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GROUND WATER—ITS OCCURRENCE AND RELATION TO THE ECONOMY AND GEOLOGY OF SOUTHWESTERN NEW MEXICO

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INTRODUCTION

The physical geography and the geology of southwestern New Mexico has determined to a great extent the type and degree of development that has taken placed since large-scale settlement began about 1860. The form of the land determined the location of principal routes of travel, and the natural endowments of minerals and climate provided a potential for economic development. However, the availability of water, and particularly ground water, is a major factor that has controlled the economic development at all times.

In a very real sense, ground water is the most important natural resource of the region; it is a commodity that is in the market place. Ground water is important not because it is abundant, or because it is very scarce, but rather because there is just enough to cause competition for its use. The economy of the region could not have developed without ground water and would decline in proportion to any curtailment of availability unless balanced by more efficient use or by development of a more valuable use for the diminished supply.

The original settlements in the southwest were of necessity located along the rivers and creeks where supplies of surface water were available or where ground water could be obtained by hand digging. The depths of wells depended in part on the industry and perseverance of the digger. An old hand-dug well in valley fill in upper Wamel Valley, 12½ miles southeast of Hachita, is about 400 feet deep. Reportedly there is from 70 to 80 feet of water in the well, and a windmill can pump it out in from 2 to 3 days. Most early-day wells were dug alongside stream channels and were no more than a few tens of feet deep at the most.

The only surface-water supplies of consequence available for development in southwestern New Mexico, west of the Rio Grande Valley, were those in the Gila and Mimbres River. These supplies were soon almost fully appropriated by farmers who had learned by 1900 that precipitation was not dependable and they could not farm without supplementary irrigation.

Records and verbal reports indicate that water in creeks and springs was more plentiful through the late 1800's than it is today; the supply began to diminish soon after the onset of a drought which Weather Bureau data show began about 1885 and continued to about 1904. The drought reduced the already meager supplies of surface water and forced an early and intensive development of ground-water resources throughout the region. The present drought, considered to have started about 1943 and considered by Schulman (1956, p. 67) to be the most severe since the drought of the late 1200's, added impetus to the development of ground water.

Small to moderate amounts of ground water generally are available in the region within economic distances from all points of need; large amounts of ground water are available locally. For purposes of reference, a "small amount" is defined as less than 20 gpm (gallons per minute); a "moderate amount" is from 20 to 100 gpm; and a "large amount" is more than 100 gpm. Generally, a supply of 2 to 10 gpm is adequate for domestic and stock use, and supplies of 100 gpm or more are needed for irrigation.

The needs for ground water vary greatly in the region but are in five general areas of economic interest: (1) rural domestic and stock, in which needs are relatively small and scattered; (2) urban, in which needs are only moderately large but are concentrated in small areas; (3) industry, in which needs range from small to large and generally are concentrated in small areas. (4) recreation, which places only small demands on ground-water supply and may be included with rural domestic and stock use or with urban, depending on the use; and (5) irrigation agriculture, in which needs are large and are spread over broad areas.

Rural living is completely dependant upon availability of ground water, and the livestock industry to prosper, must have a year-round water supply; in this region a sure supply is now available only from wells. The early settlers along the rivers and creeks relied on shallow wells because the streams sometimes failed and the water was rarely sanitary.

Sheep and goats had grazed the more arid regions before 1900 and cattle were more or less restricted to the better-watered areas. Increasing aridity and improved drilling techniques resulted in more intensive development of deep wells for both domestic and livestock supply. The discovery that ground water was available in almost all rock formations, in previously unwatered areas, was a factor in the expansion of the more remunerative cattle industry and the gradual decline of the sheep and goat industry.

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The first stimulus to growth of urban settlements west of the Rio Grande Valley came with the discovery of ore deposits in the period 1850-70. Mining towns and camps grew near the ore discoveries that were scattered throughout the region; their development created demands for water that could not be met at all times. An adequate water supply was a problem from the start for most of the communities, and for some it still remains a problem.

Pinos Altos, first known as Birchville, was established about 1860 (Graton, Lindgren, and Hill, 1910, p. 297) and has had a more or less continuous shortage of water ever since. Silver City in recent years solved a long-continuing water shortage by piping ground water from two well fields, five and six miles from town, one of which is across the Continental Divide.

All the permanent communities in the region were dependent from the earliest days upon ground water for public supplies. A few mining camps obtained water by hauling. The mining camp of Shakespeare, in the Pyramid Mountains, reportedly obtained a small supply of water from nearby springs. The camp at one time, about 1870, had a population of some 3,000 miners, promoters, and camp followers (This is Lordsburg, V. 1, No. 1, p. 11). However, the small water supply probably was never strained; if the legends are to be believed, water was used only for cooking and for watering stock. The buzzards, reportedly guided to carrion in part by smell, must have had difficulty in distinguishing their objective. Lasky (1947, p. 84) reports that water sold for $1.00 a gallon at Sylvanite (southwest of Hachita) during the boom of 1908.

The demand for water to exploit the copper deposits of Santa Rita continues to challenge the engineers of the Kennecott Copper Corp. However, the company, because of a farsighted water-development policy and a vigorous practice of water conservation, has managed well on what must be considered a tight water budget. The water supply for the Santa Rita operation—at the mine, at the precipitating plant, and at the smelter—comes almost wholly from ground-water sources. It seems safe to say that had supplies of ground water not been available, the development of the Santa Rita copper deposits would have been severely restricted.

The geologic processes that shaped the Rio Grande Valley and the interior basins created a topographic and lithologic situation ideally suited to large-scale irrigation agriculture. Only water was needed to "make the desert bloom as the rose." Surface water made irrigation possible in the river valleys in the early days of settlement, but development of irrigation in the Deming, Lordsburg, Animas, Playas, and San Simon areas had to await technological advances in economical recovery of the large quantity of water stored underground.

Irrigated farming in the Rio Grande Valley and along the Mimbres and Gila Rivers increased with the influx of homesteaders and miners after the Civil War. Increasing demands and competition for the river water rapidly led to shortages of supply. Recurring periods of drought and subnormal stream runoff aggravated the situation. An effort to solve some of the problems resulted in the construction of Elephant Butte and Caballo Dams and in the formulation of the interstate and international river compacts that now control use of water from the Rio Grande and the Gila River.

Within a few years, man's tampering with the regimen of the stream had its unexpected effect, as described by Conover (1954, p. 52-53):

> "The depth to water in the Rincon and Mesilla Valleys in the early years prior to construction of Elephant Butte Dam was considerably greater than at present. The flow of the Rio Grande at that time was unregulated and there were periods when there was no flow of water.***
>
> The first water from the Elephant Butte Reservoir was made available to the project in 1915. The reservoir not only assured a more plentiful supply of water but also resulted in clear water being available, whereas formerly silt-laden water had been used. The clear water seeped more rapidly from the canals, and as the clear water also drained faster from the irrigated lands, more water was applied to the lands. These conditions*** resulted in a rise of water level to alarming heights and caused abandonment of productive farmlands.***"

The problem of water-logged farmlands was solved by a network of drains, and the next problem, a shortage of surface water, resulted in an increase in development of irrigation wells.

Irrigation wells had been drilled as early as 1896 in the Rio Grande Valley. These wells tapped large supplies of water in transient storage. The drilling of irrigation wells alleviated water shortages caused by variability in the surface supply. However, the drilling of wells created other problems, some of which were, in some ways, as serious as those solved.

Conover (1954, p. 121) aptly pointed out, "Pumping of ground water [in Rincon and Mesilla Valleys] for supplemental use does not represent an additional supply or new source of water but rather a change in methods, time and place of diversion of available supplies." This statement applies wherever geologic conditions are similar, as in the Gila and Mimbres River valleys.

A group of New Mexico farmers on the Gila River lost the use of certain surface waters for irrigation as a result of the "Globe Decree," which adjudicated use. After they also lost the subsequent Tingley-Arizona "war," they drilled irrigation wells into the valley fill adjacent to the river. Thereafter, they had water available, without shortage, when they needed it, particularly in late summer when streamflow normally is deficient. The effect that pumping wells had on the flow of the river into Arizona can be easily imagined.

The extensive development of ground water for irrigation in the various closed basins has had adverse effects, most of which were anticipated by a few people. Water levels in all areas of development began declining as soon as pumping began. Pumping lifts increased, water yields declined, and the unit cost of water increased. The change in water levels in wells in the Mimbres Valley near Deming is shown on water-level change maps for the periods 1913 to 1940 and 1940 to 1960 (fig. 1).

The Deming area is one of the first in the State in which ground water was mined extensively, and the effects of pumping, depicted on the water-level change map of the Mimbres Valley, are previews of the effects of pumping to be expected in the Animas, Playas, San Simon and Lordsburg Valleys, and in the Nutt-Hockett basin. Although the volume of the dewatered, or "mined," ground cannot be computed precisely, it is interesting to compare it with the excavated volume of Santa Rita pit—the Santa Rita pit is a "small mine" by comparison.

The people of New Mexico recognized at an early date the necessity of controlling the use and development of ground-water resources. The State Engineer of New Mexico under authority granted by the State Constitution and the State Legislature in 1931 extended State control of ground-water development in specified areas (fig. 2), as the need for control became apparent. Gross overdevelopment has been halted with the consequent protection of large investments and the assurance of extended life for highly-developed areas.

The State Engineer assumes jurisdiction over ground-water uses "to prevent impairment of existing water rights, to insure beneficial use of available water, to provide for orderly development of the resource, and in some instances as a safeguard against possible investment in wells the use of which might be prohibited by court decree * * *. In declared underground-basins * * * no well may be drilled without a permit from the State Engineer," (New Mexico State Engineer, 1962, p. 6).

Control by the State is not restricted to development for agricultural use—it is applied to all users; nor does the State at this time attempt to determine generally what is or is not the most beneficial use of water. The economic value of available supplies of water will determine to a large extent how the supplies are used. For example, at one place in Grant County large-capacity wells were developed and used for irrigation. Kennecott Copper Corporation's need for more water led to their acquisition of the irrigation wells. Obviously, at the time and place, economics dictated that the water had a greater value for ore processing than for agriculture.

The determination of what is the most beneficial use will become increasingly a subject for careful study; and though decided at any given time, the decision always will be subject to change with changing economic and social conditions.

ROCK FORMATIONS AND THEIR AQUIFER CHARACTERISTICS

The largest quantities of water come from the alluvium and bolson fill, therefore, they may be considered the principal aquifers. But whether or not they are the most important aquifers is a matter of personal opinion. To a man who has just built a new home on an outcrop of the Colorado Shale and then drilled two or three wells from 150 to 300 feet deep searching for water, a thin stringer of sandstone that will yield 1 gpm is the principal, and most important, aquifer.

All the geologic formations present in the region yield water, at least locally, but the yields from most formations are small, and from some, highly uncertain as to permanency. It is a fact, so obvious it commonly is overlooked by the field geologist, that the hydrologic characteristics of the rock formations are matters of extreme importance to the economy of the region. Descriptions of rock formations should include, to broaden their usefulness, at least the gross hydrologic characteristics.

The descriptions that follow are intended to present only the general material needed to make qualitative estimates of the availability of ground water. The lithologic descriptions are in part from Lasky (1936, p. 14-15), from information given by W. R. Jones to F. D. Trauger in 1954, and from miscellaneous publications. Refer to the lexicon of geologic names in this guidebook for the ages of the geologic units described in this paper.

Granitoid and metamorphic rocks.—Mostly granite of the Burro Mountain batholith but including schist, gneiss, greenstone, and younger intrusive rocks. Generally dense, impermeable, and non-water-bearing. Local yields to wells range from less than 1/10 gpm to as much as 15 gpm where the rock is deeply weathered,

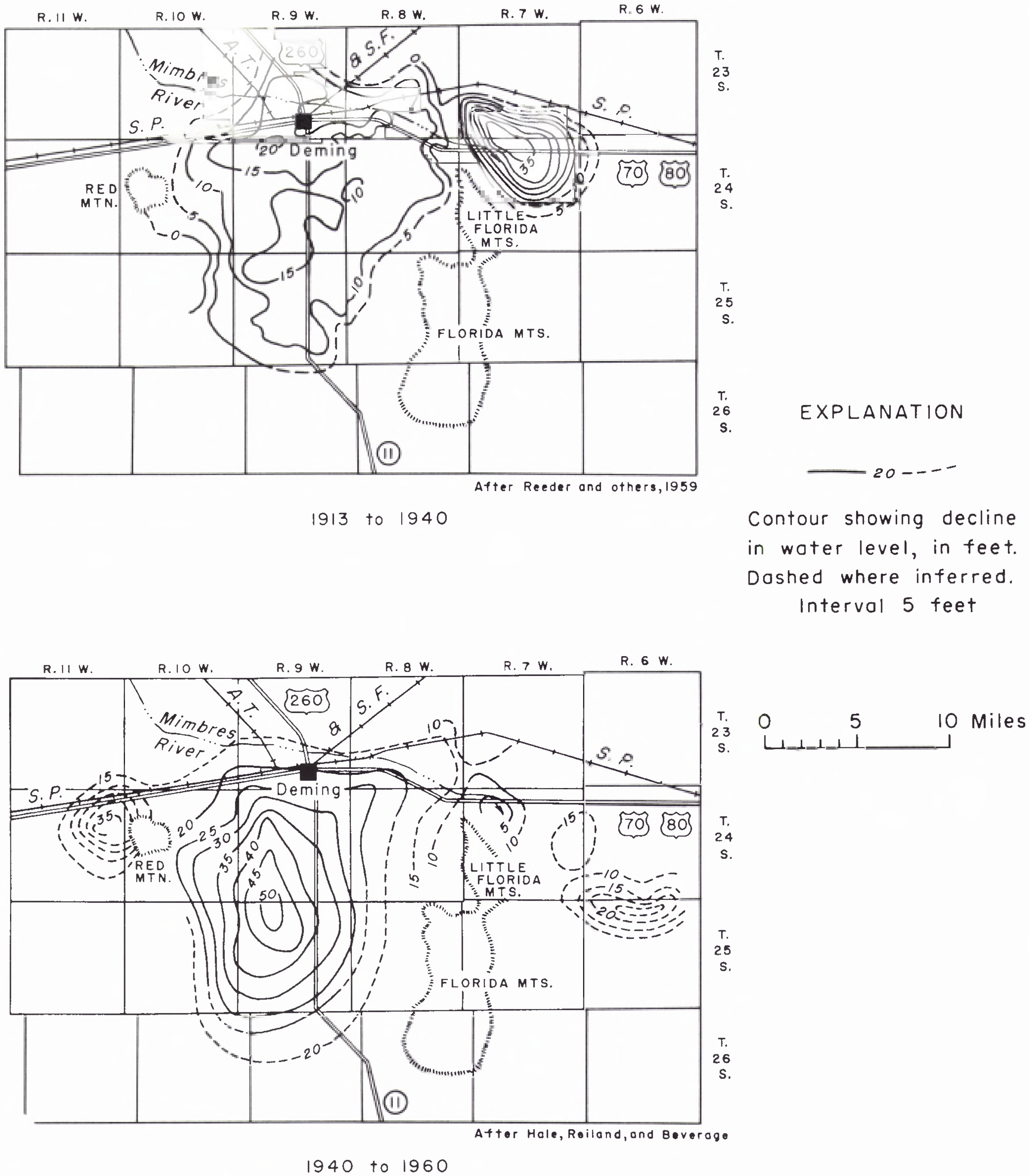
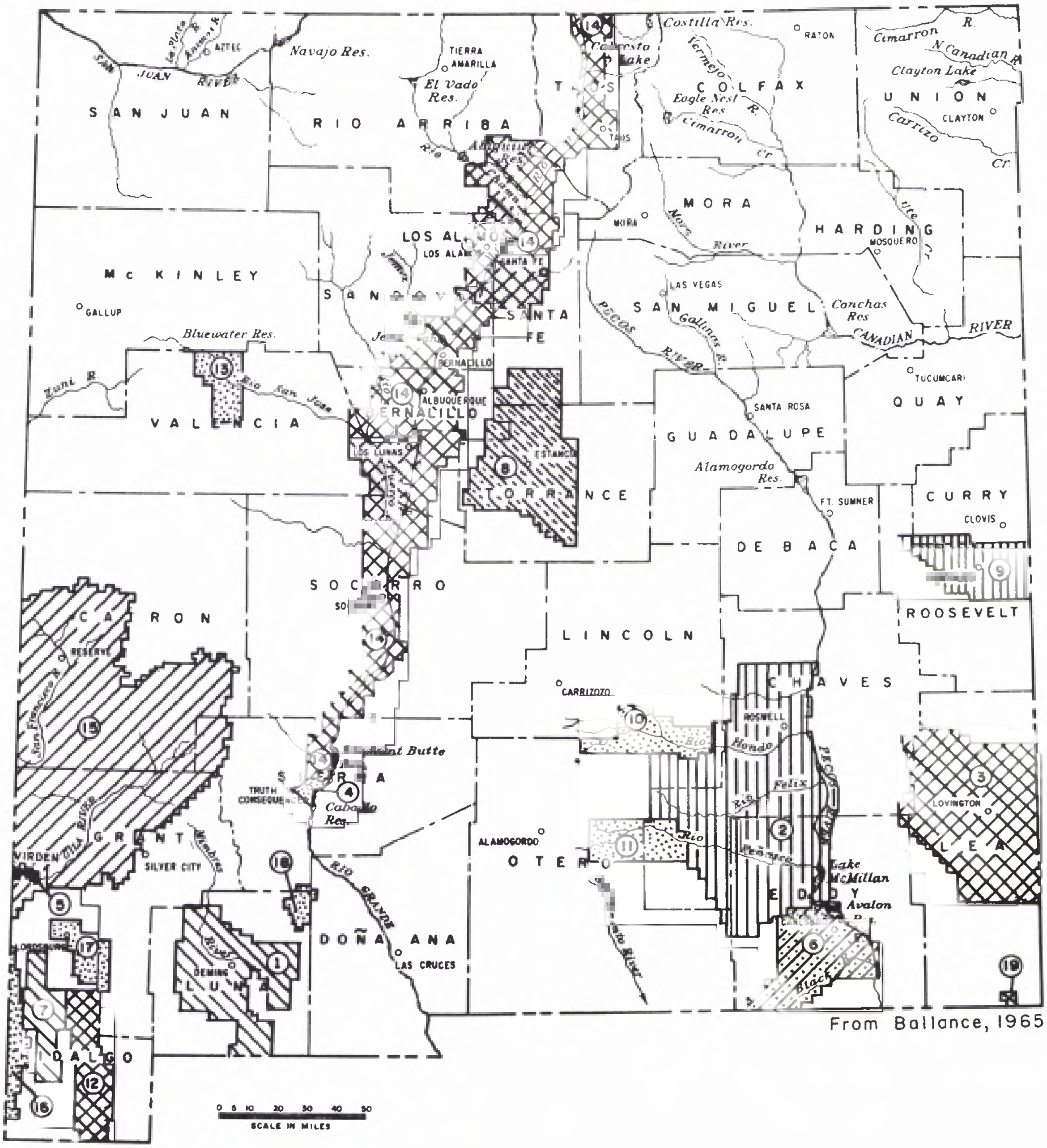


FIGURE 1

Decline of ground-water level in Mimbres Valley, Luna County, New Mexico, for the periods shown.



UNDERGROUND WATER BASINS

1. MIMBRES VALLEY
2. ROSWELL ARTESIAN
3. LEA COUNTY
4. HOT SPRINGS
5. VIRDEN VALLEY
6. CARLSBAD
7. ANIMAS VALLEY
8. ESTANCIA
9. PORTALES VALLEY
10. HONDO
11. PEÑASCO
12. PLAYAS VALLEY
13. BLUEWATER
14. RIO GRANDE
15. GILA - SAN FRANCISCO
16. SAN SIMON
17. LORDSBURG VALLEY
18. NUTT - HOCKETT
19. JAL

FIGURE 2

Underground water basins in New Mexico declared by the State Engineer as of December 1963.

intensely jointed, and/or is broken and sheared by faulting; "dry holes" are relatively common.

Bliss Sandstone.—Conglomerate (locally, at base) overlain by generally dense glauconitic and hematitic crossbedded sandstone and quartzite; contains some dense dolomite and limestone. No wells are known to obtain water from the Bliss, and the formation should be considered generally non-water bearing. As much as 5 gpm may be obtained locally where the porosity of the beds of sandstone has not been completely destroyed by cementation or where joints may provide some storage.

Fusselman Dolomite, Montoya Dolomite, El Paso Limestone, and equivalent beds.—Massive to thin-bedded, generally dense, finely crystalline, commonly cherty, limestone, dolomitic limestone, and dolomite. Generally water bearing; yields to wells are commonly small except where rocks are fractured by faulting; solution cavities are scarce. A yield of about 230 gpm is obtained from a well 2,115 feet deep that fully penetrates these beds (at a depth of 1,925 feet) in a faulted area near Santa Rita.

Percha Shale.—Green to black, soft, fissile shale and local thin interbeds of blue, argillaceous limestone and tan, calcareous shale in the lower part; gray shale, limy shale and local thin beds of crinodal limestone in the upper part. Generally non-water-bearing but locally yields as much as 1 gpm.

Naco Group, Escabrosa Limestone, Syrena and Oswaldo Formations of the Magdalena Group, Lake Valley Limestone and equivalent beds.—These rocks include a wide variety of limestone, ranging from nearly white to black, dense, thin-bedded to massive, locally highly fossiliferous, cherty, sandy, and shaly; solution cavities are uncommon. Generally water-bearing, but yields are commonly small and from jointed and fractured zones. Deep penetration is generally necessary to obtain even the small amounts of water necessary for domestic and stock use. Full penetration of the Syrena, Oswaldo, and Lake Valley by a well drilled in a faulted area in the vicinity of Santa Rita resulted in a yield of about 185 gpm.

Abo Sandstone and Hueco Limestone.—The Abo consists primarily of red shale, siltstone, and limy mudstone, locally conglomeratic; the Hueco is mostly a massive, gray, fossiliferous limestone. These rocks are sparsely distributed in southwestern New Mexico and are not known to yield water to wells. Their physical characteristics indicate that they would yield only a few gpm.

Lobo Formation, Colorado Shale, Beartooth Quartzite, Sarten Sandstone, and Bisbee Group.—The Lobo, Beartooth, and Sarten are mostly thin, well-indurated, fine- to coarse-grained clastic rocks that are generally above the water table, and where they are found below the water table they yield little or no water to wells.

The Colorado Shale in central Grant County consists of a thick (800± feet) upper sequence of interbedded tan, brown, and white well-indurated sandstone and dark, greenish-brown to black shale and a lower sequence (200± feet) of black to gray fissile shale that contains some indurated sandstone and a few gryphaea beds; the Colorado Shale is cut by swarms of dikes almost everywhere in the area. Interbedded and interfingering shale and indurated sandstone units are inherently poor aquifers. In addition, the complex of dikes has further reduced the continuity of any possible water-bearing beds. Yields from the Colorado Shale are highly unpredictable and range from less than 1/10 to 15 gpm. As many as three wells have been drilled on a ¼-acre lot in a search for domestic water in the area between Silver City and Central.

The Bisbee Group includes the conglomerate, sandstone, shale, limestone, and interbedded volcanic rocks of Early Cretaceous age described by Lasky (1947, p. 16) in the Hachita area and similar units described by Gillerman (1958, p. 43) in the Peloncillo Mountains. The limestone is mostly dense and massive to thin bedded; the clastic and pyroclastic rocks are mostly poorly sorted and highly gradational; the volcanic rocks are mostly flows of dense basalt and andesite. This sequence, in general, yields little water, but commonly will supply domestic and stock wells. Where the sequence is fractured by faulting, as is common in areas of mineralization, the units can store appreciable water, and excesses of water can be a problem in mines.

Datil Formation, Rubio Peak Formation, equivalent, and other volcanic rocks.—The Datil is a widespread, thick sequence of mostly andesite, latite, and rhyolite flows, associated pyroclastic rocks, sedimentary tuff, sandstone, and small intrusive bodies overlain by younger basalt flows, rhyolite, and interbedded pyroclastics and sediments. The Rubio Peak consists of flows, flow breccia, agglomerate, and tuff but includes thick sections of conglomerate, sandstone, and gravel. Large areas in Grant, Hidalgo, and Luna Counties are underlain by rocks not correlated with the Datil but recognized as being similar, generally contemporaneous, or only slightly older or younger.

Most of the flow and pyroclastic rocks are dense, massive, and nearly impermeable. Interbedded sediments commonly are discontinuous and poorly sorted and contain much pumiceous and tuffaceous material which further reduces porosity. Sandstone in the Datil and beds of gravel in the Rubio Peak may furnish some of the water to large-yield wells in the vicinity of

Apache Tejo and Faywood. However, in general, the volcanic rocks of southwestern New Mexico are poor aquifers.

Effective porosity in the flows and pyroclastic facies is limited largely to joints and fractures which for the most part are filled or closed at depth, and on rubble and cinder zones between flows.

A well drilled 600 feet into the volcanic rocks near the Gila Cliff Dwellings had a static water level of about 75 feet below the surface and would yield no more than 5 gpm (170 barrels per day, or about ½ miners inch). Another well, near Mule Creek, Grant County, developed about 25 gpm in red cinders at a depth of about 700 feet.

Gila Conglomerate and Santa Fe Group.—Conglomerate, gravel, sand, silt, and clay, derived locally; locally includes rhyolite, basalt, tuff and other volcanic rocks. Weakly to strongly consolidated, non-bedded to well-bedded, at places monolithic. Two major divisions of the Gila, upper and lower can be recognized in Grant County. The lower part of the Gila generally is strongly indurated, and locally deformed; the upper part of the Gila generally is no more than slightly consolidated.

Both the Gila and the Santa Fe are poor to fair aquifers, depending on the degree of sorting and consolidation. Yields to wells finished in the Gila generally range from less than 1 gpm to about 20 gpm, and locally up to 500 gpm—and perhaps more (source of water in same large-yield wells is not certain). All large yields from the Gila are from wells penetrating the upper part of the Gila. The Santa Fe, in the vicinity of Rincon and Mesilla Valleys, also yields generally small amounts of water to wells. Conover (1954, p. 193) lists only one well that yields as much as 100 gpm from deposits that most likely are part of the Santa Fe group.

Alluvium and bolson deposits.—Gravel, sand, silt, and clay, unconsolidated to locally indurated with carbonate as calcrete, with iron as ferricrete and with silica as silcrete. Mainly flood-plain and valley-fill deposits but includes pediment, terrace, and other surficial deposits and locally interbedded thin flows of basalt.

Core drilling for damsites on the Gila River show the valley fill to be as much as 50 feet thick locally (U.S. Bureau of Reclamation, 1930, p. 209). The alluvium under the flood plain of the Mimbres Valley at the McSherry Ranch, near Dwyer, is about 25 feet thick; reportedly, it overlies hard conglomerate (Gila (?)). The thickness of the alluvium ranges from about 80 to 220 feet in the Mesilla Valley and is not more than 80 feet in Rincon Valley (Conover, 1954, p. 25-26). Bryan (1938, p. 218), writing of the Rio Grande Valley, states "it seems probable that there is in the larger valleys from 100 to 250 feet of relatively recent deposits of flood-plain type above the Santa Fe formation."

The stream-valley and bolson deposits constitute the largest reservoirs for ground water in the region, and in general they are good to excellent aquifers. Shallow wells on the flood plain of the Gila River yield as much as 2,200 gpm from bouldery alluvium, and wells in Rincon and Mesilla Valleys are reported (Conover, 1954, p. 109) to yield "from about 600 to more than 2,000 gpm." Wells on the flood plain of the Mimbres River generally have smaller yields than wells along the Gila River and Rio Grande because the alluvial fill is thinner along the Mimbres.

The terrace gravels in general do not yield much water, but one well tapping these deposits near San Lorenzo, on the Mimbres River, yields about 300 gpm with a drawdown of about 32 feet.

The bolson deposits in general are not as coarse as those deposits under the flood plains, and as a consequence yields are somewhat smaller. Most irrigation wells in the Columbus, Deming, Lordsburg, Animas, Playas, and San Simon areas have yields of less than 1,000 gpm. A few wells yield more, but the maximum reported is about 1,500 gpm. Some data indicate that high yields in the Columbus and Faywood areas may come from volcanic rocks associated with the sediments.

An oil-test well drilled 18 miles southeast of Deming (6 miles east of the Florida Mountains) in 1949 reportedly bottomed in bolson deposits at a depth of 4,011 feet; an oil-test well drilled at Playas in 1929 reportedly bottomed in bolson fill at a depth of 2,150 ft. (Dixon, Baltz, Stipp, and Bieberman, 1954, p. 30-31). These and other tests show that the bolson deposits are of great thickness in most of the region. The full thickness is not known. These deposits constitute a ground-water reservoir of tremendous capacity.

THE OCCURRENCE OF GROUND WATER

The recharge, discharge, movement, depth, availability, and quality are elements of the occurrence of ground water that greatly concern the economic aspects of ground-water development and conservation. The status of ground-water development in southwestern New Mexico is such that these elements locally need to be studied quantitatively now or in the immediate future. Elsewhere, qualitative studies are all that will be needed for many years to come. For the general purposes of this paper, the treatment need only to be qualitative.

Recharge

Natural recharge of aquifers takes place by infiltration of precipitation on areas of outcrop, by infiltration of surface water, by movement from one aquifer to another, or by combination of these methods. Artificial recharge may be accomplished through wells or by surface spreading on permeable material. The method of natural recharge that contributes most to aquifers depends largely on the local geology.

Recharge to the aquifer under the flood plains of the larger rivers and streams is almost entirely by infiltration of surface flow. This recharge is rapid at most places. Ground water that was pumped, or drained away naturally during periods of low or no flow, is replaced during periods of normal or above-normal stream discharge. This method of recharge would seem to allow development and subsequent use of the aquifer without concern for eventual depletion. This is true only if the surface flow is adequate to recharge all the aquifer, from the uppermost to the lowermost parts of the valley. If it is not adequate, then down-valley pumpers eventually will experience some aquifer depletion as a result of up-valley pumping.

Recharge to bolson fill occurs by infiltration of occasional surface flow, by infiltration of occasional precipitation, or by a combination of both, but more frequently it does not occur. The mechanics of recharge through a thick overlying sequence of unsaturated alluvium to the water table in an arid to semiarid region is not fully understood and is a subject worthy of research. However, there is no doubt that the quantity of recharge is small.

A measure of recharge in the farmed areas of the closed basins may be obtained from consideration of water availability and water use. The precipitation is 8 to 11 inches per year in the lowland parts of these basins and as much as 15 inches per year in the mountains adjacent to the basins. An average precipitation of 10 inches for the total drainage area per year may be a fair estimate. Of the total average precipitation, most is evaporated directly or transpired by plants from the soil zone. As a result, very little if any of the water infiltrates to the zone of saturation. Data show that about one percent of the average precipitation becomes recharge (Doty, 1960, p. 15 and Reeder, 1957, p. 25) in the Playas and Animas Valley.

Natural recharge in upland areas is commonly by a combination of infiltration in stream beds and by infiltration of precipitation. Large areas of bare rock rapidly shed most of the precipitation, but some water infiltrates through joints, cracks, bedding planes, and other surficial openings. Thin deposits of sand and gravel in upland channels retain some runoff for longer periods and allow time for additional infiltration into channel bedrock.

A scarcity of precipitation is not the limiting factor in recharge to upland rocks; the limiting factor is the denseness of the upland rocks throughout the region.

The argument has been advanced that many small dams on upland reaches of streams would increase recharge. Such dams might be beneficial in other respects but they will aid recharge only if the controlled water is brought subsequently to a place where the rocks can absorb water.

Artificial recharge through wells and by spreading has proven effective elsewhere when properly practiced. However, many factors must be considered before such methods of recharge can be used. Obviously, the opportunity for such recharge is dependent upon an available supply of water. Supplies of water that could be so used are not readily available in the region. Experiments are now in progress to determine if precipitation can be collected from paved areas in quantities sufficient to justify recharge of locally depleted groundwater reservoirs.

Discharge

Natural discharge of water from an aquifer to the land surface, or to another aquifer, may occur as effluent seepage along a stream channel, as discharge from springs, as evapotranspiration, or as movement from one aquifer to another. Artificial discharge includes that from drains and wells. All these processes are at work in southwestern New Mexico, and most of them at one place or another have an important effect on the economy of the region. Only the discharge from springs may be considered insignificant.

Effluent seepage maintains the flow of the Gila River in the upper reaches and thus is largely responsible for maintaining nearly full saturation of the alluvium in the irrigated areas on the flood plains in New Mexico. Surface runoff in the spring would be less if channel fill had to be fully recharged before surface flow began.

The Mimbres River, though apparently dry in much of its course most of the year, has an appreciable underflow that is maintained partly by effluent seepage. This underflow is tapped by irrigation wells on the flood plain in the vicinity of Dwyer, in Grant County.

Seepage studies along the Rio Grande below Caballo dam indicate appreciable increments to flow in the River. These increments are believed to be principally as underflow through unconsolidated alluvial fill in tributary canyons, but some water probably comes also from the Santa Fe Group.

Evapotranspiration is an important process of ground-water discharge and is one of economic interest because much of the water so discharged at present is wasted. Water lost by evaporation from irrigated crops has served a useful purpose, but water discharged by evaporation from non-beneficial vegetation is a real economic loss. The amount of water that might be salvaged by eradication of non-beneficial vegetation is the subject of several investigations now in progress.

Data compiled by Gatewood and others (1950, p. 136-138) showed that a single cottonwood tree with a canopy of 50 feet may transpire as much as 500 gallons per day. Conover (1954, p. 78) estimated that native vegetation in Rincon and Mesilla Valleys transpired about 40,000 acre-feet per year. However, the amount of water that could be salvaged by eradication of non-beneficial vegetation generally would be much less than the amount now consumed.

The role of saltcedar as a water-stealing villain is well known and few people would be adverse to seeing the villain "done in." However, not many people would approve the total destruction of the cottonwoods that make such pleasing vistas along our river valleys. Here again is the question of beneficial use and to what extent aesthetics are considered beneficial. A current program to remove the pinon cover over a large part of northern Arizona, at a cost of about 75 million dollars, is not meeting with universal approval although highly beneficial results reportedly can be shown.

Interaquifer discharge is widespread though not commonly recognized because it is not readily apparent. An example of interaquifer discharge is the movement of ground water laterally from the thick sequence of volcanic rocks bordering the headwaters of the Gila into the alluvium. This discharge maintains full saturation of the channel fill and helps sustain perennial flow in the upper reaches of the Gila River.

Leakage from artesian aquifers upward through imperfectly confining beds is a relatively common type of interaquifer discharge in southwestern New Mexico because confined and semi-confined water is common. Leakage probably occurs in the vicinity of Dwyer, in Duck Creek Valley (Grant County), and in Playas, Mimbres and Hachita valleys where a few flowing wells have been developed.

Interaquifer discharge can present serious problems if the discharging water is more saline than that in the receiving aquifer. Waste water of poor quality that is discharged to one aquifer may move into another aquifer and impair the quality of the water in that aquifer also. Serious deterioration of water quality by interaquifer discharge is not known in southwestern New Mexico except on a small scale at a few isolated places in association with mining activities.

Artificial discharge from wells and drains accounts for a large volume of ground-water discharge in southwestern New Mexico. The drains constructed in Rincon and Mesilla Valleys had an average annual flow, at the drain outlets, of 249,400 acre-feet from 1930 to 1946 (Conover, 1954, p. 44). This water, according to Conover, was composed of waste from canals, seepage from canals, return seepage from irrigated lands, seepage from the Rio Grande, and flow of ground water from the mesa lands to the valley. This average annual figure is not likely to have changed much since the period of record because conditions that control the discharge have not changed greatly.

Data collected on use of water in southwestern New Mexico show annual pumpage to be about 185,000 acre-feet. Total pumpage by communities is about 15,000 acre-feet annually. (Dinwiddie, and others, in press.) Pumpage from domestic and stock wells is estimated to be about 7,000 acre-feet annually. The total amount pumped for industrial use is estimated to be 10,000 acre-feet on the basis of incomplete data. Water used for irrigation in the river valleys commonly includes both surface and ground water; the amount of each cannot, at all places, be determined. About 97,000 acres were irrigated in 1960 and possibly as much as 15,000 acre-feet of the water used was pumped. Pumpage for irrigation in the closed basins was about 147,000 acre-feet in 1960.

The water pumped in the Rincon and Mesilla Valleys and along the Gila and Mimbres Rivers is mostly from shallow aquifers and is applied to porous sandy soil. From 30 to 40 percent (Conover, 1954, p. 51) of the water applied for irrigation on these more porous soils returns directly to the water table so that the total pumpage does not represent storage depletion.

On the other hand, water pumped from the bolson deposits may be considered fully utilized. Except for rare cases, none of the water is believed to return directly to the water table in bolson deposits. Irrigation water is applied in the bolsons to soils that are clayey and relatively tight, generally in quantities sufficient to wet only the upper few feet of the soil. The interval between the wetted zone and the water table remains essentially dry.

Where pumping discharge is continuous to the land surface water may percolate down to the water table. Some of the water pumped from wells for municipal use may infiltrate to the water table after being discharged as effluent from sewage-treatment plants.

The time is forseeable when no water can be wasted and sewage effluent will also be utilized fully. The town of Silver City in the past few years has, commendably, begun using fully treated sewage effluent to develop a recreation area for which water previously was not available.

DEPTH TO WATER, THE SHAPE OF THE WATER TABLE, AND MOVEMENT OF WATER

The depth to water in southwestern New Mexico ranges from one or two feet at places in the river valleys to as much as 1,000 feet in the upland areas of parts of the Mogollon Plateau (Trauger, 1960, p. 18). Ground water in the lower part of Playas Valley is less than 4 feet below the surface of the playa; it is about 350 feet below the surface in upper Wamel Valley. The water table generally rises in altitude toward the bordering uplands and the upper ends of the valleys, but does not rise as rapidly as the land surface; therefore, the depth to water becomes progressively greater away from the low areas of the bolson. The depth to water under the intermediate slopes between the flatter central part of the bolsons and the foothills commonly is 200 to 400 feet.

Depth to water generally changes abruptly near the mountains. The change will be to greater depth if the land surface rises sharply and the water table extends under the mountains and plateau areas without equally sharp changes in gradient. This condition may develop where deep canyons cut the uplands and create a pattern of natural drains, or where, in rare instances, the mountains are composed of rock as permeable as the bolson fill. Or the change may be to shallower depth as a result of an abrupt change in the lithologic character of the rocks; as from bolson fill to granitic or volcanic bedrock. Porosity and permeability of rocks in the mountains commonly is much less than in the bolson fill, and the rate of movement of water is slower. As a result, hydraulic gradients are steep and the "water table," if you can call it such, is nearer the surface.

Bedrock locally extends out from the mountains for an appreciable distance but under a progressively thickening cover of bolson fill. Where the concealed bedrock surface dips gently under the fill the water-table gradient generally does not change sharply, but where the bedrock surface drops abruptly, as it may if faulted down, the water-table gradient may change abruptly also. The location and extent of these concealed shelves of bedrock may thus be revealed by the changes in the gradient of the water table, as reflected by closer spacing of contours and abrupt changes in the depth to water.

The water in the bolson fill or alluvial cover over the shelf of bedrock generally is at shallow depth and moves on top of the bedrock toward the edge of the shelf and then downward to a lower level and to a commonly flatter water-table surface in the bolson fill. Such a ground-water cascade occurs west of White Signal where it is believed to trace the location of a buried fault zone that truncates the bedrock of the Burro Mountain pediment.

Data from hydrologic studies in southwestern New Mexico indicate that the depth to ground water in the upland areas can be determined approximately by using the floors of the two nearest encompassing master canyons or valleys as base level. The water table is at base level if the stream is flowing, and generally the water table is within 50 feet of the channel bed if the stream is not flowing. The slope of the water table will be up and away from the valley floor, and the gradient commonly is from 100 to 300 feet per mile.

Movement of water underground has long been a subject of study and, despite the fact that a judge once ruled that "percolating water moves in a mysterious manner, in courses unknown and unknowable" (Tolman, 1937, p. 22), the general course and rate of moving ground water can be determined.

Measurements of depth to water give, initially, points on the water table at a particular time. A water-table contour map can be drawn with these points. The water table generally is a subdued replica of the land surface. A map of the water table will show the slope (gradient) of the water table, the general area of recharge, the direction of movement of water (down slope, and at right angles to the contour at any point), and the general area of discharge.

Aquifer-performance tests give information from which porosity, permeability, transmissibility, and storage coefficients of the aquifer can be approximated. Volume changes in storage can be computed using changes in water levels, porosity, and storage coefficients; rate of movement can be computed using porosity, permeability, and the hydraulic gradient.

The rate of movement through unconsolidated coarse river-valley deposits may be as much as 1.6 feet per day or about 600 feet per year where the permeability is 1,250 gallons per day per square foot, the effective porosity is 25 percent, and the hydraulic gradient is about 13 feet per mile, as in the vicinity of Cliff and Gila. But the rate through clay, clayey sand, or a moderately well-indurated conglomerate may be only a few inches or a few feet per year.

The permeability, as determined by aquifer-performance tests, is about 35 gallons per square foot in the upper part of the Gila Conglomerate at Silver City's Woodward Ranch well field, the porosity is 20 percent and the hydraulic gradient is about 100 feet per mile. Water is moving there at a rate of about one-half foot per day, or 180 feet per year. The permeability of the upper part of the bolson fill in the irrigated areas differs greatly but averages about 170 gallons per day per square foot near Deming (Conover and Akin, 1942, p. 258) and also in the Mimbres Valley (Reeder, 1957, p. 41). The porosity is about 25 percent and the hydraulic gradients in the area are about 20 feet per mile, so the water moves at a rate of about one-third foot per day, or about 120 feet per year.

AVAILABILITY AND QUALITY OF GROUND WATER

Ground water is generally available within economic distances of the places where it is most needed, and our improving technology makes possible farther transport of water as demands increase. Water had to be "at the back door," so to speak, in the past but now we can put the pump in the "south 40."

Large volumes of water are available in the bolson fill and at present are undeveloped, except locally. Much of this water is in areas not suited to irrigation agriculture, and only a small part of it is needed for domestic and stock supplies. This water is located at such long distances from heavily pumped areas that, if developed, adverse effects on present developments would be unlikely in the foreseeable future.

Yields of 100 to 500 gpm probably can be obtained in much of the bolson fill between Silver City and Deming, between Deming and Lordsburg, and in parts of the Animas, Playas, and Hachita Valleys.

Additional ground water cannot be developed in the river valleys without almost immediate effects on the flows of the rivers.

Water is available from the bedrock in almost all upland areas; however, the quantities available generally are small. The local uncertainty of getting water and local depths to water of more than 750 feet tend to discourage attempts to develop water where it is needed. With the possible exception of drilling into the densely crystalline igneous and metamorphic rocks, it may be said that a supply of water adequate for domestic or stock use can be obtained if a well is drilled deep enough to reach the water table. However, the chemical quality of deep water in some of the upland areas may be poor for domestic and stock use.

The chemical quality of ground water in southwestern New Mexico generally is good to excellent. The waters in the upland, bolson, and river-valley areas contain bicarbonate commonly ranging from 200 to 300 ppm. Chloride generally is present at less than 40 ppm. About 70 percent of the ground-water analyses made for sulfate in Grant County show it to be present at concentrations of less than 50 ppm. Slightly higher concentrations of most constituents generally are found in the water from the bolson deposits. However, the notable exception is fluoride.

Fluoride is the only chemical constituent in ground water that is commonly found in southwestern New Mexico in concentrations considered harmful to humans. Most of the high concentrations are found in water from the areas of volcanic rocks and intrusions in the drainage basins of the Gila and Mimbres Rivers. The high concentrations commonly are associated with but not restricted to thermal water.

Thermal ground water is found at numerous places in southwestern New Mexico. Best known are the hot springs at Truth or Consequences, Radium Springs, Gila, Mimbres, Faywood Hot Springs, and Frisco Hot Springs. Not so well known are drilled wells that have tapped thermal water. At least one thermal-water well is known in the bolson deposits of Lordsburg Valley, and hot-water wells have been developed in Animas Valley. Water temperatures of 210 and 220°F have been recorded in two of these wells (Reeder, 1957, p. 75).

Any discussion of the quality of water progresses normally from discussion of quality under natural conditions to quality under conditions of development and utilization. Generally speaking, utilization results in deterioration of the quality of the water used. The deterioration may be slight or extreme; if extreme, the water may be made unfit for any other purpose. Disposal of such water can result in further deterioration in quality of water in other aquifers. Waste water from mines and ore processing in the Fierro-Hanover-Santa Rita-North Hurley areas years ago infiltrated the alluvial aquifer in the valley of Whitewater Creek and forced abandonment of many domestic wells.

Improperly constructed septic tanks and unwisely located surface structures of similar purposes also may contaminate ground-water bodies that supply water to domestic wells. The danger of such contamination is greatest in densely populated areas that do not have public water systems. Especially susceptible to this type of deterioration in quality are areas such as the Santa Rita-Fierro district where shallow alluvial aquifers overlie dense and impermeable bedrock.

Use of water for irrigation generally results in appreciable deterioration of quality with respect to domestic use. Natural minerals leached from the soil, chemical and natural fertilizers, and water-soluble pesticides can be concentrated in irrigation water and carried down to shallow water tables or to drains in the river valleys. This water may be recycled several times in the course of movement downvalley, and with each cycle it generally becomes increasingly enriched in dissolved solids.

The few data concerning the quality of the deeper water in the bolsons, indicates that the deeper water is of somewhat poorer quality than that being pumped at present. The water presently being pumped in the Deming area is locally of slightly poorer quality than that pumped when development began. However, the danger seems remote that serious deterioration resulting from encroachment of naturally inferior water can occur anywhere in southwestern New Mexico.

USE OF WATER

Ground water in the southwestern closed basins accumulated over a long period of time and is limited in quantity. Water pumped from the basin areas is withdrawn mostly from storage and, in areas of large withdrawals, the annual pumpage greatly exceeds the annual recharge. Ground water in the river valleys is in transient storage and is limited only by the capacity of the rivers to recharge the aquifers after water is removed.

More water is used in southwestern New Mexico for irrigation farming than for any other purpose; the duty of water ranges from about 1.5 to 2.5 acre-feet per acre. If the average duty of water is assumed to be 2 acre-feet per acre and the recharge rate is assumed to be 1 percent of the average precipitation of 10 inches per year, the ratio of storage depletion to recharge for an irrigated acre of land is $\frac{\text{24 inches duty of water}}{\text{0.1 inch recharge}}$. Another way of saying this is that one year's pumping removed 240 years of accumulated recharge from beneath the area irrigated or that, each year, each irrigated acre uses as much water as is recharged to 240 acres.

These rough estimates are not of great accuracy; however, they indicate clearly that pumping ground water for irrigation use cannot continue at the present rate without eventually lowering the water table below the economical pumping level. Perhaps a change to some crop that yields a higher return can prolong the economic life of a pumping area; the life probably will be extended first by reduction of pumping in areas of greatest decline and later by shifts to other areas not yet developed. But ultimately, irrigation must be greatly reduced. This ultimate reduction might be further delayed or held to a minimum if recharge could be increased appreciably.

But if every drop of precipitation were conserved for recharge, it would still require an annual precipitation 2½ times the average for the region to hold the water table in equilibrium at the lowered level. No source of water other than precipitation is presently, or ever likely to be, available for recharge.

Pumping ground water from transient storage in the flood plain may provide water when the surface flow is inadequate and will provide storage in the valley fill for future excess surface flow. But there is no prospect that surface water ever will be available in quantities sufficient for transport and use as recharge in the bolson areas.

The livestock industry in southwestern New Mexico faces no greater shortages of water in either the immediate or distant future than those it has experienced in the past. Droughts will come, as in the past, and these will affect the water supply more noticeably than heavy pumping (except that which occurs close to a stock well). The comparatively small demand made on ground-water storage by a stock well, and the wider distribution of such wells in areas not generally suited to other activities that demand water, precludes the likelihood of stock-well water supplies being depleted.

The increased tendency toward urban living, even in remote areas such as southwestern New Mexico, has created local problems of water supply for both large and small communities. Cities located in bolson areas and in the river valleys generally will have no problems of water supply. Water is available, but it may be necessary to acquire additional water rights in areas of declared basins.

Water for urban use is at a premium and cities, regardless of location, must be prepared to pay a premium price that would be prohibitive to most other users. A high cost may be incurred by the necessity of bringing water from distant points, by purchase of existing nearby water rights, or both.

The people of the Los Angeles area in California engaged in a bitter dispute many years ago over a proposal to indebt themselves heavily to provide water for the growing community. The proposal involved buying water rights in Owens Valley, on the east side of the Sierra Nevada, and bringing the water some 200 miles across deserts and through mountains to the metropolitan area. One faction said, in effect, "We cannot possibly afford to do this." The other faction said, "We cannot afford not to do it." The Owens Valley aqueduct was built, and as a result (not considered beneficial by everyone) the city of Los Angeles was able to develop as it has.

Industry, at present typified in southwestern New Mexico by the mining interests, faces two problems of water supply—too much, and too little. Some mines have had problems of disposal of water whereas the ore-processing elements of the mining industry have had local problems of supply. One happy union of the two problems resulted when the Kennecott Copper Corp. acquired the use of the 500± gpm that is pumped continuously to keep American Smelting and Refining Company's Ground Hog mine dewatered to the 1,900 foot level, even when the mine is out of production.

Should additional large supplies of ground water be needed to support continued development of the mining industry, or of other industries in the southwest, they are available in the bolson deposits. These supplies can be developed at many places without interfering materially, in the foreseeable future, with supplies already developed for urban and irrigation use. The water may need to be transported appreciable distances but it is available if the need justifies the cost.

An increasing interest in water for recreation is causing some revision of the concepts of beneficial use. The increasingly large sums of money that people are willing to spend for recreation may make it worth while to divert or develop water solely for recreational use. If the water can be made to serve two uses instead of just one without appreciable loss of water, the economic gain is even greater, and such proposals merit consideration.

Mangas Creek in Grant County has a base surface flow of about 1.8 cfs just below Mangas Springs. This water could be utilized for recreation, without appreciable additional loss, in the same manner that the water of Sapillo Creek is used at Lake Roberts.

Ground water probably could be economically developed at many more places than at present for swimming pools, golf courses, and similar recreational uses, but not to maintain large bodies of surface water.

CONCLUDING STATEMENT

The geologic environment of southwestern New Mexico has created a situation whereby large supplies of ground water have been accumulated slowly over a long period of time; these supplies are locally being depleted as a result of pumping for irrigation, municipal and industrial use. These depletions have made possible and have supported the economic development of the region far beyond the capacity of the available supplies of surface water. The reserves of ground water are large, but they also are limited. They should not be wasted, and they must be conserved and used judiciously to maintain a stable economy. An expanding economy can be achieved only by (1) searching out areas where additional supplies of ground water can be developed, (2) by developing different uses for the water available, and (3) by increasing multiple use. Cooperative planning by Federal, State, and local agencies and individual property owners will be necessary to achieve the most economical and broadly beneficial use of water.

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