63-102

nm-52

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON 25, D.C.

Albuquerque, New Mexico

An appraisal of the possibilities of artificial recharge

to ground-water supplies in part of the

Roswell basin, New Mexico

By

Ward S. Motts and R. L. Cushman

An approach to the alleviation of saline ground-water

encroachment in the Roswell basin

Prepared in cooperation with the

PECOS VALLEY ARTESIAN CONSERVANCY DISTRICT

and the

NEW MEXICO STATE ENGINEER

December 1962

Open-file

An appraisal of the possibilities of artificial recharge

to ground-water supplies in part of the

Roswell basin, New Mexico

By

Ward S. Motts and R. L. Cushman

An approach to the alleviation of saline ground-water

encroachment in the Roswell basin

Contents

Contents - Continued

Contents - Continued

Contents - Continued

Contents - Continued

Illustrations--short list

(All illustrations in pocket)

Tables   Manuscript

Page

Illustrations - long list

(All illustrations in pocket)

Illustrations--long list - Continued
(All illustrations in pocket)

Reference
page

Illustrations--long list - Continued

(All illustrations in pocket)

An appraisal of the possibilities of artificial recharge

to ground-water supplies in

the Roswell basin, New Mexico

by

Ward S. Motts and R. L. Cushman

Abstract

The persistent downward trends of water levels in wells tapping
the two major aquifers (a main aquifer, consisting of consolidated
rocks, and an *alluvial* aquifer) of the Roswell basin of southeastern New Mexico
indicate that the discharge of water from these aquifers has exceeded
the replenishment since 1942. Although the supply of water in storage
is not nearly exhausted, the decline in pressure in the artesian
part of the limestone aquifer has disturbed the equilibrium of a fresh
water-saline water interface in the main aquifer, and saline water is
gradually encroaching westward to the heavily pumped Roswell-Artesia
sector of the basin.

The decline in water levels and the saline-water encroachment can be halted or retarded by reducing ~~the rate of~~ discharge, by increasing ~~the rate of~~ recharge, or by a combination of these two methods. The amount of recharge to the main and alluvial aquifers probably could be increased substantially by inducing additional infiltration of surface water through sinkholes and permeable sections of stream channels.

The recharge potential *was studied in* ~~of~~ an area that extends from the vicinity of Vaughn, N. Mex., southward to the Seven Rivers Hills and the Guadalupe Mountains, and westward from the Pecos River to the crest of the Jicarilla, Sierra Blanca, and Sacramento Mountains. ~~was studied.~~

2

The Yeso Formation, San Andres Limestone (including its Hondo Sandstone Member), and the Artesia Group, all of Permian age, crop out extensively or have been tapped by wells in the basin west of the Pecos River.

Unconsolidated, and some consolidated, gravel, sand, and silt of Tertiary and Quaternary age compose the alluvium of the lowland area.

Major structural zones, the Border Hills, Sixmile Hill, Y-O, Fourmile, Vandewart-Cornucopia, and Huapache are characterized in the study area by modified surface drainages and generally higher than average permeability.

Sinkholes and closed depressions, common in the study area, were formed by ground water under pressure moving upward in zones of weakness and dissolving the soluble rock; by surface water infiltrating the surface rocks, dissolving the soluble rocks, and carrying the dissolved materials to the water table; and by a combination of those two methods.

The main aquifer, the principal aquifer of the basin, is within the Permian rocks. Water in most of the main aquifer west of the Pecos River is under water-table conditions. From 10 to 20 miles west of the river the water table in the main aquifer intersects the base of semiconfining beds in the Artesia Formation, and from that point eastward the water in the main aquifer is under artesian pressure.

Artificial-recharge potentials of the ~~limestone~~ main aquifer are more
favorable where the aquifer is highly permeable. Areas of highest
permeability in the recharge area are along the major drainages, along
structural zones, and in the vicinity of carbonate-evaporite facies
boundaries.

The secondary aquifer of the basin is the alluvium along the Pecos
River. Water in the alluvium is under water-table conditions. Recharge
to the alluvium is inhibited in places by a layer of caliche.

The study area was divided into seven recharge areas: the western
limestone area; the eastern limestone area; the northern evaporite area;
the southern evaporite area; the northern limestone ~~western carbonate~~ area; the eastern
evaporite-alluvial area; and the alluvial lowland area.

The artificial-recharge potential of the western limestone area is
poor because much of the water put underground would appear as surface
flow within that area.

The artificial recharge potential of the eastern limestone area
is moderate to good. Dams could be constructed to impound water over
the more permeable areas of stream channels to increase the length of
time that water remains in contact with these areas of the channels. Some
water probably could be diverted to sinkholes from drainages nearby.

In the northern part of the northern limestone ~~western carbonate~~ area the surface

drainage is internal to sinkholes. Inducing additional recharge in

that area would involve increasing the infiltration rate in sinkholes

to reduce evaporation losses. Drainage is well integrated in the

southern half of the northern limestone ~~western carbonate~~ area, and small dams could be

constructed to retard streamflow over the more permeable sections of

streambeds.

The artificial-recharge potential of the eastern evaporite-alluvial

area probably is poor. Water recharged to the ~~limestone~~ main aquifer in the

northern part of the area apparently moves east of the Pecos River and

then southward; therefore, the water does not move directly to the

Roswell-Artesia sector. Ground water moving into the Roswell-Artesia

sector from much of the eastern evaporite-alluvial area probably is

highly mineralized.

The artificial-recharge potential of both the northern evaporite

area and the southern evaporite area is good.

The alluvial lowland is not a natural recharge area for the main aquifer; however, it has some potential for artificial recharge to the main and alluvial aquifers. Recharge water to the main aquifer in most places would have to be injected through recharge wells 400 to 1,000 feet deep. The most favorable places for wells recharging the main aquifer would be the western and southern halves, where the static water level in the recharge well would be several tens of feet below the land surface.

The alluvial lowland probably is more favorable for artificial recharge to the alluvial aquifer than to the main aquifer. Wells injecting water to the alluvial aquifer could be less than 200 feet deep.

Waters in the Roswell basin that probably could be made available for artificial recharge are: floodwaters in Pecos River tributaries that would be lost by evapotranspiration on floodplains; floodwaters in tributaries that debouch onto lands at the terminus of well-defined channels and would be lost by evapotranspiration; water that would be saved by controlling saltcedar growth in the basin; and water that would evaporate from ponds in sinkholes. The right to use these apparently unappropriated waters would have to be established before proceeding with their use in artificial recharge.

Introduction

Location and extent of the report area

The area of investigation for this report (fig. 1) is the major

Figure 1.--Map of part of the Roswell basin showing major

geomorphic surfaces, structural zones, generalized outline

of cultivated area in the Roswell-Artesia sector, and

an insert map of New Mexico outlining physiographic provinces

and the area of investigation (diagonal lines).

part of the recharge area for a large ground-water basin in southeastern

New Mexico. This basin is bounded on the north by a ground-water

divide in the vicinity of the town of Vaughn; on the west by

ground-water divides near the crests of the Jicarilla, Sierra Blanca,

Sacramento, and Guadalupe Mountains; and on the south by poorly

permeable rocks underlying the Seven Rivers Hills and the Guadalupe

Mountains. The eastern boundary of the basin probably is east of

New Mexico. The area described in this report is that part of the

basin west of the Pecos River in New Mexico and in this report is

referred to as the Roswell basin.

Purpose of the investigation

Large-scale development of ground water in the Roswell basin
began in the early 1900's with the discovery of artesian water in
carbonate rocks that form the main aquifer in the Roswell-Artesia
sector of the lowland adjacent to the Pecos River. The water was
used to irrigate fields on the alluvium along the river. Seepage
of irrigation water into the ground raised the water table in the
nonartesian alluvial aquifer and threatened to waterlog large parts
of the alluvium near the river. Drains and shallow wells, construc-
ted to counteract the rising water level in the alluvium, furnished
water to irrigate additional acreage. Persistent downward trends
in artesian and nonartesian water levels since 1942 indicate that
the amount of ground water used and discharged naturally from the
Roswell basin exceeds the average annual recharge to the ground=
water basin.

The depletion of ground water in storage to an uneconomical pumping level is not imminent in the Roswell basin; however, the decline in artesian pressures has disturbed the equilibrium of a fresh-water saline-water interface in the artesian system. In this report, water containing more than 1,000 ppm (parts per million) is saline water. This interface was at or slightly east of the Pecos River prior to the start of heavy pumping of artesian wells in the Roswell-Artesia sector. About 1952 the easternmost artesian wells in the vicinity of Roswell began to yield increasingly saline water. A periodic water-sampling program was started in 1952 to monitor the change in the chemical quality of water from artesian and nonartesian wells. Hood, Mower, and Grogin (1959, p. 33) indicated that if saline water continued to encroach as it did between August 1952 and September 1957, artesian wells along the eastern city limits of Roswell probably would begin pumping water with a chloride content of at least 500 ppm (parts per million) sometime in 1960. By 1960 a few artesian wells east of Roswell were abandoned and plugged because they were yielding saline water. Saline water is encroaching westward in several areas between Roswell and Artesia. The most rapid encroachment is toward the centers of heaviest pumping from artesian wells.

Most of the water recharging the nonartesian aquifer in the
Roswell-Artesia sector is from the artesian system, either as seepage
~~loss~~ from ~~artesian water applied to the~~ irrigated fields or as upward
leakage through the formation that separates the artesian ~~limestone~~ *main*
aquifer and the nonartesian alluvial aquifer. Thus, deterioration
in chemical quality of the artesian water results in deterioration in
chemical quality of the nonartesian water.

The westward encroachment of saline water must be halted, and,
if possible, the saline-fresh-water interface must be pushed back
to the east if the Roswell-Artesia sector is to be assured a perennial
supply of ground water of a quality suitable for irrigation. This
can be done by reducing ~~the rate of~~ discharge, by increasing ~~the rate~~
~~of~~ recharge, or by a combination of these two.

Studies are being made in the Roswell basin to determine ways
of restoring the balance between recharge and discharge. Some
reductions in discharge are being effected by improved irrigation
practices and the retirement from cultivation of lands that do not
have legal ground-water rights. The discharge of water by nonbeneficial
vegetation in the bottom land of the Pecos River and tributaries is
being studied to determine how much the discharge of ground water
can be reduced by eradicating the nonbeneficial bottom-land vegetation.
The investigation described in this report ~~is~~ *was* concerned with methods
of increasing recharge to the basin. ~~under prevailing climatic conditions.~~

16

Scope and methods of investigation

This investigation, made in cooperation with the Pecos Valley
Artesian Conservancy District and the New Mexico State Engineer,
was a study of the physical and geologic features in the Roswell
basin to determine whether or where artificial recharge would be
possible. The study was to define areas in which artificial recharging
might be done and in which intensive studies of some features should
be made before artificial-recharge projects were started. Some
opinions are expressed about the general type of recharge works
that might be suitable in some areas.

Most of the area shown on figure 1 was ~~covered by~~ included in a reconnaissance~~;
type study;~~ however, sinkholes, streams, and geologic formations in
the area bounded by the Pecos River, Cienega del Macho,
long 105°00" W., the Seven Rivers Hills, and the Guadalupe Mountains
were studied more intensively. ~~than similar features elsewhere in the
project area.~~

Literature describing the geology and hydrology of the basin was studied. These studies revealed that sinkholes were numerous in parts of the basin. Holes were augered in a few sinkholes to obtain soil samples for permeability studies and to determine the thickness of sediments in the sinkholes. The length of time that water remained in sinkholes after rains was noted ~~casually~~ by periodic air flights over sinkhole areas, and was measured in detail in a few selected sinkholes by periodic reading of staff gages set in the ponds. Sink-holes in which changes in pond levels were measured in detail were mapped topographically with a plane table to determine the volume and rate at which the ponded water entered the ground.

A geologic map was compiled of a part of the area using *available* ~~existing~~ geologic data. Some geologic mapping was done to delineate the more permeable geologic formations that crop out in the area.

Flood flows in a few tributaries entering the Pecos River from the Sacramento Mountains were measured or estimated to determine natural seepage losses in the middle and upper reaches of those streams. Flow losses were studied with relation to the character and type of rock in which the channel was cut to assist in classifying the relative permeability and recharge potential of certain geologic formations.

Tributaries that occasionally flood, overflow their banks, and lose water by evapotranspiration were studied to locate sites for small dams upstream from the overflow areas. The small dams could be used either for diversion of water into canals leading to suitable sites for artificial recharge or for temporary impoundment of water in a section of the channel overlying a relatively permeable formation.

Water levels were measured in numerous wells outside the cultivated areas in the Roswell-Artesia sector to define better the position and form of the water table and the general pattern of ground-water movement between the recharge area and the discharge areas. Knowledge of the pattern and rate of ground-water movement is important in selecting sites for artificial recharge. A point from which the ground water neither moves to the Roswell-Artesia sector within a reasonable time nor increases the artesian pressure in the cultivated area would not be a suitable site for artificial recharge to benefit the areas of extensive withdrawal.

19

Previous investigations

The following is a brief summary of the reports that were
especially helpful to the recharge study. Fisher (1906) reported on
the hydrologic and geologic features of the artesian aquifer of
the basin and outlined the area in which flowing wells were being
developed. Renick (1926) described briefly the geology of the
Rio Penasco drainage above Hope, N. Mex. Fiedler and Nye (1933)
described in considerable detail the hydrology and geology of that
part of the entire Roswell basin west of the Pecos River. That study led
to the enactment of ground-water laws for the State of New Mexico and
the Roswell basin. Morgan (1938) described the nonartesian-water
resources of the Roswell basin. A discussion of the geology and
ground water of the basin was included as a part of the comprehensive
study of the Pecos River system (Theis and others, 1942). Bean (1949)
made an intensive study of the Hondo Reservoir. Theis (1951) reported
on the effects of storing floodwater in the Hondo Reservoir. Hendrickson
and Jones (1952) discussed the geology and ground-water resources of
Eddy County, which contains the southern part of the Roswell basin.
Hantush (1955) presented quantitative estimates of the amount of
recharge and discharge, ground water in storage, and the perennial yield
for the Roswell basin. Hood and others (1959) pointed out that saline
water in the artesian aquifer east of the Pecos River was encroaching
westward toward areas in which artesian wells are pumped heavily for
irrigation supply.

Acknowledgments

Well-Numbering System

The system of numbering wells in New Mexico is based on the
land-survey system of the Federal Government. The well number, in
addition to designating the well, locates its position to the nearest
10-acre tract in the land net. The first segment of the well number
denotes the township, the second denotes the range, the third denotes
the section, and the fourth denotes the location within the section.
In the project area townships are north and south of the base line
and east of the principal meridian; however, all of the wells discussed
in this report are in townships south of the base line.

The fourth segment of the number, which consists of three digits, with a lowercase letter sometimes added, denotes the particular 10-acre tract in which the well is situated. For this purpose, the section is divided into four quarters, numbered 1, 2, 3, and 4 in the normal reading order for the northwest, northeast, southwest, and southeast quarters, respectively. The first digit of the fourth segment gives the quarter section, which generally is a tract of 160 acres. Similarly, the quarter section is divided into four 40-acre tracts numbered in the same manner, and the second digit denotes the 40-acre tract. Finally, the 40-acre tract is divided into four 10-acre tracts, and the third digit denotes the 10-acre tract. Thus, well 11.25.13.344 in Chaves County is in the $SE\frac{1}{4}SE\frac{1}{4}SW\frac{1}{4}$ sec. 13, T. 11 S., R. 25 E. If the well cannot be located accurately within a 10-acre tract, a zero is used as the third digit, and if it cannot be located accurately within a 40-acre tract, zeros are used for both the second and third digits. If the well cannot be located more closely than the section, the fourth segment of the well is omitted. When it becomes possible to locate more accurately a well is whose number zeros have been used, the proper digit or digits are substituted for the zeros. Lowercase letters a, b, c,... are added to the last segment to designate the second, third, fourth, and succeeding wells investigated in the same 10-acre tract. The following diagram shows the method of numbering the tracts within a section (fig. 2).

Figure 2.--System of numbering wells in New Mexico.

Topography

The project area is characterized by mountains along much of the western margin, a bedrock surface that dips gently eastward from the crest of these mountains, and a relatively flat alluvial plain near the Pecos River. (See fig. 1.) The altitude at the general crest of the Sacramento Mountains is about 9,000 feet; however, individual peaks rise considerably higher. The altitude of the highest peak, Sierra Blanca, is about 12,000 feet. The altitude of the lowest point in the project area is about 3,300 feet, where the Pecos River crosses the southeastern boundary of the Roswell basin.

The broad alluvial plain in the eastern part of the project area is referred to in this report as the lowland area, and the rocky slope that descends from the crest of the mountains on the west to the lowland area is referred to in this report as the upland area. (See fig. 3.)

Figure 3.--Generalized cross section (A-A') from the Sacramento Mountains to the Pecos River.

Lowland area

The lowland area is characterized by three constructional terraces named by Fiedler and Nye (1933, p. 10) the Lakewood ~~terrace~~, the Orchard Park ~~terrace~~, and the Blackdom terrace^s. (See Fiedler and Nye, 1933, pl. 4.)

The Lakewood terrace is a flat plain adjacent to the Pecos River and ~~about~~ is 10 to 25 feet above the bed of the river. Parts of this terrace are inundated when the Pecos River is in high flood stage, and the terrace is commonly referred to as river-bottom land. The water table is at a shallow depth beneath most of the terrace, and much of the terrace is covered by a lush growth of water-loving vegetation.

The Orchard Park terrace extends as a strip along the west side of the Lakewood terrace and for considerable distances westward along the valleys of the major tributaries. The terrace rises 5 to 10 feet above the Lakewood terrace, and it has an eastward slope of ~~about~~ 20 to 30 feet per mile. Almost all the irrigated fields of the Roswell-Artesia sector are on the Orchard Park terrace.

The Blackdom terrace rises 30 to 50 feet above the Orchard
Park terrace, and it has an eastward gradient of 30 to 40 feet
per mile. It is the most dissected of the constructional terraces
because of its greater age. The relief generally is ~~about~~ 20 to 35
feet. Low rolling hills generally capped by relatively resistant
caliche are characteristic of many parts of the terrace. The caliche
cap and the deposits underlying the Blackdom terrace are excellently
exposed in a cliff along the Rio Felix in the
NW$\frac{1}{4}$ sec. 21, T. 14 S., R. 23 E.

27

Upland area

In this report the upland area is divided into five areas or surfaces: Sacramento plain, Diamond A plain, upland surface of the Guadalupe Mountains, Embayment plain, and Vaughn-Macho plain. These are shown on figure 1 and are referred to as geomorphic surfaces, because the subdivision of the upland area was based on the similarity in land forms and their geologic history. Fiedler and Nye (1933, p. 13-14) described three surfaces in the upland area, and from highest to lowest they are: Sacramento plain, Diamond A plain, and gravel-capped mesas. In this report the gravel-capped mesas are included in the Embayment and Vaughn-Macho plains.

Sacramento plain

Remnants of an ancient surface cut mainly on carbonate rocks
of the San Andres Limestone occur near the crest of the Sacramento
Mountains. Fiedler and Nye (1933) referred to this surface as the
Sacramento plain. Near the crest of the mountains the major streams
are entrenched more than 800 feet below the surface of the plain.
In places the plain is indistinct because of its advanced stage
of dissection and because of structural deformation. The eastern
limit of the Sacramento plain was not shown on figure 1 north of
the Rio Ruidoso because it ~~the plain~~ could not be identified.

The altitude of the plain ranges from 8,400 to 8,500 feet from
Ruidoso southward to Cloudcroft. In this area it ~~the plain~~ is relatively
flat. South of Cloudcroft the altitude of the plain ranges from
9,200 to 9,600 feet along the crest of the mountains and slopes
eastward about 70 to 75 feet per mile to an altitude ranging from
8,200 to 8,600 feet along its eastern margin.

29

Diamond A plain

The surface referred to by Fiedler and Nye (1933, p. 14) as
the Diamond A plain does not exist as a true surface throughout the
area shown as the Diamond A plain on figure 1. The surface to which
they referred was a relatively uniform rock surface that has been
eroded away except for a few remnants preserved on the tops of the
higher hills and interstream divides. This report retains the name
Diamond A plain for the area once covered by that rock surface.

The area shown on figure 1 as the Diamond A plain is well
dissected and has a well-integrated drainage system. The interstream
divides generally are sharp; however, a few small divides are flat.
The surface of the plain ranges from an altitude of about 7,500 feet
on the west side to about 4,000 feet on the east side.

In general, the surface of the plain is on the San Andres
Limestone; however, in places the bedrock surface is masked by a thin
mantle of soil, gravel, and boulders. Sinkholes, developed by the
solution of the underlying rocks by surface and ground waters, are
common; although they are not as numerous as in other parts of the
project area.

Upland surface of the Guadalupe Mountains

The upland surface of the Guadalupe Mountains is an erosional surface bounded on the west by a prominent escarpment called "The Rim", which forms the western slope of the Guadalupe Mountains, and on the east by a less prominent break in topography that marks a monocline. (See Huapache structural zone in fig. 2().) The surface between The Rim and the monocline is a tableland characterized by broad swales and rolling divides. The altitude of the tableland ranges from about 6,000 feet at The Rim to less than 5,000 feet at the monocline. Canyons are incised in the tableland, some to depths of more than 600 feet. The surface cuts across several geologic formations. The missing strata for the most part, consisted of rock that was more easily eroded than the present limestone surface.

31

Embayment plain

The Embayment plain, as referred to in this report, consists
of two separate units. (See fig. 1.) The larger unit is in the
southern part of the project area. It is characterized by shallow
swales and gently rounded hills, which trend northeast; the relief
of commonly is less than 50 feet. The altitude of the land surface
in the Embayment plain ranges from 4,500 to 3,200 feet. The hills
are capped by rock, generally dolomite, that is more resistant to
erosion than the underlying gypsum and sandy and silty red beds.
Some sinkholes have developed within the swales. Many of the swales
have no exterior surface drainage.

The smaller unit of the Embayment plain is mainly in
Tps. 15 and 16 S., R. 23 E. In this area the plain is capped by
gravel, which forms a protective cover for the underlying rocks, and
is one of the areas referred to by Nye (Fiedler and Nye, 1933, p. 13)
as "gravel-capped mesas."

Vaughn-Macho plain

The Vaughn-Macho plain is cut on relatively soft and easily erodible rock. The plain is characterized by low rolling hills, swales, large closed depressions, and sinkholes. Sinkholes and depressions are more numerous in this area than in other parts of the Roswell basin. Drainage channels are poorly developed, except in the eastern and southern parts of the plain because the runoff is to sinkholes and closed depressions. The altitude of the plain ranges from 3,500 to 6,500 feet.

Sinkholes and closed depressions

Sinkholes and closed depressions (depressions with no external surface drainage) are common. A few were studied in detail, but many were ~~studied~~ only ~~casually~~ reconnoitered.

Some sinkholes resemble shallow basins and range from a few feet to several hundred feet across the top. The depths of the floors of most sinkholes range from 10 to 50 feet below the general land surface, although some are more than 50 feet deep. The bottoms of most sinkholes are covered with silt, clay, and rock rubble. Some have no visible openings through which water could drain; others have small cave-like openings in the sides and bottoms. Some are almost circular ~~in shape~~, whereas ~~while~~ others are very irregular. The sides of some are almost vertical, and others slope gently from the rim to the bottom.

34

In places several sinkholes formed within a relatively small area and subsequent erosion destroyed the rock barrier between them and formed a single large irregular-shaped depression. Some of these depressions are as much as 1 mile across.

Ephemeral ponds and small lakes appear in some sinkholes and closed depressions in the upland area after rains. The water stands until evaporated in sinkholes whose bottoms are relatively impermeable. In sinkholes having permeable bottoms, the water drains underground before much water is lost by evaporation.

Permanent ponds and lakes occupy some sinkholes in the lowland near the Pecos River. The water surface in some of these coincides with the water table; in others the water surface is above the water table and indicates a probable connection with the artesian system.

The formation of sinkholes is described in this report in the section of structural features resulting from solution. The water—retaining and recharge characteristics of some sinkholes and depressions are described in the hydrology section of this report.

Drainage

The Pecos River is the master stream of the area; it originates
north of the Roswell basin and flows southward through the basin.
The principal tributaries of the Pecos River draining the eastern
and southern parts of the Vaughn-Macho plain are Yeso Arroyo,
Arroyo de la Mora, Cienega del Macho, and Salt Creek. North of the
drainage divide in the northern part of the Vaughn-Macho plain,
drainage is internal to sinkholes and closed depressions. (See fig. 1.)
The principal tributaries draining the Sacramento and Diamond A plains
and most of the lowland are the Rio Hondo, Rio Felix, Cottonwood
Creek, Eagle Creek, and Rio Penasco. The principal tributaries
draining the upland surface of the Guadalupe Mountains and the
Embayment plain are North, Middle, and South Seven Rivers and Rocky
Arroyo.

Streams in the Roswell basin, including the Pecos River, are intermittent ~~in flow~~ through much of their reaches in the basin. The Pecos River generally is dry in much of its reach between the northern limit of the Roswell basin and Salt Creek, principally because flow from upstream areas is controlled by Alamogordo Reservoir. Springs and seeps in the river channel and man-made drains in the irrigated area discharge to the river and maintain some flow in the reach of the river between Salt Creek and the southern limit of the basin. The Rio Hondo, Rio Penasco, and some of their tributaries are perennial ~~streams~~ in their upper reaches. The Rio Hondo, Rio Felix, Cottonwood Creek, and Rio Penasco are perennial ~~streams~~ near their confluence with the Pecos River.

Development of drainage

The development of drainage and drainage patterns in the
Roswell basin is related to the type of rocks in the basin and to
structural and topographic features. The ancestral streams of the
major tributaries draining the east slope of the Sacramento Mountains
probably originated on a comparatively smooth eastward-sloping plain,
probably post-Cretaceous in age. As the streams developed on this
plain, they cut into it and helped erode the surface. Before this
surface was completely eroded away, streams had cut into the
underlying Permian rocks which form the present-day surface of the
area, and the drainage patterns that had developed on the original
surface were superimposed on the Permian rocks. The Rio Hondo and
Rio Penasco are superimposed on the Sacramento and Diamond A plains,
and the Rio Felix is superimposed on the Diamond A plain.

At places the Rio Penasco, Rio Hondo, and Rio Felix have been deflected by some of the major structural and topographic features. The Rio Penasco flows northward for 3 miles along the Vandewart= Cornucopia structural zone (fig. 1), the Rio Hondo flows northward for several miles along the Sixmile Hill structural zone, and the Rio Felix flows northward along the Y-O structural zone for about 5 miles before turning eastward. Bean (1951, p. 5) stated that the major streams cross the Y-O, Border Hills, and Sixmile Hill zones at points of structural weakness that were low topographically. He also indicated that the Rio Hondo crosses the Border Hills zone where part of the flexure is offset to the west and where the displacement along faults is reversed, with respect to upthrown and downthrown sides. Two alternate explanations can be advanced. After consequent drainage had been established and the post-San Andres rocks had been eroded, movement occurred along the structural zones. This disrupted the drainage temporarily and forced the streams to flow along the structural zone until an exit across the zone was reached at a topographic low. On the other hand, the streams may have been deflected without antecedent movement in the following manner: As the streams were incised into the bedrock, ground water was moving generally eastward and was dissolving large quantities of soluble gypsum. Ground water may have been deflected along the Sixmile Hill, Border Hills, and Y-O structural zones. The ground water would have developed permeable zones in the soluble gypsum along the flanks of the structures more easily than in the less soluble limestone in the anticlinal hills. Collapse of gypsum along the flanks of the zones may have deflected the streams into courses parallel to the structural zones.

39

After the principal superimposed drainage was established in
on the hard limestone, subsequent streams formed along the trends of
both major and minor structures [al features]. The following are examples of
the subsequent drainage: A tributary to Blackwater Draw flows
northeastward for several miles parallel to the Border Hills
structural zone in Tps. 10-11 S., Rs. 20-21 E. A tributary of the
Rio Hondo parallels the Border Hills zone for 5 miles in
T. 12 S., Rs. 19-20 E. (fig. 1). Tributaries of the Rio Penasco
and Bluewater Creek flow for several miles along the Vandewart-
Cornucopia zone. Soon after the establishment of subsequent
drainage, a well-integrated pattern of resequent and obsequent
drainage was formed on the slopes. The subsequent, obsequent, and
resequent streams have greatly dissected the Sacramento and Diamond
A plains; however, the main structural and topographic trends have
not been obliterated. The trellis pattern of drainage is typical of
drainage patterns on anticlines in the area.

In places the drainage pattern is not the same on the western and the eastern sides of the structural zones. For example, along the Border Hills structural zone from Blackwater Draw in T. 10 S., R. 21 E., to the north-western part of T. 13 S., R. 19 E., the drainage west of the structural zone consists of numerous shallow drainage lines, whereas east of the zone the drainage consists of a few but deeply incised drainage lines. The difference in drainage patterns reflects the difference in size of the drainage areas west and east of the structural zone.

Climate

The climate of the Roswell basin is semiarid. Precipitation is scant and is most intense in summer; relative humidity is low; daily temperature fluctuations are large; and most of the days are clear and sunny. The average annual rainfall at Roswell, which is in the lowland area, is about 12 inches. In the period 1878-1959 the annual precipitation at a weather station in Roswell ranged from a high of 32.92 inches in 1941 to a low of 4.35 inches in 1956. Precipitation is greater in the upland area than in the lowland area; the average annual precipitation is about 15 inches at Picacho, about 19 inches at Mayhill, about 21 inches at Ruidoso, and about 26 inches at Cloudcroft.

More than 50 percent of the annual precipitation at Roswell occurs as showers and thunderstorms between July 1 and September 30. Summer temperatures in the lowland are high and at times, from May to September, exceed 100°F. The average annual temperature at Roswell is 59.5°F. Average monthly temperatures range from 41°F in December to 83°F in July. The high temperatures and low humidity in combination with a high rate of wind movement cause high rates of evaporation. The evaporation for 1958 was 86.14 inches at Bitter Lake National Wildlife Refuge, and 98.41 inches at Lake Avalon. Precipitation and evaporation data for the years 1957-59 are given in table 1 for selected stations in the Roswell basin.

Table 1.--Climatological data from selected stations in the Roswell basin, Chaves and Eddy Counties, N. Mex. [1]

Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
				Precipitation, in inches, at Roswell									
Long-term mean	0.42	0.46	0.53	0.75	1.28	1.47	1.81	1.45	2.00	0.98	0.39	0.53	12.07
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
				Evaporation, in inches, at Bitter Lake National Wildlife Refuge									
1957	2.88	3.82	7.32	9.10	11.39	14.70	15.02	11.94	8.91	5.09	2.24	3.32	95.73
1958	2.26	3.74	3.61	9.54	10.66	13.50	13.78	11.69	7.97	3.77	3.24	2.38	86.14
1959	2.81	3.91	8.50	8.91	12.30	12.72	11.26	10.42	9.08	4.96	3.65	2.36	90.88
				Evaporation, in inches, at Lake Avalon									
1957	4.87	5.24	9.15	11.51	13.59	14.73	15.77	13.38	10.47	5.73	3.33	4.04	111.81
1958	3.20	4.88	5.37	11.25	12.26	14.72	14.36	12.65	7.48	4.77	4.10	3.37	98.41
1959	4.02	5.17	9.56	9.62	12.35	11.23	10.66	10.82	9.77	6.05	4.34	3.17	96.76

1/ Compiled from U.S. Weather Bureau records.

43

Vegetation

The study of vegetation is of considerable help in delineating
which sinkholes, depressions, flood plains, and other areas are
covered with water infrequently and which are covered with water
frequently. Areas that are frequently ~~inundated~~ covered by water have a
darkened appearance when viewed from the air, and are green if water
has covered them recently and the vegetation has benefited because
of the moisture. The areas appear ~~to be~~ black if water has not
covered the area for a considerable time and the vegetation is dead
or dormant.

Quick-growing plants can thrive in depressions and sinkholes
~~which~~ that contain water for short periods of time, even in those depressions
that receive water infrequently, possibly once every few years.
Some of the quick-growing plants of the area are: ~~pig eek~~ pigweed (Amaranthus
spp.), ragweed (Ambrosia spp.), lambs quarter (Chenepodium alba),
kochia (Kochia scoparius), and russian thistle (Salsola pestifer).

Flood plains of some of the tributaries of the Pecos River and
some sink holes receive enough water evey year to support perennial
plants. Some of the perennial plants are tobosa grass (Helaria
mutica), buffalo grass (Buchlolo dactylordes), burro grass (Sclerapogon
brevifolious), cholla cactus (Opuntia arborescens), bitterweed
(Hymenoxys odocata), and creeping muhly (Muhlenburgia repens).
Phreatophytes such as saltcedar (Tamorix gallica) and mesquite(Prosopes
juliflora) grow along the flood plain of the Pecos River and the lower
reaches of some tributaries.

Sacaton (Sporobolus wrightii) and alkali sacaton (Sporobolus anoides) are perennial plants that formerly were common in southeastern New Mexico. Sacaton grew abundantly along many of the flood plains and some sinkhole areas. In these areas, other native grasses such as blue gramma (Bouteloua gracilles) also were abundant. The dense growths of high native grasses not only retained much of the runoff but also collected considerable amounts of silt and prevented erosion. Overgrazing by cattle and sheep resulted in the removal of the protective ground cover at many places. The sacaton, alkali sacaton and blue gramma grasses have been replaced by shorter grasses that have shallower and weaker root systems, such as buffalo grass.

Runoff has increased in some of the tributaries, channels have deepened, and gullies have formed as a result of overgrazing and changes in grass cover. The deepened channels and gullies date from the late 1800's when grazing began in the Roswell area. Floodwater flows in the deeper channels in some streams rather than over the shallow flood plains. The result not only is increased erosion and gullying but also a decreased amount of growth of forage plants. A decrease in frequency of rainfall (Leopold, 1951) could also account for the modern epicyle of erosion. Leopold believes that the decrease in the number of small rains reduced the vegetation cover, which in turn resulted in less infiltration and greater runoff.

Hills as seen from the air commonly are lighter colored than nearby flatter areas owing to a sparser growth of plants such as creosote bush (Larrea tridentata). Also, the native blue and black gramma grass (Bouteloua Graciles and Bouteloua Eriopoda) now are not as common as the invading fluff grass (Tredeus puclchellus) and hairy tridon (Tridens pelosus) on the hilly areas. In the southern part of the project area the beds of silt and sandstone along the hills can be traced readily on aerial photographs by ~~the~~ vegetation. ~~growth along the clastic beds.~~ One of the common plants growing in the silt along the benches of limestones is the tar bush (Flourencia sp.).

Gyp gramma (Bouteloua breviseta) and gyp grass (Sporobolus neeleyi) are two common grasses growing in depressions underlain by gypsum.

Geology

Consolidated rock at the surface in most of the project area and to a depth considerably below the bottom of the deepest water well consists chiefly of a complex accumulation of marine rocks of Permian age deposited in various types of environments (fig. 4).

Figure 4.--Structural provinces during Permian time in southeastern New Mexico and western Texas. The wider spaced slant lines delineate the basins, the closer spaced slant lines delineate the area of deformed pre-Permian rocks, the remaining areas are shelf and platform provinces. The stippled areas delineate outcrops of Wolfcamp, Leonard, Guadalupe, and Ochoa Series of Permian age, and their equivalents (after King, 1948, p. 25).

Consolidated rocks of Triassic and Cretaceous age crop out in a small area; however, they are relatively unimportant to this report because they do not have an appreciable potential for additional recharge.

Unconsolidated gravel, sand, and silt deposited by the Pecos River and its tributaries in the Tertiary and Quaternary periods overlie the stratified bedrock with profound unconformity. These alluvial deposits are only a veneer on the Permian rocks in most of the upland area but range in thickness from a fraction of a foot to more than 300 feet in the lowland area.

Rocks of Permian age

The rocks of Permian age that crop out in the Roswell basin
comprise the Yeso Formation, the stratigraphically lowest formation
that is an aquifer on the east slope of the Sacramento Mountains,
the San Andres Limestone, and the Artesia Group. The Artesia Group
includes the carbonate and evaporite facies of the back-reef deposits
of the Guadalupe Series. The Guadalupe Series in southeastern
New Mexico is characterized by four major facies: a basin facies
consisting of quartzose sandstone interbedded with limestone, which
was deposited in the deep waters of the Delaware basin southeast of
Carlsbad; a reef facies consisting of massive limestone of the reef
complex of Guadalupe age; a carbonate facies consisting of carbonate
rocks interbedded with sandstone, which was deposited landward from
the reef complex of Guadalupe age in back-reef waters; and an evaporite
facies consisting of gypsum, anhydrite, and other evaporite rocks
interbedded with red sandstone and shale, which also was laid down
in back-reef waters. Each of these rock types was deposited at the
same time but in different environments.

Yeso Formation

The Yeso Formation is the lowest stratigraphic unit of Permian age that crops out extensively in the Roswell basin. The Yeso is overlain by the ~~Glorieta~~ *Hondo* Sandstone, *Member of the San Andres Limestone* and underlain by the Abo Sandstone. It is exposed where the large streams tributary to the Pecos River have cut deeply into the uplands of the Sacramento Mountains and where the overlying San Andres Limestone has been stripped from local uplifts (fig. 5).

Figure 5.--Generalized geologic map of part of the Roswell basin, New Mexico.

The Yeso Formation in southeastern New Mexico consists of anhydrite and gypsum interbedded with sandstone, siltstone, shale, and carbonate rocks. Sandstone and siltstone become progressively more abundant in the formation northwestward across the Roswell basin. The formation contains salt beds in the subsurface near and east of the Pecos River. The lack of salt in the formation west of the Pecos River may be the result of solution by ground water. The removal of salt from the section also could account for the thinning of the Yeso Formation west of the river. The Yeso is about 1,800 feet thick in the Sacramento Mountains and more than 2,000 feet thick east of the Pecos River in the vicinity of Roswell.

The Yeso Formation on the east slope of the Sacramento Mountains consists of brown and yellow sandstone, siltstone, shale, limestone, and gypsum. The sandstone and siltstone, which are cemented by calcium carbonate near the top of the Yeso, are similar in most respects to sandstone and siltstone in the Hondo Sandstone Member of the San Andres. Drill cuttings of the Yeso from a hole in the $NE\frac{1}{4}$ sec. 10, T. 18 S., R. 21 E., consisted of light greenish-gray shale, siltstone, mudstone, limestone, and anhydrite. The calcareous cemented quartzose siltstone ranged from yellowish brown to light yellow. Much of the shale was dark gray, and some was black with laminae less than 1 mm in thickness. Cuttings from well 7.20.16.333, PVACD 1 (Pecos Valley Artesian Conservancy District), show the upper 235 feet of the Yeso Formation to consist principally of yellow and red sandstone and siltstone, some white chalky gypsum, and light gray-brown anhydrite with minor amounts of claystone (Crawford and Borton, 1961, p. 263-269).

The Yeso Formation is the most extensive aquifer in the area. The permeability of the Yeso is low, especially where the formation underlies the San Andres Limestone. Ground water is in the coarser grained, siliceous clastic rocks and in solution channels in the carbonate rocks and evaporite rocks. The sandstones and siltstones are confining beds where they are cemented by calcium carbonate. Perched water on top of these impermeable sandstone beds discharges as springs where canyons cut into the Yeso Formation in the Sacramento Mountains. Wells tap the Yeso Formation generally west of R. 21 E., and most of them yield less than 10 gpm (gallons per minute). The water in the Yeso is potable to impotable but generally is suitable for stock use.

San Andres Limestone

Hondo Sandstone Member

The Hondo Sandstone Member is generally defined as a sandy
unit that is overlain by carbonate rock of the San Andres Limestone
and underlain by the gypsum and red siltstone of the Yeso Formation.
Locally it is difficult to distinguish the Hondo from the Yeso and
the upper part of the San Andres; for example, on the east slope
of the Sacramento Mountains, sandstones similar to those of the
Hondo occur in a zone about 150 feet thick in the overlying parts
of the San Andres Limestone.

The Hondo Member is exposed in canyons on the east slope of
the Sacramento Mountains where the tributary streams of the Pecos
River have cut deeply into the Permian rocks. This member is
mapped with the San Andres Limestone on fig. 5.

The ~~Glorieta~~ Sandstone [Hondo Member] in a well in the

NE$\frac{1}{4}$ sec. 10, T. 18 S., R. 21 E., consists of three units, an upper

yellow-orange quartzose-sandstone unit 20 feet thick, a middle

siltstone unit 10 feet thick, and a lower sandstone unit 10 feet

thick. The upper sandstone unit is [composed of] fine-to-medium grained, well-

rounded sand cemented with calcium carbonate; however, many of the

grains are poorly cemented. The lower part of this unit contains

considerable amounts of silt. The siltstone unit is light yellow

to yellow-brown and cemented with calcareous cement. The lower

sandstone unit is silty and generally light yellow-brown and is

interbedded with some light-gray shale.

The Hondo Sandstone Member of the San Andres, ~~which may be~~

~~correlative with the Glorieta Sandstone,~~ is about 150 feet thick in

the upper reach of the Rio Hondo and consists of an upper quartzose-

sandstone unit 40 feet thick; a middle silty limestone, siltstone,

gypsum, and anhydrite unit 90 feet thick; and a lower quartzose

sandstone unit 20 feet thick (W. A. Mourant, oral communication,

July 1958). The quartzose sandstone typically consists of sand that

is well rounded and well sorted and has an average grain size

ranging from medium to coarse on the Wentworth scale. In places it

contains considerable silt. The sand generally is reddish brown ~~due~~ [owing]

to a coating of limonite on the grains. Where the [Hondo] ~~Glorieta Sandstone~~

is adjacent to intrusive rocks, the sandstone may have been meta-

morphosed to quartzite.

The Hondo Sandstone Member is an aquifer in large areas of the east slope of the Sacramento Mountains. Its water-yielding properties are variable, and it may be a confining bed where the member is very silty. In parts of the Embayment plain in Tps. 20, 21, and 22 S., the upper sandstone of the Hondo forms the lower confining bed for water in the overlying part of the San Andres Limestone. Wells tap the Hondo Sandstone Member generally west of R. 21 E., and most of them yield less than 10 gpm. The water from these wells is chemically suitable for stock and domestic use.

The San Andres Limestone above the Hondo Member is the most widely exposed stratigraphic unit in the area of investigation and caps large areas of the Sacramento and Guadalupe Mountains. North and west of the town of Artesia, the upper part of the San Andres Limestone grades laterally into evaporite rocks.

The upper part of the San Andres Limestone is overlain by the Artesia group and underlain by the Hondo Sandstone Member and Yeso Formation. The San Andres-Artesia Group contact used in this report is a carbonate rock-sandstone contact, as mapped by Hayes and Koogle (1958). The contact between the upper part of the San Andres Limestone and Hondo Sandstone Member is a carbonate rock-sandstone contact, which is exposed in the deeper ravines in the Sacramento and Guadalupe Mountains.

Rocks of the carbonate facies of the San Andres Limestone have
not been studied in detail, but dolomitization of the upper part
of the carbonate facies probably is similar to that in the carbonate
facies of formations of late Guadalupe age in the southern Guadalupe
Mountains (Newell and others, 1953, p. 131-140) and ta the northern
Guadalupe Mountains (Motts in Bjorklund and Motts, 1959, p. 58-61).
Bean (1949, p. 13) pointed out that the upper part of the carbonate facies of the San Andres
Limestone has a greater amount of dolomite than the lower part.
The relationship of the upper dolomite to the lower limestone is
shown in figure 7. Thin bedding is more common in the upper part
than in the lower part. Fiedler and Nye (1933, p. 64-70) and Bean
(1949, p. 9-14) noted and described the "worm-eaten" or "honeycombed"
appearance of the upper part of the San Andres Limestone. This
appearance is characteristic of rocks of the carbonate facies where
they are subjacent to evaporite rocks of the San Andres and younger
rocks.

The vacillating front between the areas of deposition of
carbonate and evaporite rocks of the San Andres Limestone resulted
in the interbedding of evaporite rocks and dolomitic rocks, particularly
north and west of Roswell. Test holes in the
NW$\frac{1}{4}$ sec. 33, T. 4 S., R. 21 E., penetrated numerous beds of anhydrite
and gypsum interbedded with dolomite.

Variations in thickness of the carbonate facies of the San

Andres Limestone are rather consistent. The carbonate facies

decreases in thickness to the north and west at right angles to the

regional facies changes (fig. 6). However, some anomalies occur

west and southwest of Roswell. A study of well logs compiled by

Crawford and Borton (1961) indicates that the San Andres Limestone_ *above the Hondo Member*

is 243 feet thick in well 13.20.13.22 (PVACD 4), 380 feet thick in

well 11.21.18.333 (PVACD 8), and 500 feet thick in well 10.21.16.222

(PVACD 3). The apparent differences in thickness may result from the

presence of lens*es* of sandstone in the lower part of the San Andres

Limestone or from local structural ~~conditions~~ *deformation* and truncation.

Intraformational breccias *or rubble zones* (fig. 7) are common in the San Andres

---

Figure 7.--Generalized section along the Pecos River from

Carlsbad to South Spring Creek near Roswell, N. Mex.

Limestone. The breccias consist of tilted and rotated blocks of

carbonate rocks, as much as 2 feet in diameter, in a silt matrix.

The breccias probably formed when the Permian seas withdrew temporarily

and left the topographically high areas subject to erosion. Many of

the large cavernous openings in the San Andres are in the brecciated

zones. A terrace generally has formed where the brecciated beds are

exposed. Weathering by slope retreat eroded the weaker beds of

breccia and formed a bench on the underlying hard carbonate rocks.

The "worm-eaten" and "pinhead" type of porosity is more common in the

San Andres Limestone than in the stratigraphically higher carbonate

rocks of the Guadalupe Series. The size of openings ranges from that

of a pinhead to more than a foot in diameter. Many of the openings

are interconnected.

64

The carbonate rocks of the San Andres Limestone are highly permeable in many areas west of the Pecos River and yield water readily to wells. In the Roswell-Artesia cultivated ~~area~~ sector, the yields of irrigation wells generally range from 40 to 70 gpm per foot of drawdown, and the average ~~rate of~~ discharge is about 1,300 gpm.

Water in the San Andres Limestone in the recharge area and in most of the cultivated area is low in dissolved solids and generally is potable. Adjacent to and east of the Pecos River the water in the San Andres is saline.

Artesia Group

The Artesia Group extends from the top of the Tansill Formation
to the base of the Grayburg Formation and includes (descending) the
Tansill, Yates, Seven Rivers, Queen, and Grayburg Formations. The
formations of the Artesian Group crop out as easily identifiable
formational units immediately outside the southeastern margin of the
Roswell basin. The Tansill, Yates, and Seven Rivers cannot be
identified as separate formations in the Roswell basin, and equivalents
of these formations may be absent in the basin. The Queen Formation
crops out as an identifiable unit only in the extreme southeastern
part of the basin. The Grayburg Formation crops out in the
southeastern part of the basin and becomes, through a facies change
to the northwest, an evaporite unit along a line extending from about
Dayton toward Texas Hill. Recharge to the Queen, in large part, moves
from the Roswell basin, and the Queen is not considered of sufficient
importance to warrant a detailed discussion in this report.

For the purposes of this report, the name Artesia Group will be
used where the formations are well defined, and the name Artesia
Formation will be used where the units are not separable. The Artesia
Formation as used in this report includes the evaporite facies of
the Artesia Group and may include the evaporite rocks of the San
Andres Limestone and is the equivalent of the Chalk Bluff Formation
of former usage.

Grayburg Formation

The Grayburg Formation, as defined in ~~surface~~ exposures, is
a thick accumulation of interbedded dolomite and sandstone that
occupies the interval between the Queen Formation and the San Andres
Limestone. It is a rock sequence about 435 feet thick (Hayes and
Koogle, 1958) that differs lithologically from the Queen Formation
and the San Andres Limestone, and its carbonate facies grades into
evaporite rocks farther west than does the carbonate facies of the
Queen.

The Grayburg is exposed in the project area in T. 21 and 22 S., Rs. 22 and 23 E., and Tps. 19 and 20 S., Rs. 23 and 24 E. North and west of the carbonate-evaporite facies boundary, the formation grades abruptly into evaporite rock, which consists chiefly of gypsum and forms the basal part of the evaporite facies of the Artesia Formation.

The carbonate facies of the Grayburg Formation consists of interbedded sandstone and carbonate units. The Grayburg contains rubble zones (fig. 7), but they are not as common as in the San Andres Limestone. Many of the sandstone beds in the lower part of the Grayburg Formation can be traced only short distances. The inter-bedded reddish-brown siliceous sandstone units in places show fluvial cross bedding.

Bjorklund and Motts (1959, p.92) concluded that the Grayburg Formation has two aquifers. The aquifers are beds of dolomite separated by relatively impervious beds of sandstone. How far north into the Roswell basin the two aquifers extend is conjectural. Bjorklund and Motts (1959, fig. 26) indicated that water in the upper aquifer moves east toward Carlsbad and that water in the lower aquifer and underlying San Andres Limestone moves northeast toward Lakewood. A large amount of ground water moves into the Grayburg from the San Andres west and southwest of Artesia.

Stock and domestic wells in the Grayburg in the outcrop area generally yield from 5 to 10 gpm. Irrigation wells in the Grayburg in the vicinity of Artesia yield as much as 1,000 gpm.

The total dissolved solids in water in the Grayburg in the outcrop area ~~is~~ ranges from 300 to 400 ppm. Northeast and east of Artesia the dissolved solids content may be greater than 1,000 ppm (J. W. Hood, oral communication, 1960).

The Artesia Formation

The Artesia Formation (Chalk Bluff Formation of former usage) crops out in the vicinity of Hope, between Eagle Creek and Walnut Creek, and in a large area north of Roswell. (See fig. 5.) The formation underlies much of the alluvium along the Pecos River and in part forms the upper confining bed for the artesian water in the San Andres Limestone.

The formation ranges in thickness from about 1,500 to 1,800 feet in the subsurface east of the Pecos River. West of the river its thickness is considerably less, owing to erosion and to solution of the evaporite rocks.

~~The evaporite facies of~~ The Artesia Formation is chiefly gypsum and anhydrite interbedded with red siltstone and sandstone. The ~~character~~ lithologic characteristics of the formation ~~varies~~ vary with stratigraphic position. For example, in the upper and middle parts of the formation, the equivalents of the Yates and Queen Formations contain more sand and silt than the equivalents of the Tansill and Seven Rivers Formations. The Artesia Formation is poorly resistant to erosion. ~~Surface~~ Exposures are poorly preserved and show evidence of considerable solution by ground water.

The Artesia Formation is highly permeable at some places and poorly permeable at others. It commonly is highly permeable in its outcrop because ground water has dissolved large amounts of gypsum along interconnected solution channels. The formation generally is poorly permeable where it underlies several feet of alluvium. Ground water under artesian head in the underlying San Andres Limestone rises through the Artesia Formation and slowly dissolves the gypsum but leaves the silt and sand behind. This process of selective removal results in a relatively impermeable silt and sand blanket that retards the movement of ground water. The wide range in permeability of the formation is reflected by the yield of its wells. Wells that produce water where the permeability is low yield only a few gallons per minute; but wells in the highly permeable areas yield as much as 1,000 gpm (J. W. Hood, oral communication, 1959). The water generally is impotable because of the high dissolved-solids content, and in some places it is unsuitable for irrigation.

Rocks of Mesozoic age

Rocks of Triassic and Cretaceous age are in the Ruidoso-Capitan area. (See fig. 5.) The rocks of Triassic age are the Dockum Group. In the study area the Dockum Group includes a lower unit probably equivalent to the Santa Rosa ~~Formation~~ *Sandstone* and an upper unit probably equivalent to the Chinle Formation. The Santa Rosa equivalent is about 295 feet thick (Allen and Jones, 1951) and consists mostly of interbedded sandstone, siltstone, and minor amounts of chert pebble conglomerate. The Chinle equivalent is about 180 feet thick (Allen and Jones, 1951) and consists of interbedded shale, siltstone, and mudstone. The rocks of Cretaceous age include the Dakota Sandstone, the Mancos Shale, the Mesaverde Group, and possibly the Cub Mountain Formation of Bodine (1956). The Dakota Sandstone, which is about 135 feet thick, is chiefly quartzose sandstone and interbedded shale. The Mancos Shale is about 390 feet thick and consists of interbedded shale and limestone. The Mesaverde Group is about 535 feet thick; the upper 200 feet consists chiefly of quartzose sandstone (Allen and Jones, 1951). The Cub Mountain Formation (Bodine, 1956, p. 8-11) is sandstone interbedded with some conglomerate, shale, and clay. According to Bodine, the Cub Mountain Formation may be either Late Cretaceous or Early Tertiary in age.

In the general area of Ruidoso, Capitan, and Carrizozo, the rocks of Triassic and Cretaceous age are preserved in a synclinorium that has been perforated by igneous intrusions. South of the synclinorium on the Sacramento plain, rocks of Triassic and Cretaceous age have been removed by erosion except for a small area of rocks of Cretaceous age in Tps. 14-15 S., R. 13 E. (Pray and Allen, 1956). Little is known about the water-bearing characteristics of the rocks of Triassic and Cretaceous age, because only a few wells have been drilled in them (W. A. Mourant, oral communication, 1959). These rocks will not be discussed further in this report, because artificial recharge to these rocks would not be effective recharge to the Roswell-Artesia sector of the Roswell basin.

Rocks of Tertiary and Quaternary age

Unconsolidated and some consolidated gravel, sand, and silt
of Tertiary and Quaternary age comprise the alluvium (fig. 5) of the
project area. Small thin deposits of gravel at places on the
Diamond A plain and on the higher surfaces of the Sacramento plain of
the upland area are of Tertiary or Quaternary age. The well-cemented
conglomerate, gravel, sand, and clay on the gravel-capped mesas were
called limestone conglomerate by Nye (Fiedler and Nye, 1933,
p. 38). The limestone conglomerate caps hills and mesas near Melena
in the extreme southeastern part of the Vaughn-Macho plain and along
Eagle and Cottonwood Creeks north of Hope in the northern segment of the
Embayment plain.

The consolidated and unconsolidated gravel, sand, and silt
underlying the younger alluvium of the Blackdom, Orchard Park, and
Lakewood terraces of the lowland area was called quartzose
conglomerate by Nye (Fiedler and Nye, 1933, p. 35-37). Nye pointed
out that the quartzose conglomerate generally is well stratified,
firmly cemented, and in some places deformed, whereas the younger
material is commonly structureless, unconsolidated, and undeformed.
Nye considered the limestone conglomerate of the upland area to be
younger than the quartzose conglomerate in the lowland area; however,
Morgan (1938) considered the two deposits to be the same age.

Morgan (1938, p. 17) estimated that the thickness of the
alluvium ranges from a few feet to more than 300 feet and averages
about 150 feet in the cultivated part of the basin. Thicknesses
greater than 300 feet have been reported. Oil tests in
secs. 25 and 27, T. 17 S., R. 26 E., reportedly penetrated about
900 feet of alluvium--an unusually thick sequence for the Roswell
basin. This excessive thickness may be the result of incorrectly
identifying a thick rubble bed of breccia in the ~~evaporite facies
of the~~ Artesia Formation as alluvium. Fiedler and Nye (1933, p. 35)
wrote that the maximum thickness of the deposits of the Blackdom
terrace where they are exposed is at least 80 feet and may be
considerably more. Morgan (1938, p. 14), however, believed that the
actual thickness of the Blackdom sediments probably is less than
20 feet and that the 80 feet ascribed to the deposits by Nye includes
material belonging to the underlying quartzose conglomerate. Morgan
considered that the thickness of the deposits underlying the Orchard
Park terrace ranges from a few feet to 20 feet. The deposits under-
lying the Orchard Park terrace are flood-plain and channel deposits
of the Pecos River and its tributaries and consist of beds of inter-
fingering gravel, sand, and silt. The deposits underlying the Lakewood
terrace are generally similar to those underlying the Orchard Park
terrace and range in thickness from a few feet to about 25 feet. The
alluvium in the lowland area is second to the ~~limestone~~ main aquifer as a
source of water to irrigation wells in the basin.

Igneous and metamorphic rocks

Intrusive and extrusive igneous rocks are mostly in the northern part of the Sacramento Mountains (fig. 5). The Sierra Blanca and Capitan Mountain areas were sites of extensive igneous activity. The Sierra Blanca extends about 20 miles north of the Sacramento Mountains and consists of a complex of intrusive and extrusive rocks. The Capitan Mountains are about 20 miles long and extend eastward from the north end of the Sierra Blanca. The Capitan Mountains are composed chiefly of microgranite. Pajarito Mountain, an intrusive mass on the east slope of the Sacramento Mountains (fig. 5), in T. 12 S., Rs. 15-16 E., is composed mainly of syenite (which crops out in an area of slightly more than 1 square mile). The crystalline rocks of the Pajarito Mountain area are intrusive rocks of Tertiary age.

These igneous rocks have no apparent potential for artificial recharge.

Geologic structure

Major geologic structures in the project area trend northwestward, northward, northeastward, and eastward. The six major structural zones--zones along which joints, small faults, and flexures have a similar or parallel trend--are the Huapache, Fourmile, Vandewart-Cornucopia, Border Hills, Sixmile Hill, and Y-O structural zones. (See fig. 5.)

Structural features that trend northwestward

The major structural features that trend northwestward are the Huapache structural zone (fig. 5) and the faults that delimit the west side of the Guadalupe Mountains. Structural features that trend northwestward can be traced into Tps. 19 and 20 S. where they intersect structural features that trend northward and eastward. The area of intersection is highly fractured and structurally complicated.

A prominent structural feature that forms an escarpment at the eastern boundary of the upland surface of the Guadalupe Mountains is a monocline (not mapped) in the Huapache structural zone. The axis of the monocline is parallel to major faulting to the west. The monocline is the result of deep-seated faulting in the Precambrian basement during pre-Abo time. Faulting in the Huapache structural zone probably was active in Late Pennsylvanian time and throughout Early Permian time.

More than 4,500 feet of Upper Mississippian and Pennsylvanian rocks are missing west of the monocline, but are present east of the monocline. The Abo Sandstone and Yeso Formation are thin west of the monocline. The San Andres Limestone is 1,100 feet thick east of the monocline and is 900 feet thick west of the monocline. Thinning of the San Andres Limestone might be attributed to faulting during Permian time; however, it may be the result of changes of facies in the San Andres between the carbonate and evaporite facies and subsequent erosion of the rocks of the evaporite facies. Removal of these rocks would produce the thinning of the San Andres.

The Guadalupe Mountains were elevated to their present topographic position in Tertiary time. The Permian rocks in that area dip to the northeast as a result of the uplift. The northeastward dip controls the surface drainage and the movement of ground water in that area.

Structures al features that trend northward

Large structural features that trend northward are the faults at the west edge of the Sacramento Mountains (west of area mapped in fig. 5) and the Vandewart-Cornucopia structural zone. The eastward dip of the rocks of Permian age is the result of the uplift that raised the Sacramento Mountains to their present altitude. This eastward dip controls the surface drainage and the movement of ground water on the east side of these mountains.

The trend of the Vandewart-Cornucopia structural zone probably is related to deep-seated basement faulting. The trend is characterized by faults, folds, and numerous subsidiary structural features west and east of the major structural zone. West of the structural zone, in Tps. 16 and 17 S., several faults (not mapped) follow the trend of the zone. East of the structural zone, in Rs. 17 and 18 E., a series of gently dipping folds (dip 5° or less) parallel the trend of the zone. The limiting fold of this series crosses approximately through the eastern half of Tps. 16 and 17 S., R. 18 E., and extends northward into Tps. 14 and 15 S., Rs. 19 and 20 E. The Manning anticline is at the northern end of the Vandewart-Cornucopia structural zone. (See fig. 5.)

Structural features that trend northeastward

The Border Hills, Sixmile Hill, and Y-O structural zones are
major structures that trend northeastward. These structural zones
consist of long linear sharply folded anticlines that pass into
faults in places.

The Border Hills structural zone is marked by a prominent
topographic ridge. On the west and east sides of the ridge, strata
probably have buckled upward at places. Fiedler and Nye (1933, p. 78)
quote C. H. Crandall as saying that the Border Hills fault reverses
itself at several places and that for a few miles south of the
Rio Hondo the beds on the east side are downthrown relative to those
on the west side. At most places the beds on the west side of the
zone appear to be downthrown in relation to the beds on the east
side. West of the Border Hills structural zone, and south of the
Rio Hondo, several faults follow the trend of the structural zone.
The faults are in a series of grabens and horsts.

The Sixmile Hill and Y-O structural zones are sharply folded
and faulted anticlines that are not as well expressed topographically
as the Border Hills structural zone.

The origin of the structural zones that trend northeastward probably is related to deep-seated basement faulting and to slipping along bedding planes in gypsum of the Yeso Formation during Tertiary time. The Huapache and the Y-O structural zones intersect at about right angles. West of the Huapache structural zone, Pennsylvanian strata are missing and lower Permian strata have been thinned. West of the Y-O, Sixmile Hill, and Border Hills structural zones, the Pennsylvanian and lower Permian strata seem to thin in steps. Basins formed during Pennsylvanian time trend northeastward and northwestward. These data suggest that the Huapache structural zone and the structural zones which trend northeastward may be related and possibly were active in Late Pennsylvanian and early Permian time.

The uplift of the Sacramento fault block during Tertiary time produced an eastward-directed force on the east slope of the Sacramento Mountains. The contraction and subsidence that ~~which~~ resulted from cooling of the Capitan Mountains igneous mass may have produced a northeastward-directed force. These two forces may have resulted in slipping of the San Andres Limestone across the gypsiferous beds of the Yeso Formation. If slipping occurred, gypsum in the Yeso acted as a lubricant for movement of the carbonate rocks of the San Andres. The establishment of a water table in the Yeso Formation and the conversion of anhydrite to gypsum probably facilitated the movement. The movement probably was northeastward along old fault zones that formed in Pennsylvanian time. This movement caused buckling in places of both flanks of the linear, sharply folded anticlines and the thrusting of gypsum and sandstone of the Yeso and San Andres ~~Glorieta~~ Formations toward the surface. There may have been a strike-slip movement also, and the western side of the slip moved northeastward relative to the eastern side.

The Border Hills, Y-0, and Sixmile Hill structural zones seem to be areas of high permeability. The fracturing, buckling, and dislocation of the bedrock within these structural zones increased the permeability in the bedrock. Easier movement of ground water in those areas accelerated solution activity. Many sinkholes are along the Sixmile Hill structural zone. The cavernous sinkhole in which the Hondo Reservoir forms is between two limbs of the Sixmile Hill structural zone (Bean, 1949, p. 7).

Structural features that trend eastward

The intrusion that forms the Capitan Mountains and two dikes (not mapped) (Dane and Bachman, 1955) a few miles northeast of Roswell trend eastward. A general eastward trend could be inferred because the Capitan Mountains and the two dikes align.

Fourmile structural zone is between Fourmile Draw and North Seven Rivers (fig. 5). Complex faulting and jointing occur at many places along this zone west of R. 19 E., and in places the extensive fracturing has a herringbone pattern. The shattering of the Hondo Sandstone Member and Yeso Formation may have increased the permeability of those formations in the Fourmile structural zone. Information from well logs indicates an area of higher permeability along this zone. This eastward-trending zone of fracturing may be the result of differential uplift of the Guadalupe and Sacramento fault blocks during Tertiary time.

Structural feature~~s~~ resulting from solution

Sinkholes and closed depressions in the Roswell basin were formed by ground water under pressure moving upward through zones of structural weakness and dissolving the soluble rocks, by surface water percolating downward and laterally and dissolving the soluble rocks, and by a combination of these two processes.

Sinkholes formed by the upward movement of ground water are commonly characterized by a high degree of roundness and a lack of surface drainage area. A sinkhole of this type may have three or four smaller sinkholes on its periphery, thus forming a compound sinkhole.

Some of the sinkholes penetrating the San Andres Limestone in the area west of R. 21 E. probably were formed by water under pressure in the Yeso Formation moving upward along structural zones and dissolving large quantities of the San Andres Limestone. At places in these structural zones faulting has raised the lower confining beds in the Yeso against the permeable upper beds that compose the principal water-bearing beds in the Yeso, and water in the Yeso moves upward in the structural zone. Where the Hondo Sandstone Member, overlying the Yeso Formation, is silty adjacent to the structural zones, the water in the Yeso is confined by the Hondo.

The most accessible sinkholes in the Roswell basin, of the type formed by upward movement of artesian water, are those forming Bottomless Lakes (fig. 1) just east of the Pecos River near Roswell.

Sinkholes formed by infiltrating surface water may be classed
as broad depressions ~~with~~ gently-sloping sides and generally partly
filled with alluvium, and collapse sinkholes in which the walls are
steepsided.

Some collapse sinkholes in the Roswell basin are as much as
200 feet in diameter; in general, however, they are small compared
with other types of sinkholes. Many collapse sinkholes contain silt
and large tilted blocks of gypsum that have slumped and subsided.
Collapse sinkholes are common in the Vaughn-Macho plain and in parts
of the Embayment plain.

The broad depressions are most common where rocks of the evaporite
facies are covered by a thick blanket of alluvium. As the gypsum is
removed by solution, silt and clay fill the solution openings and
there is little or no slumping of the bedrock. An example is Juan
Lake sinkhole (fig. 8) where solution has been slow and a thick
layer of silt and clay has accumulated on the bottom of the sinkhole.

Figure 8.--Subareas of the recharge area, major sinkhole areas,

   and generalized pattern of water movement in the limestone aquifer

   in part of the Roswell basin, New Mexico.

There is no visible opening on the bottom of this sinkhole. Solution
almost stops when the silt and clay layer becomes very thick.

If the alluvium is thin, the solution openings in the soluble bedrock do not fill with silt and clay. An example is Antelope sinkhole (fig. 8) in which the alluvial fill is less than 25 feet thick and which has open solution cavities in the bottom. Sinkholes of the broad depression type having ~~with~~ open solution channels in their bottoms are referred to in this report as open sinkholes, and those having ~~with a~~ thick silt and clay layer and no visible openings are referred to as tight sinkholes.

Intermediate between the open sinkholes and the tight sinkholes are sinkholes having tight bottoms but permeable sides. These may form if the sinkhole is bottomed in permeable material, and the sinkhole has a large drainage area from which detrital material is washed into the sinkhole. An example of this type of sinkhole is Marley sinkhole (fig. 8) in Blackwater Draw drainage. The permeability of the bottom of this sinkhole is low because silt and clay cover the bottom to a depth of about 50 feet; however, large solution cavities in the evaporite rock of the San Andres Limestone are in the sides of the sinkhole above the silt and clay floor.

The Antelope sinkholes, like some others, are bottomed in thin alluvium and nonresistant evaporite rocks and red beds of the Artesia Formation, whereas sinkholes in other areas are bottomed in carbonate rocks of the San Andres Limestone. Some sinkholes shown on figure 8 are on topographic benches that also are structural benches. The Pajarito sinkholes, for example, are on a flat structural bench, which is the limiting area of nearby folds. The Flying H sinkholes are on a bench east of the Vandewart-Cornucopia structural zone, and the high area east of these sinkholes may be the approximate location of a fault trending north-south. The Mayhill sinkholes are on the west side of the Vandewart-Cornucopia structural zone on another topographic bench.

The sinkholes shown on figure 8 occur over such a large area that it was not possible to visit and classify all of them. Parts of the project area were studied only by using aerial photographs and by making observations from an air plane, and, thus, the sinkholes in these areas could not be classified with any degree of assurance. All the sinkholes within the project area are not shown on figure 8.

Hydrology

The description of the hydrology is given in greater detail
for the area between Tps. 7 and 22 S. and between R. 19 E. and
the Pecos River because this part was studied more intensively than
other parts of the Project. Principally those elements of hydrology
are described that relate to natural and artificial recharge of the
two chief aquifers in the basin. The reader is referred to other
publications about water resources of the basin for a more complete
description of all hydrologic elements.

Most of the ground water in the basin is in a main aquifer,
consisting of consolidated rocks, and an alluvial aquifer. The
alluvial aquifer is secondary to the main aquifer because much of
the water that recharges the alluvial aquifer comes from the main
aquifer.

Main aquifer

The main aquifer is beneath the upland and lowland areas
and extends eastward beyond the Pecos River, the eastern limit of
the project area. This aquifer is within the Yeso Formation, ~~Glorieta~~ Hondo
Member
Sandstone, San Andres Limestone, Grayburg Formation, and evaporite
facies of the Artesia Formation. These formations dip gently eastward
from the crest of the Guadalupe and Sacramento Mountains at the western
margin of the basin; the dip is modified in the vicinity of the struc-
tural zones described in the section on geology.

Occurrence of water in the main aquifer

Most of the ground water in the main aquifer between the western margin of the basin and R. 21 E. is in the Yeso Formation and the Hondo Sandstone Member of the San Andres Limestone. The main aquifer west of R. 21 E. is ground-water province A of this report (fig. 9). Ground

---

Figure 9.--Ground-water provinces of the main aquifer in the Hondo Member of the San Andres Limestone and Yeso Formation, and the San Andres Limestone, and comparative permeabilities of rocks in ground-water province A with those in ground-water province B, in part of the Roswell basin, New Mexico.

---

water in this province generally is unconfined (nonartesian); however, water may be confined under artesian pressure, beneath the Hondo in the vicinity of structural zones at places where the Hondo is highly silty. At the eastern boundary of ground-water province A the water table in the main aquifer intersects highly permeable beds in San Andres Limestone; from this boundary eastward to the Pecos River the main aquifer is referred to in this report as ground-water province B. The upper part of the San Andres Limestone is the important source of ground water in ground-water province B, although south of Artesia the water principally is in the Grayburg Formation. Aquifers in the Artesia Formation at places form a part of ground-water province B. Ground water in this province generally is unconfined from the western boundary of this province to within 10 to 20 miles of the Pecos River. At approximately this distance west of the river the water table intersects the base of beds of low permeability in the Artesia Formation. Water in ground-water province B from this point of intersection eastward is under artesian pressure.

Hydraulic properties of the main aquifer

Information is meager about the water-transmission and storage properties of much of the main aquifer. Hantush (1955, p. 28) estimated that the average coefficient of transmissibility of the aquifer in the recharge area (ground-water provinces of the Hondo and Yeso and the upper part of the San Andres) is approximately 75,000 gpd (gallons per day) per foot. This implies that 75,000 gallons of water per day would move through an average section of the aquifer 1 mile wide under a hydraulic gradient of 1 foot per mile. The value was computed from an estimate of the average annual recharge to the aquifer and the average slope of the water table in the aquifer.

Theis (1951, p. 2) estimated that the porosity of the main aquifer is about 4 percent in the principal intake area and that the porosity in the vicinity of Roswell is 5 percent or possibly higher. He estimated that the coefficient of transmissibility of the aquifer in this latter locality is between 1,000,000 gpd per foot and 3,000,000 gpd per foot.

Fiedler and Nye (1933, p. 145-146, 183-185, and pl. 1) concluded that the permeability of the main aquifer in five areas between Tps. 9 and 20 S. is greater than in the intervening areas-- based on a comparison of well yield and drawdown in wells. Their observations were made on wells tapping the main aquifer within the province of the upper part of the San Andres; no observations were made in the province of the Hondo and Yeso. They noted that the areas of apparent greater permeability are along major surface drainage lines. Where the permeability of the main aquifer is greater, the coefficient of transmissibility probably is greater also, as the coefficient of transmissibility is equal to the average permeability of the aquifer times its thickness.

Coefficients of transmissibility derived by Hantush (1955, p.29) from tests in a few wells in the artesian part of the ground-water province of the upper part of the San Andres were about 1,400,000 gpd per foot near Roswell, about 75,000 gpd per foot near Dexter, about 150,000 gpd per foot near Artesia, and about 66,000 gpd per foot near Lakewood. These tests were made in segments of the basin described by Fiedler and Nye (1933, p. 145-146, 183-185, and pl. 1) as areas of large yields from wells and areas of greater permeability than intervening areas. These coefficients can be used to make a general comparison between the transmissibility in one segment and that of other segments; however, the tests were too few and too widely spaced to give any assurance of a true sampling of the transmissibility in any one segment.

97

The average permeability of the main aquifer in the province of the Hondo and Yeso seems to be less than that of the province of the upper part of the San Andres. This difference is indicated by the smaller yield per foot of drawdown in wells in the province of the Hondo and Yeso than in the other province. The smaller yield-drawdown ratio is principally the result of lower permeability in the aquifer.

The water-transmission properties of the main aquifer in these two provinces is indicated also by a difference in hydraulic gradients between one province and the other. The average hydraulic gradient is about 70 feet per mile in that part of the province of the Hondo and Yeso shown on figures 9 and 10 and less than 10 feet per mile

Figure 10.--Contour map of the piezometric surface in the main

aquifer in part of the Roswell basin, New Mexico, 1958-59.

in the province of the upper part of the San Andres. The area having the lower hydraulic gradient has the higher transmissibility because the same or larger quantity of water must be moving through the province of the upper part of the San Andres as through the province of the Hondo and Yeso.

The permeability of the main aquifer is not uniform within the province of the Hondo and Yeso. The permeability of the aquifer in the province of the Hondo and Yeso along Fourmile and Vandewart-Cornucopia structural zones is above average for that province. The above-average permeability in the Fourmile structural zone probably resulted from fracturing of the Hondo Sandstone Member of the San Andres and Yeso Formation and, in places, by reef zones that cross the structural zone. This area of above-average permeability extends into the province of the upper part of the San Andres. Above-average permeability in the Vandewart-Cornucopia structural zone probably resulted from uplift of the upper confining bed in the Yeso Formation. In places along this structural zone, ground water has discharged from the Hondo Sandstone Member and Yeso Formation into large solution openings in the San Andres Limestone. The permeability may not be above average everywhere along this structural zone.

Causes of differences in hydraulic properties

in the limestone aquifer

The high permeabilities of rocks that compose the main aquifer
in the ground-water province of the upper part of the San Andres
are the result of the original structure, porosity, and sedimentary
characteristics of the carbonate rocks of Permian age; the position
of the carbonate-evaporite facies boundaries of the Permian shelf
rocks; and the erosion of Permian rocks in Tertiary and Quaternary
time.

Chemical and textural subfacies (the term "subfacies" is used
to differentiate rock units either by chemical composition or texture)
influenced the extent and amount of original porosity and permeability
of the carbonate rocks of Guadalupe and Leonard age in the shelf area.
The chemical and textural subfacies correlate to some extent. Adjacent
to the reef zone in most rocks of post-San Andres age, the deposits
of the carbonate facies primarily are coarse calcarenite and coquina,
and the composition is dominantly calcareous. Shelfward the coarse
calcareous materials grade into a fine-grained calcarenite whose
composition is dominantly dolomitic. Rocks having the greatest
original permeability and porosity are adjacent to the reef front.
Most of the reef and adjacent shelf rocks of the San Andres
Limestone probably have been dolomitized.

The deposition of Upper ~~late~~ Permian, Triassic, and younger rocks over

the rocks of the Leonard and Guadalupe Series protected the older rocks

from erosion. As a result, highly mineralized water probably was

entrapped in the zones of original porosity in the Permian rocks.

During the late Pliocene and Pleistocene, ~~Epochs~~ the Guadalupe and

Sacramento Mountains were uplifted, the San Andres Limestone was

exposed on the mountain slopes, and the Pecos River cut into the

younger rocks and broke the seal. The hydrostatic pressure of the

water entrapped in the rocks was increased considerably in the

Pecos Valley by the uplift. Water moved downdip by gravity and was

partly confined under pressure beneath the Artesia Formation, though

some water leaked upward through the Artesia Formation and drained

into the Pecos River. Much of the highly mineralized water west

of the river was flushed from the main aquifer by fresh water entering

the rocks on the mountain slopes. Water then had an entrance to,

a passageway through, and an outlet from the main aquifer.

As the mountains were uplifted and the level of the Pecos River was lowered, streams that drained areas of evaporite rocks formed on the east slope of the Sacramento Mountains. Few solution channels formed in the carbonate rock, and most of the water flowed over rather than infiltrated the surface. In addition, water infiltrating from the surface probably could not move to any great depth because of the entrapped highly mineralized water at shallow depth in the main aquifer. The Rio Hondo, the Rio Felix, and the Rio Penasco developed large drainage systems, which were superimposed on the carbonate rocks before the evaporite rocks were stripped from much of the area.

The evaporite rocks of the east slope of the Sacramento Mountains were stripped away, and a great amount of the carbonate rocks were dissolved along the present large drainage systems because infiltration of water was greater along the drainages.

High porosity and permeability developed in rocks of the main aquifer in the vicinity of boundaries of the carbonate-evaporite facies. The carbonate and evaporite facies of the San Andres Limestone and Grayburg Formation interfinger in the area of gradation between the gross carbonate facies and gross evaporite facies. Thus, for a given stratigraphic interval, dolomite generally grades into a sequence of dolomite interbedded with gypsum which grades into anhydrite. The upper part of the San Andres Limestone begins to grade into anhydrite a few miles north of Artesia (fig. 6), and farther to the north progressively more and more anhydrite is in the section.

The permeability of the San Andres Limestone is greatest in the Roswell area. Water that infiltrated from the Rio Hondo, Blackwater Draw, and Salt Creek probably caused much of the solution. The permeability is lower toward Artesia. The permeability of the San Andres Limestone north of Salt Creek is much lower than near Roswell. The relatively low permeability in this northern area may be related to the lack of streams. Precipitation on the Vaughn-Macho plain between Salt Creek and Vaughn flows short distances, usually in small rivulets or as sheet runoff, to ponds and small lakes in closed depressions, where much of the water evaporates and only small amounts enter the ground.

Recharge area of the main aquifer

The recharge area of the main aquifer is herein divided into seven subareas on the basis of rock type and surface-drainage features that might affect recharge. These subareas are shown on figure 8 and are referred to in this report as western limestone area, eastern limestone area, northern evaporite area, southern evaporite area, northern limestone area, eastern evaporite-alluvial area, and alluvial lowland area.

Western limestone area

The Sacramento plain and the western part of the Diamond A plain comprose the western limestone area. The western limestone area is underlaid primarily by carbonate rocks of the San Andres Limestone. Most of the area is highly dissected; however, some undissected remnants remain. Many of the undissected areas are structural benches in which sinkholes have formed. The deeper drainages have cut into the gypsum and red beds of the Yeso Formation within the western limestone area.

Precipitation is the only source of water entering the area. Precipitation on the western limestone area discharges from the area as runoff, discharges from the general land surface by evapotranspiration, infiltrates the rock surface to a depth below the zone affected by evapotranspiration, or drains to sinkholes.

109

The permeability of the San Andres Limestone on the surface
is moderate to low; water infiltrates principally through joints
and faults. Water that infiltrates this limestone surface and
passes to depth recharges either small perched bodies of water or
the main ground-water body in the province of the Hondo and Yeso.
Some of the water in the perched bodies percolates to the main
ground-water body, but much of it discharges as seeps and springs
in the canyons. In areas where deep canyons intersect the water
table of the province of the Hondo and Yeso, ground water discharges
from the main ground-water body to the stream channels and maintains
perennial flow. Some of the water reaching the water table may
move eastward in the province of the Hondo and Yeso into the
province of the upper part of the San Andres.

Some of the water that drains to sinkholes evaporates from
open water surfaces of lakes and ponds in the sinkholes, and some
water infiltrates to the subsurface through the bottom and sides
of the sinkholes.

The Pajarito sinkholes in T. 13 S., Rs. 16 and 17 E., and the
Mayhill sinkholes in T. 17 S., R. 16 E. (fig. 8), are the major
sinkholes in the western limestone area. The Pajarito sinkholes,
the largest sinkhole area in the western limestone area, consist of
approximately 100 sinkholes. This sinkhole area is on a structural
bench that is capped by carbonate rocks of the San Andres Limestone
and underlaid by sandstone and evaporite rocks of the Hondo and the
Yeso Formation. The sinkholes probably are the result of solution of
the evaporite rock in the Hondo Sandstone Member and Yeso Formation
and slumping of the overlying San Andres.

Red Lake, in secs. 9 and 10, T. 13 S., R. 16 E., and Deadman Lake, in sec. 25, T. 12 S., R. 16 E., are in the largest of the Pajariot sinkholes. Deadman Lake, the largest, is about 2,500 by 1,300 feet and has a drainage area of about 4 square miles. Red Lake is about 1,300 by 1,000 feet and has a drainage area of about 2 square miles. About 10 of the Pajarito sinkholes are from 17 to 22 acres in extent, and their drainage areas range from one-quarter to one-half square mile. The floor in most of the Pajarito sinkholes is between 20 and 40 feet below the general land surface.

About 10 sinkholes compose the Mayhill sinkholes. They range in size from a fraction of an acre to about 20 acres. The floor of the sinkholes ranges between 10 and 50 feet below the general land surface. The sinkholes were formed in carbonate rock of the San Andres Limestone.

The floor of most sinkholes in the western limestone area consists of silty sand, which is moderately permeable and silty clay, which has a relatively low permeability. If the permeability of the floor is high, water infiltrates the bottom and drains from the sinkhole in a few days. If the permeability is low, most of the water evaporates.

Infrequent observations were made of the approximate rate
that water discharged from sinkholes in Pajarito and Mayhill sink-
holes; the observations were made during air flights in 1958 and
1959. About 25 lakes in the Pajarito sinkhole area were full of
water on August 8, 1958; about the same number still contained
water on November 2, 1958; and by February 3, 1959, only 2 sink-
holes contained water. No water entered the sinkholes during this
period. Some of the water in these sinkholes was consumed by 6,000
to 8,000 cattle in that area. Mr. Fred Pellman of the Mescalero
Apache Tribe informed the senior author that 20 to 25 years ago
many of these sinkholes contained water throughout the year. This
probably can be attributed to greater precipitation rather than
lower permeability of the sinkhole floors at that time. The Mayhill
sinkholes reportedly filled with water during July and August 1958.
Four of these sinkholes contained water on November 2, 1958. On
February 3, 1959, all the sinkholes were dry. Mr. Fisher, a local
farmer, informed the senior author that if these lakes fill with
water in July and August, they generally hold water about 3 months.
He also reported that the maximum depth of the water in these
sinkholes is about 5 feet, as indicated by high-water marks on
fence posts in the sinkholes.

The great length of time that water remained in these sinkholes indicates that several tens of acre-feet of water are discharged by evaporation. Although large amounts of water enter the rocks of the western limestone area, and some additional water could be added by artificial recharge, probably only a small percent^{age} of the additional water would be effective recharge for the limestone aquifer in the Roswell-Artesia sector of the basin. Most of it probably would appear as seepage to streams in the western limestone area. The artificial-recharge potential of the area is poor.

Eastern limestone area

The upland surface of the Guadalupe Mountains and much of the eastern part of the Diamond A plain compose the eastern limestone area. North of State Highway 83, the eastern limestone recharge area is underlain primarily by carbonate rock of the San Andres Limestone; south of that highway the area is underlain primarily by carbonate rock of the Grayburg Formation. The ground-water province of the Hondo and Yeso underlies all the area except the extreme eastern part, which is underlain by the ground-water province of the upper part of the San Andres.

The area is highly dissected, and the drainage system is well integrated. In general, the interstream divides are sharp; however, there are a few small flat interstream areas. Sinkholes occur on some of the interstream areas. The Flying H sinkholes in T. 15 S., R 18 E., constitute the major sinkhole area. (See fig. 8.) The largest sinkhole of this group is about a third of a mile in diameter, and its floor is about 25 feet below the general land surface. This sinkhole is partly filled by silty sand and sandy silt and in places by a black organic silty clay.

Water enters the eastern limestone area directly as precipitation
and as surface and ground-water flow from the western limestone area.
The precipitation that neither evaporates from nor infiltrates the land
surface reaches stream channels quickly because of the sharp interstream
divides and well-integrated drainage. Little of the precipitation drains
to sinkholes. The permeability of the carbonate rock on the surface is
moderate to low, and surface water infiltrates these rocks primarily
through joints and faults. The amount of recharge to the main ground-
water body from the interstream areas probably is small. The main
ground-water body in the eastern limestone area is recharged principally
along the major streams. Much of the eastern limestone area was des-
cribed by Fiedler and Nye (1933, pl. 2) as being the principal recharge
area for the main aquifer. Recharge along the stream channels could
be increased if the streamflow could be retarded.

The quantity of water infiltrating to the subsurface through sinkholes in the eastern limestone area is relatively small, because the amount of water draining to them is small. The bottoms of the sinkholes in this area are relatively permeable, and water ~~then~~ goes underground quickly. Water accumulating in the Flying H sinkholes after thunder~~storms~~ *showers* discharges in 1 to 2 months, mostly to the subsurface.

The artificial~~-~~recharge potential of this area is moderate to good. Good sites for small dams would not be difficult to find. Dams constructed where their reservoirs would inundate the more permeable areas of the channel would increase the recharge from streams. If dam sites could not be found to impound water on the permeable areas, water could be impounded upstream from the more permeable areas and released at a rate that would increase the amount of recharge over that of uncontrolled flow in those areas. Diverting streamflow to sinkholes would increase recharge in the sinkhole areas. The greatest problem would be in getting the water from the streams to the sinkholes. A detailed study of *the recharge characteristics* Hope sinkhole in sec. 33, T. 16 S., R. 19 E. ~~to learn its recharge characteristics~~ is described in the section on water-loss studies in selected sinkholes.

Northern evaporite area

The extreme southern part of the Vaughn-Macho plain composes the northern evaporite area. The area is characterized by areas of rolling hills and valleys, broad flats, and well-integrated drainage. Sinkholes are numerous but localized by structural and lithological variations in the evaporite rocks.

The northern evaporite area is underlain by rocks of the evaporite facies of the San Andres Limestone and, to a minor extent, by evaporite facies of the Artesia Formation. The permeability of the surface and subsurface rock is moderate to high. Many of the hills are capped by carbonate rocks and underlain by gypsum that is poorly resistant to erosion.

Some of the hills are expressions of anticlines. The cores of some of the anticlines consist of gypsum in which water has dissolved channels and caverns. Large solution channels in the gypsum and older solution channels that are filled with angular slump and detrital material occur along the Sixmile Hill structural zone.

Water enters the northern evaporite area as precipitation and surface- and ground-water flow from the eastern limestone area and adjacent parts of the Vaughn-Macho plain. Much of the precipitation on the interstream areas is discharged by evapotranspiration, and some infiltrates to the subsurface. Most of the precipitation that is not discharged by evapotranspiration drains to stream channels and sinkholes.

117

Blackwater Draw, Salt Creek, and the tributaries of Cienega del
Macho drain a large part of the northern evaporite area as well as
transport water into this evaporite area from upstream sources. These
drainages lose a considerable amount of water by infiltration in the
northern evaporite area. Small cavelike solution holes are common in the
channels of several drainages, and streamflow enters the subsurface
readily through these openings. Quantitative studies were not made to
determine the amount of loss; however, the seepage loss per mile of
channel probably is greater in the northern evaporite area than in
other parts of the project area.

In some areas silt beds at shallow depth prevent the deep percola-
tion of water entering the ground. At places, streamflow entering the
subsurface through the solution holes in the channel reappears as stream-
flow emerging from other solution holes in the channel downstream.
This was observed in Middle Arroyo, where flow disappeared in solution
holes in sec. 19, T. 7 S., R. 21 E., and reappeared about 1,000 feet
downstream. Wet-weather springs are numerous in the northern evaporite area.

The permeability of the floors in sinkholes in the northern evaporite
area ranges from very low to high. Many sinkholes floored by thick silt
beds of low permeability have solution channels in the sides. The solu-
tion channels in the side of a sinkhole may be from a fraction of a foot
to a few feet above the floor, and a considerable volume of water ponds
on the floor before the water surface reaches the mouth of the solution
channel. If the permeability of the floor is very low, most of the water
ponded below the level of the channel mouth is discharged by evaporation.

118

The artificial-recharge potential of the area is good and *to excellant,*
recharge to the ~~limestone~~ *main* aquifer might be increased substantially
in the northern evaporite area. All ~~of~~ the streamflow in the
major drainages that cross the area is not lost within the
northern evaporite area; therefore, more water might be put
underground if the flow could be impounded and then released at a
rate that would infiltrate the permeable streambeds. The stream
channels are narrow, and reservoir capacity behind a dam would be
small, consequently numerous dams would be required to provide
sufficient storage capacity.

Some streamflow could be diverted to sinkholes having
permeable floors; however, the sinkholes selected should be in
areas where the water put into the subsurface would not emerge
from solution holes in nearby stream channels. Sinkholes ~~located~~
(where streamflow could be diverted to them easily) ~~but~~ floored by
material of low permeability probably could be used for artificial
recharge if recharge wells were constructed in the sinkholes. Some
sinkholes in which large quantities of water pond ~~before some water~~
~~can enter~~ *below the level of* solution channels in the sides ~~of the sinkhole~~ probably
could be made more efficient recharge points by lowering the mouths
of the solution channels.

119

Southern evaporite area

Both segments of the Embayment plain and a small part of the lowland area compose the southern evaporite area. The surface of the area is characterized by shallow swales and gently rounded hills. The drainage is well integrated. Collapse and broad-depression sinkholes are common on the interstream areas; however, the broad depression is the most common. Most of the broad depressions are open sinkholes because of solution channels in their floors.

The main aquifer in the southern evaporite area is a part of the ground-water province of the upper part of the San Andres. The transmissibility of the aquifer in the southern evaporite area seemingly is higher in the northern part than in the southern part. The reason for this difference is not entirely clear; however, it may be the result of a greater thickness of aquifer and more brecciated zones in the northern part.

The southern evaporite area is underlaid primarily by rocks of the middle and lower parts of the Artesia Formation (equivalents of the Seven Rivers, Queen, and Grayburg Formations) and to a minor extent by evaporite rocks of the San Andres Limestone. Gypsum is the major constituent of the rocks of the southern evaporite area. The permeability of the carbonate rocks is relatively high in parts of the area because of interformational breccias consisting of angular to subangular blocks of carbonate material in a calcareous silty matrix. Solution by water readily removes the carbonate and creates many interconnected channels in the brecciated zone.

Water enters the area as precipitation and surface- and ground-water flow from the eastern limestone area. Some recharge to the main ~~limestone~~ aquifer is from precipitation infiltrating the surface of the interstream areas; however, most of the recharge is from water that reaches sinkholes and stream channels. Considerably more water recharges the aquifer through streambeds than through sinkholes.

The streams in the area are not gaged; therefore, the discharge of surface water is unknown. None of the streams are perennial within the southern evaporite area, and most of the streamflow originates from precipitation on areas upstream. Much of the streamflow entering the area is depleted by infiltration within the southern evaporite area. Estimates were made of streamflow losses in Rio Penasco and Fourmile Draw after a thunderstorm on May 7, 1959. Streamflow estimated to be between 80 and 90 cfs (cubic feet per second) was lost by infiltration in the bed of Rio Penasco in a 1-mile reach within secs. 16 and 21, T. 17 S., R. 21 E. Streamflow estimated to be about 200 cfs diminished to about 125 cfs in an 8-mile reach downstream from sec. 22, T. 18 S., R. 20 E. (this 8-mile reach is within the eastern limestone area), and disappeared completely in a total channel distance of about 14.5 miles (the last 6.5-mile reach is within the southern evaporite area). Much of the water lost from streamflow enters the alluvium in the streambed and then infiltrates the underlying evaporite rocks. Parts of some streambeds are directly on the evaporite rocks, that contain solution channels, through which the streamflow disappears underground. A local rancher reported that small streamflows will not get past solution openings in the bed of Johnston Draw in the NE$\frac{1}{4}$ sec. 23, T. 16 S., R. 21 E.

122

Antelope, Tank Mill, and Fanning sinkholes (fig. 8) form the three largest groups of sinkholes in the southern evaporite area. Antelope sinkholes are in a 4-square-mile tract in T. 18 S., R. 23 E.; however, most of the sinkholes in this group, including the largest of the group, are entirely within sec. 23, T. 18 S., R. 23 E. The Antelope sinkholes are actively growing as indicated by fractures around them. Their growth is by subsidence as a result of solution of the gypsum bedrock. During growth, some sinkholes have joined and formed one large compound sinkhole. One compound sinkhole of the Antelope group has an area of about 0.4 square mile. The material on the floor of many of the sinkholes in the Antelope group is a granular coarse-grained silt that is friable. The permeability of this material is moderately high. Much of the water entering the Antelope sinkholes goes underground quickly, generally in less than 1 month, because of the permeable material and solution channels in their floors.

In general, the material flooring the Tank Mill sinkholes (T. 18 S., R. 24 E.) probably is less permeable than that of the Antelope sinkholes. Some of the sinkholes having floors of low permeability are adjacent to sinkholes having highly permeable floors. When the sinkholes having low permeability floors of become filled with water, the overflow may drain into nearby sinkholes having more permeable floors.

The Fanning sinkholes in T. 22 S., R. 22 E. consist of about 10 sinkholes. Bone Tank (T. 21 S., R. 23 E.) and Tule Lake (T. 22 S., R. 23 E.) are two of the largest in the southern evaporite area. Bone Tank sinkhole is about 1,800 feet long and 800 feet wide; Tule Lake sinkhole is roughly square, and each side is about 1,000 feet long. These were not visited but were observed from an airplane.

The artificial-recharge potential of the area is good to excellent. The larger sinkholes in the southern evaporite area generally hold water for less than 2 weeks and rarely for more than a month. The amount of water that would be saved from evaporation by putting the water underground faster artificially by wells probably would be too small to justify the construction of recharge wells in sinkholes of the southern evaporite area. It might be advantageous, however, to construct drains and channels in some of the larger sinkholes to connect ponds within a sinkhole to openings in the sinkhole. Dams either to impound water in permeable areas of stream channels or to divert water from streams to sinkholes may be feasible in the western part of the area. Streambeds in the eastern part of the southern evaporite area are broad and shallow; therefore, few places would be satisfactory for dams and reservoirs.

Some of the water infiltrating to the subsurface in the southern part of the area enters an upper aquifer in the Grayburg and Queen Formations and moves southeastward from the Roswell basin into the Carlsbad area. This water is not effective recharge to the Roswell-Artesia sector.

124

Northern limestone
~~Western carbonate~~ area

The western part of the Vaughn-Macho plain comprises the northern limestone area. The northern part ~~of the northern limestone area~~ has no integrated drainage, and drainage is internal to numerous sinkholes. The southern part of the northern limestone area is well dissected by streams. A surface drainage divide (fig. 8) is between the northern area, which has internal drainage, and the southern area, which has well-integrated drainage. Precipitation directly on the northern limestone area is the only water entering the area. Much of the precipitation evaporates from the land surface, some infiltrates the surface, and some drains to sinkholes and stream channels. Most of the recharge to the ground-water body is *by infiltration* ~~seepage~~ through sinkholes and streambeds.

Carbonate rocks of the San Andres Limestone are exposed in the area except where they are covered by a veneer of soil and gravel. The carbonate rocks are 450 to 650 feet thick in the southern part of the area and thin northward to ~~a thickness of~~ about 20 to 30 feet near Vaughn. Generally, the carbonate rocks of the San Andres Limestone are more permeable than the sandstone, siltstone, and evaporite rocks of the underlying ~~Glorieta~~ *Hondo* Sandstone *Member* and Yeso Formation.

125

Sinkholes are more common in the northern limestone area than in any other part of the recharge area of the ~~limestone~~ main aquifer. Although sinkholes are scattered throughout the area, they are more numerous and closer spaced in the following four major groups: Vaughn sinkholes, Richards sinkholes, Hasparos sinkholes, and Bogle sinkholes. (See fig. 8.) The northern limestone area was not studied in detail, and most observations of the sinkholes were made from an airplane and by studing aerial photographs; ~~consequently, the following descriptions of the sinkholes as to origin and size may be subject to some error.~~ The sinkholes ~~appear~~ seem to be of the collapse and broad depression type, and many have solution openings in their sides and floors. The diameter of the sinkholes in the Vaughn group ranges from 100 to 1,000 feet. Within the Vaughn group, sinkholes occupied less than 10 percent of the land in some parts, whereas in other parts, sinkholes occupies about 50 percent of the land. Sinkholes in the latter area are circular, are bottomed with green vegetation, and ~~appeared~~ seem to be deeper than those in areas in which the areal density of sinkholes is less. No attempt was made to compare physical characteristics of sinkholes in the Richards, Hasparos, and Bogle groups.

Two less well defined sinkhole areas, the Western and Eastern Capitan sinkholes, are a few miles north of Capitan Mountain (fig. 8). Samples of soil from the floors of the Eastern Capitan sinkholes consist of a poorly permeable silty clay.

The permeability of the materials flooring the Vaughn, Richards, Hasparos, and Bogle sinkholes was inferred from observation of the length of time water remained in the sinkholes after rains. The conclusions are approximate because flights were not made over the area after each rain. Many of the Vaughn sinkholes contained water in the period July-December 1958, and were dry by early February 1959; consequently, the permeability of the floors probably is relatively low. None of the Richards, Hasparos, and Bogle sinkholes contained water, although sinkholes adjacent to these three major sinkhole areas contained water after heavy rains in July and August 1958. The floors of the Richards, Hasparos, and Bogle sinkholes probably are highly permeable.

A considerable volume of water is evaporated from sinkholes floored by material of low permeability. Recharge wells constructed in the larger sinkholes of the Vaughn group and other sinkholes in which water ponds and evaporates would increase the recharge in the northern limestone area. Many sinkholes have solution openings that are higher than much of the floor. Water ponded in the sinkholes below the solution openings could be drained underground by lowering the mouths of the solution openings and constructing drain channels to these openings.

In that part of the northern limestone area having well-integrated drainage, dams could be constructed on some streams either to impound water over a permeable area or to divert water to sinkholes. The southern half of the northern limestone area seems to be well suited to artificial recharge because of the great thickness of the San Andres Limestone. The artificial-recharge potential of the northern limestone area seems to be moderate to good.

Eastern evaporite-alluvial area

The eastern part of the Vaughn-Macho plain composes the eastern
evaporite-alluvial area. The area is underlain by evaporite rocks
of the San Andres Limestone and younger rocks of Permian age and
by alluvium of probable late Tertiary age. The areas of evaporite
rock and areas of alluvium are not differentiated on figure 8.

Drainage is well integrated in much of the area; however, in the
northwestern part of the area drainage is internal to sinkholes. Some
water drains to sinkholes on the interstream areas.

Precipitation on the area and surface- and ground-water flow to
the area from the northern limestone area are the sources of water.
Water moving downward may enter aquifers at shallow depth in the alluvium
and Artesia Formation and then move eastward and discharge as seeps
and springs along the Pecos River. Little is known about these shallow
aquifers. In general, water moving to the subsurface in the western
part of the area probably recharges the main aquifer, and the water
moving to the subsurface in the eastern part recharges the shallow
aquifers.

Sinkholes are common in the eastern evaporite-alluvial area. Broad-depression sinkholes that have solution holes in their floors drain water to the subsurface quickly (large solution holes are in Lewis sinkhole T. 4 S., R. 22 E.), whereas water ponds and evaporates from broad-depression sinkholes floored by material of low permeability. The Steel, Wright, and Yeso sinkholes (fig. 8) comprise the major sinkhole areas; however, there are many isolated sinkholes throughout the eastern evaporite-alluvial area. The area was studied principally during flights over the area.

The possibilities for recharge of the main aquifer by artificial means are poor in the eastern evaporite-alluvial area. In the western part of the area some additional water could be put underground through recharge wells and by channeling water to solution channels within these sinkholes. Some water might be diverted to sinkholes in the western part of the area.

130

Alluvial lowland area

The alluvial lowland is not a natural recharge area for the main aquifer because water spread on the ground cannot move downward from the land surface to the main aquifer in that area. The natural hydraulic gradient is upward from the main aquifer to the alluvial aquifer. Water could be induced to enter the main aquifer through recharge wells in the alluvial lowlands.

The altitude of the artesian-pressure surface of water in the
main aquifer in the alluvial lowland might make certain areas
of the lowland more favorable than others for recharge wells. In
areas where the artesian-pressure surface is near the land surface,
water would have to be pumped into the well under pressure to
reverse the pressure gradient in the well. This would be necessary
in wells near the Pecos River in the vicinity of Roswell. Where the
artesian-pressure surface is several feet below the land surface,
water discharged into the mouth of the well would move downward into
the aquifer by gravity. Recharge wells south of Dexter would be in
this category.

The most favorable sites for recharge wells in the alluvial
lowland would be in the western and southern halves, where the water
level would be several tens of feet below the land surface.

Movement of water in the main aquifer

The direction of water movement and the rate that the water or
the pressure effects move are important factors to consider in selecting
recharge sites for the main aquifer. The pressure effects move much
faster than the water. Favorable recharge sites are those where the
recharge would increase the artesian pressure in the Roswell-Artesia
sector of the basin within a reasonable length of time and the recharged
water could move to the artesian aquifer without gaining an undesirable
concentration of dissolved solids.

If the main aquifer is recharged at a site overlying the nonartesian part of the aquifer, the rise in the water table as the result of recharge will cause some rise in the artesian pressure in the Roswell-Artesia sector long before the water reaches the artesian part of the aquifer. The difference between the travel time of the pressure effect and that of the water may be days, months, or years depending in part on the distance of the recharge site from the artesian part of the aquifer in the Roswell-Artesia sector. In general, the closer the recharge site is to the artesian part the less time it will take for the recharge to benefit the artesian part of the aquifer.

The arrows in figure 8 represent the general direction of ground-water movement. The water that enters the main aquifer in the northern quarter of the northern limestone area and the northern half of the evaporite-alluvial area probably moves east of the Pecos River and then southward, rather than directly to the Roswell-Artesia sector. Water entering the main aquifer in the southern quarter of the eastern limestone area and in the southern half of the southern evaporite area may be intercepted by wells in the Dayton-Lakewood area, but some probably moves out of the Roswell basin underground and discharges from Major Johnson Springs. Most of the water that enters the main aquifer at other points eventually reaches some part of the Roswell-Artesia sector. Artificial recharge to the main aquifer at sites within the alluvial lowland would be effective immediately in the Roswell-Artesia sector.

~~The selection of the next most favorable area with respect to distance would depend on which particular part of the Roswell-Artesia sector was to be benefited first.~~ In the Roswell-Dexter area, where the encroachment of saline water has been most pronounced, benefits from recharge would arrive faster from recharge sites in the northern evaporite area, the northern half of the eastern limestone area, and the extreme southern part of the eastern evaporite-alluvial area. The benefits from artificial recharge would arrive quicker in the area between Dexter and Lakewood from recharge sites in the southern evaporite area and the eastern limestone area; however, water recharged to the upper aquifers of the Grayburg and Queen Formations would move eastward from the Roswell basin. Most of the western limestone area, the northern limestone ~~western carbonate~~ area, the eastern evaporite-alluvial area, and the western half of the eastern limestone area probably are too remote to be considered for ~~some of the~~ initial sites for artificial recharge. Sites in those areas would not be excluded because of distance in a complete and long-term program of artificial recharge for the basin.

135

The velocity at which water moves through an aquifer is directly proportional to the permeability and hydraulic gradient and inversely proportional to the porosity of the aquifer. Because of the relatively high permeability of the main aquifer in the vicinity of some of the major drainages, artificial recharge in parts of those areas might reach the pumped area as quickly as recharge in areas closer where the permeability is less. Distance, permeability, hydraulic gradient, and porosity of the aquifer should be considered together in evaluating sites for artificial recharge.

Alluvial aquifer

The alluvial aquifer is within the alluvial-lowland area shown
on figure 8. The alluvium is not saturated in the western part of
the alluvial-lowland area. The alluvial aquifer consists of irregular
beds of gravel, sand, silt, and clay. The various beds of gravel
and sand are in part poorly connected, but these permeable beds
probably are sufficiently interconnected to form a common aquifer.

Occurrence of water in the alluvial aquifer

Water in the alluvial aquifer generally is not confined, although
it may be confined locally by beds of silt and clay.

The average thickness of the alluvium in the alluvial lowland
is about 150 feet, but the average thickness of the zone of saturation
is considerably less. The depth to the water table ranges from a
fraction of a foot near the Pecos River and the lower reaches of
major tributaries to more than 100 feet in the western part of the
aquifer and in some areas of heavy withdrawal south of Hagerman. The
water table in the alluvial aquifer is being lowered further each
year in the areas of heavy withdrawal.

138

Hydraulic properties of the alluvial aquifer

Hantush (1955, p. 27) used several irrigation wells that tap the alluvial aquifer for aquifer tests and computed an average coefficient of transmissibility of about 100,000 gpd per foot for the part of the aquifer near those wells. The coefficients obtained from the tests by Hantush ranged from 36,000 to 139,000 gpd per foot. A few tests made during the study period of this report indicated a wider range in coefficients of transmissibility in the alluvial aquifer. The transmissibility of the aquifer varies within relatively short distances probably because of the erratic occurrence of gravel, sand, and silt. Transmissibilities probably are larger near major streams crossing the alluvial lowland than in the interstream areas.

The apparent wide range in transmissibility of the aquifer is reflected in the wide range in well yields in relatively small areas. Irrigation wells in use yield from less than 500 gpm to as much as 1,500 gpm; the average yield is between 800 and 1,000 gpm. Specific capacities between 10 and 80 gpm per foot of drawdown, and averaging between 40 and 50 gpm per foot of drawdown, were obtained during a random sampling of wells in the alluvium. These yields probably are reasonable indicators of the range in rates at which water can be recharged through wells to the alluvial aquifer. Sites for large-capacity recharge wells probably would not be too difficult to find in spite of the apparent large differences in the aquifer's hydraulic properties from place to place.

Recharge to the alluvial aquifer

The recharge area of the alluvial aquifer in the Roswell-
Artesia sector is the alluvial lowland. Natural recharge to the
alluvial aquifer consists of (1) artesian water leaking upward
through the Artesia Formation from the main aquifer; (2) infiltration
of irrigation water applied to cultivated fields; (3) infiltration
of surface water from stream channels and flood plains; (4) infiltra-
tion of precipitation on the land surface; and (5) ground-water flow
entering the area in the alluvium of stream channels. Only inducing
more infiltration of precipitation and surface water could increase
the ground-water supply.

Infiltration of water to the alluvium is governed in large part
by (1) water-infiltration characteristics of the alluvium, (2) topo-
graphy of the alluvial surface, (3) thickness of the alluvium, and
(4) location in relation to the Pecos River and its tributaries.

Factors affecting water infiltration of the alluvium

In the arid climate of the Roswell basin, geologic processes retard and, in places, prevent the passage of water from the land surface to the water table in alluvial deposits. Particularly, the formation of caliche tends to reduce the amount of recharge.

In general, caliche forms when water removes calcium carbonate from the soil in the "A" horizon (the zone of leaching in the soil) and deposits it in the "B" horizon (the zone of deposition in the soil); therefore, the accumulation of caliche in the "B" horizon depends on a source of calcium carbonate in the "A" horizon and sufficient movement of water through the "A" to the "B" horizon without much water passing below the "B" horizon. Soils in the Roswell basin are rich in calcium-bearing materials. When the quantity of water is sufficient to pass through the "B" horizon, some of the calcium carbonate is leached from that horizon and carried to greater depth.

The thickest caliche deposits are in undrained areas, recent flood plains, near the apex of alluvial fans, on floors of intermittent streams, and in some irrigated areas--these are areas where water in addition to direct precipitation is available to further the weathering processes.

Caliche in interstream areas in the alluvium of the Blackdom, Orchard Park, and Lakewood terraces, *is the cause of* ~~has resulted in~~ differences in permeability and infiltration capacity of soils of those terraces. Soils underlying the Blackdom and Lakewood terraces are, in general, more permeable than those underlying the Orchard Park terrace.

A sample of the silty clay and caliche cap (fig. 11) that

Figure 11.--Particle-size distribution in soil samples from

the "B" horizon of Blackdom and Orchard Park terraces.

---

forms the "B" horizon of the soil of the Blackdom terrace contained
47 percent clay and 36 percent silt. The permeability of such materials
is relatively low and has been decreased further by cementation with
calcium carbonate. Solution channels ranging in diameter from a
fraction of a foot to several feet have formed in this cap on the flanks
of hills, and surface water enters these openings readily.

Soils underlying the Lakewood terrace have, at places, a well-
developed "B" horizon consisting of clay and silt; at other places
the soils have a poorly developed "B" horizon. The permeability of
the soils of the Lakewood terrace probably has a greater range than that
of the other two terraces.

Much of the Orchard Park terrace is underlain by a relatively
thick "B" horizon consisting of clay and caliche. The permeability of
this material is low and is further decreased by cementation.

Most of the irrigated land of the Roswell-Artesia sector is
on the Orchard Park terrace, and the low permeability of the soil
prevents a high rate of recharge to the alluvial aquifer as seepage
loss from irrigation water. Hantush (1955, p. 57) estimated that
about 20 percent of the irrigation water applied to the land
recharges the alluvial aquifer. This estimate may be too large.
After comparing samples of the "B" horizon of Reeves loam with
samples of similar lithology having a known coefficient of
permeability, the coefficient of permeability of the "B" horizon
of Reeves loam was estimated to be about 0.01 gpd per square foot.
Computations based on this coefficient indicate that the recharge
from irrigation water probably is 10 percent or less of the water
applied.

The development of caliche in the "B" horizon reduces the
infiltration capacity of soils in interstream areas, and cementation
of gravel, sand, and silt in streambeds in the alluvium by calcium
carbonate reduces the infiltration capacity of those streams.
Surface water in contact with large volumes of calcareous rocks
takes quantities of calcium carbonate and calcium bicarbonate into
solution. Calcium carbonate precipitating from solution where
water accumulates and evaporates along intermittent streams cements
the streambed materials and forms hard, relatively impermeable
conglomerate. Conglomerate formed in this manner is common in the
streambeds of the Roswell basin.

The cemented cementation of gravel, sand, and silt also is present occurs in the
alluvium, at depths below the "B" horizon beneath streamways. The
downward percolation of water is obstructed at places by confining
beds of silt and clay. If the downward movement of water is stopped
at a shallow depth, the water may accumulate and evaporate. The
deposition of calcium carbonate further lowers the permeability of
the bed. The accretions of calcium carbonate may fill the beds of
gravel and sand to the extent that the material becomes a hard cemented
conglomerate. Later, water may form solution channels in the
conglomerate similar to those in limestone. These processes of
cementation and solution probably produce the greatest differences
of permeability between the areas underlying streams of large flow
and the areas underlying streams of small intermittent flow. The
permeability is greatly reduced in the areas underlying the smaller
streams.

The amount of recharge from streams has not been determined, but quantitatively, however, it may not be as large as generally believed. Long reaches of the main tributary streams crossing the alluvium are silty in places and apparently of low permeability. Rio Felix, one of the largest and deepest of the streams crossing the alluvial recharge area, is underlain at places by well-rounded sand and gravel that is relatively permeable. At other places the sand and gravel is relatively impermeable owing to a matrix of silt and clay.

Two normally perennial ponds and an intermittent pond lie above the water table in poorly permeable parts of the Rio Felix channel. The largest of the perennial ponds, in the NW$\frac{1}{4}$ sec. 29, T. 14 S., R. 23 E., is from 400 to 500 feet long, 40 feet wide, and in places is from 5 to 10 feet deep. The other perennial pond is 2 miles upstream, in the SE$\frac{1}{4}$ sec. 25, T. 14 S., R. 22 E., and is 600 to 750 feet long and 7 to 8 feet deep. A local rancher reported that the latter pond normally holds water all year; however, during the drought in the early 1950's it was dry. An intermittent pond, in the NE$\frac{1}{4}$ sec. 22, T. 14 S., R. 23 E., holds water during and after floods. In October 1958, this pond was 800 feet long, 5 to 6 feet deep, and about 50 feet wide. Other temporary ponds, lasting from 1 to 2 months, form along the channels of the Rio Felix, Rio Penasco, Seven Rivers, and Rio Hondo after large floods. The channels of the smaller streams also have many impermeable reaches on which water accumulates in ponds after floods. Infiltration of water from the smaller tributaries seems to be much less per unit wetted area than that from the larger streams.

147

The apparent poor infiltration characteristics of interstream
areas and ~~in~~ *of* long reaches of the streams crossing the alluvial lowland
indicate that artificial recharge by ponding water on the land surface
in those areas would not be efficient. Much of the water would be
~~lost by~~ evaporat~~ion~~ *ed*. Periodically scarifying these surfaces in areas
where a surface-water supply is available for recharge might increase
the water-infiltration potential of those areas. Additional study
would be necessary to evaluate the feasibility of such an operation.

Topographic features that affect recharge of the

alluvial aquifer

Topographic
~~Surface~~ features have a bearing on the recharge characteristics
of the alluvial lowland. Most of the lowland is on the Blackdom and
Orchard Park terraces; a minor part is on the Lakewood terrace.
Topographic features superimposed on the terraces are broad shallow
swales and depressions, some sinkholes, broad flood plains along
drainages tributary to the Pecos River, and stream channels that are
entrenched a few feet below the flood plains. Swales and depressions
are very shallow, but at ~~and in~~ many places they are ~~[are]~~ more than 1,000 feet wide, ~~but~~
and extend/ing downslope several miles.

Most of the sinkholes are dry much of the time, although some
contain small perennial lakes. Lake Van and several of the Bitter
Lake sinkholes (fig. 8) contain water all year; Prichard Lake
sinkholes contain water diverted from the lower end of the Hagerman
Canal; and Juan Lake, Felix, and Clarks Lake sinkholes contain water
only after heavy rains in their vicinity.

149

Most of the sinkholes in the alluvial lowland are less than 200 feet in diameter and are shallow; however, a few are large. The relatively long time that water remains in the sinkholes after rains indicates that much of the water in sinkholes in the alluvial area is evaporated. Studies made of infiltration and evaporation of water from Juan Lake sinkhole in the alluvial area are described in the section on water-loss studies in selected sinkholes.

Many of the streams in the alluvial area have flood plains 1,000 to 3,000 feet wide, and overflow onto the flood plains is common. The inability of the stream channels to contain flood flows is more pronounced on the east side of the alluvial lowland than on the west. The permeability of the flood plains is low, and much water is lost from them by evaporation and transpiration. Drainages such as Thirteenmile Draw, Greenfield Draw, and Eagle Creek do not have well-defined channels in their lower reaches near the Pecos River. Floods in such drainages spread over large areas and damage croplands.

Western limit of the recharge area of the alluvial aquifer

The alluvium is thin in much of the western part of the alluvial
lowland, and the saturated alluvium does not extend to the western
margin of the lowland. Most of the water that infiltrates the alluvium
in that area passes through the alluvium to the underlying Artesia
Formation and the San Andres Limestone, and only a small part of the
water moves eastward in the alluvium.

Bottom lands of the Pecos River and lower reaches of its tributaries

Most of the water that enters the alluvial aquifer in the bottom
lands of the Pecos River and its tributaries in the Roswell-Artesia
sector is discharged in a relatively short time, either through seeps
and springs to those drainages or as evapotranspiration. The water
table of the alluvial aquifer intersects the channels of the Pecos
River and the lower reaches of its major tributaries. Dense growth of
saltcedar and other water-loving vegetation consume large quantities of
water annually, much of which is obtained directly from the capillary
fringe above the water table. Additional recharge to the alluvial
aquifer that would increase the natural discharge of ground water would
not add to the usable water supply in the aquifer; and, therefore, the
bottom lands would be poor areas for artificial recharge of the alluvial
aquifer.

152

Possibilities for artificial recharge of the alluvial aquifer

The widespread caliche at shallow depth in the interstream
areas, materials in streambeds, and the low permeability of sinkhole
floors would retard recharge to the alluvial aquifer except through
artificial openings. The location of recharge wells would not be
limited to any one part of the alluvial lowland but could be anywhere
that an irrigation well can be developed in the alluvial aquifer.

Water injected through wells to recharge the alluvial aquifer
should be free of suspended sediment and algae-forming bacteria that
eventually would clog the well screen and aquifer near the well if
not removed from the water. If recharge wells were constructed in
sinkholes, the sinkholes could serve as natural settling basins for
the sediment; however, settling and filtering basins could be
constructed where needed.

153

Water-loss studies in selected sinkholes

Studies of infiltration, evaporation, and chemical quality of water were made at four sinkholes--Juan Lake, Hope, Marley, and North Marley (fig. 8). These sinkholes were chosen for study because of their area, depth, and accessibility.

Topographic maps were prepared of these sinkholes. Staff gages installed in the sinkholes were read periodically to measure the change in water level. Samples of the alluvial sediments underlying the floor of the sinkholes were collected by augering and were analyzed for particle size and permeability. Samples of the water ponded in the sinkholes were collected periodically and analyzed to determine kinds and concentrations of chemicals dissolved solids in the water.

The topographic maps of the sinkholes (fig. 12) do not include

---

Figure 12.--Topographic map of Juan Lake, North Juan Lake,

Marley, North Marley, and Hope sinkholes, Roswell basin,

New Mexico.

---

the entire sinkhole. Only that part of a sinkhole was mapped that seemed appeared likely to be inundated by water during the study period. The contours for the topographic map of Marley sinkhole are referenced to mean sea-level because a bench+mark of known altitude was near the sinkhole. Contours shown on maps of the other sinkholes are referenced to assumed datums.

The volume of water that would be in a sinkhole at various altitudes of the water surface was computed from the contour maps. A graph was prepared showing the volume of water the sinkhole would contain at various contour altitudes. The volume of water in the sinkhole was determined by periodic readings of the water-surface altitude, ~~on a staff gage that was installed in the sinkhole for the period of study~~ A second graph was prepared showing the volume of the water in the sinkhole in respect to time, ~~within the study period.~~

The loss of water from the sinkhole was considered to be entirely by infiltration and evaporation. Infiltration was not measured directly but was computed as the difference between total water loss and water loss by evaporation. The evaporation rate from Juan Lake and Marley and North Marley sinkholes was computed as 0.7 of the evaporation rate that was measured in an evaporation pan near Bitter Lake, northeast of Roswell. The evaporation rate from Hope sinkhole was computed as 0.7 of the rate from a pan near Lake Avalon, south of Artesia. The rate of evaporation from water standing in sinkholes may be more than 0.7 of the pan evaporation. Additional studies are needed to determine a more nearly exact evaporation rate.

155

Juan Lake sinkhole

Juan Lake sinkhole is in secs. 30 and 31, T. 12S., R. 23 E.,
in the western part of the alluvial lowland area (fig. 8). Most of
the water enters the sinkhole from Thirteenmile Draw, which has
about 20 square miles of drainage area upstream from the sinkhole.
Water flows in Thirteenmile Draw only after moderate to heavy precipita-
tion on its drainage area. Apparently, all the water from small
flows drains into Juan Lake sinkhole, but some of the water from large
flows bypasses the sinkhole.

Test holes were augered 10 to 13 feet into the floor of Juan
Lake sinkhole to obtain samples of the fill. None of the holes
penetrated the full thickness of the fill. Analyses of these samples
indicated that the fill is a uniform dark-brown to black clay and
silty clay. (See table 3, test hole 12.) The clay has high plasticity,
compactness, and cohesiveness, and a high dry-breaking strength.
Laboratory tests using variable head permeameters indicated that the
coefficient of permeability of the alluvial fill is about 0.01 gpd
per square foot. This low permeability is the result of the high
percentage of clay (58 percent) and fine silt (29 percent) in the fill.
(See fig. 13.)

Figure 13.--Particle-size distribution in soil samples of

alluvium in Marley, North Marley, and Juan Lake sinkholes.

Juan Lake sinkhole filled with water to the 52-foot contour
(fig. 12) would have 995 acre-feet of water, a water surface area
of 236 acres, and a maximum depth of 9 feet. When the water level
in the sinkhole rises above the 52-foot contour, water spills
northward into North Juan Lake sinkhole. North Juan Lake filled to
the 46-foot contour would have 130 acre-feet of water, a water surface
area of 17 acres, and a maximum depth of 11 feet.

Although water entered Juan Lake sinkhole in September 1958,
observations of the water level in the sinkhole were not started
until October 9. The water level on that date was 46.31 feet.
Figure 14 shows the change in volume of water in the sinkhole from

Figure 14.--Depletion of water in Juan Lake sinkhole by
evaporation and infiltration in the period October 1, 1958
to March 7, 1959.

October 1, 1958, to March 7, 1959; the graph was extrapolated to
include the period October 1-9. Approximately 33 acre-feet of water
or about 30 percent of the amount in storage on October 1 was evaporated,
and 87 acre-feet or 70 percent infiltrated the bottom of the sinkhole.

Infiltration data obtained for the area of the sinkhole
inundated during the study period probably should not be extrapolated
to the area of the sinkhole above the high water level of the study
period. The surface material ~~appears~~ seemed to be more permeable at the
higher levels in the sinkhole; therefore, water loss by infiltration
probably would be larger per unit ~~surface~~ wetted area along the flank than
in the lower areas of the sinkhole. Also, the infiltration rate per
unit wetted area increases as the depth of water, or pressure head, increases.
If the infiltration rate is comparable throughout the sinkhole, a
recharge well could put several tens of acre-feet of water underground
each year that under natural recharge conditions would be lost by
evaporation.

Marley sinkhole

Marley sinkhole, the largest of the four sinkholes studied
in detail, is a compound sinkhole in T. 10 S., R. 22 E. The shape
of the sinkhole as shown by a topographic map (fig. 12), ~~suggests~~ indicates
that it was formed by the coalescing of three sinkholes. The
sinkhole, if filled to the 4,016-foot contour would contain ~~about~~
2,000 acre-feet of water, would have a ~~free~~ water surface of ~~about~~
530 acres, and would have a maximum depth of ~~about~~ 9 feet.

Test holes were augered in the sinkhole area to sample the
subsurface materials. After studying the surface of the sinkhole
and analyses of the subsurface materials, it was concluded that in
the southern two-thirds of the sinkhole the permeability of the
floor is low within the area that would be encircled by ~~a~~ the 4,011-
foot contour. The permeability of the floor above the 4,011-foot
contour is somewhat ~~higher~~ greater.

The Soil in the area of low permeability ~~predominately~~ predominantly is a silty
clay that has high plasticity and high dry-breaking strength.
Laboratory tests showed that the coefficient of permeability of
the silty clay is ~~about~~ 0.007 gpd per square foot. A particle-
size analysis for this silty clay is shown in figure 13.

The area of higher permeability is underlain in part by sand
and silt having relatively high permeability, and in part by silty
clay having low permeability. The coefficient of permeability of
a soil sample was ~~about~~ 0.2 gpd per square foot.

159

In places the silty clay is at least 48 feet thick. (See table 3, test hole 2.) This large thickness of the material suggests that the deposits of silty clay settled from flood waters that ponded in the sinkhole.

Marley sinkhole is on rocks of the evaporite facies of the San Andres Limestone. A prominent escarpment east of the sinkhole has a dolomite cap overlying gypsum. The gypsum contains numerous solution openings into which water flows when Marley sinkhole is filled to capacity.

Marley sinkhole receives large quantities of water when Blackwater Draw overflows during high floods. Water entering the sinkhole from Blackwater Draw flows into the southern part of the sinkhole. When the water surface in that part of the sinkhole rises above the 4,014-foot level, water spills into the northern part of the sinkhole.

Measurements of infiltration and evaporation in the sinkhole could not be made during the study because so little water entered. A local rancher reported that the sinkhole fills about twice in a 10-year period, and, as of March 1959, the sinkhole had not filled since 1954. When water is in the sinkhole, the water level reportedly recedes to about the level of the 4,010-foot contour within a few weeks, and water remains for several months in parts of the sinkhole below the 4,010-foot contour. Studies should be made when the sinkhole contains water to obtain more reliable infiltration characteristics.

North Marley sinkhole

North Marley sinkhole, in T. 10 S., R. 22 E., is underlain by carbonate rocks of the San Andres Limestone. These carbonate rocks are interbedded with evaporite rocks and indicate that the sinkhole area is in the evaporite facies of the San Andres. Solution channels in rocks of the evaporite facies of the San Andres exposed in adjacent areas indicate that the rocks underlying the sinkhole probably are highly permeable.

Areas along the flanks of North Marley sinkhole, particularly in the northwestern and southeastern part, are underlain by sandy silt that was transported and deposited by the ~~drainages~~ streams entering the sinkhole. Laboratory analyses indicate that the coefficient of permeability of the sandy silt is ~~about~~ 0.4 gpd per square foot. This coefficient is relatively high for alluvium in the Roswell basin and is due to the large percent of coarse silt and sand, as shown in the analysis of a sample from test hole 10 (fig. 13). The central part of the sink is underlain by a clayey silt, having a coefficient of permeability of ~~about~~ 0.1 gpd per square foot. The logs of a test hole augered in North Marley sinkhole is given in table 3.

North Marley sinkhole, if filled with water to the 130-foot contour (fig. 12), would have ~~about~~ 3,700 acre-feet of water, a water surface area of ~~about~~ 228 acres, and a maximum depth of ~~about~~ 31 feet.

North Marley sinkhole, whose drainage area is about 5 square miles, seldom contains much water. Observation of the water level in this sinkhole was started on October 3, 1958. On that date the sinkhole contained 120 acre-feet of water and had a water-surface area of 50 acres. Water remained in the sinkhole 84 days. During that period, 30 acre-feet of water was evaporated and 90 acre-feet infiltrated to the subsurface. The natural rate of infiltration for that part of the sinkhole inundated during the study period is lower than anticipated. The sinkhole if filled with water to a higher level probably would have a much higher rate of infiltration per unit area, partly because the rock forming the sinkhole walls are more permeable than the alluvium in the low area of the sinkhole.

The large depth and relatively small surface area exposed to evaporation in relation to the volume of water contained would make North Marley sinkhole an excellent site for artificial recharge.

Hope sinkhole

Hope sinkhole in sec. 33, T. 16 S., R. 19 E., is in carbonate rock of the San Andres Limestone. The walls of the sinkhole consist of carbonate rock; the floor is alluvium consisting of compact silty clay. The silty clay has high plasticity and a high dry-breaking strength. Samples of the silty clay taken from test holes in the sinkhole are similar to samples of clay from Marley sinkhole that have a coefficient of permeability of 0.007 gpd per square foot.

The area of Hope sinkhole within the 106-foot contour is ~~about~~ 85 acres; the area of alluvium (~~about~~ 70 acres) corresponds to the area within the 104-foot contour. The total volume of water required to inundate the area of alluvium is ~~about~~ 163 acre-feet. Water in excess of that amount would be in contact with carbonate rock that contains joints and solution channels.

Water entered Hope sinkhole from widespread rains on September 7, 1958 and filled the sinkhole to the 103.5-foot level, ~~or~~ equivalent to ~~about~~ 130 acre-feet of water. Water remained in Hope sinkhole for 179 days. Evaporation ~~losses~~ from a pan near Lake Avalon, which is ~~about~~ 50 miles southeast of Hope sinkhole and 1,500 feet lower in elevation, was 27.6 inches or 2.3 feet during the 179-day period. Assuming that the evaporation loss at Hope sinkhole is 70 percent of that amount, the total evaporation loss from Hope sinkhole would be ~~about~~ 1.6 feet. Therefore, ~~about~~ 80 acre-feet of water evaporated from Hope sinkhole and ~~about~~ 50 acre-feet infiltrated the floor.

Hope sinkhole contained water part of each year during the 3 years of the ~~present~~ investigation, and local ranchers report that the sinkhole contains water every year. Hope sinkhole fills more often than the other three selected sinkholes.

During the senior author's visits to Hope sinkhole, the water level was never higher than the 104-foot contour (top of the alluvium). The water level probably was higher immediately after heavy rains, but lowered quickly to the level of the upper limit of the alluvium because of the rapid infiltration of water into the joints and solution channels of the carbonate rock in the sinkhole walls above the alluvium.

A recharge well would put water underground faster than *it infiltrates* ~~occurs~~ under natural conditions through the alluvium. The 130 acre-feet of water that was in the sinkhole at the start of the 1958-59 study period probably could have been put underground by a recharge well within 1 month, and ~~reduced~~ the evaporation *could have been reduced* ~~loss~~ to no more than 15 acre-feet. A recharge well in Hope sinkhole probably would increase the recharge to the limestone aquifer by at least 100 acre-feet of water in a year of normal precipitation.

165

Probable sources of water for artificial recharge

Low flows and most of the flood flows in the Pecos River and
its tributaries are appropriated waters. Under the existing laws
have been
and compacts, these waters probably are not available for artificial
recharge of the ground-water reservoir in the Roswell basin. For
the purposes of this report the appropriated waters are not
considered as a source of water for artificial recharge; however,
if some of these waters were available, the size and scope of the
plans for artificial recharge in the basin could be increased
enormously.

Some of the flood water in tributaries normally is not a
part of any appropriator's supply and might be considered as
unappropriated water. Those waters not appropriated are waters
evapotranspiration
that overflow the banks of tributaries and are lost by evaporation
and transpiration before reaching a point of beneficial use. The
amount of water lost in this way is unknown because flows in the
tributaries are not measured in sufficient detail. The author
be
estimates that this loss might amount to several thousand acre-
feet in some years, and in other years the loss might be negligible.
Additional information on tributary flows would be required to d
determine the volume of flow certain tributaries could transport
without wasting onto flood plains.

166

If ~~it were determined that~~ certain tributaries could contain

a specified rate of flow within their banks and _if_ ~~that any rate of~~

flow in excess of that would spill and be lost, then facilities

could be built on those tributaries to impound _or_ ~~and/or~~ divert the

surplus water for artificial recharge. In this manner, the

appropriators' rights would not be impaired, and water waste would

be reduced.

Drainages such as Thirteenmile Draw, Zubi Draw, Greenfield Draw,

Fourmile Draw, and Eagle Creek do not have well-defined channels

near the Pecos River. Floods in these drainages spread over cropland

and do much damage. Much of this flood water is lost by

evapotranspiration. This loss of water, like the loss by

evapotranspiration on flood plains, might be considered as unappropriated

water, and probably could be used for artificial recharge if salvaged.

The water that accumulates naturally in sinkholes may or may

not be available for artificial recharge. The water that collects

in some sinkholes forms natural stockwatering ponds, and depleting

the water of those ponds at a faster rate than by natural means

might require the construction of a facility that would make water

available to stock in lieu of the pond water.

Another probable source of water for artificial recharge is that which might be salvaged after eradicating water-loving vegetation, particularly saltcedar, from the bottom land along the Pecos River and its tributaries in the Roswell-Artesia sector. Mower and others (in press) estimated that saltcedars consumed about 52,000 acre-feet of water in 1958 in the area extending from where U. S. Highway 70 crosses the Pecos River north of Roswell to where State Highway 83 crosses the river east of Artesia. The water was derived principally from precipitation and from the alluvial aquifer. If the saltcedar were eradicated, not all of the 52,000 acre-feet could be recovered and used for artificial recharge. Some measure would have to be taken to prevent saltcedar's regrowth, and most plans to do that would require some water. One plan would be to plant the denuded area to grasses whose water requirements would be *less than* ~~above one-fifth~~ that of saltcedar. The amount of water used annually by saltcedar minus that amount used annually by a grass cover might be put to beneficial use if it could be recovered.

Reducing water consumption in the bottom land probably would necessitate pumping some water from the alluvial aquifer by wells in the bottom land to prevent ground-water levels from rising too high. Water pumped during the summer probably would be used for crop irrigation, but water pumped in the winter might be used to artifically recharge either the main aquifer or the alluvial aquifer where the water table is several feet below the land surface. The amount of water that might be available from this operation is unknown. The ownership and probable disposal of water salvagable by control of saltcedar has not been determined.

Quality of water with respect to artificial recharge

The concentration of sediments and the dissolved-solids content of surface water used for artificial recharge should be within limits that are dictated by the particular recharge operation, otherwise the efficiency of the recharge works would be impaired. Ideally, water used for artificial recharge should be free of suspended sediment and low in dissolved-solids content. Most of the surface water that might be available for artificial recharge in the Roswell basin would be low in dissolved-solids content and, therefore, would be acceptable chemically for recharge. The concentration of sediment in these waters is light to moderate in comparison with that in other New Mexico streams.

170

Suspended sediment

Large quantities of waters containing of low to moderate concentrations of suspended sediment probably could be drained underground through solution holes and channels and recharge wells in highly permeable limestone; however, the recharge efficiency of those facilities would deteriorate slower if the sediment load in the water was reduced. Temporary storage of the water in settling basins (sinkholes and reservoirs behind impoundment dams) would result in the settling out of most of the sediment except the collodial materials.

Surface water injected in to the alluvial aquifer through recharge wells probably would require filtering in addition to a settling period to remove much of the very fine material that would fill the interstices of that aquifer in the vicinity of the well. Periodic pumping of alluvial recharge wells would help remove the sediment that enters the aquifer through the wells.

Dissolved-solids content

The dissolved-solids content of much of the potential recharge water is low and would not be a recharge problem. Water artificially recharged in some areas would reach the Roswell-Artesia sector with a dissolved-solids content too high for most uses because of the large amount of minerals taken into solution enroute. Artificial recharge in such areas would not be desirable. Natural recharge should be retarded by artificial means where the water recharged gains too high a mineral concentration enroute to the Roswell-Artesia sector. If water artificially recharged to the main aquifer in the northern part of the northern limestone area (fig. 8) and in the eastern evaporite-alluvial area moved to the Roswell-Artesia sector it probably would increase the amount of highly mineralized water in that part of the main aquifer. Additional study of water quality is needed for the northern limestone and eastern evaporite-alluvial areas to determine what areas would be less likely to contribute highly mineralized water to the Roswell area. Water entering the main aquifer is most of the other recharge areas would not adversely affect the chemical quality of the water in the Roswell-Artesia sector.

The water that accumulated in the four sinkholes selected for water-loss studies was analyzed for its chemical constituents at various times. The results of these analyses show some anomalies. The sulfate content of water in Juan Lake and Hope sinkholes decreased soon after the water entered the sinkholes and then increased during the interval in which no additional water entered. The initial decrease of sulfate content may have been the result of ion-exchange from the water to clay on the floor of the sinkholes or may have been the result of the absorption of the sulfate constituents by plants and algae in the sinkhole. Specific conductance, *and concentrations of* sodium, calcium, and potassium decreased with time in the water in North Marley sinkhole. Normally the dissolved-solids content of the water in the sinkhole should increase with time as the result of evaporation of the water. Ion-exchange between the dissolved solids in water, or their absorption by plants and algae in the sinkhole, may explain the anomaly. North Marley sinkhole contains more vegetation than either Hope or Juan Lake sinkholes.

Water *for* to be recharged in the Roswell basin *should* would be stored above ground only for short periods of time. The principal objective would be to put the water underground quickly to reduce by evaporation losses; consequently, the water probably would enter the aquifer with about the same low dissolved-solids content as it had when it entered the surface-storage basin.

Certain bacteria will produce slime and algae that quickly clog screens of recharge wells and interstices of the aquifer near the well. These bacteria can be controlled by chemical treatment of the water. Additional study would be needed to determine the extent of this problem, particularly in surface basins in which recharge wells would be used. Public health agencies would have to be assured beyond doubt that bacterial contamination of the ground water would not result if surface waters were placed underground through wells.

Conclusions

Artifical recharge is one of several methods that might assist in either counterbalancing or reversing the trend of declining water levels in the main and alluvial aquifers and in combatting the deterioration of the chemical quality of ground water in the Roswell-Artesia sector of the Roswell basin. The scope of an artificial-recharge program in the basin would be governed by the amount of water that could be made available for use in recharge of the ground-water system and where the water would be available.

Waters that probably could be made available for artificial recharge in the Roswell basin are: (1) floodwaters in Pecos River tributaries that are lost by evaportranspiration on flood plains; (2) floodwaters in tributaries that debouch onto lands at the terminus of the well-defined channels and is lost by evapotranspiration; (3) water that could be saved by controlling saltcedar growth in the basin; and (4) water that evaporates from ponds in sinkhole areas. For the purposes of this report, these waters are assumed, to be unappropriated. The right to these apparently unappropriated waters would have to be established before proceeding with their use in artificial recharge. The scope of an artificial-recharge program could be increased if some of the appropriated water in the basin--low flows and much of the flood flows in the Pecos River and its tributaries--could be used for recharge.

175

Most of the waters that might be made available for artificial recharge would be obtained by salvage methods; consequently, it would be desirable to have the points of recharge at or adjacent to the points of salvage. Flood water that would be lost on flood plains and below the terminus of well-defined channels would be salvaged upstream from the area of potential loss. One method of salvaging the water would be to restrict the streamflow to a rate at which the water would be contained within the stream banks and would infiltrate as recharge before reaching the terminus of well-defined channels. Control facilities to assist in the salvage of water from floodflows would be required on Cienega del Macho in the eastern evaporite-alluvial area; Salt Creek and Blackwater Draw in the northern evaporite area; Rio Hondo in the eastern limestone area; Thirteenmile, Zubi, and Greenfield Draws in the alluvial-lowland area; Rio Felix in the eastern limestone and alluvial-lowland areas; and Eagle Creek, Rio Penasco, Fourmile Draw, and North Seven Rivers in the eastern limestone and southern evaporite areas. The amount of water that could be salvaged from these for artificial recharge is unknown.

Salvage of water by the control of saltcedar would be in the bottom land along the Pecos River and lower reaches of some tributaries within the alluvial lowland. The amount of water consumed in the saltcedar areas less the amount consumed in the control of saltcedar would be the maximum amount that a water-salvage operation could undertake to recover without infringing on established water rights. Not all of the water recovered would be available for artificial recharge because some would be needed For irrigation.

The amount of water lost annually by evaporation from open-water surfaces in sinkholes in the recharge area of the Roswell basin was not determined during this investigation, however, it probably is several tens of thousands of acre-feet. Computations of evaporation and infiltration losses in three sinkholes in the 6-month period, September 1958-February 1959, indicated that of about 370 acre-feet of water in those sinkholes about 163 acre-feet (44 percent) discharged by evaporation. Evaporation from individual sinkholes ranged from 40 to 65 percent. Data were inadequate to compute the evaporation from those sinkholes for a complete year of normal precipitation.

177

Only a fraction of the water that might be recharged artificially to the main aquifer in some areas would reach the main aquifer beneath the Roswell-Artesia sector. Most of the water recharged to the main aquifer in the northern quarter of the northern limestone area and in the northern half of the eastern evaporite-alluvial area probably would move east of the Pecos River instead of to the Roswell-Artesia sector. Some, if not most, of the water put underground in much of the western limestone area would discharge through seeps and springs within the area. Some of the water recharged to the main aquifer in the southern quarter of the eastern limestone area would move through the Dayton-Lakewood area and discharge from the Roswell ground-water basin through springs in the Pecos River. Water recharged to the upper aquifer in the Grayburg and Queen Formations in the southern part of the area would move southeastward from the Roswell basin. Water entering the main aquifer at most other points in the seven recharge areas (fig. 8) eventually would be effective recharge for the main aquifer beneath the Roswell-Artesia sector.

question of the

The length of time required for water or its pressure effects to
move from a point of recharge to the Roswell-Artesia sector can be
consistant with
answered only in terms ~~of relativity based on~~ the knowledge available
when this report was prepared. In general, the elapsed travel time in-
creases with distance from the Roswell-Artesia sector; however, travel
time from recharge points equidistant from the Roswell-Artesia sector
probably would be different because of permeability differences in
the aquifer. The rate of water or pressure movement in an aquifer generally
is more rapid along areas of greater permeability, thus the benefits
main
of water recharged to the ~~limestone~~ aquifer along the major tributary
drainages, along major structural zones, and in the vicinity of
carbonate-evaporite facies boundaries in the Roswell basin probably
would move ~~at a~~ faster ~~rate~~ toward the Roswell-Artesia sector than
from recharge sites elsewhere in the basin. Water recharged to the
main
~~limestone~~ aquifer in the alluvial lowland, northern and southern evaporite
areas, and the southern quarter of the eastern evaporite-alluvial
area would provide effective recharge faster to the Roswell-Artesia
sector than ~~would~~ other recharge areas.

Solely on the basis of speed in getting the benefits of recharge to the main aquifer in the Roswell-Artesia sector, the full recharge potential of the alluvial-lowland, the northern and southern evaporite areas, and the southern quarter of the eastern evaporite-alluvial area should be developed first. That development probably would require water-impoundment structures in upstream areas, particularly in the eastern limestone area. Development of the full recharge potential of the eastern limestone area and the southern half of the northern limestone area would be next. Development of the full recharge potential of the remainder of the recharge area would follow; however, the elapsed time necessary for recharge benefits to move from the more distant areas probably would put plans for artificial recharge in those areas only in a long-range recharge program.

In general, the ~~concentration of~~ dissolved solids content in the water that might be available for recharge would be less than that in the water in the main aquifer in the Roswell-Artesia sector. The highest dissolved-solids content would be in the water salvaged in a saltcedar-control program.

Water recharged in some areas probably would increase the amount of highly mineralized water reaching the Roswell-Artesia sector because of the large mineral content gained enroute. Additional recharge in the northern halves of the northern limestone and eastern evaporite-alluvial areas probably would result in such recharge of highly mineralized water; additional recharge in all other areas probably would not. Some consideration should be given to retarding natural recharge in areas where the recharging waters bring highly mineralized water to the Roswell-Artesia sector.

180

The concentration of suspended sediment in floodwaters used for artificial recharge should be reduced before putting the water underground. Temporary storage in settling basins probably would reduce the sediment load to an acceptable concentration for recharge through solution opening, in highly permeable limestone. Water injected through recharge wells, particularly to the alluvial aquifer, would require filtering to obtain a sediment-free water and chemical treatment to control slime, and algae, and bacteria.

The alluvial aquifer can be artificially recharged directly only in the alluvial lowland. Water recharged to the alluvial aquifer in the vicinity of the Pecos River and its tributaries probably would discharge in part to those drainages through seeps and springs and, therefore, would be inefficient recharge of the aquifer. Water put into the alluvium in that part of the alluvial lowland beyond the western limit of the main ground-water body in the alluvial aquifer would move, in part, downward to the main limestone aquifer, and some would move laterally eastward to the alluvial aquifer. Substantial quantities of water can be put into the alluvial aquifer through recharge wells in the general vicinity of irrigation wells that tap the alluvial aquifer.

181

Natural topographic features in the Roswell basin that would
be useful in an artificial-recharge program are sinkholes and closed
depressions and parts of stream channels where several tens or
hundreds of acre-feet of water could be impounded temporarily behind
small dams. Man-made facilities that could be constructed to improve
the recharge capacity of these natural features are recharge wells,
diversion channels between streams and sinkholes nearby, and channels
within the sinkholes to obtain a more rapid distribution of water to
solution openings and other permeable areas of the sinkholes.

Wells through which water could be injected into the alluvial
aquifer should be of sufficient depth to permit pumping water from
the aquifer to remove slime, sediment, and algae that might accumulate
in the well screen and aquifer as a result of the recharge operation.
The depth of wells recharging the main limestone aquifer outside of the
artesian area probably can be less than the depth to the main water
table if most of the well bore is in highly permeable limestone.

Suggested sites for artificial recharge

The sites described in this section are the most promising

ones observed during the ~~period of the~~ field study. The reconnaissance

~~nature of the investigation~~ allowed time for a detailed inspection in

areas of the Guadalupe and Sacramento Mountains, ~~and~~ but only a general inspec-

tion in the Vaughn-Macho plain; therefore, sites ~~as good as~~ as well or better

suited to artificial recharge than some of those suggested probably

could be found during a more intensive study.

The sites suggested are in two categories: sinkholes and

impoundment areas along drainages. The sites are identified by numbers

on figure 15--the numbers are for convenience of identification and

---

Figure 15.--Selected sites for artificial recharge in a part

of the Roswell basin, New Mexico.

---

do not denote a priority preference.

Sinkholes

Marley sinkhole--site 1

The principal source of water for recharge in Marley sinkhole would be flows in Blackwater Draw. Blackwater Draw and associated tributaries upstream from Marley sinkhole have a drainage area of about 270 square miles. Marley sinkhole receives water from Blackwater Draw only during high floods--low flows bypass the sinkhole in a low-flow channel. When the amount of water entering the sinkhole exceeds the storage capacity of the sinkhole, water flows over the south rim of the sinkhole and southward to rejoin Blackwater Draw. Downstream from Marley sinkhole flows from Blackwater Draw pass through parts of Eightmile Draw, south Berrendo Creek, and the Rio Hondo before reaching the Pecos River. Large floods from Blackwater Draw cannot be contained within the channels of Eightmile Draw and South Berrendo Creek, and much water is lost by evapotranspiration on their flood plains. If the water lost by these means were considered to be unappropriated water if salvaged, then withholding some of the water and artificially recharging the main limestone aquifer in an upstream area to reduce the stage of the floods to the amount that would pass through the downstream drainages without spilling onto flood plains would be a method of salvaging the unappropriated water.

The water stage in Blackwater Draw immediately downstream from
Marley sinkhole could be regulated by ~~building~~ ^constructing^ the mouth of a
diversion channel leading to Marley sinkhole at an altitude that
would allow floods below a certain size to pass Marley sinkhole but
would divert water from floodflows that would spill over banks if
permitted to pass downstream. The construction of an adequate
diversion facility probably would be relatively simple.

Better distribution of the water in the sinkhole might increase
the recharge efficiency of the sinkhole. ~~Under existing conditions~~
the large part (southern two-thirds) of the sinkhole fills to above
the 4,014-foot contour before water flows into the smaller part
(northern one-third) of the sinkhole. If a channel was cut through
the divide between these two parts, water would fill the northern
part of the sinkhole at the time the southern part is filling, thus
putting water in contact with a larger area ^more quickly^ ~~quicker.~~ ~~Under existing~~
~~conditions~~ water enters the solution openings along the base of the
escarpment at the east side of the sinkhole only when the water
surface in the sinkhole is near the 4,016-foot level. The mouths of
these openings could be lowered and channels cut to the openings to
drain water to the openings before the water surface in the sinkhole
reached the 4,016-foot level.

185

If water would not go underground at a sufficient rate by natural infiltration of the sinkhole floor and the solution openings, the rate could be increased by using recharge wells. Test drilling would help locate the best sites for recharge wells within the sinkhole. Large-capacity recharge wells probably could be developed at a relatively shallow depth, probably less than 200 feet.

Marley sinkhole is relatively close to the area of heavy pumping from the ~~limestone~~ main aquifer in the vicinity of Roswell. According to the water-movement pattern shown on figure 8, water entering the main ~~limestone~~ aquifer at Marley sinkhole would move ~~diretly~~ directly toward the heavily pumped area.

North Marley sinkhole--site 2

North Marley sinkhole seems to have a relatively high potential for draining water underground if water were ponded at a high level in the sinkhole. The chief problem of artificial recharge in this sinkhole is ~~one of~~ water supply, because its 5-square-mile natural drainage area does not supply much water to the sinkhole. Some of the floodwaters in Blackwater Draw could be diverted to North Marley sinkhole. The diversion could be from the draw at a point upstream from Marley sinkhole. The channel leading water from Blackwater Draw would need to extend only to a point on the drainage area of North Marley sinkhole, from which the water would drain naturally to the sinkhole. Another method of diversion would be to pump water from Marley sinkhole to the nearest point on the drainage to North Marley sinkhole when water is in Marley sinkhole. The particular route and method of transporting water from the draw to the sinkhole could be decided after a detailed topographic survey is made of the area between the draw and the sinkhole.

If discharge studies of Blackwater Draw indicated that the amount of water available for recharge frequently would exceed the natural-recharge capacity of the sinkhole, it might be feasible to increase the recharge capacity of the sinkhole by constructing recharge wells. Even though the sinkhole might function satisfactorily under natural-recharge conditions for some time, the accumulation of silt from the floodwater might necessitate the construction of recharge wells later to sustain an adequate rate of recharge.

Hondo Reservoir--site 3

The Rio Hondo, like other major drainages on the east slope of the Sacramento Mountains, sometimes overflows its banks in the lowland area and loses large quantities of water by evapotranspiration. Diverting some of the water from unusually large floods to the Hondo Reservoir in T. 11 S., R. 22 E. would keep the flow of Rio Hondo within its banks and prevent wasteful flooding downstream. The water diverted to the reservoir would infiltrate underground and move toward the heavily pumped area near Roswell. The reader is referred to Bean (1949) and Theis (1951) for a description of Hondo Reservoir and its recharge characteristics.

Juan Lake sinkholes--site 4

The Juan Lake sinkholes in T. 12 S., Rs. 22-23 E., could drain to the subsurface more of the flood waters in Thirteenmile Draw if diversion structures and canals were built on the draw to shunt more water to the sinkholes. ~~Under existing conditions~~ small floods in the draw enter the principal sinkhole, Juan Lake sinkhole, but much of the water in large floods bypasses that sinkhole. The channel of Thirteenmile Draw is not continuous to the Pecos River, and floodwaters in the draw move downstream from the sinkhole and are lost by evapo~~ration and~~ transpiration when the water spreads over lands in T. 13 S., R. 25 E. The floodwaters that normally would be lost, ~~if considered to be unappropriated water,~~ could be used for artificial recharge in the Juan Lake sinkholes.

A more accurate estimate of the size of floods in Thirteenmile Draw would be required to know whether or not sinkholes in this group other than Juan Lake and North Juan Lake sinkholes would be needed to contain the floods. The construction of a diversion structure in the draw and a channel to Juan Lake sinkhole while discharge studies were in progress could be the first steps in a recharge program in the vicinity of the Juan Lake sinkholes. A channel cut through the low divide between Juan Lake and North Juan Lake sinkhole would facilitate the entry of water from the draw by keeping the general water surface low in the sinkhole while the sinkhole was filling. If the amount of water available for recharge exceeds the natural infiltration rate of the sinkhole, one or more recharge wells could be constructed in the sinkhole. This might be more economical than building diversion structures and channels for other sinkholes in this group. The permeability of the main aquifer is relatively high in the general vicinity of the Juan Lake sinkholes, according to figure 9, and large capacity of recharge wells probably could be constructed in Juan Lake sinkhole.

Most of the water infiltrating the floor of Juan Lake would discharge directly to the main aquifer, but some might move eastward through the alluvial fill and be intercepted by wells in the alluvium. Water entering the main aquifer in the vicinity of Juan Lake sinkhole would move toward the orchard Park-Hagerman area. section of that aquifer.

191

Felix sinkholes--site 5

An unnamed sinkhole in secs. 19 and 30, T. 14 S., R. 26 E.,
one of the Felix sinkholes, has an area of about 250 acres and has
a water-storage capacity of about 900 acre-feet. This sinkhole is in
the alluvial lowland, and natural infiltration of water in the sinkhole
floor would recharge the alluvial aquifer. Recharge wells could be
constructed to put water into the main aquifer; however, that might be
too costly because the wells would have to be about 1,000 feet deep.
Artificial-recharge injected through this sinkhole probably should be
used only to recharge the alluvial aquifer.

The permeability of the alluvium in the sinkhole may be low in the first few feet below land surface. The infiltration of water under natural conditions probably would be slow and much water would be lost by evaporation. Water in the sinkhole could be put into the alluvial aquifer through recharge wells at a rate that would minimize the evaporation loss. The recharge wells would be shallow, probably less than 150 feet deep in depth. Morgan (1938, pl. 1) estimated that the valley fill beneath the sinkhole is between 100 and 200 feet thick. The depth to the water table was between 90 and 100 feet in 1959, or about 50 feet below the level of 1940. If silt- and bacteria-free recharge water is used, the recharge wells probably could be less than 100 feet deep in depth, and could discharge into the alluvium at a level above the water table; however, if the wells are finished in the section below the water table, they could be pumped occasionally to remove silt and algae that might accumulate in the well and aquifer.

The sources of water for recharge probably would be the Rio Felix and water salvaged in a saltcedar-control program in the bottom land of the Pecos River. If water from floodflows in the Rio Felix is available, a canal or pipe line about 2 miles long in length would deliver the water to the sinkhole. Water from the saltcedar-control area probably would be transported by the Hagerman Canal and then pumped through a pipeline to the sinkhole.

193

Antelope sinkholes in T. 18 S., R. 23 E., are in the southern evaporite area (fig. 8). The sinkholes are bottomed in highly permeable evaporite rocks. The evaporite rocks are underlain by carbonate rocks of the ~~San Andres~~ of the upper part of the San Andres ground-water province (fig. 9), which have relatively low permeability in this area. The carbonate rocks are partly in the Grayburg Formation and partly in the San Andres Limestone.

The Antelope sinkholes have sufficient volume to hold several hundred acre-feet of water. The floors and walls of most of the sinkholes ~~appear~~ seem to be highly permeable, and water should infiltrate to the subsurface rapidly. Recharge wells in some sinkholes having less permeable floors would facilitate the drainage of water to the subsurface. ~~Additional study is required before it is decided whether or where recharge wells would be needed in these sinkholes.~~

The source of water for artificial recharge in the Antelope sinkholes would be floodflows in Rio Penasco and Fourmile Draw. The channels of these drainages are near the sinkholes, and relatively short canals would connect these drainages with the sinkholes. The flow in Rio Penasco might be increased by diverting flow from Eagle Creek into Rio Penasco west of Hope. Rio Penasco, Fourmile Draw, and Eagle Creek have about a 1,400-square-mile drainage area upstream from Antelope sinkholes. Little of the floodflow that passes Antelope sinkholes in these drainages reaches the Pecos River; most of the floodflow accumulates in swampy areas near the river and either evaporates or supplies water to a dense growth of saltcedar.

Additional data on streamflow, geology, and topography are
required for these drainages. Streamflow data *upstream from* ~~above~~ the Antelope
sinkholes would be valuable for the location and design of small
impoundment dams; streamflow data downstream from Antelope sinkholes
would help determine the amount of water lost by evapotranspiration.

According to the general pattern of water movement in the
main ~~limestone~~ aquifer (fig. 8), water entering the aquifer at the
Antelope sinkholes would move toward the Artesia-Lakewood area.

Impoundment areas along drainages

According to ~~existing~~ water laws, water may be impounded in floodwater retaining structures for 72 hours and then must be released. Proof that the water impounded would have been lost by evapo~~ration and~~ transpiration might alter the interpretation and execution of those laws. Several sites for impounding water behind dams in stream channels are shown in figure 15; the sites designated as 7, 8, 14, 15, and 16 are reaches of the channel in which dams probably could be built; the exact location of the dams are not shown because the channels were not studied in sufficient detail. Sites 9 and 10 ~~appear~~ seem to be suitable for small dams. Floodwater-retarding structures are being built at sites 11-13 by the U.S. Soil Conservation Service.

Cienega del Macho and Salt Creek--sites 7 and 8

Near sites 7 and 8 in Cienega del Macho and Salt Creek, a
series of small dams could be constructed to impound some water
from floodflows over sections of the channel ~~in which there are~~
numerous solution openings. The dams would serve to prolong the
period that water is in contact with those highly permeable
sections of the channels.

197

Rio Hondo and tributary--sites 9 and 10

At sites 9 and 10, the floor and sides of the channels of the
Rio Hondo and its tributary are highly permeable. The damsites
shown would impound water over some of the ~~permeable~~ channel area, *that is permeable*
and, in addition, water could be released from these dams ~~at a~~ slowly
~~rate~~ to allow a longer period of contact between water and channel
in areas immediately downstream from the dams.

Thirteenmile, Zubi, and Greenfield Draws--sites 11-13

The U.S. ~~Department of Agriculture,~~ Soil Conservation Service
~~Division,~~ *in 1958 was* constructing floodwater-retarding structures at sites
11, 12, and 13 to control the floods in Thirteenmile, Zubi, and
Greenfield Draws. The largest water-impoundment area of these
three is that on Zubi Draw. Recharge wells might be constructed
in the water-impoundment areas behind these structures to put some
water into the alluvial aquifer and possibly the *main* ~~limestone~~ aquifer.

Fourmile Draw and North Seven Rivers--sites 14-16

Fourmile Draw at site 14 and North Seven Rivers and its tributary
at sites 15 and 16 cut deeply into carbonate rocks, and excellent
damsites and large water-impoundment areas could be found easily.
Some of the floodwaters impounded could be injected in the main
aquifer through recharge wells in the impoundment area. Test drilling
would be necessary to determine the proper depth of the recharge wells.
The permeability of the main aquifer is relatively high at these
sites, and high-capacity recharge wells probably could be developed.
The controlled release of water from the impoundment areas after
floods probably would result in some additional recharge to the
main aquifer by increasing the infiltration of water in permeable
sections of the streambed downstream from the dams.

References

Allen, J. E., and Jones, S. M., 1951, Preliminary stratigraphic
    section, Capitan Quadrangle, New Mexico, in Roswell Geol. Soc.
    Guidebook 5th Field Conf.

Bean, R. T., 1949, Geology of the Roswell artesian basin, New Mexico,
    and its relation to the Hondo Reservoir: New Mexico State Engineer
    Office Tech. Rept. 9, p. 1-31.

Bjorklund, L. J., and Motts, W. S., 1959, Geology and water resources
    of the Carlsbad area, Eddy County, New Mexico: New Mexico State
    Engineer Office Tech. Rept. 21, 117 p., 3 pls., 13 figs.

Bodine, M. W., Jr., 1956, Geology of Capitan Coal Field, Lincoln
    County, New Mexico: New Mexico Inst. of Mining and Technology,
    State Bur. Mines and Min. Resources Div. Circ. 35, 27 p.

Bretz, J. H., and Horberg, C. L., 1949a, The Ogallala Formation
    west of the Llano Estacado [New Mexico]: Jour. Geology, v. 57,
    no. 5, p. 477-490.

_____ 1949b, Caliche in southeastern New Mexico: Jour. Geology, v.
    57, no. 5, p. 491-511.

Brown, C. N., 1956, The origin of caliche on the northeastern Llano
    Estacado, Texas: Jour. Geology, v. 64, no. 1, p. 1-15.

Cooper, James B., 1962, Note on post-Rustler red beds of Permian age
    of southeast New Mexico and West Texas: U.S. Geol. Survey Prof.
    Paper 450B, p. 24-26.

Crawford, Russell, and Borton, R. L., 1961, Logs of and water levels
    in observation wells in recharge area of Roswell artesian basin,
    in Ground-water levels in New Mexico, 1957, New Mexico State Engineer
    Office Tech. Rept. 22, p. 255 - 306, 10 tables.

References - Continued

Dane, C. H., and Bachman, G. O., 1958, Preliminary geologic map of the
southeastern part of New Mexico: U.S. Geol. Survey Misc. Geol.
Inv. Map I-256.

Dickey, R. I., 1940, Geologic section from Fisher County through
Andrews County, Texas, to Eddy County, New Mexico, in DeFord and
Lloyd, eds., West Texas-New Mexico symposium, pt. 1: Amer. Assoc.
Petr. Geol. Bull, v. 24, no. 1, p. 37-51, 1 figs.

Fenneman, N. M., 1931, Physiography of western United States: New
York, McGraw-Hill Book Co., Inc. 534 p., 173 figs.

Fiedler, A. G., and Nye, S. S., 1933, Geology and ground-water
resources of the Roswell artesian basin, New Mexico: U.S.
Geol. Survey Water-Supply Paper 639, 372 p., 46 pls., 37 figs.
incl. maps.

Fisher, C. A., 1906, Preliminary report on the geology and
underground waters of the Roswell artesian area, New Mexico:
U.S. Geol. Survey Water-Supply Paper 158, 29 p., 9 pls.

Hager, D., and Robitaille, A. E., 1919, Geological report on oil
possibilities in eastern New Mexico (unpublished) cited by
Wilmarth, 1938, Lexicon of Geologic Names of the United States,
U.S. Geol. Survey Bull. 896, p. 831.

Hantush, M. S., 1955, Preliminary quantitative study of the Roswell
ground-water reservoir, New Mexico: New Mexico Inst. of
Mining and Technology, State Bur. Mines and Min. Resources
Div., 118 p., 22 figs.

References - Continued

Harper, W. G., 1933, Soil survey of the Roswell area, New Mexico:
U.S. Dept. Agriculture, Bur. of Chemistry and Soils, ser. 1933,
no. 2, p. 34.

Hayes, P. T., and Koogle, R. L., 1958, Geology of the Carlsbad
Caverns West Quadrangle, New Mexico-Texas: U.S. Geol. Survey
Geol. Quad. Map GQ-112.

Hendrickson, G. E., and Jones, R. S., 1952, Geology and ground-water
resources of Eddy County, New Mexico: New Mexico Inst. of
Mining and Technology, State Bur. Mines and Min. Resources Div.
Ground-water rept. 3, 169 p., 6 pls., 11 figs.

Hood, J. W., Mower, R. W., and Grogin, M. J., 1959, The occurrence
of saline ground-water near Roswell, Chaves County, New Mexico:
New Mexico State Engineer Office Tech. Rept. 17, 72 p., 12 pls.,
14 figs.

Keyes, C. R., 1915, Foundation of exact geologic correlation: Iowa
Academy of Science Proc., v. 22, p. 249-267.

King, P. B., 1948, Geology of southern Guadalupe Mountains, Texas:
U.S. Geol. Survey Prof. Paper 215, 183 p., 25 pls. [1949].

Lang, W. B., 1937, The Permian formations of the Pecos Valley of
New Mexico and Texas: Am. Assoc. Petroleum, Geologists Bull.,
v. 21, no. 7, p. 833-898, 29 figs.

Lee, W. T., and Girty, G. H., 1909, Stratigraphy of the Manzano
Group of the Rio Grande valley, New Mexico: U.S. Geol. Survey
Bull. 389, 141 p., 12 pls.

References - Continued

Leopold, Luna B., 1951, Rainfall frequency, an aspect of climatic
    variation: Am. Geophys. Union Trans., v. 32, no. 3, p. 347-357.

Moran, W. R., 1954, Proposed type sections for the Queen and
    Grayburg Formations of Guadalupian age in the Guadalupe
    Mountains, Eddy County, New Mexico [abs.] in New Mexico Geol.
    Soc. Guidebook 5th Field Conf., Oct. 1954, p. 147-150, 2 figs.;
    [abs.] Geol. Soc. America Bull., v. 65, no. 12, pt. 2, p. 1288.

Morgan, A. M., 1938, Geology and shallow water resources of the
    Roswell artesian basin, New Mexico: New Mexico State Engineer
    12th-13th Bienn. Repts., 1934-38, p. 155-249, 5 pls., 5 figs.
    [also published as New Mexico State Engineer Office Bull. 5.]

Motts, W. S., 1958, Caliche genesis and rainfall in the Pecos Valley
    area of southeastern New Mexico:[abs.]: Geol. Soc. America Bull.,
    v. 69, no. 12, pt. II, p. 1737.

Mower, R. W., and others, An appraisal of potential ground-water
    salvage along the Pecos River between Acme and Artesia, New
    Mexico: U.S. Geol. Survey Water-Supply Paper, in press.

Needham, C. E., and Bates, R. L., 1943, Permian type sections in
    central New Mexico: Geol. Soc. America Bull., v. 54, no. 11,
    p. 1653-1667, 2 figs.

Newell, N. D., and others, 1953, The Permian reef complex of the
    Guadalupe Mountains region, Texas and New Mexico - study in
    paleoecology: San Francisco, W. H. Freeman and Co., 236 p.

New Mexico Geological Society, 1954, Guidebook of southeastern
    New Mexico, 5th Field Conference Oct 1954, 209 p.: Socorro, N.
    Mex.

References - Continued

Pray, L. C., and Allen, J. E., 1956, Outlier of Dakota(?) strata, southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 11, p. 2735-40.

Renick, B. C., 1926, Geology and ground-water resources of the drainage basin of the Rio Penasco above Hope, New Mexico: New Mexico State Engineer 7th Bienn. Rept., p. 103-138, 4 figs., 1 pl.

Theis, C. V., 1951, Effect of artesian aquifer on storage of flood water in Hondo Reservoir: New Mexico State Engineer Office Tech. Rept. 9, p. 33-36.

Theis, C. V., and Sayre, A. N., 1942, Geology and ground water in [U.S.] Natl. Resources Planning Board, Pecos River Joint Investigation--Reports of the participating agencies: Washington, U.S. Govt. Printing Office, p. 27-101.

Thornbury, W. D., 1956, Principles of Geomorphology: New York, John Wiley and Sons, Inc., 618 p.

Vine, J. D., 1959, Geologic map of the Nash Draw quadrangle, New Mexico: U.S. Geol. Survey open-file rept.

Table 2.--Records of selected wells in the Roswell basin, New Mexico

Location number: See page 22 of text for explanation.

Owner or name: The owner or name used for well at time of visit. PVACD, Pecos Valley Artesian Conservancy District observation well.

Depth: Reported by owner, tenant, or driller.

Diameter: The diameter of the casing, if cased, or the mean diameter of the hole if uncased.

Water level: Depths expressed to nearest tenth of a foot were measured by Geological Survey; Those expressed in whole feet were reported by owner, tenant, or driller.

Principal water-bearing bed: Determined by field observation, from well cuttings, or by interpretation from maps.

Stratigraphic unit: Py, Yeso Formation; Psh, Hondo Sandstone Member of the San Andres Limestone Pgl, Glorieta Sandstone; Psa, San Andres Limestone; Pg, Grayburg Formation; and Pa, Artesia Formation Pcb, Chalk Bluff Formation.

Method of lift: N, none; P, plunger or cylinder pump, wind driven; Pe, plunger or cylinder pump, electrically driven; Pg, plunger or cylinder pump, gasoline driven; Te,

   turbine pump, electrically driven; Tg, turbine pump, gasoline driven.

Use of water: D, domestic; Irr, irrigation; N, none; O, observation; Ps, public supply; S, stock.

Remarks: All wells are drilled; gpm, gallons per minute; Temp., temperature of water in degrees Fahrenheit.

Character of material: Siltst, siltstone; ss, sandstone; carb rk, carbonate rock; sh, shale; gyp, gypsum; dolo, dolomite; ls, limestone.

Location number	Owner or name	Driller	Year completed	Depth of well below land surface (feet)	Diameter of well (inches)	Altitude above mean sea level (feet)	Water level		Principal water-bearing bed		Method of lift and power source	Use of water	Remarks
							Depth below land surface (feet)	Date	Character of material	Stratigraphic unit			
7.20.2.340	R. L. Corn	-	-	4,604	-	4,600	540 504	1940	Blue sandy sh	-	P	S	Pumped 5 gpm.
6.410	D. Corn	-	-	700	-	4,946	600	4- 3-50	-	-	P	S	-
16.333	PVACD No. 1	K. G. Miller	1955	750	7 to 5 1/2	4,694	452	12-31-57	Ss, gyp, and carb. rk	Py and Pg1	-	O	Cased with 7-inch pipe from 0 to 20 feet and with 5 1/2-inch pipe from 475 to 657 feet.
36.220	W. J. Ball	-	-	467	-	4,376	430	3- -50	Gray sh and carb rk	-	P	D, S	Reportedly yields water of good quality. Two wells about 60 feet apart; west well not used.
7.21.12.420	Ronald Corn	George Perry	-	740	-	4,313	650	-	Ls	Psg(?)	P	D, S	Pumped 10 gpm. Reportedly yields water of good quality.
29.333	W. J. Ball	W. E. Doolin	1950	755	8	4,531	700	4- 3-50	-	-	P	S	-
7.22.19.130	Ronald Corn	Oscar Noscar	-	720	8	4,313	680	-	Ls	Psg(?)	P	S	Cased to 20 feet. Pumped 10 gpm. Reportedly yields water of good quality.
7.23.8.220	-	-	-	-	-	3,924	360	6- 1-50	-	-	P	D, S	-
23.242	Jess Corn	-	-	426	14	3,814	239.8	5-26-51	Ls and gyp	Psg and Pob(?)	Tg	Irr	-
8.20.23.410	W. B. Jones	A. Cole	1943	450	8	4,443	438	-	-	-	P	-	Pumped 5 gpm. Reportedly yields water of good quality. Sucks dry sometimes, may have caved.
33.230	C. Marley	-	-	-	-	4,408	360	4- 3-50	-	-	P	D, S	
8.21.30.300	W. B. Jones	-	-	470	-	4,260	454	-	-	-	P	D, S	-
34.240	Charles Douthitt		-	465	-	4,125	437.3	4- 4-58	-	-	P	D, S	Reportedly yields potable water.
8.22.10.214	Tom and Richard Corn	-	-	580	-	4,138	545	-	Ss	Pg1	P	S	Pumped 10 gpm.

207

Location number	Owner or name	Driller	Year completed	Depth of well below land surface (feet)	Diameter of well (inches)	Altitude above mean sea level (feet)	Water level Depth below land surface (feet)	Date	Principal water-bearing bed Character of material	Stratigraphic unit	Method of lift and power source	Use of water	Remarks
8.23.22.211	J. Corn	-	1940	410	8	3,918	365	1940	Carb rk	Ps	P	S	Pumped 15 gpm
8.24.16.333	PVACD No. 10	A. H. Lewis	1957	435	8½ to 7	3,622	78.9	12-26-57	Dolo, ss, and gyp	Ps and Pco	-	O	Cased with 8½-inch pipe from 0 to 155 feet and with 7-inch pipe from 0 to 395 feet.
9.19.35.333	S. C. Marley	-	1940	280	-	4,747	222.2	5-16-57	Siltst(?)	Pgl-ro	P	S	-
9.20.21.410	do.	A. Cole	1939	550	-	4,490	440	1955	-	Pgl(?)	P	S	-
9.21.18.110	-	-	-	-	-	4,330	426.9	4-18-50	-	-	P	S	-
31.133	Marley and Whitney	-	-	425	-	4,305	365	5-18-50	-	-	P	S	-
9.22.20.444	Alton Corn	H. R. Davis	-	725	-	4,228	675	-	White and yellow ss	Pgl	P	S	-
35.323	Dick Alexander	do.	1956	575	8	4,100	525	1956	Ss and carb rk	Pgl	P	D	Reportedly yields water of good quality.
9.23.25.324	Elmer Sons	W. E. Doolin	1948	775	10	3,675	109	1949	Ls	Ps	Tg	Irr	Cased to 297 feet. Pumped 2,000 gpm.
10.20.8.134	S. C. Marley	-	-	486	5	4,596	426	5-18-50	-	Pgl(?)	P	S	-
16.444	PVACD No. 2	K. G. Miller	1956	503	6	4,504	422.6	12-31-57	Ss and carb rk	Pgl	-	O	Cased to 503 feet.
10.21.16.222	PVACD No. 3	do.	1956	672	10 to 7	4,190	590.4	12-31-57	Ss and carb rk	Pgl	-	O	Cased with 10-inch pipe from 0 to 40 feet and with 7-inch pipe from 0 to 670 feet.
24.322a	Marley and Whitney	do.	1958	603	8	4,088	530	1958	Siltst	Pgl	P	S	-
10.23.12.212	Juan Sena	Ray Taylor	-	167	6	3,670	110	7- -56	Siltst and carb rk	Ps	-	Irr	Cased to 137 feet. Deepened from 137 to 167 feet in 1956.
15.131	J. D. and R. O. Pyeatt	-	1948	700	13	3,728	174.6	1-22-57	Ls	Ps	Te	Irr	-

Table 2.--Records of selected wells in the Roswell basin, New Mexico - Continued

Location number	Owner or name	Driller	Year completed	Depth of well below land surface (feet)	Diameter of well (inches)	Altitude above mean sea level (feet)	Water level		Principal water-bearing bed		Method of lift and power source	Use of water	Remarks
							Depth below land surface (feet)	Date	Character of material	Stratigraphic unit			
10.23.27.234	E. M. Haley	A. H. Lewis	1949	425	16	3,725	160.9	2- 3-54	Ls	Psd	Te	Irr	Cased to 168 feet. Pumped 1,200 gpm. Yields water of good quality.
33.433	C. O. Morrow	do.	1953	303	7	3,840	273	-	Ls	Psd	Pe	D	Cased to 51 feet.
11.20.20.442	R. C. Nunez	Bill Marschbanks	1955	561	8	4,699	520	4- -55	Ss and carb rk	Pgl(?)	P	S	Cased to 207 feet.
11.21.9.333	J. P. White	Smith and Gibson	1944	687	-	4,312	620	1956	-	Pgl	P	S	Pumped 10 gpm.
18.333	PVACD No. 8	A. H. Lewis	1957	524	7	4,283	399.0	12-31-57	Ss and carb rk	Pgl	-	O	Cased to 524 feet.
28.144	J. P. White	L. L. Pate and L. A. Hanson	1946	675	6	4,278	593	1946	-	Pgl	P	S	Cased to 658 feet.
32.111	Tom White	H. R. Davis or C. Keyes	1954	600	6	4,302	570	1956	-	-	P	S	Cased to 438 feet. Pumped 12 gpm.
11.22.2.131	H. L. Woods	A. Cole	-	326	-	3,888	312.8	5- 6-47	-	Psd	P	D, S	-
4.221	Marley and Whitney	-	-	433	-	3,965	412	6-15-57	Carb rk	Psd	P	S	-
18.211	H. L. Woods (State land)	Cole Bros.	1947	515	6	4,066	484.1	7-14-47	Carb rk	Psd	P	S	Cased to 18 feet.
22.111	J. P. White	-	-	410	-	3,943	362.8	5- 5-47	Carb rk	Psd	P	S	-
25.331	J. B. Patterson	-	1949	430	8	3,895	318.5	5- 5-47	Carb rk	Psd	Pg	S	-
11.23.34.143	B. L. Brown	Case Drilling Co.	1949	500	16	3,751	184.5	1-27-52	Ls	Psd	Te	Irr	-
12.20.1.131	Lee B. and Harold Corn	H. R. Davis	1945	550	8	4,559	475	-	-	Pgl(?)	P	S	-

Location number	Owner or name	Driller	Year completed	Depth of well below land surface (feet)	Diameter of well (inches)	Altitude above mean sea level (feet)	Water level Depth below land surface (feet)	Date	Principal water-bearing bed Character of material	Stratigraphic unit	Method of lift and power source	Use of water	Remarks
12.20.8.243	J. P. White	H. R. Davis	1943	870	6	5,045	810	-	-	Py(?)	P	S	-
11.341	Lee Corn	-	1916	600	-	4,680	550	-	-	-	P	S	-
12.21.16.220	S. P. Johnson, Jr.	S. P. Johnson, Jr.	1948	800	6	4,436	600	6-18-59	-	-	P	S	Yields water of good quality.
27.121	Tom White	Keyes Drilling Co.	1953	712	8	4,463	600	1956	-	Pgl(?)	P	S	Temp. 70°F.
12.22.12.144	Mrs. J. E. Bloom	-	-	-	-	3,874	293.7	5- 5-47	Ls	Pss	P	S	-
15.344	J. B. Patterson	-	-	357	-	3,929	347.5	5-21-57	-	-	-	N	-
12.23.10.331	B. L. Brown	H. R. Davis	1956	260	7	3,776	220	1956	-	Pss	-	-	Cased to 165 feet.
13.20.13.222	PVACD No. 4	K. G. Miller	1955	386	7	4,524	260.3	12-31-57	Ss	Pgl	-	O	Cased to 386 feet.
13.21.30.120	S. P. Johnson, Jr.	W. A. Melson	1950	665	6	4,786	630	6-18-59	Ls	Pss	P	S	Cased to 20 feet. Yields water of good quality.
13.22.28.232	Mrs. A. M. Threlkeld	A. F. Smith	1952	560	8	4,046	500	1952	Ls	Pss	P	D, S	-
32.211	Iva Chesser	-	-	560±	-	4,075	550	7- 7-58	-	-	P	S	Reportedly yields water of good quality.
13.23.6.312	State of New Mexico	W. A. Melson	1955	424	-	3,945	394	7- 1-58	Ls	Pss	P	S	Pumped 9 gpm for 3 hours without any significant change in discharge. Yields water of good quality.
19.321	Mrs. Savino	-	-	500+	-	3,926	364.5	10-17-58	Ls	Pss	P	S	Has large drawdown. Yields impotable water.
31.444	do.	-	-	-	10	3,917	364.8	10-25-58	Ls	Pss	P	S	Yields water of good quality.
35.333	do.	Kincaid	-	300+	10	3,834	301.6	10-25-58	Ls	Pss	P	S	Pumped 10 gpm. Yields water of good quality.
13.24.3.411	Glaze Sacra	-	-	225	5 1/2	3,689	165	4-24-58	Ls	Pss	P	S	Pumped 11 to 12 gpm. Yields water of good quality.
17.222	do.	-	1900's	-	-	3,710	148	4-23-58	Ls	Pss	P	S	-

Table 2.--Records of selected wells in the Roswell basin, New Mexico - Continued

Location number	Owner or name	Driller	Year completed	Depth of well below land surface (feet)	Diameter of well (inches)	Altitude above mean sea level (feet)	Water level		Principal water-bearing bed		Method of lift and power source	Use of water	Remarks
							Depth below land surface (feet)	Date	Character of material	Stratigraphic unit			
13.24.21.224	Glaze Sacra	-	-	225	5	3,715	160	4-24-58	Ls	Psa	P	S	Pumped 11 to 12 gpm.
14.22.13.444	Jack Price	A. Fiddler	1934	380	-	3,929	368	7- 3-58	Ls	Psa	P	D, S	Pumped 3 to 5 gpm. Reportedly yields water of good quality.
14.23.22.214	Elvin Crow	-	-	240	-	3,780	220	7- 7-58	Ls	Psa	P	S	Do.
24.444	M. D. Kincaid	-	-	-	6	3,725	152.1	7-13-51	Ls	Psa	P	S	-
33.210	Elvin Crow	-	-	400	-	3,910	360	7- 7-58	Ls	Psa	P	D	Pumped 3 to 5 gpm. Reportedly yields water of good quality.
15.20.5.130	W. F. Waller	Tom James and Ed Bryant	1914	440	-	4,800	400	7- 2-58	Ls	Psa	Pg	D, S	Pumped 15 gpm. Reportedly yields water of good quality.
30.230	C. Hendricks	H. Everett	1951	525	-	4,777	522	7- 9-58	Ss and siltst	Pgl^{sh}	P	S	Pumped 3 gpm. Sands up. Yields water of good quality.
15.21.13.330	W. F. Waller	H. R. Davis	1946	660	6	4,192	600	7- 2-58	Ss and siltst	Pgl^{sh}	Pg	S	Pumped 5 to 8 gpm. Reportedly yields water of good quality.
36.220	E. J. Treat	W. A. Melson	1947	670	-	4,192	630	7-31-58	Ls	Psa	P	S	Do.
15.22.1.121	Elvin Crow	Leonard George	1950	395	-	3,970	380	7- 7-58	-	-	P	S	Pumped 3 to 5 gpm. Reportedly yields water of good quality.
15.23.4.311	do.	Kincaid	1948	400	-	3,919	355.2	10-23-58	Ls	Psa	P	S	Do.
6.222	do.	-	1920	443	-	3,950	403	5- 5-58	Ls	Psa	P	S	Pumped 12 gpm. Yields water of good quality.
16.20.6.210	Lloyd Treat	W. A. Melson	1944	620	-	4,500	580	7- 9-58	Ss and siltst	Pgl^{sh}	P	S	Pumped 3 to 5 gpm. Reportedly yields water of good quality.
10.110	do.	-	1917	700	-	4,422	670	7- 9-58	Ss and siltst	Pgl^{sh}	P	S	Do.
16.210	R. J. Parks	-	1947	830	-	4,534	810	7-24-58	Ls	Psa	P	S	Pumped 4 gpm. Reportedly yields water of good quality. Temp. 68°F.
18.333	PVACD No. 5	K. G. Miller	1956	767	6 5/8	4,489.0	580.1	12-31-56	Ss and carb rk	Pgl^{sh} and Psa	-	O	Cased to 610 feet.
16.21.6.330	R. J. Parks	Ray Hill	1947	660	-	4,300	625	7-24-58	Ls	Psa	P	S	Pumped 3 to 4 gpm. Yields water of good quality.

211

Table 2.--Records of selected wells in the Roswell basin, New Mexico - Continued

| Location number | Owner or name | Driller | Year completed | Depth of well below land surface (feet) | Diameter of well (inches) | Altitude above mean sea level (feet) | Water level | | Principal water-bearing bed | | Method of lift and power source | Use of water | Remarks |
							Depth below land surface (feet)	Date	Character of material	Stratigraphic unit			
16.21.19.220	R. J. Parks	Glenn Stevenson	1938	760	-	4,377	710	7-24-58	Ls	Psø	P	S	Pumped 4 to 5 gpm. Reportedly yields water of good quality.
33.140	do.	Ray Hill	1948	670	-	4,220	625	1957	Ls	Psø	P	D, S	Pumped 8 gpm. Yields water of good quality. Deepened to 670 feet in 1957.
16.23.20.233	Lyle Hunter	Haskell Harris	1951	440(?)	8	3,969	400	1951	Ls	Psø	P	S	Pumped 14 gpm. Yields water of good quality. Temp. 68°F.
27.120	-	-	-	200	6	3,775	195.3	1-13-50	Ls	Psø(?)	P	S	-
16.24.6.444	C. and M. Ranch	-	-	-	6	3,659	95.4	1-10-55	Ls	Psø	P	S, O	-
7.214	Everhart	-	-	-	4	3,667	99.7	1-10-55	Ls	Psø	P	D, S	-
9.343	F. T. Boyce	-	-	180	6	3,653	117.1	1-10-55	Ls	Psø	-	N	-
10.123	do.	-	-	250	6	3,595	82.3	1-10-55	Ls	Psø	P	D, S, O	-
20.130	Henry Coffin	L. A. Summers	1946	315	8	3,666	160	7-21-58	Ls	Psø	P	S	Cased to 33 feet. Yields water of good quality.
17.20.5.420	Scharbauer Cattle Co.	H. R. Davis	1938	760	-	4,703	710(?)	7- 8-58	Ls(?)	Psø(?)	P	S	Pumped 8 gpm. Yields hard water. Temp. 62°F.
10.320	Felix Cauhape	Haskell Harris	1948	833	-	4,593	790	7- 8-58	Ls	Psø	P	D, S	Pumped 3 to 4 gpm. Yields water of good quality. Deepened to 833 feet in 1955.
18.434	PVACD No. 7	A. H. Lewis	1957	801	7	4,512	463	7- -57	Carb rk	Psø	-	O	Cased to 801 feet.
34.340	George Teel and Felix Cauhape	H. R. Davis	1939	900	-	4,700	850	7- 8-58	Ls	Psø	P	S	Pumped 3 to 4 gpm. Yields water of good quality.
17.21.15.340	Sam Hunter	C. E. Geiser	-	700	8	4,215	620	1948	Ls	Psø	P, Pe	D, S	Pumped 12 gpm. Yields water of good quality. Redrilled to 700 feet in May 1959.
17.410	E. F. Harris	Paul Stevenson	1948	750	7	4,260	660	1-11-49	Ls	Psø	P, Pe	D, S	Cased to 130 feet. Pumped 10 gpm. Yields water of good quality. Temp. 63°F.

212

Table 2.--Records of selected wells in the Roswell basin, New Mexico - Continued

| Location number | Owner or name | Driller | Year com-pleted | Depth of well below land sur-face (feet) | Diam-eter of well (inches) | Altitude above mean sea level (feet) | Water level | | Principal water-bearing bed | | Meth-od of lift and power source | Use of water | Remarks |
							Depth be-low land surface (feet)	Date	Character of material	Stratigraphic unit			
17.23.9.120	R. H. McAshan	H. Everett	1948	515	8	4,000	475	6-30-58	Ls	Psp	P	S	Cased to 40 feet. Reportedly yields water of good quality.
27.132	J. C. Ward	Haskell Harris	1950	515	7	4,000	445	7-21-58	Ls	Psp	P	S	Cased to 515 feet. Pumped 3 to 5 gpm. Yields sulfurous water of poor quality.
30.111	Hope Cooperative Corp.	Leonard George	1954	600	14	4,100	508.9	3-17-54	Ls	Psp	Te	Ps	Cased to 558 feet. Yields water of good quality.
34.420	J. J. Steele	Haskell Harris	1947	520	-	3,950	500	7-21-58	Ls	Psp	P, Pe	D, S	Pumped 3 to 5 gpm. Yields water of good quality.
17.24.3.422	Paul Jones	-	-	-	6	3,713	268.0	1- 7-55	Ls	Psp	P	S, O	-
11.342	do.	-	-	-	6	3,711	261.9	1- 7-55	Ls	Psp	P	D, S	-
13.344	-	-	-	-	6	3,694	238.3	1- 7-55	Ls	Psp	P	S	-
25.244	Paul Jones	-	-	-	6	3,667	198.1	1- 6-55	Ls	Psp	P	S	-
18.20.22.440	Jack Casabonne	H. R. Davis	1913	888	-	4,378	800	1952	-	Py(?)	Pe	D, S	Cased to 60 feet. Pumped 6 gpm. Reportedly yields water of good quality.
28.120	do.	do.	1944	940	-	4,498	875	8-16-57	-	Py(?)	P, Pe	S	Pumped 6 gpm. Reportedly yields water of good quality.
18.21.3.420	Henry Crockett	Haskell Harris	1955	669	8	4,200	640	7-15-58	-	-	Pg	S	Pumped 18 gpm. Reportedly yields water of fair quality.
8.120	Elna Teel	Paul Stevenson	1939	888	8	4,239	630	1939	Ls	Psp	Pe	S	Cased to 20 feet. Pumped 6 to 8 gpm. Reportedly yields water of good quality. Temp. 66°F.
18.23.8.141	O. L. Anderson	Reeves Drilling Co.	1949	460	8	3,950	400.9	7-16-51	Ls	Psp	-	D, S	Yields water of good quality.
8.240	R. W. Newbill	do.	1949	460	-	3,950	420	1949	Ls	Psp	Pe	D, S	Do.
12.111	J. J. Steele	Haskell Harris	1947	620	6	3,885	463.9	1- 6-55	Ls	Psp	P	S	Cased to 300 feet. Pumped 3 to 5 gpm. Yields high sulfurous water of poor quality. Deepened from 540 to 620 feet in 1956.

213

Location number	Owner or name	Driller	Year completed	Depth of well below land surface (feet)	Diameter of well (inches)	Altitude above mean sea level (feet)	Water level		Principal water-bearing bed		Method of lift and power source	Use of water	Remarks
							Depth below land surface (feet)	Date	Character of material	Stratigraphic unit			
18.23.15.113	Paul Jones	-	-	-	6	3,933	441.1	1- 6-55	Ls	Psg√	P	S	-
15.130	Mrs. Edgar Williams	-	-	540	-	3,950	475	7-21-58	Ls	Psg√	P	S	Pumped 3 to 5 gpm. Reportedly yields water of good quality. Deepened from 480 to 540 feet in 1956.
20.410	W. M. Tulk	Black	-	500	-	4,025	460	1957	Ls	Psg√	P	S	Yields water of fair quality.
18.24.11.222	Paul Jones	-	-	-	8	3,680	222.0	1- 5-55	Ls	Psg√	P	S	-
19.20.3.310	Jack Casabonne	H. R. Davis	1938	1,157	8	4,600	1,050	1938	-	Py	P	S	Cased to 20 feet. Pumped 5 gpm. Reportedly yields water of good quality.
16.111	PVACD No. 6	K. G. Miller	1956	1,120	10 1/4 to 9 to 7	4,591	993.2	12- -56	Ss and carb rk	Pg√	-	O	Cased with 10¼-inch pipe to 40 feet, with 9-inch pipe to 180 feet, and with 7-inch pipe to 1,120 feet.
19.21.5.230	Elna Teel	Paul Stevenson	1947	850	10	4,375	820	1956	Ls	Psg√(?)	Pe	D, S	Pumped 6 to 8 gpm. Reportedly yields water of good quality. Deepened from 815 to 850 feet in 1956.
19.23.4.222	Frank Runyan	-	1955	400	5	3,950	370	8-28-58	Ls	Psg√	P	S	Cased to 200 feet. Reportedly yields sulfurous water of fair quality.
6.335	do.	-	1934	585	6	4,025	502	8-28-58	Ls	Psg√	P	D, S	Pumped 3 to 5 gpm. Reportedly yields water of good quality.
20.20.19.330	W. M. Tulk, Jr.	-	-	1,050	8	5,000	970	7-24-58	-	Py or Pg√	P	S	Cased to 40 feet. Pumped 6 to 8 gpm. Yields water of good quality. Deepened to 1,050 feet in 1947.
20.23.26.131	Frank Runyan	-	1925	485	6	3,950	455	8-28-58	Ls	Psg√	P	S	Cased to 485 feet. Pumped 3 to 5 gpm. Yields sulfurous water of fair quality.
21.20.35.240	Armstrong and Armstrong	-	1952	1,200	-	5,250	1,000	10-22-58	-	Py or Pg√	P	S	Cased to 20 feet. Pumped 4 to 6 gpm. Yields water of excellent quality.

214

Table 2.--Records of selected wells in the Roswell basin, New Mexico - Continued

| Location number | Owner or name | Driller | Year completed | Depth of well below land surface (feet) | Diameter of well (inches) | Altitude above mean sea level (feet) | Water level | | Principal water-bearing bed | | Method of lift and power source | Use of water | Remarks |
							Depth below land surface (feet)	Date	Character of material	Stratigraphic unit			
21.21.7.430	Armstrong and Armstrong	-	1924	1,300	-	4,760	1,100	10-22-58	-	Py or Psa Psh	P	D, S	Cased to 140 feet. Pumped 4 to 6 gpm. Yields water of good quality.
36.213	C. F. McWilliams	T. Hillyer	1941	962	6	4,550	942	1948	Ls	Psa	P	S	-

215

Table 3.--Logs of selected shallow test holes

(See figures 10 [11] and 12 [13] for particle-size distribution of material

in selected intervals in these test holes.)

Test hole 2--Marley sinkhole--sec. 20, T. 10 S., R. 22 E.

	Thickness (feet)	Depth (feet)
Alluvium		
Clay, slightly silty, calcareous, dark-brown, cohesive, compact, high plasticity, very high dry-breaking strength; contains much organic material -------------------------------	5	5
Clay, similar to 0-5, but has less organic material -----------------------	8	13
Clay, slightly silty, calcareous, light yellowish-brown, cohesive, compact, high plasticity, high dry-breaking strength -------------------------------	15	28
Clay, silty, calcareous, light brownish-yellow, cohesive, compact, high plasticity, medium dry-breaking strength -------------------------------	5	33
Clay, silty, calcareous, yellowish-brown, cohesive, medium plasticity, medium dry-breaking strength ----------	15	48

Table 3.-- Logs of selected shallow test holes - Continued

Test hole 3--Marley sinkhole--sec. 20, T. 10 S., R. 22 E.

	Thickness (feet)	Depth (feet)
Alluvium		
Silt, calcareous, slightly sandy, yellowish-tan, coarse-grained, well-sorted, low plasticity; contains a scattering of granule to small pebble-size gravel partly coated with calcium carbonate ---	6.5	6.5
Clay, silty, similar to 0-6.5, but contains more gravel --------------------	1	7.5
Silt, calcareous, slightly sandy, yellowish-tan, well-sorted; contains a scattering of granule to medium pebble-size gravel partly coated with calcium carbonate -------------------------------------	1	8.5
Silt, gravelly, sandy, coarse-grained, well-sorted, low plasticity; contains well-sorted, very fine-~~grained sand~~, and coarse-~~grained~~ sand to angular, medium pebble-size gravel --------------	4.5	13

Table 3.--Logs of selected shallow test holes - Continued

Test hole 3--Marley sinkhole - Continued

	Thickness (feet)	Depth (feet)
Alluvium - Continued		
Gravel, calcareous, sandy and silty, granule- to medium pebble-size,$\frac{d}{1}$ subangular to subrounded, poorly sorted; matrix is predominantly very fine-grained sand ----------------------------	3	16

Table 3.--Logs of selected shallow test holes - Continued

Test hole 10--North Marley sinkhole--sec. 7, T. 10 S., R. 22 E.

	Thickness (feet)	Depth (feet)
Alluvium		
Silt, slightly sandy, calcareous, coarse-grained, well-sorted, low plasticity, low dry-breaking strength -------------------------------	3	3
Silt, sandy, calcareous, coarse-grained, poorly sorted; contains some sand and granule-size gravel --------------------	4	7
Gravel, mostly limestone, angular to well-rounded; ~~up to~~ *as much as* 1 inch in diameter ------------------------------	6	13

Table 3.--Logs of selected shallow test holes - Continued

Test hole 12--Juan Lake sinkhole--sec. 31, T. 12 S., R. 23 E.

	Thickness (feet)	Depth (feet)
Alluvium		
Clay, calcareous, dark-brown to black, cohesive, compact, high dry-breaking strength ---------------------------------	4	4
Clay, silty, yellowish-tan, cohesive, medium plasticity, high dry-breaking strength ---------------------------------	9	13

Table 3.--Logs of selected shallow test holes - Continued

Test hole 15--Blackdom terrace--SW¼ sec. 31, T. 12 S., R. 23 E.

	Thickness (feet)	Depth (feet)
Clay, silty, yellowish-tan, high plasticity; contains a few silty lenses and calcareous nodules ---- -----------------	8	8
Silt, clayey, sandy, calcareous, yellowish-tan, poorly sorted; contains subangular to subrounded granule-size gravel -------------	5	13
Gravel, limestone, sandy, granule- to large pebble-size, subangular to subrounded; contains some coarse-grained sand ----------	4	17

Table 3.--Logs of selected shallow test holes - Continued

Test hole 16--Orchard Park terrace--SW¼SW¼SW¼ sec. 24, T. 12 S., R. 25 E.

	Thickness (feet)	Depth (feet)
Sand, quartz,^ose brown, medium-grained, sub-rounded to well-rounded, well-sorted -------	0.8	0.8
Sand, very silty and clayey, poorly sorted --	.2	1.0
Silt and sand, reddish-brown, moderately *well* sorted, wet; contains coarse-grained silt and very fine-grained sand; some caliche --	1.5	2.5
Silt, clayey, very dark-brown with white spots, low plasticity, friable; scattered sand grains; impregnated with white caliche -------------------------------------	1.5	4.0
Silt, very sandy, slightly clayey, yellowish-brown, coarse-grained, moderately sorted, low to medium plasticity; some very fine to fine-grained sand; scattered caliche, amount decreases from 4.0-6.0 feet ----------------	2.5	6.5
Sand, siliceous, slightly silty, brown, very fine- to medium-grained, subangular to well-rounded, moderately well sorted -----------	1.5	8.0

NM-52

Recharge in Roswell Basin, N. Mex.

By

Ward S. Motts and R. L. Cushman

Figures 1 - 15.