GROUND-WATER STUDY RELATED TO PROPOSED EXPANSION OF POTASH MINING NEAR CARLSBAD, NEW MEXICO

by

Geohydrology Associates, Inc.

for

BUREAU OF LAND MANAGEMENT
Denver, Colorado

Contract No. YA-512-CT7-217

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INTRODUCTION

The Carlsbad potash area, in southeastern New Mexico, lies in a region of limited rainfall, no perennial streams, and ground water high in dissolved solids. Availability of fresh water for agricultural, industrial, and domestic use is of major importance in determining the uses of land. The Bureau of Land Management (BLM) is responsible for the administration of 80 percent of the 969,875 acres involved. In 1974, the BLM suspended action on potash leases and prospecting applications pending the preparation of an Environmental Analysis Record (EAR) assessing the impact of expanded potash mining on the area. After completion of the EAR, however, questions remained about the effect of brine disposal by the potash industry on the limited quantities of fresh water in the area.

The primary questions are:

1. Is fresh water in the Carlsbad potash area in danger of contamination from current or expanded potash mining activity?

2. Is the brackishness of the Pecos River below Malaga Bend due in whole or in part to mining activity?

3. Is the amount of leakage from brine-disposal ponds significant when compared to the tremendous volumes of naturally occurring brine?

During the past several decades a number of studies have been made in the potash area. Robinson and Lang (1938) showed that water drains from all directions toward the large, natural Salt Lake in lower Nash Draw. They concluded that brine from this lake is not discharging to the Pecos. Overuse of wells (Hood, 1963) and phreatophytes along the river (Mower and others, 1964; Thomas,1936b) have been implicated as causes of damage to water quality in the Pecos River entirely unrelated to the potash industry. Gilkey and Stotelmeyer (1965) concluded from calculations that the brine-disposal ponds leak significantly, whereas industry spokesmen maintain that the ponds are sealed by fine sediments in the tailings. Research on brine-pond construction indicates that it is technically possible for ponds to be substantially sealed (Morrison, 1970). It has been shown in other areas of the country that leaking brine-disposal pits can cause significant damage to ground-water supplies (Lehr, 1969); whereas in the Carlsbad potash area, the ground-water quality before the presence of the potash industry was questionable because of abundant natural salt deposits near the surface.

The BLM recognized that a complete hydrologic study of the Carlsbad potash area would be time-consuming and expensive. To better understand the situation and to decide what studies were necessary to answer the questions relating to ground-water pollution, the BLM financed the present study under contract number YA-512-CT7-217. The Statement of Work for this project required the Contractor:

1. To review the previous studies of the area and supplement this information with a limited amount of newly gathered data.

2. To make a preliminary estimate of brine-pond leakage.

3. To prepare a water budget for the area.

4. To recommend future studies.

Geohydrology Associates, Inc., does not believe that this report represents the final answer to the questions proposed above. In addition to presenting information and conclusions, this report proposes several future studies that may lead to a comprehensive understanding of the ground-water hydrology of the Carlsbad potash area.

The system of numbering wells used in this report is the same as that used by the Water Resources Division of the U. S. Geological Survey and the Office of the New Mexico State Engineer. It is based on the common subdivision of sectionized land. Each well is assigned a number divided into four segments (fig. 1). The first segment indicates the township south of the New Mexico base line. The second segment indicates the range east of the New Mexico principal meridian. The third segment indicates the section number. The fourth segment of the well number consists of three or more digits which indicate the particular 10-acre tract in which the well is located.

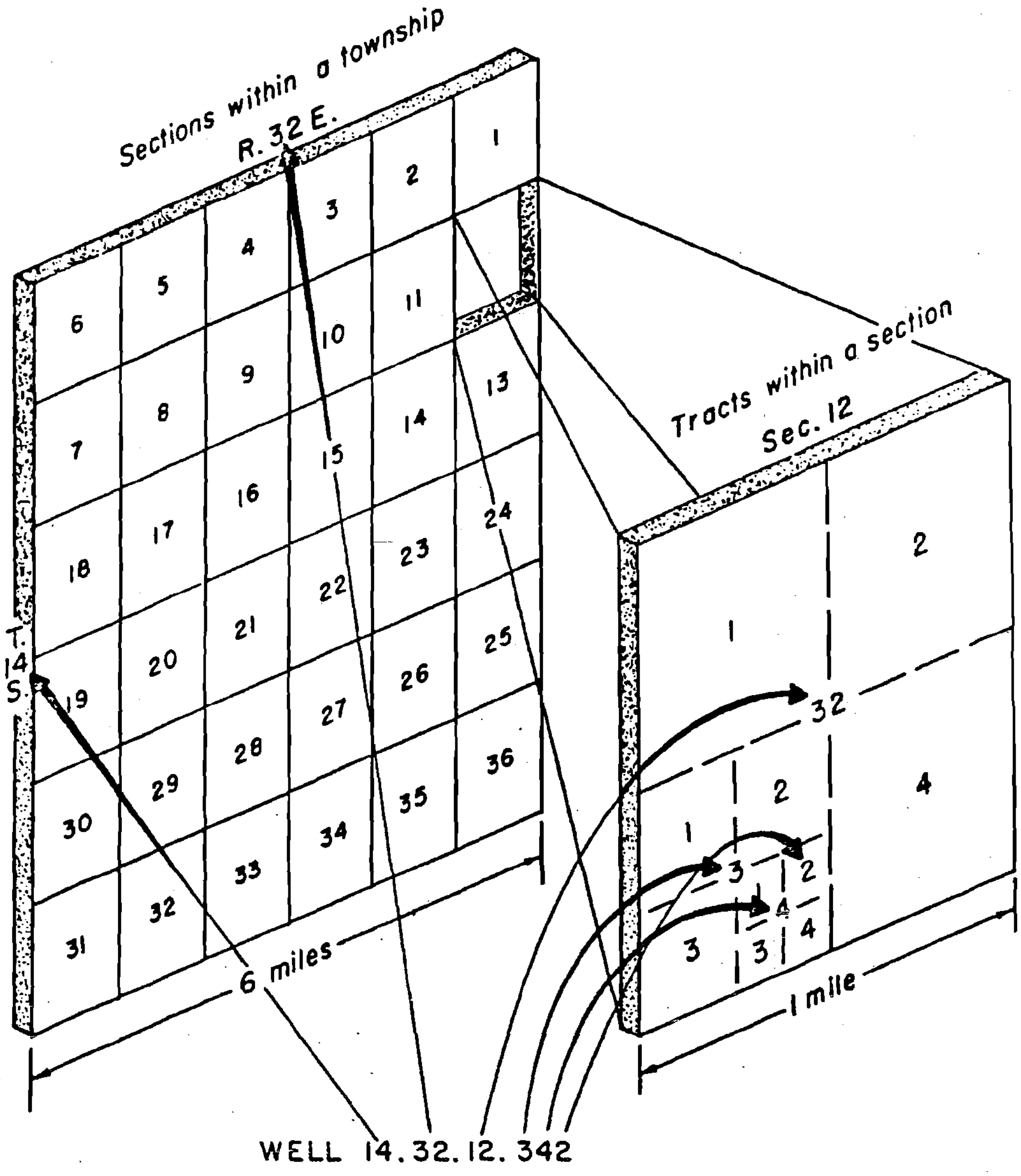

Figure 1.--System of numbering wells in New Mexico.

GEOLOGY OF CARLSBAD POTASH AREA

Numerous studies have been made on both the geology and the ground-water hydrology of the Carlsbad potash area. The geology of the area is well understood, partly because of the important oil, gas, and potash resources present. King (1942) presented a lengthy study of the stratigraphy and geologic history of the Permian rocks of west Texas and southeastern New Mexico. Vine (1963) studied the surface geology of the Nash Draw quadrangle. The geology and hydrology of the Carlsbad potash area were discussed by Brokaw and others (1972), that of Eddy County by Hendrickson and Jones (1952), and that of Lea County by Nicholson and Clebsch (1961). Except for minor differences in nomenclature, these and other studies are in virtual agreement about the geology of the area.

Structure

The basic tectonic structure of the Carlsbad potash area is a simple homoclinal dip of about 2^{o} to the east which developed mainly in pre-Pliocene time. It is superimposed on a structural basin which began forming in Pennsylvanian time and was filled by late Permian time. This interpretation is based primarily on data from deep wells (Vine, 1963).

The more complex surficial structure of the potash area exerts a more immediate effect on the hydrology. The area is typified by collapse of the Rustler Formation and overlying beds due to solution within the Rustler and at the top of the Salado Formation. Beds of the Rustler generally dip toward the larger depressions (Vine, 1963). In addition, hydration of anhydrite to gypsum causes localized doming. Sinkholes and domes influence the direction of ground-water movement, which in turn controls the development of collapse structures.

Pre-Ochoan Rocks

Pre-Ochoan rocks do not have a great effect on the hydrologic questions presented by the potash industry. Variations in thickness of the Castile and Salado Formations mask the structure of the pre-Ochoan rocks; consequently, they have little or no effect on shallower rocks. The Capitan Limestone is an aquifer, but the impermeable Salado Formation separates it from shallower aquifers above the Salado. For these reasons, the pre-Ochoan rocks of the potash area are only briefly described here.

Precambrian basement rocks are 17,000 to 19,000 feet deep in the potash area (Brokaw and others, 1972). Ordovician through Pennsylvanian rocks are marine shales and carbonates about 5,000 feet thick in the vicinity of the potash mines.

Pre-Ochoan Permian rocks are noted for the presence of reefs and for lateral facies changes. The total thickness is 8,000 to 9,000 feet. The central part of the ancestral Delaware Basin typically is composed of shale, fine-grained sandstone, and dark limestone. Shallow-water carbonates and reefs are found near and at the edges of the Basin. On platforms behind the reefs, the rocks consist of dolomite with smaller amounts of limestone, clastic rocks, and some anhydrite (Brokaw and others, 1972).

Ochoan Rocks

Castile Formation.

The Castile Formation, of Ochoan age, underlies the study area. It is readily divided into three members: upper and lower anhydrite members and a thick middle salt member. In the north-central portion of the potash area, the salt member pinches out and the anhydrite thins rapidly. The Castile Formation pinches out entirely a few more miles to the north.

Salado Formation.

The Salado Formation is of unique importance in the Carlsbad potash area--geologically, hydrologically, and economically. The formation consists of more than 75 percent halite where it has not been thinned by ground-water solution. The remaining 25 percent of the formation is composed of potassium minerals and minor amounts of clastic rocks, anhydrite, and dolomite. An areally extensive and persistent unit where not removed by ground-water solution, it underlies the entire potash area and extends far beyond it. Outcrops are altered extensively; salt is removed by solution and the polyhalite and anhydrite are altered to gypsum. The main outcrop of Salado Formation in the potash area is near Lake Avalon (Brokaw and others, 1972). The formation is gradational with the underlying Castile Formation and conformable with the underlying Tansill Formation wherever the Castile is absent. The Salado appears to grade upward into the Rustler Formation. The depth to the Salado Formation in the central part of the potash area ranges between 200 and 700 feet and increases northeastward and southeastward to about 1,300 feet (Brokaw and others, 1972).

The Salado Formation divides naturally into three informal units. The upper and lower units contain very little potash or magnesium-rich evaporites. The middle unit, the McNutt potash zone (Kroenlein, 1939), is rich in a number of potassium and magnesium evaporites, with at least 10 zones of potential economic importance (Jones, 1972).

The Salado appears to be free of circulating ground water, although pockets of entrapped water and/or gas, sometimes under considerable pressure, are occasionally encountered (Cooper and Glanzman, 1971). The Salado Formation thus serves as a barrier between deeper, fresher water in the Capitan Limestone and shallower, saturated brine occurring in the brine aquifer in the base of the Rustler Formation. As a soluble unit underlying the entire potash area, the Salado exerts major control over the shallow and surficial structure of the area. Collapse structures, of which Nash Draw is the most notable, are widespread and exert control over the deposition of eolian and alluvial material. For example, Vine (1963) considers Quahada Ridge to be the site of a former depression, filled with alluvial material in Gatuna time.

The amount of brine occurring naturally as a result of solution of the Salado Formation should not be underestimated. Robinson and Lang (1938) estimated that the base of the Rustler Formation contains approximately 625,000 acre-feet of brine, or 160 million tons of sodium chloride.

Rustler Formation.

The Rustler Formation as originally described (Richardson, 1904) consisted of 150 to 200 feet of calcareous buff sandstone overlain by fine-textured white magnesian limestone. These units are thought to be equivalent only to the lower part of the Rustler Formation in the potash area; there the formation ranges from 200 to 500 feet in thickness (Vine, 1963; Brokaw and others, 1972). Primary constituents in the Rustler Formation are gypsum and/or anhydrite, with dolomitic limestone, siltstone, and halite. The halite is removed by solution and does not crop out. The Rustler and Salado Formations are separated by a leached zone approximately 60 feet thick. This insoluble residue or brine aquifer is regarded as basal Rustler Formation by some authors (e.g., Cooper and Glanzman, 1971) and as uppermost Salado Formation by others (e.g., Vine, 1963).

The lower part of the Rustler Formation consists of 60 to 120 feet of siltstone and fine-grained sandstone (to the east) interbedded (to the west) with gypsum, anhydrite, and halite (Brokaw and others, 1972). This lower part is overlain by the Culebra Dolomite Member, a distinctive and persistant marker bed about 30 feet thick. The Culebra Dolomite is a uniformly fine-textured microcrystalline gray dolomite or dolomitic limestone. It is characterized by the presence of many small spheroidal cavities from 1 to 10 mm (millimeters) in diameter, which are apparently unrelated to surface weathering (Vine, 1963). Locally the Culebra is finely oolitic.

The Culebra Dolomite is overlain by the Tamarisk Member (Vine, 1963) of the Rustler Formation. It consists of about 115 feet of massive, coarsely crystalline gypsum in outcrop but is chiefly anhydrite in the subsurface. There is a siltstone bed 5 feet thick about 20 feet above the base, which apparently represents the insoluble residue of halite beds present in the subsurface to the east (Jones and others, 1960, fig. 1). In many exposures, the massive crystalline gypsum is altered to gypsum rock, composed of loosely packed gypsum grains about one millimeter in diameter. Surficial deformation has locally draped the Tamarisk Member into large irregular folds and tilted blocks. Locally it has been completely removed by solution (Vine, 1963).

Another persistant and distinctive stratigraphic marker is provided by the Magenta Member of the Rustler Formation, about 20 feet thick. It is characterized by wavy or lenticular laminae of dolomite and anhydrite or gypsum. In some collapse areas the rock is brecciated and the gypsum partially removed, but the wavy laminae of dolomite still permit identification (Vine, 1963).

The Magenta Member is conformably overlain by the Forty-niner Member (Vine, 1963) of the Rustler Formation. In outcrop, the Forty-niner consists of 40 to 65 feet of broken and slumped gypsum, with a siltstone bed 5 to 10 feet thick near the base. In the subsurface, the siltstone is separated from the Magenta Member by about 20 feet of gypsum and anhydrite. The siltstone is thought to be an insoluble residue of halite beds present in the subsurface to the east (Jones and others, 1960, fig. 1).

The Rustler Formation is overlain by the Dewey Lake Redbeds with apparent conformity over broad areas, but with apparent unconformity near the western edge of the Dewey Lake Redbeds. In outcrop, the contact is obscured by hydration, solution, and removal of the evaporites (Brokaw and others, 1972).

Dewey Lake Redbeds.

The Dewey Lake Redbeds, which were called the Pierce Canyon Redbeds, are the only unit in the Ochoan Series which is entirely free of evaporites (Brokaw and others, 1972). The Dewey Lake Redbeds consist entirely of siltstone and fine-grained sandstone and are 200 to about 500 feet thick in the potash area. North of the potash area, the Dewey Lake Redbeds thin and pinch out. The rocks are exposed in a number of low bluffs in the potash area, especially in the region of Nash Draw, as in Mimosa and Livingston Ridges and Maroon Cliffs. The reddish-orange to reddish-brown sandstone and siltstone are thinly laminated with very small scale cross-laminae. Ripple marks are present in the upper part of the formation. Exposures of the Dewey Lake Redbeds are frequently draped into simple structures due to either solution or hydration of underlying evaporite rocks (Vine, 1963). Generally the Dewey Lake Redbeds are not an aquifer.

Post-Ochoan Rocks

Santa Rosa Sandstone.

The Dewey Lake Redbeds are unconformably overlain by the Santa Rosa Sandstone (Brokaw and others, 1972). North of the potash area, where the Dewey Lake Redbeds are absent, the Santa Rosa directly overlies the Rustler Formation (Hendrickson and Jones, 1952). The Santa Rosa Sandstone consists primarily of gray and red sandstone and conglomerate lenses, 3 to 15 feet thick, with partings of reddish-brown siltstone and claystone. The Santa Rosa Sandstone is coarser grained, less well sorted, and thicker bedded than the underlying Dewey Lake Redbeds (Vine, 1963).

Gatuna Formation.

Wherever present, the Gatuna Formation of Pleistocene (?) age unconformably overlies the Permian rocks in the Carlsbad potash area. In most places, it is three to five feet thick and is directly overlain by Recent caliche, which provides protection from erosion (Vine, 1963). The formation consists of reddish-brown to reddish-orange, poorly consolidated sandstone and siltstone, with smaller amounts of conglomerate, clay, gypsum, and shale. It is locally up to 200 feet thick (Hendrickson and Jones, 1952). The substantial and rapid changes in thickness have led Vine (1963) to conclude that deposition of the Gatuna accompanied or immediately followed a period of active solution of the Salado or Rustler Formations.

Caliche and Alluvium.

A thin layer of caliche unconformably overlies the Gatuna Formation. It forms a fairly continuous, ten-foot thick, resistant mantle. Sink-holes in the caliche are a common result of solution of underlying gypsum. Mounds or ridges of caliche may result from a variety of causes, such as a thermal expansion or hydration of anhydrite to gypsum (Vine, 1963).

The alluvium in the potash area is generally locally derived by sheetwash and intermittent streams. It forms a thin veneer over most of the area. The alluvium intertongues with playa deposits (Vine, 1963). Windblown sand also covers substantial areas.

GROUND-WATER HYDROLOGY

The ground-water hydrology of Carlsbad potash area and vicinity has been the subject of numerous studies. Detailed geohydrologic information is provided by Brokaw and others (1972), Havens (1972), and Cooper and Glanzman (1971). Other studies are listed in the bibliographies of this report and the accompanying Eastside Roswell Range EIS Area report.

Three hydrologic units control the hydrology of the potash area (Brokaw and others, 1972). These are the Pecos River, water-bearing rocks above the Salado Formation, and water-bearing rocks below the Salado Formation. Within Nash Draw and Clayton Basin, the Salado Formation is an effective barrier between the lower and upper rocks. Because most water-use activities in the potash area do not affect the lower aquifer, this unit will not be discussed.

Ground water can be obtained from nearly all geologic formations above the Salado, but the principal water-yielding units are the Culebra Dolomite Member and the basal solution breccia zone of the Rustler Formation, the Santa Rosa Sandstone, and alluvium (Brokaw and others, 1972, p. 53). These aquifers are thought to form a single hydrologic system. The Rustler Formation is present at or near the surface in Nash Draw and Clayton Basin. It is the principal aquifer of the potash area, supplying some stock, domestic, and industrial water. It receives discharge from the potash refineries.

Ground-Water Movement

Brokaw and others (1972) stated that the Pecos River receives nearly all ground-water discharge from the Carlsbad potash area. Cooper and Glanzman (1971, plate 1) indicated that ground water from the area of the potash mines will eventually discharge to the Pecos. However, Robinson and Lang (1938) found the potentiometric surface in the brine aquifer sloped toward Salt Lake (Laguna Grande de la Sal) and concluded that water in the lake could not be leaking toward the Pecos. The discharge at Malaga Bend is estimated to be about 200 gallons per minute (gpm) of saturated brine, which significantly degrades the water quality of the lower Pecos (Theis, 1942; Havens, 1972). The basal solution breccia zone of the Rustler Formation is the source of the brine.

It is important to determine whether Salt Lake does or does not leak to the Pecos. As shown on figure 2, the lake is in a position, both geographically and hydrologically, to intercept discharge from all of the potash refineries as well as all recharge which occurs in the basin above the lake. Selected surface-water bodies and measuring points on selected wells within Nash Draw and Clayton Basin were surveyed during March 1978. Depth to water was determined with a steel tape. These data were used to construct the water-level contours shown on figure 2. Some reported water levels from outside the area were also used.

Figure 2 shows a south-trending water-table trough in Clayton Basin which opens into Nash Draw and continues southwesterly in the Draw.

The general direction of ground-water movement is from north to south. Recharge areas are the sand dunes of Chaves and Lea Counties; ground-water discharges into the Pecos River along most of its length in these two counties.

The surveyed water level at the north end of Salt Lake is the same as the level of the Pecos River in sec. 13, T. 23 S., R. 28 E. Water-level data between these points is not available. Two interpretations are possible from these water levels and the relative positions of the lake and the river (fig. 3). Joining the 2,950-foot contour between the lake and the river would show that the lake was hydrologically connected to the Pecos (fig. 3a). However, the 2,950-foot contour may encircle the lake (fig. 3b). In this case a ground-water divide would exist between Scoggin Flat near the Pecos River and Tempe Costa Church at the southwest edge of Salt Lake. Water-level measurements in this critical area are lacking.

Work by Robinson and Lang (1938, p. 100) has shown that ground-water contributed to Salt Lake was derived from two different sources: the underlying artesian (brine) aquifer, and shallow ground water which empties toward the lake under water-table conditions. Havens (1972, p. 132) has shown that brine enters the Pecos River through the river bed, an indication of an artesian source beneath the river. Thus Salt Lake and the bed of the Pecos River are hydrologically connected through the artesian aquifers which underlie both features, but the contaminants in the Pecos are not derived from Salt Lake. The shallow ground-water system near Scoggin Flat is unrelated to the deep artesian system.

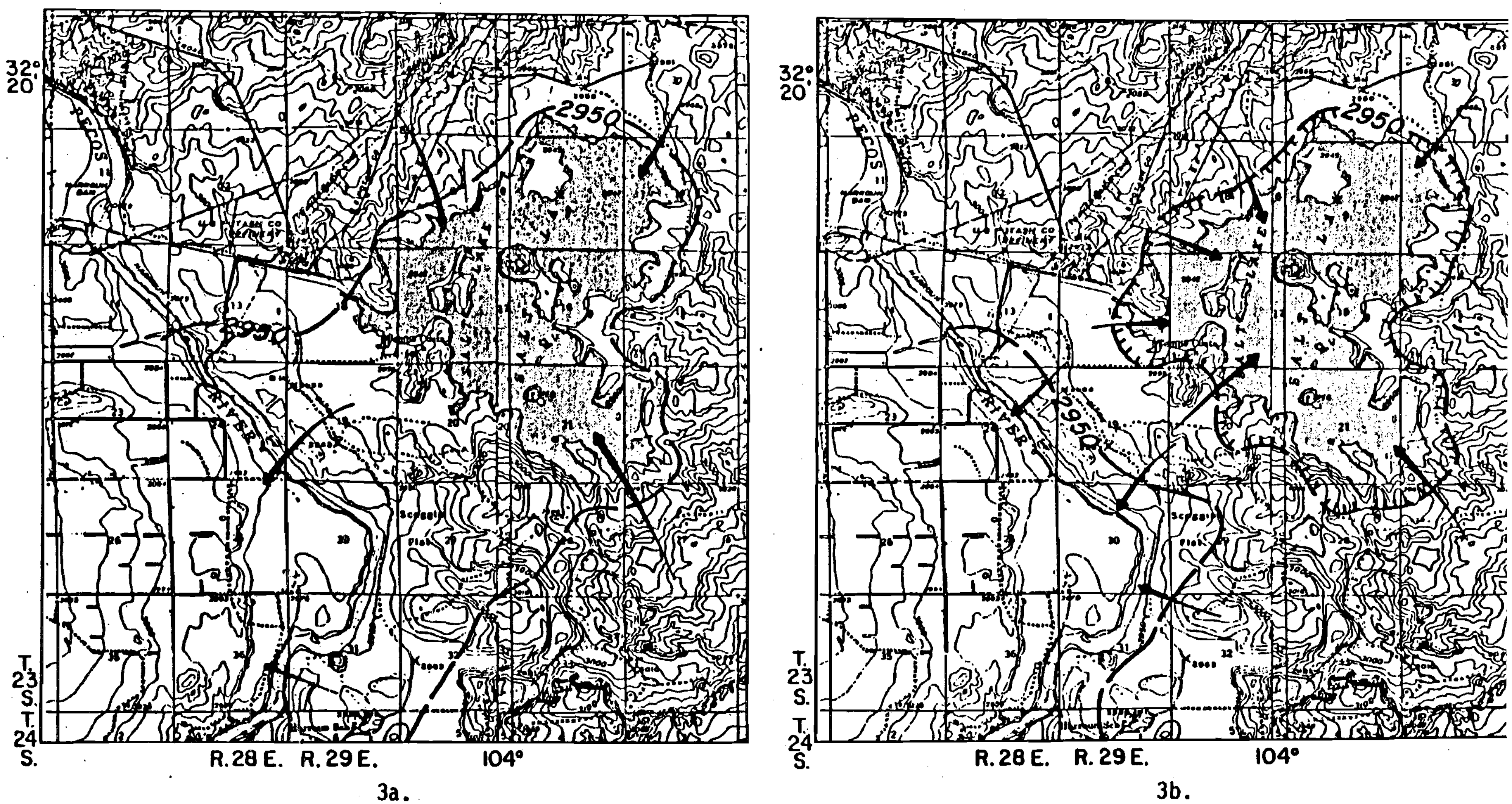

Figure 3.--Alternative ground-water configurations in the vicinity of Salt Lake and Malaga Bend.

Water Quality

Chemical data shown with water-level data (fig. 2) indicate that water quality is better in areas where the water table is high and poorer toward water-table troughs. The lower part of the aquifer in the Rustler Formation is known to contain brine. Therefore the water-quality data in figure 2 demonstrate that water-quality zones are stratified in the aquifer. Potable water is present at the top of the aquifer, floating on the more dense brine.

It is apparent from the location of certain wells in conjunction with the water-table map (fig. 2) that past residents of the area realized that better quality water could be obtained from shallow wells which tapped the very top of the brine aquifer. Some of those wells are Nash well, the J Bar F well, Clayton well, and Chimney well. These wells are now covered by brines, but they were on dry land during October 1973 as shown by a series of air photos.

Surface-water levels rose in Nash Draw between 1973 and 1975, as shown by a second series of air photos taken in May 1975. No other data are available to document the rise in water level except for several well measurements taken about 1948. The 1975 air photos show the wells to be inundated. Probably the change visible between 1973 and 1975 was due to a refinery discharge, as will be discussed in the Regional Water Budget.

When ground water discharges to the ponds and lakes in Nash Draw and Clayton Basin, fresh and saline waters are mixed by wave action and the fresh water is contaminated. Evapotranspiration by phreatophytes also degrades the quality of fresh water before it is discharged to lakes and ponds. Examples of the natural degradation process were noted in the vicinity of the Potash Company of America (PCA) brine-disposal ponds and near Tamarisk Flat, south of the International Minerals and Chemical Corporation (IMC) refinery.

Near PCA, water from well 20.30.7.112 is being used for stock and is presently potable. Water from wells at 19.29.25.443 and 20.30.20.142 is also being used for stock. A water sample from green pond, shown in figure 2, was not potable and shows that natural degradation has occurred. Green pond (discussed further on p. 82) is a naturally occurring pond, down-gradient from the wells supplying potable water but up-gradient from and discharging to the PCA brine pond. Green pond is a deep collapse structure open to much of the aquifer. Ground water entering the ponds is mixed by wave action. Phreatophytes up-gradient from it remove fresh water and increase the salinity. Also, water from green pond, while not potable, was of much better quality than water found in refinery brine ponds. Water quality data, the observed direction of flow in this area, and water level data shown in figure 2 indicate that ponds in the PCA area are a major discharge site for ground water in Clayton Basin.

Water quality at well 22.29.33.241 southwest of IMC is significantly better than water quality in the nearby lakes, Laguna Uno and Lindsey Lake, which are at higher elevations than the water level in the well. The water-level contours show that brine from these higher lakes is moving toward the well. Data are lacking to prove that water-quality degradation is occurring in this area, although recent air photos (1975) show that there are no saltcedar on Tamarisk Flat, 1½ miles east of well 22.29.33.241. If Tamarisk Flat was named for dense stands of saltcedar which have been destroyed, water quality degradation has occurred and would provide evidence that the quality of water produced by well 22.29.33.241 will be affected.

The water quality from a spring east and up-gradient from the IMC discharge at Laguna Uno is distinctly different from that of the industrial brine. Most notable, the spring-water content of calcium and silica is higher than the plant discharge, indicating travel through formations found at the surface in the area rather than the ore-producing Salado Formation. The spring water is not potable, suggesting that water quality changes near Tamarisk Flat would occur even if mining had not taken place.

Brokaw and others (1972, p. 56) have stated that mining has detrimentally affected the area's water quality. This was based on their finding that water in the vicinity of the mines was of generally poorer quality than in wells away from the mines. Data obtained during this study indicates that water in the topographic and water-table troughs would not be potable even if mining had not occurred. Most of the potash refineries are located in these troughs and all of the refineries discharge brine to natural depressions, many of which are at or near the water table. It is therefore likely that mining has affected area water quality; however, considering the degradation of potable water in the troughs by the natural processes described above, it is unlikely that any potable water has been destroyed by mining. Ground water beneath the higher areas, which is being used for domestic and stock purposes, is not affected by mining or natural degradation in the troughs. This water will remain potable if land use practices in these areas protect the fresh water resource.

Rates Of Ground-Water Movement

To calculate the rate of movement of ground water and thereby estimate the travel time required for contaminants from a particular source to reach a well or discharge point (Table 1), certain hydrologic factors and rock characteristics must be known. These are: the water-table gradient, the hydraulic conductivity, and the porosity of the aquifer. The water-table gradient is easily measured from a water-table map, such as figure 2. The hydraulic conductivity and porosity of the rocks in the upper part of the aquifer must be estimated.

Aquifer performance tests made by the U. S. Geological Survey at Malaga Bend and at the Project Gnome Site are the nearest tests to the potash area for which data are available. From tests at Malaga Bend (Havens, 1972), the hydraulic conductivity of the brine aquifer of the lower Rustler Formation is estimated to be 25 to 50 feet per day, based on transmissivity determinations of 2,800; 8,000; and 12,000 ft^2/day

Table 1.--Travel time estimates.

Source	Destination	Distance (feet)	Gradient (ft/ft)	Rate of movement (feet/day)	Travel time (years)
AMAX	Clayton Lake	22,000	0.001	0.4	164
National	Clayton Lake	40,000	.006	3.7	30
Duval	Laguna Uno	60,000	.003	1.9	84
PCA	Laguna Uno	85,000	.002	1.5	150
PCA	Clayton Lake	8,000	.001	.8	29

and a saturated thickness of 150 feet. The hydraulic conductivity of the Culebra Domomite Member at Malaga Bend is estimated to be 1,000 feet per day, based on a transmissivity of 53,500 ft^2/day and a saturated thickness of 50 feet. At the Project Gnome Site, the hydraulic conductivity is about 16 feet per day, based on a transmissivity of 470 ft^2/day and a thickness of 30 feet (Cooper and Glanzman, 1971). The wide range in the aquifer characteristics of the Culebra Dolomite probably is due to variations in secondary porosity. Solution of dolomite along fractures can cause significant increases in secondary porosity and therefore in the transmissivity and hydraulic conductivity.

Brine wastes are discharged to members of the Rustler Formation above the Culebra Dolomite. No aquifer test data for these rocks within the potash area are available. Based on the test data from Malaga Bend and the Project Gnome Site, the hydraulic conductivity in Nash Draw is assumed to be 100 feet per day.

Data on the average effective porosity of the rocks in Nash Draw are not available,so this aquifer characteristic must be estimated. For preliminary travel time estimates, an effective porosity of 15 percent will be assumed.

BOTANICAL EVALUATION OF THE NASH DRAW AREA

Vegetation and Its Distribution

The localities of special interest within the study area are those that either potentially or actually contribute to ground-water recharge. These sites are primarily small, shallow, closed drainage areas and salt lakes. The closed-drainage areas, often termed swales or ephemeral ponds, are formed by salt dissolution followed by collapse.

The ponds and salt lakes are important to the potash area for several reasons. They appear to be a major recharge source. Because of their water concentrating properties, the ponds have higher productivity and density of grasses. Therefore they provide good forage and seed reserve. The increased grass productivity also serves to bind the soil. When water is present in the ponds, they serve as an additional water source for livestock. Because of the water-concentrating properties and the higher plant density, the areas also have higher evapotranspiration rates than the surrounding area. The salt lakes, with open water surfaces and phreatophytic vegetation, are also likely to have higher rates.

Vegetation in these swales or ponds differs from surrounding vegetation in size, density, and species composition. This is also true of vegetation around the salt lakes. Possibly the vegetation of these areas could provide information about the amount of recharge, the length of time standing water is present, the amount of water present, the evapotranspiration of the area, and the quality of the water present.

Distinct vegetative patterning is present in and around the ponds or swales: Snakeweed (Xanthocephalum sarothrae Willd.) marks the outside periphery of the ponds. (Nomenclature follows Correll and Johnston, 1970.) It rarely grows below that line. It can therefore be used to delineate the pond area. Mesquite (Prosopis glandulosa Torr.) is present both in the ponds and outside them. However, its larger size in the ponds indicates the presence of more soil moisture in those areas. On the slopes leading down to the ponds, mesquite is seldom more than three feet tall.[1] Its density is much greater outside the ponds.

Some other species present above the periphery on the slopes are occasional four-wind saltbushes (Atriplex canescens (Pursh) Nutt.), black grama (Bouteloua eriopoda (Torr.) Torr.), three-awns (Aristida spp.) dropseeds (Sporobolus spp.), and more snakeweed.

The pond floors are generally covered with perennial grasses. In smaller ponds, the primary species is buffalo grass (Buchloe dactyloides (Nutt.) Engelm.). Creeping muhly (Muhlenbergia repens (Presl.) Hitchc.) is also present in some ponds. In some larger ponds, Sporobolus sp. is present. Tobosa grass (Hilaria mutica (Buckl.) Benth.) is probably present in some of these areas. In addition to the perennial grasses and the mesquite plants, tumbleweed (Salsola kali L.), spiny cocklebur (Xanthium spinosum L.), blueweed (Helianthus ciliaris DC), Conyza spp., Verbena sp., frog-fruit (Phyla sp.), Hedyotis sp., globe mallow (Sphaeralcea sp.), and spikerush (Eleocharis sp.) are often found near the center of

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1 In the Botanical Section, metric or English units are used according to the usage in the references cited.

the ponds. Spikerush generally indicates fairly wet soil conditions.

Saltcedar (Tamarix sp.) is present around some salt lakes. Salt grass (Distichlis spicata (L.) Greene), alkali sacaton (Sporobolus airoides (Torr.) Torr.), and tobosa grass are likely to be found in the vicinity. The presence of saltcedar generally indicates a soil containing more moisture than the surrounding area.

There appear to be three classes of ponds. These are ponds with (1) "mixed-concentrated vegetation"--large mesquites scattered around the periphery and occasionally near the center and perennial grasses present from the periphery to the center; (2) "concentrated grasses"--a few large mesquite plants sometimes present in an area primarily covered with perennial grasses; and (3) "barren"--same description as (2), but with a barren zone in or near the center of the pond.

Some swales or ponds are subject to periodic flooding. Annuals, because of their reproductive strategy, will grow and reproduce only when environmental conditions are favorable. However, perennial species present must be physiologically adapted to both extremes of the hydrological cycle: drought and inundation. They are already established and must be able to adjust to existing conditions or die. Consequently, a knowledge of how long various species in the ponds can withstand waterlogged conditions should provide information on the length of time these areas are flooded or waterlogged and, possibly, on the quantity of water present.

For example, if there are no perennials in the center of a pond, it could be because water stood too long for them to survive or because stock trampled the area when grazing or getting water. However, if it is known that a certain species of perennial can withstand low aeration for a maximum of two weeks and it is well established, then it is evident that water-logged conditions did not prevail for more than two weeks.

There are wide variations among plants in tolerance to flooding and poor aeration. Damage from flood or low aeration is dependent on climate, duration of flooding, water depth, siltation, water movement, plant species present (Colman and Wilson, 1960), and developmental stage (Kramer, 1969). Some tree species have survived 30 days of complete submergence (Hosner, 1960). Dormancy, cooler weather, and cloudy days increase plant tolerance (Kramer, 1969), and partial submergence of plants is less damaging than complete submergence (Conway, 1940).

Plant roots may survive short periods of waterlogging even though that species cannot tolerate permanent oxygen deficiency. Mesquite roots stop growing when oxygen is lacking or where the concentration of CO_2 is greater than 25 percent (Cannon and Free, 1917). That fact could possibly explain the absence of mesquite in the center of most ponds. If the roots of saltcedar are submerged too long with resulting poor aeration, some of the plants will not survive (Tomanek and Ziegler, 1962). Even phreatophytes can get too much water.

More work is needed to determine inundation tolerance of the species present in the ponds or swales. In addition, it may be possible with tree-ring dating and the development of successional patterns of ponds to determine relative ages of these sites. Areas where collapse occurred earlier should be more complex vegetatively and have the oldest mesquites.

There are also some areas with standing water where saltcedars have been drowned. Possibly, comparison of tree rings of dead trees to those still living along the shore will determine the time that flooding occurred.

Evapotranspiration

Evapotranspiration can be defined as water withdrawn from soil by evaporation and plant transpiration (Robinson, 1970). Transpiration is the escape of water from plants in vapor form. It is basically an evaporative process which is affected by plant structure and stomatal behavior as well as the physical factors which control evaporation (Kramer, 1969).

Many factors affect the rate of water lost by evapotranspiration. Some of these factors are the salinity of the soil and water; the amount of soil moisture present; depth to ground water; environmental conditions; exposure; plant size, morphology, and developmental stage; plant densities; and species present (Branson, 1975; Briggs and Shantz, 1913; Cable, 1977; Cline and others, 1977; Gatewood and others, 1950; Jarvis and Jarvis, 1972; Kramer, 1969; Keisselbach, 1916; Ogata and others, 1960; Rantz, 1968; Robinson, 1965, 1970; van Hylckama, 1970, 1974).

Some environmental conditions that affect evapotranspiration are temperature, relative humidity, wind movement, solar radiation, amount and season of occurrence of precipitation, and length of the growing season.

Wind movement removes the boundary layer of moist air surrounding the transpiring leaf surface and replaces it with less moist air (Kramer, 1969; Robinson, 1970). By cooling leaves, wind acts to decrease transpiration. Most of the increase or decrease occurs at very low velocity (Kramer, 1969). At low levels of radiation, wind movement should increase transpiration; at high levels, however, when leaves tend to be warmer than the air, it should decrease transpiration (Knoerr, 1966).

Ephemeral ponds and salt lakes and their vegetation are the major sources of evapotranspiration in the study area. One estimate of water used in evapotranspiration is 80 to 90 percent of the precipitation that reaches rangeland (Branson and others, 1972). Another study (Rich, 1951) obtained values up to 98 percent. Of all the water absorbed by plants, about 95 percent is transpired and 5 percent or less is used in the plant (Kramer, 1969).

The smaller fraction of evapotranspiration is usually evaporation from the soil surface (Robinson, 1970); however, there are exceptions. Experiments with corn plants in Illinois indicate that approximately 50 percent of the evapotranspiration loss was evaporation from the soil surface (Peters and Russell, 1959).

A portion of incoming precipitation is intercepted by vegetative cover and lost by evaporation before it ever reaches the soil. In a study in Illinois, during a summer with 25.5 centimeters (cm) of rainfall, 5.0 cm was intercepted by the corn plants and evaporated, and 20.5 cm reached the soil. Transpiration used 20.5 cm and evaporation 13.2 cm.

Total water use exceeded, by 13.2 cm, the precipitation reaching the soil. The difference was supplied by soil moisture (Reimann and others, 1946).

Water Use

The two shrubs, or trees, that appear to be most important in the ponds and salt lakes are saltcedar and mesquite. Under suitable environmental conditions, saltcedar develops a widespreading and deep root system. Tomanek and Ziegler (1962) reported a lateral spread of 30 feet from a single plant. At a depth of 16 feet, the tap root was still 3/16 of an inch in diameter. Van Hylckama (1974) stated that saltcedar can use ground water from 30 feet or more.

The root system of mesquite is also widespreading and deep. Fisher (1950) stated that the depth of root penetration is from 20 to 60 feet with a lateral root spread of 50 feet from the base of the plant. Cable (1977) found velvet mesquite extending 15 meters beyond the edge of the crown of the plant.

Phreatophytic species use more water than non-phreatophytes. Tiedeman and Klemmedson (1977) stated that mesquite uses two to three times more water than herbaceous vegetation.

In studies done in Nevada, the average water use by greasewood (Sarcobatus vermiculatus (Hook.) Torr.) ranged from 1.21 to 1.45 acre-feet per acre in two tanks; rabbitbrush (Chrysothamnus sp.) used 1.66 acre-feet per acre; and willow (Salix sp.) used 3.03 acre-feet per acre

(Robinson, 1970). Therefore, there are water use differences among various species of phreatophytes.

Robinson (1965) stated that water consumption by saltcedar varies from 120 to 275 cm per year depending on exposure, climate, water-table depth, and salinity. Gatewood and others (1950) found saltcedar could use six to nine acre-feet of water per year. Van Hylckama (1970) believed that value to be too high.

A study done in south-central Washington (Cline and others, 1977) provides an example of different water strategies used by different plant communities exposed to similar conditions. Soil water use by two different communities in the spring and summer of 1974 was studied. The two communities were a 30-year-old stand of cheatgrass (Bromus tectorum L.) and a native stand of sagebrush-bluebunch wheatgrass (Artemisia tridentata Nutt.--Agropyron spicatum (Pursh) Scribn. and Smith). At the beginning of the growing season, average precipitation from 1971 to 1974 was 15 and 17 cm, respectively, and soil water storage was 30 and 29 cm, respectively. With the beginning of summer, growth in the cheatgrass community was arrested; soil water stored below 0.5 meter and was not fully used. However, the bluebunch wheatgrass community used deep soil water throughout the summer.

In a study done near Buckeye, Ariz., the effect of salinity on the water use of saltcedar was studied (van Hylckama, 1974). One set of three evapotranspirometer tanks was flushed while the other set of three was not. Total water use, excluding rainfall, in the flushed tanks in 1965 was 269.6 cm and in the unflushed tanks, 166.3 cm. The better quality water available in the flushed tanks resulted in a 62 percent increase in water used.

Van Hylckama (1974) showed that water lost to evapotranspiration decreases as depth to ground water increases. When the water level was 1.5 meters below the surface, the average water use by saltcedar was 215 cm per year; at 2.1 meters, the average use was 150 cm per year; and 2.7 meters, the average use was 100 cm per year. Other studies show the same patterns (Table 2).

Table 2.--Evapotranspiration (ET) and Depth to Water Table

Location	Depth to Water (feet)	Annual ET (ac-ft/ac)	Source
Carlsbad, New Mexico	2	5.5	Blaney and others, 1942
	4	4.7	
Safford Valley, Arizona	4	9.2	Gatewood and others, 1950
	8	7.0	

Evapotranspiration will increase as soil moisture increases (Briggs and Shantz, 1913; Kiesselbach, 1916). Near field capacity, water movement toward roots is rapid, and the transpirational rate is controlled by plant and atmospheric factors (Kramer, 1969). However, as soil water is depleted, the transpiration rate decreases as the water supply to the roots becomes a limiting factor (Ogata and others, 1960). Increasing soil water deficit is likely to reduce water uptake; the corresponding decrease in plant water potential and consequent stomatal closure will limit transpirational loss (Etherington, 1975).

Mesquite extracts soil water most rapidly where and when soil water is highest. When soil water levels are low, extraction rates are also low (Cable, 1977).

Robinson (1970) found, in a study in Nevada, that the groundwater use by rabbitbrush, greasewood, and willow during the peak month was 27 to 28 percent of the seasonal total. During the period June through August, 1966, use of ground water by rabbitbrush and willow was about 67 percent of the seasonal total and by greasewood about 72 percent. Evapotranspiration increased as the temperatures increased.

Because this study was not done during the growing season, it was not possible to get specific values for evapotranspiration and water use. Plant communities on vegetation maps presently available are too generalized to allow good estimates of vegetative water loss from pond and salt-lake areas. However, species present in these areas clearly indicate that larger quantities of water are available. Consequently, evapotranspiration is higher. These areas are therefore important in a regional water budget.

If the transpiration by several representative stands of saltcedar and mesquite were measured throughout the growing season, factors important in the water budget and the effects of salinity on evapotranspiration could be determined.

BRINE-POND AND NATURAL BRINE-LAKE INVENTORY

A specific task required for this study was an inventory of the brine ponds and natural brine lakes. This inventory might be useful in estimating the amount of brine produced by natural processes within the area. A field examination made in the fall of 1977 compared present conditions to conditions shown in infrared photos taken late in May 1975. Some hydrologic features of the area, particularly ponds and wetlands near some potash mines, were not covered by this photo series. However, several features relating to the origin, structure, biology, and distribution of the ponds were noted.

The topography west of Nimenin and Livingston Ridges, particularly in Nash Draw and Clayton Basin, is dominated by sinkholes and collapse structures. The sinkholes and collapse structures which currently exist are expanding, but no new ones are forming. These structures were formed due to solution and removal of salts from the underlying Rustler and Salado Formations. Drainage patterns are poorly developed, and run-off usually collects in these existing depressions within a short distance. Much of the precipitation collected in these depressions is returned to the atmosphere by evapotranspiration. However, a portion of the ponded water infiltrates through the soil to the Rustler Formation, which is at or near the surface throughout the southern and western portions of the area. The infiltrating fresh water dissolves salt deposits forming brine which gradually migrates away from the recharge site. Eventually, cavities created by a solution become so large that the overlying rock and soil collapse. In this way, sinkholes expand and capture more precipitation and run-off, and the expansion process is accelerated.

Because nearly all drainages discharge directly to solution-caused depressions or to sand dunes which fill these depressions (as at the Tut wells area, T. 21 S., R. 30 E., sec. 28), all available run-off is contributing to the expansion of existing depressions.

North of Laguna Plata and east of Nimenin Ridge, a thick sequence of non-evaporite-bearing Upper Permian and Triassic formations is present at the surface. The water-level map (fig. 2) shows that recharge occurs in this area and that ground water moves toward Clayton Basin. New collapse structures may be forming here, but sand dunes of the Querecho Plains may mask the early stages of sinkhole development. The dunes may also increase the amount of recharge by rapidly transmitting precipitation downward through the loose sand and away from the high evapotranspiration potential found near the surface.

It was noted in the field that local vegetation is extremely sensitive to variations in water availability. Surface depressions barely perceptible to the eye are distinctly shown on infrared air photos taken during times of plant activity. Therefore, all ponds and natural brine lakes will be visible on infrared photographs made during periods of plant activity. Even the earliest stages of depression development should be visible because of the selective favorability of these sites to plants with strong near-infrared irradiance. The grass patches appear as red areas on the infrared photos. Mesquite is always present and visible on the photos. In some areas outside Nash Draw and Clayton Basin, sand dunes may fill the depressions in the early stages and prevent the establishment of vegetation in noticeable concentrations.

Various stages of depression development are visible on the air photos and can be defined based on vegetation distribution patterns.

The shallowest depressions, which have mixed-concentrated vegetation patterns, are the most numerous. Patches of grasses are concentrated much more densely on the low areas than on the immediately adjacent land. Usually, randomly scattered mesquite occur throughout the grasses, but sometimes mesquite is more dense as well. Depressions with mixed-concentrated vegetation patterns are broad and shallow; most water entering by precipitation is rapidly transpired. The small percentage of water not transpired will recharge the underlying aquifer and dissolve soluble material in the process. Eventually, all depressions of this type will evolve into larger, deeper depressions with accompanying changes in the vegetation pattern.

Concentrated-grasses type depressions are distinguishable from the mixed-concentrated-vegetation type depression by the exclusion of mesquite from the deepest part of the depression. Mesquite is probably excluded due to excess water. The grassy central areas are always surrounded by a ring-like zone of mixed-concentrated vegetation. The outer edge of this outside ring may be marked by the exclusion of snakeweed, which is very common away from the depressions. The presence or absence of snakeweed cannot be visually verified from air photos. Solution-collapse features, particularly partially filled trench-shaped depressions, are often present in the deepest parts of the grassy zone. These features show that sufficient water has been available at times to percolate through the soil and rock to soluble beds, where fresh recharge water has dissolved the salts until collapse of the unsupported overburden occurs.

Barren depressions are characterized by a central zone void of vegetation, surrounded by irregular rings of concentrated grass and mixed-concentrated vegetation patterns. The barren area may be caused by standing water at critical times in plant life cycles, by concentration of precipitation to salinity levels beyond plant tolerance, or by trampling of bottom mud by livestock.

Field observations show that there are two subclasses of the barren vegetation pattern: salt bottom and mud bottom. Solution-collapse features were not observed in any salt-bottomed lake or pond but were observed in the barren zone of mud-bottomed ponds. This suggests that salt-bottomed ponds are sites of discharge by evaporation for water which entered the system as precipitation or ground-water inflow. The mud-bottomed ponds do not hold precipitation near the surface long enough to evaporate and form salt deposits. Water which percolates from these ponds becomes recharge.

If the area of these ponds within the study area and run-off to the ponds could be estimated, and if the evapotranspiration rates from the ponds were known, the amount of recharge could be calculated. Because permeability through collapse structures is higher than through the relatively undisturbed beds below the mixed-concentrated type depressions, the amount of recharge should be greater.

An attempt was made to determine the area of the natural ponds in each class from air photos of the potash area taken in October 1973. The vegetation patterns could be distinguished, although not as easily as on the color infrared photos of the selected areas taken in May of 1975. The area of the inventory was bounded on the southwest by the Pecos River between Malaga Bend and Avalon Reservoir, on the west by the common line between R. 26 E. and R. 27 E., on the north by the common line between T. 19 S., and T. 20 S., and on the east by the common line between R. 31 E. and R. 32 E. to the common line of T. 23 S. and T. 24 S. The results of the inventory were:

mixed-concentrated	:	more than 1,200 acres
concentrated grasses	:	535 acres
barren	:	mud bottom, 110 acres; salt bottom, 3,671 acres

The inventory was made by determining the length and width of each pond with a scale graduated in tenths of an inch. The photo scale is 1:31,680. The mean pond size is estimated to be less than eight acres.

The area of salt-bottomed barren ponds is the sum of the areas of four natural salt lakes as determined by planimeter from the 1973 photos. These included Laguna Grande de la Sal (Salt Lake), Laguna Plata, Laguna Gatuna, and Laguna Tonto. Salt Lake and Laguna Plata have been modified by mining activities. Laguna Gatuna and Laguna Tonto are relatively undisturbed. No new or previously unidentified salt-bottomed ponds were found during the inventory.

The results of this inventory are considered to be conservative and not useful as input for a regional water budget for the following reasons:

1. Except for the salt-bottomed ponds, the determination of pond areas has a large margin of error due to the small size of most ponds.

2. In some cases, one-half of an air photo, about 6,000 acres, was covered by mixed-concentrated vegetation depressions too numerous to count. This occurred most often on or near outcrops of Rustler Formation.

3. Only the area of vegetation concentration could be measured. The size of the input area of each pond could not be determined.

4. Evapotranspiration rates are unknown.

5. The 1973 complete photo coverage of the potash area was flown during the wrong season to easily define vegetation concentration with infrared photography.

6. As shown by comparison of the 1973 and 1975 photo coverage, annual and seasonal changes greatly affect pond area determination.

7. Natural and man-made brine ponds are intimately related by use, process of origin, and geography. Natural ponds frequently are used as brine disposal ponds. Therefore they cannot be evaluated separately, as requested by the Statement of Work.

Summary And Conclusions

Natural brine ponds can be detected even in the earliest stages of development on color infrared aerial photographs taken during times of plant activity. New depressions related to mine subsidence or covered by sand dunes are the only exceptions. An accurate inventory of the area of natural ponds in the vicinity of the potash mines by manual count and measurement from air photos probably is not possible. An accurate, reproducible inventory could be made by computer mapping of color infrared photography. The cost of a computer-based survey has been shown to be about one-tenth the cost of conventional vegetation inventories (Culler and others, 1976; Jones, 1977). The photo inventory did show that in any area where relatively fresh water is able to recharge the Rustler Formation, natural depressions have developed. These depressions will, in turn, increase the amount of recharge and the rate of depression enlargement. Because the Rustler Formation underlies the entire study area, this process is under way throughout the area. The rates of the process are dependent on the local structure and ground-water flow system.

WEATHER

The Carlsbad potash area lies within the semi-arid portion of the Pecos River Basin in southeastern New Mexico. Average annual precipitation is about 12½ inches, with the majority of the rainfall occurring in summer. The months of May through August each have average total rainfalls of one to two inches at most weather stations in southeastern New Mexico. In contrast, the months of November through April have total rainfalls of less than ½ inch for the most part.

Potential evapotranspiration in the potash area is about 34 inches (Tuan, 1973, fig. 48). Thus, the annual moisture deficit is about 22 inches, and the annual frost-free season moisture deficit is about 21 inches. Soil-moisture recharge occurs during December and January, when precipitation is greater than potential evapotranspiration (Tuan, 1973, figs. 49, 50, 55).

Precipitation

Precipitation records for 25 stations in and near the Eastside Roswell Area have been used to prepare a map of the mean annual rainfall for Lea, Eddy, and Chaves Counties (fig. 4). The mean annual rainfall for each point and the years for which data are available are given in Table 3. Table 4 gives average rainfalls for selected decades for which eight or more data points are available. Figure 5 is a graph of the precipitation record for Roswell, N. Mex.

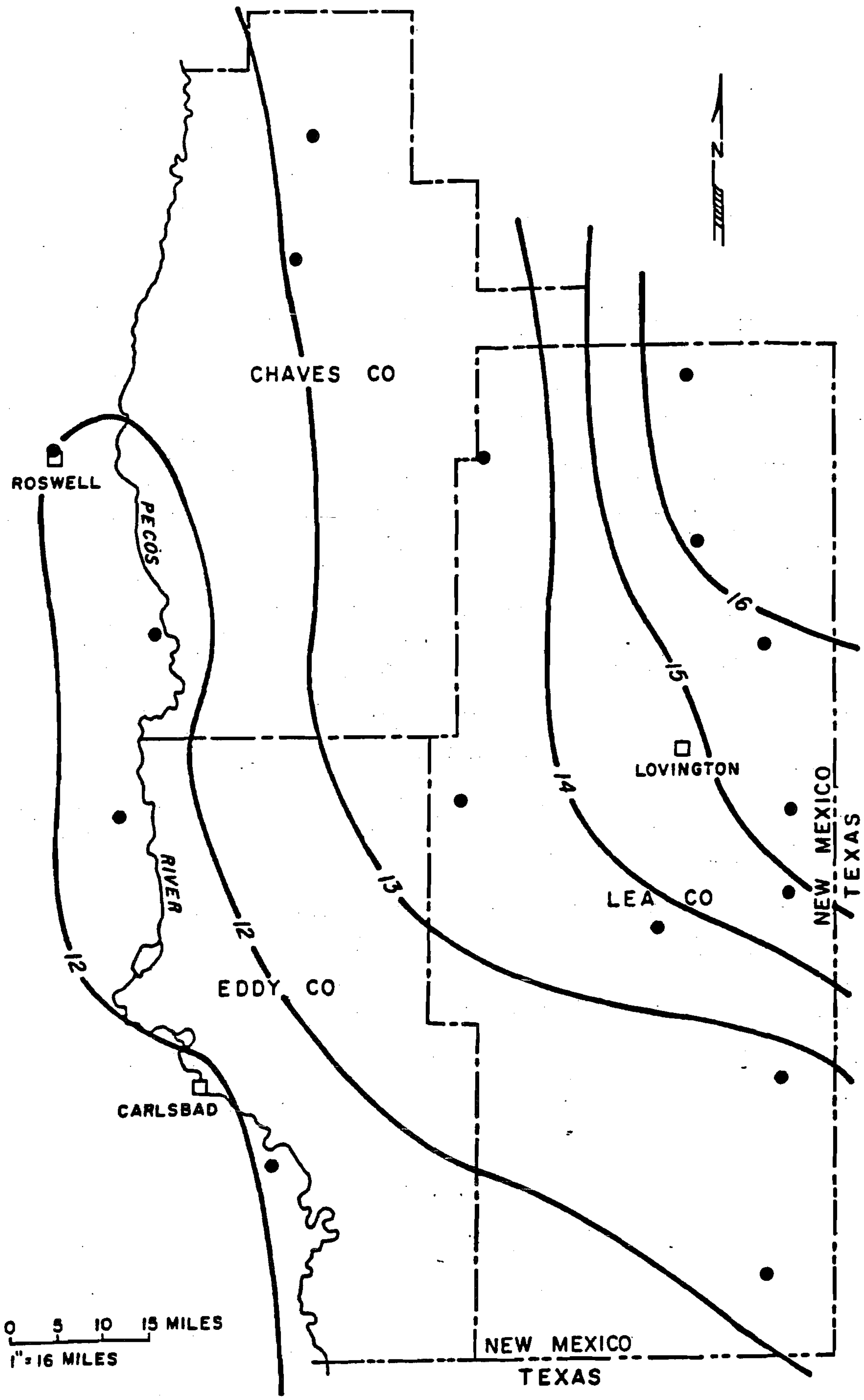


Figure 4.--Mean annual precipitation, in inches, in Eastside Roswell area. Dots represent precipitation measuring stations. Periods of record given in Table 3.

Table 3.--Average annual precipitation (since 1900).

Station	Average precipitation in inches	Years for which data are available (1977: Jan.-Sep.)
LEA		
Caprock	13.07	1941, 1943, 1945-47, 1952-54
Crossroads	16.40	1930-36, 1940-41, 1949-53, 1955-77
Eunice	12.42	1931-33
Hobbs	14.97	1913-26, 1938-77
Jal	12.45	1920, 1923, 1941-77
Knowles	15.30	1911-15, 1917
Lovington	14.93	1906-08, 1911-15, 1917, 1920-22, 1924-25, 1932-45, 1947, 1949-66
Maljamar	13.75	1947-77
Ochoa	10.95	1943-46, 1949-50, 1953-76
Pearl	13.70	1906-08, 1917, 1919-22, 1927, 1930, 1935-1937, 1940-48, 1950, 1952-76
Prairieview	15.74	1912-15, 1920-27, 1930-36, 1939-42, 1944, 1946, 1947
Tatum	16.17	1921, 1923, 1929-44, 1948-65, 1967-77
CHAVES		
Bitter Lakes	10.90	1951-77
Elkins	13.03	1910-38, 1946, 1947
Hagerman	11.13	1932-37, 1942-45, 1948-59
Olive	13.23	1910-12, 1921-25
Roswell	12.00	1900-1977
EDDY		
Artesia	11.25	1906, 1910-34, 1936-77
Carlsbad	12.58	1902-48, 1951, 1953-77
Carlsbad CAA	10.49	1949-1977
Duval Potash	13.71	1955-67, 1969-77
Lake Avalon	11.41	1915, 1917-76
Lakewood	9.67	1912-15, 1917, 1919-24, 1927
Loving	11.88	1918-19, 1922-29, 1931-36, 1938-45
Otis	11.84	1909-13

Table 4.--Ten-year average precipitation (in inches) for selected decades.

DECADE	1881-1890	1911-1920	1941*-1950	1967-1976
Roswell	19.03	14.21	13.55	12.68
Artesia		12.79	13.27	11.27
Carlsbad		14.97	14.78**	12.87
Lake Avalon			13.06	13.64
Hobbs		16.99**	16.56	17.01
Jal			15.35	13.26
Pearl			14.75***	16.66

* 1941 wettest year on record
** 8 years of record
*** 9 years of record

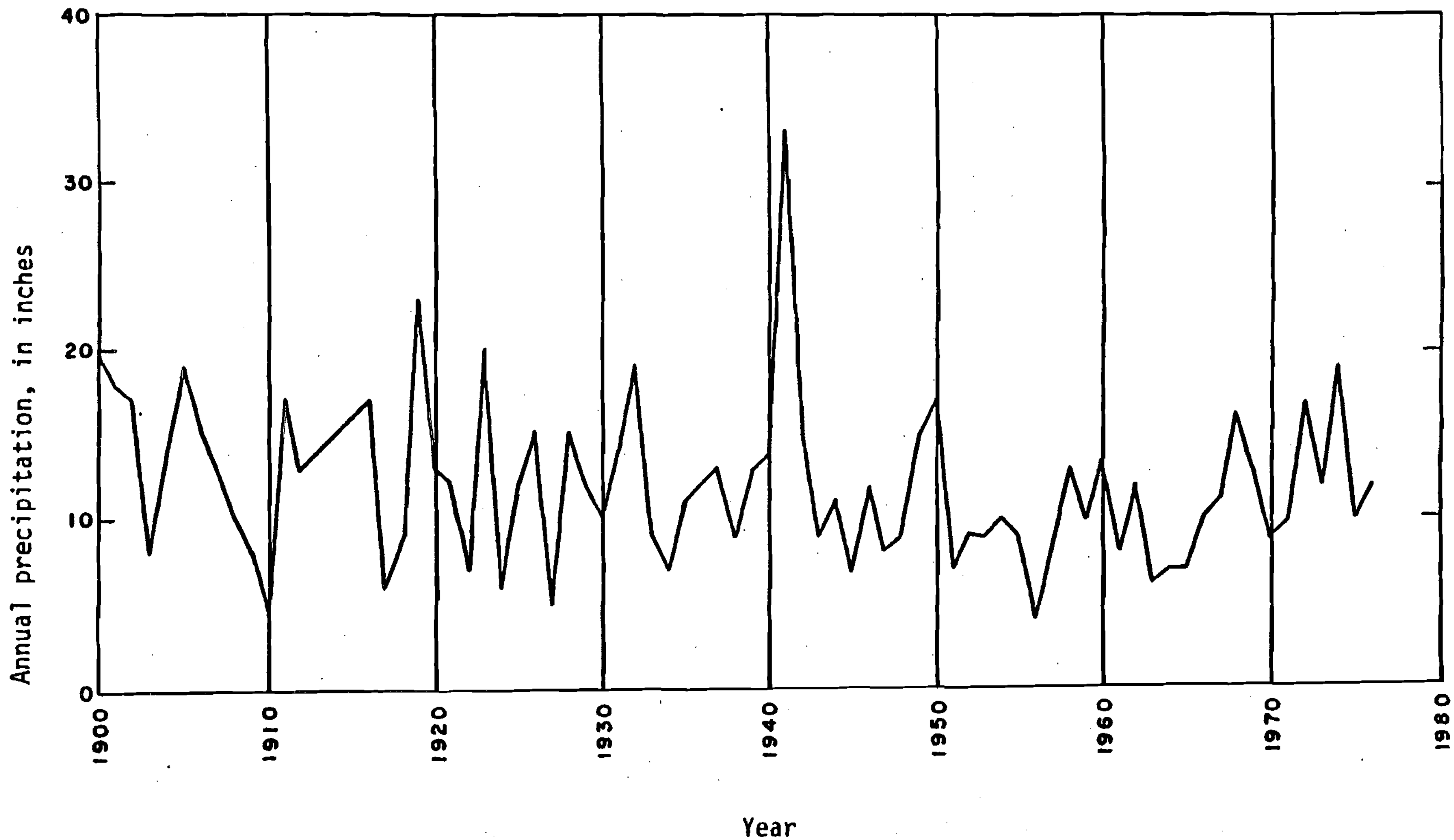


Figure 5.--Annual precipitation at Roswell, New Mexico, 1900 to 1977.

Examination of figure 5 and Table 4 shows a very gradual long-term drying trend in the Eastside Roswell Area. In addition, a study of drainage channels in the Eastside Roswell Area showed that streams are underfit and provides more evidence that current conditions are drier than in the past. Therefore, it may be concluded that long-term averages slightly overestimate the current rainfall. For most stations, information is available for only a short period of years and probably reflects current conditions.

The potash study of 969,875 acres (EAR, p. I-3) receives an average annual precipitation of 12½ inches or 1.04 feet per year. The total average annual precipitation on the potash area, P_T, is:

P_T = 1.04 feet x 969,875 acres

= 1,008,670 acre-feet

or approximately 1 million acre-feet per year.

Run-Off

Approximately 700 square miles of the Eastside Roswell Area is included in integrated drainage basins which actually drain water out of the area at some time during the year. Most of the area, however, has either internal drainage or no drainage apparent on topographic maps or air photos. The potash area in particular has only a few square miles of surface which are in drainage basins discharging from the area; these are offset by a few square miles which drain from outside into the area. Therefore, the run-off term of the water budget is considered negligible. There is no run-off from the potash area to the Pecos River.

Evapotranspiration From Land Areas

Published consumptive use data are usually limited to irrigated crops. However, most of the Eastside Roswell area is unirrigated range land. Therefore, potential evapotranspiration figures published for crops are of little value.

However, one study (Rich, 1951) has dealt with consumptive use on unirrigated forest and range land. Rich measured consumptive use under a variety of vegetative and climatic conditions and obtained values of 68 to 98 percent. Under conditions most similar to those of the potash study area, the consumptive use rate ranged from 89 to 98 percent, with most values between 92 and 96 percent.

Tuan (1973) illustrates precipitation and potential evaporation for Roswell; the consumptive-use rate calculated from his figure is 95.9 percent (fig. 6). The estimated soil moisture recharge, occurring when potential evaporation is less than precipitation, is less than 0.45 inches.

When the consumptive-use rate is calculated using the method of Thorthwaite and Mather (1957), it is found to be 96 percent (Table 5).

These three sources are in excellent agreement on a consumptive-use rate for the Roswell area of about 96 percent. Furthermore, Tuan (1973, p. 122) states that in southeastern New Mexico the consumptive-use rate does not vary appreciably.

Therefore:

Precipitation = 1,000,000 acre-feet
Consumptive use rate = 96 percent
Evapotranspiration = 1,000,000 x 0.96
= 960,000 acre-feet.

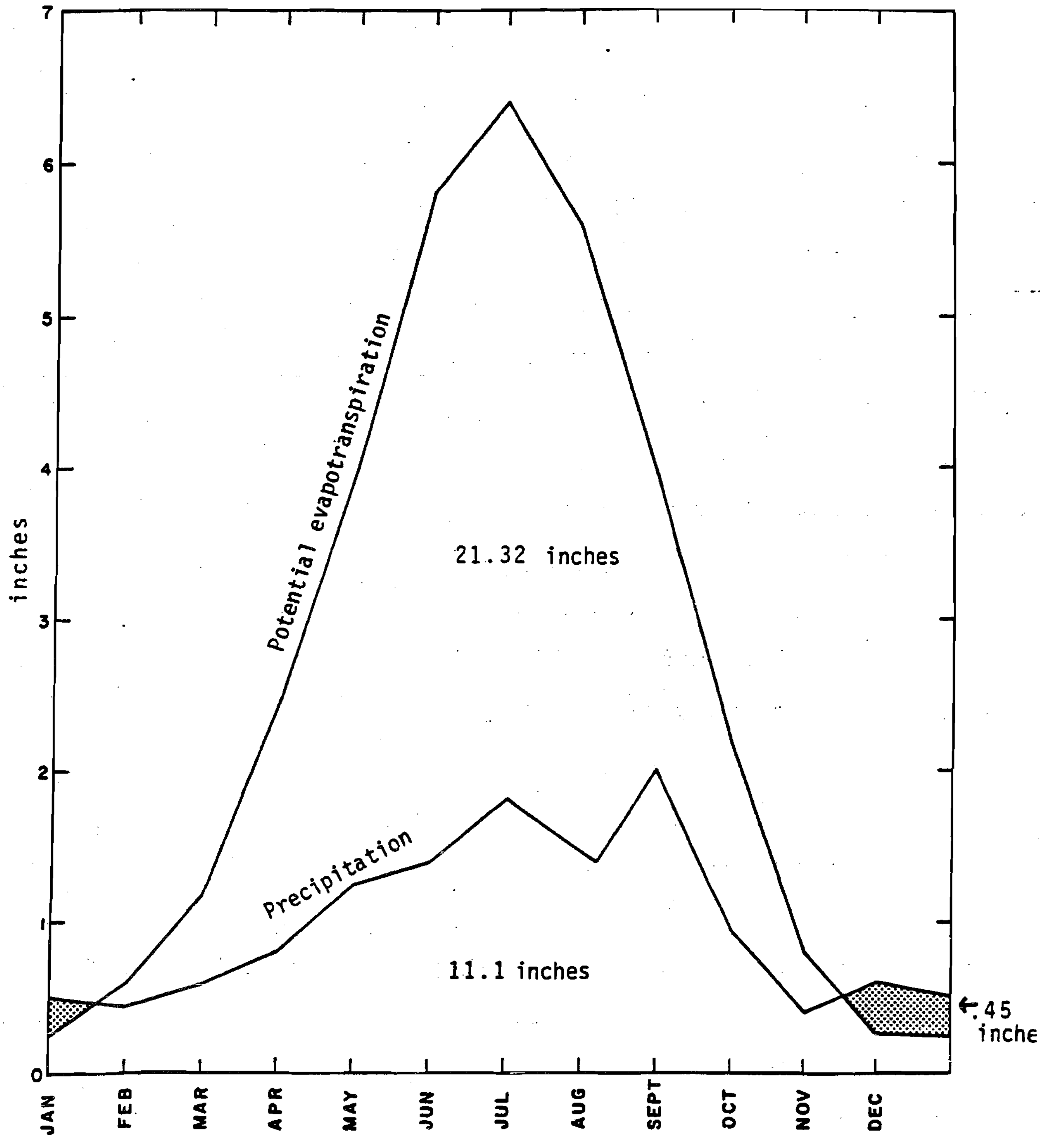


Figure 6.--Potential evapotranspiration graph for Roswell. (After Tuan, 1973, fig. 55)

Table 5.--Potential evapotranspiration for Roswell.
(calculated from Thornthwaite and Mather, 1957)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
T	42.7	42.9	49.3	59.7	68.5	77.0	79.2	77.9	70.4	59.6	46.9	39.3
i	1.30	1.33	2.69	5.49	8.33	11.43	12.29	11.78	8.99	5.46	2.15	.73
I		71.97										
Unadj. PE	.02	.02	.03	.07	.11	.16	.17	.17	.13	.07	.02	.00
Adj. PE	.528	.516	.927	2.29	3.94	5.74	6.19	5.88	4.02	2.04	.522	.00
P	.39	.47	.54	.70	.94	1.24	1.76	1.68	1.84	1.04	.52	.46

Total available moisture for soil-moisture recharge=.46 inches
Consumptive use=96 percent

T : mean air temperature in degrees Fahrenheit, from publications of the U. S. Weather Bureau
i : monthly heat index, from Table 1, Thornthwaite and Mather (1957)
I : heat index, sum of all i's
Unadj. PE: unadjusted daily potential evapotranspiration, from Table 3, Thornthwaite and Mather (1957)
Adj. PE : adjusted potential evapotranspiration; multiply unadjusted PE by correction factor from Table 6, Thornthwaite and Mather (1957)
P : precipitation, from publications of the U. S. Weather Bureau

The sum of monthly values for P-PE, where PE>0, is .46 inches

This calculation disregards the irrigated land near Carlsbad.

More information is available for evaporation from water surfaces. In the Carlsbad potash area, ponds of fresh water are greatly outnumbered by ponds of saturated brine. Thus, evaporation studies based only on fresh-water evaporation pans are of limited value.

Havens (1972) has conducted experiments to determine pan evaporation rates using brines at Malaga Bend, just southwest of the potash area. The brine-pan evaporation rate at Malaga Bend was compared with fresh-water pan evaporation at Lake Avalon. Accoding to Weather Bureau statistics, annual pan evaporation at Lake Avalon is about 110 inches. Using the correction figure of 67 percent (Kohler and others, 1959), fresh water pond evaporation in the potash area is approximately 74 inches, or 6.1 acre-feet per acre per year. Havens' (1972) measurement of brine-pan evaporation averaged 6.3 feet per year; multiplying by 0.67 to correct for pond evaporation, the evaporation rate is 4.4 acre-feet per acre per year for brine ponds in the potash area (Table 6).

Table 6.--Brine evaporation.

	Class A brine pan[1]	Pond (0.7 pan)[2]
January	0.238[3]	0.167[3]
February	.243	.170
March	.506	.354
April	.671	.470
May	.762	.533
June	.820	.574
July	.901	.631
August	.708	.496
September	.527	.369
October	.447	.313
November	.327	.229
December	.195	.137
	6.345 feet	4.442 feet

[1]Class A pan evaporations modified from Havens (1972, table A). Average of monthly brine-pan evaporation at Malaga Bend, 1963-1968.

[2]Evaporation rate for brine ponds in the potash area.

[3]Figures are acre-feet per acre per year.

REGIONAL WATER BUDGET

'A water budget is an account of the "amounts of water applied to, and lost from a particular container, area, or type of surface" according to van Hylckama (1974, p. 2), commonly applied in the form of a simplified input-output model. A regional water budget can be expressed by the mass balance equation:

$$P + I + U_i - E - O_s - U_o \pm \Delta S = 0$$

where:

P = precipitation

I = surface inflow

U_i = underground inflow

E = evaporation

O_s = surface outflow

U_o = underground outflow

ΔS = change in storage

Over a long period of time, most natural hydrologic systems are in equilibrium (Meinzer, 1931). Undoubtedly the water balance of Clayton Basin and Nash Draw was in equilibrium prior to the earliest mining in the area in about 1938. At that time the limited ground-water development, in the form of scattered stock wells, would have had virtually no impact on the ground-water system. Therefore, ground-water inflow to the area was probably equal to the ground-water outflow along the Pecos River.

Although mining has little impact on the hydrologic system in the area, the refining process requires the importation of large quantities of water. The release of this water, in the form of saturated brine, has changed the water balance. Small modifications in the parameters of the mass balance equation are necessary to evaluate the water balance in the potash area. Some of these parameters can be approximated with a reasonable degree of accuracy; others cannot. The inflow parameters are precipitation (P), underground inflow (U_i), and the multifaceted surface inflow (I). Outflow parameters include evaporation and transpiration (E), underground outflow (U_o), and surface outflow (O_s). Change in storage (ΔS) cannot be estimated with the data currently (1978) available. Therefore:

$$\text{Inflow } (P + U_i + I) - \text{Outflow } (E + U_o + O_s) = \text{Change in storage } (\Delta S)$$

Water-Budget Inflow Parameters

Most of the annual precipitation in the potash area falls during the summer months as brief but intense thunderstorms. Monthly precipitation averages recorded at the Duval Nash Draw mine for the period 1955 to 1977 are used for the potash area water budgets. These data (Appendix A) differ slightly from the average precipitation for the entire potash area which were presented previously.

A number of studies have estimated the amount of recharge in southeastern New Mexico. In a study of the High Plains of Lea County, it was concluded (Theis, 1934, p. 152) that recharge was one-half inch or less per year and that "no plausible method of estimated recharge from the data available can be made to indicate more than one inch of recharge a year". Havens (1966) used a water-budget equation to determine that recharge in northern Lea County for the period 1949-1960 averaged 0.82 inches per year. Rabinowitz and others (1977) determined that recharge in the Roswell area is between 0.166 inches for 4.05 inches of precipitation and 4.5 inches for 21.03 inches of precipitation. Most values were between 0.3 and 0.9 inches. 8mm to 23mm

Tuan and others (1973) showed that December and January comprise the soil-moisture recharge period for the Roswell area (fig. 5). Although precipitation during December and January is only about four percent of the annual total, this is the only period during which precipitation exceeds potential evaporation. This figure can not be used directly as ground-water recharge, because soil moisture deficiencies will claim part of the surplus.

This report assumes an average evapotranspiration rate of about 96 percent and that soil-moisture recharge claims one percent of the total annual rainfall. Assuming that the average annual precipitation at the Duval mine, 14.01 inches, is representative of precipitation of Nash Draw and Clayton Basin, the rate of recharge is about 0.42 inches of precipitation per year. The area contributing ground water to the potash area is about 1,250 square miles (Brokaw and others, 1972), which is about 80 percent of the Carlsbad potash study area. Thus the total recharge which occurs in Nash Draw and Clayton Basin is 28,300 acre-feet per year.

The ground-water system in the potash area is assumed to be in an equilibrium established through thousands of years of geologic evolution of southeastern New Mexico. There is no evidence to indicate that the amount of ground-water discharge to the Pecos River has increased since the beginning of potash refining in the area. Therefore it is assumed that ground-water inflow to the area is equal to ground-water outflow.

Surface inflow (I) is more complicated. This parameter normally is used to consider the amount of surface water flowing into the basin in channels. In the potash area, the surface inflow parameter is used to identify imported refining waters and oil field brines that are dumped in the area. The imported water is fresh ground water that is piped into the area for use in potash refining. Because some water is consumed by in-plant processes, the input to the regional hydrologic system is the sum of refinery discharges rather than the total amount of imported water. The amount of imported water and the estimated discharge for each potash refinery is presented in Table 7. Total estimated annual discharge is approximately 19,100 acre-feet. In the following section of this report, each refinery process is evaluated in detail.

Oil field brines act as surface inflow to the hydrologic system through leakage from brine ponds. Estimated oil field brine production in 1968 was 15,985 barrels per day, or 750 acre-feet per year (New Mexico Oil Conservation Commission, 1968, Case 3806, Exhibit 5). The oil slick usually found on the water surface in these ponds retards evaporation; much of this water seeps into the ground as recharge.

Table 7.--Summary of water use by potash refineries.

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

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

For purposes of the regional water budget, the annual recharge from oil field brine production in the potash area is arbitrarily assumed to be 500 acre-feet per year.

On the basis of these considerations, the annual water inflow to the regional hydrologic system is:

Precipitation (P)	=	28,300 acre-feet
Surface inflow (I)	=	19,600 acre-feet
Total		47,900 acre-feet

Water-Budget Outflow Parameters

There are three outflow parameters generally included in the mass balance equation: surface outflow (O_S), underground outflow (U_O), and evaporation and transpiration (E).

There is no surface outflow (O_S) from Nash Draw or Clayton Basin. Consequently, surface outflow $O_S = 0$ and can be disregarded in the mass balance equation.

The Pecos River receives ground-water discharge from the potash area. This underground outflow (U_O) has been estimated to be 200 gpm (Theis and others, 1942; Havens, 1972) or approximately 323 acre-feet per year. This figure represents the maximum possible discharge of ground water from the potash area.

In the potash area, the single most important outflow parameter in the mass balance equation is evapotranspiration (E). This value is determined from the acreage involved and the rate per acre. Table 8 is a

Table 8.--Water-budget parameters for the potash area.

Input	Rate	Area	Amount (acre-ft/yr)
Precipitation recharge	0.42 inches/acre/year		+28,300
Potash refinery input			19,100
Petroleum brines			500
		Total Input	47,900

Output	Rate	Area	Amount (acre-ft/yr)
Brine-pond evaporation	4.4 feet/acre	1,560 acres	6,850
Spoil-pile evaporation	4.0 feet/acre	1,290 acres	5,100
Mud flat and dense vegetation	3.0 feet/acre	4,804 acres	14,400
Natural ponds and lakes	4.4 feet/acre	655 acres	2,900
Natural salt lakes	4.0 feet/acre	3,671 acres	15,000
Underground outflow (U_0)	200 gallons/min.		323
		Total Output	44,573
		Change in Storage	3,327 (increase)

summary of the acreage involved in evapotranspiration in the potash area. The total area is approximately 12,000 acres. The sum of brine ponds, natural ponds and lakes, and natural salt lakes (Table 8) is 5,886 acres and closely matches a similar inventory presented in the EAR (1975, p. II-176-177), which listed 5,722 acres.

The evaporation rate used for the brine-pond water budget calculations (see the following section of this report) was 4.4 feet per year. If this evaporation rate is applied to the brine ponds and natural ponds (Table 8), potential annual evaporation is about 9,750 acre-feet per year. The potential annual evaporation from the spoil piles is calculated in the refinery water budgets which follow; the total is 5,100 acre-feet.

The evaporation rate from mud flats and areas of dense vegetation is difficult to estimate. For areas of bare soil with the water table close to the surface, the evaporation rate approaches the rate for a pond surface. Phreatophytic grasses along the Pecos River near Carlsbad have been reported to consume 30 inches of water per year. Saltcedar along the Pecos near Carlsbad have been reported to consume three to six feet of water annually depending on the depth to water and the density of the stand (Blaney and Hanson, 1965). If the evapotranspiration rate from mud flat and dense vegetation areas is arbitrarily chosen to be three feet per year, the evapotranspiration from these areas would be 14,400 acre-feet per year.

The only remaining category in the water-budget output is evaporation from natural salt lakes. The evaporation rate from ponds of saturated brine has been determined to be 4.4 acre-feet per acre per year. However, many of the salt lakes do not have standing water all year round. Therefore, for the purposes of this water budget analysis, evaporation from salt lakes is assumed to be 4.0 acre-feet per year.

The largest sources of error in the water-budget calculations arise from the assumptions concerning the refinery brine-disposal ponds: constant pond area, effective pile-evaporation area, and pile/pan evaporation ratio. If pond area and wetted pile area could be determined on a monthly basis, the pile/pan evaporation factor could be adjusted until the water-budget model matched the observed change in storage in the pond. Increased seepage induced by an increase in the head would be taken into consideration automatically.

It has been stated that the mass balance equation for the potash area consists of three parts--inflow, outflow, and change in storage. The values for the various inflow and outflow parameters are tabulated in Table 8; the difference between the two represents the change in storage (ΔS). In the case of the potash area, there is an increase in water storage of 3,327 acre-feet per year.

An increase in the amount of water in storage in the potash area is apparent from ground-water-level changes in the major refinery discharge areas. Clayton well (20.30.3.223) is located about 1½-miles northeast of the outfall of the refinery waste water from PCA. On December 23, 1948, the static water level in this well was 6.0 feet below land surface (Hendrickson and Jones, 1952, p. 99); aerial photographs taken on October 11, 1973, show that this well had been inundated by Clayton Lake and was under approximately two feet of water. This represents a minimum change in storage of about eight feet in the Clayton Basin area.

An even greater change has occurred in the J Bar F well (22.30.30.240), located near the discharge point of the IMC refinery. On December 17, 1948, the static water level in this well was 134.0 feet below the land surface; in June 1978, the water table was at the land surface near this abandoned well. Nash well (23.30.6.420) was an operative stock well in December 1948, but at the present time (June 1978) the well is inundated by a salt lake.

These changes in storage cannot be attributed to precipitation. Work by Havens (1972, p. 143) showed that several years of abnormal precipitation near Malaga Bend resulted in a net ground-water rise of about seven feet. However, the rise in water table recorded in wells near the refineries show significantly greater changes. There are several wells in Nash Draw which have changed very little between 1948 and 1978. A well at the old Crawford Ranch (22.30.10.310) had a static water level of 56.0 feet below land surface on December 23, 1948; the water level was 56.96 feet below land surface on June 7, 1978. A well (22.29.33.240) located north of Salt Lake had a static water level of 56.2 feet below land surface on December 17, 1948; this same well had a static water level of 53.73 feet below land surface on June 7, 1978. Both of these wells are several miles from the nearest outfall of refinery waste; the static changes in water levels represent the true hydrologic conditions in the unimpacted parts of the potash area. Therefore, the significant changes in water levels in Clayton well, J Bar F well , and Nash well can only be attributed to changes in storage within the hydrologic system.

As shown in Table 8, the net change in storage is 3,327 acre-feet per year. It should be noted that this volumetric estimate is based on a large number of assumptions, particularly as related to evaporation and transpiration. Nevertheless, these assumptions are based on the best available data. The 3,327 acre-feet per year is seven percent of the total input water to the potash area. It has been shown that the change in storage cannot be attributed to precipitation. There is no evidence of changes resulting from leakage from oil field brine ponds. Therefore, the only source for a positive change in storage must be in imported water discharged by the refineries. The net change in storage is approximately 17 percent of the annual total of imported water.

REFINERY WATER-BUDGET EVALUATIONS

To determine the amount of seepage from each of the seven refinery disposal ponds, it was necessary to make a detailed water-budget analysis of each. The water budgets were determined using the mass-balance equation:

$$D + PA_1 + PA_2 - E_1A_1 - E_2A_2 - S = 0$$

where $E_1 = YE_3$ and $E_2 = ZE_1$

and D = industrial brine-discharge in acre-feet /month

P = precipitation in feet/month

A_1 = pond area in acres

A_2 = wetted-pile area in acres

E_1 = pond evaporation in feet/month

E_2 = pile evaporation in feet/month

E_3 = brine evaporation from Class A pan in feet/month

Y = ratio of pond evaporation rate to pan evaporation rate

Z = ratio of wetted-pile evaporation rate to pond evaporation rate

S = seepage from the pond in acre-feet/month

With the exception of seepage (S), all factors in this equation can be measured or estimated reasonably well. If all input factors are placed on one side and all output factors on the others, S represents the residual, unknown output required to balance the budget. Where S is large, the equation demonstrates that the ponds probably cannot evaporate all input, which indicates that leakage must be occurring.

A number of assumptions that form the brine-pond model must be made to apply this simple budget equation to the complex brine-pond hydrology. Most importantly, pond area is considered to be constant throughout the year despite significant monthly precipitation and evaporation-rate fluctuations. The model therefore assumes that the ponds are broad, flat-bottomed containers with vertical sides, which maintain uniform area even when the water is infinitely shallow. This assumption was necessary because only one area measurement (October 1973) could be obtained for each pond. If monthly area measurements were available pond area could be considered as a variable. Pond geometry would not be a factor and storage changes in the ponds would be considered automatically.

The monthly precipitation (P) and pan evaporation data (E_3) used are presented in Appendix A and Table 6. As discussed previously, pond-to-pan evaporation ratio of 0.7 was demonstrated for the Malaga Bend area (Havens, 1972) and is assumed to be reasonable for the pond-to-pan evaporation ratio (Y) in the potash area.

It is industry practice to discharge brine at the top of the spoil pile to allow some brine to evaporate from the pile surface before reaching the ponds.

The spoil-pile-to-pond evaporation ratio (Z) is difficult to determine. Evaporation loss from a light-colored surface of variably textured salt and clay is unknown, but for the brine-pond water budget estimates, Z is assumed to be 90 percent of pond evaporation (E_1).

The amount of spoil pile area which is wetted and actively contributing to evaporation changes constantly. Buried channels are present in the spoil piles as evidenced by collapse of the pile surfaces observed during a flight over the area on February 3, 1978. Water in these channels will not evaporate except near the discharge point at the toe of the pile. At some piles, the numerous large springs observed at the toe of the pile suggest that a significant portion of the applied brine does escape evaporation on the piles. For the brine-pond water budgets, it is assumed that the effective evaporation area is less than the entire area of the pile. The effective evaporation area was set at 50 percent of the total pile area.

Precipitation on the unwetted portion of the pile was assumed to evaporate and was neglected in the water budget.

Although each factor used in the water budget is thought to be conservative, the cummulative error could be large. The largest sources of potential error in the water-budget calculations are the assumption concerning constant pond area, effective pile-evaporation area, and pile/pan evaporation ratio. If pond area and wetted pile area could be determined on a monthly basis, the pile/pan evaporation factor could be adjusted until the water-budget model matched the observed change in storage in the pond. Increased seepage induced by an increase in the head would be taken into consideration automatically. During a long-term study, the model could be tuned as more reliable data became available, until the predicted response matches observed changes in pond-surface area and pond storage.

The following budgets for the potash refinery brine ponds should be viewed as tentative.

AMAX Chemical Corporation

Current data concerning water use at the AMAX refinery was supplied by Mr. Milton H. Klein (written commun., Feb. 13, 1978). The data provided are thorough and complete and his cooperation is gratefully acknowledged.

AMAX imports 1,400 gpm of fresh water for use at its plant. An additional 550 gpm of saline water is pumped from the Rustler Formation at the site. Discharge to the tailings pond is 2,200 gpm, but a large percentage of this discharge is composed of solids in suspension and solution. The water content of the waste-brine is reported to be 1,900 gpm. The pond area is 90 acres and the estimated total effective evaporation area is reported to be 125 acres. For the water budget, 35 acres was used as the pile area. Surface-water run-off from the pond's natural drainage area is assumed to have been minimized and is neglected.

The results of the AMAX water budget are shown in Table 9. The annual ratio of seepage to plant discharge for the given assumptions is 0.87. The total seepage expressed as an average rate is 1,659 gpm.

Table 9.-- PLANT DISCHARGE WATER BUDGET: AMAX

COMPANY OR SITE NAME AMAX

PLANT DISCHARGE IN ACRE-FEET /MONTH 255.4 (1900 gpm)

POND AREA IN ACRES 90

PILE AREA IN ACRES 35

PAN EVAPORATION CONVERSION FACTORS Pond/ Pan = 0.7

Pile/Pond = 0.9

	JAN	FEB	MAR	APR.	MAY	JUN	JUL	AUG	SEP	OCT.	NOV	DEC	TOTALS
PRECIPITATION (FEET)	0.028	0.031	0.041	0.042	0.113	0.120	0.214	0.169	0.189	0.138	0.038	0.058	1.2
CORRECTED POND EVAPORATION (FEET)	0.167	0.170	0.354	0.470	0.533	0.574	0.631	0.469	0.369	0.313	0.229	0.137	4.4
DISCHARGE (ACRE-FT)	255.4	255.4	255.4	255.4	255.4	255.4	255.4	255.4	255.4	255.4	255.4	255.4	3064.8
PRECIPITATION (ACRE-FT)	3.5	3.9	5.1	5.3	14.1	15.0	26.8	21.1	23.6	17.3	4.8	7.3	147.8
POND EVAPORATION (ACRE-FT)	15.0	15.3	31.9	42.3	48.0	51.7	56.8	42.2	33.3	28 2	20.6	12.3	397.6
PILE EVAPORATION (ACRE-FT)	5.3	5.4	11.2	14.8	16.8	18.1	19.9	14.8	11.6	9.9	7.2	4.3	139.3
SEEPAGE (ACRE-FT)	238.6	238.6	217.5	203.5	204.8	200.7	205.5	219.5	234.2	234.6	232.3	246.0	2675.8
SEEPAGE/DISCHARGE	0.93	0.93	0.85	0.80	0.80	0.79	0.80	0.86	0.92	0.92	0.91	0.96	0.87
EVAPORATION IN EXCESS OF INPUT(ACRE-FT)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

INPUT - EVAPORATION= SEEPAGE

(DISCHARGE + PRECIPITATION)-(POND EVAPORATION+ PILE EVAPORATION)=SEEPAGE

ANNUAL SEEPAGE AS PERCENT OF DISCHARGE: 87 %

ANNUAL SEEPAGE-EXCESS EVAPORATION AS PERCENT OF ANNUAL DISCHARGE: 87 %

TOTAL ANNUAL SEEPAGE EXPRESSED AS AVERAGE GALLONS PER MINUTE = 1659

AVERAGE SEEPAGE RATE MINUS RECYCLED WATER, IN GPM = 1109

The 550 gpm pumped from the Rustler Formation beneath the property is returned to the formation by seepage from the pond. Therefore, the net seepage is 1,109 gpm. The rate of seepage calculated by Mr. Klein is 1,012 gpm. The method and specific factors used to make the AMAX estimate are unknown, but for practical purposes, the results are identical.

AMAX personnel report that the actual seepage is less than the calculated seepage, a conclusion based on the observed increase in pond level and volume. Presumably, the loss of pond volume due to salt deposition has been eliminated as the cause of water-level rise.

The EAR (1975, p. II-186) concluded that because Hackberry Lake normally contained fresh water, the AMAX pond does not leak. However, water-level data at Hackberry Lake show that the lake bed is 15 feet above the water table; thus ground water, which may contain leakage from the AMAX pond, cannot enter Hackberry Lake. Water in the lake is from precipitation and of high quality.

The AMAX pond is different in many ways from other potash-brine ponds. First, the topographic setting limits the amount of surface-water inflow, although some inflow is apparent on the 1975 air photos. Diversion of this fresh-water inflow to Hackberry Draw below the retention dam would improve the water balance of the pond. Second, the pond surface is approximately 100 feet above the regional water table which eliminates the possibility of ground-water inflow to the pond. Third, there is no surface-water outlet. Fourth, the actual area of the pond is more easily determined than for any other refinery. Fifth, since industrial brine is the only major water input, the solution in the pond will be at or near saturation at all times. Collapse of the pond bottom from solution of the underlying salt beds is not likely to occur even though the plant vicinity is prone to natural collapse. Therefore, the only mechanism by which seepage can occur is by infiltration through the bottom sediments. No other refinery site offers such controlled conditions for the evaluation of evaporative loss from a potash refinery spoil pile.

Duval Corporation

Few data are available for computing a water budget for the Duval refinery. The pond was not shown on the the May 1975 air photo series and was completely dry on the October 1973 series. It did contain water from November 1977 to March 1978. The pond area planimetered from the 1973 photos, based on deposition patterns, is 62 acres. The pile area measured 379 acres. The pond area reported in the EAR (1975) was 60 acres. Alluvial deposits on the pile suggest that at times, up to 50 percent of the pile may be wetted. The pond is perched above the water table and is, therefore, isolated from ground-water inflow.

Gilkey and Stotelmeyer (1965) reported the discharge to the tailings ponds to be about 485 gpm and state that the small size of the pond was due to the permeability of the underlying formation. Irby (1967) reported the discharge to the ponds to be about 700 gpm.

Current water use at the plant, reported by Mr. M. P. Scroggin (written commun., Feb. 1, 1978) is as follows:

Inflow	:	1,343 gpm
Flow to tailings ponds	:	1,278 gpm
Evaporation from tailing ponds	:	1,019 gpm
Seepage from tailings ponds	:	259 gpm

The methods used for this determination are unknown. Based on the above information and the estimated wet pile and pond areas, a trial water budget for the Duval pond (Table 10) shows that 64 percent of the discharge seeps from the pond. However, the model assumes a constant pond area while the available data shows that this pond has a history of pronounced surface-area fluctuation. Table 10 predicts that the pond will contain water 12 months of the year. If the pond regularly becomes dry, as in October 1973, the model must be tuned until the predicted response matches the observed response. Table 10 is presented as a trial water budget and may not reflect the actual response of the Duval pond to industrial brine loading.

International Minerals and ChemicalsCorporation

International Minerals and Chemicals Corporation (IMC) discharges brine from its refinery to its spoil pile and to Laguna Uno. Although several retention dams obviously have been constructed by IMC in the past, during this investigation these dams had been breached and all refinery discharge was flowing directly into Laguna Uno. Both Laguna Uno and the spoil pile are large and cover 562 and 619 acres respectively, as determined by planimeter from the 1975 air photos.

Table 10.-- PLANT DISCHARGE WATER BUDGET : Duval Corporation

COMPANY OR SITE NAME Duval Corporation (Trial Budget)

PLANT DISCHARGE IN ACRE-FEET /MONTH 171.8 (1,278 gpm)

POND AREA IN ACRES 62

PILE AREA IN ACRES 379x0.5= 189.5 wetted acres

PAN EVAPORATION CONVERSION FACTORS Pond/Pan = 0.7

Pile/Pond = 0.9

	JAN	FEB	MAR	APR.	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
PRECIPITATION (FEET)	0.028	0.031	0.041	0.042	0.113	0.120	0.214	0.169	0.189	0.138	0.038	0.058	1.2
CORRECTED POND EVAPORATION (FEET)	0.167	0.170	0.354	0.470	0.533	0.574	0.631	0.496	0.369	0.313	0.229	0.137	4.4
DISCHARGE (ACRE-FT)	171.8	171.8	171.8	171.8	171.8	171.8	171.8	171.8	171.8	171.8	171.8	171.8	2061.6
PRECIPITATION (ACRE-FT)	7.0	7.8	10.3	10.6	28.4	30.2	53.8	42.5	47.5	34.7	9.6	14.6	297.0
POND EVAPORATION (ACRE-FT)	10.4	10.5	21.9	29.1	33.0	35.6	39.1	30.8	22.9	19.4	14.2	8.5	275.4
PILE EVAPORATION (ACRE-FT)	28.5	29.5	60.4	80.2	90.9	97.9	107.6	84.6	62.9	53.4	39.1	23.4	758.4
SEEPAGE (ACRE-FT)	140.0	140.0	99.8	73.0	76.3	68.5	78.9	98.9	133.5	133.7	128.1	154.5	1325.2
SEEPAGE/DISCHARGE	0.81	0.82	0.58	0.43	0.44	0.40	0.46	0.58	0.78	0.78	0.75	0.90	0.64
EVAPORATION IN EXCESS OF INPUT (ACRE-FT)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

INPUT - EVAPORATION= SEEPAGE

(DISCHARGE + PRECIPITATION)-(POND EVAPORATION+ PILE EVAPORATION)=SEEPAGE

ANNUAL SEEPAGE AS PERCENT OF DISCHARGE: 64 %

ANNUAL SEEPAGE-EXCESS EVAPORATION AS PERCENT OF ANNUAL DISCHARGE: 64 %

TOTAL ANNUAL SEEPAGE EXPRESSED AS AVERAGE GALLONS PER MINUTE: 822

TOTAL EVAPORATION EXPRESSED AS AVERAGE GALLONS PER MINUTE: 641

According to the Office of the New Mexico State Engineer in Roswell, the amount of water imported by IMC during 1977 was 1,894,622,800 gallons (F. Henninghausen, oral commun., Mar. 24, 1978). The discharge from the plant is estimated to be 90 percent of the total imported water (EAR, 1975, p. II-197). This is 5,233 acre-feet per year or 3,244 gpm.

The water budget for IMC-Laguna Uno assumed that 50 percent of the spoil pile area was wet and contributing to evaporation (Table 11). In this budget, the ratio of seepage to discharge is 0.48; however, much of this "seepage" actually represents surface-water outflow from Laguna Uno, which has not been measured. Also, the surface of Laguna Uno represents the level of the local water table and there are numerous springs and seeps along the east and south sides of the lake. The amount of this inflow and outflow cannot be determined from existing data; therefore, an accurate water budget for Laguna Uno and IMC cannot be calculated.

Kerr-McGee

Kerr-McGee discharges refinery wastes into two ponds at the refinery site and also into Laguna Toston. The areas of the Kerr-McGee ponds and spoil piles, planimetered from the 1973 photos, are:

South pond	33 acres
West pond	57 acres
Laguna Toston	67 acres
	157 acres
Refinery pile	245 acres
Laguna Toston pile	143 acres
	388 acres

Table 11.-- PLANT DISCHARGE WATER BUDGET: International Minerals and Chemicals Corp.

COMPANY OR SITE NAME International Minerals and Chemicals Corporation
PLANT DISCHARGE IN ACRE-FEET /MONTH 436.1 (3244 gpm)
POND AREA IN ACRES 562
PILE AREA IN ACRES 619 x 0.5 = 309.5 wetted acres
PAN EVAPORATION CONVERSION FACTORS Pond/Pan = 0.7
Pile/Pond = 0.9

	JAN	FEB	MAR	APR.	MAY	JUN	JUL	AUG	SEP	OCT.	NOV	DEC	TOTALS
PRECIPITATION (FEET)	0.028	0.031	0.041	0 042	0.113	0.120	0.214	0.169	0.189	0.138	0.038	0.058	1.2
CORRECTED POND EVAPORATION (FEET)	0.167	0.170	0.354	0.470	0.533	0.574	0.631	0.496	0.369	0.313	0.229	0.137	4.4
DISCHARGE (ACRE-FT)	436.1	436.1	436.1	436.1	436.1	436.1	436.1	436.1	436.1	436.1	436.1	436.1	5233.2
PRECIPITATION (ACRE-FT)	24.4	27.0	35.7	36.6	98.5	104.6	186.5	147.3	164.7	120.3	33.1	50.5	1029.2
POND EVAPORATION (ACRE-FT)	93.9	95.5	198.9	264.1	299.5	322.6	354.6	278.8	207.4	175.9	128.7	77.0	2496.9
PILE EVAPORATION (ACRE-FT)	46.5	47.4	98.6	130.9	148.5	159.9	175.8	138.2	102.8	87.2	63.8	38.2	1237.8
SEEPAGE (ACRE-FT)	320.1	320.2	174.2	77.6	86.5	58.2	92.2	166.4	290.6	293.2	276.7	371.5	2527.4
SEEPAGE/DISCHARGE	0.73	0.73	0.40	0.18	0.20	0.13	0.21	0.38	0.67	0.67	0.63	0.85	0.48
EVAPORATION IN EXCESS OF INPUT(ACRE-FT)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

INPUT - EVAPORATION= SEEPAGE

(DISCHARGE + PRECIPITATION)-(POND EVAPORATION+ PILE EVAPORATION)=SEEPAGE

ANNUAL SEEPAGE AS PERCENT OF DISCHARGE: 48 %

ANNUAL SEEPAGE-EXCESS EVAPORATION AS PERCENT OF ANNUAL DISCHARGE: 48 %

The company did not respond to a written request (Jan. 27, 1978) for water use, discharge, and seepage information. The quantity of fresh water imported for the refinery was obtained from the company mining plan (Feb. 1977) filed with the U. S. Geological Survey. Reported water usage at the refinery was 1,600 gpm plus recycled water from the brine ponds. Only imported water is considered as input to the water budget. Discharge from the plant is unknown; but it is estimated to be 90 percent of the inflow, or 1,440 gpm.

The water budget prepared for Kerr-McGee brine disposal (Table 12) assumes 50 percent of the pile area is wetted and contributes to evaporation. This budget predicts that seepage will occur all year long and that about one-half of the plant discharge will leak from the ponds annually.

Mississippi Chemical Corporation

The pond and pile areas could not be determined for the Mississippi Chemical Corporation plant due to the lack of suitable aerial photos. However, the following data were supplied by Mr. J. R. Walls (written commun., Feb. 6, 1978) of MCC:

Inflow	855 gpm
Flow to tailings ponds	1,700 gpm
Recycle from tailings ponds	900 gpm
Seepage from tailings ponds	0 gpm

"Of the 1,700 gpm flow to tailings pond, approximately the equivalent of 400 gpm is solid-phase salt and unsoluble material. Any differences would be due to evaporation."

Table 12.-- PLANT DISCHARGE WATER BUDGET: Kerr-McGee

COMPANY OR SITE NAME Kerr-McGee
PLANT DISCHARGE IN ACRE-FEET /MONTH 193.6 (1440 gpm)
POND AREA IN ACRES 157 acres
PILE AREA IN ACRES 388 x 0.5 = 194 acres wetted
PAN EVAPORATION CONVERSION FACTORS Pond/Pan = 0.7
Pile/Pond = 0.9

	JAN	FEB	MAR	APR.	MAY	JUN	JUL	AUG	SEP	OCT.	NOV	DEC	TOTALS
PRECIPITATION (FEET)	0.028	0.031	0.041	0.042	0.113	0.120	0.214	0.169	0.189	0.138	0.038	0.058	1.2
CORRECTED POND EVAPORATION (FEET)	0.167	0.170	0.354	0.470	0.533	0.574	0.631	0.496	0.369	0.313	0.229	0.137	4.4
DISCHARGE (ACRE-FT)	193.6	193.6	193.6	193.6	193.6	193.6	193.6	193.6	193.6	193.6	193.6	193.6	2322.7
PRECIPITATION (ACRE-FT)	9.8	10.9	14.4	14.7	39.7	42.1	75.1	59.3	66.3	48.4	13.3	20.4	414.5
POND EVAPORATION (ACRE-FT)	26.2	26.7	55.6	73.8	83.7	90.1	99.1	77.9	57.9	49.1	36.0	21.5	697.6
PILE EVAPORATION (ACRE-FT)	29.2	29.7	61.8	82.1	93.1	100.2	110.2	86.6	64.4	54.6	40.0	23.9	775.7
SEEPAGE (ACRE-FT)	148.0	148.1	90.6	52.5	56.5	45.3	59.4	88.4	137.5	138.2	131.0	168.5	1264.0
SEEPAGE/DISCHARGE	0.76	0.76	0.47	0.27	0.29	0.23	0.31	0.46	0.71	0.71	0.68	0.87	0.54
EVAPORATION IN EXCESS OF INPUT (ACRE-FT)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

INPUT - EVAPORATION= SEEPAGE

(DISCHARGE + PRECIPITATION)-(POND EVAPORATION+ PILE EVAPORATION)=SEEPAGE

ANNUAL SEEPAGE AS PERCENT OF DISCHARGE: 54 %

ANNUAL SEEPAGE-EXCESS EVAPORATION AS PERCENT OF ANNUAL DISCHARGE: 54 %

The elevation of surface of the pond was surveyed during this study and found to be approximately 100 feet above the area water table. As noted in the EAR, the plant is located in an area of karst topography. Unfortunately the limited amount of available data precludes determination of the water budget at the present time (June 1978).

National Potash Company

The brine disposal process at the National Potash Company refinery is complex; the information necessary for preparation of even a preliminary water budget is unavailable. Some factors precluding the use of the water budget model for National Potash Company are the numerous discharge areas, which receive seasonally varying amounts of brine, and the reported water surface-area fluctuations.

The following information was provided by Mr. C. R. Cable (written commun., Feb. 2, 1978). His report of water use at the plant and his personal observations concerning this disposal process were very useful and are appreciated.

Plant inflow	700 gpm
Process water	84 gpm
Discharge to tailings	616 gpm

Brine is discharged to the piles and ponds in Williams Sink, which is a natural depression. The Sink is reported to be dry when evaporation rates are high. When evaporation rates are low, 400 to 500 gpm of brine are discharged to Laguna Plata, a natural salt-bottomed depression. Williams Sink and Laguna Plata are at similar elevations.

Several features of the National-Williams Sink-Laguna Plata complex are unexplained. An accurate budget and detailed water-level data might shed light on the regional hydrology. One such feature is the salt in Laguna Plata, Laguna Gatuna, and Laguna Tonto. Stratigraphically, these lakes are several hundred feet above the top of the Rustler Formation, the uppermost salt-bearing unit. It is difficult to attribute all the salt in Laguna Plata to mining when Laguna Gatuna and Laguna Tonto do not appear to have received much man-introduced salt. The origin of these high salt lakes is probably different from that of Laguna Grande de la Sal.

The May 1975 air photos show several small natural depressions along the south side of Laguna Plata. These were higher than the lake, full of water, and discharged to Laguna Plata. This indicates that ground-water levels were higher along the south side of the lake than in the lake itself. The north side was not photographed. The lake contained water. Inflow from National was obvious, so presumably, disposal ponds in Willimas Sink were full at this time also. May is one of the highest evaporation periods, and the lake should have been dry.

Laguna Plata was dry in October 1973. The lake and adjacent ponds were dry during December 1977 and January 1978, the lowest evaporation months of the year. Possibly seepage from Williams Sink and from Kerr-McGee discharge at Laguna Toston is moving toward Laguna Plata and being discharged by transpiration when the water table is low and by flow into Laguna Plata when the water table is high. However, vegetation patterns around the ponds along the south side of Laguna Plata suggest that this water may be of better quality than in the brine lakes.

Brokaw and others (1972, p. 44) indicated that a water-table mound existed below Williams Sink. A regional water-table map completed as part of the Eastside Roswell Range study does show a water-table ridge trending north-easterly from Williams Sink. Water-table control for this map may not have been sufficient to detect a mound, or the mound may not have been present during this study. If a mound is present below Williams Sink at any time during the year, potash refinery discharge is the most likely source.

Understanding the hydrology and geologic processes active in this area is probably the key to predicting the eastward expansion of Nash Draw. The origin of the high salt lakes and the interaction of Nash Draw with the recharge area beneath the sand dunes of the Querecho Plains would also be better understood. Additional water-level data are needed in this area.

Potash Company of America

Potash Company of America (PCA) discharges refinery wastes to part of Clayton Basin. The following data concerning water use at PCA were reported by Mr. Dave Rice (written commun., Feb. 8, 1978):

Total inflow plant water	2,750 gpm
Flow to tailings ponds	2,550 gpm
Calculative evaporation from tailings ponds	2,550 gpm
Estimated seepage from tailings ponds	Indeterminate

A preliminary water budget for the PCA plant is presented in Table 13. The budget uses the areas of the pond and pile determined from the October 1973 air photos, which were 498 and 503 acres respectively. One-half of the pile area was considered to be wetted and contributing to evaporation. Inspection of part of the pile along Highway 31 showed that areas of the pile which were dry on the surface had numerous large springs discharging undetermined amounts of water at the base. Water moving through the pile is less subject to evaporation.

The water budget predicts that 43 percent of the discharge from the plant seeps from the ponds. The water surface of Clayton Lake is the lowest point in the vicinity; therefore, leakage from the nearby PCA pond should discharge to Clayton Lake. The lake is surrounded by dense stands of saltcedar on all but the southwest side, which is closest to the PCA ponds. Water was observed discharging to the lake from seeps south of Clayton Lake during this study. These could be the discharge points of seepage from the PCA pond; however, the specific conductance of the seepage and pond do not substantiate this.

The evaporation rate reported by PCA matches the reported plant discharge rate. Thus the pond could be expected to be dry, or at least very nearly dry, during periods of high evaporation. The water budget (Table 13) suggests that the pond should be nearly dry from April to July. The time of year that the present study was done did not permit observation of the PCA pond during the high-evaporation season. However, the water level in the portion of the pond visible on the May 1975 photos

Table 13.--PLANT DISCHARGE WATER BUDGET : Potash Company of America

COMPANY OR SITE NAME Potash Company of America

PLANT DISCHARGE IN ACRE-FEET /MONTH 342.8 (2550 gpm)

POND AREA IN ACRES 498

PILE AREA IN ACRES 503 x 0.5 = 251.5

PAN EVAPORATION CONVERSION FACTORS Pond/Pan = 0.7
Pile/Pond = 0.9

	JAN	FEB	MAR	APR.	MAY	JUN	JUL	AUG	SEP	OCT.	NOV	DEC	TOTALS
PRECIPITATION (FEET)	0.028	0.031	0.041	0.042	0.113	0.120	0.214	0.169	0.189	0.138	0.038	0.058	1.2
CORRECTED POND EVAPORATION (FEET)	0.167	0.170	0.354	0.470	0.533	0.574	0.631	0.496	0.369	0.313	0.229	0.137	4.4
DISCHARGE (ACRE-FT)	342.8	342.8	342.8	342.8	342.8	342.8	342.8	342.8	342.8	342.8	342.8	342.8	4113.6
PRECIPITATION (ACRE-FT)	21.0	23.2	30.7	31.5	84.7	89.9	160.4	126.7	141.7	103.4	28.5	43.5	885.2
POND EVAPORATION (ACRE-FT)	83.2	84.7	176.3	234.1	265.4	285.9	314.2	247.0	183.8	155.9	114.0	68.2	2212.7
PILE EVAPORATION (ACRE-FT)	37.8	38.5	80.1	106.4	120.6	129.9	142.8	112.3	83.5	70.8	51.8	31.0	1005.5
SEEPAGE (ACRE-FT)	242.8	242.9	117.1	33.8	41.4	16.9	46.1	110.2	217.1	219.5	205.4	287.0	1780.2
SEEPAGE/DISCHARGE	0.71	0.71	0.34	0.10	0.12	0.05	0.13	0.32	0.63	0.64	0.60	0.84	0.43
EVAPORATION IN EXCESS OF INPUT(ACRE-FT)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

INPUT - EVAPORATION= SEEPAGE

(DISCHARGE + PRECIPITATION)-(POND EVAPORATION+ PILE EVAPORATION)=SEEPAGE

ANNUAL SEEPAGE AS PERCENT OF DISCHARGE: 43 %

ANNUAL SEEPAGE-EXCESS EVAPORATION AS PERCENT OF ANNUAL DISCHARGE: 43 %

TOTAL ANNUAL PILE PLUS POND EVAPORATION EXPRESSED AS AVERAGE GALLONS PER MINUTE: 2000 is noticeably higher than in October 1973. It is not known to what this change is attributable.

In the EAR (1975, p. II-187), the PCA pond was noted to contain undersaturated brine, which was attributed to storm run-off. During a flight over the PCA ponds on February 3, 1978, two unusual, small ponds south of the main pond were observed to be discharging to the PCA pond. The discovery of these strangely colored ponds (hereafter called "blue pond" and "green pond") led to some of the most significant findings of this study. The pond locations and water levels, which were surveyed in March 1978, are shown in figure 2. An examination of the site revealed two connected ponds through which water flowed to the much larger PCA pond.

The lower pond, blue pond, was estimated to be about one foot above the water surface of the PCA pond. It covers about 1.5 acres. The pond is a sink hole containing deep blue water with thick aquatic vegetation. Saltcedar are abundant in the area. The total dissolved solids of this water are about 43,615 ppm.

Green pond was one foot above the surface of blue pond. It is also a sink hole, at least 10 feet deep, about 50 feet in diameter, and filled with very clear, greenish water. Saltcedar are present around portions of the pond. A water sample taken from green pond had a TDS content of 23,364 ppm.

Inflow to green pond is from the south in a channel thick with saltcedar; on the adjacent higher ground, saltcedar is absent. The channel is thought to be a solution cave with a partly collapsed roof. It is discharging ground water which has a total dissolved solids content of about 15,665 ppm.

Both the water quality and direction of flow in this area are important. Two previous studies (Hendrickson and Jones, 1952; Brokaw and others, 1972) and figure 1 of this report have shown the water table in Clayton Basin to be a south-trending trough opening to Nash Draw. Data obtained during the present study suggest that within this trough there is a closed depression in the water table which centers on Clayton Lake and the PCA ponds. It was noted in the EAR (1975, p. II-187 and App. A-7) that although progressive pollution of Clayton Lake and concentration of salts by evapotranspiration were occurring, "the lake was not too saline to support many forms of marine life". A large input of relatively fresher water is needed to maintain this condition. Water moving toward the depression includes precipitation recharge from a large area, all leakage from the AMAX refinery, and possibly some leakage from the Duval and National refineries. More water-level data is needed to accurately define the direction of ground-water movement in this area.

If Clayton Basin does contain a closed water-level depression, leakage from the PCA ponds does not leave the basin but is diluted by precipitation. It is evaporated or transpired from the large area of natural ponds and wetlands which occur over an estimated 1,000 acres near PCA. This is in addition to the 1,000 acres of pond and pile area considered in the PCA water budget presented in Table 13.

How the movement of unsaturated brine through the underlying rock will change the topography and hydrology of the area is unknown. The existing ponds and sinkholes will probably continue to expand and gradually lower the land surface. This process can be observed at Laguna Siete (EAR, 1975, p. II-187) where tall saltcedars are now dead and almost completely immersed in the growing natural pond.

Summary of Brine-Pond Water Budgets

The Statement of Work for this project requested the contractor to make a "best preliminary estimate of the volumetric average annual brine leakage from man-made ponds and natural brine lakes whose underlying general geology or other site suitability characteristics makes them leakage suspects and rank in importance". However, there are a large number of variables which preclude making accurate determinations of these leakage values. Probably the most significant potential errors are in the assumption of constant pond area and in the arbitrary assignment of spoil pile evaporation rates.

The data collected and the water budgets show conclusively that none of the man-made brine disposal ponds investigated can evaporate all brine discharged into it. Therefore, it is concluded that all disposal ponds leak. The amount of seepage varies for each pond and depends primarily on the total pond and pile acreage contributing to evaporation. Seepage estimates range from one-third to over three-quarters of total refinery discharge. However, some of the leakage moves toward natural evaporation sites and ultimately is totally evaporated.

Natural Brine Lakes.

Natural brine lakes do not leak to the hydrologic environment; rather ground water is discharged to the natural brine lakes. The evaporation of this ground water results in the natural formation of salt deposits. Salt Lake is a prime example. Surprise Spring, at the north end of the lake, is discharging several hundred gallons per minute of brine ground water to the lake bed. The water is evaporated and thick salt deposits have accumulated. Similar conditions exist at Laguna Plata, Laguna Gatuna, and Laguna Toston. Throughout most of the year these lakes are dry, indicating that ground-water discharge is less than the evaporation rate at the lakes.

Clayton Lake contains highly mineralized water, but it is seldom dry and therefore differs from the better known brine lakes described above. The specific conductance of a water sample from Clayton Lake was 59,200 umhos, about 38,500 ppm dissolved solids, on June 14, 1978. The fact that this lake is seldom dry can be attributed to several factors. First, Clayton Lake is deeper and narrower than most of the other brine lakes in the area; thus there is less evaporation per cubic foot of water. Second, the surface drainage area to Clayton Lake is larger than that to Lagunas Gatuna, Plata, or Toston. Thus, there is more surface-water run-off into this lake. Third, ground-water discharge probably exceeds that to most of the other brine lakes, with the possible exception of Salt Lake. Consequently, Clayton Lake is a natural brine discharge point which retains a perennial water supply.

Lindsey Lake is another example of a perennial brine lake that probably is a natural discharge point for ground water.

Artificial Brine Ponds.

Virtually all brine released by International Minerals and Chemicals Corporation enters the hydrologic system. All previously constructed retention dams have been breached and refinery waste flows directly from the plant to Laguna Uno. It subsequently passes through a series of brine lakes and eventually empties into Salt Lake. Much of the water is lost by evapotranspiration and the dissolved salts precipitate. It is likely that IMC discharge is primarily responsible for the change in storage of ground water in Nash Draw.

Potash Company of America releases all of its refinery waste to the large natural depression bordering the spoil pile on the south and west. There is a large amount of natural ground-water discharge into this same depression. The water-table contours indicate that there is a rather large area contributing to the PCA pond. Therefore, it seems likely that this was a natural ground-water discharge area prior to the start of mining operations. Refinery wastes probably raised the water table to the land surface, with an increase in storage of ground water. At the present time (1978) it remains a natural ground-water discharge area in which the brine pond level is maintained by PCA and other ground-water sources.

All refinery discharge from National Potash Company is piped to natural depressions, including Williams Sink and Laguna Plata. Subsurface information indicates that both depressions are natural ground-water discharge points. Consequently, as in the case of PCA, refinery wastes are contained in the natural depressions because ground-water movement is toward the depressions rather than away from them.

There is no evidence of surface leakage or discharge of refinery brine from the AMAX Chemical Corporation pond. However, Mr. M. H. Klein has calculated that about 1,000 gallons per minute are lost from the AMAX brine pond by leakage. This agrees with the water budget for the site. The karst topography of the area indicates that vertical permeability along fracture planes is high; however, at the present time there is insufficient data to calculate the change in storage resulting from leakage.

Mississippi Chemical Corporation retains all of its refinery waste in one brine pond below the spoil pile. There is no evidence of surface leakage. The refinery and brine pond are in an area of active collapse, so it is likely that vertical leakage occurs beneath the brine pond. An abandoned stock well located about one mile south of the MCC pond has become unusable for stock since the development of potash mining and refining in the area. The lack of adequate aerial photos precluded the development of a water budget.

Waste from Kerr-McGee Corporation is discharged into two brine ponds and into Laguna Toston. It has been calculated from the water budgets that leakage from the brine ponds does occur. However, there are insufficient production and discharge data to compile an accurate water budget. Water-table contours of Nash Draw indicated that the leakage, which results in a change in storage of ground water, moves southwestward in Nash Draw toward the area of TUT wells and the Crawford Ranch. Refinery waste piped to Laguna Toston will be retained in the same manner as in Laguna Plata and Laguna Gatuna. Laguna Toston is a natural ground-water discharge area, which prevents the escape of refinery wastes; all of the solids pumped into Laguna Toston will be precipitated as the water is lost by evaporation.

Brine waste from Duval Corporation is pumped into natural depressions and further contained by a retention dam. However, a by-pass has been constructed in the dam so that overflow can be released before the dam is breached. Field evidence indicates that brine is periodically released through the by-pass.

The natural depressions in the vicinity of the Duval brine pond are collapse structures which allow leakage into the ground-water system. Several natural ponds below the Duval disposal pit are maintained by ground-water discharge, possibly from Duval.

In summary, all brine from PCA and National is emptied into natural ground-water discharge areas where the brine probably is totally evaporated. Part of Kerr-McGee's waste enters Laguna Toston and is also contained by natural ground-water conditions. AMAX, Duval, MCC, and the remainder of the Kerr-McGee waste is confined by man-made ponds which leak to the ground-water system. Much of this leakage constitutes the change in ground-water storage identified in the regional water budget. All waste brine from IMC is released to the hydrologic system, where it produces a major change in storage.

ANDERSON LAKE AND USGS WELL NO. 8

The poor chemical quality of water in the Pecos River has been a major problem for many years for several reasons. Water from the Pecos has been diverted for irrigation in the Roswell area, but south of Carlsbad, the increased sodium chloride content precludes irrigation. Below Langtry, Texas, the Pecos River joins the Rio Grande, which is the common border between the United States and Mexico, and thus, it is an international stream.

Numerous studies have been conducted in order to determine the sources of the salts that contaminate the Pecos River. Methods to alleviate the problem have also been studied. It is generally recognized that the salt content in the Pecos increases rather abruptly near Malaga Bend south of Carlsbad. This has been attributed to leakage of brine from ground-water aquifers present at shallow depths beneath the bed of the Pecos River.

In an effort to reduce the amount of brine discharged to the river, a series of aquifer tests were conducted by the U. S. Geological Survey in cooperation with state and federal agencies. The purpose of the tests was to determine the feasibility of lowering the potentiometric head of the brine aquifers beneath the river. Preliminary tests were made in 1953 and 1954, but the major test effort began on USGS well No. 8 in July 1963. Initially, this well was pumped at a rate of 543 gpm with a drawdown of 35.6 feet. With continuous pumping from 1963 to 1969, the final pumping level was 41.2 feet.

Most studies of this test are unpublished and several reports are still in preparation or review (W. E. Hale, oral commun., Dec. 14, 1977). Unpublished data were made available for this study; it is assumed that additional data will be released by the U. S. Geological Survey.

The aquifer-test data indicated that sufficient impact was exerted on the aquifers to reduce the artesian head. The brine discharged from the well was pumped into Anderson Lake where it was allowed to evaporate. However, the lake was not entirely water-tight. Some brine was leaking back to the ground water. The chemical composition of the brine produced by USGS well No. 8 indicated that unsaturated ground water was being drawn into the area of influence of the well. Consequently, freshwater aquifers were being adversely affected. Therefore, the test was discontinued.

During these tests it was established that the cone of depression created by pumpage of USGS well No. 8 did not extend as far as Salt Lake (Havens, 1972, fig. 5). Therefore, any effect of the potash mining and refining operations must be reflected in the water quality produced by the well.

Various brine-saturated aquifers in the vicinity of Anderson Lake and Nash Draw were sampled during this study to compare chemical parameters (Table 14). Additional information was available from other sources. These data indicate a strong similarity between brines from several different source areas. Although there is a wide range of total mineralization,

Table 14.--Chemical analysis of brine samples from Nash Draw and Malaga Bend area, Eddy County, New Mexico. (values in mg/l)

Sample site	Ca	Mg	Na	K	HCO_3	SO_4	Cl	B	TDS
USGS well No. 8	455	2,230	99,100	4,110	84	10,800	156,000	12	273,000
Surpirse Spring	425	5,250	91,875	11,812	169	5,500	178,697	11.8	334,892
IMC discharge	350	3,750	106,250	10,000	179	8.250	188,400	14.2	361,380
AMAX well No.2	1,810	2,125	66,500	7,625	136	4,350	131,500	4.8	244,500
MCC well	2,400	1,625	23,750	2,500	124	4,000	48,020	2.5	96,400

the general water characteristics are similar (fig. 7). Cation ratios in samples from USGS well No. 8, IMC refinery discharge, AMAX well No. 2, and Surprise Spring are similar. Anion ratios in the IMC discharge and the MCC well are similar to that produced from USGS well No. 8. However, there is a wide range in total dissolved solids.

Comparison of selected individual ions has been made to determine whether one or more of these could provide evidence that potash mining effluent was produced from USGS well No. 8. The ions of particular interest are calcium (Ca), sodium (Na), potassium (K), magnesium (Mg), sulfate (SO_4), bicarbonate (HCO_3), chloride (Cl), bromine (Br), boron (B), and chromate (CrO_3). Total dissolved solids were also evaluated.

Calcium is a common constituent in most ground water; however, it comprises less than one percent of the cation content from USGS well No. 8. Inasmuch as calcium is frequently derived from solution of gypsum, which is present in the Rustler Formation, it is possible that the calcium originally in the Rustler water has been reduced by base exchange for sodium. The calcium content of USGS well No. 8 is similar in concentration and proportion to that of Surprise Spring and of IMC discharge. However, the content is lower than calcium levels in the AMAX and MCC wells, which tap the Culebra Dolomite Member of the Rustler Formation.

Most of the sodium in water produced from USGS well No. 8 probably is derived from evaporite deposits in the Salado Formation. Ninety-six percent of the cations in water from USGS well No. 8 is sodium. This high concentration and similar proportions of cations in other samples preclude the use of sodium as an indicator of contamination.

9-2001 USGS WRD, Nov. 1951

WATER-ANALYSIS DIAGRAM

Area of circle indicates dissolved solids in parts per million, thus:

Scale of diameters

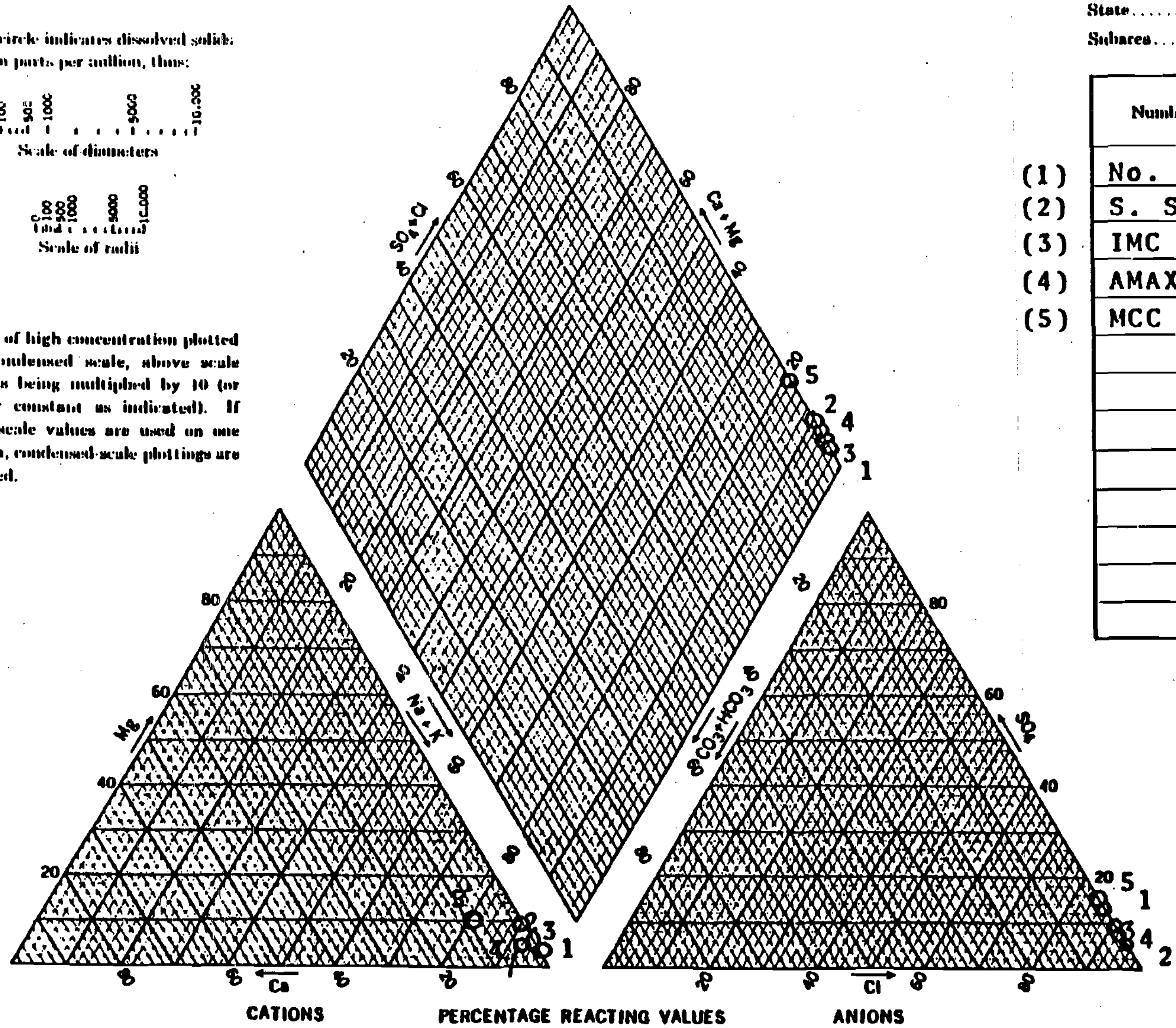
Scale of radii

Waters of high concentration plotted at condensed scale, above scale values being multiplied by 10 (or other constant as indicated). If two scale values are used on one graph, condensed-scale plottings are shaded.

State.......New Mexico

Subarea.... Potash Study Area

	Number	Date	Dissolved solids (ppm)	Aquifer
(1)	No. 8	1/64		Rustler
(2)	S. Spr.	2/78		?
(3)	IMC	2/78		none
(4)	AMAX	2/78		Rustler
(5)	MCC	2/78		Rustler



Plotted by............

Checked by............

Date............

Figure 7.--Trilinear diagram showing ion distribution in samples from brine samples in the Nash Draw area. Samples listed on Table 14.

Potassium is the principal constituent of potash ore. It also forms a very soluble salt that readily remains in solution. Large quantities of potassium are present in the IMC discharge and in Surprise Spring; however, potassium levels in samples from USGS well No. 8 are relatively low.

Magnesium is usually associated with potash minerals. Once in solution, it has a stronger tendency to remain in solution than does calcium with which it is frequently associated. Data from Table 14 show that the magnesium level is relatively consistent in all the brine samples in the area. Because high magnesium levels are likely to be present in both natural and contaminated water, it would be difficult to use this cation to indicate possible origin.

Gypsum forms one of the major lithologic units in the Rustler Formation. As calcium sulfate, the mineral is readily soluble and is present in water originating from the Rustler. Samples from USGS well No. 8 show higher levels of sulfate than is present in other brine samples from the area. The proportion of the sulfate anion in samples from USGS well No. 8 and the Rustler well used by MCC are quite similar, 15 and 13 percent, respectively. The IMC discharge contained 9 percent. The proportion of sulfate to other anions may be useful in identifying water from the Rustler, but it could not be used to indicate the presence of refinery waste.

Bicarbonate is present in small quantities in most of the brine samples, including that from USGS well No. 8 (Table 14). The low level, less than one percent in all samples, makes laboratory analysis difficult and it is unlikely that bicarbonate can be used as an indicator ion.

Chloride is the principal anion in the samples. The chloride in these samples probably is derived almost entirely from the Salado Formation. The proportion of chloride ions is lower in samples from USGS well No. 8 and the MCC well tapping the Rustler, but the difference is not great enough to use chloride as an indicator of aquifer of origin. Chloride could not be used as an indicator of contaminants.

Bromine is a common constituent of evaporite deposits; the bromine in ground water of Eddy County is probably derived from these deposits. Inasmuch as bromine is chemically similar to chloride, the two anions are frequently associated. The procedures for determination of the bromide ion are less accurate at low concentrations than those for chloride. Therefore, there is reason to question the accuracy of chemical analyses for bromine for the USGS well No. 8 samples. However, bromide concentrations in California ground waters have been used to differentiate between sources of salinity (Piper and others, 1953, p. 91-92). Additional analyses in the potash area might prove the technique to be useful.

Borate salts and the element boron are commonly found in the Salado Formation. The analyses in Table 14 show that the level of boron is similar in samples from USGS well No. 8, Surprise Spring, and the IMC discharge. Boron levels in the two wells tapping the Rustler Formation, MCC and AMAX well No. 2 are quite low. Additional sampling would be required to establish the background levels of boron in each brine aquifer and in the refinery waste. After background levels are determined, boron may prové to be a valuable natural tracer.

The TDS in brine samples from the area shows a wide range of concentrations--from highly mineralized to saturated. It is unlikely that TDS could be used as an indicator of contamination.

Chromate may prove valuable as an indicator. Natural chromates are very rare; there is no known natural source in the Nash Draw area. However, chromates are added to the cooling systems of all refineries in the area and enter the ground-water system in refinery discharge. Unfortunately, few data are available for study. Additional work should be performed to establish the background levels of chromates in the Eddy County brines.

Ions of sodium, chloride, and magnesium are present at high concentrations in most ground waters of the potash area. They are not useful as indicators. Bicarbonate concentrations are too low to be useful. Calcium is probably reduced by base exchange and is therefore not representative of the aquifer of origin. TDS varies widely.

Potassium is potentially useful in indicating the presence of refinery waste. Sulfate may indicate water from the Rustler Formation. There is a strong possibility that bromine, boron, and chromate concentrations would be useful indicators if background levels were known.

SUMMARY: POTASH AREA

1. The Carlsbad Potash Area is underlain by several thousand feet of evaporite rocks. Solution of these rocks by ground water forms collapse structures on the surface and large volumes of saturated brine in the aquifers.

2. There are no perennial streams and a limited number of ephemeral fresh-water ponds in the potash area. Well water is generally of poor quality. The water-table gradient is generally from northeast to southwest. Water from troughs in the water table is unpotable; water from ridges in the water table is of better quality.

3. Vegetation patterns in the potash area can be used qualitatively as an indicator of the amount and quality of soil moisture present. The possibility exists that further study would reveal a more quantitative use for vegetation patterns.

4. In areas not influenced by the potash mining industry, no new collapse structures are forming. Existing collapse structures are expanding in size.

5. Water budgets for each potash plant show that all industrial brine ponds are leaking.

6. Recharge to the ground water in the potash area is about 0.42 inches per year. Evapotranspiration consumes about 96 percent of all water entering the potash area annually.

7. Studies of Anderson Lake and USGS Well No. 8 show that it is possible, by pumping, to lower the potentiometric head of saline ground water entering the Pecos River at Malaga Bend. However, such pumpage has an adverse effect on the area's fresh water.

RECOMMENDATIONS FOR CORRECTIVE ACTION

1. It is not advantageous to line disposal ponds. Lining the ponds would be expensive, would disturb the environment over a larger area than presently affected by mining, and would not prevent ground-water contamination by mine discharge. Water budgets indicate that none of the ponds are large enough to evaporate all of the brine effluent. Lined brine ponds would have to be significantly larger than the present ponds. Because saturated brines contain about 17 percent dissolved solids, plus suspended sediments and slimes, the volume of a sealed pond would decrease by approximately 25 percent of the plant discharge each year. Construction costs of a lined pond which could be cleaned would be high. Seepage from the piles would continue. Removal of saturated-brine seepage from beneath the ponds would permit the natural solution and collapse process to resume and eventually cause failure of the pond lining.

2. Relocation of disposal ponds would serve no practical purpose, and might contaminate high quality water found outside water-table troughs. No ground water in the troughs of Nash Draw and Clayton Basin is potable. The potash refineries are located in, or near, these troughs. Although the refinery discharge contributes to the total mineralization of ground water in the area, retention of the mine waste will not add fresh water to the system.

3. It is not recommended that the mining companies be required to return spoil-pile material to abandoned mined areas underground. Due to

the breakdown of the ore during the mining and refining process, it is unlikely that spoil piles could be recompacted to be contained in the mine workings. The greatest source of contamination of ground water is the liquid effluent and not the solids; the spoil piles add to ground-water contaminants only when precipitation falls on the piles and becomes surface run-off. Spoil piles will remain as part of the landscape long after a mining and refining operation has been terminated. Therefore, it might be advantageous to require the mining company to return as much of the spoil pile as possible to mine workings prior to total abandonment.

4. Insufficient information is available to evaluate the usefulness of Salt Lake or other natural lakes for brine disposal. Preliminary evidence obtained during this investigation suggests that Laguna Plata, Laguna Toston, and Salt Lake are all natural discharge points for the ground-water aquifers. If this can be substantiated by future studies, natural lakes would be superior to man-made disposal ponds for storage of liquid waste.

5. Test drilling and pumping to relieve pressure on the hydrologic system proved to be impractical at Anderson Lake and USGS well No. 8. The greatest problem is disposal and retention of the brine that is produced. If it can be shown that Salt Lake is a natural discharge point for ground water, it would be difficult to justify the expense of a test-pumping relief system.

6. Expansion of wetland areas, particularly in the vicinity of PCA, Clayton Lake, and Laguna Uno, will increase evapotranspiration output from the natural hydrologic cycle and decrease potential outflow to the Pecos River.

RECOMMENDATIONS FOR FUTURE STUDY

1. Complete a program of testing existing wells to determine hydrologic parameters of aquifers in the area. Such a program would include aquifer tests on industrial wells owned by MCC and AMAX.

2. Drill and test wells at sites in Nash Draw and Clayton Basin where hydrologic data are needed, such as between Salt Lake and the Pecos River. All wells should be completed as observation wells for continued monitoring and sampling.

3. Complete a water-quality sampling program to obtain additional data on the composition of brines in the area. After background levels have been established, contaminants will be more readily apparent. Analyses should be obtained for all major anions and cations and pertinent minor elements, including chromium and boron.

4. Maintain an observation-well network and periodic water-quality sampling. This will provide background data for future reference.

5. Acquire data necessary to refine the brine-pond budgets presented in this report. At a minimum, data similar to that obtained from AMAX should be obtained from every potash refinery in the area.

6. Determine the relationship between near-surface water quality and vegetative patterns. This would include a study of the feasibility of water-quality mapping from air photos.

7. Investigate the possibility of using tree ring data to determine the flooding history of Clayton Lake, Laguna Quatro, and other natural lakes.

8. Measure the evapotranspiration of several representative stands of saltcedar and mesquite to determine the appropriate water-budget factors and the effects of increasing salinity on evapotranspiration.

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APPENDIX A

Monthly and Annual Precipitation Summary, 1955 - 1977, for Crossroads (2 NE)
(in inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1955	.67	.00	.05	.64	1.67	.06	4.75	E.63	E3.06	E5.14	.00	.00	16.67
1956	.10	1.02	.00	T	1.45	.70	1.42	.88	.27	1.73	.00	T	7.57
1957	.08	.52	.85	1.01	2.23	2.10	.91	3.61	.84	2.55	E .60	.00	E 15.30
1958	.86	.45	2.15	1.55	1.36	2.53	1.63	.45	6.92	2.02	.92	T	20.84
1959	.00	.00	T	.74	4.01	3.06	3.39	1.54	.32	3.02	.00	.97	17.05
1960	.70	.45	.35	.45	.78	3.03	6.01	1.54	.42	3.56	.00	1.70	18.99
1961	.30	.75	1.42	.25	.87	1.84	5.17	2.47	.30	.16	1.13	.14	14.80
1962	.15	.35	.00	.15	.57	3.60	2.58	.73	2.45	1.51	.25	.32	12.66
1963	.00	.45	.00	1.32	2.30	2.53	2.46	1.64	.79	.28	.60	.10	12.47
1964	.22	.10	.10	.00	1.40	1.42	.85	1.28	2.57	.00	.47	.20	8.61
1965	.05	.63	.11	.71	1.30	4.05	.74	2.01	.56	.18	.20	.44	10.98
1966	.10	.20	.12	2.02	.45	4.31	.12	7.68	2.15	.00	.08	.00	17.23
1967	.00	.04	.28	.23	.24	4.89	4.04	.62	1.04	T	.20	.25	11.83
1968	1.50	.61	1.88	.21	1.93	.29	4.89	3.72	.74	.39	.32	.18	16.66
1969	.00	.73	E 1.53	.68	3.40	3.36	1.50	2.20	2.99	4.80	.00	.35	E 21.54
1970	.00	.20	1.04	1.75	.10	1.85	1.38	1.03	4.05	.85	.00	.00	12.25
1971	.27	E .54	.26	T	.13	1.18	4.56	5.03	2.35	1.08	.64	.78	E 16.82
1972	.00	.00	.20	.00	1.92	3.45	3.13	5.43	3.48	1.98	.25	.35	20.19
1973	.95	.85	1.50	.60	.60	1.16	4.68	1.46	1.05	.77	.00	.00	13.62
1974	.86	.05	.15	.90	.12	.77	.44	8.35	5.08	3.39	.40	.70	21.21
1975	.14	1.53	.05	.45	1.36	2.35	3.75	.22	2.77	.35	.00	.26	13.23
1976	.00	.25	.00	1.02	.68	.81	8.21	.56	2.70	.62	.30	.00	15.15
1977	.10	.30	1.04	2.24	2.52	2.87	.85	2.46	.18				

E=estimated
T=trace

Monthly and Annual Precipitation Summary, 1955 - 1977, for Hobbs

(in inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1955	.43	T	.11	T	3.86	.23	1.91	.27	2.71	2.48	.30	.00	12.30
1956	.02	.80	T	.14	1.93	.59	.15	1.20	.47	3.05	.00	.28	8.63
1957	.04	.77	.36	1.58	4.81	.99	.90	3.68	1.51	3.39	1.17	.00	19.20
1958	1.84	.99	1.70	.55	.87	1.16	.94	2.15	4.87	3.02	.89	T	18.98
1959	T	.05	.01	.74	2.64	2.52	2.68	2.09	.52	2.25	.04	1.10	14.64
1960	.38	.34	.19	.01	.63	1.35	9.06	2.45	.37	3.72	T	1.91	20.41
1961	1.28	.11	1.19	.02	.85	1.03	2.40	.63	1.07	.03	1.03	.12	9.76
1962	.48	.07	.20	.28	.25	3.18	1.94	2.26	3.98	.94	.03	.47	14.08
1963	T	.19	T	.88	4.12	1.86	1.34	2.88	.63	.20	.21	.29	12.60
1964	.11	.12	.54	T	1.40	1.56	.77	.37	1.60	.33	.14	.54	7.48
1965	T	.19	.03	.64	.77	1.76	2.04	2.11	.89	.28	T	.43	9.14
1966	.21	.15	.85	2.20	.89	1.65	.23	6.64	2.40	T	T	.02	15.24
1967	.00	.03	.13	.59	.07	2.10	2.18	.96	.26	.00	.48	.65	7.45
1968	.93	.94	2.11	.54	1.93	.88	5.96	3.88	.11	.61	1.63	.27	19.79
1969	.02	1.09	1.57	.79	3.23	.55	1.98	.66	3.51	6.31	.15	.78	20.64
1970	T	.43	1.53	.60	.48	2.37	1.03	.41	3.21	.54	.00	.01	10.61
1971	.03	.03	.07	1.26	1.01	.05	.42	8.49	4.89	1.35	.18	.93	18.71
1972	.20	.04	.27	.02	1.13	2.66	2.19	4.20	6.32	3.09	.56	.04	20.72
1973	1.28	2.21	.62	.07	1.27	1.75	2.44	.88	.73	1.02	.03	.00	12.30
1974	.02	.05	.31	.99	1.96	1.62	.33	6.85	8.46	5.93	.43	.39	27.34
1975	.45	1.19	.05	.22	3.72	1.46	7.25	1.76	2.41	.14	.00	.28	18.93
1976	.20	.36	.04	1.52	1.35	.39	4.44	.58	1.75	1.57	1.45	.00	13.65
1977	.18	.05	1.10	1.44	2.09	3.41	1.60	.79	.53				

E=estimated
T=trace

Monthly and Annual Precipitation Summary, 1955 - 1977, for Jal

(in inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1955	.47	T	T	.00	2.29	1.01	2.55	.19	.55	.46	.33	.00	7.85
1956	T	.20	.00	.26	2.15	T	.19	.74	.34	.65	T	.10	4.63
1957	.07	1.17	T	.18	.99	.25	.88	.84	.88	2.73	1.05	.10	9.14
1958	1.36	.86	.98	.58	1.04	.92	3.44	4.04	6.06	1.10	.62	.00	21.00
1959	T	.17	.10	.65	2.80	.42	1.57	.73	.86	1.62	.57	.71	10.20
1960	.83	.07	.11	T	.78	.57	5.73	1.56	.04	6.90	T	1.50	18.09
1961	.57	.04	1.08	.00	1.73	1.05	.73	.32	.29	.00	.78	.48	7.07
1962	.31	.03	.11	1.12	.16	1.12	2.69	.33	3.30	1.39	.00	.37	10.93
1963	T	.40	T	.54	2.48	2.52	1.45	2.25	.33	.02	T	.33	10.32
1964	.11	.03	1.02	.00	.74	.42	.11	.50	1.66	.88	.12	.55	6.14
1965	.02	.39	T	.26	.52	2.12	.68	3.13	.57	.05	.34	.40	8.48
1966	.30	.10	.34	1.28	.55	1.79	.05	5.77	.75	.10	T	T	11.03
1967	.00	.07	.53	.03	.05	2.85	.59	.48	2.47	.21	.53	.70	8.51
1968	.74	.85	1.76	.31	1.96	.25	5.40	1.24	.63	.39	2.41	T	15.94
1969	T	1.14	.28	3.15	1.53	1.24	1.37	.19	1.58	6.17	.87	.34	17.86
1970	T	.46	1.66	.12	.38	3.14	.46	2.15	.98	.68	.00	.10	10.13
1971	.02	T	T	T	1.85	.27	1.86	6.06	3.40	1.33	.17	.37	15.33
1972	.12	T	T	.00	1.78	1.85	.11	2.51	.74	1.04	T	.01	8.16
1973	1.10	1.48	.91	.16	.90	.32	4.08	.30	.30	.28	T	.00	9.83
1974	.64	.10	.55	.09	.84	.66	.03	5.35	7.33	4.01	.56	.41	20.57
1975	.24	.96	.03	.17	1.29	2.37	4.69	T	3.29	.20	.14	.30	13.68
1976	.05	.12	.30	2.12	1.36	.53	3.10	.43	2.74	1.13	.70	T	12.58
1977	.16	T	.90	1.18	.96	1.70	1.62	.70	.42				

E=estimated
T=trace

Monthly and Annual Precipitation Summary, 1955 - 1977, for Lovington
(in inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1955	.27	.02	.10	.74	.95	.04	3.36	.54	1.45	5.92	.34	.00	13.73
1956	.01	1.70	.00	.12	1.98	1.14	1.86	1.15	.57	1.82	.00	.38	10.73
1957	.30	.61	.59	.35	3.72	.37	.99	1.54	.61	2.58	1.13	.00	12.79
1958	1.30	.85	2.25	.70	.76	1.19	3.36	1.91	7.12	2.41	.69	.04	22.58
1959	.05	.14	T	.20	2.25	1.36	4.34	.98	.92	1.87	.06	.82	12.99
1960	1.05	.60	.34	.41	.40	5.05	7.28	1.02	.18	4.24	.08	2.48	23.13
1961	.96	1.82	1.51	T	.86	1.11	4.20	2.17	.71	.55	1.55	.45	15.89
1962	.40	.40	.14	1.35	.26	2.35	4.79	.89	4.17	.91	.53	.20	16.39
1963	.01	.48	.75	1.42	2.14	2.08	1.16	3.40	.20	.31	.20	.28	12.43
1964	.10	.36	.05	.00	1.50	1.38	.23	.41	2.66	.21	.71	.70	8.31
1965	.00	.45	T	.30	2.04	2.78	2.82	.76	1.94	.68	.18	1.36	13.31
1966	.38	.03	.30	1.86	.87	1.85	.34	9.34	.42	.02	T	.02	15.43
1967	.00	.16	-	-	-	-	-	-	-	-	-	-	-
1968													
1969													
1970													
1971													
1972													
1973													
1974													
1975													
1976													
1977													

E=estimated
T=trace

Monthly and Annual Precipitation Summary, 1955 - 1977, for Maljamar (4 SE)
(in inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1955	.79	E .10	.02	.66	.72	.84	4.27	.70	1.06	4.55	.12	T	E 13.83
1956	T	.74	T	.10	1.56	.34	2.44	.81	.07	1.01	T	.31	7.38
1957	.07	.35	1.05	.25	2.74	.08	.43	1.77	.31	2.56	.37	.00	9.98
1958	.15	.44	1.65	.25	2.20	1.29	.62	2.33	7.30	2.78	.95	.10	20.06
1959	T	.00	T	.25	3.00	1.85	1.85	.75	.20	1.80	T	.30	10.00
1960	.33	T	.20	.20	.55	1.95	10.26	5.67	.40	4.70	.00	1.40	25.66
1961	1.65	1.00	1.25	.00	.80	1.70	1.10	2.25	.50	.00	1.81	.43	12.49
1962	E .84	.44	.15	.60	.18	.86	6.04	2.13	3.91	1.00	T	T	E 16.15
1963	T	.30	.34	.29	3.35	.15	.10	2.27	T	.36	.15	.09	7.40
1964	.15	.26	.16	T	2.04	1.76	T	.22	1.79	.00	.00	.29	6.67
1965	T	.43	T	.20	1.88	2.07	.59	2.12	1.79	.00	.27	1.22	10.57
1966	.33	.00	.27	2.22	.18	2.83	1.11	6.92	1.87	.00	T	T	15.73
1967	.00	.01	.21	T	.29	2.67	1.45	.69	1.19	T	1.13	E .45	E 8.09
1968	E .15	1.13	1.54	.30	1.22	.16	4.23	2.10	.00	.85	.84	.17	E 12.69
1969	.00	.69	1.33	.82	E 2.15	.56	.95	1.90	2.42	5.99	.22	.60	E 17.63
1970	T	.33	.85	.47	3.60	1.82	1.45	E .97	3.03	E .55	.02	.02	E 13.11
1971	E .04	.20	E .08	.31	T	.18	2.92	6.70	3.37	.35	3.90	1.65	E 19.70
1972	E .35	.00	E .14	T	.45	4.46	2.52	10.88	5.65	1.87	.96	.40	E 27.68
1973	.72	1.66	E .80	T	1.60	.35	5.47	.35	.74	.51	T	T	E 12.20
1974	.22	.18	.58	.76	.48	.16	1.47	8.89	6.33	4.78	.21	1.07	25.13
1975	.41	1.60	.30	.13	1.43	1.25	6.74	.85	1.52	.26	.88	.43	15.80
1976	.42	.31	.13	.76	1.98	.63	3.74	.72	4.29	1.15	.51	T	14.64
1977	E .13	.47	1.34	1.05	1.89	1.27	.70	.80	.09				

Monthly and Annual Precipitation Summary, 1955 - 1977, for Ochoa
(in inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1955	.70	.00	.00	.21	.31	.65	1.80	.67	.41	.76	.30	.00	5.81
1956	.00	.40	.00	T	.97	.00	.00	.42	.17	.50	.00	T	2.46
1957	T	1.29	.00	T	2.05	1.07	.61	.74	.92	1.75	.41	T	8.84
1958	1.50	1.00	.94	.20	.45	1.86	.64	2.81	3.59	1.95	1.22	.00	16.16
1959	.00	T	.15	.85	2.41	.90	1.18	1.71	.00	.70	.03	.51	8.44
1960	.41	.06	.02	.00	.70	T	5.41	3.11	.00	4.00	.10	1.16	14.97
1961	.60	T	.75	.00	.62	.80	1.59	.20	.86	.00	.90	.25	6.57
1962	.13	.12	.12	.45	.37	2.71	3.11	3.05	E 2.51	.68	.00	E .32	E 13.57
1963	.02	.31	.00	1.08	1.55	.64	.00	2.04	.56	.00	.06	.11	6.37
1964	.00	.00	.76	.00	.10	1.38	.30	1.36	.64	.30	T	.39	5.23
1965	.00	.17	.00	.88	.77	1.95	.00	2.33	1.12	.00	.25	.30	7.77
1966	.59	.00	.40	.97	.89	2.36	.90	4.34	.44	.29	.00	.00	11.18
1967	.00	.10	.30	E .63	1.07	1.29	.68	.14	1.49	.00	.60	.39	E 6.69
1968	.70	1.01	1.81	.95	2.89	.30	3.15	2.60	1.06	.40	2.19	.00	17.06
1969	T	.73	.60	2.09	1.88	1.66	1.21	.00	2.63	7.88	.51	.43	19.62
1970	.00	.79	3.55	.18	1.20	.40	2.38	.28	3.70	.78	.00	.00	13.26
1971	T	T	.00	.22	2.04	.56	1.04	2.86	4.25	E .30	.00	.40	E 11.67
1972	.00	.00	.17	.00	.20	2.13	.28	3.71	1.29	.68	.40	.00	8.86
1973	1.66	E 1.29	.99	.00	.96	.49	3.32	.00	.60	.12	.00	.00	E 9.43
1974	.45	.13	.13	.32	.35	.12	.46	6.07	7.42	2.87	E .36	.46	E 19.14
1975	.50	E 1.35	E .11	.12	2.26	1.10	3.43	.39	2.19	.00	.00	.20	E 11.65
1976	.05	.00	.13	1.98	.82	.84	1.95	.22	1.32	1.32	T	.00	8.63
1977													

E=estimated
T=trace

Monthly and Annual Precipitation Summary, 1955 - 1977, for Pearl
(in inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1955	.11	.02	.09	.47	1.85	1.34	.53	1.90	3.02	2.12	.42	.00	11.87
1956	T	E 1.17	.00	.15	1.06	E.84	.67	.43	.17	1.07	.00	.23	E 5.79
1957	.14	.77	.37	1.32	2.99	.58	E1.30	3.13	1.45	2.26	1.05	T	E 15.36
1958	1.15	.86	1.44	.54	.92	.72	1.48	4.07	4.38	2.76	.53	T	18.85
1959	.03	.05	.04	.18	3.47	1.06	1.66	.75	.17	1.41	.05	.73	9.60
1960	.33	.30	.28	.28	.79	1.11	8.70	2.12	.13	2.59	.02	1.69	18.34
1961	1.37	.40	1.18	.09	1.22	.88	3.15	.54	1.37	.05	1.49	.08	11.82
1962	.33	.15	.08	.30	.20	5.79	2.90	3.15	2.43	.93	T	E.26	E 16.52
1963	T	.17	T	.90	1.90	1.63	2.48	2.73	.40	.00	.03	.28	10.52
1964	T	.16	.20	T	1.07	1.24	.17	1.21	.81	.22	T	.30	5.38
1965	.00	.12	T	.18	1.05	2.89	.97	2.76	.95	.39	.11	.54	9.96
1966	.23	.07	.73	1.25	.43	2.04	1.30	7.13	1.99	.00	T	T	15.17
1967	.00	.06	.82	1.83	.08	3.47	1.99	1.06	4.39	.02	.44	.68	14.84
1968	.66	1.09	1.54	.64	3.24	.64	4.89	1.28	.07	.39	1.94	.21	16.59
1969	.00	.99	.85	.66	3.00	1.75	.89	.87	2.19	8.45	.25	.53	20.43
1970	T	.31	1.20	.02	.50	2.00	2.81	.49	1.93	.51	.00	.00	9.77
1971	.04	T	T	.60	1.20	.53	1.47	7.13	3.64	1.08	T	1.11	16.80
1972	.09	T	.28	.00	1.65	6.37	.64	2.14	4.47	1.87	.41	T	17.92
1973	.73	1.82	.68	T	1.06	.69	E3.26	.57	2.39	.42	.00	.00	11.62
1974	.10	T	.49	.54	.85	1.77	.40	5.89	7.35	3.67	.33	.71	22.10
1975	.57	1.44	.11	.24	5.23	1.40	12.31	1.15	1.30	.35	.28	.30	24.68
1976	.27	.20	.03	.82	1.43	.70	2.08	.65	3.53	1.21	.95	.00	11.87
1977		.24	.85	1.03	1.89	1.62	.13	1.09	.05				

E=estimated
T=trace

Monthly and Annual Precipitation Summary, 1955 - 1977, for Tatum
(in inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1955	1.14	T	.15	.06	3.13	.10	1.52	.88	1.83	7.26	.30	.00	16.37
1956	.04	1.93	.00	.11	1.87	1.38	1.37	1.18	.50	1.80	.00	.11	10.29
1957	.12	.97	.85	1.01	4.09	1.68	1.17	3.33	1.49	2.30	1.03	.00	18.04
1958	1.00	.54	2.42	1.60	1.18	2.91	3.03	1.28	7.17	1.95	.75	.11	23.94
1959	.02	.08	.08	.25	2.52	.83	1.95	2.36	.74	1.56	.28	.67	11.34
1960	.51	.19	.32	.26	.43	4.71	7.25	1.93	1.54	3.88	.00	1.83	22.85
1961	.80	1.41	1.18	.17	1.98	2.51	E4.61	2.79	.40	T	1.20	.25	17.30
1962	.18	.51	.12	.17	T	2.83	5.03	1.69	3.63	1.96	T	.35	16.47
1963	.01	.68	T	1.88	4.63	3.41	2.47	2.29	1.16	.11	.56	.18	17.38
1964	.08	.23	.15	.00	1.26	1.22	.12	.82	2.73	.00	.45	.10	7.16
1965	.04	.45	T	.27	1.88	3.89	E1.59	.80	2.20	T	T	E .82	E 11.94
1966													–
1967	.00	T	.75	.15	.10	3.95	2.63	.65	.77	.00	T	E .01	E 9.01
1968	1.71	.92	1.80	.82	2.30	4.19	6.84	2.77	T	.50	1.11	.18	23.14
1969	.00	.77	1.94	1.61	5.91	1.59	1.21	.40	2.88	5.84	.36	1.15	23.66
1970	.00	.15	1.15	1.20	1.29	2.10	2.00	.72	2.27	1.10	.00	.00	11.98
1971	T	.50	.25	.74	.42	.11	1.46	4.87	4.06	1.69	1.41	.63	16.14
1972	T	.00	.40	.00	.75	2.61	3.63	6.84	3.64	1.25	.55	.25	19.92
1973	E 1.32	1.90	2.03	.16	.90	1.13	3.66	2.90	.92	.40	T	.00	E 15.32
1974	.48	T	.37	.62	.10	1.75	.35	9.62	7.10	3.25	.25	E .72	E 24.61
1975	E .14	1.07	.15	.57	1.75	2.36	3.98	.31	2.19	.38	.49	.57	E 13.96
1976	.00	T	.11	.33	.93	1.94	3.52	1.14	.57	.92	.64	.00	10.10
1977	T	.36	1.17	1.94	1.28	2.16	1.15	3.87	1.22				

E=estimated
T=trace

Monthly and Annual Precipitation Summary, 1955 - 1977, for Bitter Lakes WL Ref
(in inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1955	.25	.00	.02	.33	1.39	.34	4.56	1.56	4.81	2.02	T	.00	15.28
1956	.02	1.30	T	T	.15	T	.53	.57	00	.54	.00	T	3.11
1957	.09	.35	.97	.02	.30	.38	.51	1.43	T	3.02	.61	.00	7.68
1958	1.43	.79	2.27	.91	.37	.03	.51	1.83	3.36	1.29	.39	.02	13.20
1959	T	T	T	.67	1.75	1.95	4.79	2.18	.24	.24	T	.73	12.55
1960	.97	.15	.02	.00	.93	1.23	5.42	.64	.57	4.28	.00	1.37	15.58
1961	.43	.05	.76	.11	.17	.64	.79	1.40	1.25	.55	2.02	.28	8.45
1962	.52	.44	.12	.12	.18	1.10	4.13	.76	3.49	.82	.35	.41	12.44
1963	.17	.57	T	.10	1.82	1.11	.03	2.13	1.65	T	.49	.02	8.09
1964	.54	.87	.03	T	.63	.67	.22	.15	2.40	.00	.28	.09	5.88
1965	.13	.34	.08	.95	.47	.85	2.82	1.64	1.08	.00	.31	.38	9.05
1966	.32	T	.45	2.41	1.25	.76	.46	3.61	.82	.00	.00	.00	10.08
1967	.00	.08	.08	.00	.29	5.88	1.23	3.16	1.15	T	.15	1.48	13.50
1968	2.15	1.18	1.63	.01	.61	.43	5.15	1.95	.00	.30	.61	.23	14.25
1969	T	.34	.61	.61	.32	.35	1.70	.40	3.52	3.54	.03	2.11	13.53
1970	.00	.16	.29	T	.49	2.64	1.69	.52	.78	.52	.05	.23	7.37
1971	.02	.21	.01	.29	.18	.07	3.29	4.63	1.95	.94	.74	.36	12.69
1972	.15	T	.00	.00	.88	1.37	1.20	6.27	3.63	1.18	.55	.73	15.96
1973	1.46	1.49	1.35	.29	.66	.73	2.52	.03	.95	.39	.07	T	9.94
1974	.21	E .10	.45	.17	.48	.19	.20	5.66	5.68	4.19	.15	.69	E 18.17
1975	.14	1.54	.32	.65	.24	1.84	3.54	.23	1.60	.12	.03	.10	10.35
1976	.08	.39	.17	.69	1.14	1.06	4.12	.39	2.18	.83	1.08	.00	12.13
1977	.13	.43	.62	.95	.69	.04	.60	7.19	.95				

E=estimated
T=trace

Monthly and Annual Precipitation Summary, 1955 - 1977, for Hagerman
(in inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1955	.20	T	E .04	.17	.59	.64	3.63	1.07	1.52	2.11	.24	.00	E10.21
1956	.06	.76	.00	.08	.23	1.36	1.34	1.34	.29	.65	.00	.03	6.14
1957	.37	.34	.53	.05	1.58	.07	1.11	1.63	1.19	3.51	.98	T	11.36
1958	.86	.97	1.69	1.33	.16	2.28	.60	1.05	6.98	1.64	.18	T	17.74
1959	.00	.05	T	.31	3.59	.57	2.66	.54	T	.60	.15	.32	8.79
1960	1.18	E .29	.10	-	-	-	-	-	-	-	-	-	-
1961													
1962													
1963													
1964													
1965													
1966													
1967													
1968													
1969													
1970													
1971													
1972													
1973													
1974													
1975													
1976													
1977													

E=estimated
T=trace

Monthly and Annual Precipitation Summary, 1955 - 1977, for Roswell (WSD)
(in inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1955	.29	T	.10	.19	.41	.15	2.25	.61	2.95	1.71	.05	T	8.71
1956	.02	1.42	.03	.03	.40	.04	.54	1.13	.16	.54	T	.04	4.35
1957	.09	.64	.80	.31	.43	.06	.87	1.23	1.18	2.91	.80	.00	9.32
1958	1.57	.84	1.93	.84	.77	.20	.66	1.27	3.56	.98	.19	.25	13.06
1959	.02	.10	.03	.59	1.44	.82	2.98	1.87	.16	.52	.24	.75	9.52
1960	1.26	.43	.04	T	1.03	1.24	3.31	.16	.45	3.53	T	2.12	13.57
1961	.68	.04	.81	.02	.44	.62	1.08	1.37	.44	.44	1.62	.29	7.85
1962	.38	.51	.12	.09	.21	.97	3.44	1.31	3.51	.50	.62	.15	11.81
1963	.44	.77	.00	.16	.88	.60	.21	2.26	.62	.15	.05	.16	6.30
1964	.80	1.25	.15	.02	.30	1.10	.17	.57	2.05	T	.33	.24	6.98
1965	.12	.84	.21	.38	.35	1.09	1.50	.83	.76	.05	.08	.47	6.68
1966	.53	.03	.25	1.97	.54	2.35	.15	2.89	.97	T	T	T	9.68
1967	.00	.20	.07	T	.11	3.55	.97	4.00	.85	.02	.22	1.07	11.06
1968	1.50	1.17	1.93	.06	.57	.60	5.50	2.67	.10	.41	1.11	.22	15.84
1969	.01	.47	1.14	.44	.10	.35	1.32	.71	2.67	4.34	T	1.78	13.33
1970	.01	.28	.51	.02	.48	2.72	2.07	.52	.97	.78	.09	.18	8.63
1971	.18	.23	.11	.26	T	.18	1.88	3.62	1.57	.76	.45	.80	10.04
1972	.20	.00	.03	.00	.16	2.06	5.43	3.35	3.25	1.27	.49	.26	16.50
1973	.73	.92	1.48	.15	.73	.97	2.26	1.27	2.55	.51	.01	.02	11.60
1974	.24	.01	.11	.50	T	.03	.31	6.48	6.47	3.81	.09	.60	18.65
1975	.20	1.06	.27	.29	.13	.57	2.75	1.28	2.83	.16	T	.05	9.59
1976	.12	.22	.24	.79	.82	1.55	2.44	1.98	2.29	.69	.41	.00	11.55
1977	.07	.36	.27	1.25	2.43	.25	.46	4.45	.29				

E=estimated
T=trace

Monthly and Annual Precipitation Summary, 1955 - 1977, for Artesia (6S)
(in inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1955	.44	.00	.00	.15	.63	.34	3.95	.45	1.34	1.85	.24	.00	9.39
1956	.05	.45	T	.04	.91	2.08	.81	1.68	.12	.87	.00	T	7.01
1957	.15	.28	.26	.06	.88	.07	.60	.47	.07	2.48	.64	.00	5.96
1958	1.44	1.14	2.67	1.19	.14	2.97	1.34	2.06	4.76	1.79	.70	.01	20.21
1959	T	.13	.01	.19	2.48	.31	2.15	.29	.00	.23	.04	.28	6.11
1960	.82	.18	.14	.29	.16	1.18	3.74	.74	.20	3.26	.11	E1.69	E12.51
1961	.71	.16	.45	T	.48	.99	.99	1.10	.27	.14	1.41	.30	7.00
1962	.45	.41	.11	.67	.66	.92	3.31	.21	2.31	1.39	.25	.62	11.31
1963	.08	.68	T	.11	.92	1.39	.18	2.11	.10	.17	.16	.05	5.95
1964	T	.23	.32	.02	.81	1.71	.10	.80	.71	.00	.17	.28	5.15
1965	.02	.36	.06	.05	.82	.84	1.64	2.05	.67	.11	.05	E1.03	E 7.70
1966	.50	.03	.58	1.23	.39	1.07	.40	6.67	.59	T	T	T	11.46
1967	E .00	E .15	E .09	.00	.16	.46	.67	2.06	.68	.00	.65	.49	E 5.41
1968	1.73	.81	.81	.27	1.11	.01	3.94	2.37	.03	1.05	1.41	.26	13.80
1969	.02	.30	.44	.69	.54	.11	1.86	1.47	1.55	4.03	.09	1.10	12.20
1970	T	.44	.71	.06	2.93	.86	.34	1.71	2.36	.54	.05	.00	10.00
1971	.02	.02	.03	.32	.10	.75	1.06	5.26	2.04	.55	.90	.48	11.53
1972	.01	.06	T	.00	.70	1.42	1.79	2.09	3.67	1.36	.61	.35	12.06
1973	1.09	2.22	1.13	.05	1.12	1.38	1.49	.67	1.33	.79	.02	.00	11.29
1974	.17	.10	.18	.05	.36	.20	.46	1.95	7.11	7.02	.20	.71	18.51
1975	.13	1.24	.30	.04	.90	.32	2.22	.69	1.71	.06	T	.23	7.84
1976	.16	.05	.17	.06	1.22	.98	1.99	.71	2.85	.94	.94	T	10.07
1977	.31	.11	1.08	1.68	1.39	2.43	.34	3.95	.81				

E=estimated

T=trace

Monthly and Annual Precipitation Summary, 1955 - 1977, for Carlsbad
(in inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1955	.39	T	.04	.11	.71	1.28	1.59	.34	1.13	1.80	.47	.00	7.86
1956	.00	.70	.00	.00	.55	.11	.95	1.65	.00	.28	.00	.16	4.40
1957	.14	.22	.77	.05	1.82	.55	.26	1.44	1.02	3.86	.59	.00	10.72
1958	1.37	1.10	2.05	1.12	.18	.84	1.21	3.19	6.20	3.08	.62	T	20.96
1959	.04	.16	.28	.09	5.55	.92	1.65	2.05	.10	.77	.02	.19	11.82
1960	.36	.17	.21	T	.39	1.48	4.76	2.93	.41	3.76	T	2.09	16.56
1961	1.06	.37	.80	T	.40	1.19	.79	.27	.28	.41	1.89	.12	7.58
1962	.51	.16	.13	.66	.94	2.37	4.36	.04	2.58	.99	.01	.31	13.06
1963	.15	.38	.04	1.93	1.50	.29	.45	4.76	.35	.08	T	.23	10.16
1964	.02	.12	.26	.00	.31	.52	.31	.71	1.89	.10	.13	.10	4.47
1965	.00	.64	.03	.58	3.08	.95	.62	1.69	1.59	.02	.36	.91	10.47
1966	.51	T	.45	1.50	.67	.54	.70	7.62	1.73	.11	.00	T	13.83
1967	.00	.03	.22	.05	.34	3.17	.97	.75	.80	.00	.27	.37	6.97
1968	E 1.73	.93	1.26	.13	1.97	.59	4.89	1.86	.00	.41	1.53	.00	E 15.30
1969	.09	.32	.57	.91	.23	1.22	1.57	1.79	1.32	3.40	.37	.61	12.40
1970	T	.72	.95	.00	.97	1.19	.63	.23	2.65	.75	.00	T	8.09
1971	.13	.08	.03	.37	.01	.02	2.50	3.97	2.26	.24	.54	1.00	11.15
1972	.04	.08	.00	.00	1.69	4.93	2.08	2.02	5.32	1.86	.68	.04	18.74
1973	.86	1.83	E .84	.00	.64	.83	2.88	.03	2.72	.84	T	.00	11.47
1974	.52	.10	.11	.09	.29	.61	.15	4.43	10.05	5.78	.18	.80	23.11
1975	.15	1.80	E .18	.07	.01	.19	5.37	.29	1.50	.08	T	.58	E 10.22
1976	.27	.10	.09	.17	2.74	.02	1.82	.93	2.94	1.12	1.06	.00	11.26
1977	.30	.13	1.17	2.33	.96	2.02	.65	2.21	.71				

E=estimated
T=trace

Monthly and Annual Precipitation Summary, 1955 - 1977, for Carlsbad FAA Airport
(in inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1955	.47	T	.08	.73	.23	.40	3.16	1.17	1.93	1.81	.43	.03	10.44
1956	.27	1.32	T	.04	1.07	1.32	.66	.86	.00	.17	.00	.05	5.76
1957	.06	.40	.55	.08	.85	.30	.60	1.48	.02	2.97	.69	T	8.00
1958	1.63	1.02	1.01	.95	.21	.61	1.29	3.04	5.45	2.72	.56	.02	18.51
1959	.02	.17	.31	.10	3.45	.26	1.35	1.26	.29	.65	.03	.36	8.25
1960	.35	.38	.18	T	.19	1.00	5.06	2.66	.28	3.16	T	1.58	14.84
1961	.87	.12	.38	T	.52	1.10	.40	.06	.29	1.68	.95	.11	6.48
1962	.69	.02	.13	.63	.88	1.02	4.13	.06	2.01	.99	.38	.11	11.05
1963	.10	.21	.87	.43	1.14	.38	.66	2.52	.24	.03	T	.24	6.82
1964	T	.03	.23	.00	.66	.35	.13	1.24	3.15	.09	.01	T	5.89
1965	T	.22	.04	.02	1.76	1.06	.75	1.45	2.34	T	.64	.49	8.77
1966	.35	T	.07	1.83	.78	.71	T	8.02	1.08	.23	.00	T	13.07
1967	T	.01	.17	.09	.13	1.91	1.78	.16	1.19	.01	.11	.27	5.83
1968	1.50	.80	1.20	.33	1.35	.05	4.71	1.75	T	.18	1.57	.02	13.46
1969	.10	.36	.33	.40	.17	.56	.66	1.23	2.36	3.99	.49	.49	11.14
1970	.01	.84	1.06	.00	.23	1.84	T	.81	2.77	.78	T	.03	8.37
1971	.05	.02	.01	.24	.13	.00	3.70	5.34	1.90	.24	.34	.91	12.88
1972	.14	.00	.00	.00	1.54	2.04	2.19	3.98	3.32	1.36	.56	.07	15.20
1973	.97	1.77	.27	T	1.31	.57	3.01	.52	1.66	.58	.01	.00	10.67
1974	.54	.08	.20	.46	.15	.27	.79	4.96	9.23	3.43	.18	.76	21.05
1975	.31	1.00	.17	.04	.13	.22	3.46	.87	1.56	.04	T	.18	7.98
1976	.18	.01	.05	.66	.71	.04	2.31	.73	4.74	.76	.91	.00	11.10
1977	.42	.08	1.04	2.18	1.47	.54	.87	1.58	.99				

E=estimated
T=trace

Monthly and Annual Precipitation Summary, 1955 - 1977, for Duval Nash Draw Mine
(in inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1955	.35	T	.05	.05	1.63	1.72	3.29	.29	3.78	.95	.35	.00	12.46
1956	.12	.32	.00	.07	1.89	.92	1.45	.14	.36	2.32	.00	.29	7.88
1957	.08	.41	.85	1.66	2.64	.10	1.46	2.80	1.21	2.85	.52	T	14.58
1958	.94	.85	1.32	1.01	1.51	.55	1.90	2.84	6.84	2.87	.76	.00	21.39
1959	.08	.19	.33	.12	6.24	1.06	1.28	.56	1.10	1.30	.05	.25	12.56
1960	.83	.27	.43	T	.57	1.92	12.65	4.67	.15	5.83	.01	1.52	28.85
1961	.87	.47	.35	.01	.71	2.18	1.20	1.20	.84	.65	1.74	.21	10.43
1962	.65	.00	.13	.62	.61	.69	3.62	.05	1.81	.82	.06	.27	9.33
1963	E .01	.20	.82	1.35	.91	2.21	.20	3.44	1.55	.23	.04	.43	E11.39
1964	.06	.12	.39	.00	1.14	2.83	.36	.93	1.52	.07	.16	.19	7.77
1965	.01	.41	T	.67	2.21	2.27	2.37	2.08	2.02	.03	.14	.76	12.97
1966	.45	.18	.21	1.51	.46	1.93	1.45	5.36	1.81	.02	.00	.04	13.42
1967	.00	.10	.37	.02	.31	4.82	1.16	.36	.62	.00	.32	.45	8.53
1968	-	-	1.35	.26	1.50	.24	3.56	3.79	.01	.08	2.18	.08	-
1969	.01	.44	1.10	.72	.82	2.00	.74	2.32	2.27	7.30	.33	.58	18.63
1970	.00	.67	.73	.09	.47	1.56	2.08	1.62	2.66	1.11	T	T	10.99
1971	T	T	.00	.40	.12	1.37	4.25	5.10	2.16	.32	.81	1.19	15.72
1972	.21	.08	.00	.00	.35	1.45	4.12	1.42	7.05	2.05	.49	.09	17.31
1973	E .80	1.31	1.25	.11	.81	.56	3.42	.82	2.21	.57	.05	.00	E11.91
1974	1.22	T	.27	.16	1.24	.06	.20	4.24	6.75	3.99	.55	.81	19.49
1975	.40	1.64	.19	.09	1.43	.31	6.01	1.78	1.45	.15	E .08	.39	E13.92
1976	E .01	.33	.15	1.27	2.36	.10	1.82	.71	3.97	2.82	1.15	.00	E14.69
1977	.12	.17	1.08	1.32	1.40	2.25	.55	.26	.17				

E=estimated

T=trace

Monthly and Annual Precipitation Summary, 1955 - 1977, for Lake Avalon
(in inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1955	.39	.00	T	.06	.99	.77	3.09	.11	2.39	3.03	.22	T	11.05
1956	.02	.27	.00	.07	.67	1.32	.91	2.26	.04	.53	T	.20	6.29
1957	.04	.35	.75	.01	3.30	.02	.86	1.27	.05	4.06	.94	.00	11.65
1958	1.35	.82	.95	1.05	.40	.58	1.11	4.03	5.97	2.98	.83	T	20.07
1959	.04	.08	.15	.17	4.47	.65	2.66	1.25	.19	.79	T	.29	10.74
1960	.25	T	.13	T	.55	1.63	3.28	1.69	.19	4.52	.00	1.84	14.08
1961	.99	.29	.71	T	.24	1.16	.05	.08	.46	.05	1.90	.12	6.05
1962	.74	.12	.13	.79	.88	1.54	3.58	T	2.35	.72	T	.26	11.11
1963	.09	.24	.00	1.49	1.09	.18	.20	3.44	.22	.27	T	.18	7.40
1964	.03	.09	.24	.00	.29	.27	.84	.58	2.14	T	.10	.35	4.93
1965	.00	.63	.10	.30	2.04	.39	.46	1.15	1.38	T	.10	.81	7.36
1966	.34	T	.76	1.37	.16	.33	.47	6.65	1.26	T	.00	.00	11.34
1967	.00	.00	.17	T	.56	2.00	1.00	1.06	1.82	.00	E .49	.28	E 7.38
1968	1.37	.98	1.24	.06	1.96	.10	6.43	2.51	.08	.32	1.89	.15	17.09
1969	.09	.46	1.42	.89	.37	.84	1.70	1.97	E .66	5.05	.14	E .90	E 14.49
1970	.00	.71	.92	.00	.16	1.16	1.02	.44	3.02	1.03	.00	.00	8.46
1971	E .37	T	T	.44	T	.20	1.92	4.38	2.12	.49	.71	.59	E 11.22
1972	E .10	.06	.00	.00	.88	3.46	1.34	1.52	4.85	4.64	1.23	.04	18.12
1973	.94	1.59	1.00	.27	.70	1.15	3.67	T	4.55	1.30	E .03	.00	15.20
1974	.38	.13	.29	.41	.00	.50	.70	3.81	8.31	5.45	.19	.80	20.97
1975	.33	2.13	.19	.15	.64	.00	3.56	.29	3.19	.60	.00	.52	11.60
1976	.90	.00	.20	.10	2.02	.00	1.77	.67	4.65	1.09	.50	.00	11.90
1977	E .16	.14		1.51	.72	1.70	.07	2.34	.44				

E=estimated

T=trace