UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

APPRAISAL OF GROUND-WATER RESOURCES OF TULAROSA BASIN AND ADJOINING AREAS, NEW MEXICO AND TEXAS

By

E. H. Herrick

and others

Prepared for

U. S. ARMY, CORPS OF ENGINEERS

1957

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Errata: TB Rept.

P. 60-61 (Blank sheet enclosed)

Part 6 - p. 3, 2nd pg., last line - "nudules"

Part 6 - p 7, 1st pg. 6th line - "controus"

6 - p 7, 2nd pg. 1st line -- the area[s] ultim

6 - p 14, 3rd pg. 3rd line - should "irrigation" be make "water" stricken?

Fred L

This copy is as nearly like copies sent to Lohman 7/8/58 as it is humanly possible to make it.

→ J.E. Weir Jr.

TB errata 7/9/58 JEW

ly

-- p. 8-3 line 11 -- and it is probable that

p. 9-1 -- next to last line

Playas

~~p. [illegible]~~

p 11-1 comma after New Mexico next to last line

p-11-2 comma after Tipas
line 9

p.11-3 line 11 "featheredge" is
one word

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Ground Water Branch, Albuquerque, N. Mex.

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AUTHOR(S): E. H. Herrick, J. E. Weir, Jr., J. R. Rapp, F. D. Trauger, J. B. Cooper, L. J. Bjorklund

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APPRAISAL OF GROUND-WATER RESOURCES OF TULAROSA BASIN AND ADJOINING AREAS, NEW MEXICO AND TEXAS

By

E. H. Herrick and others

ABSTRACT

This report discusses the ground-water resources of an area of more than 12,000 square miles in south-central New Mexico and adjoining parts of El Paso and Hudspeth Counties, Texas. A large part of the area is controlled by the Defense Department, and the development of adequate water supplies is a problem of major concern to the several military installations and the nearby towns in the area.

Most of the ground water underlying the central and northern parts of the Jornada del Muerto, in the western part of the area, is impotable. However, the western and northern flanks of the Cerro Colorado volcanic mass, about 6 miles west of Stallion Site Camp, are underlain by ground water of potable and near potable quality. A few wells in the vicinity of Mockingbird Gap and at the foot of the Sierra Oscura escarpment also yield small quantities of potable and near potable water.

In the northern part of Tularosa Basin potable ground water is known to occur in only a few, relatively small localities, mostly along the east side of the basin. A small area in the vicinity of Oscura contains relatively shallow wells that yield up to 50 gpm of water containing less than 300 ppm of sulfate. Deeper wells in the Carrizozo area reportedly yield water of similar quality from sandstone of Cretaceous age. However, most of the shallow ground water in alluvium in the vicinity of Carrizozo contains more than 400 ppm of sulfate.

Wells yielding about 100 gpm of near potable water have been developed in the Three Rivers drainage basin at the west side of Sierra Blanca. In that area, Three Rivers and Indian Creek had a combined total flow of about 1,800 acre-feet during the 12-month period from October 1956 to September 1957. It is estimated that a dependable supply of about 1,000 acre-feet per year of potable water can be developed from surface-water and ground-water sources in that area.

Two large springs, Salt Creek and Malpais Spring, in the north-central part of the Tularosa Basin yield ~~200~~ about 450 and more than 1,000 gpm, respectively, of impotable water. Several other small springs in that area yield small quantities of highly mineralized water.

The Tularosa-Alamogordo area contains fairly large sources of both surface and ground water. Much of the ground water in that area is impotable but is utilized for irrigation. The Boles well-field area, south of Alamogordo, has been, until the completion of the Bonito Lake pipeline, the principal source of water to Holloman Air Force Base. The dependable capacity of that well field has been estimated to be about 1,000 acre-feet per year.

Southeast of Valmont, and adjacent to the Sacramento Mountains, about 12 miles southeast of the Boles well field, an area of approximately 50 square miles apparently is underlain by ground water of potable or near potable chemical quality. This area has not been studied in detail but has been suggested as a possible potential source of potable ground water. The area is north of and adjacent to the Sacramento River-Orogrande pipeline, which presently carries an estimated 250 gpm of potable water to Orogrande from springs in the upper part of the Sacramento River Canyon. It has been estimated that the quantity of water diverted to that pipeline could be approximately doubled by improving the water-collection system at the springs.

In most of the Hueco plateau the ground water contains sulfate considerably in excess of 250 ppm although a few stock wells in the eastern part of the area yield potable water.

The Crow Flats - Dell City area in southeastern Otero County, New Mexico and northeastern Hudspeth County, Texas contains a large supply of shallow, highly mineralized ground water. The area is extensively developed with irrigation wells, but most of the water contains excessive quantities of sulfate for drinking.

The northern part of the Hueco Bolson and the southwestern part of Tularosa Basin apparently contain the largest potential supply of potable ground water, with the exception of the Rio Grande valley, in the entire area covered by this report. That part of the Hueco Bolson in Texas is extensively developed with large-capacity wells supplying the city of El Paso, Biggs Field, and Fort Bliss. However, it has been estimated that at least 6 million acre-feet of potable ground water is stored in the bolson deposits in the New Mexico portion of this area.

The potable water body underlying the re-entrant area at White Sands Proving Ground apparently is continuous with the area described above. The wells in the headquarters area of White Sands Proving Ground presently produce a total of about 1,000 acre-feet of water per year. As a result of the pumping, water levels in that area are declining, but the available data indicate that this quantity of water can be pumped annually for many years without danger of contaminating the ground-water supply with saline water.

The central Part of Tularosa Basin northeast of White Sands Proving Ground contains only a few known sources of potable water. These apparently are very limited localities along the east side of the San Andres Mountains, where a few stock wells have been developed.

The alluvium along the Rio Grande in the Mesilla Valley in the vicinity of Las Cruces contains large supplies of water, much of which is potable. This area has been extensively developed with irrigation wells to supplement surface water from the Rio Grande. The Rio Grande Valley in the vicinity of Bosque del Apache also contains large supplies of potable ground water. The available data indicate that wells producing at least 1,000 to 1,500 gpm of potable or near potable quality can be developed in that area. However, the Bosque del Apache is within the Rio Grande Underground Water Basin, closed by the New Mexico State Engineer to additional drilling except for domestic supplies and substitution for existing surface-water rights.

Potable ground water has been developed in the southern part of the Jornada del Muerto, where at least one well is reported to yield more than 1,000 gpm.

It is estimated that at least 30,000 acre-feet per year of potable ground water can be developed in the Rio Grande Valley in the vicinity of Bosque del Apache and possibly as much as 60,000 acre-feet per year in the southern Tularosa Basin and northern Hueco Bolson. The southern part of the Jornada del Muerto and the Rio Grande Valley in the vicinity of Las Cruces are estimated to contain at least 2 million acre-feet of potable ground water. Other important occurrences of potable water are the Three Rivers area, Boles well-field area, and the Upper Sacramento River Canyon, where it is estimated that about 1,000, 1,000, and 800 acre-feet per year, respectively, can be developed. There are other occurrences of potable water in the region, and though small, these occurrences are very important because of their locations.

Water of inferior chemical quality, much of which could be used for potable supplies, occurs throughout the region, except in the central parts of the basins. The most important known sources are the Carrizozo area and the area southeast of Valmont, where it is estimated that approximately 20,000 and 1,000 acre-feet per year can be developed, respectively.

It is estimated that at least 150 million acre-feet of impotable water is stored in the area covered by this report. Although most of this highly mineralized water probably has little or no value at the present time, it is possible that impotable water can be used for non-drinking purposes and may at a future time be economically de-mineralized, at least in areas where naturally potable water does not occur.

INTRODUCTION

It long has been recognized that the potable water resources of the Tularosa Basin in New Mexico are definitely limited. The only real development of the basin, prior to the establishment of military bases during and following World War II, was along the eastern ~~margin of the basin~~, where both surface and ground water could be readily utilized. Only widely scattered ranches occupied the central and western parts of the basin. During World War II, Holloman Air Force Base and White Sands Proving Ground were established in the basin, and since then many smaller outlying military camps have been established. Today all the central and western parts of the basin and adjoining areas on the north, west, and south are restricted to military use by Holloman Air Force Base, White Sands Proving Ground, and Fort Bliss.

The increased use of water caused by the growth of the military bases and resulting growth of the nearby towns in the Tularosa Basin has created considerable concern regarding the quantity of potable water available to the area. Practically all the perennial surface water in the area is fully utilized, and a large part of the known ground-water resources has been developed. Although present requirements for water are being met and few really serious shortages have developed in the past, it has become apparent that the growing population of the area soon will impose a serious strain on existing water supplies. Some of the existing supplies already are over-developed, and continued heavy pumping in some areas eventually will result in serious declines of the ground-water levels and possibly contamination of fresh ground-water bodies by saline water.

In 1955 the City of Alamogordo acquired the Bonito Lake reservoir on the eastern slope of Sierra Blanca, and in 1957 a pipeline from Bonito Lake to Alamogordo and Holloman Air Force Base was completed under contract by the U. S. Army, Corps of Engineers. It has been estimated (Turney, W. F. and Associates, January 1954) that Bonito Lake will furnish an average of approximately 1 billion gallons (3,000 acre-feet) of water per year to Alamogordo and Holloman Air Force Base. Investigations are being carried out along the route of the pipeline in an attempt to develop additional water of acceptable chemical quality to supplement the water from Bonito Lake reservoir. It is believed that the acquisition of Bonito Lake will provide only temporary relief for only the Alamogordo-Holloman Air Force Base area.

Purpose and Scope of this Report

On November 7, 1956 a meeting was held at the office of the State Engineer in Santa Fe, New Mexico to discuss ways of providing additional water to the Tularosa Basin to meet increasing military and municipal requirements. The meeting was attended by personnel from the office of the New Mexico State Engineer, the Interstate Stream Commission, the U. S. Army Corps of Engineers, Holloman Air Development Center, White Sands Proving Ground, the U. S. Bureau of Reclamation, the U. S. Geological Survey, W. F. Turney and Associates, Armour Research Foundation, and the City of Alamogordo. At that meeting several possible sources of additional water were discussed, including the ~~Colorado-~~San Juan-Chama diversion, the Gila River, and the Canadian River. From data presented at the meeting, it was apparent that, if water from any of the three sources mentioned above could be made available to the Tularosa Basin, it would be several years before those sources ~~actually~~ could be utilized. Furthermore, it was generally agreed that all sources of water in and near the Tularosa Basin should be fully explored and utilized before water from distant sources was diverted to the basin. It was decided that all aspects of the problem should be thoroughly studied. The Geological Survey was requested to assemble a report of the quality and quantity of ground water in and adjacent to the Tularosa Basin.

The principal objective of this report is to summarize as completely as possible all available basic data relating to the ground-water resources of the Tularosa Basin and adjoining areas shown on figure 1 and plate 1. Practically all the data used in compiling this report were in the files of the Geological Survey or in existing reports. Only a few additional data were collected for this report in those areas for which information was totally lacking. All existing reports, published and unpublished, have been drawn upon in the preparation of this summary. These reports are listed in the following annotated bibliography.

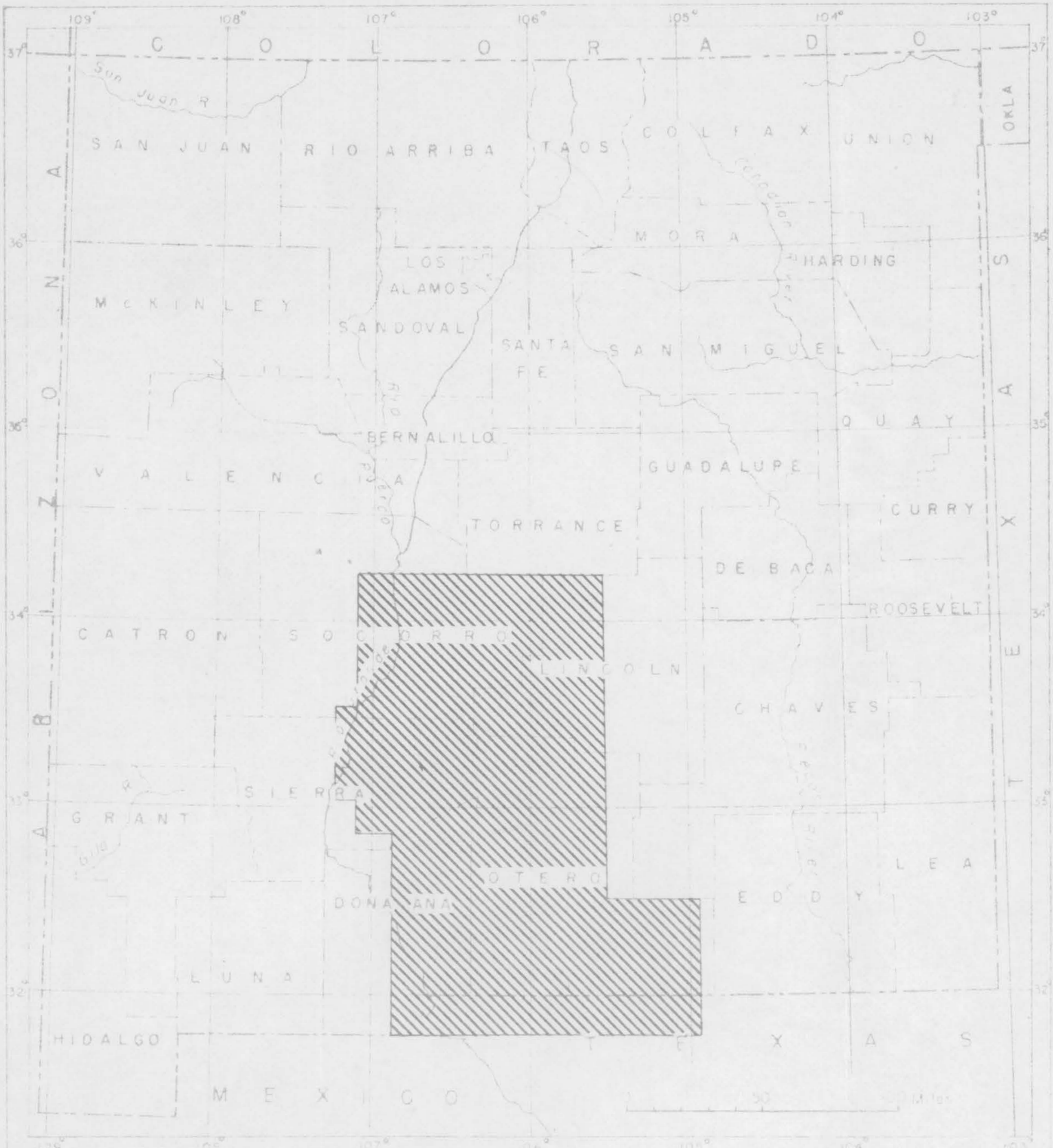

Figure 1.-- Map of New Mexico and adjoining part of Texas showing area (shaded) discussed in this report

Previous Investigations and Annotated Bibliography

The geology and occurrence of ground water have been studied in detail in only a few parts of the area covered by this report. In 1915 the U. S. Geological Survey published a general report (Water-Supply Paper 343) by Meinzer and Hare on the geology and water resources of the Tularosa Basin. In 1928 the U. S. Geological Survey published a geologic map of New Mexico, compiled by N. H. Darton, but that map was necessarily generalized and, because data were lacking, is inaccurate in some areas. A revised geologic map of the state is being prepared but is not yet available. The recognition of existing and future water-supply problems have resulted in several recent ground-water studies of specific areas in and near Tularosa Basin by the Geological Survey in cooperation with the Corps of Engineers. Some of those studies included geologic mapping. Reports and other literature, both published and unpublished, pertaining to the geology or water resources of the Tularosa Basin and adjoining areas are listed in the following annotated bibliography:

1. Bjorklund, L. J., January 1957, Reconnaissance of ground-water conditions in the Crow Flats area, Otero County, New Mexico: New Mexico State Eng. Tech. Rept. 1. (Describes the general geologic, physiographic, and geographic features of the Crow Flats area; describes the occurrence, fluctuations, movement, utilization, and quality of ground water in the Bone Spring limestone and the alluvium or valley fill; estimates the quantity of water pumped from the principal aquifers in a larger area including the Dell City area in Texas and shows relationship to development and water levels; makes some conclusions as to the possible development of the area. Includes a general geologic and depth-to-water map, hydrographs showing water-level fluctuations, a table of well records, and a table of chemical analyses.)

2. Bodine, M. W., Jr., January 1956, Geology of Capitan coal field, Lincoln County, New Mexico: New Mexico Bur. Mines and Mineral Res. Circ. 35. (Describes the geology of the Capitan coal field. Includes a geologic map and descriptions of several geologic sections.)

3. Conover, C. S., 1954, Ground-water conditions in the Rincon and Mesilla Valleys and adjacent areas in New Mexico: U. S. Geol. Survey Water-Supply Paper 1230. (Discusses the occurrence and quality of ground waters in the Rincon and Mesilla Valleys of the Rio Grande. Contains maps showing location of wells, contours on the water table, and depth to water.)

4. ____________, Herrick, E. H., Hood, J. W., and Weir, J. E., Jr., November 1955, The occurrence of ground water in south-central New Mexico: N. Mex. Geol. Soc., Sixth Field Conference, Guidebook of southcentral New Mexico. (Discusses the general occurrence of ground water in the Jornada del Muerto, Tularosa Basin, and adjacent areas. Contains a map showing the generalized geology and approximate altitude of the water table.)

5. Darton, N. H., 1922, Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726-E. (Discusses the general stratigraphy and structural features of the state, and contains several geologic maps and cross-sections.)

6. ____________, 1928, "Red beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794. (A general discussion of the geology of the state, containing detailed geologic maps and cross-sections of several areas in the state.)

7. Darton, N. H., 1928, Geologic map of New Mexico: U. S. Geol. Survey.

8. Dunham, K. C., 1935, The geology of the Organ Mountains: New Mexico Bur. Mines Bull. 11. (Describes the geology of the Organ Mountains in detail and of Doña Ana County in general. Includes geologic maps and detailed maps of several mining localities.)

9. Follett, C. R., 1954, Records of water-level measurements in Culbertson, Hudspeth, and Jeff Davis Counties, Tex.: Texas Bd. Water Eng. Bull. 5415. (Gives water-level data and location of wells in the Dell City area in Texas.)

10. ___________, 1954, Records of water-level measurements in El Paso County, Texas: Texas Bd. Water Eng. Bull. 5417. (Gives water-level data and location of wells in El Paso County, Texas.)

11. Guidebook of southcentral New Mexico: New Mexico Geol. Soc., Sixth Field Conference, Nov. 11, 12, and 13, 1955. (Contains geologic road logs east and northeast from Truth or Consequences, several geologic papers, geologic maps, and other illustrations. Includes the paper "The occurrence of ground water in south-central New Mexico" by C. S. Conover and others.)

12. Hendrickson, G. E., May 1949, Ground-water availability at campsite of Guadalupe Bombing Range, Otero County, N. Mex.: Manuscript report in open files of U. S. Geol. Survey. (A short report containing two maps and two pages of text. Discusses the occurrence of ground water in the valley fill near the campsite and recommends areas for drilling to obtain such water.)

13. Hendrickson, G. E., June 1949, Ground-water resources of the Carrizozo area, New Mexico: Manuscript report in open files of U. S. Geol. Survey. (Describes briefly the general occurrence of ground water, and contains chemical analyses of water from several wells and springs in the vicinity of Carrizozo.)

14. Herrick, E. H., December 1953, Memorandum on the ground-water supply at Holloman Air Force Base, Otero County, N. Mex.: Manuscript report in internal files of U. S. Geol. Survey. (Describes briefly the wells at Boles well field and makes recommendations for a detailed study of the area.)

15. ____________, February 1955, Summary of availability of ground water in the headquarters area, White Sands Proving Ground, Doña Ana County, N. Mex.: Manuscript report in internal files of U. S. Geol. Survey, and released to the U. S. Army, Corps of Engineers only. (Summarizes briefly the occurrence of ground water, and contains maps showing the geology, altitude of the water table, depth to water, and thickness of the saturated valley fill.)

16. ____________, 1955, Ground-water resources of the headquarters (cantonment) area, White Sands Proving Ground, Doña Ana County, N. Mex.: U. S. Army, Corps of Engineers, Albuquerque, N. Mex.: (Contains results of a detailed study of the occurrence and chemical quality of ground water. Includes detailed records of test holes and wells, analyses of pumping tests, several maps, and other illustrations. Estimates the probable future effects of pumping and makes recommendations for additional development of ground water in the area.)

17. Herrick, E. H., 1955, Rehabilitation of wells in the headquarters area, White Sands Proving Ground, Doña Ana County, N. Mex.: Manuscript report in internal files of the U. S. Geol. Survey and released to U. S. Army, Corps of Engineers only. (Describes procedures used to rehabilitate four wells, appraises results, and makes recommendations for future operation of the wells.)

18. __________, December 1956, Reconnaissance of groundwater conditions southeast of Valmont, Otero County, N. Mex.: Manuscript report in internal files of U. S. Geol. Survey and released to U. S. Army, Corps of Engineers only. (Describes very briefly the occurrence of ground water in an area about 12 miles south of Boles well field. Contains a map showing the altitude of the water table, depth to water, and sulfate content of the ground water. Makes recommendations for additional study, including test drilling, in the area.)

19. __________, July 30, 1957, Summary of test drilling to date in the Three Rivers area, Otero and Lincoln Counties, N. Mex.: Dittoed report in internal files of U. S. Geol. Survey and released to U. S. Army, Corps of Engineers only. (Contains logs, chemical analyses of water, and results of test pumping six test holes in the Three Rivers area.)

20. Hood, J. W., March 1956, Ground water in the vicinity of the Atlas site, Holloman Air Force Base, Otero County, N. Mex.: Manuscript report in internal files of U. S. Geol. Survey and released to U. S. Army, Corps of Engineers only. (Discusses the occurrence of ground water and makes recommendations for test drilling. Contains well tables and a map.)

21. Hood, J. W., March 1956, Ground water in the vicinity of South McGregor Range campsite, Otero County, N. Mex.: Manuscript report in internal files of U. S. Geol. Survey and released to U. S. Army, Corps of Engineers only. (Discusses the occurrence of ground water and makes recommendations for test drilling. Contains well tables and a map.)

22. __________, March 1956, Summary of results of ground-water investigations in the vicinity of Boles well field, Otero County, N. Mex.: Manuscript report in internal files of U. S. Geol. Survey and released to U. S. Army, Corps of Engineers only. (Summarizes briefly the occurrence of ground water in the area and contains maps showing location of wells, altitude of the water table, and sulfate content of the ground water.)

23. __________, May 1956, Availability of ground water in the vicinity of Cloudcroft, N. Mex.: Manuscript report in internal files of U. S. Geol. Survey and released to U. S. Army, Corps of Engineers only. (Discusses the occurrence of ground water in the vicinity of the proposed solar furnace site and makes recommendations for test drilling. Contains well tables and a map.)

24. __________, 1957, Ground-water resources and related geology in the vicinity of Holloman Air Force Base, Otero County, N. Mex.: U. S. Army, Corps of Engineers, Albuquerque, N. Mex. (Contains results of a detailed study of the occurrence and chemical quality of ground water. Contains detailed records of test holes and wells, analyses of pumping tests, several maps, and other illustrations. Estimates the future effects of pumping and makes recommendations for additional development and efficient operation of the well field.)

25. Kelley, V. C., November 1955, Geologic map of the Sierra County region, New Mexico: N. Mex. Geol. Soc., Sixth Field Conference, Guidebook of southcentral New Mexico. (Geologic map at scale of approximately 1 inch = 2.5 miles.)

26. __________, and Silver, C., 1952, Geology of the Caballo Mountains: N. Mex. Univ. Pub. Geol. Ser., No. 4. (A general discussion of the geology, with special reference to regional stratigraphy and structure and to mineral resources. Includes a geologic map and stratigraphic correlation charts.)

27. Keyes, C. R., 1905, Geology and underground water conditions of the Jornada del Muerto, N. Mex.: U. S. Geol. Survey Water-Supply Paper 123. (A brief report of a reconnaissance study of the Jornada del Muerto with postulation on possible development of the ground-water resources of the area. A geologic sketch map, several geologic diagrams, and several photographs are included.)

28. King, P. B., 1948, Geology of the southern Guadalupe Mountains, Tex.: U. S. Geol. Survey Prof. Paper 215. (Describes the geology, geologic history, structure, and stratigraphy of the southern Guadalupe Mountains. Discusses the Salt Basin which, at its north end, is adjacent to Tularosa Basin. Contains maps, sketches, and sections illustrating the geology and physiography of the area.)

29. King, P. B., 1949, Regional geologic map of parts of Culbertson and Hudspeth Counties, Tex.: U. S. Geol. Survey Oil and Gas Inv. Prelim. map 90. (Shows the surface geology of a section of the Salt Basin and the southern Guadalupe Mountains extending 9 miles northward into New Mexico. Shows the position of faults and igneous intrusions.)

30. Knowles, D. B., and Kennedy, R. A., August 1956, Ground-water resources of the Hueco Bolson, northeast of El Paso, Tex.: Texas Bd. Water Eng. Bull. 5615. (Contains a general discussion of the geology and occurrence of ground water, tables and logs of test holes and wells, results of pumping tests, and several maps showing the altitude of the water table and saturated thickness of fresh water-bearing bolson deposits. Also contains chemical analyses of water from wells and test holes and electrical logs of test holes. Estimates the quantity of potable water available in the area.)

31. Kottlowski, F. E., Flower, R. H., Thompson, M. L., and Foster, R. W., 1956, Stratigraphic studies of the San Andres Mountains, New Mexico: New Mexico Bur. Mines and Min. Res. Mem. 1. (A comprehensive description of the stratigraphy with emphasis on the almost complete section of Paleozoic sedimentary rocks. Contains location maps, graphic columnar sections, several photographs, and several photomicrographs of sedimentary and igneous rocks of the area.)

32. Lee, W. T., 1907, Water resources of the Rio Grande Valley in New Mexico and their development: U. S. Geol. Survey Water-Supply Paper 188. (A brief but relatively comprehensive report of the Rio Grande Valley from Santa Fe, N. Mex. to the Texas-New Mexico boundary. Contains three maps, many photographs, and several geologic diagrams. Ground-water data are compiled mainly from existing sources rather than by field observation.)

33. Leggat, E. R., August 1957, Memorandum on the water-supply wells at Biggs Air Force Base, El Paso, Texas: Manuscript report in internal files of U. S. Geol. Survey and released to U. S. Army, Corps of Engineers only. (Summarizes data on the water-supply wells at Biggs Air Force Base and discusses the effects of rehabilitation of the wells. Discusses methods of developing additional water for the base. Includes a map showing location of wells and test holes in the vicinity, several figures, and records of selected wells.)

34. __________, August 1957, Memorandum on ground-water conditions and suggestions for test drilling in the Logan Heights area, El Paso, Texas: Manuscript report in internal files of U. S. Geol. Survey and released to U. S. Army, Corps of Engineers only. (Discusses the occurrence of ground water in the Logan Heights area, and recommends five sites for test drilling. Includes maps showing location of wells and test holes and saturated thickness of fresh water-bearing materials, and records of selected wells.)

35. Meeks, T. O., March 1950, The occurrence of ground water in the Alamogordo-Tularosa area of the Otero Soil Conservation District, N. Mex.: U. S. Dept. Agr., Soil Cons. Service Reg. Bull. 111, Geol. Ser. 2. (Discusses the geology and general occurrence of ground water. Contains several well logs, tables of wells and chemical analyses of water, and maps showing location of wells, altitude of the water table, depth to water, and chemical quality of the water.)

36. Meinzer, O. E., and Hare, R. F., 1915, Geology and water resources of Tularosa Basin, N. Mex.: U. S. Geol. Survey Water-Supply Paper 343. (Describes the geology and general occurrence of water. Contains several maps showing geology and general ground-water conditions, several photographs of geologic and topographic features, and tables of wells, springs, and chemical analyses of water from wells, springs, and streams.)

37. Mourant, W. A., March 1957, Reconnaissance of water resources in the upper part of Sacramento River canyon, New Mexico: Manuscript report in internal files of U. S. Geol. Survey and released to U. S. Army, Corps of Engineers only. (Describes the cienagas of the upper Sacramento River canyon from which water is diverted to the Orogrande pipeline. Suggests methods of diverting more water to the pipeline than is presently being diverted. Includes a map and several photographs.)

38. Murray, C. R., April 11, 1947, Memorandum on the possibilities of developing ground water for the Alamogordo Army Air Base, Otero County, N. Mex.: Manuscript report in open files of the U. S. Geol. Survey. (A very short report containing some data on the first wells drilled at the Boles well field and makes recommendations for test drilling.)

39. Needham, C. E., and Bates, R. L., 1943, Permian type sections in central New Mexico: Geol. Soc. America Bull., vol. 54, pp. 1653-1667. (A re-description of Abo, Yeso, Glorieta, and San Andres formations at the various type localities from Glorieta Mesa to Rhodes Canyon. Includes columnar sections and descriptions of measured sections.)

40. Newell, N. D., and all, 1953, The Permian reef complex of the Guadalupe Mountains region, Texas and New Mexico: W. H. Freeman and Co., San Francisco. (Describes and discusses the geology, geologic history, stratigraphy, paleontology, diagenesis, and ecology of the Guadalupe and Brokeoff Mountains bordering the Salt Basin on the east in Texas and New Mexico.)

41. Pray, L. C., 1952, Stratigraphy of the escarpment of the Sacramento Mountains, Otero County, N. Mex.: Manuscript report on file at N. Mex. Bur. Mines, Socorro, N. Mex. (Describes in detail the stratigraphy and geologic structure of the Sacramento Mountains escarpment. Includes a geologic map.)

42. Pray, L. C., 1954, Outline of the stratigraphy and structure of the Sacramento Mountains escarpment: N. Mex. Geol. Soc. Guidebook of southeastern New Mexico, pp. 92-107. (Describes the stratigraphy and geologic structure of the Sacramento Mountain front in the vicinity of Alamogordo and contains a geologic map.)

43. Rapp, J. R., April 1957, Summary of test drilling and ground-water conditions in the Atlas Project area, Holloman Air Force Base, Otero County, N. Mex.: Manuscript report in internal files of U. S. Geol. Survey and released to U. S. Army, Corps of Engineers only. (Summarizes results of drilling four test holes in the Atlas Project area, and contains a general discussion of ground-water conditions in the area. Includes a map and tables of wells and test holes.)

44. _________, October 1957, Summary of test drilling and ground-water conditions in the McGregor Range area, Otero and Doña Ana Counties, N. Mex., and El Paso County, Tex.: Manuscript report in internal files of U. S. Geol. Survey and released to U. S. Army, Corps of Engineers only. (Summarizes results of drilling three test holes in the vicinity of McGregor Range Camp, and discusses the general occurrence of ground water in the area.)

45. Sayre, A. N., and Livingston, Penn, 1945, Ground-water resources of the El Paso area, Texas: U. S. Geol. Survey Water-Supply Paper 919. (Describes the geology and occurrence of ground water in the northern part of the Hueco Bolson in El Paso County, Tex., and southeastern Doña Ana County, N. Mex. Contains a map showing the location of wells and contours on the water table, records of wells, hydrographs, and several photographs.)

46. Scalapino, R. A., 1949, Ground-water resources of the El Paso area, Texas; Prog. Rept. 6: Texas Bd. Water Eng. (Discusses pumpage from wells and fluctuations of water levels in the El Paso area. Includes brief discussions of experimental artificial-recharge studies and chemical quality of the water.)

47. ______________, 1950, Development of ground water for irrigation in the Dell City area, Hudspeth County, Tex.: Texas Bd. Water Eng. Bull. 5004. (Describes the climate, geology, and the occurrence and use of ground water in the Dell City area. Contains tables of well data, well logs, and chemical analyses of ground water. Also contains a map showing the surface geology and the location of irrigation wells.)

48. Schmalz, R. F., 1955, Geology of the eastern part of the Three Rivers quadrangle, New Mexico: Manuscript and geologic map in internal files of N. Mex. Bur. Mines and Min. Res. (The detailed geologic map was prepared for a graduate thesis on a scale of 1: 24,000. The detailed map was modified for use in this report.)

49. Smith, R. E., 1956, Ground-water resources of the El Paso area, Texas; Prog. Rept. 7: Texas Bd. Water Eng. Bull. 5603. (Contains a brief discussion of the geology and ground-water conditions, and tables of water levels and chemical analyses of water. Includes hydrographs and a map showing the location of observation wells.)

50. Sundstrom, R. W., and Hood, J. W., July 1952, Results of artificial recharge of the ground-water resources at El Paso, Tex.: Texas Bd. Water Eng. Bull. 5206. (Describes experimental tests in artificial recharge carried on from 1947 to 1952. Contains data on the effect of artificial recharge on water levels and chemical quality of the ground water.)

51. Theis, C. V., February 27, 1942, The availability of irrigation water at the Alamogordo Air Base, Otero County, N. Mex.: Manuscript report in internal files of U. S. Geol. Survey. (A very brief report discussing the probable availability of ground water for irrigation at Holloman Air Force Base. Includes a table of chemical analyses and other data concerning springs and wells near the base.)

52. ____________, May 19, 1942, Memorandum of the water supply of Alamogordo, Otero County, N. Mex.: Manuscript report in internal files of U. S. Geol. Survey. (A very brief report describing the general ground-water conditions and including recommendations for test drilling in the vicinity of Boles well field.)

53. Theis, C. V., July 1942, Ground-water conditions in the vicinity of Orogrande, N. Mex.: Manuscript report in internal files of U. S. Geol. Survey. (A very brief report describing ground-water conditions and making recommendations for test drilling at the proposed site of an anti-aircraft firing range west of Orogrande.)

54. ________, Date unknown, Memorandum on ground-water supplies near Valmont, N. Mex.: Manuscript report in internal files of U. S. Geol. Survey. (A very brief report discussing the possibilities of obtaining a water supply for a proposed camp at Valmont.)

55. U. S. Geol. Survey, Albuquerque, N. Mex. Letter memoranda to U. S. Army, Corps of Engineers, on ground water in the vicinities of Stallion site, Oscura Peak, Red Canyon Range Camp, and Oscura Range Camp, White Sands Integrated Range, N. Mex.

56. U. S. Geol. Survey, Albuquerque, N. Mex., Unpublished water-level data: To be published in cooperation with the State Engineer of New Mexico.

57. U. S. Geol. Survey, Austin, Tex., Unpublished water-level data: To be published in cooperation with the Texas Board of Water Engineers.

58. Wilpolt, R. H., and Wanek, A. A., 1951, Geology of the region from Socorro and San Antonio east to Chupadera Mesa, Socorro County, N. Mex.: U. S. Geol. Survey Oil and Gas Inv. Map Om 121. (A geologic map covering most of five 15-minute quadrangles. Includes columnar sections, seven structure cross-sections, and a brief description of the geology.)

Well-Numbering System

The system used in this report of numbering wells and springs in New Mexico is that used by the Geological Survey and is based on the common subdivisions in sectionized land. By means of it the number, in addition to designating the well or spring, locates its position to the nearest 10-acre tract in the land net. The number is divided by periods into four segments. The first segment denotes the township south or north of the New Mexico base line; the second denotes the range east or west of the New Mexico principal meridian; and the third denotes the section. All of the area discussed in this report is south of the base line, and most of the area is east of the principal meridian. A small part of the area is west of the meridian, and in those cases where confusion may arise, an E has been placed after the second segment of the number if the well or spring is east of the meridian. Also in such cases a W has been placed after the second segment of the number if the well or spring is west of the meridian.

The fourth segment of the number, which consists of three digits, denotes the particular 10-acre tract in which the well or spring 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 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 22.4.24.222 at White Sands Proving Ground is in the NE$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 24, T. 22 S., R. 4 E., as shown in figure 2. If a well or spring cannot be located accurately within a 40-acre tract, zeros are used for both the second and third digits. If the well or spring cannot be located more closely than the section, the fourth segment of the well number is omitted. When it becomes possible to locate more accurately a well or spring in whose number zeros have been used, the proper digit or digits are substituted for the zeros. Letters a, b, c, ... are added to the last segment to designate the second, third, fourth, and succeeding wells or springs in the same 10-acre tract. An S in front of the number indicates a spring.

Insofar as possible, those wells in Texas that are referred to in this report by a location number are numbered according to a similar system, except that the second segment of the number denotes the block rather than the range. Thus, well 1.78.6.140 is in the SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 6, T. 1, Blk. 78. The blocks contain varying numbers of sections; for example, block 79 in township 1 contains 48 sections, but block 81 in township 1 has an irregular shape and contains 38 sections.

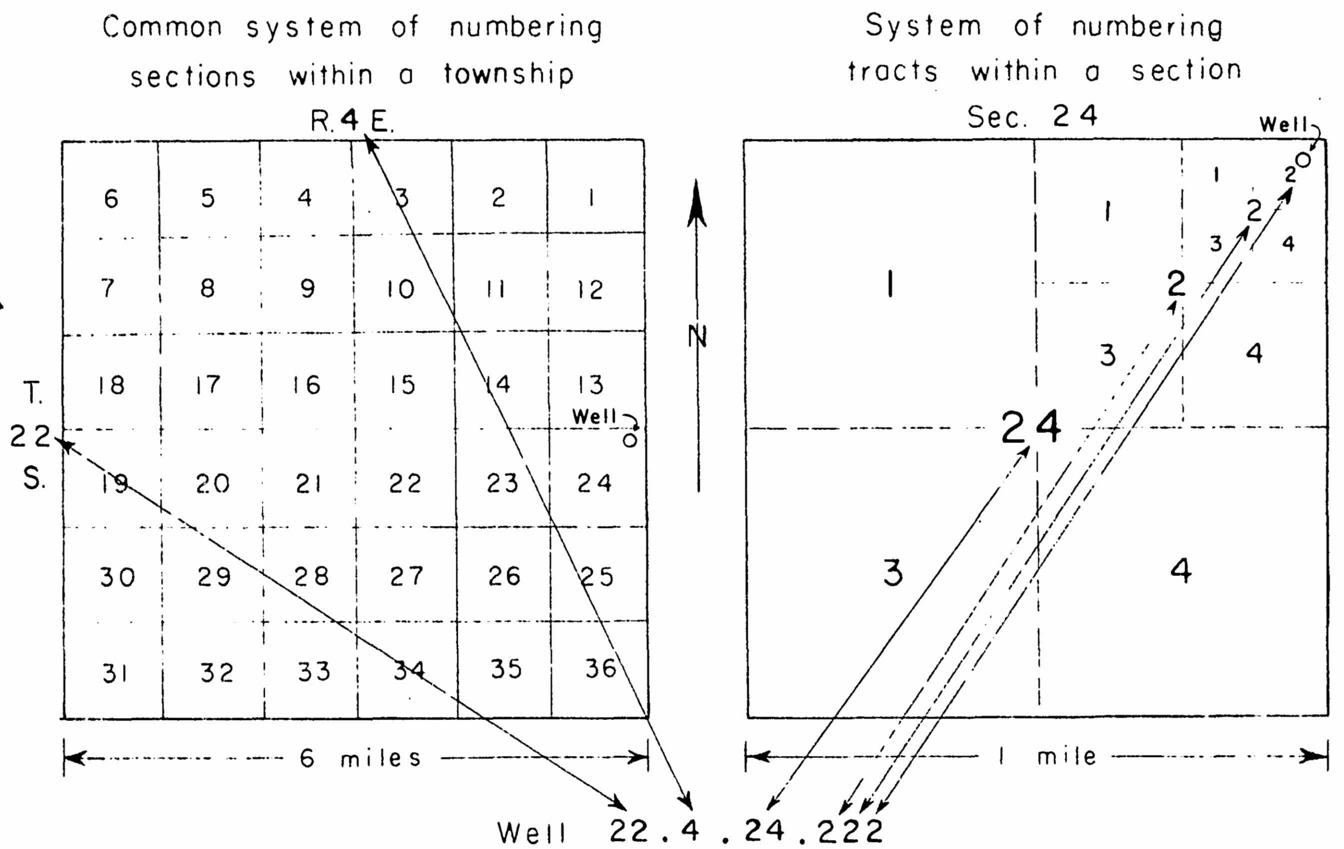

Figure 2 -- System of numbering wells in New Mexico

GENERAL DESCRIPTION OF THE AREA

Location and Extent of Area Covered

The Tularosa Basin is about 120 miles long from north to south and averages about 35 miles in width. It extends from the southern end of Chupadera Mesa in southeastern Socorro County and western Lincoln County, New Mexico almost to the New Mexico-Texas boundary in southeastern Doña Ana County and southwestern Otero County, New Mexico.

The area considered in this report includes all the Tularosa Basin; the western slopes of the Hueco and Sacramento Mountains and Sierra Blanca; the southern end of Chupadera Mesa; the Oscura, San Andres, Organ, and Franklin Mountains; the northern and southern parts of the Jornada del Muerto; the Mesilla Valley of the Rio Grande in the vicinity of Las Cruces, New Mexico; the northern part of the Hueco Bolson; the Hueco Plateau; and the Crow Flats-Dell City area. The total area covered includes more than 12,000 square miles and is shown on figure 1 and plate 1.

Topography and Drainage

The Tularosa Basin is an intermontane basin which is part of a large structural depression more than 200 miles long and from 24 to 60 miles wide, extending from southeastern Socorro County, N. Mex. southward through parts of El Paso and Hudspeth Counties, Tex., and south of the Rio Grande into the State of Chihuahua, Mexico. The Tularosa Basin is separated from the Hueco Bolson to the south by a generally low topographic divide just north of the New Mexico-Texas boundary.

The interior plain of the basin has low relief, with altitudes ranging from about 4,000 feet on the south and west to about 4,400 feet on the north and east sides. The surrounding mountains rise abruptly to altitudes of 7,000 to 12,000 feet.

The floor of the basin contains many playas, the largest of which lie along the lowest part of the basin near its western margin. The springs on the floor of the basin, the largest of which are Malpais Spring and those along Salt Creek in the northern part of the basin, yield only highly mineralized water. The extensive dunes of gypsum, known as the White Sands, in the central part of the basin, and the extensive lava flow, locally called the Malpais, in the northern part of the basin, comprise the most striking physiographic features.

The Sacramento Mountains rise abruptly above the basin floor, forming westward-facing escarpments more than 1,000 feet high. Sierra Blanca, northwest of the Sacramento Mountains, contains the highest peak in the area, 12,000 feet above sea level. The Sierra Oscura, San Andres, and Organ Mountains, which have peaks ranging from 7,000 to ~~over~~ more than 9,000 feet in altitude, separate Tularosa Basin from the Jornada del Muerto to the west. A few springs and perennial streams occur in the mountains; the largest of these are in the Sacramento Mountains and Sierra Blanca at the east side of the basin.

The Jornada del Muerto, a broad, essentially flat synclinal basin, lies between the Sierra Oscura, and the San Andres and Organ Mountains on the east and the Fra Cristobal and Caballo Mountains and the Rio Grande Valley on the west. This basin ranges from 12 to 30 miles ~~in width~~ and is approximately 120 miles ~~in length~~ from north to south. The eastern boundary of the Jornada del Muerto is somewhat more distinct than the western boundary because of the continuous positive relief, whereas the western boundary consists of an element of negative relief, the Rio Grande valley, over about half its length. Very few physiographic highs ~~exist~~ in the Jornada del Muerto to break the monotony of the slightly undulating surface of the basin.

The floor of the Jornada del Muerto contains many playas but no perennial streams. The only springs near the basin are in the surrounding mountains, and most of these yield only small quantities of water, much of which is impotable.

The Hueco Bolson, south of Tularosa Basin, trends northwest-southeast and has an average width of about 20 to 25 miles. Its length is about 40 miles along its west side and about 60 miles along its east side. On the west the bolson is bounded by the Franklin Mountains, and on the south by the Sierra del Presidio, Sierra de Guadalupe in Mexico, and the Rio Grande. On the east it is bounded by the Quitman, Malone, Finlay, and Hueco Mountains. The floor of the bolson appears to be a nearly level plain, but actually its altitude ranges from less than 3,900 feet along its west side near Fort Bliss, to more than 4,200 feet above sea level on its east side near the Hueco Mountains. The Rio Grande, which crosses the western part of the bolson and forms part of its southwestern boundary, is the only perennial stream in the bolson. Only the northwestern part of the Hueco Bolson in southern Doña Ana and Otero Counties, New Mexico, and El Paso County, Texas, is discussed in this report.

East of the Hueco Bolson the Hueco Mountains form a more or less regular escarpment about 1,000 feet ~~in height~~ high. This escarpment forms the western boundary of what is referred to in this report as the Hueco Plateau, an eastward-sloping highland south of the Sacramento Mountains. The Hueco Plateau is more than 5,000 feet above sea level on the west, and slopes to less than 4,000 feet above sea level about 45 miles to the east where it forms the western boundary of the Crow Flats-Dell City area. The plateau contains several large basins at the southern end of drainages ~~which~~ that originate in the Sacramento Mountains.

East of the Hueco Plateau and bounded on the east by the Brokeoff and Guadalupe Mountains, is a long, closed, topographic depression known as Salt Basin (fig. 3). That part of the depression discussed in this report as the Crow Flats-Dell City area extends from about 35 miles north to about 20 miles south of the New Mexico-Texas boundary, and its average width is about 20 miles. The southern part of the area is occupied by large playa lakes, locally called the Salt Lakes.

Climate

The climate of the basin areas discussed in this report is typical of the continental arid regions of southwestern United States. The days generally are clear and warm even in the winter, but the diurnal range in temperature is large. High winds and sandstorms are common in the spring.

The average annual precipitation in the basin areas is less than 10 inches; at the White Sands Proving Ground Air Weather Station the average annual precipitation for the period 1948-1953 was 8.31 inches. In the foothills of the surrounding mountains the average annual precipitation is about 12 inches, and in the higher mountains it is more than 25 inches ~~per year~~. A large part of the precipitation occurs in heavy showers of local extent, largely in July, August, and September.

The average relative humidity of the basin areas probably is less than 40 percent. The average annual evaporation at the Jornada Experimental Range west of the San Andres Mountains at an altitude of 4,265 feet is 96 inches. The mean annual temperature at this station is 59° F.

General Geology

The Tularosa Basin is essentially a graben, bounded on both the east and west sides by tilted fault-block mountains and, in part, by batholithic intrusives. Faulting has produced steep scarps on the west side of the Sacramento Mountains and the east side of the San Andres Mountains. In the Sacramento Mountains the strata dip gently to the east, and in the San Andres Mountains they dip to the west. In the central portion of the basin, Permian rocks are exposed in several low hills trending north from the Jarilla Mountains. These low hills suggest a partially buried fault-block ridge, indicating possible step-faulting along the east side of the basin. Southward, the Tularosa Basin is separated by a generally low topographic divide from the Hueco Bolson, which also is bounded by steep scarps on the west side of the Hueco Mountains and on the east side of the Franklin Mountains. On the north, the Tularosa Basin is bounded by the nearly horizontal strata comprising the Chupadera Mesa. The basin floor is underlain mostly by unconsolidated bolson deposits of varying thickness that exceed 4,000 feet in the southern part of the basin.

The Jornada del Muerto is a synclinal basin, bounded on the east by the westward dipping strata of the San Andres Mountains and on the west by the eastward dipping strata of the Caballo Mountains and the Fra Cristobal Range. The rocks of Sierra Oscura, along a part of the eastern boundary of the Jornada del Muerto, dip eastward away from the basin and under the Chupadera Mesa. The bolson deposits covering the floor of the Jornada del Muerto apparently have a considerably less average thickness than those in the Tularosa Basin and probably are not more than 500 feet thick in much of the Jornada del Muerto.

Precambrian rocks, consisting mostly of granite and some metamorphic rocks, crop out along the east flanks of the Franklin, Organ, and San Andres Mountains, along the west flank of the Sierra Oscura, and in a few places at the base of the Sacramento Mountains southeast of Alamogordo. The Organ Mountains and Sierra Blanca are composed mainly of intrusive rocks, flanked by volcanic rocks, probably of Tertiary age. The youngest consolidated rocks in the region are the Recent basalt sheet in the northern part of the Tularosa Basin west of Carrizozo and possibly the basalt in the Jornada del Muerto northeast of the Fra Cristobal Range.

Sedimentary rocks in the region range in age from Cambrian through Recent. The pre-Mississippian rocks are thickest in the southern part of the region and pinch out in the Sierra Oscura. Cretaceous and Triassic rocks are present mainly in the northern part of the region, although Lower Cretaceous sedimentary rocks have been mapped along the west side of the Franklin Mountains and in the Hueco and Cornudas Mountains. The following descriptions of the sedimentary rocks are based largely upon Kottlowski and others (1956).

The Bliss sandstone, of Upper Cambrian and Lower Ordovican age (apparently the formation transgresses the time boundary and is generally younger ~~in age~~ in the northern part of the region) has a thickness of 225 feet in the type section in the Franklin Mountains, varies from 6 to 120 feet in thickness in the Sacramento Mountains, and pinches out in the central part of Sierra Oscura. The Bliss is a basal sandstone unit, containing much quartzite and some indurated shales.

The El Paso limestone is of Lower Ordovician age and conformably overlies the Bliss sandstone in most of the region. Nearly 1,600 feet of the formation has ~~have~~ been measured in the Franklin Mountains. It has a maximum known thickness of about 420 feet in the Sacramento Mountains, 760 feet in the San Andres Mountains, and is only about 40 feet thick at Mockingbird Gap at the northern end of the San Andres Mountains. The formation consists mainly of massive limestone and dolomite.

The Montoya limestone of Upper Ordovician age is separated from the underlying El Paso limestone by an unconformity and, in many places, by the Cable Canyon sandstone wedge. The formation is about 250 feet thick in the southern part of the region and thins to about 30 feet at the northern end of the San Andres Mountains, pinching out in the Sierra Oscura. The formation in the Sacramento Mountains consists of two units, the lower massive cherty dolomite unit attaining a maximum thickness of about 225 feet, and the upper limestone unit attaining a total thickness of about 200 feet.

The Fusselman dolomite, of Silurian age, conformably overlies the Montoya. The formation has a thickness of about 1,000 feet in its type section in the Franklin Mountains and a maximum thickness of about 100 feet in the Sacramento and San Andres Mountains. ~~The formation~~ It is absent in the northeastern part of the Sacramento Mountains and pinches out about 6 miles south of Rhodes Canyon in the San Andres Mountains. The Fusselman is a relatively pure, massive-bedded dolomite.

Devonian rocks are represented in this region by thin units of shale, siltstone, and limestone that have been assigned to several formations. The aggregate thickness of Devonian rocks in the Sacramento Mountains is about 100 feet and in the San Andres Mountains about 80 feet. The Devonian rocks unconformably overlie the Fusselman dolomite in most places but rest directly on eroded El Paso limestone ~~rocks~~ in the central part of the San Andres Mountains.

Mississippian rocks in this region are separated from the Dovonian by an unconformity. The Mississippian ~~section has~~ a maximum thickness of about 300 feet in the San Andres Mountains and possibly 400 feet in the Sacramento Mountains. They have a thickness of only 20 feet near Mockingbird Gap at the northern end of the San Andres Mountains and are absent in the Sierra Oscura. The Mississippian has been divided into five formations in this region. The Caballero formation consists of silty, calcareous shale and nodular limestone, probably having a total thickness of about 60 feet in both the Sacramento and San Andres Mountains. The overlying Lake Valley formation consists of limestones and shales, represented by six members in the San Andres Mountains, and attains a total thickness of nearly 400 feet in the southern part of the San Andres Mountains. The overlying Las Cruces and Ranchería formations, consisting of hard, grayish-black limestones, have a total thickness of about 300 feet in the Franklin Mountains, and are present in both the Sacramento and San Andres Mountains. The Helms formation, consisting mostly of siltstone and shale, is present in the Sacramento Mountains but apparently is absent in the San Andres Mountains.

Pennsylvanian rocks in this region comprising mainly the Sandia and Madera formations of the Magdalena group are about 3,000 feet thick in both the Sacramento and San Andres Mountains and thin to less than 1,000 feet at the north end of Sierra Oscura. The Pennsylvanian strata consist of a wide variety of rocks, mainly clastic in the lower part and massive-bedded limestone with interbedded shale in the upper part.

Permian rocks are widespread in this region, forming the back slopes of the San Andres and Sacramento Mountains and Sierra Oscura and capping the Chupadera Mesa and most of the Hueco Plateau. They form the principal aquifer in the Crow Flats-Dell City area and probably underlie the bolson deposits in the northern part of the Jornada del Muerto and in most of the Tularosa Basin.

The Bursum formation, consisting mostly of arkose, limestone, and interbedded shale, interfingers with Pennsylvanian rocks north of this region and with the Abo formation in the Sacramento Mountains and probably has a maximum thickness of about 300 feet in the San Andres Mountains and about 400 feet in the northern part of the Sacramento Mountains, near Tularosa. The overlying Abo formation consists mostly of red shale and sandstone having a maximum reported thickness of about 1,400 feet in the subsurface northwest of Carrizozo.

The Abo formation interfingers with and grades into the Hueco limestone, which is about 1,500 feet thick in the Hueco Mountains. The Hueco limestone thins to about 300 feet at the north end of the San Andres Mountains and apparently is absent in the northern Sierra Oscura. The Hueco apparently represents a marine facies of the Abo formation. The Yeso formation, overlying the Abo formation and consisting of gypsum, red shale and sandstone, and limestone, has an average thickness of about 1,000 feet but ranges from a few hundred to as much as 4,000 feet (reported in an oil test northwest of Carrizozo). The latter thickness may be due to a local thickening caused by gypsum and halite flowage.

The Glorieta sandstone overlies and intertongues with the Yeso formation and has a thickness of several hundred feet in the area around Corona, New Mexico, but thins southward to less than 50 feet at the south end of Chupadera Mesa. In much of the area of this report the Glorieta is not a mappable unit.

Overlying the Glorieta sandstone are limestones, dolomites, and some sandstones of the San Andres formation, which has a maximum thickness of about 700 feet in the Sacramento Mountains. In the San Andres Mountains the formation apparently has a maximum thickness of about 600 feet. The Bone Spring limestone, which underlies the Crow Flats-Dell City area, consists mostly of gray to black limestone. The formation is about 1,600 feet thick in the Guadalupe Mountains, but its thickness under the Crow Flats-Dell City area is not known. The Bone Spring limestone is correlative with the Yeso and lower part of the San Andres formation to the west and northwest.

In the northern part of the region red and reddish-purple siltstone, shale, and sandstone of the Dockum group (or formation) of Triassic age are present. They occur in scattered outcrops in the vicinity of Carrizozo and south of Three Rivers and underlie the Dakota sandstone in the prominent cuesta east of the Malpais and southwest of Carrizozo. Triassic rocks are present at one small locality in the San Andres Mountains, north of Rhodes Pass. They also crop out in the Three Rivers area and in a relatively large area about 15 miles north of Carrizozo. No rocks of Jurassic age are known to occur in this region.

Lower Cretaceous rocks have been mapped along the west side of the Franklin Mountains and in the Hueco and Cornudas Mountains. Cretaceous rocks in the northern part of the region include the Dakota sandstone, consisting mainly of light-gray to white quartzitic sandstone and ranging in thickness from about 50 to possibly 300 feet. This unit crops out in the Caballo Mountains, in the Carthage coal-field area north of Cerro Colorado, in the Three Rivers and Carrizozo-White Oaks area, and at the east side of Sierra Blanca. Dakota sandstone caps the prominent cuesta east of the Malpais and southwest of Carrizozo. The Mancos shale, consisting mostly of gray to black and some green shale and some thin limestone and sandstone beds, overlies the Dakota sandstone. The thickness of this unit in the Oscura-Three Rivers area has been estimated to be at least 1,000 feet. However, the contact between the Mancos shale and the overlying Mesaverde formation is somewhat arbitrary, and some of the rocks in that area assigned to the Mancos may be Mesaverde. The Mesaverde formation consists of shale, siltstone, and sandstone, with local coal beds and has a total thickness of more than 500 feet in the Three Rivers area. In the Carthage coal field about 1,000 feet of Mesaverde has been encountered in test drilling, and more than 2,000 feet of the unit has been noted in the Caballo Mountains. The McRae formation of Kelley and Silver (1952, p. 115), consisting in the lower part of the shales and sandstones similar to those of the underlying Mesaverde formation and of conglomerates, tuffs, siltstones, and sandstones in the upper part, has been mapped in the northwestern part of the region between the Caballo Mountains and the Fra Cristobal Range, on the east side of Elephant Butte Lake. The formation has an estimated thickness of 3,300 feet in the type locality and apparently is of late Cretaceous age. The McRae formation of Kelley and Silver apparently is restricted in outcrop mainly to the area between the Caballo Mountains and the Fra Cristobal Range, although it may have equivalents in other parts of the region.

Tertiary rocks are widespread throughout the region under discussion. On the eastern, northern, and western flanks of Sierra Blanca and in the outlying hills between Three Rivers and Carrizozo, yellow to gray sandstones, siltstones, and variegated and red shales have been assigned by Bodine (1956, p. 8) to the Cub Mountain formation. These rocks may be correlative with the McRae formation of Kelley and Silver and may be Cretaceous in age. The thickness of the formation is at least 500 feet and may be as much as 1,000 feet. The Baca formation, consisting of grayish-red conglomeratic sandstones, siltstones, and conglomerates, is prominently exposed at the west side of Cerro Colorado. This formation, possibly as much as 1,000 feet thick, apparently is Eocene in age. In the foothills of the San Andres Mountains and along the west side and at the south end of the Organ Mountains, conglomerates and siltstones comprising a total thickness of about 2,000 feet have been assigned to the Love Ranch formation by Kottlowski and others (1956, p. 69). The age of the formation is not known, but it is believed to be approximately correlative with the Baca formation and probably Eocene. In the Cerro Colorado area, a thick sequence of volcanic rocks including minor amounts of conglomerate have been assigned to the Datil formation. The formation has an estimated thickness of about 1,000 feet and is post-Baca, probably Miocene, in age. Sandstones and sands of the Santa Fe group of Miocene to Pleistocene age probably make up an appreciable part of the bolson deposits in the Jornada del Muerto and the Tularosa Basin. The thickness of the group in these basins is not known, although along the Rio Grande Valley in southern New Mexico more than 2,000 feet of Santa Fe rocks have been described.

The upper parts of the bolson deposits are Quaternary in age. The thickness of the Quaternary section of these deposits is not known but probably does not exceed 500 feet in most places. These deposits are mostly unconsolidated, consisting of clay, sand, and gravel derived from the surrounding higher areas. Quaternary deposits are widespread along the stream valleys and in the lower areas. These deposits constitute the most important single source of ground water in the region.

General Occurrence of Water

Because of the range in climatic conditions in the Tularosa Basin and adjoining areas, and because the many kinds of rocks present differ greatly in their capacity to absorb, store, and yield water, the occurrence of both surface and ground water varies greatly in different parts of the area covered by this report.

It is not the purpose of this report to discuss surface water in the area in great detail; however, the more important perennial streams will be mentioned here and some will be discussed in other sections of the report.

The only important occurrences of surface water, aside from infrequent flood flows, are the Rio Grande and several streams in the Sacramento Mountains and Sierra Blanca. Rio Bonito, Eagle Creek, and Rio Ruidoso, on the east slope of Sierra Blanca, are tributary to the Rio Hondo. Rio Bonito water is stored in Bonito Lake, from which the water is diverted to the Alamogordo-Holloman Air Force Base area through the recently constructed Bonito pipeline. Eagle Creek is under consideration as a possible source of additional water to the Tularosa Basin communities. On the west slope of Sierra Blanca, the Three Rivers drainage system contains some perennial flows in the upper parts of Three Rivers Canyon and Indian Creek. Both the surface and ground water of this area are being studied in some detail and are treated at greater length in a later section of this report. Rio Tularosa is an important perennial stream northeast of the town of Tularosa. The water from both Rio Tularosa and the La Luz-Freznal drainage system, southeast of Tularosa, probably is fully appropriated; however, consideration can be given to the purchase of water rights on these streams. At the south end of the Sacramento Mountains is the Sacramento River which flows southward to the so-called Hueco Plateau. The principal water right on the Sacramento River is owned by the Southern Pacific Railroad but reportedly can be purchased. The Rio Peñasco, east of Cloudcroft on the east slope of the Sacramento Mountains, furnishes water to the Peñasco Valley and is not discussed in this report.

The occurrence of ground water in the area of this report is extremely varied, both as to the quantity available and the chemical quality. The Rio Grande valley south of Truth or Consequences contains one of the most dependable supplies of water in New Mexico, whereas large areas in the Jornada del Muerto and Tularosa Basin apparently have no usable water supplies.

The intrusive igneous rocks generally are relatively impermeable and, consequently, are poor aquifers and act as barriers to the movement of water, except where they are fractured or weathered. The Precambrian granitic and metamorphic rocks exposed along the west-facing escarpment of the San Andres Mountains, and the Tertiary intrusive rocks of Sierra Blanca and the Organ Mountains do not readily absorb precipitation but are important areas from which water runs off to adjacent areas where it becomes available for ground-water recharge. A few springs occur in those rocks, and the water from those springs generally is not highly mineralized. Most of the fine-grained igneous extrusives are similarly impermeable, but some basalt flows are extremely permeable, and represent important recharge areas because precipitation is readily absorbed before much of it evaporates. Also, the more recent basalt flows, such as those in the northern parts of the Tularosa Basin and the Jornada del Muerto, support very little vegetation ~~which~~ that might intercept the precipitation before it reaches the water table.

The Bliss sandstone and the dense limestones of early Paleozoic age, exposed in the southern part of this area, mainly in the San Andres, Franklin, and Sacramento Mountains, are relatively impermeable and are not important aquifers. Springs issuing from those rocks in the mountains yield only small quantities of water, which generally is hard but potable. The Madera limestone of the Pennsylvanian Magdalena group yields small quantities of water to stock and domestic wells in the vicinity of Organ, along the east slope of the Oscura Mountains, and elsewhere. In some parts of New Mexico the Madera reportedly yields sufficient quantities of water for irrigation, although these occurrences are localized, as in the western part of the Estancia Valley. Ground water ~~occurring~~ in the Madera generally has a high carbonate hardness but is potable, unless it has dissolved objectionable mineral matter from other rocks before reaching the Madera. The Bursum and Abo formations of Permian age yield relatively small quantities of water to a few stock and domestic wells in the northern part of the Tularosa Basin. A well at Mockingbird Gap, between the Oscura and San Andres Mountains, produces 30 ~~gallons per minute~~ gpm from a fault zone in the Abo formation, but the ground-water storage is ~~limited~~ small, and the well is not capable of this yield steadily for more than a few months.

The Yeso formation of Permian age is an aquifer in some areas, but generally the formation contributes calcium sulfate, and other minerals, to the ground water in objectionable quantities. Almost all the water ~~occurring~~ in the Yeso formation on Chupadera Mesa is impotable or nearly so. Much of the high sulfate content of the ground water ~~occurring~~ in the valley fill in the northern parts of the Tularosa Basin and the Jornada del Muerto has been derived from the gypsum and gypsiferous silts of the Yeso formation. The Glorieta sandstone may furnish some water to wells on Chupadera Mesa, but, except where the sandstone is fractured, the formation yields relatively small quantities of water.

The San Andres formation yields water to some wells on Chupadera Mesa and is a very important aquifer in the Roswell basin. In the southern part of Chupadera Mesa the formation contains a considerable amount of gypsum; consequently, in that area the ground water in the formation is potable only locally where it has moved only short distances through the formation. Gypsum is relatively impermeable unless it contains solution channels or fractures, and ground water in gypsum generally contains large quantities of sulfate and is impotable.

Most of the Mesozoic sedimentary rocks in this area are not good aquifers, although some of the Cretaceous sandstones yield small quantities of water to wells in the northeastern part of the Tularosa Basin in the vicinity of Carrizozo. Generally, the water obtained from these sandstones in this area is impotable.

The Tertiary and Quaternary unconsolidated alluvial deposits contain the most important aquifers in the area. For the most part, these deposits are relatively very permeable--particularly the coarse stream-laid floodplain deposits along the Rio Grande, where many irrigation wells yield more than 1,000 gpm. The alluvial deposits generally contain water of good chemical quality along the margins of the basin, but the ground water becomes increasingly mineralized toward the centers of the basins. In some areas, as in the north-central part of the Tularosa Basin, the ground water even in the marginal deposits is highly mineralized, partly because the deposits have been derived from gypsiferous rocks and partly because the ground water has migrated from rocks containing readily soluble minerals.

As a guide in the classification of waters for various uses, the U. S. Public Health Service (1946) has indicated that, for interstate carriers, drinking water should contain not more than 1,000 ppm (parts per million) and preferably not more than 500 ppm of dissolved solids. Water containing several thousand ppm of dissolved solids, however, is often used for irrigation and for watering stock. Sulfate and chloride are the principal undesirable constituents of ground water in south-central New Mexico. Both, in association with calcium and magnesium, contribute so-called "permanent" hardness which is difficult and costly to remove. According to the standards adopted by the U. S. Public Health Service (1946), water used for domestic purposes should not contain more than 250 ppm of either sulfate or chloride. In most of the Jornada del Mureto and Tularosa Basin the ground waters do not meet these standards. Many of the waters derived from the limestones contain bicarbonates of calcium and magnesium, causing the water to have a "temporary" hardness, which generally is removed easily. Some waters contain less common mineral constituents, such as fluoride and nitrate, in objectionable quantities. These constituents are difficult to remove but, fortunately, usually are not present in large quantities.

SUMMARY OF AVAILABILITY OF WATER

This report covers a region that includes more than 12,000 square miles, and the geology, topography, and even the climate ~~vary~~ differ to a large degree among the various parts of the region. Consequently, the occurrence of water also ~~varies~~ differs greatly in different parts of the region.

Insofar as possible, an attempt is made in this report to appraise the water resources of the region, both qualitatively and quantitatively. It must be realized that, because of the paucity of data in some areas, the estimates of available water are not of consistent accuracy. However, it is believed that most of the estimates are in the right order of magnitude and will have value for planning purposes when used with this realization in mind.

With regard to potable and inferior water as defined below, the amount of water that can be developed as a dependable, long-term yield has been estimated, wherever possible. Economic factors affecting developments have been largely ignored, but physical factors have been considered in attempting to estimate the quantities of such water that can be developed feasibly. Some of these physical factors are: 1) the estimated area underlain by potable water; 2) the estimated average potential yields of wells; and 3) the estimated number of such wells that can be developed without seriously overpumping the aquifers.

In attempting to estimate the quantity of water available in the region covered by this report, it was apparent that impotable water, as defined below, could best be estimated as the total quantity of such water in storage. In much of the region practically no data are available on the yields of large wells producing impotable water, because such wells have been developed only in areas where crops can be irrigated with the water. It should be emphasized that the quantity of ground water stored in an area does not represent the quantity of water that can be recovered by pumping. The latter quantity depends upon a great many factors, both physical and economic, many of which cannot be considered in this report. The physical factors, of course, are not constant from area to area, and the economic factors can be evaluated only for a certain time under certain conditions. A development that is economically infeasible one day may be entirely feasible the next day, or one that is economically infeasible in one area may be feasible in another.

In the region covered by this report, sulfate and chloride are the principal minerals that render much of the water unfit for human consumption. Generally, if neither of these constituents is present in objectionable quantities, the water does not contain other dissolved minerals in objectionable quantities. In this report, the term, potable, has been used for water that contains less that 250 ppm sulfate and less than 250 ppm chloride, as recommended by the U. S. Public Health Service (1946). Water containing between 250 and 500 ppm of either sulfate or chloride and less than 750 ppm of both is called inferior, or near potable. Water containing more than 500 ppm sulfate or chloride or more than 750 ppm of both is called impotable.

The chemistry of water and the effects on the human body of drinking water of various chemical qualities are very complex subjects, and it is beyond the scope of this report to discuss the physiological effects of drinking water that contains excessive quantities of dissolved minerals. ~~While~~ Although the standards for drinking water established by the U. S. Public Health Service are used in this report to define potable water, it should be emphasized that in many parts of southwestern United States the available water does not meet those standards, and water containing dissolved minerals in much higher concentrations is used apparently without ~~bad~~ detrimental physiological effects. In fact, some military installations in the Tularosa Basin presently are using water that contains considerably higher concentrations of dissolved minerals than recommended by the U. S. Public Health Service, because water of better chemical quality is not available.

Probably most waters in at least the lower part of the near-potable, or inferior, range, as defined above, should be considered potable but undesirable, at least where water of better chemical quality is not available. In many cases, water even in the higher part of the near-potable range usually can be used for short periods or can be mixed with less mineralized water to produce a potable product. Thus, it is apparent that a computation of the quantity of potable water in the region does not represent the quantity of water in the region that, by careful development and utilization, can be used for potable purposes. Also, it is possible that much of the water that is impotable in its natural occurrence can be successfully demineralized by one of the several methods that have been or are being developed. These possibilities are not considered in detail in this report but obviously must be considered in any long-range plans for full development of the water resources of the region.

Potable Water

The largest supplies of potable ground water, as defined above, in the region covered by this report (pl. 1) are in the Rio Grande Valley in the vicinities of Bosque del Apache and Las Cruces, New Mexico, and in the southwestern part of the Tularosa Basin and northwestern part of the Hueco Bolson, between White Sands Proving Ground, New Mexico, and El Paso, Texas. Potable ground water also underlies parts of the southern Jornada del Muerto and relatively small areas at the sides of the Tularosa Basin. In the rest of the region potable ground water has a very limited occurrence in very small areas. Potable surface water occurs in Rio Bonito, Eagle Creek, and Rio Ruidoso on the east slope of Sierra Blanca, the Three Rivers drainage system on the west slope of Sierra Blanca, the Rio Penasco east of Cloudcroft on the east slope of the Sacramento Mountains, and the Sacramento River at the south end of the Sacramento Mountains. Most of the surface water has been appropriated, and only the Three Rivers drainage and the Sacramento River are discussed in this report.

It has been estimated, on the basis of very limited data, that possibly as much as 30,000 acre-feet of potable water can be pumped annually from wells in the Rio Grande Valley in the vicinity of Bosque del Apache, south of San Antonio, New Mexico (pl. 2). This estimate is based on the assumption that at least 25 wells yielding an average of about 1,500 gpm can be developed in that area. Only two large-capacity wells have been constructed in the Bosque del Apache by the U. S. Fish and Wildlife Service; one reportedly was tested at a rate of 1,500 gpm and the other at a rate of more than 2,000 gpm. This area is within the Rio Grande Underground Water Basin that has been closed to additional appropriation of water, except for domestic use, by the State Engineer of New Mexico. Presumably, additional large wells can be developed in this area only if appropriations of surface and/or ground water equaling in quantity the amount to be pumped from the new wells were discontinued.

The Mesilla Valley of the Rio Grande in the vicinity of Las Cruces, New Mexico (pl. 18), is underlain by large supplies of potable and inferior ground water. This part of the Rio Grande Valley is much larger and contains a considerably larger supply of ground water than the Bosque del Apache area. It is estimated that at least 2,500,000 acre-feet of potable and near potable water are stored under that part of the valley shown on plate 18 between Leasburg Dam and the south line of T. 24 S. However, it is estimated that only about 20 percent of this ground water is of potable chemical quality, as defined in this report. Also, the area is extensively developed for irrigation, both by diversions from the Rio Grande and by wells. Although this part of the Rio Grande Valley has not yet been closed to additional development by the State Engineer of New Mexico, all the surface water is fully appropriated and any attempts at additional large-scale development of ground water in the valley undoubtedly ~~would~~ will be met with strong protests from local and down-stream users of the water.

In the southwestern part of the Tularosa Basin and the northwestern part of the Hueco Bolson a zone of potable ground water extends from the headquarters area of White Sands Proving Ground along the east side of the Organ and Franklin Mountains to the El Paso area (pls. 15 and 16). Knowles and Kennedy (August 1956) estimated that the Hueco Bolson in New Mexico contains about 6.2 million acre-feet of theoretically recoverable potable water and that the bolson in Texas contains about 7.4 million acre-feet of theoretically recoverable potable water. They state that by proper well-field planning at least 50 percent of the potable water in storage probably ~~could~~ can be recovered before the water becomes so contaminated by highly mineralized water as to be unusable for public supply. The average annual pumpage of ground water in the El Paso area east of the Franklin Mountains in 1954 was about 28 million gallons a day (Knowles and Kennedy, August 1956, p. 46) or about 30,000 acre-feet per year. The headquarters area of White Sands Proving Ground (pl. 16) was not included by Knowles and Kennedy in their estimate of the quantity of potable water in storage. Pumpage in that area in 1954 was about 1,000 acre-feet per year, and probably that rate of pumping ~~could~~ can be maintained for a long period of time without seriously depleting the ground-water resources of the area.

In the Boles well-field area, south of Alamogordo, N. Mex. (pl. 10), an area of about 8 square miles is underlain by potable ground water, as defined in this report. During 1955 about 249 million gallons, or more than 750 acre-feet, of water was pumped in the Boles well field. It is estimated that the maximum dependable yield of the Boles well field is not more than 1,000 acre-feet per year, and Hood (1957, p. 195) believes that saline water would eventually encroach even if pumping were continued at only one-half the 1955 rate.

Potable ground water underlies a part of the southern Jornada del Muerto in the vicinity of T. 21 S., R. 2 E. where well 21.2E.14.300 reportedly yields about 1,000 gpm of water containing only about 500 ppm total solids. Additional data are needed to fully evaluate this occurrence of potable ground water. However, it is estimated that at least 1.5 million acre-feet of potable water underlies an area of about 300 square miles there.

In the Hueco Plateau area (pl. 13) most of the ground water is impotable, or at least inferior. It is estimated that only about 250,000 acre-feet of potable ground water underlies the area. Only stock and domestic wells have been developed in that area, and the depth to water is generally greater than 500 feet.

Other occurrences of potable ground water, small in volume but important because of their locations, are as follows. In the northern part of the Jornada del Muerto (pl. 2), the Fite PW well (6.2.4.300), the Hardin Ranch well (12.2.27.211), and the Trail Canyon well (6.5.36.343) produce small quantities of potable water. In the northern part of the Tularosa Basin (pl. 3), the Baca well (6.6.34.200) and the Mockingbird Gap well (9.5.15.143) produce small quantities of potable water. In the west-central part of the Tularosa Basin (pl. 17), the Lucero Ranch well (19.5.22.343) yields potable water, and the Bairds Ranch well (17.4.23.433) yields near potable water. A very small amount of potable ground water can be developed in the Crow Flats-Dell City area (pl. 14) in alluvium along some of the canyons and arroyos, but most of the ground water in that area is impotable. Most of the ground water in the Three Rivers area (pl. 6) and the area southeast of Valmont (pl. 11) is of inferior quality, as defined above. However, much of the ground water in both areas is only slightly above potable limits of mineralization and can be utilized for public supply if yields of wells prove to be adequate. Also, both areas are close to sources of potable surface water. Indian Creek and Three Rivers had a total measured yield of about 1,800 acre-feet during the period October 1956 to September 1957. It has been estimated that the Upper Sacramento River (pl. 12) would yield about 500 gpm, or about 800 acre-feet per year, of potable water, if the water-collection system were more efficiently developed.

Inferior Water

Ground water of inferior chemical quality, as defined in this report, occurs in most parts of this region except in the central parts of the basins, where all the ground water is impotable. In several areas water of inferior chemical quality is utilized for domestic and public supply.

The largest supplies of inferior water in the region covered by this report are in the southern part of the Jornada del Muerto (pl. 18), the Mesilla Valley of the Rio Grande in the vicinity of Las Cruces, New Mexico (pl. 18), the Carrizozo area (pl. 4), the southern part of the Tularosa Basin and northern part of the Hueco Bolson (pl. 15), the Hueco Plateau (pl. 13), the area southeast of Valmont, New Mexico (pl. 11), and the Crow Flats-Dell City area (pl. 14).

It is estimated that approximately 6 million acre-feet of inferior ground water underlies the southern part of the Jornada del Muerto and that more than 2 million acre-feet of inferior ground water is stored in the alluvium of the Rio Grande Valley in the vicinity of Las Cruces. Much of this water is only slightly higher than the potable limits of mineralization as used in this report and presumably could be used for public supply. Probably some of the ground water in the Bosque del Apache area of the Rio Grande Valley (pl. 2) is of inferior chemical quality, although data on the quality of the water in that area are very limited. Properly constructed and developed wells in the alluvium of the Rio Grande Valley can be expected to produce at least 1,000 gpm; several single wells there are reported to yield more than 2,000 gpm. Wells in some parts of the southern Jornada del Muerto should produce several hundred gallons per minute, although in much of that area only small stock wells have been developed. The lower shafts and tunnels of the Stevenson-Bennett mine (22.3.11.400), south of Organ, contain water of inferior chemical quality, and it is reported that water was pumped from this mine at a rate of 800 gpm in a futile attempt to dewater the mine to permit mining operations. Data are not ~~presently~~ available with which to substantiate this report.

Practically all ground water in the Carrizozo area (pl. 4) is of inferior and impotable chemical quality, although the water is used for public supply. It is estimated that about 20,000 acre-feet of inferior water ~~could~~ can be pumped annually in the Carrizozo area.

In the southern part of the Tularosa Basin and northern part of the Hueco Bolson (pl. 15) it is estimated that at least 5,000 acre-feet of inferior water ~~could~~ can be pumped annually from the bolson deposits. In that area the transition from ground water of potable quality to ground water of impotable quality apparently is very abrupt, the water of inferior quality apparently occurring in only a very limited zone.

In the Hueco Plateau area (pl. 13) it is probable the nearly 1 million acre-feet of inferior ground water is stored, mainly in limestone. No wells in that area are known to have large yields but very few of the wells have been tested for maximum yield. The depth to water is generally several hundred feet, and most of the wells are equipped only with windmills.

The area southeast of Valmont (pl. 11) has been suggested as a potential source of water for military installations and worthy of additional study. Most of the ground water in that area apparently contains more than 250 ppm of sulfate and therefore falls in the range of inferior quality. However, much of the water probably contains less than 300 ppm of sulfate and therefore probably should be considered useable for public supply. It is possible that the area could be developed to produce as much as 1,000 acre-feet of such water annually, although additional data are needed to predict accurately the potential capacity of wells in that area.

It is estimated that about 1,000 acre-feet of inferior water ~~could~~ can be pumped annually in the Crow Flats-Dell City area. However, most of the water presently being pumped in that area is impotable, and it is likely that the quality of the water will deteriorate even more if heavy pumping is continued.

One additional source of inferior water should be mentioned in this summary because of the importance of its location. The Murray well (8.5.32.431) at the north end of the San Andres Mountains (pl. 2) produced, during a pumping test, 100 gpm of water containing about 300 ppm sulfate and less than 700 ppm total solids. The Murray well is one of the few existing sources of useable water in that area and presently supplies water for Oscura Range Camp and Stallion Site Camp.

Impotable Water

In this report water containing more than 500 ppm of either sulfate or chloride or more than 750 ppm of both chloride and sulfate is called impotable. Water in this range of chemical quality is extensively used for irrigation and watering stock and even for drinking in a few areas where water of better chemical quality is not available. Extensive supplies of impotable ground water underlie almost all parts of the region covered by this report. It is estimated that at least 150 million acre-feet of impotable water is stored in the region covered by plate 1. In the southern part of the Tularosa Basin and the northern part of the Hueco Bolson, shown on plate 15, it is estimated that at least 65 million acre-feet of impotable ground water is stored. In the west-central part of the Tularosa Basin (pl. 17) at least an additional 40 million acre-feet of impotable ground water is stored. In both these areas the principal aquifer is the mainly unconsolidated bolson fill. Some of the ground water underlying the central part of the Tularosa Basin is very highly mineralized, even exceeding sea water in this respect. In the northern part of the Tularosa Basin (pl. 3) it is estimated that at least 6 million acre-feet of impotable water is stored. In the northern part of the Jornada del Muerto (pl. 2) it is estimated that at least 11 million acre-feet of impotable water is stored in the bolson deposits alone. It is not possible with available data to estimate the amount of impotable water that may be stored in the consolidated rocks underlying the bolson deposits. In the Hueco Plateau and the Crow Flats-Dell City area an additional estimated 11 million acre-feet of impotable water is stored, mainly in limestone, although the unconsolidated valley fill in the Crow Flats-Dell City area probably contains at least 2 million acre-feet of impotable water. The Tularosa-Alamogordo area (pl. 9) is estimated to contain at least 8 million acre-feet and the Carrizozo area (pl. 4) at least 1.5 million acre-feet of impotable water. In both areas impotable water is used for watering stock and for irrigation, and even for drinking in a few places where water of better chemical quality is not available.

In the north-central part of the Tularosa Basin (pl. 3), Malpais Spring (12.7.8.244) yields an estimated 1,500 gpm of water containing about 1,900 ppm sulfate and 1,200 ppm chloride. Salt Creek in Tps. 12 and 13 S., R. 6 E. flows an estimated 500 gpm of water containing more than 4,000 ppm sulfate and about 8,000 ppm chloride. Both sources apparently are dependable, although their yields fluctuate.

The following ~~table~~ (table 1) is a tabulation of the estimated quantities of water of various qualities in the Tularosa Basin and adjoining areas shown on plate 1. The table is not complete in that some surface-water sources not discussed in this report, such as Rio Tularosa, Alamo Springs, and others, are not included here. Also, the quantities as given represent total quantities, not quantities that are presently unused. There has been no attempt in the table to take into consideration the present uses of water.

Table 1. Summary of Estimated Quantities of Water in Tularosa Basin and Adjoining Areas.

Area	Potable Water (Potential yield in acre-ft. per year except where noted otherwise.)	Inferior Water (Potential yield in acre-ft. per year except where noted otherwise.)	Impotable Water (acre-ft. in storage)
Northern Jornada del Muerto	30	200	10,000,000
Rio Grande Valley at Bosque del Apache	30,000	-	-
Northern Tularosa Basin	30	200	6,000,000
Carrizozo area	-	20,000	2,000,000
Three Rivers area	1,000	1,000	200,000
Tularosa-Alamogordo area	1,000	500	8,000,000
Area southeast of Valmont	100	1,000	1,000,000
Upper Sacramento River Canyon	800	-	-
Hueco Plateau	300,000 1/	700,000 1/	7,000,000
Crow Flats-Dell City area	300	1,000	4,000,000
Southern Tularosa Basin-Hueco Bolson	60,000	4,000	70,000,000
W.S.P.G. Headquarters area	2,000	-	3,000,000
West-central Tularosa Basin	30	60	50,000,000
Southern Jornada del Muerto	1,000,000 1/	6,000,000 1/	3,000,000
Mesilla Valley at Las Cruces	600,000 1/	2,000,000 1/	-

1/ Acre-feet in storage.

Summary of Suggested Additional Study

Available data on the ground-water resources of the Rio Grande valley in the vicinity of Bosque del Apache are very limited, as indicated previously. If the area were to be considered for large-scale development of ground water, it would be advisable to conduct a fairly detailed study of the area. This study should include reconnaissance mapping of the geology of the area, chemical analyses of water samples from all existing sources of water, and a test-drilling program, consisting of drilling 6 to 10 test holes, obtaining accurate logs of the holes, chemical analyses of the water encountered, and adequate pumping tests of several of the test holes.

A published report of ground-water conditions in the Mesilla Valley of the Rio Grande (Conover, 1954), contains a considerable amount of basic data and provides a valuable background for a consideration of the additional development of ground water in that area. However, some additional study would be desirable if any extensive development were to be undertaken. Additional study should be made of the probable effect upon the river and drain discharge of ~~additional~~ heavy pumping from wells. This study should include THE analysis of records of both river and drain discharge, and fluctuations of water levels in wells. As much of the ground water is of inferior chemical quality, water samples from a large number of wells should be chemically analyzed, and test holes should be drilled to determine where wells yielding adequate quantities of chemically suitable water can be developed.

In the southern part of the Jornada del Muerto, seismic or electrical resistivity surveys should provide much information regarding the subsurface strata, and should indicate whether a test-drilling program would be worthwhile in that area. Several test holes would be necessary to determine how much water of useable quality can be developed. More data are needed to evaluate the occurrence of water in the belt of fractured limestone along the west slope of the Organ Mountains. Apparently, these rocks yield large quantities of near-potable water at the Stevenson-Bennett mine, but no carefully controlled pumping tests have been conducted. Additional geologic study of the west front of the Organ and San Augustin Mountains might reveal additional similar areas that would be worthy of test drilling.

The report by Knowles and Kennedy (August 1956) states (p. 43) that the Hueco Bolson in New Mexico contains about 6.2 million acre-feet of theoretically recoverable potable water. The report concludes that by proper well-field planning at least 50 percent of that water probably can be recovered before it becomes so contaminated as to be unusable for public supply. However, the report adds that the computations for the amount of potable water in storage are more accurate for the Texas than the New Mexico part of the bolson, where only a small number of widely spaced test holes were drilled. The report further states that "additional test drilling, especially near the Organ Mountains where the fresh-water-bearing materials appear to be thickest, will be necessary to determine accurately the volume of fresh water in storage in the Hueco bolson in New Mexico." If large-scale development of ground water in that area is considered, not only should additional test holes be drilled, but extensive pumping tests of several holes in the area should be conducted to determine more accurately the characteristics of the aquifer and to estimate its capacity. A poorly planned well field, developed without adequate knowledge of the area, probably would deplete or contaminate potable water supplies much sooner than if the development were based on a firm knowledge of ground-water conditions in the area. Such information is not yet available.

Pumpage in the White Sands Proving Ground headquarters area is approximately 1,000 acre-feet annually. Water levels are continuing to decline but not at a serious rate. The present program of measuring water levels in observation wells in that area at regular intervals under the Corps of Engineers Continuing Program should be maintained. The water-level recording gages installed on two production wells are presently inoperative. These should be placed back in operation to provide records of water-level declines in those wells. A short report of the possibilities of impounding flood flows for artificial recharge or underground storage is presently being prepared by the U. S. Geological Survey. If it is likely that water consumption at the Proving Ground will increase appreciably in the near future, consideration should be given to additional investigations of the feasibility of artificial recharge by obtaining more complete flood-flow records and drilling a few shallow test holes in the vicinity of the proposed dam and reservoir. Any additional production wells in the area should be drilled initially as test-pilot holes to obtain as much information as possible on ground-water conditions at the sites. By use of such data, more efficient development of wells can be accomplished.

Under the Corps of Engineers Continuing Program, water levels in several wells in the Boles well field are measured at regular intervals. This program should be continued, and provision should be made for inspection of cuttings from any additional wells or test holes that may be drilled in the area. As it appears probable that saline water eventually will encroach in the area, water samples from selected wells in and immediately west of the well field should be analyzed chemically at least once a year.

It is estimated that approximately 1,000 acre-feet per year of potable water can be developed in the Three Rivers area if both surface-water and ground-water sources are utilized. Most of the ground water in that area is of inferior chemical quality, but the surface waters of both Three Rivers Canyon and Indian Creek are potable. The surface water can be mixed with inferior ground water to produce a potable water. The area is about 15 miles east of U. S. Highway 54 and the Bonito pipeline. Additional records of flows in Three Rivers Canyon and Indian Creek should be obtained to provide a longer record. More slope-area measurements should be made and analyzed to determine the extent of flood flows in the area and the feasibility of storing and utilizing flood-flow water. Extensive pumping tests should be made in any proposed well-field areas, so that the capacity of the aquifers and the effect of long-term pumping on water levels and chemical quality of the water can be estimated.

The area southeast of Valmont (pl. 11) has been suggested as a possible source of potable ground water, on the basis of only a small amount of data. Probably much of the ground water in that area is inferior, by the standard used in this report. However, the available chemical analyses indicate that much of the ground water is in the lowest part of the inferior range, containing less than 300 ppm sulfate, and is of better chemical quality than much of the water used in the Tularosa Basin. The area is convenient to the Sacramento River-Orogrande pipeline and U. S. Highway 54 and is only about 12 miles south of the Boles well field. If ground-water conditions there are similar to those at Boles well field, it is possible that the area southeast of Valmont might be developed to produce as much as 1,000 acre-feet of water annually containing less than 300 ppm sulfate. Some reconnaissance geologic mapping and about 10 test holes are needed to evaluate the area accurately. The test holes should be so designed and located that the extent of the occurrence of usable ground water and the nature of the bolson fill can be determined. Provision should be made for adequate pumping tests of the most promising holes to permit an estimate of the potential yields of wells in the area.

Springs in the upper part of the Sacramento River Canyon represent an apparently dependable source of water of very good chemical quality. In December 1956 (Mourant, ~~March~~ 1957), it was estimated that about 250 gpm of water was being diverted to the Sacramento River-Orogrande pipeline. Mourant concluded that, by improving the water-collection system, the quantity of water delivered to the pipeline could be increased to about 500 gpm, or about 800 acre-feet per year. The Southern Pacific Railroad reportedly plans to sell this water system, but probably it would be necessary to replace most or all of the pipeline, particularly if the system is improved to divert a larger quantity of water. The principal springs should be tightly boxed in at their discharge points, and the water should be diverted to the pipeline at those points. In order to determine how much water [~~actually~~] is available in the canyon, it is suggested that several test holes ~~should~~ be drilled to determine how much water is moving down the canyon in the canyon fill and, if possible, to what extent water moves into permeable bedrock underneath the cienaga (marsh) deposits. It may be feasible to build galleries in the main parts of the cienagas in addition to catchments at principal spring areas. Several conditions are possible, and only a more detailed study will reveal how much additional water can be diverted to the pipeline.

Several additional small but important occurrences of potable water are described in this report. Suggestions for additional investigation of these occurrences, if warranted, have been included in the following descriptions of each area.

In view of the limited supplies of potable water in the Tularosa Basin, it appears that an extensive investigation of the possibilities of using inferior and impotable water should be made. Much inferior water apparently can be used even for drinking without serious physiological effects. The possibilities of mixing waters of various qualities to obtain adequate quantities of water of useable chemical quality should be carefully considered, particularly in isolated areas where potable water is very limited. The feasibility of demineralizing highly mineralized water should be investigated. The use of impotable water for irrigation, sanitary purposes, and some industrial uses should be very carefully considered. Large quantities of potable water presently are used in the area for irrigation, particularly of lawn areas at the larger military installations. Such use of the limited supplies of potable water should be kept to a minimum, and more highly mineralized water should be used for such purposes wherever possible. Consideration should be given to the use of plants and grasses that require relatively small quantities of water, when an area is being landscaped. Native plants can be used far more extensively than has been done; most of these native plants require only small quantities of water. Careful, conservative use of water for such purposes as irrigation of lawns should be strictly enforced. The importance of keeping such water uses to a minimum can be realized when it is considered that well over 50 percent of the water consumed at the larger military installations during the summer months is used for watering lawns and shrubs.

GROUND-WATER CONDITIONS BY AREAS

Most of the areas discussed in this report offer some possibilities for the development of ground water. However, in some areas the depth to water is too great for the development of the resources to be feasible. In others, the yield of wells is so small that development is not feasible. In still other areas much of the ground water is impotable and cannot be economically utilized at the present time. For these reasons and because each of the various areas contains some features not common to the others, this report treats each of the several areas individually.

The ground-water resources of some areas, where previous studies have been made, can be discussed in some detail; whereas, the ground-water conditions in many large areas are only partly known, and only generalized conclusions can be drawn. As much as possible of the available ground-water data in this report appears on the detailed maps of each area. The areas covered by detailed maps and the titles of the maps which correspond to the related subheadings in this section of the text are shown on plate 1. General quality-of-water maps of Doña Ana, Lincoln, Otero, Sierra, and Socorro Counties, New Mexico are contained as an appendix in a pocket at the end of the report.

NORTHERN JORNADA DEL MUERTO AND ADJACENT AREAS, SOCORRO AND SIERRA COUNTIES, NEW MEXICO

By

J. E. Weir, Jr.

The area discussed in this section of the report is bounded approximately on the north by U. S. Highway 380, on the east by the Sierra Oscura and San Andres Mountains, on the south by State Highway 52, and on the west by the range line between Ranges 1 and 2 west. The general location of the area is shown on plate 1 and details of the area are shown on plate 2.

The desert basin between Chupadera Mesa, Sierra Oscura, San Andres Mountains, and Organ Mountains on the east, and Mesa Redonda, Joyita Hills, Fra Cristobal Range, Caballo Mountains, and Rio Grande on the west is called the Jornada del Muerto. These physiographic features essentially close the basin at its northern and southern extremities. Almost all the Jornada del Muerto from U. S. Highway 380 to the south line of T. 12 S., is treated in this section of the report and is shown on plate 2.

Approximately 400 square miles of the White Sands Integrated Range lies in the north-central part of the Jornada del Muerto. Stallion Site Camp, in the NW$\frac{1}{4}$ sec. 5, T. 6 S., R 3 E., is the only permanent troop installation in the Jornada del Muerto.

Stallion Site Camp-Cerro Colorado Area

In most of the area around Stallion Site Camp and Cerro Colorado only highly mineralized, impotable ground water is available. The impotable water occurs in Tertiary and Quaternary strata ranging in thickness from approximately 200 feet in the areas a few miles east and south of Stallion Site Camp, to perhaps as much as 1,000 feet in localities north and west of Stallion Site Camp. Water levels in wells in the Stallion Site locality range from 150 to 450 feet below land surface, from east to west respectively. The depth to water at the Stallion Site troop shelter is estimated to be approximately 225 feet below land surface.

The chemical constituents that are responsible for the impotability of ground water in this area are the sulfates, mainly calcium sulfate dissolved from the gypsiferous deposits of the Tertiary-Quaternary basin fill. Therefore, the concentration of sulfate in the water is used as the principal measure of potability in this area. Ground water in the immediate vicinity of Stallion Site Camp probably contains about 2,000 ppm sulfate.

Chemical analyses of water from existing wells and three test holes drilled in 1956 indicate that the western and northern flanks of the Cerro Colorado volcanic mass are underlain by water of potable and near potable quality. The concentration of sulfate in the ground waters underlying this area ranges from 218 to about 900 ppm. Approximately one-fourth to one-third of the area underlain by water of good to fair quality is within the boundary of the Integrated Range; however, water underlying only a small part of this area within the Integrated Range contains 250 ppm sulfate or less. The sulfate concentrations of well waters in the area are shown on plate 2. Yields from the three test holes drilled near Stallion Site range from 2 to 40 gpm, the larger yield being from the holes nearest the camp that yields the water poorest in chemical quality of the three.

Two test holes approximately 600 to 700 feet deep along the north and west boundaries of the Integrated Range would further delineate the limits of potable and relatively better water and, of course, would provide additional data on the general availability of ground water in that area. A test hole at Stallion Site Camp would furnish information regarding the availability and chemical quality of ground water there, in the event that a de-mineralization unit were considered feasible for this installation. It is not possible to predict accurately the capacity or dependability of wells at Stallion Site, but a test hole drilled 2 miles west of Stallion Site Camp apparently will yield 40 gpm with 40 to 50 feet of drawdown. This estimate is computed from a specific capacity of one gallon per minute per foot of drawdown, the performance of the test hole during a six-hour pumping test conducted in May 1956. The static water level in this test hole is 318 feet below land surface. It is possible that a well about 500 feet deep at Stallion Site Camp would yield more than 20 gpm of water containing approximately 2,000 ppm sulfate. No definitely reliable data are available as to the cost of operation and efficiency of a de-mineralization unit in this area.

Assuming 10 gallons a day per troop to be an approximate water requirement for drinking and cooking, it appears likely that an adequate supply of potable water for about 600 men can be developed near the northwest corner of the Integrated Range about 6 miles from Stallion Site Camp. Such a development would probably require two wells. An existing stock well in the SW$\frac{1}{4}$ sec. 4, T. 6 S., R. 2 E., might furnish half this supply, although this well has not been tested for maximum dependable yield.

It is further assumed that an additional 40 gallons a day per troop will be required for purposes other than drinking. This additional water, which constitutes the bulk of the total supply, could be impotable. Water from wells which could be drilled at Stallion Site Camp would furnish water of sufficiently good quality for most uses other than drinking and cooking.

Central and Western Basin Area

The central part of the Jornada del Muerto is along the axis of a broad syncline or bedrock trough filled with an unknown thickness of unconsolidated sediments and impure evaporites which have been derived from the bedrock highs surrounding the basin. Most of the clastic deposits in the central basin are fine grained and contain varying amounts of gypsum and carbonates precipitated from flood waters that have flowed through and collected in the area following infrequent rains.

Extrapolation from bedrock outcrops around the margin of the Jornada del Muerto indicates that strata of Permian age underlie the Tertiary-Quaternary fill throughout most of the central part of the basin. Few reliable subsurface data are available for most of this area, and test holes might reveal strata of Cretaceous age underlying the fill in a large part of the basin.

The Dakota sandstone of Cretaceous age reportedly yields about 100 gpm to the Sun Oil test hole in sec. 25 T. 10 S. R. 1 W., about 20 miles north of Engel, New Mexico. However, the main source of the artesian water is the San Andres formation of Permian age. This test hole has been completed as a flowing water well and yields an estimated 800 to 1,000 gpm of highly mineralized water (1.660 ppm sulfate).

It is probable that the San Andres formation and perhaps the Dakota sandstone may be capable of yielding large quantities of mineralized water to wells in the north-central as well as the west-central part of the basin. Also, the Yeso formation of Permian age, which underlies the San Andres formation, may possible yield as much as 100 gpm to properly constructed wells in the central parts of the basin.

The Dakota, San Andres, and Yeso formations, from youngest to oldest respectively. constitute a potentially water-yielding interval, 1,300 to 1,500 feet thick, underlying the fill in much of the central basin. Most of the water contained in these rocks probably is highly mineralized and thus impotable.

The shallower water of the central part of the basin occurs in the fill and, like the deeper waters of the bedrock formations, generally is highly mineralized. The maximum yield of wells completed in the basin fill is about 50 gpm of water containing from about 1,500 to about 3,500 ppm sulfate.

There is little possibility that potable ground water exists in the central Jornada del Muerto; however, great quantities of moderately to highly mineralized waters are available, and some of these waters might feasibly be de-mineralized. Almost all the ground water in the area could be used for construction purposes as well as for many military purposes.

At least one test hole in the central basin is needed to test the Permian strata through the Yeso formation. Such a test hole might be as much as 1,500 feet deep ~~in depth~~, depending on which formation underlies the fill at the location chosen for the test. This deep test hole and perhaps four or five test holes 300 to 500 feet deep ~~in depth~~ should adequately sample and test the water-bearing rocks of the Integrated Range part of the central Jornada del Muerto. These holes also should reveal much geologic data that will aid in evaluating the water resources of the region.

In choosing locations for test holes that ~~which~~ are likely to test only those aquifers that yield impotable water, several considerations that are not necessarily geologic or hydrologic in scope are important. Some of these considerations are: 1) localities of future needs for construction water, 2) areas of future expansion and development, and 3) areas where mineralized waters might feasibly be treated to reduce the chemical concentrations to levels of potability. These considerations may also apply to exploration drilling in the Tularosa Basin.

Western Slope of San Andres Mountains

Most of the ~~existing~~ wells and springs on the western, back slope of the San Andres Mountains derive water from the Madera, Yeso, or San Andres formation, or from Quaternary alluvium. Water from the Madera formation generally is hard (carbonate hardness) but potable and usually appears in springs and collection galleries of very low yield, located high on the back slope. Only a few of these springs are perennial, and many are now dry as a result of prolonged drought. Stock wells completed in the Yeso and San Andres formations yield up to 10 gpm of water high in sulfate content and generally impotable. The alluvium, like the fill of the Jornada del Muerto, is gypsiferous and yields small quantities of impotable water to shallow wells where the alluvium is more than about 20 feet thick.

The area contains one known, apparently reliable source of potable water, the Hardin Ranch well in the NE$\frac{1}{4}$ sec. 27, T. 12 S., R. 2 E., about one mile north of New Mexico Highway 52 at the crest of Rhodes Pass, within the boundaries of the Integrated Range. This well derives water from the Abo formation of Permian age and is probably completed in a fracture zone. Water from the Hardin Ranch well is moderately hard (carbonate hardness) but contains only about 200 ppm sulfate. The static water level in the well is 204 feet below land surface, and the well yields at least 5 gpm ~~gallons a minute~~.

The Skillet Knob installation is about 9 road miles up the back slope eastward from Hardin Ranch. Small quantities of water could feasibly be hauled from the Hardin Ranch well to supply the Skillet Knob station. Water might also economically be hauled or piped from the well to the installations near the northwest flank of the San Andres Mountains, 12 to 20 road miles north of Hardin Ranch.

The area around the northwest flank of the San Andres Mountains has no known source of potable ground water and apparently only meager quantities of highly mineralized ground water. There is, however, one locality near the north end of the San Andres Mountains ~~which~~ that is worthy of one exploratory test hole about 100 to 300 feet deep ~~in depth~~. There is what appears to be a rather extensive alluvial fan deposit in the central southeast part of T. 9 S., R. 4 E., that may contain potable water.

Possibilities are few for the development of large water supplies, potable or impotable, in that part of the back-slope area of the San Andres Mountains which is within the northern part of the White Sands Integrated Range. The single known source of potable water, the Hardin Ranch well, should be tested to determine its capacity, and an exploratory hole near the north end of the mountains might yield a small amount of potable water.

Present military installations in this area currently use only small quantities of water. Skillet Knob personnel, who stay at the station only on days when missiles are being tested, are supplied with drinking water hauled from Tularosa.

Mockingbird Gap Hills - Oscura Gap Area

In the area around Mockingbird Gap Hills and Oscura Gap, usable ground water has been obtained with difficulty. Several holes have been drilled between Mockingbird Gap Hills and the northern end of the San Andres Mountains, including one dry 400-foot test hole drilled for the Corps of Engineers 0.5 mile south of George MacDonald's Murray well. The Murray well (8.5.32.431), the only existing source of ground water in this area, is completed in a fault zone in the upper part of the Yeso formation or the lower part of the San Andres formation. Pumping tests of the Murray well indicate a specific capacity of about 5 gpm per foot of drawdown at a pumping rate of 100 gpm. Static water level in the Murray well is 192 feet below land surface. Water from the well contains 298 ppm sulfate and 684 ppm total dissolved solids.

Since the time the Corps of Engineers test hole was drilled near the Murray well, geologic mapping in the area has indicated that the water-bearing fault zone trends southwest-northeast through the well location, thus crossing the structural graben in the area. This fault zone may yield water elsewhere in the graben valley between Mockingbird Gap Hills and the San Andres Mountains, but probably the most favorable site for another well here would be approximately 0.25 to 0.75 mile northeast of the Murray well. Such an additional well approximately 300 to 400 feet deep, finished in the same fault zone as the Murray well, probably would be the optimum development for this aquifer.

If further development of water supplies in this area is deemed desirable, test holes approximately 500 feet deep might be drilled into the marginal fault zones of the graben. The following locations are proposed for exploration in the marginal faults and possible subsequent development: 8.5.33.143 and 9.5.5.313. These locations are subject to confirmation after field reconnaissance of the exact sites.

Oscura Gap, between Mockingbird Gap Hills and the southern end of the Sierra Oscura, is a fault strike valley covered with a relatively thin deposit of alluvium. Rocks of the Yeso and Abo formations underlie most of the alluvium of this small valley. Scattered small outcrops suggest that granite and Pennsylvanian(?) limestone may underlie a narrow strip of alluvium along the east side of Oscura Gap, thus also suggesting the existence of two parallel faults in this area; one along the base of the west escarpment of Sierra Oscura and another, alluvium covered, in the bedrock underlying the Gap. The approximate trace of the covered fault can be extrapolated fairly accurately from the area north of the gap. The possibility of developing a ground-water supply in the alluvium-covered fault zone could be verified by a test hole approximately 500 feet deep in the $NW\frac{1}{4}NE\frac{1}{4}NW\frac{1}{4}$ sec. 14, T. 8 S., R. 5 E.

The Murray well will supply 100,000 gallons per day of water of fairly good quality. An additional well finished in the Murray well fault zone, approximately 0.5 mile east-northeast from the existing well, might furnish an additional 100,000 gallons a day. Thus, the Murray well area probably has a dependable, potential water supply for 2,000 to 4,000 troops. Two to four test holes ranging in depth from 300 to 500 feet should be adequate to explore the Murray well area for water of usable chemical quality. This area and the area to the south of Mockingbird Gap are the most promising for development of water supplies of any locality in the northern part of the Integrated Range. Also, this locality is about equi-distant from Stallion Site Camp and Oscura Range Camp and more or less in the geographic center of the northern part of the Integrated Range.

Eastern Marginal Area

The area along the east side of the Jornada del Muerto, adjacent to the western escarpment of the Sierra Oscura is primarily a pediment surface sloping westward toward the center of the basin. An exception is the strip between Hansonburg Hills and Sierra Oscura, which is a fault valley much like Oscura Gap.

Very little ground water is known to occur in this area and the water from most of the known sources is highly mineralized, with one exception, Trail Canyon well (6.5.36.343).

The Trail Canyon well derives water from alluvial-fan debris deposited in a front-scarp canyon at the base of Sierra Oscura. Little is known of the quantity of the water available here, but the chemical quality is very good (400 ppm total solids and 109 ppm sulfate).

About five to seven test holes are needed along the eastern side of the Jornada del Muerto to thoroughly explore the area for potable ground water. Most of these holes would explore fault zones in the area and might be as much as 700 feet deep. The remainder of the exploratory drilling in this area would investigate alluvial deposits and other shallow sources.

Summary

Potable water is available from wells in three areas of limited extent in the northern Jornada del Muerto. These areas are: west and southwest from Cerro Colorado; Hardin Ranch (12.2.27.211); and Trail Canyon (6.5.36.343).

In the area southwest of Cerro Colorado, stock well called "Fite PW" (6.2.4.333) is to be tested by pumping to determine its maximum dependable yield. A test hole drilled 0.7 mile northwest of this well yields only 2 gpm of potable water. It is estimated that the Fite PW well may yield 10 gpm, and an additional well nearby should yield as much or more. Such a development would supply drinking water for about 1,000 to 2,000 troops at Stallion Site Camp 6 miles east.

The Hardin Ranch well also will yield about 10 gpm; thus, a total supply for 150 troops is available here from a pumping installation operated about 12 hours daily. This is computed on the basis of an average use of 50 gallons per day per troop. Data for the Hardin Ranch area are insufficient to determine whether further development of water is feasible in this area.

The Trail Canyon well reportedly yields 3 gpm. A properly constructed, 12-inch diameter well in this vicinity might yield 25 gpm. Lack of reliable data for this area precludes estimates of dependable yields of present and future wells, but it is doubtful that wells here could supply more than about 70 troops.

The Murray well (8.5.32.431) on the north side of Mockingbird Gap yields 100 gpm of near potable water, some of which is being hauled to supply Oscura Range Camp, 19 road miles east. Estimates indicate that with one additional similar well in this area, 2,000 to 3,000 troops could be supplied with water of relatively good quality. However, exhaustive pumping tests should be conducted in conjunction with any future development here in order to determine conclusively the dependability of the water supply.

Most of the wells in the central part of the northern Jornada del Muerto are 6 inches in diameter and were drilled to supply small quantities of water for livestock. All known water from these wells is highly mineralized and thus impotable. Two large-diameter, relatively deeper wells completed in the area yield 500 gpm or more and indicate a vast quantity of impotable water available from bedrock formations underlying the unconsolidated basin-fill materials. Moreover, from data obtained in test drilling near Stallion Site Camp and other reasonably reliable reported data, moderate quantities of impotable water may be available from wells 300 to 500 feet deep in many parts of the Jornada del Muerto. In these wells the Tertiary-Quaternary fill apparently contains the principal, if not the only, water-bearing beds. These data dictate a conclusion that at least 50 gpm of impotable water may be available from properly constructed wells which could be drilled in almost any part of the northern Jornada del Muerto. Exploratory drilling should reveal a considerable number of acceptable camp sites where impotable ground water is available, some of which might be feasibly treated to reduce the concentration of dissolved minerals to within the limits recommended for drinking water.

NORTHERN TULAROSA BASIN AND ADJACENT AREAS, SOCORRO, LINCOLN, SIERRA, AND OTERO COUNTIES, NEW MEXICO

By

J. E. Weir, Jr.

Most of that part of the Tularosa Basin from its northern extremity near Tecolote Hill to the south line of T. 12 S. is discussed in this section of the report. This area, shown on plate 3, includes such intra-basinal features as The Malpais, Phillips Hills, Bull Gap Ridge, Transmalpais Hills, and the intervening basin flats. Also, parts of marginal physiographic features such as Chupadera Mesa, Sierra Oscura, and Mockingbird Gap are discussed.

Approximately 750 square miles of the area covered in this section is within the boundaries of the Integrated Range. About two-thirds of the area lies within the physiographic limits of the northern Tularosa Basin.

Mockingbird Gap Area

The area immediately south of Mockinbird Gap is underlain mainly by rocks of Permian age with only a small area adjacent to Mockingbird Gap underlain directly by rocks of Pennsylvanian age. Pennsylvanian strata are represented by the upper part of the Madera formation composed mostly of arkosic limestone. Permian strata are represented by the Bursum, Abo, and Yeso formations. The Bursum formation consists of alternating layers of limestone with purplish-red sandstone, conglomerate, siltstone, and shale, and is the transition zone from marine Pennsylvanian rocks to basal Permian continental deposits. The Abo formation consists of red sandstone and siltstone, underlying the Yeso formation which is composed of alternating layers of gray limestone, gypsum, pink shale, and siltstone. The strata in these formations, except for fractures, are virtually impervious to the movement of water. A fracture zone in Bursum rocks at the apex of an anticlinal fold near Mockingbird Gap is the most dependable source of water in this locality.

The Mockingbird Gap well (9.5.15.143), which derives potable water containing less than 100 ppm sulfate from the fracture zone in the Bursum formation mentioned above, yields approximately 30 gpm with a short-term drawdown of 5 to 9 feet. However, residual lowering of the water level progresses with continued pumping during periods of no rainfall, and the pumping water level reaches the pump intake, about 135 feet below land surface, when approximately 2 to 3 million gallons, depending on the amount of rainfall, has been withdrawn from the well. The nonpumping water level in the Mockingbird Gap well has been as high as 25 feet below land surface following heavy rains in the area and, reportedly, this well has flowed occasionally during the past 30 years. When the water level is 25 feet or less below land surface, there is apparently at least 3 million gallons (9 acre-feet) of water in storage above the level of the pump setting (135 feet).

Mockingbird Gap well responds within a few days to recharge from rainfall that is of sufficient quantity to cause flow in the arroyo near the well. Recharge to the fracture-zone aquifer occurs in the immediate vicinity of the well, probably upstream less than 100 yards. From comparison of periodic water-level measurements with observations of Mr. Alexander, who lives at Mockingbird Gap well, it is apparent that the longer periods of storm flow in the arroyo cause far more effective recharge to the aquifer than brief freshets. A means of impounding a part of the runoff in one or more earthen reservoirs along the arroyo upstream from Mockingbird Gap well should facilitate recharge from lighter rains.

The fracture zone that comprises the underground reservoir for Mockingbird Gap well is definitely limited in size, as shown by the relatively small quantity of water in storage. Since the fracture zone apparently is of a fold-failure type, it is remotely possible that the more competent strata in the anticlinal fold may separate less competent strata which are fractured and are the reservoir or aquifer rocks. Thus, offset wells drilled along the axis of the fold might encounter sources of water other than the source for Mockingbird Gap well. Likewise, it is conceivable that deepening Mockingbird Gap well might reveal other aquifers below the present bottom of the well, which is reportedly about 160 feet below land surface. The Mockingbird Gap well probably penetrates the full thickness of shallower saturated fractures at that site.

Fractures in the type of consolidated rocks comprising the Abo and Bursum formations generally tend to be better developed near the ground surface than at depths greater than 200 feet. Therefore, wells 200 feet in depth offset from Mockingbird Gap well are more likely to develop additional water than a deeper well at the present well site or deeper offset wells. A test hole 0.25 to 0.5 mile upstream (northerly) and a test hole about 0.25 mile downstream (southerly) from the Mockingbird Gap well should adequately test possibilities for obtaining water from fractures in other strata but in the same zone of fractures in this area. The down-stream hole also may help in establishing the southern limit of occurrence of potable water in the area.

When the pumping water level is within reach of the pump in Mockingbird Gap well, Oscura Range Camp hauls about 6,000 gallons daily to supply troops living at the Camp. In recent months, the supply for Oscura Range Camp has been hauled from Murray well, 3 road miles north, when water was not available from Mockingbird Gap well.

Western Marginal Area

The area adjacent to the San Andres Mountains south of Mockingbird Gap in this area has no known source of water that meets with Public Health Service standards for drinking water. The chloride concentrations in most of the waters are high, ranging from 1,000 to 5,000 ppm in wells to more than 8,000 ppm in Salt Creek, which apparently is a discharge area for ground water throughout most of its 18-mile course.

The discharge of Salt Creek varies seasonally over a fairly wide range. Random field estimates of flow in Salt Creek are the only data available presently. These estimates indicate a base flow of about 450 gpm just north of the mouth of Salt Creek. The base flow on the upper reach of Salt Creek is estimated to be at least 50 gpm.

Thousands of very small fish live in Salt Creek. These fish apparently are capable of rapidly adapting themselves to great changes in water salinity. During infrequent periods of rainfall, Salt Creek carries a considerable quantity of runoff which undoubtedly dilutes the concentration of dissolved solids in the water a great deal, and of course brings about abrupt but brief changes in the environment of the fish.

Most of the shallow water of this area occurs in Quaternary, and perhaps some Tertiary, alluvial deposits. These deposits apparently are thickest toward the south end of the area and thin northward to a feather edge a few miles south of Mockingbird Gap. Very little reliable subsurface geologic data are available in this area. Three to seven test holes ranging in depth from 300 to 700 feet should be adequate to test the availability of non-potable water in this area, and it is possible that the deeper tests might encounter water of better quality. In conjunction with the drilling program, a series of flow measurements of Salt Creek, which is hydraulically connected to the ground water, would yield data that could be used in a rather comprehensive evaluation of the hydrology. Monthly measurements of the flow of Salt Creek at three points for a period of about one year, then decreased in frequency to quarterly for another year, should supply enough data on the creek for a fairly accurate evaluation of the water in the area.

Detailed locations for test holes and a definite plan for measuring Salt Creek flow should be based on some additional field reconnaissance and analysis of existing data. Water from wells and springs in the area has been used mainly for watering livestock, and domestic supplies have been obtained from rain-water cisterns or by hauling. Road construction contractors and maintenance groups have used water from this area for road compaction during the past few years. Most of the compaction water was obtained from Salt Creek and shallow sump holes near springs at the edges of the playas.

North-Central Tularosa Basin

The north-central Tularosa Basin, for the purpose of this report, includes that area having its southwest corner near Malpais Spring, bounded approximately on the east by U. S. Highway 54, and having an irregularly shaped northwestern limit described by physiographic highs from Tecolote Hill, north of Carrizozo about 30 miles, to the southern end of Sierra Oscura. Because of physiographic, geologic, and hydrologic dissimilarities in the northern part of the basin, three subareas are discussed separately. The valley flat, including The Malpais and the peripheral plain, one part of which extends northward to the vicinity of Tecolote Hill, forms one such subunit. The other two units are the southern Chupadera Mesa-Transmalpais Hills area, and the back slope of the Sierra Oscura. Although the last two areas are part of the topographic highs that form the boundaries of the Tularosa Basin, they are hydrologically related to the basin.

Most of the north-central part of the basin is underlain by rocks of Permian age covered in some areas by an unknown thickness of basin fill which is Quaternary and perhaps partly Tertiary in age and derived mainly from gypsiferous beds of the Permian Yeso formation. The basin fill thickens southward from the northern limits of the basin. In the south-central parts of the Tularosa Basin, approximately 30 miles south of the area covered by this section, the fill attains a thickness of several thousand feet as shown by a few deep wells. Very few reliable subsurface data in the northern part of the basin are available.

Along the east margin of the basin, rocks of Triassic, Cretaceous, and Tertiary age crop out on the topographic highs, and some of this sequence of rocks may occur at unknown depths in the subsurface of the central parts of the basin. However, extrapolation of the pattern of outcrops that occur mainly on the edges of the basin tend to indicate that strata of Permian age underlie the fill in most places.

The basin fill is the principal aquifer in the central part of the basin. The Yeso formation of Permian age might also yield water to deep wells in the central basin but no wells are known to penetrate the Yeso there.

Water of reasonably good chemical quality is known to occur in only a very few, relatively small localities within the northern part of the basin. Most of these occurrences are along the east side of the basin. A small area north and east of the village of Oscura contains relatively shallow wells that yield as much as 50 gpm of water containing less than 300 ppm sulfate. Deeper wells in the Carrizozo area reportedly yield up to 50 gpm of water similar in chemical character to water yielded by wells at Oscura. The source of the ground water at Oscura is apparently either Quaternary or Tertiary strata in the shallow subsurface, whereas the better water of the Carrizozo area apparently comes from Cretaceous sandstones of either the Dakota sandstone or Mancos formation. Aquifers containing highly mineralized water in the central part of Tularosa Basin are capable of yielding 500 to 1,000 gpm or more; these quantities differ greatly in various localities.

Malpais Spring, at the south end of The Malpais, perennially discharges more than 1,000 gpm of water containing 1,910 ppm sulfate, 1,200 ppm chloride, and 5,100 ppm total dissolved solids. A well at Oscura Range Camp will yield 500 gpm of water containing 1,900 ppm sulfate, 640 ppm chloride, and about 4,000 ppm total dissolved solids. Most of the stock-watering wells in the basin apparently yield only about 10 gpm.

Known or reported sources of potable water in the northern part of the basin are outside the boundaries of the Integrated Range. These sources might be obtained and developed by an agreement with those who presently control the lands where they occur. Pumping lifts in the Oscura area would be less than 150 feet and lifts in the Carrizozo area may range up to 300 feet to obtain the deeper, better quality water. If these areas are thought to be desirable for development, pumping tests and test holes will be necessary to augment the rather scanty data available.

Wells in the Oscura area are used mainly for domestic and stock water. There is a well (9.8.35.142) about 1.5 miles west of Oscura, which has been used to irrigate about 40 acres of diversified crops. The well is about 90 feet deep and yields about 300 gpm of water containing approximately 750 ppm sulfate. This well and others around Oscura delineate the limits of the good-water area and show the apparent absence of the better water at shallow depths less than 2 miles south or west of the village.

The Transmalpais Hills, an outlier mass of Chupadera Mesa, lie adjacent to and west of The Malpais and are geologically and hydrologically similar to Chupadera Mesa. A thin sequence of San Andres formation caps these features and beneath the cap is the Yeso formation. Here the San Andres is dry and water occurs in the Yeso formation at depths of 200 to about 700 feet depending on the topography. All water analyzed from the Yeso formation in this area contains 3,000 ppm or more total dissolved solids and 2,000 ppm or more sulfate. One 700-foot well recently drilled near Red Canyon Range Camp yields 100 gpm per foot of drawdown from solution channels in the Yeso formation. This well and one other well were drilled to supply non-potable water to Red Canyon Range Camp. Most of the wells in the area supply water for livestock and yield less than 20 gpm; however, near the north end of the Transmalpais Hills and beyond the limits of the map (pl. 3) one irrigation project has been conducted fairly successfully for the past few years. Water for irrigating about 100 acres of forage crops is presently pumped from one well (5.9.25.333) approximately 90 feet deep. The well reportedly yielded 2,000 gpm originally, but soon after it was put into use the yield declined, and it now produces only about 300 gpm.

Stevens Tank well (7.8.29.144) within the Integrated Range about 3 miles south of Red Canyon Range Camp in the Chupadera Mesa area yields water of fair quality (678 ppm sulfate). No data are available as to the capacity of the well, but it probably will yield about 10 gpm.

A pumping test at Stevens Tank well and one or two test wells drilled nearby should adequately test the possibility of developing water of usable quality in this area. If a need for more non-potable water is imminent around Red Canyon Range Camp, several other test holes may be necessary to obtain information leading to development.

The back slope of Sierra Oscura is here considered to include the area from the crest of the range eastward to Red Canyon. Pennsylvanian and Permian strata crop out in this area in strips more or less parallel to the Sierra Oscura escarpment. Monzonite-diorite sills of Tertiary age occur in the Pennsylvanian and lower Permian rocks.

Almost all the ground water in the Pennsylvanian outcrop areas occurs in joints and fractures in the limestone and appears in springs, shallow wells, and collection galleries located on the back slope. These sources yield only very small quantities of water, but the water is potable.

Known sources of water from Permian rocks in the area yield small quantities of water that is generally poor in quality. The Bursum formation, of earliest Permian age in the area, yields potable water at two localities, Brush Tank canyon and near R. C. Withers Tanks in sec. 18, T. 7 S., R. 7 E. A well at each of these places yields less than 5 gpm of potable water; however, an upper water-bearing zone in the Brush Tank Canyon area yields 7 to 15 gpm. The water in this upper zone contains over 100 ppm nitrate, which makes the water unfit for use by infants, but is otherwise of good quality. The single well near R. C. Withers Tanks is reportedly a very weak well, but the water from the well is of good quality, containing only 205 ppm sulfate. The yield of this well might be increased by treatment with acid.

Infrequent use is made of water from Red Canyon Spring (7.7.15.421) for settling dust and compacting roads in the Red Canyon area. Red Canyon Spring yields about 3 gpm of water containing 1,880 ppm sulfate. The spring water issues from joints and cracks in the Abo formation of Permian age.

Test drilling in lower Brush Tank Canyon might encounter worthwhile sources of potable water. About three holes, 250 to 500 feet deep, should be adequate to test the lower Brush Tank Canyon area. One or two test holes in the R. C. Withers Tanks area should give a good indication of the availability of ground water in that area.

One other locality in the Sierra Oscura back slope area that warrants exploratory drilling, is Black Muley Draw. One or two test holes in the fault zone on the east side of the draw, and possibly one hole near the drainage axis of the draw probably will constitute a fairly thorough investigation of this locality.

Most of the ground water of the Sierra Oscura back slope and the Chupadera Mesa-Transmalpais Hills area apparently moves southward and into either the fill or Permian rocks of the northern Tularosa Basin. Very little water is discharged from springs in the marginal, high areas around the basin; therefore, some of the water that probably percolates into the ground in the boundary areas moves from the mountain and mesa rocks into the aquifers of the central basin. In some areas the aquifers underlying the highlands may be the same as the basin aquifer, such as the Yeso formation in the northernmost Tularosa Basin; however, water in the Yeso formation in the northern part of the basin probably moves into the fill as it migrates southward.

Water-level contours indicate a general movement of ground water toward The Malpais and thence southwestward. Some of the water that moves southwestward through the lower part of the basalt, or perhaps through the sediments that underlie the basalt sheet, discharges from Malpais Spring at the southern end of The Malpais. The fact that ground water does move toward The Malpais suggests that the basalt was ejected or flowed into a perennial stream. Wells drilled through the basalt might yield considerable quantities of water. Most of the water beneath The Malpais probably is fairly highly mineralized except possibly following periods of relatively heavy rainfall when considerable recharge percolates downward through the joints and cracks in the basalt, and dilutes the highly mineralized water that comes from areas adjacent to The Malpais. However, several test holes drilled through The Malpais might encounter a few sources of water of fairly good quality.

Summary

The occurrence of potable water in the northern Tularosa Basin is confined to (1) the back slope of Sierra Oscura, (2) the Mockingbird Gap area, and (3) the east side of the basin. Quantities available from existing sources in the Sierra Oscura are small, ranging from 2 to 20 gpm. Springs and shallow wells obtain water from joints and cracks in limestones which crop out over almost the entire area. Only one well (Baca 6.6.26.333) yields as much as 20 gpm. Other sources yield less than 5 gpm each. There is a possibility that acid treatment might increase the yield from some of these wells and springs. As one might expect, water from the limestones of this area has a high hardness as calcium carbonate, but is potable. Most of the carbonate hardness is temporary and may be removed by simple processing through a zeolite column.

The Mockingbird Gap well (9.5.15.143) yields 30 gpm of potable water from a fairly small fault fracture reservoir. Withdrawal of 2 to 3 million gallons of water from the Mockingbird Gap well lowers the water level to the pump intake. However, the water level in the well responds very quickly to storm flow in the arroyo near the well. The installation of two or more check dams on the arroyo above Mockingbird Gap well should induce more effective recharge. One or two other wells drilled in this area might develop some additional water not now available to the Mockingbird Gap well. With proper conservation measures, the Mockingbird Gap well area should supply water for about 75 people.

Water of inferior or near potable quality is derived from both shallow and deep wells in the area along the east side of the northern Tularosa Basin. Wells in the vicinity of Oscura, sec. 36, T. 9 S., R. 8 E., yield about 50 gpm from depths ranging from 50 to 75 feet. Near potable water also is obtained by wells in Cretaceous rocks in the Carrizozo area at depths ranging from 300 to 1,000 feet. The wells yield about 50 gpm and the non-pumping water levels are about 200 feet. Both of the two sources of water mentioned above apparently could be developed more extensively to obtain water for military or municipal purposes, however both areas are on privately controlled land.

The area of shallow, near potable water around Oscura is relatively small and thus the total quantity of water available probably is small. On the other hand, the deeper source of water in the Carrizozo area may underlie a rather large area on the east side of the basin and consequently may constitute a supply of considerable magnitude. Only one well (8.10.2) is known to derive water from the deeper Cretaceous rocks around Carrizozo, and it has not been used for many years. Exploratory holes penetrating these Cretaceous water-bearing beds, followed by pumping tests, will be necessary to establish any quantitative estimates of the water available.

Moderate to large quantities of impotable water are available to wells and springs in almost every part of the north-central Tularosa Basin. Malpais Spring (12.7.8.422) yields about 1,500 gpm, whereas the few other springs in the area yield 20 gpm or less. Although most of the sources of impotable water developed in this area are small quantities for use in watering livestock, the few wells constructed for obtaining larger quantities generally have yielded 500 gpm or more. Most of the high-yield wells are 10-inches or more in diameter and are drilled to depths greater than 200 feet.

Some of the vast quantity of water available in northern Tularosa Basin contains high concentrations of dissolved minerals which make it unfit for drinking and many other purposes. However, some of the water should be satisfactory for supplying military installations with all but drinking and cooking water, which might be obtained by treating the available impotable water with some of the newly developed demineralization devices such as a solar still.

CARRIZOZO AREA, LINCOLN COUNTY, NEW MEXICO

By

J. B. Cooper

The portion of the Tularosa Basin described in this section of the report is in the vicinity of Carrizozo, east to Nogal, and south to Oscura. The area covers about 150 square miles between Sierra Blanca on the east and the Malpais (lava flow) on the west. (See pl. 4.) An investigation of the water resources of this area was made by personnel of the U. S. Geological Survey in April 1957. The results of this investigation have not as yet been released; however, data collected at that time have been used in the preparation of the present report. Geological mapping has been done in the area by several investigators The results of their work have been compiled in generalized form to show the main geologic features of the area (pl. 4).

Principal Aquifers

Wells in the area obtain water from formations that range in age from Permian to Quaternary. Most wells obtain water from either unconsolidated deposits of Quaternary age or consolidated rocks of Cretaceous age. These formations contain the principal water-bearing beds in the area and are the only aquifers discussed in this report.

Quaternary Alluvium

The principal water-bearing formation in the area is the alluvium of Quaternary age which is the surface formation in the central part of the basin and on the plain east of Carrizozo (see pl. 4). It consists mostly of unconsolidated clay, silt, sand, gravel, and boulders which form a heterogeneous deposit that differs considerably in texture over short lateral distances. Boulders and coarse gravel commonly are found near the mountains and fine-grained deposits are predominant at lower elevations in the basin. The alluvium contains much gypsum. Most of the clayey deposits are gypseous and grade into deposits of nearly pure gypsum. The thickness of the alluvium ranges from a featheredge northwest and west of Carrizozo to more than 100 feet to the east and south. The majority of the wells in the area obtain water from the alluvium, and wells capable of yielding several hundred gpm have been constructed in it near Carrizozo.

Cretaceous Rocks

Water is yielded to wells at many localities in the area from rocks of Cretaceous age. These rocks underlie the alluvium and also are exposed at various places. (See pl. 4.) The rocks are mostly shale, sandstone, and limestone in alternating beds. Their aggregate thickness has not been established; however, the maximum thickness is thought to be in excess of 600 feet and may be as much as 1,000 feet in a part of the area.

Most wells finished in Cretaceous rocks obtain water from sandstone layers within the formation. The Southern Pacific Company drilled deep wells at Carrizozo and Oscura in the early nineteen hundreds. At Carrizozo the deepest well (8.10.2.410) was drilled to a depth of 1,125 feet. At Oscura well 9.9.31.133 was drilled to a depth of 965 feet. These wells were reported to have been pumped at rates of about 50 gpm each but have not been used for many years.

Nature of Ground-Water Occurrence

Ground water occurs in the alluvium under water-table conditions; that is, the water is unconfined at the upper surface of the zone of saturation. There is no indication that ground water in the Cretaceous rocks is influenced by artesian pressures, and it appears probable that, at least in a part of the area, there is a hydraulic connection between water in the alluvium and water in rocks of Cretaceous age.

Recharge to the ground-water reservoir in the vicinity of Carrizozo is largely from runoff from an area of about 50 square miles, or about 32,000 acres, in the mountains east of the town. About 40,000 acre-feet of water is received in the area each year. Probably the greatest amount of recharge to the alluvium is in the upper gravelly parts of the stream-built slopes. It is probable that there is some recharge to the Cretaceous rocks in the Malpais area where the lava flow overlies Cretaceous sandstone.

Depth to Water

The altitude and approximate shape of the water table is shown on plate 4. From the mountains ground water moves west and northwest beneath the Carrizozo plain and in general follows the direction of Nogal Arroyo northwest past Carrizozo to the Malpais. Southwest of Carrizozo water moves generally northwestward toward the Malpais. There are numerous small springs in the area. They either are associated with rock outcrops that form barriers that impound the ground water or issue from unconsolidated deposits at localities where rock ledges form subsurface dams. The water table is not a plane surface but has irregularities comparable with and related to those of the land surface, although the water table is less rugged. The irregularities are caused chiefly by local differences in geology and topography. In general the water table slopes downward from the mountains toward the valley. Near the mountains the depth to the water table seldom exceeds 100 feet and commonly the depth decreases with decreased altitude of the land surface.

Quality of Water

Much of the ground water in the area is highly mineralized. A total of 16 chemical analyses of water from wells finished in the alluvium indicates that the water is very hard and usually contains large amounts of sulfate. Water from the wells sampled contained 391 to 2,340 ppm sulfate and had a calcium and magnesium hardness, as calcium carbonate, ranging from 565 to 2,980 ppm. The quality of the water from wells believed to be completed in rocks of Cretaceous age is similar to that contained in the alluvium; however, the sulfate content of several samples was less than that of water from the alluvium. The results of 16 chemical analyses of water from Cretaceous rocks indicate that total hardness ranged from 571 to 1,660 ppm and that the sulfate content ranged from 304 to 2,210 ppm. The analysis of water from the Carrizozo railroad well no. 4 (8.10.2) indicates less mineral constituents than was indicated by analysis of water from other wells in the area. Water from this well is reported to contain 790 ppm total solids and 255 ppm sulfate. The town well at Carrizozo yields water that contains 620 ppm sulfate and that has a total hardness of 754 ppm. The sulfate content of water from individual wells is shown on plate 4.

Present Development

Ground water in the area covered by this report is utilized mainly for stock and domestic purposes. Approximately 100 stock and domestic wells are in use at the present time. In addition to these there are 2 public supply wells, 2 industrial wells, and about 10 irrigation wells in the area.

Capacities of Wells

Stock and domestic wells in the area are pumped at rates of only a few gallons per minute. The town well at Carrizozo (8.10.14.222) was reported to have been tested at a rate of 460 gpm. The operating irrigation and industrial wells in the area are pumped at rates ranging from 60 gpm to 500 gpm. Near Nogal and Carrizozo, wells capable of yielding several hundred gallons per minute have been developed. Yields as high as 850 gpm are reported for wells completed in the alluvium near Carrizozo. In the vicinity of Nogal, wells produce as much as 400 gpm from a combination of the alluvium and Cretaceous aquifers. Well 8.10.21.300, which is southwest of Carrizozo and which apparently obtains its entire yield from rocks of Cretaceous age, is reported to be capable of producing 1,080 gpm.

Depth of Wells

Wells presently in use in the area range in depth from less than 50 feet to about 300 feet. The deeper wells are finished in rocks of Cretaceous age, although part of the water yielded by them may be furnished to the well from the alluvium. A test well (8.10.21.300) 412 feet deep has been drilled about 3 miles southwest of Carrizozo, and wells have been drilled at Oscura and Carrizozo to depths of about 1,000 feet; however, these wells are not now in use.

Potential Supplies

Large quantities of ground water of inferior quality apparently are available from the alluvium east and south of Carrizozo. Certain rock formations of Cretaceous age, which underlie this area, may also contain fairly large amounts of near potable water. On the basis of presently available data it is estimated that the Carrizozo area could be developed to produce as much as 20,000 acre-feet of inferior ground water annually.

Suggested Additional Study

Additional studies are needed to obtain quantitative data necessary for full utilization of the total water resources of the area. No quantitative data on the hydrologic characteristics of the alluvium are presently available. Information is needed on the trend of ground-water levels, pumping water levels, specific capacities of wells, transmissibility of the water-bearing formation, and effects of pumping on other wells in the area. Development of large water supplies from the alluvium should be preceded by a test-drilling program to locate the thickest and most permeable section of water-bearing material available in the locality desired for production wells. Pumping and development tests should be made in test wells prior to completion of a final well, and samples of water encountered should be chemically analyzed. The water-bearing zones within rocks of Cretaceous age should be explored at several locations in the area by means of test holes. These test holes should be drilled and constructed so that water from the alluvium is excluded from the hole after the Cretaceous rocks are reached. Accurate sampling and logging of the formations encountered during drilling would be an integral part of this program as well as periodic water sampling and tests to determine the yield of water-bearing formations encountered during drilling. The depths of test holes to explore the Cretaceous aquifers would depend upon their location in the area and upon the formations encountered during drilling; however, it is anticipated that 1,000 feet would be near the maximum depth of any individual test hole. Additional wells may be drilled in the future by land owners of the area. An attempt should be made to obtain reliable records of these wells from either the driller or the owner.

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THREE RIVERS AREA, OTERO AND LINCOLN COUNTIES, NEW MEXICO

By

E. H. Herrick

The area described in this section of the report comprises approximately 150 square miles between the west slope of Sierra Blanca and U. S. Highway 54, at the boundary between Otero and Lincoln Counties about 20 miles north of Tularosa, New Mexico (pls. 5 and 6). The area is drained by Three Rivers and its tributaries. Two of the tributaries, Three Rivers Canyon and Indian Creek, have perennial flows in their upper reaches at the west side of Sierra Blanca.

Both the surface water and ground water of this area are being studied in some detail to determine the feasibility of developing additional water for the Bonito Lake pipeline, which has been constructed along U. S. Highway 54. The geology of the Three Rivers area was mapped in 1956 (pl. 5), and most of the wells and springs were investigated. Nine test holes had been drilled by the end of 1957. Stream-flow records of both Three Rivers Canyon and Indian Creek have been obtained since the summer of 1956. A detailed report of the occurrence of water in the area will be prepared when available data have been collected and analyzed. The report by Meinzer and Hare (1915) contained some information on the occurrence and chemical quality of ground water in the Three Rivers area, but only a small amount of data were available at that time, and their report was necessarily generalized. A progress report on recent test drilling in the area (Herrick, July 30, 1957) was prepared for the U. S. Army, Corps of Engineers.

General Geology

Sierra Blanca apparently has a syenite core intruded by large monzonite stocks and dikes, but the western flank of the mountain is composed mostly of volcanic rocks, including andesite porphyry, breccia, agglomerate, tuff, and associated rhyolite and latite flows of Tertiary(?) age. The Godfrey Hills are composed mainly of extrusive rocks.

Sedimentary rocks in the mapped area (pl. 5) range in age from Triassic to Recent. They are exposed between Sierra Blanca and the Godfrey Hills, and west and south of the Godfrey Hills. The consolidated rocks include, in ascending order, the Chinle formation of Triassic age, the Dakota sandstone, Mancos shale, and Mesaverde formation of Cretaceous age, and the Cub Mountain formation of Tertiary(?) age. The lower parts of the area are covered to variable depths with a mantle of mostly unconsolidated alluvium of Quaternary age. The alluvium consists of a heterogeneous mixture of clay, silt, sand, and gravel which were derived from the flanking mountains. The alluvium apparently has its maximum thickness in the delta-shaped area between Three Rivers and Indian Creek; a thickness of more than 125 feet has been reported by drillers and observed in test drilling, but the thickness probably is greater in a few places.

Dikes and sills of varying composition, including andesite, latite, quartz monzonite, rhyolite, and lamprophyre are numerous, and many topographic prominences have resulted from the resistance of these dikes and sills to erosion.

The regional geologic structure is characterized by eastward dips of low to moderate angle in the western part of the area. Considerable change in attitude occurs in the re-entrant area where the dips are generally northeast. This deviation of attitude is caused by faulting and, locally, by the numerous intrusions. Major faulting in the area trends northwest and northeast, with displacements, in some places, of several hundred feet. Minor faulting is widespread, with a general northeast trend. The extensive veneer of alluvium and talus conceals many of the faults.

Surface Water

Both Three Rivers Canyon and Indian Creek have perennial flows in their upper reaches, and all the drainageways carry flood flows, some of which are of major proportion, during and following the infrequent heavy showers. Four stream-gaging stations are maintained on the two streams by the Geological Survey, and records have been obtained since the summer of 1956. The run-off in Three Rivers Canyon and Indian Creek fluctuates widely through the year, as indicated in table 2.

Table 2.--Run-off, in acre-feet, at stream-gaging stations on Three Rivers Canyon and Indian Creek.

Month	Three Rivers Canyon above Lincoln Canyon (10.10.34.110)		Indian Creek above diversions (11.10.10.410)		Indian Creek Flume (11.10.9.221)		Indian Creek at mouth (11.9½.13.410)	
	1956	1957	1956	1957	1956	1957	1956	1957
January		0		18		8.4		0.65
February		11		26		19		.81
March		61		96		89		1.4
April		127		206		167		.63
May	0	89		229		193	0.7	.20
June	0	24	6.9	83	8.6	69	26	0
July	0	5.4	70	35	17	19	45	176
August	7.3	64	419	211	177	127	220	114
September	0	217	13	275	18	40	1.9	86
October	0		16		11		.44	
November	0		15		8.1		.52	
December	0		13		6.6		.54	
Oct. 1956 - Sept. 1957		598		1,223		757		381

It will be noted that, for the period October 1956 to September 1957, the run-off in Three Rivers Canyon above Lincoln Canyon (10.10.34.110) was 598 acre-feet, while for the same period the run-off in Indian Creek above diversions (11.10.10.410) was 1,223 acre-feet and that Three Rivers Canyon at the gaging station contained no flow during parts of the year. However, after the installation of the gaging station on Three Rivers Canyon, it was noted that the canyon above the station apparently maintained a perennial flow although it was very small during parts of the year. Therefore, the flow of Three Rivers Canyon in several places above the gaging station is now being measured periodically. The measurements obtained in the upper part of Three Rivers Canyon to date are contained in table 3.

Table 3.--Miscellaneous measurements of flow in the upper part of Three Rivers Canyon.

Description and location of measuring point	Flow (cfs)				
	5/21/57	6/24/57	7/23/57	8/20/57	9/18/57
North branch, north fork Three Rivers Canyon; NW¼NW¼SW¼ sec. 30 (projected), T. 10 S., R. 11 E.	0.50	No measurement	0.15	0.07	0.31
South branch, north fork Three Rivers Canyon; NW¼NW¼SW¼ sec. 30 (projected), T. 10 S., R. 11 E.	.81	No measurement	.01	.56	.61
North Fork Three Rivers Canyon; SE¼SE¼SE¼ sec. 25, T. 10 S., R. 10 E.	1.33	No measurement	.02	.42	.47
Three Rivers Canyon below south fork; W½NE¼ sec. 36, T. 10 S., R. 10 E.	1.92	No measurement	.08	.72	.81
Three Rivers Canyon 500 ft. above Dry Canyon; NE¼NE¼ sec. 35, T. 10 S., R. 10 E.	1.29	0.11		.17	.68
Three Rivers Canyon 500 ft. below Dry Canyon NW¼NE¼ sec. 35, T. 10 S., R. 10 E.	1.57	.04	.02	.36	.96
Gaging station on Three Rivers Canyon above Lincoln Canyon; NW¼NW¼ sec. 34, T. 10 S., R. 10 E.	1.39	0	0	.18	.67

Most of the water samples collected from the base flow of Three Rivers Canyon have contained only small amounts of dissolved solids, ranging from about 250 to about 350 ppm. However, flood waters in the creek sometimes contain a considerably larger quantity of dissolved minerals. A sample of water collected on April 17, 1957, from Three Rivers Canyon at the ford in the NW¼ sec. 34, T. 10 S., R. 10 E. contained about 700 ppm of ~~total~~ dissolved solids and 283 ppm of sulfate. However, a sample of water collected on April 25, 1957, from Three Rivers in the NW¼ sec. 13, T. 11 S., R. 9½ E., about 5 miles below the point where the above sample was collected, contained only about 350 ppm of total dissolved solids. Apparently, the chemical quality of the flood waters varies considerably, probably depending on the principal source area of the water and the duration of the flood. All samples collected of the base flow of Three Rivers have been of fairly uniform, potable quality.

Most of the water samples collected from the base flow of Indian Creek also have contained only small amounts of dissolved minerals. The water is very similar in chemical quality to that from Three Rivers Canyon, but generally contains even less dissolved solids, about 200 ppm. However, the chemical quality fluctuates, particularly during flood flows, and the water in Indian Creek has contained as much as 800 ppm of total dissolved solids.

Ground Water

The principal aquifers in the Three Rivers area are the Quaternary alluvium, and sandstone in the lower part of the Cub Mountain formation and in the upper part of the Mesaverde formation. The depth to water in the area ranges from less than a foot in parts of the creek beds to as much as 150 feet (see pl. 6). In the lower parts of the re-entrant, in the northwestern part of T. 11 S., R. 10 E. and the southwestern part of T. 10 S., R. 10 E., the average depth to water is between 20 and 50 feet.

As indicated by the water-table contours on plate 6, the ground water moves southwestward from the re-entrant area toward the main part of Tularosa Basin. There are several small springs where eastward-dipping impermeable beds force the ground water to the surface.

The only apparent source of potable ground water in the Three Rivers area is the eastern part of the re-entrant area, bounded roughly by Indian Creek on the south and the Godfrey Hills on the west. As can be seen from the data presented on plate 6, much of the ground water underlying the re-entrant area is of relatively good chemical quality, although most of it contains sulfate somewhat in excess of the U. S. Public Health Service standard of 250 ppm for drinking water. At the southern end of the Godfrey Hills, the ground water contains more than 400 ppm of sulfate. From there southwestward down the gradient of the water table, the sulfate content of the water increases. In the vicinity of the Ryan Ranch (sec. 25, T. 11 S., R. 9 E.), the ground water contains more than 1,000 ppm of sulfate. All three wells south of Indian Creek in the western part of T. 11 S., R. 10 E. also yield water containing more than 1,000 ppm of sulfate.

Most of the wells in the Three Rivers area are used to obtain water for stock. Three wells yield water for domestic use. The Bosque well (11.9½.13.244) is used to irrigate a small orchard and garden, and several other wells (11.9½.22.244, 11.9½.22.330, 11.9.26.430, and 11.9½.28.210) along Three Rivers have been used to irrigate small areas in the past. The Bosque well yields an estimated 400 gpm when first pumped, but the yield declines rapidly after the well has been pumped for a few hours. Well 11.9½.28.210 is reported to have originally yielded 350 gpm, but more recent estimates indicate a yield of less than 150 gpm. The other wells yield generally less than 50 gpm. Most of the stock wells yield less than 10 gpm with existing equipment, although it is reported that a few were tested at rates greater than 50 gpm.

The high initial yield of the Bosque well probably is due to its unusual construction. The well was dug prior to 1915 and reportedly consists of a vertical shaft 50 feet deep and a horizontal tunnel, 100 feet long, connecting with the shaft at the 33-foot level. The horizontal tunnel reportedly was constructed in coarse stream deposits containing numerous boulders.

Between November 1956 and September 1957 eight test holes were drilled in the Three Rivers area under contract by the U. S. Army Corps of Engineers. Test hole 10.10.32.334 yielded 75 gpm with a drawdown of 134 feet after pumping for 5 hours at rates ranging from 50 to 100 gpm. The water, which contained 742 ppm of total dissolved solids and 292 ppm of sulfate, was obtained from sandstone in the lower part of the Cub Mountain formation and the upper part of the Mesaverde formation. Test hole 11.10.6.333 yielded water of similar quality (691 ppm of total dissolved solids and 293 ppm of sulfate) from alluvium. A pumping test of the latter hole indicated a safe maximum yield of 75 gpm. Test hole 11.10.8.311 yielded the least mineralized water (261 ppm of sulfate) of all the test holes, but yielded only 10 gpm from alluvium. Water from test hole 11.10.6.433 contained 915 ppm of total dissolved solids and 416 ppm of sulfate, and the hole had an indicated maximum yield of only 30 gpm. Test holes 11.10.5.314 and 11.9½.13.234 also yielded impotable water (853 and 451 ppm of sulfate, respectively), and both holes yielded less than 50 gpm. The principal aquifer of the three latter holes is alluvium. Test hole 11.10.7.232b yielded more than 100 gpm during a pumping test that indicated the hole was not fully developed. The test indicated that the hole, if properly developed, might yield as much as 200 gpm. The casing of the hole was perforated in both the alluvium and sandstone in the lower part of the Cub Mountain formation and possibly the upper part of the Mesaverde formation. However, the water, after the hole had been pumped for 5 hours, contained 452 ppm of sulfate. Test hole 11.9½.23.141 produced only 50 gpm of highly mineralized water (792 ppm of sulfate) from sandstone in the Mesaverde formation.

These data indicate that ground water of potable and near potable chemical quality is limited to the central and eastern part of the re-entrant area in the northwestern part of T. 11 S., R. 10 E. and the southwestern part of T. 10 S., R. 10 E. In those areas, there are no wells or test holes that yield more than 100 gpm. The northeastern part of the area has not been investigated by test drilling, and it is possible that wells yielding as much as 100 gpm can be developed in that area if sandstones of the Cub Mountain formation and the Mesaverde formation are fully penetrated. Along Indian Creek near its junction with Three Rivers, in the northeastern part of T. 11 S., R. $9\frac{1}{2}$ E. and the northwestern part of T. 11 S., R. 10 E., wells producing at least 200 gpm of water containing about 450 ppm of sulfate can be developed.

As the deposition of alluvium in the re-entrant area has been very erratic, most of the more permeable sands and gravels have only a very limited occurrence and apparently pinch out within short distances. Therefore, locating the most permeable lenses in the alluvium is difficult, but it is possible that a properly developed well in an unusually permeable lens in the alluvium might produce as much as 200 gpm, at least for short periods of pumping. As indicated by the performance of the Bosque well, a well with an extremely large wall surface exposed in such a lens will produce an even larger quantity of water, at least for short periods.

Potential Supplies

It is apparent that the water resources of the Three Rivers area can be most fully and most economically developed by mixing waters of inferior chemical quality with potable water to yield a product water of potable or near potable quality to the pipeline. This may be accomplished in a number of ways. For example, data indicate that wells producing at least 100 and possibly as much as 200 gpm can be developed in the vicinity of test hole 11.10.7.232. Although the ground water in that area may be expected to contain from 300 to 500 ppm of sulfate, by mixing this water with less highly mineralized surface and ground water, the final product reaching the Bonito Lake pipeline should be of reasonably good quality. Available data indicate that the base flows of Three Rivers and Indian Creek probably have an average sulfate content of about 100 ppm. If such water comprises 50 percent of the water developed in the area, ground water containing an average of as much as 400 ppm of sulfate can be mixed with it to produce a product water containing about 250 ppm of sulfate delivered to the pipeline.

It is estimated that a dependable supply of at least 1,000 acre-feet per year of water containing an average of not more than 250 ppm of sulfate can be developed in the Three Rivers area, if both surface-water and ground-water sources are utilized. This estimate includes diversions on both Three Rivers and Indian Creek and approximately 6 wells. It is probable that more than 1,000 acre-feet per year can be developed if more wells are drilled or a somewhat more inferior quality of product water is developed.

Suggested Additional Study

Records of flows of Three Rivers and Indian Creek cover only a short period, and it is not known how representative these records are. Therefore, the stream-gaging stations on the two creeks should be maintained and additional miscellaneous measurements in the upper part of Three Rivers Canyon should be obtained as parts of a continuing data-gathering program. Some slope-area measurements have been made. These should be fully analyzed to determine the extent of flood flows in the area and the feasibility of storing and utilizing flood-flow water. More slope-area measurements should be made.

Before firm planning of well fields in the Three Rivers area is done, it would be advisable to obtain more complete data on the hydrologic characteristics of the aquifers, so that the capacity of the area and the effects of long-term pumping on water levels and chemical quality of the water can be estimated. It is suggested that at least one test hole or well in each of the proposed well-field areas be test pumped for a period of 2 to 4 weeks.

In order to compute coefficients of storage, observations of the effects of pumping on water levels near the pumped well are essential. With the present distribution of wells and test holes in the area, such effects can be observed only at test hole 11.10.7.232. Ideally, two observation wells should be drilled at distances of about 100 and possibly 200 to 300 feet from and preferably on opposite sides of the pumped well. The wells would serve as observation wells during test pumping and would provide additional valuable data on the character and thickness of the alluvium.

The cost of the test pumping suggested above and drilling of additional observation wells would appear to be a rather small addition to the total estimated cost of the development. From the data obtained it should be possible to determine more accurately the optimum spacing of wells and to estimate with some assurance the effects to be expected from pumping.

TULAROSA-ALAMOGORDO AREA, OTERO COUNTY, NEW MEXICO

By

F. D. Trauger

Tularosa and Alamogordo lie at the foot of the Sacramento Mountains, on the east side of the Tularosa Basin. The economy of the area, once based solely on agriculture and livestock, has been profoundly altered since 1940 by the establishment and operation of Holloman Air Force Base about 7 miles southwest of Alamogordo. The following summary of ground-water resources is concerned with the area surrounding the two towns and extending west from the foothills of the mountains for a distance of about 12 miles, north from Tularosa about 10 miles, and south from Alamogordo about 7 miles (pls. 7, 8, 9, and 10).

Principal Aquifers

In the Tularosa-Alamogordo area the valley fill may be divided into two parts, a thick section of older alluvium and an overlying, relatively thin section of younger alluvium. Underlying the older alluvium, and constituting the so-called "bedrock", are sedimentary rocks of Paleozoic age. At places on the floor of the Tularosa Basin the bedrock projects through the valley fill, and the rocks thus exposed are identical with those of similar age exposed in the Sacramento Mountains.

As a group, the varied rock types of Paleozoic age underlying the valley fill are not productive aquifers, being generally too dense to contain water recoverable in appreciable quantities. However, at the top of the Paleozoic sequence in the general area, the Yeso formation and overlying San Andres formation of Permian age may be considered as potential aquifers. According to Meeks (1950, p. 12) the principal aquifer in the 1,440-foot Champion well (14.10.19.240) near Tularosa is a porous limestone at a depth between 1,100 and 1,200 feet (log, Meeks, 1950, p. 26, indicates porous lime and water between 1,250 and 1,360 feet). The well reportedly produced 500 gpm. Whether the aquifer encountered is a limestone of the Yeso or San Andres formation was not determined. The Yeso and San Andres formations are believed to underlie the bolson deposits throughout the area. The Yeso formation has a thickness ranging from 1,200 to 1,800 feet (Pray, 1954, p. 93) and consists of limestone, red and yellow sandstone, gypsum, and minor amounts of fine grained, quartz sandstone. According to Hood (May 1956, p. 10) the limestones of the Yeso formation constitute the principal aquifers in the Cloudcroft area east of Tularosa.

The San Andres formation, overlying the Yeso, has an observed thickness of 700 feet in the Sacramento Mountains (Hood, May 1956, p. 11). The San Andres consists primarily of limestone and interbedded dolomite, with one or two relatively thin sandstone beds, tightly cemented with calcium carbonate, generally being found in the lower part of the formation. The San Andres formation is noted generally for the profuse development of solution cavities. Solution cavities are common in exposures in the Sacramento Mountains and in the subsurface in the Roswell basin of the Pecos Valley. It is probable that the San Andres in this area also has solution cavities similar to that in the Roswell area where it constitutes the primary aquifer.

The fact that the Yeso and San Andres formations are covered generally by a thick mantle of older and younger alluvium and that any waters they may contain are likely to be highly mineralized, precludes the liklihood of development of these rocks for potable supplies of ground water. Only in the event water is urgently needed, is not available elsewhere, and quality is not an important factor, is it likely that ground water in the Yeso or San Andres formations will be worth developing.

The older valley fill, of Tertiary age, is thick. The log of well 16. 9.26.210 near Alamogordo shows that the older fill extends from a depth of about 150 feet to at least 1,000 feet in that locality (Hood, 1957, p. 43). Near Valmont, in well 18.9.14.700, the fill is at least 1,800 feet thick. The log of the Southern Pacific well at Temporal (13.9.14.440) indicates the older fill there extends from a depth of about 200 feet to at least 800 feet. According to Hood (1957, p. 43) the older fill consists mostly of clay, with ~~only~~ little material coarser than very fine-grained sand. Some test holes in the Boles well field area indicate that the older fill becomes coarser toward the mountains. This is borne out also by the log of the Southern Pacific well at Temporal (Meeks, 1940, p. 25). The older fill contains appreciable quantities of calcium carbonate in the form of caliche and disseminated flakes of nodules (Hood, 1957, p. 43).

No large capacity wells are known to obtain water primarily from the older alluvium; stock and domestic water generally can be developed in quantities sufficient to meet most needs, but as a rule the older alluvium is a relatively poor aquifer owing to the generally fine-grained sediments composing the aquifer.

The younger alluvium, of Quaternary age, is the most widespread and dependable aquifer in the area, and the only aquifer that can be depended upon generally to yield moderate to large quantities of water. Meinzer (1915, p. 67) reports that in the vicinity of Alamogordo three distinct sand and gravel strata are recognized locally, but that available well logs do not show these strata to occur at the same horizon in different areas, or that they are everywhere present. The normal characteristics of alluvial fan deposits are such that continuity of individual beds is not to be expected, and correlation of an individual bed from well to well over a broad area is virtually impossible. Because of the discontinuity of the individual water-bearing beds in the vicinity of Alamogordo it is difficult to predict ~~cannot be said~~ with any degree of certainty the depth to ~~that~~ a particular water-bearing bed. ~~will be encountered at a stated depth.~~

The younger alluvium is composed of rock debris carried out of the mountains by the present streams and deposited over the older alluvium. This recently deposited debris is somewhat coarser grained than the older alluvium and locally is very coarse grained. The debris was deposited in beds that fan outward in the valley from the mouths of the various canyons. The deposits in these alluvial fans are generally coarsest and thickest near the mouths of the canyons, becoming finer grained and thinner toward the valley floor. The fan deposits are composed of clay, silt, sand, and gravel, generally poorly sorted but locally occurring in well defined beds. The gravel beds are commonly composed of limestone and are close to the mountains. The sand beds are generally fine to very fine, the quartz grains composing the beds having been derived by weathering of sand and silt beds of the Abo and Yeso, and other formations which crop out in the mountains.

The younger alluvium is much thinner generally than the older alluvium. Hood (1957, p. 48) reports that 100 to 250 feet of fan material rests upon the eroded surface of the older fill in the Boles well field, and that west of the Boles field the thickness is 50 feet or less. Meeks (1950, p. 12) reports that it is generally considered useless to drill a well below 250 feet in the vicinity of Tularosa, implying that below that depth only the older alluvium would be encountered. The log of Southern Pacific well 13.9.14.440 at Temporal indicates the younger alluvium there is about 194 feet thick. The log of the Champion well 14.10.19.240 (Meeks, 1950, p. 26) at Tularosa shows younger alluvial deposits to be at least 250 feet thick near ~~at approximately~~ the mouth of Tularosa Creek. Between Tularosa and Alamogordo, about 1 to 2 miles west of the mountain front, in well 15.10.7.400 (Meeks, 1950, p. 26) the younger alluvium extends to a depth of at least 224 feet, the bottom of the well.

It seems safe to assume that in the area being considered, from Temporal south to Valmont, the younger alluvium along the mountain front is not much more than 250 feet thick, and that it thins westward to a featheredge on the nearly level floor of the inner Tularosa Valley.

Nature of Ground-Water Occurrence

Ground water in the area occurs under both unconfined, or water-table, and confined, or artesian conditions in the older and younger alluvium. The water in the upper part of the saturated zone generally is unconfined, whereas the water at depth generally is under confinement. According to Hood (1957, p. 59) both confined and unconfined water is found in the Boles well field area, and commonly both types of aquifers have been tapped by the same well. However, extensive pumping tests indicated that the artesian conditions were generally local, because of the irregular and discontinuous distribution of the sand beds in the fill, and that following long periods of ground-water withdrawal, water-table conditions prevailed generally. It is probable that both confined and unconfined water will be found to exist in the alluvial fill throughout the area.

Too little is known of the occurrence of water in the bedrock to state whether artesian conditions are usual or exceptional. Meeks (1950, p. 12) suggested the possibility that some artesian pressure might exist in the deep aquifer encountered in the Champion well (14.10.19.240) at Tularosa but pointed out that the water level in the well was 156 feet below land surface, about the depth to the water table in the younger alluvium. Meinzer (1915, p. 123) cites data for several deep wells near Alamogordo that suggest that water in some of the deeper water-bearing zones may be under artesian pressure, but he states that generally the structure of the bedrock underlying the Tularosa valley is unfavorable for producing artesian pressures. The bedrock exposed in the Sacramento Mountains on the east side of the valley, and the San Andres on the west side of the valley dip away from the valley, and are separated from the equivalent beds underlying the valley floor by faults having displacements of thousands of feet. Thus, there is no hydrologic continuity between the aquifers in the mountains and the aquifers underlying the valley fill, and the structure is not favorable to the formation of artesian pressures in these older rocks in the valley.

Movement of Water

The general movement of ground water in the area is westward from the mountains, and southward. Interpretation of the water-table contours, as shown on plate 8, leads to the conclusion that water moves rapidly through the coarse stream deposits laid down westward from the mountains by the Rio Tularosa and Alamo Creek, and moves more slowly through the finer-grained deposits in the inter-stream areas. The coarse deposits act as drains, as indicated by the contours, and receive some water from the finer grained deposits of the inter-stream areas, as well as from the infiltration of surface water into the coarser deposits underlying the stream channels.

The ground water that moves southwestward through the area ultimately reaches the inner valley of the Tularosa basin. The water-table gradient there is slight, 5 to 10 feet per mile, or less, and the water is presumed to move slowly southward.

Depth to Water

The depth to water in the area ranges from more than 200 feet near the mountains to 10 feet or less at the western edge of the area. A depth-to-water map based on recent data is included in this report as plate 7.

In the vicinity of Alamogordo the depth to water in wells ranges from a little less than 25 feet in wells 1½ miles west of town to 75 feet in wells in town, and to 210 feet in wells about 2 miles north and southeast of town. The depth to water near Tularosa ranges from 45 feet 3 miles west of town to 245 feet at the mouth of the canyon of Rio Tularosa, one-half mile northeast of town. In the town of Tularosa, the range is from slightly less than 125 to a little more than 200 feet.

Quality of Water

Although ground water generally can be obtained in moderate to large quantities in much of the area, obtaining water of good quality is a problem. In general, the ground water of the region in all the aquifers is highly mineralized, particularly with calcium bicarbonate, sodium chloride (common salt), and calcium sulfate (gypsum). Calcium sulfate occurs in the ground water in quantities sufficient to render the water unfit for human or livestock use. Unusually large concentrations of sodium chloride and calcium and magnesium bicarbonate occur also and generally render the water unfit for agricultural use, and for use by humans and livestock. For some industrial purposes the highly mineralized water may prove satisfactory in spite of the high mineral content.

In local areas, as in the vicinity of the Boles well field south of Alamogordo, and in the area southwest of La Luz (pl. 9), water of potable to near potable quality can be found. Such occurrences are the result of a combination of factors involving both geology and hydrology. The mineral matter in the water is derived from the minerals dissolved from the rocks with which the water come in contact. The mineral content of the valley fill near the mountain front depends largely upon the source rocks from which it was derived. In the larger fans, at the mouths of streams having large drainage basins that reach back to areas where the Yeso formation is exposed, the fill contains larger amounts of gypsiferous material than do smaller fans at the mouths of canyons that drain only areas having limestone and similar rocks exposed. Ground water in the larger fans in the area thus generally has a higher concentration of sulfate than does water in the smaller fans. This relation is clearly shown by the configuration of the lines showing equal concentration of sulfate in ground water on plate 9.

The general quality of ground water and its suitability for human use can be judged on the basis of the sulfate content of the water. Although the term potable, as used in this report, refers to water containing less than 250 ppm of sulfate or chloride, ~~water having a sulfate content of less than 300 ppm is usually considered suitable for continuous domestic use.~~ Water containing sulfate in concentrations as high as 500 ppm may be used if nothing better is available; however, such concentrations may cause physiological effects.

Practically no ground water in the vicinity of Tularosa is of good quality, and only local areas have ground water that can be classed as fair. Meeks (1950, p. 22 and pl 3), using U. S. Department of Agriculture standards of water quality for irrigation, has shown on the basis of total dissolved solids the general distribution of water of poor, fair, and good quality in the area. To a degree this distribution holds also for water of quality suitable for human consumption. It may be stated that generally the ground water becomes more highly mineralized with increasing distance from the mountain front, for example -- water from well 16.10.5.342, northeast of Alamogordo, has a specific conductance (indicative of the amount of ~~total~~ dissolved solids) of 1,750 micromhos, water from well 17.9.5.122, west of Alamogordo, has a specific conductance of 5,010 micromhos, and water from well 17.8.13.311, on Holloman Air Force Base, has a specific conductance of 61,700 micromhos (Hood, 1957, p. 98). This relation also occurs in the vicinity of Tularosa (pl. 9).

In the vicinity of the Boles well field (pl. 10) the quality of ground water differs vertically as well as laterally and, with respect to quality of water, two distinct water-bearing zones in the younger alluvium can be differentiated--a deep, thick zone containing water of generally potable quality and a shallow, thin zone containing water of generally inferior quality (Hood, 1957, p. 101). Meinzer (1915, p. 133) noted a similar relation in the younger alluvium in the vicinity of Tularosa and in the area between Tularosa and Alamogordo, but stated that generally the differences in quality between the shallow water and the deeper water in the younger alluvial fill at any particular location were not great.

It is probable, however, that water from the deeper part of the older alluvium is generally of poor quality. Meinzer (1951, p. 133) stated that water from a depth of 890-1,200 feet in a deep well near Dog Canyon (south of the Boles well field) was reported to be salty. Presumably this well tapped the lower part of older alluvial fill, and did not penetrate to the bedrock.

Water from the bedrock underlying the valley fill is believed to be generally highly mineralized. A sample of water from well 18.8.5.431, about 6 miles southwest of Holloman Air Force Base, which probably taps the Yeso formation, contained about 8,400 ppm ~~total~~ dissolved solids, about 3,000 ppm sulfate, about 2,500 ppm chloride, and had about 2,600 ppm calcium carbonate hardness (Hood, 1957, p. 389).

Present Development

Ranches and farms throughout the area depend almost entirely on ground water for their domestic and livestock needs. Some ground water is developed for irrigation purposes, and the amount is increasing. Many home owners in Tularosa maintain domestic wells to supplement the municipal supply of water obtained from Rio Tularosa, which is fed by springs. Prior to 1947, Alamogordo and the Holloman Air Force Base obtained all their domestic water from a common source in springs in the mountains east of the city. Supplies of ground water were developed in about 1947 to supplement the drought-shortened supply of surface water and to meet the increasing needs of the air base and city. By the spring of 1957 the Boles well field was the principal source rather than a supplementary source of water for Holloman Air Force Base, and Alamogordo was obtaining about 15 to 20 percent of its municipal water supply from wells. An additional supply of surface and ground water was made available to the city and air base in 1957 when a pipeline was completed to bring water from Bonito and Nogal Lakes and from wells at Carrizozo. It is estimated by Hood (1957, p. 76) that about 3,100 acre-feet of water was pumped from the Boles well field in the period 1947-1955, of which 60 percent was pumped in the last 3 years of that period.

Irrigation wells in the Tularosa-Alamogordo area have been utilized since early in the 20th Century; Meinzer's (1915) investigation was prompted by the interest shown in developing wells for irrigation water and reference is made (Meinzer, 1915, p. 210) to the installation of irrigation wells as early as 1911-12. It would be impossible to determine with any degree of accuracy how much ground water has been pumped for irrigation since development first began, but it was estimated that 3,000 acres of land was irrigated in 1955 with ground water alone, 1,000 acres was irrigated using both ground water and surface water, and a total of about 10,000 acre-feet of water was pumped. This water was supplied by an estimated 100 wells.

The capacity of individual wells differs greatly in the area -- Meeks (1950, p. 15) reports that yields of irrigation wells ranged from about 150 to about 700 gpm in the Tularosa area, with the average being about 50 gpm. In the vicinity of Alamogordo the range in yield of five irrigation wells reportedly was from 100 to 1,200 gpm, with the average being 570 gpm. Specific capacities of wells range from 4 to 30 gallons per minute per foot of drawdown. The Alamogordo No. 1 well (17.9.35.242) reportedly produces about 1,080 gpm and has a specific capacity of about 16. Yields of wells in the Boles well field range from 95 gpm to 395 gpm, and specific capacities, after 12 hours of pumping, range from about 1 to 12. The average capacity of ten operating wells in the Boles well field during 1955 was about 220 gpm. Wells close to one another in many instances have greatly differing specific capacities, a relation commonly found throughout the area, indicating that the yield of a planned well cannot be predicted with any certainty. ~~of accuracy.~~

The depth to water at any particular point in the area can be determined approximately, but only test drilling can determine if one, several, or no highly productive water-bearing strata will be encountered. It might be that only sediments of low permeability would be encountered below the water table, and a well completed in them would have a low yield. The heterogeneity of the alluvium requires that test drilling be done to determine the probable yield, quality of water available, and the depth to which a production well should be drilled at a given location.

The depth of most of the irrigation and public supply wells in the area is less than 300 feet. The depths of wells and test holes in the Boles well field range from 162 to 386 feet, with the average depth of production wells being about 250 feet (Hood, 1957, table 17).

In the Tularosa area, Meeks (1950, p. 12) has stated there is little to be gained by drilling below a depth of 250 feet for irrigation water. Presumably large quantities of water might be developed in the bedrock at a depth of about 1,000 feet, but the water most likely would be of poor quality, suitable only for limited industrial use.

Along the western margin of the area, from north of Tularosa to south of the air base, wells are commonly less than 100 feet deep, as a consequence of the shallower depths to water. Virtually no large capacity wells have been developed in the western part of the area, however, because of the almost universally poor quality of the water.

Potential Supplies

It may be stated with some certainty that large quantities of water can be obtained from the younger alluvium at most places in the area, and from the bedrock underlying the valley fill, but that generally the water will be highly mineralized and commonly unfit for domestic, stock, or agricultural use. Water of good to fair quality, suitable for most of these needs, can be obtained in certain localized areas. The most important of these, and the area concerning which most is known, is in the vicinity of the Boles well field.

According to Hood (1957, p. 192) approximately 25 square miles is underlain by ground water having 500 ppm or less of sulfate, of which about 20 square miles is in the vicinity of the Boles well field; underlying approximately 10 square miles, of which the Boles well field is a part, there is about 130,000 acre-feet (42,000 million gallons) of water having less than 300 ppm of sulfate available for pumping. However, not all this water can be pumped without drawing saline water into the pumped area. Recharge to the area amounts to about 700 acre-feet annually (Hood, p. It would seem reasonable to presume on the basis of data presently available that additional development of ground water can be made in the general vicinity of the Boles well field, and particularly in the eastern part of secs. 18 and 19, T. 17 S., R. 10 E., and in the eastern $\frac{1}{4}$ of secs. 25 and 36, T. 17 S., R. 9 E. (Hood, 1957, p. 160).

The data (pl. 9) showing the quality of water from selected wells and springs indicate that water of inferior quality (300-500 ppm of sulfate) can be found in a limited area northwest of Alamogordo, for the most part in secs. 2, 3, 4, 12, and 13, T. 16 S., R. 9 E. Analyses of water from wells in the immediate vicinity of Tularosa indicate that virtually all ground water in that area contains sulfate in quantities undesirable for domestic use.

Surface Water

Presumably all perennial supplies of surface water in the region have been appropriated and no additional water is available for domestic or industrial use unless other irrigation rights are purchased. The quality of surface waters of the area and the feasibility of purchasing local surface-water rights should be investigated if it is determined that adequate supplies of water are not otherwise available. The recent (1957) aquisition and importation of supplies of surface and ground water from outside the area -- from Bonito Lake and from wells at Carrizozo -- may preclude the necessity of obtaining local surface-water rights in the foreseeable future.

If the imported water is available at certain times of the year in quantities greater than are needed for immediate use, methods of storing the water locally should be developed. The feasibility of storing water underground has been proved in numerous instances in recent years and Hood (1957, p. 165) has described the advantages to be gained by using such a method of storage in the Boles well field.

Suggested Additional Study

Because moderate to large quantities of ground water are available generally throughout the area, and because the quality of water is the factor determining its usability, it is possible that a comprehensive program of water sampling and analysis would be worthwhile. Water from as many wells as can be sampled should be tested for conductivity, and if the conductivity is less than about 2,000, the water should be tested for chloride and sulfate content. In this manner, isolated or localized bodies of water of fair to good quality might be located.

The analysis of the water from a test well reported drilled in sec. 3, T. 14 S., R. 9 E., northwest of Tularosa, shows the sulfate content to be about 400 ppm. All wells in the vicinity of the reported test well should be sampled, and perhaps other test wells drilled in the area to determine the depth to water, and the permeability of the alluvial deposits should also be tested.

Presently available data on quality of water indicate that water of good quality may also be found south and southeast of the Boles well field area; therefore, sampling and test drilling should be extended in that direction to determine if the zone of good quality water is more or less continuous from the Boles well field area to the vicinity of Valmont, where a similar large body of potable and near potable water has been roughly delineated (pl. 11).

The water-table contour map (pl. 8) can be utilized, in conjunction with the map showing the sulfate content of water (pl. 9), in selecting areas to test for water. The steepness of the water table gradient bears a relation to the transmissibility of the aquifer, in that a steep water table indicates a low permeability; hence, the potential yield of wells in the aquifer may be indicated by the slope of the water table. This relation is illustrated by the capacity of wells near Tularosa and the Boles well field.

In the vicinity of the Boles well field the water table gradient is about 25 to 50 feet per mile and the average yield of the wells is about 200 gpm (Hood, 1957). The gradient in the area west of Tularosa, where irrigation wells are in use, is between 10 and 25 feet per mile and the average yield of the wells is about 445 gpm (Meeks, 1950, p. 15).

If it is determined that large quantities of impotable water can be used for nondomestic needs, thus effecting an appreciable saving of potable water, the feasibility of developing such supplies should be investigated. Water containing high concentrations of sulfate and relatively normal quantities of other minerals can generally be used without harmful effects for irrigation of lawns, trees, and shrubs, for sanitary facilities, and for swimming pools and other recreational facilities.

AREA SOUTHEAST OF VALMONT AND NORTH OF OROGRANDE PIPELINE, OTERO COUNTY, NEW MEXICO

By

E. H. Herrick

An area about 12 miles south of the Boles well field and along the east side of Tularosa Basin, southeast of Valmont and north of the Orogrande pipeline, has been suggested as a possible source of potable ground water. The area comprises about 150 square miles adjacent to the Sacramento Mountains and northeast of the Jarilla Mountains, in the central part of Otero County, New Mexico. (See pl. 11.)

Topography and Drainage

The land surface in the basin part of the area slopes generally westward from the mountains with a gradient decreasing from about 100 feet per mile near the mountains. In the western part of the area, in the vicinity of U. S. Highway 54, the land surface is regionally almost flat but is broken by numerous sand dunes and shallow depressions. The Sacramento Mountains escarpment is very pronounced in the northeastern part of the area, in places rising more than 1,000 feet above the basin floor. In the southeastern part of the area, south of Grapevine Canyon, the mountain front is less pronounced, and there are numerous low foothills southeast of the Orogrande pipeline.

The escarpment is cut by numerous large canyons, at the mouths of which pronounced alluvial fans have developed. A particularly broad fan has developed beyond the mouth of Grapevine Canyon. There are no perennial streams in the area, with the exception of a small flow that issues from small springs at and near the floor of Dog Canyon. Several arroyos extend from the mouths of the canyons across the alluvial fans to shallow depressions in the western part of the area.

General Geology

The western part of the Sacramento Mountains in the northeastern part of the area shown on plate 11 is composed mainly of Paleozoic limestones with only minor amounts of clastic rocks. In the southeastern part of T. 20 S., R. 11 E., are limestones, sandstones, siltstones, and shales of the Abo and Yeso formations of Permian age.

The bolson fill of the basin is composed mostly of unconsolidated gravel, sand, silt, and clay derived from the consolidated rocks of the mountains. In general, it can be expected that the bolson fill near the mountains is heterogeneous and contains numerous boulders. In the western part of the map area, the fill is probably fairly well sorted but probably contains a large proportion of silt and clay. The thickness of the bolson fill is not known. An oil test hole in the NW$\frac{1}{4}$ sec. 15, T. 20 S., R. 9 E., apparently encountered the base of the fill at a depth of about 470 feet. It is probable that the base of the fill is somewhat deeper than this in the northern and central parts of the area shown on the map.

General Occurrence of Ground Water

Ground water in the bolson fill moves southwestward and westward from the mountains toward the lower part of the basin, as indicated by the water-table contours on plate 11. The water-table gradient apparently ranges from about 25 feet per mile in the southeastern part of T. 19 S., R. 9 E., to about 50 feet per mile in the southwestern part of T. 18 S., R. 10 E. Data are not available with which to determine the configuration of the water table in the southern part of T. 19 S., R. 10 E., and in T. 20 S., R. 10 E. It is probable that the ground water in these areas is moving westward at gradients of 25 to 30 feet per mile. The depth to water in the bolson fill in the area shown on plate 11 ranges from less than 30 feet in the northwestern part of the area, in the vicinity of Valmont, to at least 200 feet in the southern part of T. 19 S., and the northern part of T. 20 S., Rs. 9 and 10 E.

The shapes of the water-table contours and the lines showing the approximate sulfate content of the ground water indicate that the water being recharged to the bolson fill in Ts. 19 and 20 S., R. 10 E. from Grapevine Canyon and other nearby canyons is not highly mineralized. Although data are not available with which to determine the exact position of the lines showing the sulfate content in the central and southern parts of the map area, it appears that most of the ground water under Ts. 19 and 20 S., R. 10 E. contains less than 500 ppm sulfate. Much of the ground water underlying those townships probably contains less than 300 ppm sulfate and only minor amounts of chloride. However, within this area practically no subsurface information is available.

It should be emphasized that the contours on the water table, and lines showing depth to water and sulfate content of the water on plate 11 have been drawn on the basis of very little data, but it is believed that the map presents the general ground-water conditions.

Suggested Additional Study

In order to delineate the boundary between potable and impotable ground water more precisely and to determine the nature of the bolson fill aquifer and to what extent the potable water can be developed, it appears advisable to drill approximately 8 to 10 test holes in the area. These test holes should be designed to furnish as much information as possible regarding the occurrence of the ground water. Some test holes should be in the vicinity of the range line between Rs. 9 and 10 E. in Ts. 19 and 20 S., primarily to determine the position of the contact between potable and impotable ground water. Others should be in the northwestern part of T. 20 S., and in the southwestern part of T. 19 S., R. 10 E., to determine the nature of the bolson fill and the quality of the ground water. It might be possible to so design the test holes that they could be developed into production wells if a satisfactory water supply is indicated.

It would be desirable also to do some reconnaissance geologic mapping along the escarpment and in the southeastern part of the area shown on plate 11. This would aid in an interpretation of the drill cuttings from test holes and would permit a more complete and accurate analysis of ground-water conditions in the area.

UPPER SACRAMENTO RIVER CANYON, OTERO COUNTY, NEW MEXICO

By

E. H. Herrick

The Sacramento River originates in the Sacramento Mountains in central Otero County, New Mexico, about 10 miles southeast of Alamogordo. The upper part of the Sacramento River flows southeastward through canyons several hundred feet deep. The valley floor is extremely narrow except in the cienaga (marshy) areas where it is several hundred feet wide. The river at the present time has a perennial flow only in these cienaga areas, and the Southern Pacific Railroad was diverting about 250 gpm of water from two of the cienaga areas in December 1956 (Mourant, March 1957). The water is transported by pipeline to Orogrande, about 35 miles southwest (see plates 11, 12, and 15).

General Geology

In that part of the Sacramento River Canyon considered in this section of the report, only rocks of the San Andres and Yeso formations of Permian age and canyon fill of Quaternary age are exposed.

The Yeso formation in this area consists of 1,200 to 1,800 feet of silty sandstone, limestone, siltstone, shale, and gypsum. Silty sandstone and limestone comprising the upper few hundred feet of the Yeso formation are exposed in several places above the floor of the canyon, and the siltstone, shale, and gypsum beds of the lower part of the formation are below the canyon floor.

The San Andres formation, consisting mainly of medium bedded limestone, in part dolomitic, probably is about 500 feet thick in the upper Sacramento River area. The limestones form the crest of the Sacramento Mountains and the higher parts of the eastern slopes.

Several deposits of calcareous tufa of Quaternary age occur in the Sacramento River canyon and apparently are partly responsible for the formation of the cienagas. The tufa deposits, although somewhat porous, act as dams at the lower ends of the cienagas and are probably as much as 30 feet thick in some places. Behind the lower ends of the cienagas, tufa and unconsolidated fill have been deposited in the main parts of the cienagas. The thickness of these deposits is not known but probably does not exceed 50 feet in most places, and may be considerably less in many places. In the steeper, more narrow parts of the canyon, the fill is generally coarse, consisting of a large percentage of gravel and boulders, and probably is relatively thin, possibly less than 25 feet in most places.

General Occurrence of Water

Ground water in the Sacramento River canyon area is under water-table conditions, mainly in the upper part of the Yeso formation. The depth to water in the wells in sec. 34, T. 17 S., R. 11 E., which furnish water to the installation at Sacramento Peak, is about 200 feet. In many places in the Sacramento River canyon in T. 18 S., Rs. 11 and 12 E., the ground water discharges through springs. (See pl. 12.) The depth to water in well 19.12.15.144, at the Circle Cross Ranch, is about 170 feet. The wells in sec. 34, T. 17 S., R. 11 E., are reported to yield 50 gpm. Well 19.12.15.144 is not equipped with a pump, and the yield of the well is not known. The Yeso formation throughout this area of the Sacramento Mountains probably contains saturated zones, and it is probably that wells drilled in most of the upper part of the Sacramento River canyon generally can be expected to yield at least 50 gpm and possibly as much as 100 gpm. The development of wells a short distance upstream from the spring areas probably would cause the yields of the springs to decline very rapidly.

Much of the ground water in the Yeso formation in this area moves underground to the southeast out of the area, but, as mentioned above, some is discharged by springs into the cienaga areas of the canyon. The yields of the three principal springs have been estimated by Mourant (March 1957) to be as follows: spring 18.11.11.422, 200 gpm; spring 18.12.30.141, 23 gpm; spring 18.12.30.412, 12 gpm. The concentration of total solids in water samples collected from those springs in December 1956 ranged from about 300 to about 400 ppm. None of the water contained objectionable quantities of any dissolved mineral, although the water was moderately hard (200 to 350 ppm hardness as $CaCO_3$).

Suggested Additional Study

The Southern Pacific Railroad reportedly plans to sell the Sacramento River-Orogrande water system, which represents a somewhat limited but apparently dependable source of potable water. Mourant (March 1957) concluded that, by improving the water-collection system at the cienagas, the quantity of water delivered to the Orogrande pipeline can be increased from 250 to about 500 gpm. Mourant's report contained several suggestions for determining how much water is available from springs in the cienagas of the upper Sacramento River canyon.

It would be advisable first to determine how much water is moving down the canyon as underflow in the canyon fill. Three test holes should be drilled through the canyon fill to bedrock in the Sacramento River canyon below its junction with Scott Abel Canyon in sec. 29, T. 18 S., R. 12 E. If water is encountered in the canyon fill, one hole should be test pumped and the effect of pumping on the water level in at least one other hole should be carefully observed. The third hole should be approximately 0.5 mile up the canyon from the pumped hole to provide data on the gradient of the water table. These data will permit an estimate of the amount of water moving down the canyon as underflow through the canyon fill. It is possible, of course, that below the cienaga water moves into permeable bedrock. Several test holes should be drilled to bedrock in each of the cienaga areas downstream from the principal springs. These should be cased to permit observations of the water levels.

The principal springs of the cienagas should then be tightly boxed in at their discharge points, and the water should be diverted into the pipeline at those points. Following this improvement to the collection system, the water levels in the test holes below the springs should be observed for a period of several weeks. If, after the springs are developed and the water diverted directly into the pipeline, the water levels in the test holes in the cienaga decline appreciably, discharge or leakage from the cienaga must exceed any recharge that may be contributed by additional, undeveloped springs, if they exist. If, however, the water levels in the test holes do not decline appreciably, springs in addition to the principal springs must discharge appreciable quantities of water, and it might be feasible to build galleries in the main parts of the cienaga in addition to a catchment at the principal spring area.

Some water may be leaking through the tufa deposits at the lower ends of the cienagas. It should be possible to determine if there is leakage by drilling holes through the canyon fill immediately downstream from the tufa deposits. If it is found that a considerable quantity of water is leaking from the cienaga either through or below the tufa deposits, it may be feasible to construct tight dams to bedrock upstream and directly behind the tufa deposits. Thus, additional water could be salvaged by diverting it to the pipeline at the lower ends of the cienagas.

Several conditions are possible, as suggested above, and only a more detailed study will reveal how much additional water can be diverted to the pipeline. However, the data presently available indicate that the quantity of water diverted to the pipeline apparently can at least be doubled.

HUECO PLATEAU AREA, OTERO COUNTY, NEW MEXICO

By

J. R. Rapp

Most of the area discussed in this section of the report occupies part of an eastward-sloping plateau in southeastern Otero County, New Mexico that herein is called the Hueco Plateau (pl. 13). The Hueco Plateau is bounded on the southwest by the Hueco Mountains, on the west by a scarp that marks the eastern margin of the Tularosa Basin-Hueco Bolson lowland, on the north and northeast by the Sacramento Mountains, and on the east and southeast by Salt Basin (pl. 1). Southward, the Hueco Plateau is more-or-less continuous with the Diablo Plateau in Texas.

Previously, little data on the occurrence of ground water in this area have been available. During this particular investigation, approximately five days were spent in the field, mainly to collect data on representative wells and to collect water samples for chemical analyses.

Topography and Drainage

Foothills of the Sacramento Mountains comprise the northern and northeastern part of the area. The rugged, steep-sided Cornudas Mountains consist of several isolated peaks and occupy the south-central part. On the west the area is bounded largely by a scarp which slopes, in places very steeply, westward toward the lowland. The central part is occupied by the eastward-sloping plateau. The western part of the plateau is quite hilly, but eastward the land surface generally becomes more subdued. The central and southeastern part of the plateau consists of three basins that are separated by relatively low, gently rolling hills. The lower parts of these basins are characterized by flats and playas. The hills bounding the Playas apparently reflect local flexures of the underlying limestone beds.

There are numerous sinks both on the sides and crests of the hills and in the valleys suggesting the early stage in the development of karst topography. Most of the sinks are in the form of shallow, saucer-shaped, closed depressions that are of small areal extent; however, there are several collapse and fracture features. The sink in sec. 32, T. 23 S., R. 15 E. is about 40 feet deep in the lowest part and about 150 yards long by about 100 yards wide. Except for slump and toppled blocks, the walls of the sink are nearly vertical. There are fractures on the floor of the sink, and near its walls there are several vertical pipes, one of which is about 3 feet in diameter and about 15 feet deep. At the 15-foot depth what appears to be the floor of a fissure cave extends laterally out of sight from the top of the pipe. Several other collapse features were reported in the area and are shown on plate 13. There is a system of parallel fractures in secs. 21, 27, 28, and 34, T. 23 S., R. 15 E. Although the system extends for a distance of about 1½ miles, the individual fractures are less than 100 feet long and as much as five feet wide and 20 feet deep. Locally, the fractures are known as "dangerous cracks" owing to their size and abruptness. These visible fractures, and those that occur at depth throughout most of the limestone beds in the area, probably developed primarily as a result of structural movements in the area. As the relatively brittle limestone beds were at or near the surface, they lacked the compressive force of overlying beds and, therefore, fractured in response to warping stresses. Water collected in the fractures and widened and altered them through solution and abrasion. This has resulted in various degrees of slumping of the surface materials to form sinks. Local residents report that during periods of heavy runoff they have heard the water moving underground through the fractures.

In the area all the streams are ephemeral; the Sacramento River however, is perennial in its upper reaches and water is diverted by pipeline to the town of Orogrande in the lowland to the west. In its lower reaches and in the Hueco Plateau area, the Sacramento River is dry except during storm runoff. The Sacramento Basin is closed, and the Sacramento River channel drains onto the flats in the southeastern part of the basin in T. 23 S., R. 14 E. Shiloh Draw begins near the rim of the plateau and drains the central part of the area. This drainage basin herein is called the Brownfield Basin after Brownfield Flats, part of which is in the extreme eastern part of the area in Tps. 24 and 25 S., Rs. 15 and 16 E. where the stream channels merge with the flats in the lower end of the basin. Brownfield Basin also is closed. The third closed drainage in the area is the Lee Basin, which is of relatively small areal extent. Part of the Cornucopia drainage basin occupies the northeastern part of the area along the foothills of the Sacramento Mountains. Cornucopia Draw originates in the mountains to the north and extends southward through the area and then eastward to Crow Flats. The Cornudas Basin, including the Cornudas Mountains and the surrounding highland, is drained by Cornudas Draw. The draw extends eastward through the area to Salt Flats to the southeast.

General Geology

Rocks ranging in age from Permian to Quaternary crop out in the area. The Quaternary deposits are valley fill comprising stream alluvium, slope wash, talus, and aeolian and playa deposits. The alluvium occurs along the courses of the streams in the area and, according to reports, is as thick as 100 feet along some of the major streams. The alluvial deposits consist mainly of sand, gravel, cobbles, and boulders in or near the mountain courses of the streams; however, with increasing distance from the mountains the deposits become finer grained. The thickness of the Quaternary deposits underlying the playas is not known. For the most part these deposits probably are fine grained, but, owing to their proximity to the mountains, may contain lenses of sand and gravel. Aeolian deposits occur mainly on and around the playas where they form only a thin veneer. Slope wash mantles the slopes and bases of the hills as a thin veneer. Talus occurs on the steeper slopes of the mountains, especially the Cornudas Mountains in the southern part of the area.

Tertiary rocks in the area are mainly igneous, consisting of syenite porphry and trachyte. These rocks crop out in the Cornudas Mountains, which are conspicuous topographic features. According to King (1949), a narrow band of Cretaceous rocks of the Washita group occurs on the west side of Wind Mountain.

Rocks of Permian age underlie most of the area. They consist mainly of limestone and attain a thickness of more than 2,000 feet in the eastern part of the area. Along the scarp in the western part of the area the Permian rocks comprise the Abo, Yeso, and San Andres formations in ascending order. The Abo and Yeso formations are predominantly reddish. The Abo formation consists mainly of sandstone and shale, whereas, the Yeso formation consists of gypsiferous shale, sandstone, and earthy limestone. The San Andres formation is predominantly limestone that generally is light to very dark gray. East of the scarp, probably within a distance of 10 miles, the Yeso formation and the lower part of the San Andres formation grade eastward into the Bone Spring Limestone, which is described in the discussion of the Crow Flats-Dell City area. In oil test 26.16.5.410, in the southeastern part of the area, a thickness of 2,170 feet of the Bone Spring Limestone was penetrated above granite. The eastward extension of the Abo formation is known only in part.

General Occurrence of Ground Water

In the Hueco Plateau area ground water is found mainly in the Bone Spring limestone of Permian age. Most of the water is produced from fractures and other permeable zones in the limestone. The fractures, which apparently originate from upwarping stresses on the limestone, have been enlarged and altered through solution by ground water. In addition to altering the fractures, solution has produced zones of many small openings, giving the limestone a honeycomb structure in places. Some ground water occurs in the valley fill; however, the valley fill generally is above the water table, and serves as a catchment for precipitation. Ground water probably occurs in the coarse alluvial deposits along Cornucopia Draw, but additional data are needed to determine whether or not the deposits contain a sufficient amount of ground water to be considered for development.

According to reports, the depth to water in the area ranges from 70 to 900 feet. All the water levels shown on plate 13 were reported by local residents, as it was not feasible to measure the wells in the short time alloted for the study. In most wells, water is contained in fractures and permeable zones at various levels in the limestone. Often a small "flow" will be bypassed and the well deepened to obtain a more dependable supply of water from a lower more permeable zone. For this reason the depths to water in wells differ considerably. (See pl. 13.) In sec. 19, T. 22 S., R. 13 E., the depth to water in one well is 315 feet and the depth to water in a nearby well is 850 feet. The shallow well did not yield a dependable supply of water and was abandoned, but the deeper one has proved reliable through long use.

The main zone of saturation in the area apparently is at a considerable depth below land surface. In the central part of the Sacramento Basin the reported depth to water is 850 to 900 feet, and in the southeastern part of the basin the depth to water is about 500 feet. The depth to water in Lee Basin is about 800 feet. In the north-central and southeastern parts of the Brownfield Basin the reported depth to water ranges from 550 to 620 feet. In the southern part the main zone of saturation is at depths of 550 to 950 feet.

The movement of ground water in the area is southeastward. Recharge is from precipitation in the southern part of the Sacramento Mountains and locally within the plateau area. Recharge to the ground-water reservoir is by infiltration of precipitation through the valley fill and through the fractures in the limestone. Immediately north of the Cornudas Mountains ground water derived from local precipitation apparently moves northward through the valley fill into the limestone and then southeastward through the limestone.

Chemical Quality of Water

Water samples from 16 wells and springs in the area have been chemically analyzed. The wells in the extreme southeastern part of the Sacramento Basin and in the northeastern part of the Brownfield Basin supply potable ground water. Well 22.13.19.142 in the Sacramento Basin yields water of near potable quality. Most of the wells in the central and southern part of the area yield impotable water. Locally, relatively shallow wells produce potable to inferior water. Well 22.16.32.444, yields potable water, probably from the alluvium along Cornucopia Draw.

Utilization of Ground Water

The wells in the area are used for domestic and stock purposes. As the depth to water in most of the wells exceeds 400 feet, the wells are equipped with large pump jacks and large windmills. Most of the wells as presently equipped produce less than 5 gpm, but some were reported to have been tested at rates as high as 20 gpm.

Suggested Additional Study

This brief reconnaissance indicates that additional study is needed to evaluate the ground-water resources of the area. Owing to the occurrence of potable and inferior ground water in the area, additional study should include the following:

(1) The geology of the area should be studied and mapped. Reconnaissance mapping probably would provide adequate geologic data and control.

(2) A complete inventory of the wells in the area should be made. This inventory should be made in the near future while the long-time residents are still in the area. The inventory should include collecting samples of ground water for chemical analysis, measurement of the depth to water and the depth of the well where possible, and interviewing landowners or residents of the area for information on the wells. Additional data are needed especially in the northern and western part of the area.

CROW FLATS-DELL CITY AREA, OTERO COUNTY, NEW MEXICO AND HUDSPETH COUNTY, TEXAS

By

L. J. Bjorklund

The Crow Flats-Dell City area straddles the New Mexico-Texas state line about 80 miles east of El Paso, Tex. The area discussed in this report is in Otero County, New Mexico, and Hudspeth County, Texas, and extends from about 36 miles north of the state line to about 20 miles south of the line and is about 20 miles wide from east to west. It is within the closed topographic depression known as Salt Basin which is east of Tularosa Basin and separated from it by the Hueco Plateau. (See fig. 3.) The area is bounded on the east and northeast by the Brokeoff and Guadalupe Mountains, on the west and northwest by the limestone uplands of the Hueco Plateau, and on the south by an arbitrary line across the valley about 2 miles south of U. S. Highway 62-180. (See plate 14.)

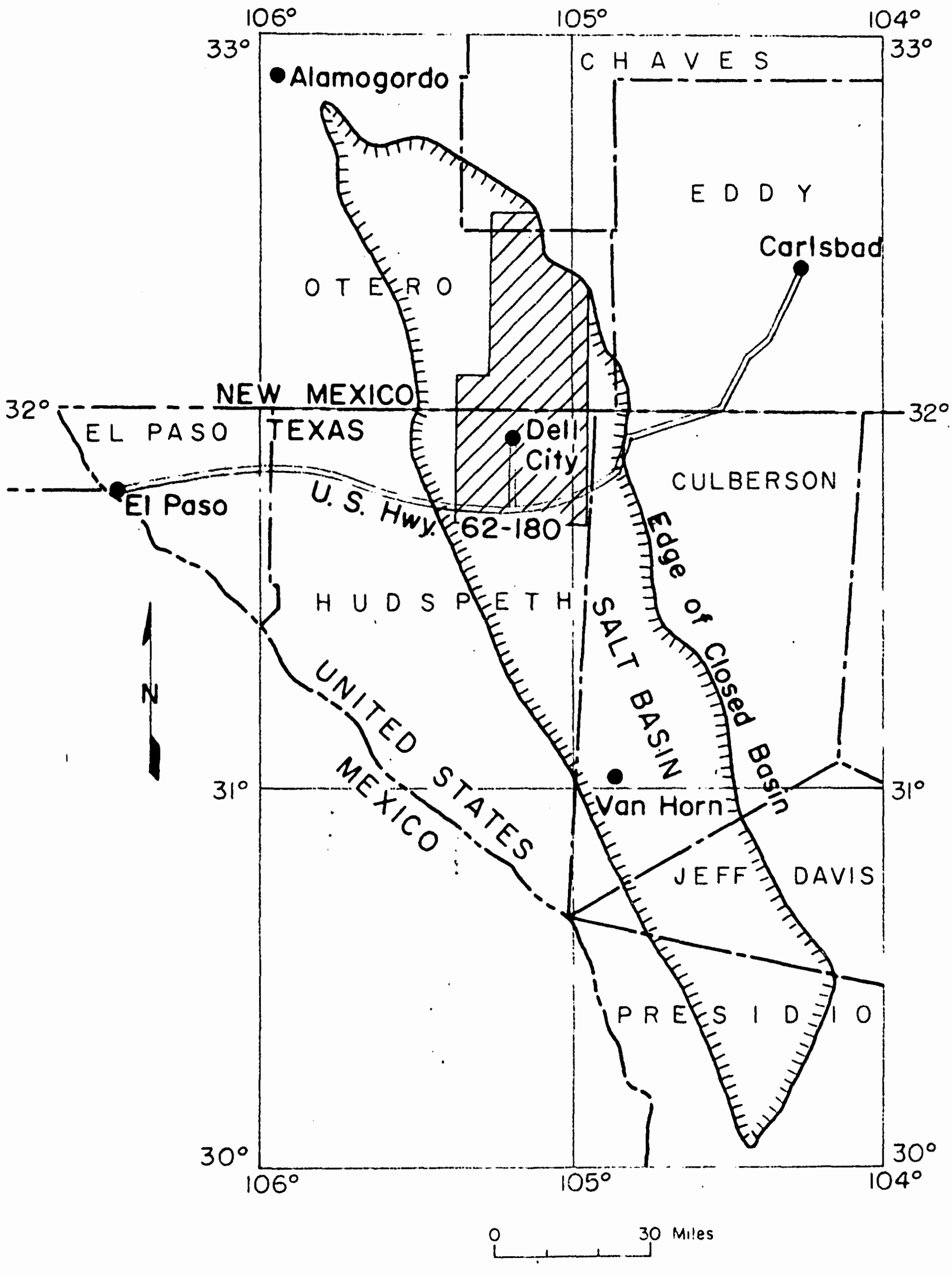

Figure 3.-- Southeastern New Mexico and western Texas showing Salt Basin and Crow Flats-Dell City area (shaded).

Occurrence of Ground Water

In the Crow Flats-Dell City area ground water occurs in two principal aquifers, the Bone Spring limestone of Permian age and the valley fill or alluvium of Quaternary age.

Bone Spring Limestone

The Bone Spring limestone of Permian age is described by King (1948, p. 13) as being several thousand feet thick and as consisting almost entirely of limestone. Water occurs in interconnected solution channels developed along joints and cracks by the dissolving action of ground water. When these openings are encountered in a well below water level they yield large quantities of water. They may occur as large cavities or as a zone of numerous small cavities forming what is called "honeycomb limestone" by local drillers and well owners. The yield of water is large in either case. Solution openings in the limestone are encountered at depths ranging from less than 100 feet to more than 1,000 feet and, according to reports from drillers, the openings are not encountered at any particular depth.

Water moves with such ease within the interconnected solution channels in the Bone Spring limestone that an almost level piezometric surface is maintained. Furthermore, the water levels in wells fluctuate largely as a unit, as water is added or removed from the aquifer.

The area underlain by the permeable or productive part of the Bone Spring limestone is indicated by the uniform water levels mentioned above. This area is large and according to well records, reaches from approximately 16 miles north of the New Mexico-Texas State line, in the Crow Flats area, to at least 17 miles south of the line, in Texas, and is about 15 miles wide. Thus, it is evident that the highly productive aquifer, in general, underlies an area of at least 500 square miles.

Valley Fill

The valley fill, or alluvium of Quaternary age, in the Salt Basin is composed of boulders, cobbles, gravel, sand, silt, and clay, and underlies the valley floor to depths ranging from a feather edge to at least 1,620 feet (Scalapino, 1950, p. 5). Alluvium more than 500 feet thick was encountered near the New Mexico-Texas State line (Bjorklund, January 1957, p. 11). The depth of alluvium encountered in the drilling of most irrigation wells, however, ranges from about 25 feet to 300 feet. Ground water occupies interstices or voids between the various sized particles that compose the alluvium.

The piezometric surface formed by water levels in the alluvium, in general, is similar in shape, slope, and altitude to the very flat piezometric surface in the underlying Bone Spring limestone because water undoubtedly moves from one aquifer to the other in many places. On the other hand in areas where the alluvium probably does not lie directly on the Bone Spring limestone, such as in Tps. 21, 22, and 23 S., in the northern part of the Crow Flats area, the water table in the alluvium slopes southward at gradients that probably amount to 10 or more feet to the mile.

Depths to Water

Water levels in wells in the Crow Flats-Dell City area range from less than 10 feet below land surface in low-lying areas adjacent to the alkali flats to more than 500 feet in the higher areas on and bordering the limestone uplands on either side of the valley floor. As the piezometric surface in most of the area is essentially flat, the depth to water is largely a function of the land-surface altitude. Most of the ground-water levels in the area are at an altitude between 3,610 and 3,615 feet above sea level. In the developed area where large quantities of water are pumped for irrigation, the depth to water ranges from about 20 feet to about 300 feet below land surface. Depths to water below land surface are shown in plate 14.

Quality of the Water

Twenty water samples were collected in the Crow Flats area in New Mexico during April 1956 and analyzed for mineral constituents. Hardness ranged from 352 to 2,500 and averaged 1,125 ppm. Water from the valley fill ranged in hardness from 352 to 2,500 and averaged 1,316 ppm, whereas water from the Bone Spring limestone ranged from 665 to 1,060 and averaged 886 ppm. It is apparent, therefore, that the softest and also the hardest water is from the valley fill. On the other hand, the water from the Bone Spring limestone in this area is consistently hard with a rather moderate range in hardness.

Water samples from 20 wells and a spring were collected in the vicinity of Dell City, Texas, during 1948 and 1949, and were analyzed and the results tabulated (Scalapino, 1950, p. 7-38). Total hardness ranged from 766 to 3,300 and averaged 1,155 ppm. This is slightly greater than the average hardness of water collected in the Crow Flats area. It is believed that the general mineral content of the ground water increases from the Crow Flats southward, especially toward Alkali Flats. Furthermore, it is believed that the mineral content of the ground water is increasing because of return of water from irrigated lands.

The water from the Bone Spring limestone, although consistently hard and of inferior to impotable quality, is used by most of the residents of the area for domestic and livestock use and for the irrigation of cotton and alfalfa. The water in the alluvium generally is impotable, especially in wells situated in low parts of the valley, but it is used for irrigation. A few wells in outlying areas derive potable water from the alluvium.

The mineral constituents of ground water in the Crow Flats-Dell City area consist chiefly of the bicarbonates, sulfates, and chlorides of calcium, magnesium, and sodium. The total dissolved solids in samples collected range from 400 to 6,850 ppm and average 1,879 ppm. Detailed information derived from the analyses is tabulated in the reports by Scalapino (1950) and Bjorklund (January 1957). The sulfate and chloride content of water samples from wells are given on plate 14.

Development of Ground-Water Resources

Development of Wells

The first irrigation wells in the Crow Flats-Dell City area were drilled near Dell City in 1947; since that time the area has developed rapidly. In April 1956 approximately 228 wells were in use to irrigate about 32,000 acres. At that time a considerable amount of new land was being cleared for farming, and additional wells were being drilled. Most of the irrigation wells derive water from the Bone Spring limestone. In the Crow Flats area alone, about 3,000 acres was being irrigated from 17 wells, and 6 additional irrigation wells were not being used.

The yield of irrigation wells in the Crow Flats-Dell City area ranges from about 350 gpm to about 4,000 gpm. Bjorklund (January 1957, p. 16) measured a discharge of 3,620 gpm with a drawdown of 10 feet (a specific capacity of 362 gpm per foot of drawdown) in a well deriving water from the Bone Spring limestone. A well in the alluvium had a measured discharge of 840 gpm with a drawdown of 40 feet, or a specific capacity of 21 gpm per foot of drawdown. By far the largest yields and the most consistent (but inferior to impotable) quality of water is from the limestone.

Declines of Ground-Water Levels

Water levels in the Bone Spring limestone have been steadily declining since the development of irrigation began in 1947 in the Crow Flats-Dell City area. This decline has amounted to about 15 feet in the 9 years of record ending with January 1957 and is effective over a large area.

In addition to the general decline indicated above, there are seasonal fluctuations in water levels . Water levels decline during the pumping season and then partly recover between pumping seasons as water moves in from adjacent areas and partly fills the depressions in the piezometric surface caused by previous pumping.

Potential Development

The natural discharge of ground water from the Bone Spring limestone upward through the alluvium into the Alkali Flats has virtually ceased as the piezometric surface in the limestone has declined to an altitude below the altitude of the Alkali Flats. It is inferred, therefore, that the consumptive use of water due to irrigation is greater than the natural recharge to the Bone Spring limestone. Inasmuch as about 100,000 acre-feet of water has been pumped annually during recent years the natural recharge per year is less than that amount. However, there is a large amount of water in storage that can be developed although the additional water supply will be taken from storage.

A general deterioration of the quality of water in the area is possible as water levels continue to decline. The natural direction of movement of water toward the Alkali Flats will reverse in some areas, as some water will move from the materials underlying the Alkali Flats toward the pumped wells. As the water underlying the Alkali Flats and vicinity is highly mineralized, this mixing will increase the mineral content of water in some wells. The wells closest to the Alkali Flats will be affected first.

Small to moderate quantities of potable and inferior water can be developed in the alluvium in the northern part of the Crow Flats area 10 miles or more from the Alkali Flats. Depths to water in this part of the area are about 150 feet to more than 500 feet. The best possibilities for development of wells probably would be along Piñon Creek and Cornucopia Draw.

Studies in the Crow Flats and Dell City areas so far do not indicate any aquifers other than the Bone Spring limestone and the alluvium. Some perched ground-water zones, however, may occur in the San Andres formation in the northern part of the Crow Flats area; if so, the quantity of water available probably would be small.

Suggested Additional Study

The area northward and westward from the Crow Flats-Dell City area needs additional geologic and hydrologic study in order to determine more accurately the areal extent of the Bone Spring limestone, and especially the extent of the permeable part of the limestone. A water-table contour map based on spirit leveling and water levels in wells may indicate the boundary of the aquifer. Some test drilling to water-bearing zones in areas where no wells exist and in marginal areas may be necessary to define boundaries.

The ground water in the Crow Flats and Dell City areas should be sampled and analyzed periodically and compared to the published analyses (Scalapino, 1950 and Bjorklund, January 1957) to detect any progressive change in quality.

SOUTHERN TULAROSA BASIN - HUECO BOLSON AREA, DOÑA ANA AND OTERO COUNTIES, NEW MEXICO, AND EL PASO COUNTY, TEXAS

By

J. R. Rapp

The Southern Tularosa Basin - Hueco Bolson area occupies part of an extensive, north-south trending, structural lowland which on the north is called the Tularosa Basin and on the south the Hueco Bolson. These two topographic divisions are separated by a generally low divide that extends approximately from near the state line in southeastern Doña Ana County, New Mexico, northeastward through the Jarilla Mountains. The report area includes the extreme southern end of the Tularosa Basin and the northern part of the Hueco Bolson that lies north of the Rio Grande. (See pl. 15.) On the west the area is bounded by the Franklin and Organ Mountains, and on the east the boundary is the west front of the Hueco Mountains and the Hueco Plateau, an eastward sloping upland that lies between the Hueco and Sacramento Mountains. (See pl. 13.) The northern boundary of the area is the north line of T. 21 S., and the approximate southern boundary is the Rio Grande. The valley of the Rio Grande does not terminate the Hueco Bolson but merely breaches it, with the bolson continuing a considerable distance southward into Mexico. The report area comprises about 1,750 square miles, of which about two-thirds lies in southwestern Otero County, New Mexico and the remainder is in southeastern Doña Ana County, New Mexico, and El Paso County, Texas.

Although the area consists of two topographic subdivisions, they are considered as a unit for the purpose of this report. The water table is continuous, and the contours on the water table (see pl. 15) show that ground water moves southward from the Tularosa Basin into the Hueco Bolson. On the basis of quality and quantity of ground water produced by wells, the report area is subdivided into two units, the Orogrande-Newman area and the Doña Ana - El Paso area.

A detailed study of the ground-water resources of the El Paso area, Texas was made by Sayre and Livingston in 1945. This study was followed in 1953 and 1954 by an extensive test-drilling program in the area north of El Paso and throughout much of the central and southern parts of the report area. The results of this test-drilling program are given in the report on the ground-water resources of the Hueco Bolson by Knowles and Kennedy (1956). Data from those reports and data collected from wells and other test holes in the area are summarized in this report.

Orogrande-Newman Area

The Orogrande-Newman area includes the area that extends southward from T. 21 S. to the Rio Grande. The western boundary in New Mexico lies approximately along the Doña Ana-Otero County line. In the vicinity of the New Mexico-Texas State Line the boundary swings eastward to run north-south in the vicinity of the range line between Blocks 79 and 80. On the east the boundary is the west front of the Hueco Mountains and the west edge of the Hueco Plateau.

Locally, the continuity of the almost flat surface of the lowland area is broken by the Jarilla Mountains, which are composed of igneous rocks and some limestone, and, near the Hueco Mountains, by a line of isolated hills which are composed mainly of limestone. From Davis Dome (at the McGregor Range Camp) southward, these outlying hills occur in association with igneous rocks.

The central and eastern part of the area is underlain by older bolson fill which consists mainly of deposits of fine sand, silt, and gypsiferous clay. As a unit the older bolson fill has a relatively low permeability. Toward the mountains the deposits become coarser grained with a resulting increase in permeability. The extreme eastern part of the area is underlain by younger bolson fill which has been deposited on the older fill in the form of alluvial fans that originate at the mouths of canyons along the mountain front. Near the mountains these deposits are very coarse and quite permeable, but westward from the mountain front the deposits progressively become thinner and finer grained and their permeability decreases accordingly. The thickness of the bolson deposits ranges from a feather edge to about 4,900 feet, the depth of fill reportedly penetrated in a well about 2 miles south of Newman. Between Davis Dome and the west front of the Hueco Mountains, the bolson deposits are more than 700 feet thick as evidenced by test hole 26.8.2.131 which bottomed in coarse-grained bolson deposits at a depth of 705 feet.

In the central part of the area the depth to water ranges from about 240 feet to about 360 feet. In much of this area the water level apparently rises several feet above the depth at which water is encountered. This condition probably results from the water table being in relatively impermeable material which restricts the yield of water to such an extent that the yield in the upper part of the zone of saturation is undetected during normal drilling and testing procedures. Thus, when a more permeable, saturated body is encountered the higher yield results in the water rising rapidly to the static level, giving the impression that the water is under artesian pressure. In the eastern part of the area, near the line of outlying hills and eastward, the depth to water generally is more than 450 feet. Locally, perched water may be encountered at shallower depths. In well 26.8.23.120 the water level is 162 feet, in contrast to a nearby well, 26.8.33.120a, in which the water table is indicated by a water level of 453.

In the Orogrande-Newman area the movement of ground water generally is southward with local deflections caused by bedrock outliers and permeability differences. (See pl. 15.) The highly mineralized water within the basin moves southward into and through the area. Local areas, which serve as catchment areas for recharge from precipitation, are characterized by depressions and troughs that apparently pierce the caliche layer and thus permit infiltration of precipitation to the ground-water reservoir. Wells and test holes in these areas where local recharge is effective, show a thin zone (generally less than 100 feet thick) of potable water overlying the highly mineralized water. The U. S. Army well at Alvarado, which is 441.5 feet deep, produces about 20 gpm of water that contains 380 ppm chloride and 310 ppm sulfate. This water exceeds the desired limits of mineralization (250 ppm sulfate and 250 ppm chloride), although the water is usable and therefore is classed as inferior water. In test hole 24.7.34.411 water of inferior quality containing 232 ppm chloride and 387 ppm sulfate was encountered in a zone about 45 feet thick overlying the highly mineralized water. Well 25.6.20.343 at the U. S. Army Hueco Range Camp is about 440 feet deep and produces about 250 gpm of water containing 438 ppm chloride and 50 ppm sulfate. During 1956 about 1,710,000 gallons reportedly was pumped in a 10-month period from the well at the Hueco Range Camp, but water from this well and the well at Alvarado is not drunk by troops.

In August 1957 well 26.6.1.220 was drilled at Hueco for irrigation purposes. The well, which is about 600 feet deep, reportedly had a discharge of about 975 gpm during a 24-hour period of test pumping. Partial analysis of a water sample collected during pumping showed the water to have a specific conductance of 3,760 micromhos and to contain about 575 ppm chloride and estimated dissolved solids of 2,900 ppm.

In the eastern part of the area ground water apparently is discharged eastward from the bolson deposits into the underlying solution channels and fractures in the rocks that comprise the Hueco Mountains. (See water-table contours in the vicinity of the McGregor Range Camp on plate 15.) Locally, there are perched zones of potable water (less than 250 ppm of chloride or sulfate) along the west front of the mountains. Well 26.8.33.120 produces water containing 41 ppm chloride and 136 ppm sulfate. Reportedly the yield of this well is small and is dependent upon recharge from water collecting in a nearby playa. Apparently much of the precipitation that falls on the mountains is discharged by evapotranspiration, but some water percolates to the water table and then moves eastward into the mountains. However, during periods of moderate to heavy runoff, water reaches the playas where that which is not discharged through evapotranspiration percolates downward to replenish the perched zones of water.

Doña Ana-El Paso Area

The Doña Ana-El Paso Area comprises a relatively narrow belt that lies along the east front of the Organ and Franklin Mountains including that part of Fillmore Pass east of the divide. The area is about 35 miles long and widens from about 6 miles in the north part to about 11 miles in the vicinity of the Rio Grande. (See pl. 15.)

Owing to its proximity to the mountains, the area is underlain by rather thick beds of coarse sand and gravel. Granitic rocks are exposed in most of the Organ Mountains and in conjunction with rhyolite porphyry along much of the lower part of the east front of the Franklin Mountains. As erosion of these rocks was rapid, weathering was not complete and beds of coarse-grained arkosic sand and gravel were deposited near the mountains. In test hole 1.81.26.222 a thickness of 1,635 feet of bolson deposits was penetrated, with individual beds attaining a maximum thickness of about 100 feet.

The greater depths to water in the area occur near the principal recharge areas along the slopes of the mountains and in Fillmore Pass. In well 1.81.26.222, which is near the Franklin Mountains, the depth to water is 423 feet, and in well 25.4.18.249, which is on the topographic divide of Fillmore Pass, the depth to water is 381 feet. Southward and eastward on the mesa the depth to water ranges from about 350 to 200 feet with a marked decrease southward through El Paso. In the Rio Grande Valley, south of the mesa, the depth to water is less than 50 feet.

Recharge to the Doña Ana-El Paso Area is from precipitation. The coarse-grained alluvial fans that issue from the mountains, especially the Organ Mountains, serve as catchment areas for recharge by infiltration. In Fillmore Pass a low ground-water divide lies several miles west of the topographic divide indicating that water from the south end of the Organ Mountains discharges both to the east and west. In the vicinity of the principal recharge area the hydraulic gradient is quite steep, averaging about 30 feet per mile eastward. In the unpumped areas away from the intake area the slope of the water surface is south to southeastward with a very low gradient. There are two cones of depression indicating heavily pumped areas in the vicinity of El Paso. The northern cone of depression is on the mesa near the well fields of Fort Bliss and the city of El Paso. The mesa is the upland area that lies north of the Rio Grande Valley. The other cone of depression is in the valley of the Rio Grande where large withdrawal of water is made for municipal and industrial uses.

Throughout much of the area large supplies of potable water are yielded by wells. Yields of the larger production wells range from about 1,000 to more than 1,500 gpm with specific capacities ranging from about 20 to 85 gpm per foot. The potable water occurs in a trough of irregular depth and width along the front of the mountains. The quality of the water and the thickness of the potable water sands are extremely variable. In places the potable water sands are quite deep -- in well 1.81.26.222 they extend to a depth of over 1,200 feet. In well 1.81.14.444, which is about $2\frac{1}{2}$ miles N-NE of well 1.81.26.222, water containing 450 ppm chloride and 62 ppm sulfate was obtained from a depth of 555 feet. These local zones of more highly mineralized water are sharply defined and probably indicate areas of relatively low permeability in which flushing of the highly mineralized water by potable water has been restricted.

Large amounts of ground water are pumped by wells from bolson deposits in the vicinity of El Paso. In 1953 the average daily pumpage from wells for municipal, industrial, and military use was about 27.9 million gallons a day of which about 13,200,000 gallons a day was pumped from wells on the mesa (Knowles and Kennedy, 1956, p. 20). In addition, an estimated 3 million gallons per day was pumped for irrigation on the mesa a short distance north of El Paso. According to Mr. E. G. Lucas, foreman of the water plant at Fort Bliss, the average daily pumpage at Fort Bliss was about 2.8 million gpd in 1953 and about 4 million gpd in 1956. The supply in 1956 was obtained from 8 wells, which range in reported yield from 750 to 1,160 gpm. Only in water from one well did the chloride or sulfate content exceed 100 ppm, and the water from this well contained only 107 and 101 ppm, respectively. According to records, an average of about 1.07 million gpd was pumped by Biggs Air Force Base in 1953 and an average of about 0.86 million gallons a day was pumped in 1956. The water was supplied by two wells, the yields of which decreased about 20 percent over the 3-year period. At the Doña Ana Camp, Mr. Lucas reported that in 1956 the average monthly pumpage was about 207,000 gallons. (No pumping was reported for September, and therefore only the pumpage for the other 11 months was averaged.) The well at Doña Ana Camp reportedly yields about 100 gpm of water that contains 47 ppm chloride and 62 ppm sulfate (1956 analysis).

According to Knowles and Kennedy (1956) about 13.6 million acre-feet of "fresh" water (water containing less than 250 ppm chloride) theoretically is recoverable in the Doña Ana-El Paso area. This figure is based on a saturated thickness of fresh-water bearing materials in excess of 100 feet. On the basis of 50-percent recovery, it was estimated that 30 million gallons a day could be withdrawn from storage in this area for a period of 110 years.

In addition to the "fresh" water, it was estimated in the above report that about 3.5 million acre-feet of "inferior" water (water containing 250-700 ppm chloride) was available in the Hueco Bolson. However, as the term inferior is used herein (water containing between 250 and 500 ppm of chloride or sulfate and less than 750 ppm of both), the total amount of inferior water in storage in the overall report area probably does not greatly exceed 2 million acre-feet.

Summary and Conclusions

Orogrande-Newman Area

In the Orogrande-Newman area potable water is encountered only locally. Apparently potable water occurs mainly in scattered perched zones. Potable water may also occur in places as a relatively thin zone in the upper part of the zone of saturation as is indicated on electric logs of a few of the test holes. Inferior water occurs in places in the central and southern part of the area. Yields of wells producing inferior water are not known to exceed about 250 gpm. The thickness of inferior-water sands probably does not greatly exceed 200 feet. The occurrence of the potable and inferior water probably can be attributed to local recharge. Electric logs of test holes and chemical analyses of water collected from test holes show that below the zone of inferior water the mineralization of the water increases markedly with depth. In most cases a mixing of the water is indicated near the base of the inferior water zone. Therefore, impotable water underlies the entire area. Well 26.6.1.220 has a reported yield of 975 gpm of water that is impotable. The intended use of the water is for irrigation.

In the northeastern part of the area the ground water is high in sulfate. In the central part the water contains about equal amounts of sulfate and chloride, but in the western, south central, and southern parts of the area the ground water is high in chloride.

Doña Ana-El Paso Area

The Doña Ana-El Paso area is the only favorable part of the report area for the development of large supplies of potable ground water. A deep trough of potable water extends in a general north-south direction along the east front of the Organ and Franklin Mountains. This belt of potable water apparently is wide in the extreme northern part of the area, then it narrows southward to about the State line, south of which it again widens. Several test holes drilled along the mountain front encountered potable-water strata to a depth of about 1,200 feet. Eastward the potable-water trough thins abruptly, giving way to inferior water, with lenses of potable water extending into the inferior water area and vice versa.

Large amounts of potable water are pumped from wells in the vicinity of El Paso. In 1953 an estimated 16,200,000 gallons a day was pumped from the wells on the mesa for municipal, industrial, military, and irrigation use. Yields of the larger production wells range from about 1,000 to more than 1,500 gpm with specific capacities ranging from about 20 to about 85 gpm per foot.

North of the Texas-New Mexico State line the ground-water supplies are only slightly developed. Test-hole data, however, indicate that large volumes of potable water, which are comparable to those in the developed areas south of the State line, occur in this area. Apparently, this potable water zone is continuous with the body of potable ground water underlying the headquarters area at White Sands Proving Ground.

Knowles and Kennedy (1956) estimated that about 13.6 million acre-feet of "fresh" water (less than 250 ppm chloride) theoretically is available in the Doña Ana-El Paso area. In addition to the "fresh" water it was estimated that about 3.5 million acre-feet of "inferior" water (250-700 ppm chloride) is available. Of this amount about 2 million acre-feet is inferior water as herein used and the other 1.5 million acre-feet is classified as impotable.

Suggested Additional Study

The western part of the report area, namely, the Doña Ana-El Paso area, is the most favorable for developing large supplies of potable to inferior ground water. A considerable part of the area in the vicinity of El Paso has been or is being developed by the city and by the military installations. However, north of the developed well fields, in New Mexico, very little development has taken place. Test holes drilled in this area during the 1953-1954 test-drilling program (Knowles and Kennedy, 1956) indicate a zone of potable water of considerable extent parallel to the east front of the Organ Mountains. The potable water zone is immediately underlain by impotable water, and eastward the material containing potable water decreases rapidly in thickness, the potable water apparently lensing out into beds containing water of inferior quality.

Plans for the development of large supplies of ground water from this area should include a preliminary detailed test-drilling program. The test-drilling program should be carried out as follows:

(1) The test holes should be carefully located and spaced, utilizing data already available in the area.

(2) The drilling should be carefully observed to obtain accurate logs of the holes.

(3) Representative ground-water samples should be collected for determination of the chemical constituents.

(4) Electric logs should be obtained upon completion of the drilling of each test hole to better determine the position and permeability of aquifers and to aid in establishing the potable water-inferior or impotable water contact, if possible.

(5) The test holes should be cased, complete with screens, the placing of which should be determined from the sample and drilling logs, the electric log, and the chemical character of the water encountered.

(6) Pumping tests should be made to determine the hydrologic properties of the aquifer.

HEADQUARTERS AREA, WHITE SANDS PROVING GROUND, DONA ANA COUNTY, NEW MEXICO

By

E. H. Herrick

The headquarters of White Sands Proving Ground is principally in sec. 24, T. 22 S., R. 4 E., in eastern Doña Ana County, about 25 miles east of Las Cruces, New Mexico, and about 40 miles north of El Paso, Texas. The headquarters area lies within a re-entrant in the mountains bordering Tularosa Basin on the west. This re-entrant encompasses an area of about 40 square miles and is bounded on the south and southwest by the Organ Mountains, on the northwest by the San Augustin Mountains, and on the north by the San Andres Mountains. (See pl. 16.) The principal wells supplying water to the Proving Ground headquarters are in sec. 13 and the northern part of sec. 24, T. 22 S., R. 4 E., at the mouth of the re-entrant.

Geology

The Organ and San Augustin Mountains are composed principally of Tertiary intrusive and extrusive rocks. In the northern part of the San Augustin Mountains and in the San Andres Mountains, Paleozoic sedimentary rocks overlie Precambrian granite. The north half of the re-entrant is a pediment surface developed on a Precambrian basement complex. Several prominent hills of Precambrian rock rise above the pediment surface. The south half of the re-entrant is underlain by unconsolidated bolson deposits which resistivity measurements indicate to be more than 1,500 feet thick in places. The general geology of the area is shown on plate 16.

The bolson deposits consist of alternating layers of clay and sand and some gravel. Most of the layers of sand and gravel penetrated by test holes and wells contain some clay, and many of the clays are sandy. Well-defined layers of sand generally are less than 20 feet thick. None of the test holes and wells have been drilled close enough to each other to permit a definite correlation of beds between adjacent holes. It is probably that the various beds change character or completely pinch out within a distance of a few hundred feet.

In general, the coarsest material of the bolson deposits occurs near the mountains; however, the deposits in that area are poorly sorted and therefore probably are relatively impermeable. Beyond the alluvial fans and throughout much of the central part of the re-entrant the deposits are better sorted but still contain a considerable amount of coarse material. East of the access highway, several miles from the mountains, the bolson deposits are well-sorted but contain a large amount of fine material, including much clay. These deposits are less permeable than those in the central part of the re-entrant. Thus, there appears to be generally a transition from material having a low permeability near the mountains to a zone of most permeable material beyond the alluvial fans and finally to fine, relatively less permeable material in the main part of Tularosa Basin.

Ground Water

General Occurrence

The igneous and consolidated sedimentary rocks in the mountains yield small quantities of water to springs, and Precambrian granite furnishes water to a few stock wells in the northern part of the headquarters area. However, the unconsolidated bolson deposits are the principal source of ground water in the area, and the occurrence of ground water in these deposits has been studied in some detail. Because the character of the bolson deposits changes markedly within short distances, the occurrence of ground water in the deposits also differs considerably in different parts of the area.

The direction of slope and the gradient of the water table within the re-entrant are shown by means of contours on plate 16. The contours indicate that within that part of the re-entrant between Antelope Hill and the central part of the Organ Mountains the ground water moves eastward through the bolson deposits at a gradient ranging from about 450 feet per mile near the mountains to about 50 feet per mile in the vicinity of the access highway at the mouth of the re-entrant. East of the re-entrant in the lower part of Tularosa Basin the water table slopes southeastward toward the Hueco Bolson at an estimated gradient of less than 5 feet per mile.

The depth to water within the re-entrant, as shown in figure 4, ranges from a few feet near the mountains to more than 400 feet in parts of secs. 1 and 12, T. 22 S., R. 4 E. The water table is more than 350 feet below land surface in most of sec. 12, the southern part of sec. 1, and parts of secs. 11, 13, and 14, T. 22 S., R. 4 E., and parts of secs. 6 and 7, T. 22 S., R. 5 E., north of the well field. It is estimated that the depth to water below the playas east of the re-entrant is about 150 feet.

The total volume of saturated bolson deposits underlying that part of the re-entrant west of the access highway is estimated to be about 4 million acre-feet. If an average porosity of 25 percent is assumed, the total quantity of ground water within the re-entrant is approximately 1 million acre-feet. A large part of this water is not available to wells, of course.

Recharge

The source of all the ground water in the headquarters area is the precipitation that falls within the re-entrant and in the nearby mountains, an area of about 40 square miles. It is estimated that the average annual precipitation for the entire area of the re-entrant west of the access highway probably is about 13 inches.

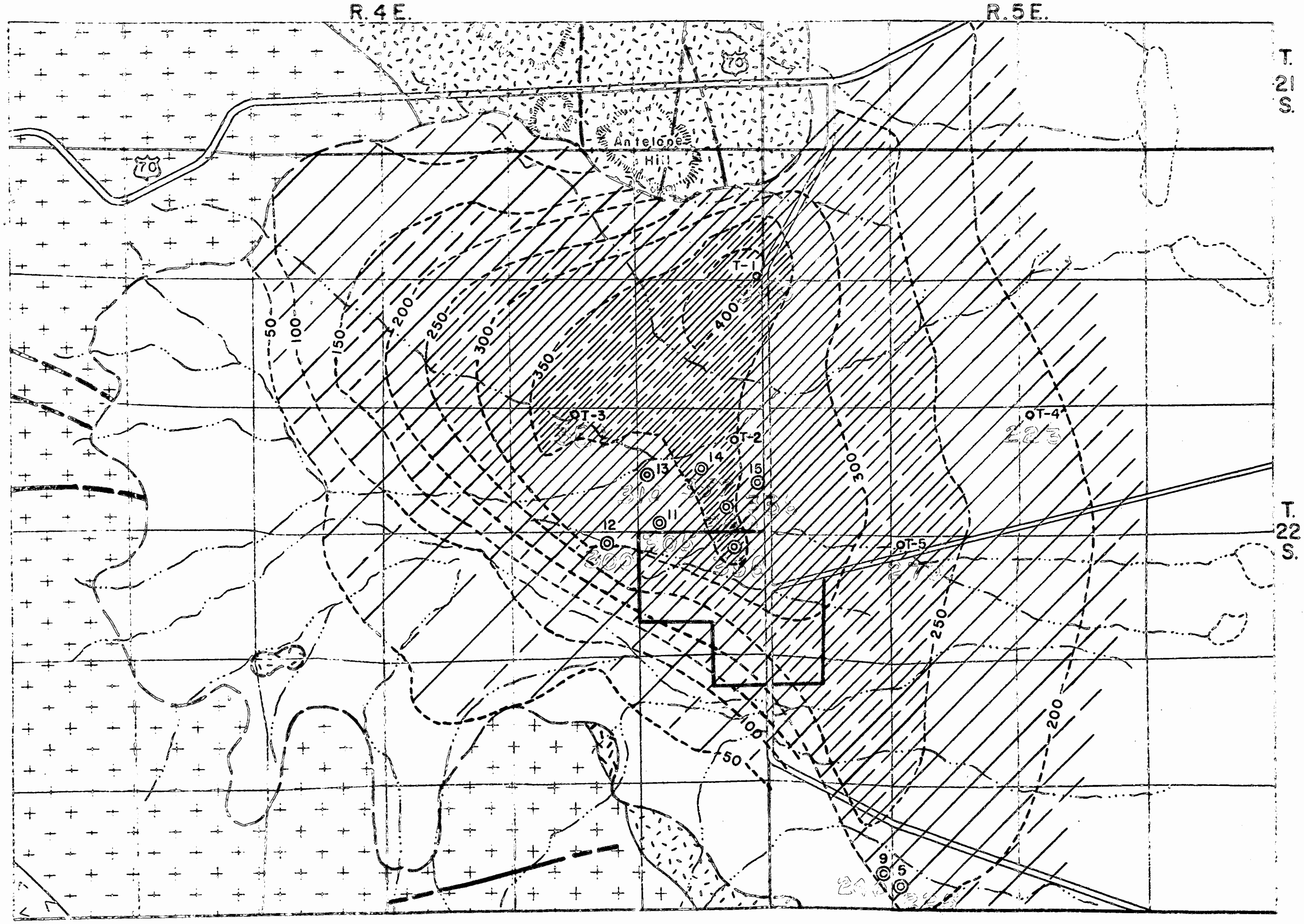

Figure 4.--Depth to water in feet below land surface in the headquarters area, White Sands Proving Ground, 1954

(For explanation of geology and well symbols, see plate 16.)

◎ Well, equipped with turbine pump
310 Depth to water in feet below land surface
○ Test hole

Sayre and Livingston (1945, p. 72) assumed that 25 percent of the precipitation in the catchment area in and near the Franklin and Organ Mountains at the west side of the Hueco Bolson becomes recharge to the ground-water body. The recharge conditions in that area and the re-entrant at the headquarters area are similar. Studies in other areas indicate that this estimate probably is high for the headquarters area, but it probably is safe to assume that 25 percent represents the maximum amount of precipitation that becomes recharge in the area. By using this figure, it is computed that the maximum annual recharge to the area is approximately 2,000 million gallons or 6,500 acre-feet. By computing the amount of water flowing through a cross section of the area, the maximum annual recharge has been estimated to be about 6,000 acre-feet. These estimates are based upon a meager amount of data and many assumptions. It is possible that the recharge is appreciably less than has been indicated above.

If the precipitation, specific yield of the aquifer, and pumpage in an area are known, the amount of recharge can be estimated from a study of water-level fluctuations. At this time few conclusions regarding the recharge in the headquarters area can be drawn from these data, as records of water-level fluctuations and precipitation cover only a short period. As additional records become available, recharge in the area probably can be estimated with greater accuracy.

Discharge

Within the headquarters area the only appreciable discharge of ground water from the bolson deposits is by transpiration and, artificially, by pumping. Most of the ground water is discharged outside the area.

The total amount of ground water pumped in the headquarters area in 1954 was about 300 million gallons. This is equal to approximately 15 percent of the estimated maximum annual recharge to the aquifer. However, water levels in the area are declining and will continue to decline, if the present rate of pumping is maintained, until the water table has become adjusted to the new discharge, and approximate equilibrium is again established. This can occur only if recharge is increased or discharge decreased, or both, in an amount equal to the quantity of water pumped from wells. There is no rejected recharge in the area, and pumping cannot move back the ground-water divide to appreciably increase the recharge area. The principal natural discharge of ground water from the bolson deposits is many miles from the headquarters area and cannot be reduced in the foreseeable future by pumping of wells in the re-entrant. Therefore, it follows that pumping in the headquarters area must continue, at least for a long time, to remove ground water from storage. Consequently, water levels in the re-entrant will continue to decline.

Chemical Quality

All the wells supplying water to the housing and cantonment areas of the Proving Ground produce water of exceptionally good chemical quality. Wells 5 and 9, in secs. 31 and 32, T. 22 S., R. 5 E. in the old well field, produce water containing less than 200 ppm of dissolved solids, and the seven larger wells within the re-entrant produce water containing an average concentration of about 240 ppm of dissolved solids. Although the deeper water obtained from wells 14 and 15 during drilling was more highly mineralized than the shallow water, the deeper water is of a chemical quality well within potable limits, at least to a depth of 1,000 feet.

The water from stock and domestic wells in the pediment area north of U. S. Highway 70 and near the mountains west of the cantonment area contains greater concentrations of dissolved minerals than the ground water underlying the cantonment area. However, the chemical quality of the water is within potable limits in all respects except fluoride. Water from wells 21.4.21.231 and 21.4.25.232 contained 4.0 ppm fluoride. A sample of water collected in March 1953 from well 21.5.15.411 at the Small Missile Range contained 464 ppm dissolved solids and 1.6 ppm fluoride.

Eastward from the cantonment area the ground water contains increasing amounts of dissolved solids, with the deeper water having the higher concentrations. Shallow water from test hole T-4, 2 miles east of the access highway, contained only 329 ppm dissolved solids, but a water sample obtained from a depth between 956 and 1,003 feet in the same test hole contained 7,480 ppm dissolved solids, mostly sodium chloride. The electric log of test hole T-4 indicates that the ground water at that site is highly mineralized below a depth of approximately 760 feet. It is reported that even the shallow water farther east in the central part of Tularosa Basin is highly mineralized and unfit even for watering stock. Chemical analyses of ground water from that area are not available.

It is evident from the available chemical analyses that the ground water moving into the re-entrant from the Organ Mountains south and southwest of the headquarters area is the least mineralized of the ground water in the area. The ground water in the crystalline rocks of the pediment area is considerably more highly mineralized, but most of that water moves southeastward to the main part of the basin and therefore does not reach the area of the Proving Ground well field.

East of the headquarters area the fresh water mixes with highly mineralized water moving to the south and southwest through the main part of Tularosa Basin. Immediately east of the re-entrant the fresh water apparently overrides the highly mineralized water. It is not known how far east of the headquarters area the upper water is potable, but it is reported to be fresh at least to the vicinity of the playas, about 4 miles east of the access highway. It is suspected, however, that highly mineralized water would be encountered a short distance below the water table, if not at the water table, in the area of the playas.

The ground water underlying the lower part of the basin east of the headquarters area moves to the south and southeast, and the available data indicate that immediately southeast of the headquarters area fresh water probably is confined to a relatively narrow belt close to the base of the Organ Mountains.

Utilization

Prior to the establishment of White Sands Proving Ground in 1946 the only use of ground water in the headquarters area was for watering stock and for domestic use at a few ranches. In 1946 ten wells were drilled in secs. 31 and 32, T. 22 S., R. 5 E. Records of these wells are very incomplete and, in some cases, nonexistent. However, most of the wells apparently produced less than 50 gpm, and most pumped a considerable amount of fine sand. All the water used at the Proving Ground before 1949 was pumped from wells in this area.

Well 10, in the NE$\frac{1}{4}$ sec. 24, T. 22 S., R. 4 E., was completed and equipped in the fall of 1948 and apparently supplied about one-third of the water pumped in 1949. Seven wells in secs. 13, 23, and 24, T. 22 S., R. 4 E., now supply almost all the water used at the Proving Ground.

Total pumpage at the Proving Ground in 1954 was about 307 million gallons. The total water consumption at the Proving Ground is about three times greater during the summer than during the winter. It can be safely assumed that the much greater consumption of water in the summer is due mainly to irrigation of grass, and, to a less extent, to consumption by air conditioners.

The population of the Proving Ground is increasing, and it is estimated that the population will be about 10,000 in a few years. If the present trend of per capita water consumption continues, when the population reaches 10,000 at least 450 million gallons, or 1,400 acre-feet, of water will be used at the Proving Ground annually. The accuracy of this estimate depends upon many factors, of course. Unless water use, particularly for irrigation, is curtailed to some extent, as it has been at times in the past, water consumption may far exceed the above estimate. Also, if additional large areas are landscaped, water consumption probably will exceed this estimate, even if conservative irrigation practices are followed.

It has been estimated (Herrick, 1955) that the average decline of water levels in wells at the Proving Ground in 30 years will be about 35 feet. These estimated declines are based on an average pumping rate of 1 million gallons per day and will be proportionately greater if the average pumping rate from the well field is higher. The greater declines for equal rates of pumping will occur in the lower capacity wells (11, 12, 13, and 14) in the western part of the well field where danger of contamination from saline water is least. If pumping is distributed uniformly among the wells, declines of the water levels will be spread throughout the well field and the danger of an excessive decline at any one well will be reduced to a minimum.

It is possible that highly mineralized water may extend beneath the wells at a depth below 1,000 feet, although this is speculative. It has been suggested (Herrick, 1955) that samples of water from the easternmost wells should be analyzed chemically at about 6-month intervals to determine if highly mineralized ground water eventually reaches the wells. However, it is believed that migration of highly mineralized water to the present wells will not be a serious threat in the near future.

Potential Supplies

The available data indicate that the most permeable bolson deposits underlie the eastern part of sec. 13 and the northeastern part of sec. 24, T. 22 S., R. 4 E. Mainly on the basis of resistivity data, much of secs. 11 and 12, T. 22 S., R. 4 E., also is underlain by relatively permeable bolson deposits. The depth to water in these areas (fig. 4) ranges from less than 350 feet in the eastern part of sec. 13 and the northwestern part of sec. 11 to about 400 feet in the north-central part of sec. 12. The thickness of the saturated bolson deposits, as interpreted from resistivity measurements, ranges from less than 500 feet in the southwestern part of sec. 11 to more than 1,000 feet in the central and eastern parts of sec. 12, the eastern part of sec. 13, and the northeastern corner of sec. 24.

Drilling and resistivity measurements indicate that the bolson deposits differ considerably within short distances. Therefore, not all parts of the area outlined would be equally favorable for the development of wells. The eastern part of sec. 13 appears to be the most favorable location for an additional well, but the chemical quality of the ground water at depth should be carefully determined if additional wells are drillled in that area. The saturated deposits underlying the western half of sec. 11 are relatively thin; therefore, the eastern half of that section and sec. 12 probably should be given preference over the western half of sec. 11 in future test drilling.

The bolson deposits become increasingly finer grained and probably less permeable east from the access highway; also, the danger of encountering highly mineralized water is much greater in that direction. For these reasons, it does not appear advisable to attempt the development of large-capacity wells for potable water east of the access highway.

The spacing of wells is an economic as well as a hydrologic problem. With shorter spacings between wells, less pipe and other materials are required, but interference between wells may increase pumping costs. More materials are required with greater spacings, but the possibility of interference becomes less. It is believed that a spacing between wells of $\frac{1}{4}$ to $\frac{1}{2}$ mile is adequate for the headquarters area.

WEST-CENTRAL TULAROSA BASIN, DOÑA ANA, OTERO, AND SIERRA COUNTIES, NEW MEXICO

By

J. E. Weir, Jr.

Almost all the area discussed in this section (pl. 17) lies between the west line of R. 4 E., and the east line of R. 8 E., and between the south line of T. 20 S., and the north line of T. 13 S. The area includes White Sands National Monument, Lake Lucero and associated alkali flats, fans, and pediments adjacent to the eastern front of the San Andres Mountains, and sand-dune and basin-flat regions bordering these major features. U. S. Geological Survey Water-Supply Paper 343 (Meinzer and Hare, 1915), is virtually the only publication dealing with the occurrence of ground water in this area. Pertinent data from that paper together with some additional hydrologic data collected recently in the field were used in the preparation of this section.

Principal Aquifers

Most of the ground water occurs in the relatively thick basin fill of Quaternary and Tertiary(?) age. This fill consists of sand, gravel, silt, and clay with a considerable amount of gypsum. The gypsum makes up the bulk of the dunes of the White Sands and occurs as crystalline selenite and fibrous satin spar around the playas and alkali flats, and is interbedded with the clastic constituents of the basin fill.

Very few subsurface data are available in the area, but it is known that the basin fill is generally more than 700 feet thick in the central part of the basin. The fill is more than 4,000 feet thick in the southern part of the basin and may be equally as thick in parts of the central basin discussed here.

Chemical Quality of Water

Most of the water in the area contains more than 4,000 ppm of dissolved solids, more than 900 ppm of sulfate dissolved from the gypsum of the basin fill, and more than 1,500 ppm of chloride. The source of the chloride is not known, but presumably it comes from salt deposited in the fill as a result of repeated evaporation of water from playas as the basin was filled with sediments. Water containing high concentrations of chloride and sulfate occurs very near to the mountains in most places, and almost invariably occurs under the central parts of the basin. Potable water has been found in a few localities near the base of the San Andres Mountains.

Almost all wells and springs in the area are or have been used for watering stock. A few wells yield water of acceptable quality for domestic purposes, and water from a few sources has been used for small irrigation projects in the past. However, most wells yield water that is too highly mineralized for human consumption, and people inhabiting the area have used rain-water cisterns or have hauled their drinking water.

Yields of Wells

Depth to the water table in the area ranges from 1 foot or less under the playas to about 250 feet near the San Andres Mountains. Depths of wells range from approximately 20 to 300 feet. Yields of the wells and springs in the area range from less than 1 to about 85 gpm. Very few wells are capable of yielding as much as 100 gpm; however, it is estimated that properly constructed, relatively deep, large-diameter wells, which might yield as much as 200 gpm, could be drilled in some parts of the area where only stock water has been sought previously.

Sources of Potable Water

Water of relatively good quality is yielded by two wells along the western side of the basin near the front of the San Andres Mountains. Lucero Ranch well (19.5.22.343) yields potable water containing 502 ppm of ~~total~~ dissolved solids, 161 ppm of sulfate, and 58 ppm of chloride (pl. 17). As Lucero Ranch well was formerly used to obtain domestic and stock water, it is presumed the well may yueld 10 gpm; however, a properly constructed well in that area might yield as much as 50 gpm.

Well 17.4.23.443 at Baird's Ranch yields 12 gpm of water of marginal chemical quality on the basis of standards for drinking water recommended by the U. S. Public Health Service. However, many municipalities in the Tularosa Basin and other parts of New Mexico use water containing higher concentrations of dissolved salts than the water from Baird's Ranch well.

It is believed that at least a moderate quantity of water of potable and inferior chemical quality could be developed by drilling wells in the Lucero Ranch and Baird's Ranch areas. It is probable that there are other similar occurrences of potable ground water of limited extent along the east side of the San Andres Mountains.

Hardin Ranch well (12.2.27.211), about 10 airline miles west-northwest of the northwest corner of the map of the area (pl. 17), yields potable water containing 771 ppm of ~~total~~ dissolved solids, 198 ppm of sulfate, and 70 ppm of chloride. This well is within the boundaries of the Integrated Range. The well probably will yield at least 10 gpm, and the water could be hauled or piped to installations in the vicinity, such as Pole 1,788 Camp and Skillet Knob. A pumping test of this well should indicate whether more than 10 gpm can be withdrawn from the well without depleting the aquifer.

Suggested Additional Study

Pumping tests of the wells at the Baird and Lucero Ranches should give an approximate value of the productivity of aquifers yielding water to these wells. For a comprehensive and reliable evaluation of ground-water resources in any of these areas, test holes are needed which would penetrate the entire thickness of the aquifer or aquifers.

It is probable that the basin fill is as much as 1,000 feet thick in some parts of the area where test holes would be needed. The fill very likely is at least 300 feet thick in most parts of the basin area which should be tested by drilling.

Virtually no subsurface geologic data are available for the area, and almost nothing is known about the hydrologic characteristics of the aquifers. It is estimated that a minimum of 9 and a maximum of 15 test holes would be required for an adequate hydrologic exploration program in the western margin of the basin adjacent to the San Andres Mountains. Approximately 5 to 10 test holes, one of which might be deeper than 1,000 feet, would be needed to explore the area east of U. S. Highway 70, where almost no data are available. At least 3 to perhaps 12 test holes would be desirable in the alkali flat-sand dune area to determine the quantity of impotable water available in that area.

As shown on plate 17 there are several wells and springs in the area about which no information was collected. Some of the wells may be very old and in such poor condition because of lack of maintenance that field data concerning them can no longer be obtained. Much data might be collected through interviews with residents and former residents in the area. Interview data will become increasingly more difficult to obtain as time passes.

The additional study suggested for a rather complete evaluation of the ground water in the area may be summed up as follows:

1. Collection of all hydrologic data available in the area.

2. Reconnaissance mapping of geology in the San Andres Mountains to the west of the area.

3. Approximately 15 to 40 test holes ranging in depth from 300 to 1,500 feet, all with at least temporary casings and some with permanent casings.

4. Pumping tests of each test hole and some of the existing wells.

5. Chemical analyses of water samples from test holes and wells.

SOUTHERN JORNADA DEL MUERTO AND MESILLA VALLEY IN THE VICINITY OF LAS CRUCES, DOÑA ANA COUNTY, NEW MEXICO

By

F. D. Trauger

The Rio Grande between Caballo Reservoir in the southern part of Sierra County, N. Mex., and El Paso, Tex., flows through two fairly distinct valleys separated by an area in which the river flows through narrow canyons. The more southerly valley, extending from Leasburg Dam, (15 miles northwest of Las Cruces) to about 4 miles northwest of El Paso, is called the Mesilla Valley. The altitude of the Mesilla Valley ranges from about 3,975 to about 3,720 feet, and the valley floor has a slope of approximately 4.5 feet per mile. The valley has a maximum width of 5 miles in the vicinity of Las Cruces. Steep bluffs of loosely cemented sand, silt, clay, and gravel, about 50 to 100 feet high, border the valley, and from these bluffs gently sloping plains extend back to the mountains. The plain on the east side of Mesilla Valley is a continuation of the southern end of the Jornada del Muerto. It is a nearly flat plain, 10 to 20 miles wide, bounded on the east by the San Andres Mountains. The plain west of the Mesilla Valley slopes southward from Las Cruces into Mexico and is known as La Mesa. It is similar in most respects to the Jornada del Muerto, and the two formed a continuous plain previous to the cutting of the Mesilla Valley by the Rio Grande.

This section of the report discusses briefly the occurrence of ground water in the Mesilla Valley in the vicinity of Las Cruces, the southern part of the Jornada del Muerto, and along the western side of the Organ, San Augustin, and southern San Andres Mountains. The map as plate 18 has been adapted from Conover (1954, pl. 1).

Principal Aquifers

For the purpose of this discussion the rocks of the area may be divided into three groups: 1) the younger unconsolidated to semiconsolidated sediments of Pleistocene and Recent age; 2) the older unconsolidated to semiconsolidated sediments of Tertiary (Santa Fe) age; and 3) the consolidated rocks, both igneous and sedimentary, of Archean to Tertiary age, that make up the mountain masses and underlie the Tertiary and Quaternary rocks of the bolson fill.

The younger sediments of Pleistocene and Recent age constitute the most important aquifer in the area. They overlie the older sediments, of Santa Fe age, and occur mainly as fan deposits and outwash from the mountains, and as alluvium underlying the present inner valley and flood plain of the Rio Grande. These deposits are composed mainly of gravel and sand and contain only minor amounts of clay. They are unconsolidated, and the individual beds are relatively well sorted so that "running" sands are frequently encountered in wells. Large volumes of water are pumped from these deposits by wells developed for irrigation, industrial, and public supplies. On the Jornada del Muerto the deposits of the alluvial fans are the source of water for stock and domestic use but do not yield large volumes of water.

The younger alluvium in Mesilla Valley is as much as 220 feet thick in the central part of the valley but is thinner toward the margins (Conover, 1954, p. 25-26). On the Jornada del Muerto and on La Mesa, the thickness of the younger alluvium increases toward the margins of the plain, and along the foot of the mountain masses, and in the fans at the mouths of canyons the younger alluvium may be several hundred feet thick.

The older sediments of Santa Fe age make up the bulk of the deposits underlying the Jornada del Muerto, La Mesa, and the deeper deposits underlying the flood plain of the Rio Grande. They are composed mainly of alternate layers and lenses of gravel, sand, silt, and clay which have little or no continuity. The permeability of these deposits depends on the degree of sorting and the amount of cementation and compaction they have undergone. Clay constitutes, on the average, about 50 percent of the material making up the rocks of Santa Fe age (Sayre and Livingston, 1945, p. 27-33).

The older sediments are an important source of water in the Mesilla Valley, and possibly in the Jornada del Muerto. However, these older sediments in general, because of the high clay content, do not yield as much water, per foot of penetration of aquifer, as do the younger sediments. To obtain large quantities of water from the older sediments, wells must be drilled deeper and penetrate greater thicknesses of the aquifer.

The older sediments under Jornada del Muerto may yield reasonably large quantities of water to properly developed deep wells. It is believed that well 21.2E.14.300 obtains most of its water from the older sediments although this is not proven. The water may come from older consolidated rocks underlying the sediments.

The older sedimentary deposits differ greatly in thickness from place to place, which indicates an uneven and rough surface on the underlying bedrock. Bedrock reportedly underlies the Mesilla Valley at depths of 86 to 331 feet (Conover, 1954, p. 25). A well on La Mesa, west of Las Cruces, reportedly was drilled in Tertiary or younger sediments to a depth of about 550 feet without encountering the older consolidated rocks (Conover, 1954, p. 24).

The consolidated rocks that make up the mountain masses and underlie the older and younger bolson fill consist of Precambrian granite, schist, and gneiss; Paleozoic sediments, mostly dolomite and limestone; possibly Mesozoic sediments (sandstone) of Cretaceous age; and volcanic lava and tuff of somewhat indeterminable age, but believed by Dunham (1935, p. 53) to be Tertiary. The Paleozoic section in the Organ Mountains was measured by Dunham and found to be over 2,000 feet thick, and the series of Tertiary lava and tuff deposits was found to be over 1,000 feet thick.

The consolidated rocks generally do not yield large quantities of water because they are mostly dense and impermeable. For the most part they deeply underlie the younger valley fill, and to explore at depth for possible supplies has not been feasible. In the upland areas the consolidated rocks lie mostly above the regional water table, and joints and fractures are drained. Locally, in zones of faulting along the foot of the mountain ranges, the older rocks may be severely fractured. Where the free movement of water is restricted or where the fractured zones lie below the regional water table, water may be stored in the fractured zones and may be a source of large quantities of water.

In the northern part of the Jornada del Muerto, wells of moderate to large yield are reported to obtain water from a sandstone of Cretaceous age and from the San Andres limestone of Permian age, both of which underlie the older Tertiary sediments of the bolson fill. It is possible that the Cretaceous and Permian water-bearing formations also underlie the older Tertiary sediments in the southern part of the Jornada del Muerto and La Mesa. As the thickness of the deposits making up the bolson fill is unknown, it is not possible to say at what depth the older consolidated rocks might be found under the fill in the southern part of the Jornada del Muerto.

Occurrence of Ground Water

The following discussion of the occurrence of ground water in the area is based mainly on data collected by the Geological Survey, and in part published in Water Supply Papers 919 (Sayre and Livingston, 1945) and 1230 (Conover, 1954), and on data reported by Dunham (1935).

Ground water occurs under both water-table and artesian conditions in the consolidated bedrock and the unconsolidated bolson fill. The specific occurrence of confined or unconfined water is generally unpredictable because the occurrence and limits of confining strata in the various deposits are unknown. It may be stated that, in general, unconfined water occurs in the younger alluvial deposits of the Rio Grande Valley and in the upper parts of the older valley fill, and that confined water occurs generally in the lower parts of the older valley fill and in the fan deposits of the younger alluvium. The occurrence of ground water in the bedrock underlying the bolson fill is virtually unknown, because no wells penetrating the bedrock to any appreciable depth have been reported.

In the upland areas the bedrock locally contains ground water in appreciable quantities, depending mainly on the nature and attitude of the rocks in which it is found. Generally speaking, the granitoid and volcanic rocks yield water under nonartesian conditions whereas artesian conditions are likely to be encountered in the bedded and deformed rocks of the Paleozoic sedimentary series.

Depth to Water

The average depth to water in Mesilla Valley in 1946 was about 6 feet (Conover, 1954, p. 54). That water levels fluctuate within a range of only 8 feet, more or less, is a consequence of the application of irrigation water to the valley lands, and the subsequent action of drains constructed to prevent water logging of irrigated lands.

Because the water table rises less rapidly than the land surface with distance away from the river, the depth to water under La Mesa and the tableland lying between Las Cruces and the Organ Mountains generally increases toward the mountains (pl. 18). Close to the river the water level stands at about river level, generally at a depth of 25 feet, or less. On the uplands, midway between the river and the mountains, the depth to water may be as much as 400 feet. At the toe of the slopes of the mountain front the depth to water generally decreases somewhat and may be between 100 and 300 feet.

Conover (1954) reports the depth to water to be generally between 200 and 400 feet in the Jornada del Muerto, north of the Doña Ana Mountains, and to be 200 feet or less northwest of the Doña Anas, the depth decreasing toward the river.

The depths to water in the mountain areas are generally unpredictable. Water may be perched above the general water table, and be encountered, generally in small quantities only, at relatively shallow depths. According to Dunham (1935), ground water occurs in appreciable quantities in a narrow belt one to two miles long, extending from near Organ southward along the mountain front, at a depth of about 350-450 feet in fault-fractured cavernous limestone and dolomite of Paleozoic age. In April, 1957, the depth to water in the main shaft of the Stevenson-Bennett mine was 325.5 feet below land surface.

Quality of Water

The quality of the ground water in Mesilla Valley in the upper few hundred feet of sediments improves generally with depth. In only a few wells has the quality of the deeper water been found poorer than that of the shallow water (Conover, 1954, p. 84). According to Conover (1954, p. 81) the water pumped from wells above the flood plain, and not immediately adjacent to it, generally has less dissolved solids but a higher percentage of sodium than water obtained from shallow wells in the flood plain of the valley. Water in the valley fill of the Rio Grande generally is low in fluoride, high in calcium, sulfate, chloride, and dissolved solids, has a moderate percent of sodium, and is hard. Sulfate concentrations in the alluvial fill range from a low of about 65 ppm to as high as 747 ppm; chloride ranges from about 40 ppm to 436 ppm. The concentration of dissolved solids ranges from 207 to 1,950 ppm, with the average being about 900 ppm. The percent sodium ranges from 27 and 61 (Conover, 1954, p. 82, 153).

Some of the water underlying the Jornada del Muerto east of Las Cruces is of unusually good chemical quality, as indicated by one analysis of water which had only 205 ppm of dissolved solids and a percent sodium of 36. Water from irrigation well 21.2E.14.300 on the Jornada del Muerto, northeast of the Doña Ana Mountains, contained 495 ppm total solids and had a percent sodium of 17. This well reportedly yields 1,000 gpm, with 35 feet of drawdown. The source of the water is not known. It may be from older sediments of the Santa Fe formation of Tertiary age, or from rocks of Cretaceous age underlying the valley fill.

The quality of water obtained from wells in the mountain areas is generally good. The water from wells penetrating the limestone rocks is generally harder and higher in total dissolved solids than that obtained from the igneous rocks. An analysis of water from the Stevenson-Bennett mine, south of Organ, showed a total dissolved solids of 602 ppm, a percent sodium of 9, and a sulfate content of 292 ppm. The analysis showed no copper, no lead, 0.14 ppm of zinc, and 1.2 ppm of fluoride. Water is reported to have been pumped at a rate of 800 gpm from this mine in a futile effort to control the inflow and permit mining operations.

Present Development

Ground water is used for nearly all domestic and public supplies in the area under discussion. Surface water is used generally only for irrigation purposes. The towns of Doña Ana, Las Cruces, and Mesilla, and the Agricultural College have large-capacity public-supply wells drilled in the valley alluvium. Individual small-capacity wells supply water to most ranch and suburban homes.

In 1947 the city of Las Cruces pumped about 300 million gallons, or about 920 acre-feet, of water from 6 wells. In 1955 consumption was estimated to be about 2.32 million gallons per day, or 2,600 acre-feet per year. This supply was derived from 12 wells.

Several hundred large-capacity irrigation wells have been constructed in Mesilla Valley between Leasburg Dam and the north line of T. 25 S. since 1947 to supplement surface-water supplies. These wells produce 600 to 2,000 gpm, and have specific capacities ranging from less than 20 to about 100 gpm per foot of drawdown. Some irrigation wells have been drilled on the slopes above the valley fill, but on the average these wells do not have specific capacities as high as those drilled in the valley fill, and some attempts to get water on the mesa for irrigation have failed because of low yields (Conover, 1954, p. 108).

The depths of the large-capacity wells in the valley fill generally do not greatly exceed 200 feet, and many are less than 100 feet. Large-capacity wells on La Mesa and on the Jornada del Muerto generally are much deeper, and may exceed 700 feet. Irrigation well 21.2E.14.300 reportedly is 600 feet deep and yields 1,000 gpm with 35 feet of drawdown. The greater initial depth to water and the generally lower specific capacity of wells drilled in the older alluvium underlying La Mesa and the Jornada del Muerto necessitate deeper drilling to obtain large amounts of water.

Potential Supplies

Wells yielding large quantities of water can be developed over most of that part of the floor of Mesilla Valley shown on plate 18, and locally on La Mesa and the Jornada del Muerto. With respect to pumping from alluvial deposits in Mesilla Valley, consideration must be given to the relation of surface water and ground water in the valley. Conover (1955, p. 113) has stated: "Because of the interrelation between surface water and the ground water in the Rincon and Mesilla Valleys, pumping of ground water does not represent an additional supply or new source of water to the project [Elephant Butte Irrigation District], but rather essentially a change in the method, time, and place of diversion of supplies already available. Depletion of ground-water storage is, in effect, borrowing upon future surface-water supplies." In essence, the statement applies also to ground-water pumped from under La Mesa and the Jornada del Muerto because ground water under these areas moves toward and ultimately discharges into the alluvium of the Rio Grande Valley, to become part of the surface and underflow down the Rio Grande channel.

As an indication of the amount of surface water available to recharge ground-water withdrawals in the Rincon and Mesilla valleys, the average annual discharge of the Rio Grande River at Caballo dam, for 15 years of record to 1954, was 760,200 acre-feet. It must be understood, of course, that all this water is appropriated under agreements of the Rio Grande compact and to indirectly divert any appreciable amount of this surface water to recharge the ground-water aquifers of the valley, as a consequence of large-scale pumping withdrawals, would undoubtedly result in protests by downstream users of the river water.

For the least effect on water supplies in the valley, and for maximum production, large-capacity wells in the valley should be located as far as possible from the river and the drains, should be drilled as far as practicable from the mountain masses and the northern end of Mesilla Valley, should be drilled near arroyo mouths where possible, and should be drilled no deeper than necessary to secure an adequate supply of water (Conover, 1954, p. 131).

Suggested Additional Study

Before any extensive program of development of ground water is undertaken in this area, some additional studies need to be made. Records of both river and drain discharge, and fluctuations of water levels in the Mesilla Valley should be analyzed and interpreted to determine in so far as possible the probable effect upon river and drain discharge of heavy pumping from wells, particularly if the water to be pumped were to be transported for use outside the valley.

It would be necessary to conduct a program of test drilling to determine the location of adequate quantities of water of acceptable quality. It is probable that some wells with high yields would have water of a quality unsuited for human consumption.

Troughs in the water table, as shown by the contours on plate 18, indicate that ground water moves southwestward toward the Rio Grande from both the north and south side of the Doña Ana Mountains. The axis of the lines of these troughs in the water-table contours would seem to be likely areas in which to prospect for ground water. The belt of fractured cavernous dolomite and limestone along the west slope of the Organ Mountains also appear worthy of exploration by test drilling in the light of data on ground water in the mining area, as described by Dunham (1935). Additional geologic study of the west front of the San Augustin and the southern end of the San Andres Mountains might reveal additional structural features making development of ground water feasible in those areas. Several seismic surveys across the Jornada del Muerto in the vicinity of the Jornada Experimental Range should provide useful information concerning the subsurface strata and should indicate whether or not a test-drilling program might be advisable in that area.