted in several places. A large ground-water ridge that extends from northern Eddy County to Lake McMillan and Lake Avalon gives rise to a region of southeasterly flow, mostly into Clayton Basin. Clayton Basin itself is a ground-water sink that receives some flow even from the southwest. South of Grama Ridge and west of The Divide, ground-water flow is to the southeast. San Simon Swale is another ground-water sink, receiving some flow from the southeast.

Ground-Water Flow Near Clayton Basin

The water table in and near Clayton Basin and Nash Draw seems to be hummocky; however, the water-level contours on Plate 1 and Figure 9 present a reasonable interpretation of the best available data. The 3250-ft contour opens broadly to the south. The water-level contour at 3200 ft in Clayton Basin is closed (Figure 9). Water levels rise gently to the north, east, and west. Water levels in the alluvium, the Rustler Fm., the Dockum Group, and undivided Triassic rocks are between 3169 ft and 3200 ft inside the closed contour. The water table is at the surface in parts of Clayton Basin. The depth to water is <50 ft in much of the Basin (Geohydrology Associates, 1978a, Figure 15). An east-west ground-water divide, roughly 25 ft in height, is present in the vicinity of Mimosa Ridge on the southern edge of Clayton Basin. A second 3200-ft contour, south of the closed contour, runs roughly east and west in Ts. 20 and 21 S.

Mercer has suggested (1983, e.g. p 53), based on the work of Lang (1938), that Bear Grass Draw and Clayton Basin are recharge areas for water discharging from the Rustler Fm. at Malaga Bend. Bachman (1984, p 19) reiterated this suggestion, based on the work of Mercer. Lang presented no evidence to support the suggestion, and in fact, no data or maps at all as far north as Bear Grass Draw. The current configuration of the water table in Bear Grass Draw and Clayton Basin (Plate 1) does not support Lang's suggestion. Bear Grass Draw does not seem to have an important impact on water levels one way or the other, although there are so few water wells in the area that no firm conclusion can be drawn. Recharge to the Rustler Fm. seems to be occurring at the ground-water ridge between Lakes McMillan and Avalon and Northern Eddy County and also to the east of Clayton Basin. Local ground-water discharge from the Rustler Fm., Triassic rocks, and alluvium takes place in Clayton Basin.

Sinkholes in Burton Flat, on the west side of Clayton Basin, seem to be sites of point recharge to the ground water (George Bachman, pers. comm., 5/9/84). Springs and ponds in Clayton Basin, such as the "green pond" and "blue pond" of Geohydrology Associates (1978b, p 82), however, are sites of point discharge. Water levels in these ponds are above the level of the Potash Company of America tailings pond. Water in the ponds is substantially fresher than the nearly saturated brine tailings; inflow to green pond has total dissolved solids of 15,665 ppm. Geohydrology Associates concluded that a closed depression in the water table centers on Clayton Lake and the PCA pond. Water entering this depression, including the ground-water discharge referred to above, precipitation recharge from a large area, PCA and AMAX refinery wastes, and possibly some Duval and National refinery wastes, evaporates or is transpired. In addition to the industrial spoil piles and ponds, Geohydrology Associates estimated that there are 1000 acres of natural ponds and wetlands in the area. Examination of a depth-to-water map (Geohydrology Associates, 1978a, Figure 15) reveals that roughly 14 mi^2 in this part of Clayton Basin has a depth to water of ≤ 25 ft, well within the zone of phreatophytic evapotranspiration. Wells drilled by Amax have encountered artesian conditions in the Culebra Dolomite in Clayton Basin (T. E. Kelly, pers. comm., 11/21/84).

If the ground-water divide between Clayton Basin and Nash Draw blocks the flow of water to Nash Draw from the north, then a very large volume of water must be discharged from Clayton Basin. The volume must be at least as large as the sum of the recharge to the study area north of Highway 180 and the discharge of the PCA, AMAX, and possibly Duval and National refineries. Water is removed from Clayton Basin by evaporation from the industrial spoil ponds and piles and from natural ponds and wetlands. Transpiration by phreatophytes can easily remove water from depths of 25 ft. The total evapotranspiration is estimated to be 26,000 ac-ft/yr (Table 12). PCA, AMAX, Duval, and National discharge a total of 10,000 ac-ft/yr, but probably not all of the Duval and National wastes enter Clayton Basin. Clearly, a substantial amount of natural ground water, at least 16,000 ac-ft/yr, is removed from the WIPP water-balance study area by evapotranspiration from Clayton Basin. Theis (1934, p 152) estimated recharge to the Ogallala Fm. to be 0.5 in. or less per year. In that case, 16,000 ac-ft/yr is equivalent to the recharge to at least 380,000 ac, or the northern third of the WIPP water-balance study area. Ground-water flow into the study area from the north and east is offset by water flowing west from the ground-water ridge between Clayton Basin and the Pecos River. Clearly, no ground-water need flow into Nash Draw from the north to maintain equilibrium between inflow to and evapotranspiration from Clayton Basin.

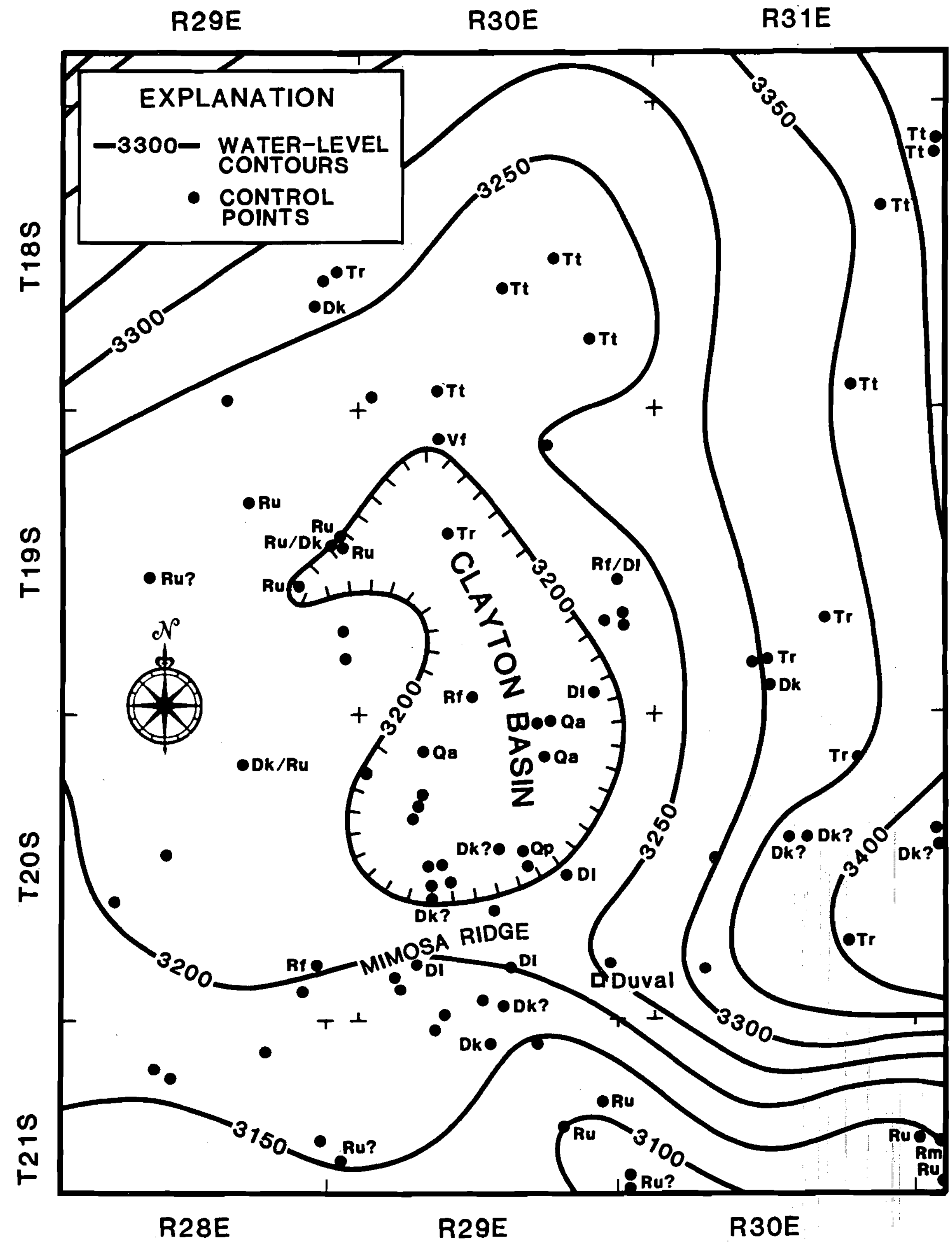


Figure 9. Water Levels In and Near Clayton Basin (in feet). (Aquifers: Qa, Quaternary alluvium; Vf, Valley fill; Tt, Tertiary rocks, undivided; Dk, Dockum Group; Tr, Triassic rocks, undivided; Dl, Dewey Lake Redbeds; Ru, Rustler Fm., undivided; Rf, Rustler Fm., Forty-niner Member; Rm, Rustler Fm., Magenta Member)

Table 12. Evapotranspiration in Clayton Basin

	Area (ac)	Rate (ft/yr)	Amount (ac-ft/yr)	Source*
PCA pile and ponds			3,218.2	GA78b, p 81
AMAX pile and ponds			536.9	GA78b, p 68
Natural ponds and wetlands	1000	4.4	4,400	GA78b, pp 59, 83
Phreatophytes	8960 (14 mi^2)	2†	17,900	GA78a, Fig.15; GA78b, pp 30 ff
Total			26,000	

*GA = Geohydrology Associates
†Estimated from a summary on the pages given

It could be suggested that the ground-water ridge between Clayton Basin and Nash Draw is an artifact of waste disposal by Duval Potash Company. If so, then the above discussion of ground-water discharge from Clayton Basin will only apply in detail until refining ceases and the artificial ground-water ridge dissipates. The ground-water ridge is ~25 ft high and covers an area of roughly 6 mi^2 or 3840 ac. If the ridge has a porosity of 0.1, it contains ~9600 ac-ft of water. Geohydrology Associates (1978b, pp 71-72) roughly estimated Duval's pond seepage to be 822 gpm (1326 ac-ft/yr), although Duval's own estimate was only 259 gpm (418 ac-ft/yr). The refinery has been in operation since 1951 (Geohydrology Associates, 1979, p 65). Between 14,000 and 45,000 ac-ft of water has seeped into the ground above the ground-water ridge. Of course, the mound created in this way will tend to dissipate even as it forms. On the whole, Duval's discharge might be adequate to form and maintain the ground-water ridge.

It is also possible that Duval's location on the ground-water ridge is a coincidence, and that there is some natural cause for the ridge. Examination of the precipitation map (Figure 3) reveals that precipitation is locally high in the vicinity of the ground-water ridge. Although there are no stations in the surrounding area, there is a long precipitation record at the Duval refinery. If precipitation at the refinery is 14 in./yr, precipitation to the north and south is 13 in./yr, and recharge is 4% of rainfall, then there is a 0.04-in./yr difference in recharge between the two areas. A difference of 25 ft (at 0.1 porosity) would fall in only 63 yr. Thus, natural precipitation might also be adequate to form and maintain the ground-water ridge.

Without water-quality data, it is impossible to determine the origin of the ground-water ridge and thus impossible to say whether or not, in the long term, Clayton Basin is separate from Nash Draw hydrologically. The industrial brine is so distinctive chemically that probably only a few samples of the ground-water in the ridge would be required to determine its origin.

To summarize, it appears that Clayton Basin is currently a ground-water discharge area for undivided Triassic rocks, the Dockum Group, the Rustler Fm., and the alluvium. Precipitation recharge north of Highway 180, potash refinery waste, and ground-water inflow all apparently discharge by evapotranspiration. Water levels in the Capitan aquifer in Clayton Basin are roughly 3133 ft (Figure 10). The many existing wells have revealed no hydraulic connection between the rocks overlying and underlying the Salado Fm. If a connection does exist, water from the water-table aquifers flows downward to the Capitan and then eastward. Clayton Basin seems to be hydraulically separate from Nash Draw and the WIPP site. If the ground-water ridge underlying the divide between Clayton Basin and Nash Draw is an artifact of potash refining, Clayton Basin could discharge into Nash Draw in the future.

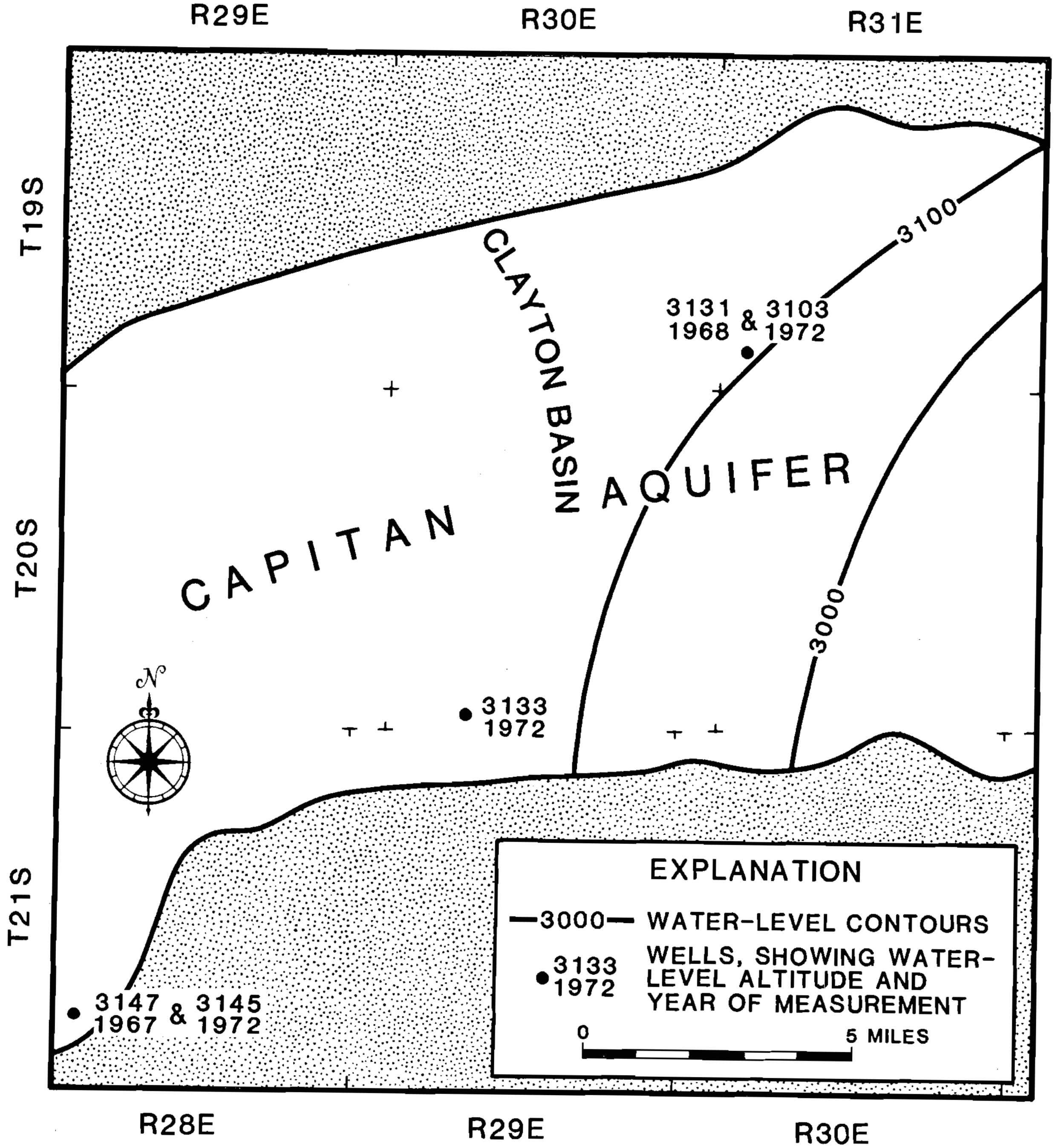


Figure 10. Water Levels in the Capitan Ls. In and Near Clayton Basin (in feet)

Ground-Water Flow Near San Simon Swale

San Simon Sink has collapsed actively and suddenly in historic times (Nicholson and Clebsch, 1961, pp 14, 46). Sudden collapse of as much as 5 ft reportedly took place around 1925. A sugarberry tree, now dead, was alive but partly buried by 1961. Nicholson and Clebsch estimated that deposition of roughly 1 ft of sediment every 5 yr was required to bury the tree. They believed that the absence of precipitates in San Simon Sink indicates that seepage is occurring too rapidly for effective evaporation. They also believed that much material has been removed by deflation as well as by collapse. They documented the presence of a second sink, no longer active, in Sec. 33, T. 21 S., R. 33 E., and suggested that other inactive sinks may be completely filled by alluvium and dune sand. Bachman (1984, p 20) and Lambert (1983, p 82) have postulated that San Simon Sink is an actively forming breccia pipe.

The water-level contour at 3150 ft in San Simon Swale is closed (Figure 11). The 3200-ft contour opens to the southeast. Water levels rise fairly rapidly to the northeast, southwest, and northwest. There are three possible explanations for the closed contour line. The first explanation is that contouring the Triassic aquifer and the Ogallala aquifer together is inaccurate, and that the closed contour is an error. Based on the available data, this does not seem to be the case. Water levels in the two aquifers near San Simon Swale are comparable. There is no reason to assume that the two aquifers are hydraulically separate. Three wells east and south of San Simon Swale (23.35.36.24234, 24.34.35.122, and 25.34.1.132, Geohydrology Associates, 1978a, Appendix A), finished in Triassic rocks, have water levels 19 to 122 ft higher than the southeasternmost Triassic well in San Simon Swale.

Evidence is lacking for the second possibility, ground-water discharge to the land surface in San Simon Swale. The depth to water is 100 to 300 ft in most of the Swale (Geohydrology Associates, 1978a, Figure 16), making discharge by evapotranspiration unlikely. Vegetation in the Swale is not especially lush compared with surrounding areas.

The third possibility is that the closed contour indicates leakage from the Triassic aquifer to a lower aquifer. Some water-level data are available for the Capitan Ls. near San Simon Swale. These data (Figure 12) show that water levels in the Capitan Ls. are ~600 ft lower than water levels in the Triassic aquifer and that water in the Capitan flows to the southeast. According to Hiss (1975, p 272), prewithdrawal flow in the Capitan Ls. near San Simon Swale was to the northeast. Although recharge from the Triassic aquifer to the Capitan Ls. would require a hydraulic connection between the two aquifers that has not been documented, such a connection must be small to maintain the large head differential and might well have escaped detection during the drilling of the small number of existing wells.

The Rustler Fm. is also present beneath San Simon Swale. Water levels in the Rustler Fm. at the WIPP site are at ~3150 ft and below. Water levels in the Triassic rocks at San Simon Swale above the Rustler are also ~3150 ft. If water in the Triassic rocks flows downward, then water levels in the Rustler Fm. cannot be higher than 3150 ft in San Simon Swale. It does not seem likely that water levels in the Rustler Fm. in San Simon Swale are high enough to create a gradient in the Rustler from San Simon Swale to the WIPP site; more likely, the water in the Rustler Fm. also leaks downward to the Capitan Ls.

San Simon Swale does not seem to be connected hydrologically to the WIPP site. It is topographically separated from the site by The Divide. Water in the Triassic aquifer is separated from the site by a ground-water divide. Any water recharging the Capitan Ls. flows to the southeast. If there is no connection to the Capitan Ls., then water is flowing to the southeast in the Triassic aquifer or discharging to the surface by evapotranspiration, in spite of the comparatively great depth to water.

Ground-Water Flow Near Nash Draw and the WIPP Site

Ground-water flow in and near Nash Draw and the WIPP site has been discussed recently by Mercer (1983) and Geohydrology Associates (1979, 1984). Figure 13 summarizes the information presented by those authors for the aquifers nearest the land surface. There are ground-water divides in the general vicinities of The Divide, separating flow near the WIPP site and Nash Draw from flow near San Simon Swale, and of Mimosa Ridge, separating the flow from flow near Clayton Basin. Near-surface flow in and near Nash Draw seems to be directed toward Laguna Grande de la Sal, although this may be a coincidence rather than an indication that the lake is a primary discharge area. The Pecos River at Malaga Bend could be the primary discharge area, rather than the lake. North of the lake, flow is to the south; water flows down the Draw toward the lake; and water in the Magenta Member flows to the west, more or less east of the lake.

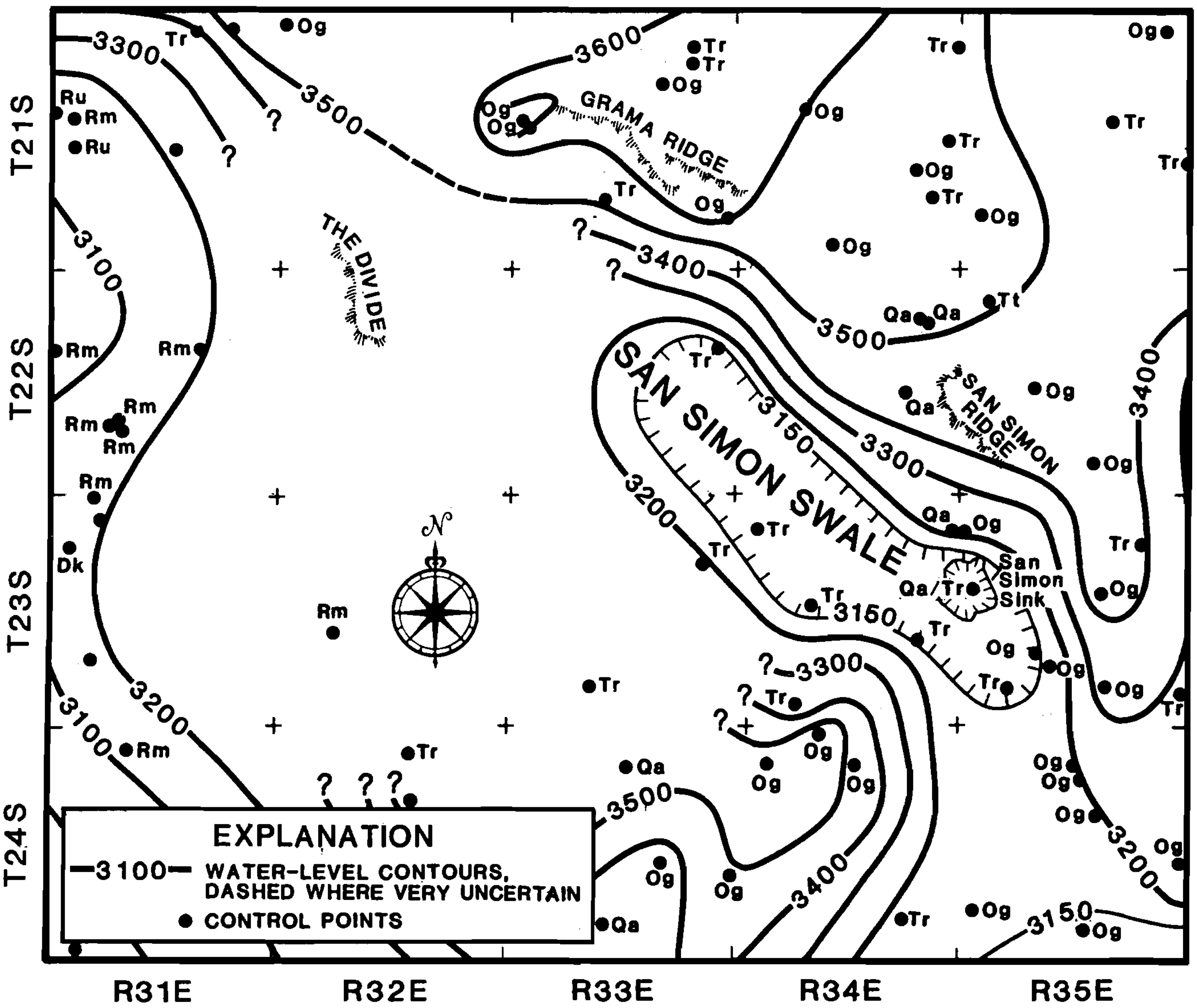


Figure 11. Water Levels In and Near San Simon Swale (in feet). (Aquifers: Qa, Quaternary alluvium; Og, Ogallala Fm.; Tt, Tertiary rocks, undivided; Dk, Dockum Group; Tr, Triassic rocks, undivided; Rm, Rustler Fm., Magenta Member; Ru, Rustler Fm., undivided)

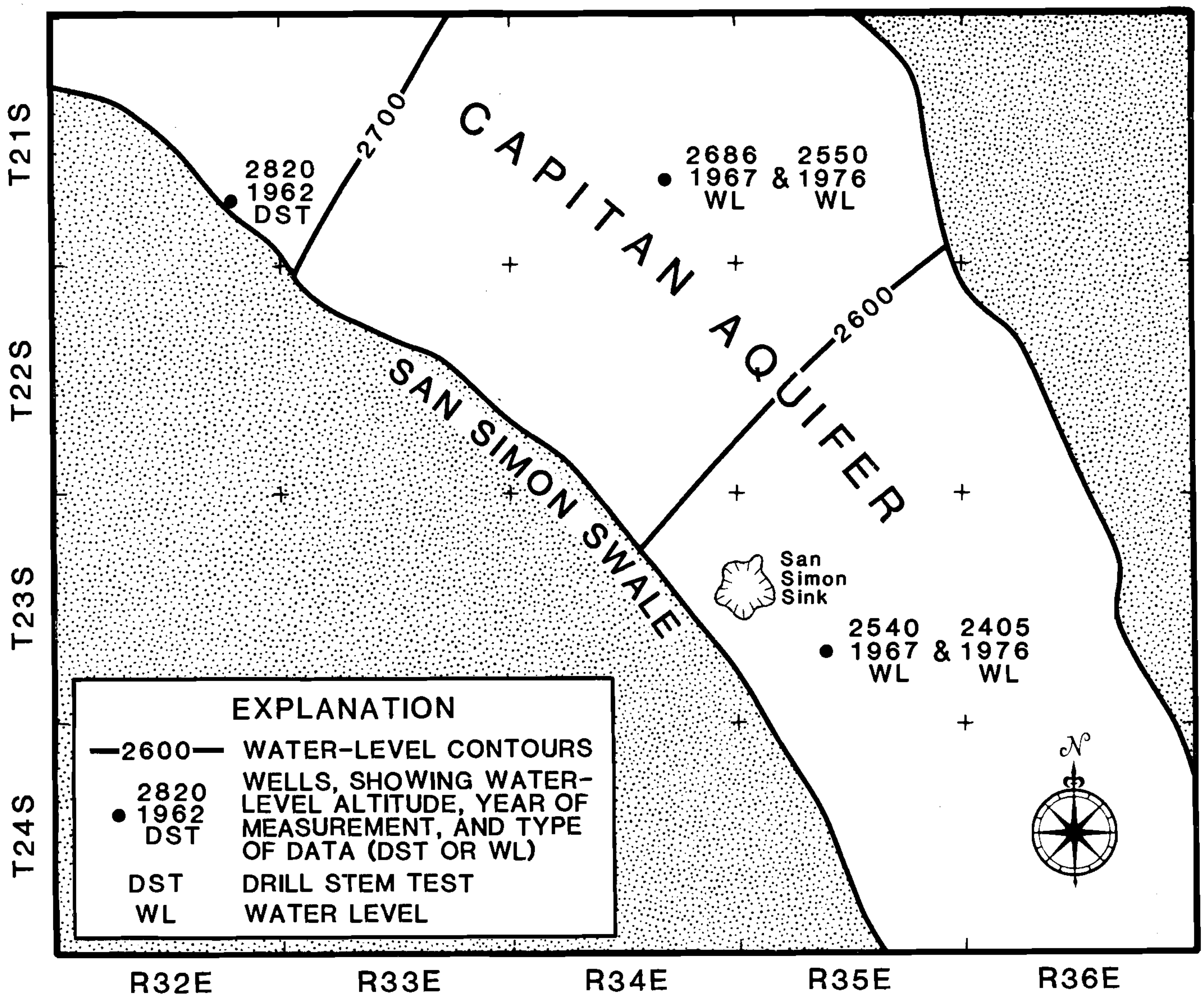


Figure 12. Water Levels in the Capitan Ls. In and Near San Simon Swale (in feet)

At a finer level of examination, the water levels in Nash Draw are hummocky. The aquifers form a complex of water-table, semiperched, semiconfined, and stratified areas, but it is unlikely that any aquifer above the Rustler-Salado brine aquifer is truly confined or separate from the others throughout Nash Draw. Several factors support this conclusion.

First, geologic units in the Draw are broken and rubbley, and some units are missing in places. The Magenta and Culebra Dolomite Members, which are unquestionably separate and confined at the WIPP site, crop out extensively in south-central Nash Draw, east of Laguna Grande de la Sal. There the two units are juxtaposed (the Tamarisk Member is missing) and brecciated and lie in the immediate vicinity of permanent natural and artificial lakes (Bachman, 1981, Plate 3). The water-level altitude in the Culebra Dolomite in WIPP-29 was 2969 ft (Mercer, 1983, p 112), while the nearby surface-water altitude was variously reported as 2969 ft (Geohydrology Associates, 1979, Figure 17) and 2970 ft (Bachman, 1981, Plate 3 base map). Although the top of the Culebra Member is 4 ft below the water level, the unit is not "confined" at WIPP-29; cased wells in water-table aquifers commonly flow (or at least, water rises in the casing) in discharge areas (Lohman, 1972, p 7). The Magenta Dolomite Member crops out in the bluff on the west side of Nash Draw as far north as T. 22 S., R. 29 E.,

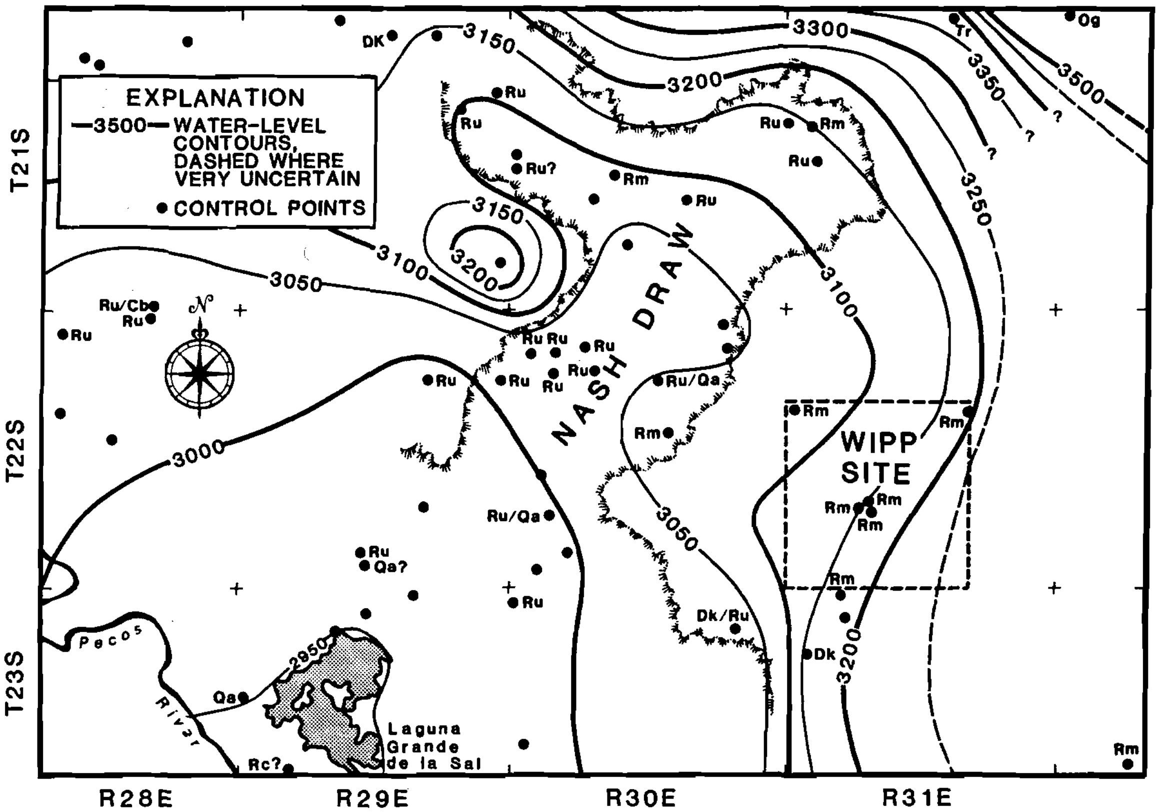


Figure 13. Water Levels In and Near Nash Draw and the WIPP Site (in feet). (Aquifers: Qa, Quaternary alluvium; Og, Ogallala Fm.; Tr, Triassic rocks, undivided; Dk, Dockum Group; Ru, Rustler Fm., undivided; Rm, Rustler Fm., Magenta Dolomite Member; Rc, Rustler Fm., Culebra Dolomite k, Chalk Bluff Fm.)

Sec. 1. Because all of Nash Draw is generally believed to have a common origin, dissolution accompanied by collapse, there is no particular reason to believe that the rocks are completely intact anywhere in the Draw.

Second, available data indicate that in any one area in Nash Draw, heads in wells of different depths are about the same (Table 13). Three wells in the southwest quarter of Sec. 18, T. 21 S., R. 30 E., range in depth from 139.3 ft to 184.0 ft. The depths to water in the three wells range over only about 1.4 inch, at 3077 ft. About 2 mi east of these three wells, Magenta and Culebra water levels have been measured in WIPP-27. Even though the unit tops are 116 ft apart, the water levels differ by only 3 ft. The Magenta water-level altitude is 3075 ft. Of the three wells to the west, the 176-ft well is completed in the Rustler Fm. (probably Magenta). The 139-ft well does not seem to be completed in the Magenta because the well is only 4 ft deeper than the water level, whereas Magenta water rises 74 ft above the unit in WIPP-27. In WIPP-25, the tops of the Magenta and Culebra are 145 ft apart, but the water levels differ by only 6 ft. In WIPP-28, the tops are 135 ft apart, but the water levels differ by only 74 ft. In the northeast quarter of Sec. 33, T. 22 S., R. 29 E., two wells that vary 15 ft in depth have water

Table 13. Data for Selected Wells In and Near Nash Draw

Well	Depth of Well (ft)	Depth to Water (ft)	Aquifer	Date of Measurement	Source
21.29.11.421	244.0	213.29	Ru	2/22/78	GA78a*
21.30.18.330	139.0	135.07	—	11/9/77	GA78a
18.331	184.0	134.95	—	10/25/77	GA78a
18.333	176	134.99	Ru	3/9/76	GA78a
22.29.33.214	70.3	53.75	Ru	10/19/77	GA78a
33.240	65	56.2	Qa?	12/17/48	GA78a
23.30. 2.440	300	250	Dk/Ru	12/22/48	GA78a
19.132	59.6	54.90	—	10/20/77	GA78a
WIPP-25	302 to 328	159.0	Rm		Mercer, 1983
	447 to 472	165	Rc		
WIPP-27	176 to 194	102.0	Rm		Mercer, 1983
	292 to 318	105	Rc		
WIPP-28	285 to 310	202.8	Rm		Mercer, 1983
	420 to 446	277	Rc		

*GA78a = Geohydrology Associates, 1978a

levels varying <3 ft. One is completed in the Rustler Fm., the other in probable alluvium. The wells described in Table 13 that are only slightly deeper than their water levels cannot be reconciled with the suggestion of confined conditions throughout Nash Draw. Wells with the same heads for different aquifers are difficult to reconcile with the suggestion of perched conditions for the shallow aquifers throughout Nash Draw. Mercer (1983, p 67) concluded that some hydraulic connection exists between zones in all the WIPP test holes in Nash Draw except W-28. Even at W-28, the head difference between the Magenta and Culebra Members is only half the difference at the WIPP site, indicating that the units, at the very least, are beginning to respond to the effects of the vertical connections elsewhere in Nash Draw.

Finally, the best available chemical data (Lambert and Robinson, 1984, Table 6-1) show that water in the Magenta and Culebra Dolomite Members is nearly indistinguishable between members in WIPP-25 and -27, although there are differences between wells. Data for $\delta^{18}O$ also do not distinguish between the Culebra and Magenta Members, although there are marked differences between the Magenta and Culebra and the Rustler/Salado brine aquifer (Lambert, 1983, Figures VIII-6 and VIII-7; Lambert, 1984).

In Nash Draw, the Rustler/Salado brine aquifer is under a slight artesian head in some areas in and near Laguna Grande de la Sal (Havens, 1972), although brine under water-table conditions is also continually present there. Current water levels near the lake indicate that some water may flow from the lake to the Pecos River (Geohydrology Associates, 1979, p 72). The current water levels (under water-table conditions) in Nash Draw directly to the west of the WIPP site are ~3000 ft. Water levels have risen in this part of Nash Draw some 135 ft in the last 30 yr, apparently in response to discharge from potash refineries.

It has been long assumed that the Nash Draw brine aquifer discharges at Malaga Bend. Recent field work (Geohydrology Associates, 1984) suggests that the brine aquifer may also be discharging to the surface in Laguna Tonto, northeast of Nash Draw: no near-surface source for the precipitates and brine in Laguna Tonto could be identified.

At the WIPP site, water in the Magenta Member of the Rustler Fm. is confined. The water level is ~3150 ft in the center of the site and ~3100 ft at the western edge of the site (Mercer, 1983), giving rise to a gradient of ~16 ft/mi across the site. It would be impossible to maintain the gradient in the Magenta Member across the WIPP site to the west without a discharge point from the Magenta Member into either the alluvium or the rubble in Nash Draw or into the Culebra Dolomite Member somewhere between the western edge of the WIPP site and Livingston Ridge. Mercer (1983, p 67) also concluded that the Magenta discharges in Nash Draw, probably by draining into the Culebra or Forty-niner Members.

Water in the Culebra Dolomite Member is also confined at the WIPP site; water-level altitudes are ~3000 ft. Although Mercer (1983, Figure 17) showed flow to the south at the WIPP site, the flatness of the potentiometric-surface combined with the sparsity of data south of the site make this conclusion tentative. The Culebra Dolomite Member crops out in Nash Draw almost due west of the WIPP site, however (Bachman, 1981, Plate 3), where water is present under water-table conditions (as discussed above) at an altitude of 2970 ft.

It appears that the ground-water system that includes flow through the WIPP site is much smaller than the WIPP water-budget study area. It is of interest to construct a "mini water budget" for the smaller area, although the available data are so sparse for this small area that the mini water budget is only an outline for future study, and not a finished product. The mini-water-budget area includes the nine townships in Ts. 21 through 23 S., Rs. 29 through 31 E.; 36 sections on the western edge of Ts. 21 through 23 S., R. 32 E.; and 36 sections on the southern edge of T. 20 S., Rs. 30 through 32 E., a total of 400 mi^2. There is no ground-water inflow because the northern and eastern boundaries are the ground-water divides discussed above, and the western and southern boundaries are flow lines. There is no surface-water inflow or outflow, although there is local surface-water flow during heavy rains. Some of this flow may be related to karstic processes, including dissolution of gypsum in and near Nash Draw. There are no municipalities, but four potash refineries discharge a total of 12,800 ac-ft/yr. The only other inflow is precipitation. The only known outflows are transpiration; evaporation from the brine ponds, spoil piles, and natural brine lakes; and ground-water discharge to the Pecos River. Two mini water budgets may be constructed—one for the natural system, and one for the perturbed system. The two budgets are described in Table 14.

The average precipitation in the minibudget area may be as low as 12 in. or as high as 13 in./yr (Figure 3a, 3b). For the entire WIPP water-budget area, an evapotranspiration rate of 96% was chosen to represent the best estimate. For the smaller minibudget area, the uncertainty in the evapotranspiration rate is large. In the natural system, there is no inflow other than precipitation and no known outflow other than

Table 14. Mini Water Budget—Nash Draw and the WIPP Site

	Perturbed System (ac-ft/yr)	Natural System (ac-ft/yr)
Inflow		
Surface water	0	0
Imports (refinery discharge)		
IMC	5,233.2*	
Kerr McGee	2,322.7*	
Mississippi Chemical	1,300*	
Duval	2,060*	
Total	10,900	0
Precipitation (12 to 13 in./yr)	256,000 to 277,000	256,000 to 277,000
Ground water	0	0
Internal Transfers		
Recharge from precipitation	1,280 to 5,540	1,280 to 5,540
Change in storage (industrial)	3,400	0
Outflow		
Surface water	0	0
Exports	Negligible	0
Evapotranspiration		
Precipitation on rangeland	250,000 to 276,000	250,000 to 276,000
Laguna Grande de la Sal		
Ground water	924	924
Precipitation	4,856	4,856
Potash brine	7,200	0
Spoil piles and ponds (includes Laguna Uno)	6,800*	0
Other lakes	4,500	0
Ground water to Pecos River	300 to 4,500	300 to 4,500

*From or estimated from data in Geohydrology Associates, 1978b evapotranspiration and ground-water discharge to the Pecos River. There is no change in storage. The greatest uncertainty in volume, 21,000 ac-ft/yr, is, of course, in precipitation. The biggest uncertainty as a percentage of the volume, slightly more than an order of magnitude, is in ground-water discharge to the Pecos River.

To balance the natural minibudget, the calculated recharge (precipitation minus evapotranspiration from rangeland) should equal the calculated discharge (evaporation of ground water from Laguna Grande de la Sal plus discharge to the Pecos River). Natural evaporation of ground water from Laguna Grande de la Sal seems to be about 1000 ac-ft/yr. Discharge to the Pecos River between stations 4052 and 4070 is between 600 and 9000 ac-ft/yr, but at most about half of this should be coming from the minibudget area, east of the River. Discharge to the river from the minibudget area is at most 300 to 4500 ac-ft/yr. Therefore, the calculated discharge of ground water is between 1300 and 5500 ac-ft/yr.

If the recharge is equal to the discharge, then the 256,000 ac of the minibudget area receive an average of 0.06 to 0.26 in. total recharge annually to all aquifers, which is 0.5 to 2% of the 12 to 13 in. of rainfall. The calculated recharge rates are not so much lower than the regional rate of 4% as to be unreasonable, especially since the vicinity of Laguna Grande de la Sal is known to be a discharge area, not a recharge area. These recharge rates require evapotranspiration rates of 98% to 99.5%.

In addition to the inflows named for the natural budget, the perturbed minibudget receives ~10,900 ac-ft/yr of water imported by the potash industry. There has been an increase in storage of 3400 ac-ft/yr. Laguna Grande de la Sal has expanded and evaporates more water, ~13,000 ac-ft/yr total. Spoil piles and ponds evaporate ~6800 ac-ft/yr. New brine lakes evaporate ~4500 ac-ft/yr of ground water. If recharge from precipitation is taken as an inflow and precipitation and evapotranspiration from rangeland are neglected, then the total inflow to the perturbed system is 12,180 to 16,440 ac-ft/yr. The change in storage is 3400 ac-ft/yr. The outflow (neglecting precipitation evaporated from Laguna Grande de la Sal) is 19,700 to 23,900 ac-ft/yr. The minimum discrepancy between the inflow and outflow for the perturbed minibudget area is 3260 ac-ft/yr. The discrepancy may indicate that a change of storage is still occurring, but more likely it indicates significant errors in the values used in creating the water budget for the perturbed system. On the time scale of interest to a WIPP performance assessment, potash refining is an ephemeral perturbation of the water budget. If it is possible to substantially improve the natural budget by gathering and analyzing some of the information discussed in the Recommendations, then it is probably unnecessary to thoroughly understand the perturbed budget.

Change in Storage

A hydrologic system that is in equilibrium has no long-term change in storage. Any inflow of surface water, ground water, or precipitation recharge is balanced by surface- or ground-water outflow and evapotranspiration. Changes in storage are thus *prima facie* evidence of hydrologic disequilibrium.

The most common change in storage in developed areas is lowering of water levels as a result of pumping water for municipal, industrial, or agricultural use. In and near the Carlsbad Irrigation District, major development of irrigation wells took place between 1930 and 1947, when the Carlsbad Underground Water Basin was declared by the State Engineer (Bjorklund, 1959). Water-level studies began in 1942. Water levels declined markedly between 1947 and 1955, with cumulative declines of 5 to 40 ft over the entire CID (Bjorklund, 1959, Figure 115). Declines slowed or ceased in the 1950s, with selected observation wells showing only seasonal changes in water level since that time (compare Bjorklund, 1959, Figure 104, with Hudson, 1978, Figures 20 through 22 and Tables 29 through 31). At this time, ground-water withdrawals in and near the CID from both the limestone and alluvial aquifers seem to be roughly in equilibrium with recharge from precipitation and irrigation seepage. The water-table gradient is presumably lower than before large-scale irrigation and municipal pumpage began. If irrigation and municipal pumpage were to cease, water levels would rise and the natural gradient would be restored. The natural gradient is unknown.

Old and new data on water levels in domestic and stock wells throughout the rangeland of the study area (Geohydrology Associates, 1978a, Appendix A) suggest that there has been no large-scale lowering of the water levels outside the CID.

Another type of change in storage, much less common than that discussed above, is a rise in water levels. Rising water levels in Nash Draw are well documented. The rise is apparently due to the discharge of industrial brines by the potash industry. In 1942, when the only refinery in operation was the US Potash Co. (T. 23 S., R. 29 E., Sec. 18), Laguna Grande de la Sal was apparently the only perennial lake in Nash Draw (National Resources Planning Board, 1942). At that time the lake had been receiving the plant effluent for several years. The area of the lake, determined by planimetering a map of the lake (National Resources Planning Board, 1942, Figure 12, p 66) was 1970 ac.

By 1965, the area of the lake had increased to 2890 ac (determined by planimetering the lake on USGS 15′ topographic maps, *Nash Draw, N. Mex.* and *Carlsbad, N. Mex.)*, and ephemeral lakes had developed at the sites of Lindsey Lake, 66 ac; Laguna Uno, 122 ac; Laguna Tres, 154 ac; Laguna Quatro, 75 ac; and two small unnamed lakes south of Laguna Tres, 80 ac total.

By 1979, lake areas had increased (as determined by planimetering Figure 17, p 70, Geohydrology Associates, 1979). Laguna Grande de la Sal remained about the same, at 2880 ac. Permanent lakes had developed at Lindsey Lake, 94 ac, Laguna Uno, 710 ac; Laguna Dos, 47 ac; Laguna Tres, 522 ac; Laguna Quatro, 212 ac; and Tamarisk Flat, 160 ac. The two smaller lakes to the south had disappeared.

The altitude of the central part of Tamarisk Flat was 2968 ft before the lake formed. The altitude of the water surface in 1979 was 2970 ft. The altitude of the site of Laguna Dos was <2980 ft before the lake formed. In 1979, the altitude of the water surface was 2984 ft. The altitude of the central part of the site of Laguna Uno was <2990 ft before the lake formed. The altitude of the water surface was 3004 ft in 1979. The depth to water in the J Bar F well, now inundated by Laguna Uno, was 134.0 ft in 1948 (Hendrickson and Jones, 1952, pp 134-135). The altitude of the site of Laguna Tres was <2970 ft before the lake formed. The altitude of the water surface was 2976 ft in 1979. The altitude of the central part of the site of Laguna Quatro was less than 2980 ft before the lake formed. The altitude of the water surface was 2982 ft in 1979.

Assuming a porosity of 0.15, a rise in water level of 134 ft over the 9 mi^2 that encompass these lakes requires an increase in storage of 116,000 ac-ft. The formerly dry lakes now contain water to minimum depths of 2 to 14 ft. Taking 5 ft as the average depth over a total of 4,623 ac, the lakes contain 23,000 ac-ft of brine. Total change in storage is roughly 139,000 ac-ft. Geohydrology Associates (1978b, p 59) calculated a rate of increase in storage of 3327 ac-ft/yr, based on inflow and outflow. Considering that the refineries have been operating for ~40 yr, these two calculations give almost identical results.

It is reasonable to attribute the 116,000 ac-ft of increased ground-water storage to the period 1940 through 1965 (4640 ac-ft/yr) and the 23,000 ac-ft increase in surface-water storage to the period 1965 through 1979 (1643 ac-ft/yr). As long as the industrial brine was able to enter the ground, it was not subject to high evaporation rates. Once the water table rose above the ground surface, evaporation tended to reduce the volume of the lakes. Eventually, the lake surfaces became large enough to evaporate the entire volume of entering brine. Over periods of one or a few years, depending on temperature, humidity, and precipitation, the lakes will be in equilibrium. As stated above, the experimental perturbed water budget for Nash Draw and the WIPP site presented here only balances if the change in storage is still occurring.

Speculations on Long-Term Changes in the Hydrologic System

It would be unrealistic to assume that the hydrologic system of the study area will remain unchanged over the next 10,000 yr. It would be equally unrealistic to assume that the area could be subject to the worst possible change that can be imagined. For this study, an attempt has been made to ascertain the types of changes in the hydrologic system that can reasonably be expected to occur during the next 10,000 yr.

Changes in Climate

One way to assess the possible climatic changes that might occur during the next 10,000 yr is to examine the changes that have occurred during the last 10,000 yr. The existing literature on the archeology, Cenozoic paleontology, and caliche of the study area is extremely limited (e.g., Bachman, 1980, pp 92 ff; 1976, pp 141 ff); neither are readily applicable studies from outside the area abundant. No detailed studies in the literature describe the climate of the study area during the last 10,000 yr. The studies that bear on the past climate of the study area do so either because they describe the climate of nearby areas or of larger areas that include the study area, or because they discuss other aspects of the study area that are related to climate. Not all the literature reviewed for this discussion is in agreement about the climate of southeastern New Mexico during the past 10,000 to 13,000 yr.

A cave near the confluence of the Pecos River and the Rio Grande has been examined for evidence of climatic change during Holocene time (Patton and Dibble, 1982). The cave contains evidence of almost continuous human occupation since ~9500 B.C. Flood deposits and pollen present in the cave indicate that the climate in west Texas has become steadily more arid during the last 10,000 years. From 9000 to 7000 yr ago and from 3000 to 2000 yr ago, the trend was temporarily interrupted, although apparently the humidity did not increase to the level of 10,000 yr ago. The cave is located ~240 mi southwest of the WIPP site.

Four archeological sites near El Paso, Texas, have yielded pollen indicating that more water, probably as a result of greater precipitation, was available during the times of occupation than today (Horowitz and others, 1981). The sites range in age from ~2500 B.C. to ~1700 A.D. The sites are ~150 mi west of the WIPP site.

Late Pleistocene through Holocene vertebrates found in a pitfall cave west of Isleta, New Mexico, indicate that the area has become steadily warmer and drier (Harris and Findley, 1964). Rainfall has decreased to 8.3 in. from a probable late Pleistocene value of ~16 in. Average temperatures have increased from ~27°F in January to 31.6°F, and from ~67°F in July to 77.4°F. There is no evidence for an intervening period warmer and dryer than today. Isleta is ~240 mi northwest of the WIPP site.

Fossils and archeology throughout the Southwest indicate a change to warm and dry postglacial climates ~12,000 yr ago (Martin and Mehringer, 1965). There is some evidence that the period of maximum warmth and dryness was 8000 to 4000 yr ago (Baumhoff and Heizer, 1965).

Examination of caliche in the water-budget study area indicated that late Pleistocene to Holocene climates have alternated between relatively arid and relatively humid phases (Bretz and Horberg, 1949; Bachman, 1976, 1980). Bachman (1980, p 91) estimated that annual rainfall has been no less than 3 in. and no more than 30 in. for extended periods during the last 300,000 to 500,000 yr and concluded that the climate has been continuously semiarid. He also stated (Bachman, 1976, p 138) that the present is not the driest period during Holocene time.

Fossil and archeological evidence indicates a more steady warming and drying trend in New Mexico during the past 10,000 yr than does the caliche. While the fossils may be a more sensitive indicator of temperature and precipitation, only caliche studies have been done inside the study area. Bachman's range of 3 to 30 in. of precipitation almost certainly bounds the changes that have taken place in the last 10,000 yr. There are no studies that bound temperature changes. A narrower bounding range for precipitation and some bounds on temperature might be possible if paleontologic and isotopic studies were done inside the study area.

Changes in Stream Flow

The Pecos River drainage as it exists today is a product of late Pleistocene and Holocene time (Bachman, 1976). During early and middle Pleistocene time, the headwaters of the Pecos Rivers were in the vicinity of Roswell and also in San Simon Swale. In late Pleistocene time, the headwaters of the Pecos captured the headwaters of the Portales valley drainage system near Fort Sumner. During late Pleistocene and Holocene time, the Pecos River has become entrenched near its present channel. Stream gradients and sediment-carrying capacity have decreased (Bachman, 1976).

Geohydrology Associates (1978a, p 6) concluded that most of the drainages in the Eastside Roswell Range are occupied by underfit channels; that is, the drainage system was eroded by a stream larger than the existing channel. Drainage systems like Long Arroyo and Monument Draw seem to represent wetter climatic conditions than exist now. This conclusion agrees with the evidence presented above that the climate has become drier over the past several thousand years. In contrast, the National Resource Planning Board (1942, p 64) suggested that some of the drainages in question were formed by the integration of chains of sinks. Bachman's work on evaporite dissolution (1976, 1980) does not include the locations of Long Arroyo, Monument Draw, Beargrass Draw, or Dagger Draw. However these topographic features formed, an increase in rainfall could create or restore the through drainage to the Pecos River that is currently rare or absent. Through drainage would tend to decrease ground-water recharge by allowing precipitation to run off. At the present time, most of the study area has no integrated drainage: precipitation either evaporates or recharges the ground water.

Changes in Usage

Long-term changes in the volumes of water put to various beneficial uses in the study area are impossible to predict with confidence. Uncertainties about demographic changes alone are so great that predictions about beneficial use for the long term would be meaningless. Some useful predictions might be made about the short term, however.

During the next 100 yr, present allocations of water to municipalities and to the Carlsbad Irrigation District will probably remain more or less unchanged, because only a small portion of the study area is outside declared underground water basins (Sorensen, 1982, Figure 4). After an underground water basin is declared, new water rights become more difficult to obtain (Sorensen, 1977, p 8).

Potash and hydrocarbon reserves in the study area will probably be exhausted within the next 50 to 100 yr. There are no other known mineral resources in the area requiring large volumes of water for recovery or refining. The water rights to the 20,000 ac-ft of water imported annually by the potash industry could eventually be diverted to some other use, probably municipal use and irrigation. Up to 6700 ac of rangeland could be irrigated, with associated evaporative losses of 12,000 ac-ft/yr. Per capita water usage in Carlsbad in 1980 was ~350 gal/day (calculated by using population figures from Bureau of Business & Economic Research, 1980, p 176). At that rate, 20,000 ac-ft/yr would support an additional population of 51,000 persons, with 10,000 ac-ft/yr evaporative losses. Present-day return flow from municipal and agricultural use enters the Pecos River, whereas almost all water used by the potash industry seems to be evaporated eventually. Fresh water currently used by the oil industry could also be diverted to municipal or agricultural use.

Without industrial brines, the brine lakes in Nash Draw and Clayton Basin, except for Laguna Grande de la Sal, would disappear and the water level in the brine aquifer would drop locally. Water quality in the potash-refining areas might improve locally after the cessation of mining, especially in the uppermost portion of the aquifer. Precipitation runoff from the large existing spoil piles will contaminate the shallow ground water indefinitely; however, the volume of brine would be substantially less than the present-day refinery wastes. Improvement in water quality over large areas would require large volumes of fresh water flowing through the contaminated aquifers; this seems unlikely.

Model of the Water Budget

Previous sections have examined in detail the data available for use in constructing a model of the flow of water through the study area. The model itself, described in this section, abstracts and idealizes the data; detail and uncertainty are the price of overview and clarity.

Because water is not created or destroyed in the hydrologic cycle, any water budget will balance of its own accord with enough accurate information. Even with inadequate data, any water-budget model can be forced to balance because of the very large uncertainty in evapotranspiration. No great significance should be attached to the equality of inflow and outflow in the model presented here; rather, the importance of the model lies in the relationships between its parts and in the greater or lesser uncertainty in the underlying data.

Description of the Model

A model of the WIPP regional water balance is shown in Figure 14. Ground water and surface water are represented as partially connected conduits flowing through the study area. Evapotranspiration is represented as a sink. All other water-budget parameters are represented as pools that can give water to or receive water from the conduits or the sink. The model can be viewed as a detailed, concrete representation of Eq (1).

Inflows

The model shows that water enters the regional hydrologic system from several distinct sources. Precipitation, ground- and surface-water inflow, and imported water are represented by I in Eq (1). Conclusions drawn from hydrologic studies of the WIPP region must take into account the volumes and origins of the various waters in the region. The largest inflow of water is precipitation, at 1.47×10^6 ac-ft/yr roughly an order of magnitude greater than the next largest inflow, surface water. Much of the precipitation evaporates or is transpired immediately. A small portion recharges the ground water. A very small portion runs off and joins the Pecos River. An average of 113,700 ac-ft/yr of surface water enters the study area from the north in the Pecos River. A small but variable amount of surface water also enters from the west in the Black River. Ground water flows into the study area along the northeastern boundary and may flow out to the south; the volume has not been estimated in this report.

Minor amounts of ground water are imported into the study area by artificial means. These agricultural, industrial, and municipal imports are shown separately in the model to emphasize that their origins may differ. For example, water imported by the City of Carlsbad originates in the Capitan Ls., while oil-field brines originate in rocks older than the Capitan Ls. and in the Ogallala Fm. Artificially imported water, though small in volume, is important to hydrologic studies for two reasons. First, small volumes of imported water may cause major perturbations in flow in the natural hydrologic system, depending on the point of discharge into the system. Water discharged into the Pecos River may be almost invisible because of the natural variation in stream flow; nevertheless, the volumes could be an important source of error in calculations of ground-water discharge made from seepage runs. Water discharged into Nash Draw, on the other hand, will be immediately apparent as a dramatic change in storage and is thus less likely to be overlooked in hydrologic studies. Second, the imported waters probably differ chemically from each other and from the waters that they join inside the study area. The results of hydrochemical studies inside the study area would be biased in unknown ways if the percentage and chemical nature of the imported water in a sample were not known.

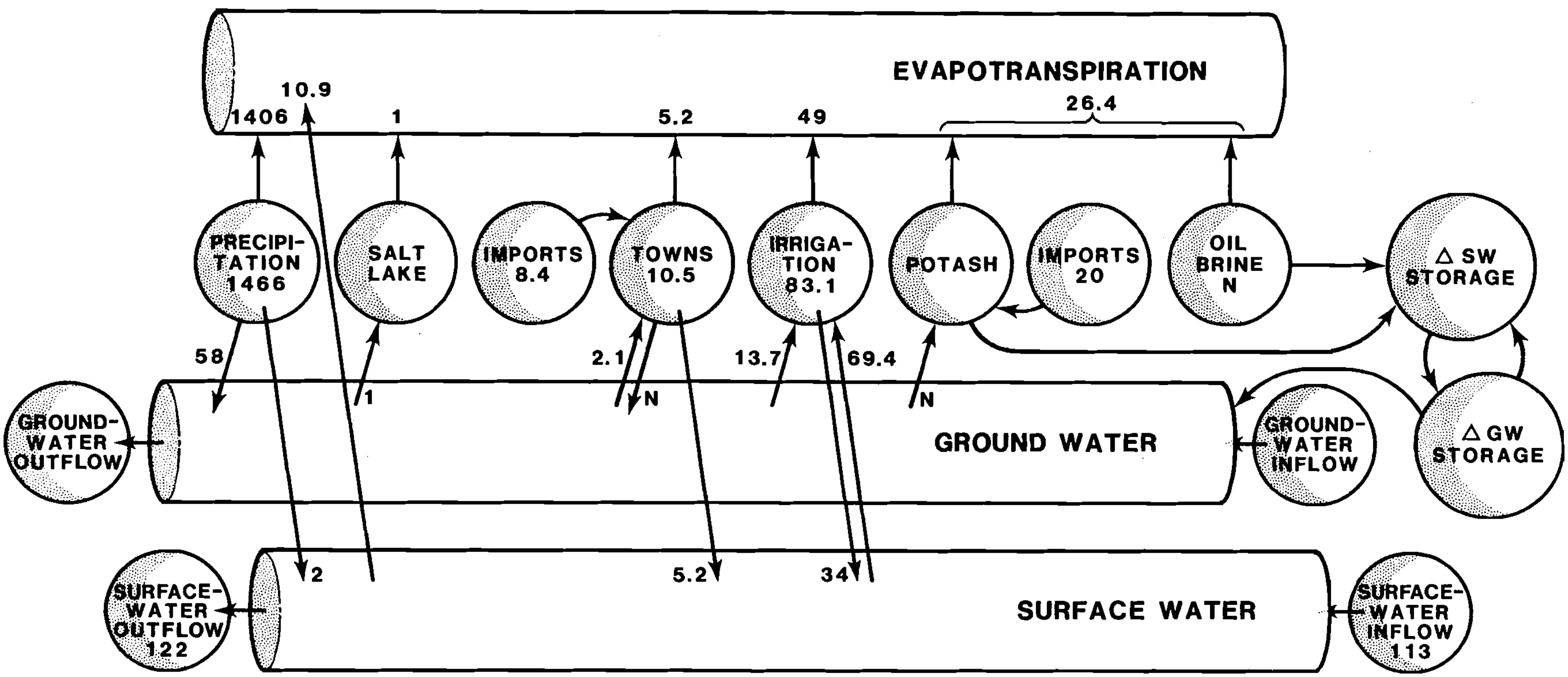


Figure 14. Model of the WIPP Regional Water Balance. (Values in thousands of ac-ft/yr. Format for the model after Geohydrology Associates, 1978c.)

Outflows

The model shows that water leaves the regional hydrologic system in three ways. Evapotranspiration and surface- and ground-water outflow are represented by O in Eq (1). Evapotranspiration is by far the largest sink, accounting for roughly 1.5×10^6 ac-ft/yr. Water evaporates directly from precipitation, surface water, and ground water. In addition, there are intentional or incidental evaporative losses of water from municipalities, agriculture, and industry. Because evapotranspiration is calculated, not measured, no significance can be attached to the rough agreement between inflow and outflow volumes.

Ground-water outflow is uncertain because no potentiometric-surface maps are available for aquifers below the topmost aquifer for most of the study area. The potentiometric-surface map of the topmost aquifer indicates that ground water discharges to the Pecos River rather than to flow out of the study area. This may not be the case for lower aquifers.

Surface water is gaged at the Red Bluff gaging station, about nine river miles before leaving the study area. Presumably the Pecos River continues to gain water between the final gaging station and the point at which it leaves the study area. An average of slightly more than 122,000 ac-ft/yr leaves the study area as surface water. The volumes of ground-water and surface-water outflow are important primarily because of the bounds they place on parameters used in ground-water modeling.

Changes in Storage

Changes in storage are represented by ΔS in Eq (1). Changes in surface- and ground-water stoorage in Nash Draw are well documented, although apparently a new equilibrium has been reached between industrial additions and losses from newly formed lakes.

Industrial brines, mostly from potash refineries but also from oil fields, have been discharged into surface ponds for more than 40 yr. Brine seeps from many of the ponds into the ground, eventually joining and creating a mound in the water-table aquifer. In some cases, the water table has risen above the land surface, creating new ponds that do not receive industrial brines directly. From the ground-water mounds in Nash Draw, industrial brines probably join the regional flow of ground water, eventually either flowing out of the study area or discharging to the Pecos River. In addition, some of the industrial brine may join the flow of natural brines from Laguna Grande de la Sal to the Pecos River. The industrial brines may have initiated or slightly increased a flux of brine from Laguna Grande de la Sal to the Pecos River because they have raised the altitude of the surface of the lake. Mixing the industrial brines with the natural brines in the lake probably also changes the hydrochemistry of any discharge to the Pecos River. Circumstances in Clayton Basin are similar to those giving rise to the changes in storage in Nash Draw; however, data are inadequate to determine whether there have been similar changes in storage in Clayton Basin. The changes in storage in Nash Draw are likely to be reversed after the cessation of potash refining. Changes in storage are important because they indicate a hydrologic system in disequilibrium, but hydrologic modeling commonly assumes that equilibrium conditions exist.

Usage

Only inflow, outflow, and changes in storage are explicitly included in Eq (1). In a developed region like the WIPP water-balance study area, however, it may be difficult to determine the value of each term of the equation without carefully examining the usage of water in the study area. In the WIPP area, water usage changes the inflow to the region by artificially importing water for municipal, agricultural, and industrial purposes. Water usage changes the outflow both by adding water to the Pecos River as municipal and agricultural return flow and by consumptive use. Water usage changes the volumes of ground water and surface water in storage by raising and lowering the water table. In addition, usage may divert water from one flow stream to another. For example, irrigation diverts water that would normally leave the study area by ground-water outflow to surface-water outflow and evapotranspiration.

Major Uncertainties in the Model

Uncertainties in the model arise from three qualitatively distinct sources: measurement error, parameter variability, and interpretation. Measurement errors are inevitable in data collection. Errors can be classed as accidental errors, systematic errors, or blunders (Kissam, 1956, pp 13 ff). Accidental errors represent the limits of accuracy of the instruments or of the skill of the operators. Systematic errors arise from biases in the instruments or procedures. Blunders are mistakes in observation. Items in the water budget that are most likely to contain systematic errors are evaporation and ground-water flow parameters. These items and all measured budget items also contain accidental errors and probably blunders. For the most part, measurement errors are presumed to be small.

Every item in the water budget varies in space, time, or both. Precipitation and evapotranspiration vary greatly from place to place and year to year. Surface-water flow varies from year to year, but channel locations can remain substantially unchanged for thousands of years. Ground-water flow parameters like hydraulic conductivity vary greatly from place to place but change little over time. Different kinds of parameter variability demand different data collection schemes to ensure a representative sample. Spatially varying parameters should be sampled at many points, but the time period of data collection does not matter. Temporally varying parameters must be resampled periodically.

Uncertainty also arises during interpretation of the data and of relationships between different parameters. Correct interpretation depends on data density, data accuracy, good physical insight, and correct scale. The necessary density of data varies with the variability of the parameter. Inaccurate data can increase the known uncertainty or even lead to totally incorrect interpretations. Good physical insight depends on the training and experience of the researcher and on adequate data. Choosing a correct scale for a complex problem requires a preliminary conceptual model. Boundaries that include too much area may complicate the interpretation by introducing extraneous factors. Boundaries that include too small an area hide parameter variability, complicate the process of identifying bad data, and may lead to erroneous interpretation.

The portion of the water balance of major interest to the WIPP project is ground-water inflow, outflow, recharge, discharge, and change in storage. None of these items can be measured directly; each must be calculated from other measured or calculated factors. Thus uncertainties in ground-water flow are exacerbated by uncertainties in many other parts of the water balance.

The large uncertainties in precipitation and evapotranspiration give rise to equally large uncertainties in ground-water recharge. Because most of the study area has no integrated drainage, ground-water recharge depends only on precipitation and evapotranspiration.

Ground-water inflow and outflow have not been estimated here; they are included in the model for the sake of a water balance that is correct in principle. The change in ground-water storage depends on the storage coefficient, assumed to be 0.15 in the absence of data, and on the area of water-table rise.

Uncertainties in surface-water inflow and outflow are small. Although inflow and outflow are variable, they are carefully and frequently measured. A moderately large uncertainty is introduced into the value of change in surface-water storage by the assumption of uniform depth in the lakes in Nash Draw.

No data are available to calculate the uncertainty in values for municipal, industrial, and agricultural water usage and return flow. Because these items are small compared to precipitation and evapotranspiration, however, their uncertainty cannot contribute significantly to the overall uncertainty in the water balance. Most of the pumpage is metered. Municipal return flow is estimated from values for municipalities that meter both pumpage and sewage effluent; irrigation return flow is estimated from values for aquifer dewatering and consumptive use by crops (James Wright, Roswell State Engineer Office, pers. comm., 7/23/84).

An Arithmetic Check of the Model

Discharge to the Pecos River serves as a check on the calculated recharge. The best estimate of recharge as the difference between precipitation and evapotranspiration in the main part of the study area is 51,600 ac-ft/yr. This estimate is a factor of 1.8 higher than the total discharge, 28,700 ac-ft/yr. The discharge is the sum of half the maximum calculated discharge to the Pecos River (11,800 ac-ft/yr), natural ground-water discharge from Laguna Grande de la Sal (924 ac-ft/yr), and the natural ground-water discharge from Clayton Basin (at least 16,000 ac-ft/yr). The two figures can be completely reconciled by calculating the recharge to be 24,820 ac-ft/yr, using the lowest estimated precipitation and the highest evapotranspiration rate. The differences between the best estimates of recharge and discharge are well within the limits of accuracy of the data.

Summary

This water balance for the area surrounding the WIPP site has been carried out as a part of the Geotechnical Site Evaluation. The purpose of the water balance is twofold: first, to satisfy the suggestion of the New Mexico Environmental Evaluation Group, and second, to illuminate inadequacies in the hydrologic data currently available. An additional benefit that has come out of the water balance is a description of boundary conditions for use in ground-water-flow modeling and of the relative magnitudes of the individual budget items.

The study area for the water balance includes ~2000 mi^2 in Eddy County east of the Pecos River, the Carlsbad Irrigation District, and Lea County southeast of the High Plains. Only rocks above the Salado Fm. and below the Ogallala Fm. are considered in detail.

A water balance is simple in theory: because no water is created or destroyed in an area under consideration, what comes in must either go out or change the amount of water in the system. This can be mathematically expressed as

$$\sum_{1}^{n} I_i + \sum_{1}^{n} O_i + \Delta S = 0$$

where

I_i = a given inflow volume

O_i = a given outflow volume

ΔS = change in storage within the region.

The inflows to the WIPP water-balance area are precipitation, surface water, ground water, and artificially imported water. The outflows are evapotranspiration, surface water, and ground water.

Precipitation is spatially and temporally variable in the study area, although even with the apparently inadequate data base, the uncertainty in the total volume of precipitation is only 6%. This small percentage of precipitation is nevertheless greater in volume than are most other factors in the water budget. Evapotranspiration is the largest item in the water budget and the most uncertain. Roughly 96% of the precipitation in the study area is immediately evaporated or quickly transpired without ever entering into the rest of the hydrologic cycle.

Surface-water inflow can vary enormously from year to year. The data available to describe surface-water inflow and outflow are of good quality and quantity; however, the Pecos River is such a highly regulated stream that applying the outflow data directly in the water budget is impossible. The primary usefulness to the WIPP project of stream-flow data is in the bounds that they place on ground-water discharge from the study area, an important parameter in ground-water modeling.

To determine the ground-water discharge to the Pecos River requires assessing usage of water by various human agencies. Agriculture is the biggest water user in the area. Water is diverted in large quantities from the Pecos River, is applied to fields in the Carlsbad Irrigation District, and then flows back through the shallow alluvial aquifer to the River. About two-thirds of the agricultural water evaporates during this process. Municipal water is pumped from the Capitan Ls. or from the alluvial aquifer and returned either directly to the Pecos River after treatment or indirectly through the alluvial aquifer after disposal in septic tanks. About half of the municipal water evaporates during this process. Industrial water is pumped either from the Ogallala Fm. outside the study area or from Pre-Ochoan oil fields. It is disposed of either in water-flooding operations in the oil fields or in brine tailings ponds. Currently all or nearly all of the industrial water is ultimately evaporating, although past disposal has caused large increases in storage in Nash Draw.

Ground water is recharged in the northwestern part of the study area and enters from the northeast. Much or all of the ground water that enters the study area north of Highway 180 evaporates from Clayton Basin. Ground water in the area of San Simon Swale seems to percolate slowly downward and leave the study area to the southeast. Based on the available data, the only part of the study area genuinely connected hydrologically to the WIPP site is 400 mi^2 south of Highway 180, west of The Divide, and east of the Pecos River. This area includes all of Nash Draw. Recharge to this area seems to occur at the Divide and at Mimosa Ridge. Discharge occurs from Laguna Grande de la Sal, by evaporation, and to the Pecos River. If these are the only recharge and discharge areas, then the rate of evapotranspiration is higher in the WIPP site—Nash Draw area than in the study area as a whole. Details of the predevelopment water levels in Nash Draw are unknown. In the WIPP site—Nash Draw area, ground-water flow in the water-table aquifer in Nash Draw is down the Draw. Flow in the Magenta Member of the Rustler Fm. at the WIPP site is to the west. Flow west of Nash Draw is to the south.

Changes in water usage for the long term are impossible to predict, although the most likely change seems to be a diversion from the mining and refining of oil and potash to agricultural and municipal use. Such a diversion would tend to increase the flow of the Pecos River and to decrease total evapotranspiration in the area. In the past 10,000 yr, the climate in the area seems to have become warmer and drier. A return to the less warm and dry conditions of 10,000 yr ago would leave the area arid to semiarid and reasonably warm. Greater rainfall would not necessarily increase recharge, because it could establish a more integrated drainage system and could increase runoff.

The water balance for the WIPP area is modeled as two conduits—surface- and ground-water flow through the area, a sink—evapotranspiration, and several pools of water that can add water to, take water from, or divert water between the conduits and sink. The difference between the calculated recharge to and discharge from the total hydrologic system, a useful check of the completeness of the model, is within the limits of accuracy of the basic data.

Recommendations

A primary purpose of this study has been to discover inadequacies in the available hydrologic data. Although the water-balance technique is not sensitive to all types of data, it is particularly well suited to discovering discrepancies between data on different types of boundary conditions. For example, a water budget can reveal whether the presumed recharge areas and recharge rates for a flow system are in agreement with the known or presumed ground-water discharge from the system. Because boundary conditions are especially important in ground-water modeling, the results of the water budget should be of use to WIPP modelers. The recommendations that follow not only reflect the major weaknesses of the water budget, but also indicate the types of data most needed for ground-water modeling. They are listed in the order that the data have been discussed in the main body of the report.

Precipitation Network

Uncertainties in the distribution of precipitation, and therefore in the volume of precipitation falling on the study area, dominate the total uncertainty in the regional water budget. Uncertainty in precipitation is one of two factors that directly control the uncertainty in the volume of evapotranspiration and of recharge to the ground water. (The second factor is the percentage of precipitation that evaporates or is transpired.) Better precipitation data would be helpful in two ways. First, because a knowledge of recharge to the ground-water system can be useful in choosing the boundary conditions for ground-water modeling, reduction in the uncertainty of precipitation would be useful in regional ground-water modeling. Second, reduced uncertainty in precipitation would directly reduce the overall uncertainty in the water-budget model by bounding the volume of water available to flow through the WIPP site.

For these reasons, a more accurate water balance would require establishing a precipitation network and maintaining it for as long as possible, preferably for the operating lifetime of the WIPP. The six inactive stations listed in Table 1 should be reestablished to take greatest advantage of the existing data and to establish some long-term records. In addition, new stations should be established, at a minimum, in the vicinities of Bear Grass Draw, Clayton Basin, Nash Draw, and San Simon Swale, although not necessarily only in topographically low areas. At least one pair of stations with as great a ratio as possible of vertical to horizontal displacement (for example, at the top and bottom of a ridge) should be included. Monthly readings would probably be adequate at most stations for most purposes. Establishing and operating the precipitation network need not be expensive (Kelly, 1967). Weather data collected at the WIPP site should also include temperature, relative humidity, wind speed, and evaporation from a Class A pan. A lysimeter at the WIPP station would also be useful.

In addition, there should be an attempt to derive a more sophisticated algorithm for extracting long-term means from short-term data than that presented in this report. The success of the simple algorithm presented here suggests that still greater accuracy could easily be achieved.

Ground-Water Mound Samples

The existence of a naturally occurring, permanent discharge area in Clayton Basin, coupled with a permanent ground-water mound in one or more aquifers between Clayton Basin and Nash Draw, could be of major significance in the regional ground-water modeling. If the discharge area and ground-water mound are natural, and therefore permanent under existing climatic and geologic conditions, then much of the current study area is hydraulically separate from the portions of the aquifers in and near the WIPP site. If, on the other hand, the ground-water mound is an artifact of brine disposal by the potash industry, then after cessation of refining, evaporative discharge in Clayton Basin will decrease and the hypothesized flow from Bear Grass Draw to Malaga Bend might become a reality.

For these reasons, available wells in T. 20 S., R. 30 E., Secs. 19 through 36 should be reinvestigated (see Figure 9, p 40). Well logs should be reexamined to determine or confirm the aquifers represented, water levels should be remeasured, and major-ion water chemistry determined. It should not be necessary to drill new wells. This fairly limited data-collection program should be adequate to definitively include or exclude the northern third of the current study area, (that is, almost the entire area north of Highway 180), from further consideration in the WIPP hydrologic studies.

Water Levels in R. 32 E.

At and near the WIPP site, ground-water flow in the members of the Rustler Fm. is to the south or southwest. In and near San Simon Swale, flow in the Capitan Ls. is currently to the southeast; flow in the Triassic rocks is downward and thence to the southeast. Although only one water level is available for the Rustler Fm. to the east of R. 31 E., a ground-water divide could exist in the members of the Rustler Fm.

in Ts. 21 through 23 S., R. 32 E. (see Figure 11, p 45). Such a ground-water divide could be a result of the conflicting influence of Nash Draw and the Pecos River Valley to the west and the presumed active dissolution and collapse at San Simon Swale to the east. A ground-water divide would represent a useful boundary for regional ground-water modeling and would provide the final justification for excluding San Simon Swale from further consideration in the WIPP hydrologic studies.

For this reason, water-level data, at least for the various members of the Rustler Fm., but preferably for all aquifers above the Salado Fm., should be collected in Ts. 21 to 23 S., R. 32 E. Existing wells (if any) could be used if the well logs are adequate to identify the aquifer. Water-level data in at least one well in the Rustler Fm. in San Simon Swale would be desirable.

Water-Level Data

It has not been possible to determine with certainty the directions of ground-water flow throughout the region, the points of ground-water discharge from various aquifers, or the volumes of interaquifer transfer of water by using the available data. Many more data on water levels are essential to the precise determination of flow-paths and volumes of any discharge between the WIPP site and the accessible environment.

For this reason, a comprehensive program of water-level measurement should begin. Water-level determinations should be concentrated in Nash Draw and south of the WIPP site. To the greatest extent possible, separate water levels for all aquifers above the Salado Fm., rather than composite heads, should be obtained. This is especially important in Nash Draw, where there is localized variation in the connectedness of the aquifers.

Ground-Water Contamination Data

Surface and ground waters imported from outside the boundaries of the study area are dumped into the study area by various municipalities, the potash, oil, and agriculture industries, and possibly other agencies undetected in the course of this study. Imported water comes from the Capitan Ls., the Ogallala Fm., Pre-Ochoan oil-bearing rocks, and from meteoric waters precipitated under slightly different climatic conditions from those in the study area (e.g., surface water used for irrigation). Most of the imported water is dumped into Nash Draw or the Pecos River, two areas of primary concern to ground-water modeling of the WIPP hydrologic regime. The imported water changes the volumes, rates, and gradients of ground- and surface-water flow in the region. It also changes the chemistry of samples collected to assist in determining the values of the same flow variables.

For this reason, a file-data search should be conducted in the Offices of the State Engineer and of the Oil Conservation Commission to determine the sources, volumes, and disposal points of all waters imported to the area and to determine whether compositional data are available for these fluids.

Seepage Runs

The volume of ground-water discharge into the Pecos River would be a convenient boundary condition for use in modeling flow through the WIPP area. The data available for this report, while providing some guidelines to modelers, are nevertheless accurate to only about an order of magnitude. More precise estimates of ground-water discharge would greatly reduce uncertainty in the water budget and modeling.

For this reason, seepage runs should be conducted on the Pecos River between USGS gaging stations 4052 and 4075. The runs should be conducted in late winter to minimize the effects of irrigation in the Carlsbad Irrigation District. Some irrigation takes place in the winter; CID personnel should be consulted about the exact timing of the seepage runs. Seepage runs should be conducted during periods of no precipitation and no snow melt. The seepage runs should be accompanied by water-quality sampling and by an attempt to monitor municipal usage, so that regional ground-water discharge may be distinguished from municipal return flow. It might be useful in planning the seepage runs to reexamine the data collected from an extensive temporary gaging network established in connection with the Joint Pecos River Investigation in the late 1930s and early 1940s (National Resources Planning Board, 1942, p 24).

Paleoclimatic Data

Ground-water modeling and scenario analysis for the WIPP performance assessment will be required to simulate a 10,000-yr period for comparison with the appropriate regulatory standard (US Environmental Protection Agency, 1985). Climatic changes can be, although they are not necessarily, dramatic during a period of 10,000 yr. No climatic data specific to the WIPP region were found during this study. If paleoclimatic data such as relative precipitation, humidity, and wind direction were available, then it would be possible to compare past and present conditions and make reasonable guesses about past and future recharge to the ground-water flow systems.

For this reason, a brief scoping study should be conducted of the feasibility and relative usefulness of palynological, vertebrate and invertebrate paleontological, dendrochronological, and isotopic studies for the purpose of collecting data useful in long-term climatic modeling (10,000 to 100,000 yr). Studies determined to be both feasible and useful should be carried out and followed by long-term climatic modeling.

Evapotranspiration and Infiltration

Presuming that the ground-water divides between Clayton Basin and Nash Draw and between the WIPP site and San Simon Swale are ultimately found to be real, permanent, and useful for ground-water modeling, the region of concern to ground-water modeling and scenario analysis for the WIPP performance assessment is relatively small—roughly 400 mi^2. Over such a small area, the evapotranspiration rate used in this report, 96% of precipitation, becomes more uncertain even as the demand for accuracy in the modeling becomes greater. Geohydrology Associates (1978b, p 35) and Barrows (1982) have suggested that surface depressions in the area (called variously "ponds," "dolines," or "blowouts," depending on the author) are sites of point recharge to the ground-water system, although Bachman (1985) believes that most or all of the depressions are sites of pan-type evaporation without recharge.

For this reason, evapotranspiration and infiltration studies should be conducted at as many localities as possible throughout the area of immediate concern to the WIPP ground-water system. Water evaporation or seepage from one or more of the surface depressions, both at the WIPP site proper and in the possible areas of recharge to the ground-water systems flowing through the site, should be investigated in some way at least as sophisticated as that used in investigating seepage from the potash brine-disposal ponds (Geohydrology Associates, 1979). That investigation included both winter and summer measurements of numerous climatic variables and of pond levels, in a way that allowed calculating evaporation and seepage. The investigations suggested here should also include shallow wells, open at the top of the caliche, to determine whether any seepage from the surface of the depressions actually enters the ground-water system or remains perched until transpired by mesquite and other phreatophytes.

In addition to these field studies of possible recharge through the depressions, aerial photography should be used to determine the seasonal fluctuations in all natural and artificial brine ponds and lakes in Nash Draw. Photographs should be taken during at least one wet and one dry year. All perennial and ephemeral springs in Laguna Grande de la Sal should be sampled to determine, if possible, the origin of the water. An attempt should be made to determine actual volumes of water disposed of by the potash refineries in and near Nash Draw during the period of investigation. With this information, it might be possible to calculate the natural evaporation from Laguna Grande de la Sal, as the difference between the potash seepage and the total evaporated volume. Another possibly useful recharge study is to compare pumpage of stock and domestic wells throughout the potential recharge areas with documented drawdowns over the period of record. Field data on both the saturated and unsaturated zones are essential to subsequent evapotranspiration studies. Existing data are inadequate to determine evaporation from and recharge to the ground-water system near the WIPP site.

APPENDIX A

Precipitation, 1977-1982

(in inches)

Chaves County

Monthly and Annual Precipitation Summary, 1977 Through 1982, for Roswell WSO (NOAA) (33°18′, 104°32′, el. 3669 ft)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Departure
1977	0.07	0.36	0.27	1.25	2.43	0.25	0.46	4.45	0.29	0.62	0.48	0.02	10.95	0.34
1978	0.50	0.48	0.39	0.02	1.81	4.31	0.52	3.49	3.58	1.47	1.25	0.43	18.25	7.64
1979	0.41	0.44	0.13	0.32	1.25	1.56	1.44	2.28	0.15	0.18	T	0.37	8.53	-2.08
1980	0.85	0.19	0.00	1.06	0.85	0.29	0.01	2.45	6.58	T	0.77	0.15	13.20	2.59
1981	0.27	0.17	0.10	0.79	3.35	4.55	6.27	4.73	2.70	1.02	0.25	0.13	24.33	13.72
1982	0.66	0.20	0.12	0.41	0.20	0.76	1.03	0.93	2.00	0.20	0.92	1.62	9.05	-1.56

Normal = 10.61
T = trace

Eddy County

Monthly and Annual Precipitation Summary, 1977 Through 1982, for Artesia 6S (NOAA) (32°46′, 104°23′, el. 3320 ft)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Departure
1977	0.31	0.11	1.08	1.68	1.39	2.43	0.34	3.95	0.81	1.36	0.25	0.02	13.73	3.29
1978	0.50	0.49	0.57	0.11	0.94	9.77	0.60	1.16	7.71	1.98	1.33	0.39	25.55	15.11
1979	0.38	1.09	0.15	0.09	1.75	1.08	2.36	4.27	0.63	T	0.09	0.71	12.61	2.17
1980	0.86	0.37	T	1.06	1.20	E.35	0.27	1.30	9.06	0.74	0.72	0.15	E16.07	5.63
1981	0.46	0.08	0.25	0.58	1.05	0.86	2.32	2.27	4.19	2.48	0.19	0.08	14.81	4.37
1982	0.60	0.10	0.06	0.21	1.63	0.68	1.70	2.20	2.77	1.10	0.94	E1.39	E13.38	—

Normal = 10.44
E = estimated
T = trace

Eddy County (continued)

Monthly and Annual Precipitation Summary, 1977 Through 1982, for Carlsbad (NOAA) (32°25′, 104°14′, el. 3120 ft)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Departure
1977	0.30	0.13	1.17	2.33	0.96	2.02	0.65	2.21	0.71	2.06	0.25	E.00	E12.79	0.88
1978	0.17	0.91	0.25	0.33	1.82	1.97	1.92	1.16	7.98	2.11	4.51	0.37	23.50	11.59
1979	0.34	0.48	0.04	0.15	2.83	2.44	2.50	2.10	0.67	0.00	0.03	0.91	12.49	0.58
1980	0.83	0.59	0.00	1.18	0.69	0.91	0.52	0.90	12.27	0.30	1.03	0.20	19.42	7.51
1981	0.59	0.18	0.43	3.55	E.98	1.53	3.63	2.08	2.08	0.76	0.00	0.00	E15.81	3.90
1982	E.36	0.24	0.00	0.35	2.26	0.19	2.08	0.63	0.96	2.34	1.06	2.38	E12.85	—

Normal = 11.91
E = estimated

Eddy County

Monthly and Annual Precipitation Summary, 1977 Through 1982, for Carlsbad FAA Airport (NOAA) (32°20′, 104°16′, el. 3260 ft)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Departure
1977	0.42	0.08	1.04	2.18	1.47	0.54	0.87	1.58	0.99	1.45	0.14	T	10.76	—
1978	0.22	0.34	0.16	0.21	1.40	2.33	0.36	1.01	8.44	1.57	3.42	0.32	19.78	—
1979	0.20	0.46	0.03	0.11	2.74	0.90	4.49	2.53	0.62	T	0.07	0.58	12.73	—
1980	0.45	0.13	T	0.80	1.00	0.10	0.09	2.08	7.61	0.09	1.07	0.20	13.62	—
1981	0.77	0.32	0.62	1.23	1.91	0.35	3.47	2.80	2.48	0.66	—	—	—	—
1982	—	—	0.04	1.26	1.76	0.10	2.06	0.82	2.01	1.46	1.25	1.86	—	—

Mean (1955 through 1980) = 11.25
T = trace

Eddy County

Monthly and Annual Precipitation Summary, 1977 Through 1982, for Duval Potash Mine (NOAA) (32°32′, 103°54′, el. 3520 ft; Sec. 35, T. 20 S., R. 30 E.)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Departure
1977	0.12	0.17	1.08	1.32	1.40	2.25	0.55	0.26	0.17	1.60	0.11	0.00	9.03	—
1978	0.14	0.52	0.23	0.24	0.96	2.20	0.43	1.29	6.50	1.47	2.90	0.03	16.91	—
1979	0.41	0.40	0.04	0.30	1.73	1.32	6.82	1.15	0.63	0.00	0.11	0.50	13.41	—
1980	0.71	0.51	0.03	0.52	1.61	0.03	0.10	0.86	10.13	0.08	1.94	0.01	16.53	—
1981	0.24	0.00	0.41	2.94	1.73	2.25	3.49	6.37	1.97	1.47	0.06	0.08	21.01	—
1982	0.32	0.34	0.02	0.36	1.61	0.38	1.74	1.17	3.07	0.53	1.30	1.75	12.59	—

Mean (1955 through 1982) = 14.21

Eddy County (concluded)

Monthly and Annual Precipitation Summary, 1977 Through 1982*, for Lake Avalon (NOAA)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Departure
1977	E.16	0.14	—	1.51	0.72	1.70	0.07	2.34	0.44	1.48	0.00	0.00	E9.05	–1.96
1978	0.40	0.62	0.37	0.30	1.40	2.72	0.63	0.79	8.54	1.93	3.52	E.21	21.43	10.42
1979	0.71	0.32	E.30	0.03	—	—	—	—	—	—	—	—	—	—

Normal = 11.01
E = estimated
* = data collection discontinued

Lea County

Monthly and Annual Precipitation Summary, 1977 Through 1982, for Hobbs (NOAA) (32°42′, 103°08′, el. 3615 ft)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Departure
1977	0.18	0.05	1.10	1.44	2.09	3.41	1.60	0.79	0.53	1.00	0.06	0.01	12.26	–2.10
1978	0.37	0.65	0.48	0.44	1.95	2.23	0.57	0.75	7.14	1.51	4.33	0.31	20.73	6.37
1979	0.29	E.47	0.53	0.32	2.26	4.96	1.59	2.83	0.45	0.11	0.28	0.74	E14.83	0.47
1980	1.12	0.37	0.02	0.29	4.00	1.31	0.22	3.73	7.05	0.04	1.45	0.09	19.69	5.33
1981	0.31	0.42	0.41	2.86	2.27	1.26	7.29	3.07	2.27	2.73	0.26	0.27	23.42	9.06
1982	E.35	0.05	1.25	1.28	4.73	1.55	4.25	0.87	1.67	0.69	1.59	2.26	E20.54	—

Normal = 14.36
E = estimated

Lea County

Monthly and Annual Precipitation Summary, 1977 Through 1982, for Jal (NOAA) (32°06′, 103°12′, el. 3060 ft)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Departure
1977	0.16	T	0.90	1.18	0.96	1.70	1.62	0.70	0.42	1.04	0.06	T	8.74	–2.93
1978	0.17	0.45	0.23	0.30	1.62	1.87	0.40	0.75	6.32	1.56	3.30	E.23	17.20	5.53
1979	—	—	—	—	1.25	3.45	1.57	6.04	0.45	0.07	0.13	0.87	—	—
1980	0.80	1.46	0.02	0.44	0.98	1.64	0.01	0.54	7.64	0.05	1.33	0.32	15.23	3.56
1981	0.94	0.61	0.64	2.99	1.41	0.74	1.40	2.25	2.08	2.55	0.02	0.05	15.68	4.01
1982	0.29	0.06	0.31	1.07	2.54	0.84	1.28	1.04	0.75	0.13	1.16	1.83	11.30	–0.37

Normal = 11.67
T = trace

Lea County (continued)

Monthly and Annual Precipitation Summary, 1977 Through 1982, for Maljamar 4SE (NOAA) (32°49′, 103°42′, el. 4000 ft)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Departure
1977	E.13	0.47	1.34	1.05	1.89	1.27	0.70	0.80	0.09	1.54	0.15	T	E9.86	—
1978	0.52	0.52	0.35	0.18	1.58	2.05	0.90	0.89	5.84	1.52	1.85	0.11	16.31	—
1979	0.34	0.63	0.14	0.30	2.17	0.83	2.15	2.56	1.59	T	0.10	0.53	E11.34	—
1980	1.60	0.54	0.07	0.55	1.44	0.80	T	1.12	6.35	0.33	0.34	0.22	13.36	—
1981	0.23	0.33	0.14	1.73	0.96	2.10	4.16	3.89	1.71	1.41	0.14	0.20	17.00	—
1982	0.39	0.22	0.38	0.59	1.26	1.02	2.81	1.36	4.44	0.70	1.43	1.21	15.81	—

Mean (1955 through 1982) = 14.51
E = estimated
T = trace

Lea County

Monthly and Annual Precipitation Summary, 1977 Through 1982, for Ochoa (NOAA) (32°11′, 103°26′, el. 3460 ft; Sec. 35, T. 24 S., R. 35 E.)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Departure
1977	—	—	—	—	—	—	—	—	0.50	0.86	E.13	T	E6.74	–4.43
1978	0.10	0.50	0.18	0.25	2.15	4.38	0.00	1.83	9.53	1.94	E2.03	0.00	22.89	11.72
1979	0.50	0.38	0.07	0.11	0.66	2.19	3.11	E3.31	0.76	0.00	0.24	0.85	E12.18	1.01
1980	1.69	0.30	0.00	0.00	0.75	0.50	T	0.90	E8.49	0.00	0.80	0.25	E13.68	2.51
1981	0.50	0.82	E.69	3.10	1.54	1.35	1.92	0.91	0.26	0.66	0.40	0.32	E16.19	5.02
1982	0.20	0.00	T	0.56	2.19	1.40	0.99	1.71	0.49	0.00	0.38	0.95	8.87	–2.30

Normal = 11.17
E = estimated
T = trace

Lea County (concluded)

Monthly and Annual Precipitation Summary, 1977 Through 1982, for Pearl (NOAA) (32°39′, 103°23′, el. 3800 ft; Sec. 19, T. 19 S., R. 36 E.)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Departure
1977	—	0.24	0.85	1.03	1.89	1.62	0.13	1.09	0.05	1.05	0.18	T	E9.42	–3.90
1978	0.28	0.32	0.44	0.33	1.84	4.94	0.45	0.57	5.75	1.27	1.28	T	17.47	4.15
1979	0.27	0.30	0.12	0.00	1.27	4.55	2.02	2.68	0.47	T	0.09	0.92	12.69	–0.63
1980	0.88	0.36	T	0.47	3.15	0.33	0.00	1.06	6.80	0.01	1.80	0.10	14.96	1.64
1981	0.26	0.43	0.30	2.20	1.68	5.62	3.35	2.26	2.25	2.69	0.10	0.20	21.34	8.02
1982	0.31	0.11	0.19	1.47	2.14	0.82	0.90	1.18	2.11	0.28	1.12	1.74	12.37	–0.95

Normal = 13.32
E = estimated
T = trace

APPENDIX B

Well Data

The wells included here have been used in preparing Plate 1. The following abbreviations are used in the Appendix:

Qa	Quaternary alluvium
Qp	Quaternary playa lake deposits
Vf	Valley fill
Tt	Tertiary rocks, undivided
Og	Ogallala Fm.
Dk	Dockum Group
Dl	Dewey Lake Redbeds
Tr	Triassic rocks, undivided
Cb	Chalk Bluff
Tn	Tansill
Cl	Carlsbad
Ru	Rustler Fm., undivided
Rf	Rustler Fm., Forty-niner Member
Rm	Rustler Fm., Magenta Member
Rt	Rustler Fm., Tamarisk Member
Rc	Rustler Fm., Culebra Dolomite Member
TDS	Total dissolved solids
*	Altitude corrected here
GA78a	Geohydrology Associates, 1978a
GA78b	Geohydrology Associates, 1978b
GA79	Geohydrology Associates, 1979
GA84	Geohydrology Associates, 1984
Mcr 83	Mercer, 1983
W-15	Sandia National Laboratories Division 4511 and University of New Mexico Department of Geology, 1981

Well locations are given by a number, such as 17.27.12.413. The first part designates the township; the second part, the range; and the third part, the section. Quarter sections and further subdivisions are numbered thus: $\begin{matrix} 1 & 2 \\ 3 & 4 \end{matrix}$. A well designated by 17.27.12.413 is located in the southwest quarter of the northwest quarter of the southeast quarter of Sec. 12, T. 17 S., R. 27 E. "Zero" usually designates a well in the center of the given subdivision.

Well Location	Date of Data Collection	TDS	Specific Conductance	Altitude of Water Level (ft)	Depth of Well (ft)	Aquifer	Source
16.27.27.133	04/ /63	—	—	~3380	180	Qa?	GA78a
16.27.27.331	01/ /63	—	—	3466	1070	Cb	GA78a
16.27.36.212	10/13/77	—	>8000	3407	61.4	Cb	GA78a
16.28. 3.210	10/14/77	—	4600	3568	30.0	—	GA78a
16.28.12.212	10/14/77	—	4100	3532	49.8	—	GA78a
16.30.24.122	10/17/77	—	1560	3497	380.1	—	GA78a
16.31.14.300	12/09/48	—	—	~4110	—	Dk?	GA78a
17.27. 3.120	12/01/48	—	—	<3320	—	Cb	GA78a
17.27. 5.444	10/16/52	—	—	3324	80	—	GA78a
17.27.11.110	12/01/48		—	~3380	—	Cb?	GA78a
	12/21/48	2690					
17.27.12.413	04/ /54	—	—	3357	250	—	GA78a
17.27.16.344	01/18/66	—	—	3253	—	—	GA78a
17.27.17.4	—	—	—	3296	300	—	GA78a
17.27.18.234	02/ /63	—	—	3201	138	Qa	GA78a
17.27.32.32	08/ /56	—	—	3304	330	—	GA78a
17.28. 2.240	12/01/48	—	—	~3570	—	Dk?	GA78a
17.28.14.220	—		—	~3520	—	Dk?	GA78a
	12/06/48	3920					
17.28.19.200	12/02/48	—	—	~3380	—	Cb/Ru	GA78a
17.28.22.230	12/01/48	—	—	~3560	—	Ru/Dk	GA78a
17.28.24.224	10/14/77	—	—	3651*	33.88	—	GA78a
17.29. 8.231	10/14/77	—	—	3527	92.7	—	GA78a
17.29.22.110	11/29/48	—	—	3470	—	Dk?	GA78a
17.29.29.400	12/03/48	—	—	~3290	—	Dk?	GA78a
17.31.34.000	12/06/48	893	—	<3528	—	Dk	GA78a
17.32. 4.442	06/03/54	—	—	4097	—	Qa	GA78a
18.27. 8.240	01/09/64	—	—	3324	—	—	GA78a
18.27.10.200	01/09/64	—	—	3423	—	—	GA78a
18.27.28.140	01/09/64	—	—	3324	—	—	GA78a
18.27.33.42	09/ /69	—	—	3398	90	—	GA78a
18.28. 8.330	12/03/48	—	—	~3570	—	Cb/Ru	GA78a

Well Location	Date of Data Collection	TDS	Specific Conductance	Altitude of Water Level (ft)	Depth of Well (ft)	Aquifer	Source
18.28.30.110	12/02/48	—	—	3423	—	Cb?	GA78a
18.29.24.142	10/18/77	—	2600	3280	—	—	GA78a
18.29.24.23311	04/08/71	—	—	3276	—	Tr	GA78a
18.29.24.300	04/28/50	1730	—	3272	—	Dk	GA78a
18.29.34.324	03/ /60	—	—	3210	250	—	GA78a
18.30.21.4200	12/09/65	—	—	3229	—	Tt	GA78a
18.30.22.2220	04/08/71	—	—	3190	—	Tt	GA78a
18.30.26.4140	12/14/77	—	1100	3228	223.0	Tt	GA78a
18.30.31.323	11/18/77	—	—	3212	161.0	—	GA78a
18.30.32.32422	04/08/71	—	—	3219	—	Tt	GA78a
18.31. 1.44432	04/07/71	—	—	3337	—	Tt	GA78a
18.31.12.23144	04/07/71	—	—	3340	600	Tt	GA78a
18.31.14.22133	04/06/71	—	—	3354	400	Tt	GA78a
18.31.35.31324	04/05/71	—	—	3370	300	Tt	GA78a
18.32.16.22433	03/18/68	—	—	3709	100	Og	GA78a
18.32.20.13311	02/23/71	—	—	3291	270.0	Tt	GA78a
18.32.22.32322	04/06/71	—	—	3329	—	Tt	GA78a
18.32.34.22241	04/06/71	—	—	3604	—	Tt	GA78a
18.33. 3.34133	04/05/66	—	—	3955	—	Qa	GA78a
18.33.10.23244	02/09/71	—	—	3963	75	Qa	GA78a
18.33.11.4433	02/09/71	—	—	3944	—	Qa	GA78a
18.33.12.44211	02/05/71	—	—	3952	—	Qa	GA78a
18.33.13.44244	02/08/71	—	—	3926	—	Qa	GA78a
18.33.14.11140	03/06/68	—	—	3940	46.0	Qa	GA78a
18.33.19.142	12/09/58	—	—	<3680	—	Tr?	GA78a
18.33.23.23140	02/09/71	—	—	3835	58	Qa	GA78a
18.33.34.133	12/09/58	—	—	3583	200.0	Tr	GA78a
18.34.29.11213	02/05/71	—	—	3912	—	Qa	GA78a
19.27.13.310	09/03/48	—	—	3389	75	Cb	GA78a
19.27.14.242	01/20/50	—	—	3368	95?	Cb	GA78a

Well Location	Date of Data Collection	TDS	Specific Conductance	Altitude of Water Level (ft)	Depth of Well (ft)	Aquifer	Source
19.27.16.13	01/ /69	—	—	3324	926	—	GA78a
19.28. 2.122	12/13/48	4740	—	3332	160	Ru?	GA78a
19.28. 2.23311	04/02/68	—	—	3285	—	Ru	GA78a
19.28. 5.21114	01/28/71	—	—	3396	160.0	Ru	GA78a
19.28. 5.411	11/ /69	—	—	3385	312	—	GA78a
19.28. 9.31	05/13/66	—	—	3280	365	—	GA78a
19.28.13.21441	02/01/71	—	—	3216	160	Ru	GA78a
19.28.18.120	09/03/48		—	3419	—	Cb?	GA78a
	1/20/50	350					
19.28.18.12113	01/28/71	—	—	3417	100	Ru	GA78a
19.28.19.11	03/ /72	—	—	3404	100	—	GA78a
19.28.24.32233	02/01/77	—	—	3221	—	Ru	GA78a
19.28.33.21422	01/28/71	—	—	3224*	125	Ru	GA78a
19.28.36.43233	02/01/71	—	—	3220	87	Ru	GA78a
19.29.10.43211	02/01/71	—	—	3224	153.0	Ru	GA78a
19.29.13.410	02/21/48	1050	—	3187	250	Ru/Dk	GA78a
19.29.13.41224	12/09/65	—	—	3197	—	Ru	GA78a
19.29.13.412243	02/01/71	—	—	3200	—	Ru	GA78a
19.29.20.220	12/13/48		—	3242	—	Ru?	GA78a
	12/21/48	2400					
19.29.23.23144	02/01/77	—	—	3199	85.0	Ru	GA78a
19.29.25.232	10/18/77	—	2950	3291	125.7	—	GA78a
19.29.25.441	10/18/77	—	—	3258	125.7	—	GA79
19.30. 3.44	03/14/79	—	—	3255.14	220	—	GA79
19.30. 5.32	03/14/79	—	—	3203.88	170	Vf	GA79
19.30.17.441	02/01/71	—	—	3186	—	Tr	GA78a
19.30.24.133	03/07/79	—	—	3209.95	70	Rf/Dl	GA79
19.30.25.12133	02/01/71	—	—	3219	—	Tr	GA78a
19.30.25.123	03/14/79	—	—	3223	42	—	GA79
19.30.26.222	01/ /79	—	—	3208	Hackberry Lake		GA79
19.30.33.31	03/15/79	—	—	3196.27	50	Rf	GA79
19.30.35.23	03/14/79	—	—	3185.94	100	Dl	GA79

Well Location	Date of Data Collection	TDS	Specific Conductance	Altitude of Water Level (ft)	Depth of Well (ft)	Aquifer	Source
19.31.27.21144	02/01/71	—	—	3430	—	Tr	GA78a
19.31.28.3332	12/15/77	—	2200	3296	200.0	—	GA78a
19.31.28.33433	02/01/71	—	—	3334	180	Tr	GA78a
19.31.33.110	11/29/48		—	3349	160	Dk	GA78a
	05/01/50	3340					
19.32. 8.200	12/09/58	—	—	3285	—	Tr	GA78a
19.32.29.32	03/15/79	—	—	<3449.61	100 (dry)	—	GA79
19.32.34.421424	01/28/71	—	—	3299*	575	Tr	GA78a
19.33. 5.12322	12/09/58	—	—	<3411	—	Tr	GA78a
19.33.17.11224	01/28/71	—	—	3532	131.0	Tt	GA78a
19.33.18.133223	01/28/71	—	—	3423	800	Tr	GA78a
19.33.26.244	07/01/54		—	3507	101	Qa	GA78a
	09/25/72	1700					
19.34. 6.34143	03/18/68	—	—	3542	—	—	GA78a
19.34. 9.114	06/03/54		—	3761	33	Tr?	GA78a
	12/09/58	3680					
19.34.16.33410	03/19/68	—	—	3511	—	—	GA78a
19.34.31.131	11/17/65	—	—	3566	66	Qa	GA78a
20.26.36.411	10/06/48	—	—	3120	—	Cl	GA78a
20.27. 1.110	09/07/48	—	—	3181	200+	Cl	GA78a
20.27. 2.42	—	—	—	<3220	145	—	GA78a
20.27.14.42	05/ /72	—	—	3249	81	—	GA78a
20.27.21.	02/ /63	—	—	3088	171	—	GA78a
20.27.29.440	10/06/48	—	—	3115	125	Cl	GA78a
20.28.14.123	10/24/73	—	—	3106	171	—	GA78a
20.28.28.200	01/20/50	3110	—	3195	—	Ru?	GA78a
20.28.36.140	12/27/48	—	—	3191	—	Ru?	GA78a
20.29. 3.433	12/13/48		—	3208	—	Dk/Ru	GA78a
	04/29/50	2360					

Well Location	Date of Data Collection	TDS	Specific Conductance	Altitude of Water Level (ft)	Depth of Well (ft)	Aquifer	Source
20.29. 3.434	12/13/48	—	2300	3212	95.8	—	GA78a
20.29.16.434	12/15/77	—	—	3207	103.1	—	GA78a
20.29.20.311	12/15/77	—	2700	3202	62.8	—	GA78a
20.29.25.33	03/08/79	—	—	3200.91	180	Rf	GA79
20.29.35.24	08/20/67	—	—	3173	339	—	GA78a
20.30. 3.2	03/ /78	—	—	3183	Clayton Wells Pond		GA79
20.30. 3.223	12/23/48		—	3169	—	Qa	GA78a
	05/01/50	2400					
20.30. 3.424	12/23/48		—	3177	—	Qa	GA78a
	05/01/50	2930					
20.30. 5.310	12/23/48	—	—	3181	—	Qa	GA78a
20.30. 7.112	12/15/77	—	2600	3200	42.8	—	GA78a
20.30. 8.32	03/ /78	43615	—	3189	Blue Pond		GA78b,79
20.30. 8.323	03/ /78	23364	—	3190	Green Pond		GA78b,79
20.30. 8.34	03/ /78	—	—	3194	Stock Pond		GA78b,79
20.30.15.31	03/15/79		—	3195.92	40	Qp	GA79
	02/02/79	10260					
20.30.15.33	/ /79	—	—	3191	pond or spring		GA79
20.30.16.420	05/01/50	3370	—	3190	—	Dk?	GA78a
20.30.17.33	03/ /78	—	—	3197	—	—	GA78b
20.30.17.433	12/15/77	—	—	3189	66.0	—	GA78a
20.30.20.13	03/ /78	—	—	3197	—	—	GA78b
20.30.20.130	12/22/48		—	3165	60	Dk?	GA78a
	05/01/50	3050					
20.30.20.2	03/15/79	—	—	3187	—	—	GA79
20.30.21.434	01/16/74	—	—	3225	335	—	GA79
20.30.23.11	03/15/79		—	3202.48	100	Dl	GA79
	02/02/79	4016					
20.30.25.33	03/15/79	—	—	3269.16	340	—	GA79
20.30.28.44	03/14/79	—	—	3199.81	170	Dl	GA79

Well Location	Date of Data Collection	TDS	Specific Conductance	Altitude of Water Level (ft)	Depth of Well (ft)	Aquifer	Source
20.30.29.33	03/14/79	—	—	3198.67	—	Dl	GA79
20.30.31.214	10/16/77	—	8000	3197	180.1	—	GA78a
20.30.31.23	03/15/79	—	—	3198	—	—	GA79
20.30.32.43	03/15/79	—	—	3165	—	—	GA79
20.30.33.32	03/31/67	—	—	3185*	235	—	GA78a
20.30.33.440	12/27/48		—	3176	240+	Dk?	GA78a
	05/01/50	3860					
20.31. 2.34	03/14/79	—	—	3346.35	160	Tr	GA79
20.31.13.42	10/05/77	—	>8000	3426	32.5	—	GA78a
20.31.13.440	12/22/48	7080	—	3246	—	Dk?	GA78a
20.31.15.130	12/22/48	—	—	3387	70?	Dk?	GA78a
20.31.16.240	10/05/77		—	3397	110.0	Dk?	GA78a
	12/22/48	3220					
20.31.17.33	03/15/79	—	—	3271.59	240	—	GA79
20.31.27.24	03/08/79	—	—	3415.80	150	Tr	GA79
20.31.30.44	03/15/79	—	—	3345.70	320	—	GA79
20.32. 1.322	07/01/54	not potable	—	3488	30	Qa	GA78a
	01/25/84			3488			GA84
20.32.17.13	03/15/79		—	3440.5	100	Qp	GA79
	02/02/79	172828					
20.32.18.233	03/24/54	—	—	3361	400	Tr	GA78a
20.32.22.33	03/15/79		—	3482.87	170	Tr	GA79
	02/02/79	3136					
20.32.23.43312	01/25/84	—	—	3513	78	Tr	GA84
20.32.24.33333	02/02/71		—	3517	65	Og	GA78a
	09/11/72	493					
	01/25/84			3516			GA84
20.32.25.111	12/16/77	—	—	3520	67.5	—	GA78a
20.32.27.144	06/11/54	—	—	3533	25	Qa	GA78a
20.32.27.32411	02/02/71	—	—	3513	75	Og	GA78a
20.32.30.142	06/11/54	—	—	3520	—	Qa	GA78a
20.32.31.13	03/15/79	—	—	3414.83	250	—	GA79

Well Location	Date of Data Collection	TDS	Specific Conductance	Altitude of Water Level (ft)	Depth of Well (ft)	Aquifer	Source
20.32.36.214	06/06/55		—	3541	60	Qa	GA78a
	09/18/72	1270					
20.32.36.21424	01/25/84	—	—	3538	65	Qa	GA84
20.32.36.221	12/16/77	—	2000	3543	53.7	—	GA78a
20.33. 5.34321	02/02/71	—	—	3271	680	Tr	GA78a
20.33.15.221	04/20/55	—	—	3234	—	Tr	GA78a
20.33.18.12322	03/19/68	—	—	3270	—	Tr	GA78a
20.33.20.22224	02/03/71	—	—	3499	—	Tr	GA78a
20.33.21.111	01/25/84	—	—	3501	47.5	Tr	GA84
20.33.24.124	02/03/71		—	3219	676	Tr	GA78a
	09/22/72	892					
20.34. 4.444	02/03/71		—	3463	200+	Tr	GA78a
	02/10/72	7280					
20.34.17.334	07/01/54		—	3495	200	Tr	GA78a
	10/02/72	2930					
20.34.22.222333	02/03/71	—	—	3441	250	Tr	GA78a
20.35. 1.221	11/16/53	—	—	3631	35	Qa	GA78a
20.35. 5.31424	03/08/61	—	—	3623	—	—	GA78a
20.35. 7.44420	01/26/71	—	—	3636	—	Og	GA78a
20.35.31.113	06/25/54	—	—	3672	85	Og	GA78a
20.35.33.43413	01/26/71	—	—	3607	—	Og	GA78a
20.35.35.33432	01/26/71	—	—	3594	—	Og	GA78a
20.36.32.11321	01/28/71	—	—	3424	621	Tr	GA78a
21.26.23.133	01/21/70	—	—	3103.31	418	Cl	GA78a
21.26.24.424	01/10/75	—	—	3104.68	320	Tn	GA78a
21.26.25.344	01/16/74	—	—	3107.05	—	Tn	GA78a
21.26.36.212	01/10/75	—	—	3099.70	200	Vf	GA78a
21.27. 1.420	12/27/48	—	—	3167	30	Ru/Qa	GA78a
21.27. 6.140	09/03/48	—	—	3156	—	Cl?	GA78a

Well Location	Date of Data Collection	TDS	Specific Conductance	Altitude of Water Level (ft)	Depth of Well (ft)	Aquifer	Source
21.27. 9.333	04/ /66	—	—	3146	92	—	GA78a
21.27.19.334	02/18/75	—	—	3106.76	320	Tn	GA78a
21.27.25.233	05/29/75	—	—	3061	270	—	GA78a
21.27.28.331	—	—	—	3110	350	—	GA78a
21.27.29.311	01/03/62	—	—	3099.78	236	Cl	GA78a
21.27.31.214	01/10/75	—	—	3088.68	—	Vf	GA78a
21.28. 2.24	11/ /66	—	—	3157	308	—	GA78a
21.28. 4.413	12/16/77	—	2470	3184	39.5	—	GA78a
21.28. 4.442	12/16/77	—	—	3155	185	—	GA78a
21.28.12.444	06/06/73	—	—	3153	275	—	GA78a
21.28.18.130	01/21/50		—	3131	—	Qa?	GA78a
	01/30/50	6090					
21.28.30.141	01/09/75	—	—	3091	—	Cl	GA78a
21.28.35.333	10/25/77	—	2600	3023	146.3	Ru/Cb	GA78a
21.29. 2.14	03/15/79	—	—	3148.28	400	—	GA79
21.29. 3.120	12/23/48	—	—	<3170	302	Dk	GA78a
21.29. 4.121	12/15/77	—	4900	3198	240 ± 5	—	GA78a
21.29.11.421	02/22/78		>5000	3098	244.0	Ru	GA78a
	02/23/78	4204					
21.29.12.211	02/23/78	—	—	3205	>300.0	Ru	GA78a
21.29.18.130	12/30/48		—	3155	160	Ru?	GA78a
	05/03/50	4880					
21.29.25.423	01/10/79		—	3246	—	Rc?	GA79
	02/02/79	4400					
21.30.18.331	10/25/77	—	—	3077	184.0	—	GA78a
21.30.18.333	03/09/76	—	—	3085	176	Ru	GA78a
21.30.20.243	04/ /63	—	—	3110	888	—	GA78a
21.30.21.1(W-27)	/ /82		—	3075	—	Rm	Mcr83
	07/24/80	106000					
21.30.22.423	03/17/76	—	—	3059	220?	Ru	GA78a

Well Location	Date of Data Collection	TDS	Specific Conductance	Altitude of Water Level (ft)	Depth of Well (ft)	Aquifer	Source
21.30.28.0	12/19/77	—	—	3014	269.0	—	GA78a
21.31. 2.221	10/19/77	—	—	3539	31.87	—	GA78a
21.31. 3.22	03/15/79		—	3378.78	200	Tr	GA79
	02/02/79	424					
21.31. 7.3(W-28)	/ /82	—	—	3144	—	Rm	Mcr83
21.31. 7.331	09/14/72	3260	3500	3158	367.0	Ru	GA78a
21.31.15.33	03/15/79	—	—	<3182	360	—	GA79
21.31.18.411	03/17/76		3200	<3152	—	Ru	GA78a
	09/14/72	1870					
21.32. 6.11131	02/03/71	—	—	3553	55	Og	GA78a
21.33. 2.24141	11/16/65	—	—	3687	120	Tr	GA78a
21.33. 2.422334	11/16/65	—	—	3689	100	Tr	GA78a
21.33.11.11144	02/04/71	—	—	3675	195	Og	GA78a
21.33.18.114	11/16/65		—	3744	160	Og	GA78a
	09/12/72	323					
21.33.18.12314	02/04/71	—	—	3738	123	Og	GA78a
21.33.25.42322	02/04/71	—	—	3607	—	Og	GA78a
21.33.28.12443	02/04/71	—	—	3509	224	Tr	GA78a
21.34. 1.24122	02/10/71	—	—	3593	—	Tr	GA78a
21.34. 8.42341	02/10/71	—	—	3600	—	Og	GA78a
21.34.13.324	/ /43	—	—	3455	335	Tr	GA78a
21.34.23.223	/ /54	—	—	3510	220	Og	GA78a
21.34.25.13141	02/10/71	—	—	3577	196	Tr	GA78a
21.34.33.233441	02/04/71	—	—	3577	92	Og	GA78a
21.35. 1.12222	02/10/71	—	—	3448	—	Og	GA78a
21.35. 7.211	/ /40?	—	—	3360	430	Tr	GA78a
21.35.14.11111	02/10/71	—	—	3387	250	Tr	GA78a
21.35.24.24124	02/10/71	—	—	3407	—	Tr	GA78a
21.35.30.41133	02/10/71	—	—	3573	—	Og	GA78a
22.27. 1.1222	12/15/77	—	—	3093	caved	—	GA78a
22.27. 4.2111	01/24/50	—	—	3099	55	Ru/Qa	GA78a
22.27. 5.141	01/24/50	—	—	3080	400	Ru	GA78a
22.27. 8.314	01/10/75	—	—	3077	110	Vf	GA78a

Well Location	Date of Data Collection	TDS	Specific Conductance	Altitude of Water Level (ft)	Depth of Well (ft)	Aquifer	Source
22.27. 9.333	01/10/75	—	—	3061	—	Vf	GA78a
22.27.10.111	01/05/66	—	—	3052	227	Vf	GA78a
22.27.10.333	01/10/75	—	—	3063	169	Vf	GA78a
22.27.12.333	08/ /62	—	—	3032	64	—	GA78a
22.28. 2.1111	12/04/70	—	—	3021	—	Ru	GA78a
22.28. 4.130	12/17/48	—	—	3011	—	Ru?	GA78a
22.28.10.33	05/ /57	—	—	3068?	175	—	GA78a
22.28.15.323	12/16/77	—	3800	3021	100.8	—	GA78a
22.28.16.113	12/16/77	—	2800	3031	151.4	—	GA78a
22.28.30.443	01/09/56	—	—	3028	136	Vf	GA78a
22.29.11.000	05/21/49	—	—	2952	400	Ru	GA78a
22.29.12.224	05/18/49	—	—	3021	—	Ru	GA78a
22.29.26.1	03/ /78	—	—	2970	Lindsey Lake		GA78a,79
22.29.33.214	10/19/77	—	3700	2964	70.3	Ru	GA78a
22.29.33.240	12/17/48	1660	—	2964	65	Qa?	GA78a
22.30. 2.232	03/16/76	—	—	3027	344.0	—	GA78a
22.30. 2.431	03/16/76	—	—	3044	217.0	—	GA78a
22.30. 5.431	05/18/49	—	—	3033	—	Ru	GA78a
22.30. 6.344	05/20/49	20200	—	3035	—	Ru	GA78a
22.30. 6.444	05/18/49		—	3038	—	Ru	GA78a
	09/19/72	9650					
22.30. 7.244	05/18/49	—	—	3034	250	Ru	GA78a
22.30. 8.241	05/18/49	—	—	3040	—	Ru	GA78a
22.30.10.310	12/23/48		—	3074	77	Ru/Qa	GA78a
	04/30/50	2280					
22.30.15.3(W-25)	/ /82		—	3054	—	Rm	Mcr83
	09/04/80	18700					
22.30.19.3	03/ /78	—	—	3006	Inlet Laguna Uno		GA78a,79

Well Location	Date of Data Collection	TDS	Specific Conductance	Altitude of Water Level (ft)	Depth of Well (ft)	Aquifer	Source
22.30.30.240	12/17/48		—	2866	75	Ru/Qa	GA78a
	04/30/50	3290					
22.30.31.4	03/ /78	—	—	2984	N. Nash Well Pond		GA78a,79
22.30.32.114	03/15/79	—	—	2993	92.0	—	GA79
22.31.15.2(H-5A)	/ /82	—	—	3162	—	Rm	Mcr83
22.31.18.1(H-6A)	/ /82	—	—	3056	—	Rm	Mcr83
22.31.29.1(H-2A)	/ /82		—	3145	—	Rm	Mcr83
	02/22/77	12000					
22.31.29.2(H-1)	/ /82		—	3151	—	Rm	Mcr83
	06/04/76	18900					
22.31.29.2(H-3)	/ /82		—	3151	—	Rm	Mcr83
	05/10/77	32000					
22.33.13.23113	12/04/70		—	3129	508	Tr	GA78a
	09/21/72	1740					
22.34.11.22442	12/04/70	—	—	3509	62	Qa	GA78a
22.34.12.114	03/17/54	—	—	3502	16.0	Qa	GA78a
22.34.23.23131	09/08/71	—	—	3425	60	Qa	GA78a
22.35. 6.44114	12/04/70	—	—	3549	—	Tt	GA78a
22.35.20.22442	12/04/70	—	—	3441	—	Og	GA78a
22.35.34.12224	12/04/70	—	—	3421	—	Og	GA78a
22.36. 6.41220	12/03/70	—	—	3403	174	Og	GA78a
23.28. 1.11	03/14/79	—	—	2913.12	300	—	GA79
23.28. 8.131	01/10/75	—	—	2998	—	Vf	GA78a
23.28. 8.421	01/15/65	—	—	2982	89	Vf	GA78a
23.29. 3.1	03/ /78	—	—	2958	Salt Lake tributary		GA78a,79
23.29. 3.2	03/ /78	—	—	2969	Mile Marker 2		GA79a,79
23.29. 4.3	03/ /78	—	—	2950	Salt Lake		GA78a,79
23.29.18.14	03/13/79		—	2952.11	35	Qa	GA79
	02/02/79	55876					
23.29.20.33	03/14/79		—	2940.33	60	Rc?	GA79
	02/02/79	153404					
23.29.26.12	03/06/79	—	—	2923.13	160	Dl/Rf	GA79

Well Location	Date of Data Collection	TDS	Specific Conductance	Altitude of Water Level (ft)	Depth of Well (ft)	Aquifer	Source
23.29.28.41	03/14/79		—	2947.19	100	Rt	GA79
	12/28/78	283492					
23.29.30.333	07/25/77	—	—	2932	—	—	GA78a
23.30. 1.33	03/15/79	—	—	3011	—	—	GA79
23.30. 2.440	12/22/48		—	3000	300	Dk/Ru	GA78a
	04/30/50	3940					
23.30. 6.110	12/22/48	—	—	2890	200	Ru	GA78a
23.30.11.222	12/19/77	—	5800	2985	284.0	—	GA78a
23.30.19.132	10/20/77	—	—	2981	59.6	—	GA78a
23.31. 5.1(H-4A)	/ /82		—	3144	—	Rm	Mcr83
	12/14/78	22300					
23.31. 5.324	03/09/76	—	—	3199	231.0	—	GA78a
23.31. 7.220	—		—	3170	180	Dk	GA78a
	04/12/48	3330					
23.31.29.113	10/19/77	—	—	3194	144.0	—	GA78a
23.32.20.4(H-10A)	/ /82		—	3100	—	Rm	Mcr83
	03/21/80	270000					
23.33.12.312423	01/13/71	—	—	3204	400	Tr	GA78a
23.33.28.334	—	—	—	3175	575	Tr	GA78a
23.34. 1.444	11/25/53	—	—	3223	144±	Qa	GA78a
23.34. 6.43314	06/11/68	—	—	3141	600	Tr	GA78a
23.34.16.333312	01/13/71	—	—	3139	400	Tr	GA78a
23.34.23.42332	01/13/71	—	—	3139	500	Tr	GA78a
23.34.32.42433	01/13/71	—	—	3348	550	Tr	GA78a
23.35. 6.333	11/18/77	—	—	3218	149.42	Og	GA78a
23.35.11.22343	12/09/70	—	—	3434	205	Tr	GA78a
23.35.12.24142	12/09/70	—	—	3319	140	Tr	GA78a
23.35.15.42314	12/09/70	—	—	3432	60	Og	GA78a
23.35.18.143	10/19/79		—	~3145	810.5	Qa/Tr	W-15
(WIPP-15)	03/12/79	1220					
23.35.27.443421	01/13/71	—	—	3355	—	Og	GA78a

Well Location	Date of Data Collection	TDS	Specific Conductance	Altitude of Water Level (ft)	Depth of Well (ft)	Aquifer	Source
23.35.28.111111	12/09/70	—	—	3140	—	Og	GA78a
23.35.28.12321	10/17/67	—	—	3151	795	Og	GA78a
23.35.29.33431	12/09/70	—	—	3135	400	Tr	GA78a
23.35.36.24234	01/12/71	—	—	3257	250	Tr	GA78a
23.36.31.21443	01/01/79	—	—	3253	200	Og	GA78a
24.29.16.1	08/ /53	—	—	2883	180	—	GA78a
24.29.17.44	10/07/53	—	—	2917	260	—	GA78a
24.29.26.444	—	—	—	3088	62	—	GA78a
24.30.19.421	12/19/77	—	>10000	2939	279.8	—	GA78a
24.30.23.2(H-8A)	/ /82		—	3028	—	Rm	Mcr83
	02/12/80	9410					
24.30.23.314	10/19/77	—	2800	<2989	450.3	—	GA78a
24.30.36.333	10/19/77	—	850	2963(est.)	464.2	—	GA78a
24.31. 4.1(H-9A)	/ /82		—	3123	—	Rm	Mcr83
	02/05/80	5460					
24.31.17.111	12/19/77	—	620	3442*	153.7	—	GA78a
24.32. 3.322	10/15/53	—	—	3174	—	Tr	GA78a
24.32.10.344	11/18/77	—	—	3556	40	—	GA78a
24.32.33.422	02/18/58	—	—	3197	367.0	Tr	GA78a
24.33.10.113	11/27/53	—	—	3570	36±	Qa	GA78a
24.33.23.311	11/27/53	—	—	~3350	232	Og	GA78a
24.33.24.44444	11/27/53	—	—	3497	—	Og	GA78a
24.33.33.231	03/17/54	—	—	3367	—	Qa	GA78a
24.34. 4.11321	12/08/70	—	—	3516	70	Og	GA78a
24.34. 7.22222	12/08/70	—	—	3528	—	Og	GA78a
24.34.10.11222	12/08/70	—	—	2989.70	—	Og	GA78a
24.34.35.122	03/29/53	—	—	3186	258.0	Tr	GA78a

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24.35.10.1100	12/09/70	—	—	3107	—	Og	GA78a
24.35.10.13333	12/09/70	—	—	3201.31	190	Og	GA78a
24.35.15.2300	12/09/70	—	—	3354	—	Og	GA78a
24.35.24.4240	12/14/70	—	—	3256.63	—	Og	GA78a
24.35.30.34411	12/08/70	—	—	3184.21	150	Og	GA78a
24.35.34.14344	12/08/70	—	—	3110.61	112	Og	GA78a
25.29.16.441	10/26/77	—	—	2876	190.6	—	GA78a
25.29.32.211	03/11/49		—	2870	698.5	Ru	GA78a
	05/01/49	17200					
25.30. 8.224	10/26/77	—	3500	2899	384.8	Ru?	GA78a
25.30. 9.100	03/10/49		—	<2955	—	Dk	GA78a
	05/01/49	2470					
25.30.21.330	03/10/49		—	2939	—	Dk	GA78a
	05/01/49	1180					
25.31. 2.23413	08/18/66	—	—	3053	1016	—	GA78a
25.31.21.412	10/26/77	—	1590	2966	429.7	—	GA78a
25.32.31.141	11/08/77	—	—	<3027	278.8	—	GA78a
25.33.20.443	08/18/58	—	—	3145-3195	—	Tr	GA78a
25.33.31.242	11/08/77	—	1490	3145	276.18	Tr?	GA78a
25.34. 1.132	04/15/53	—	—	3154	300+	Tr	GA78a
26.29.23.113	02/03/78	—	—	2850	74.0	—	GA78a
26.30. 5.33441	04/03/72	—	—	2920	770	—	GA78a
26.30. 8.110	12/15/48	662	—	2908	200	Dk	GA78a
26.31. 1.000	03/10/49		—	2977	340	Dk	GA78a
	05/01/49	2920					
26.31. 8.310	—		—	2985	338	Dk	GA78a
	12/ /48	383					
26.31. 8.411	10/26/77	—	615	2965	297.2	—	GA78a
26.32.21.322	07/23/54	—	—	2960	253	Tr?	GA78a
26.32.31.212	11/08/77	—	1180	2923	210.86	—	GA78a

1841	R. B. Diegle
1841	N. R. Sorensen
3310	W. D. Burnett
6000	E. H. Beckner
6253	D. A. Northrop
6253	A. R. Sattler
6257	R. R. Beasley
6257	J. K. Linn
6258	B. J. Thorne
6300	R. W. Lynch
6310	T. O. Hunter
6311	L. W. Scully
6312	G. E. Barr
6312	F. W. Bingham
6314	J. R. Tillerson
6330	W. D. Weart
6331	A. R. Lappin
6331	S. J. Lambert
6331	W. B. Miller
6331	K. L. Robinson
6331	C. L. Stein
6332	A. J. Arguello
6332	R. Beraun
6332	C. L. Christensen
6332	D. M. Ellett
6332	R. V. Matalucci
6332	M. A. Molecke
6332	D. E. Munson
6332	E. J. Nowak
6332	J. C. Stormont
6332	T. M. Torres
6332	L. D. Tyler (10)
6332	F. G. Yost
6332	Sandia WIPP Central Files (HLW) (2)
6334	L. H. Brush
6400	A. W. Snyder
6430	N. R. Ortiz
6431	R. M. Cranwell
6431	R. L. Hunter (25)
7000	R. L. Peurifoy
7100	C. D. Broyles
7110	J. D. Plimpton
7112	C. R. Mehl
7112	G. H. Miller
7116	E. S. Ames
7116	C. W. Cook
7116	S. R. Dolce
7120	M. J. Navratil
7125	J. T. McIlmoyle
7125	G. L. Ogle
7130	J. D. Kennedy
7133	C. W. Gulick
7133	R. D. Statler
7135	P. D. Seward
8310	R. W. Rohde
8314	N. R. Moody
8314	M. W. Perra
8314	S. L. Robinson
8315	D. H. Doughty
8315	D. A. Nissen
8430	L. D. Bertholf
8024	P. W. Dean
3141	S. A. Landenberger (5)
3151	W. L. Garner (3)