Hydrogeologic Framework of the Mesilla Basin Region of New Mexico, Texas, and Chihuahua (Mexico)—Advances in Conceptual and Digital-Model Development

Appendix C
Review of Hydrogeology-Related Investigations in the United States Part of the Mesilla Basin Region—1890 to 2010

John W. Hawley

USGS geologist Willis T. Lee on his cutting-edge, Atchison, Topeka and Santa Fe Railway field vehicle during a Jornada del Muerto mapping expedition, *circa* 1904-1906.

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APPENDIX C[1]

REVIEW OF HYDROGEOLOGY-RELATED INVESTIGATIONS IN THE UNITED STATES PART OF THE MESILLA BASIN REGION—1890 TO 2010

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[1]APPENDIX C *in* Hawley, J.W., Swanson, B.H., Walker, J.S., Glaze, S.H., and Ortega Klett, C.T., 2025, Hydrogeologic Framework of the Mesilla Basin Region of New Mexico, Texas, and Chihuahua (Mexico)—Advances in Conceptual and Digital Model Development: NM Water Resources Research Institute, NMSU, Technical Completion Report No. 363, 359 p., 8 Appendices.

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APPENDIX C

REVIEW OF HYDROGEOLOGY-RELATED INVESTIGATIONS IN THE UNITED STATES PART OF THE MESILLA BASIN REGION—1890 to 2010

The southeastern Basin and Range (B&R) physiographic province has been the center of major advances in the Earth sciences since the Civil War, with many pioneering contributions made by early "giants" of North American geology. The area of primary interest includes the Mexican Highland section of the B&R province and the southern Rio Grande rift tectonic province in New Mexico, Trans-Pecos Texas, and Arizona (e.g., Gile et al. 1981, Mace et al. 2001, Connell et al. 2005, Hawley 2005). It is located in "Ground Water Region 7—Central Alluvial Basins" as defined by Heath (1988), and described by Anderson and others (1988). Emphasis here is on the evolution of conceptual hydrogeologic-framework models of intermontane-basin and river-valley aquifer systems in the United States part of the Mesilla Basin region (**Fig. C1-1**) between 1890 and 2010.

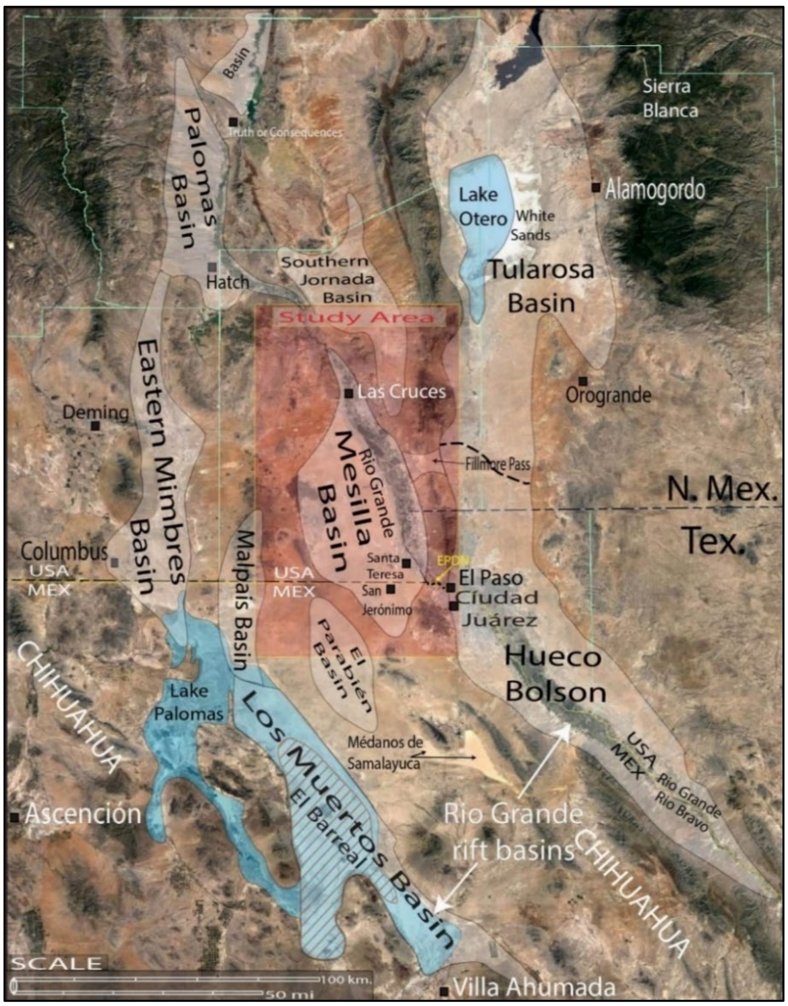

Figure C1-1. Index map of the Mesilla Basin region (MBR) showing locations of the NW WRRI Study Area (beige rectangle), major landscape features in the Mexican Highland section of the B&R province, and structural basins of the RG-rift tectonic province. Blue shading shows the approximate extent of the areas inundated by pluvial-Lakes Palomas and Otero at their respective Late Pleistocene high stands in the Los Muertos, and the Tularosa RG-rift basin areas. El Paso del Norte is shown as a yellow EPdN. Swanson Geoscience, LLC compilation on a 2017 Google Earth® image-base.

C1. PIONEERING-PHASE INVESTIGATIONS—1890 to 1945

The first part of this review comprises a series of illustrated short descriptions of seminal contributions of individuals and institutions with strong ties to the southeastern B&R province, especially studies that focused on geologic (geomorphic, hydrostratigraphic, lithofacies, and structural) controls on groundwater flow and hydrochemistry. Many subsequent advances in characterization of hydrogeologic systems in this arid/semiarid region have their conceptual roots in the cited pioneering work.

Following its establishment in 1879, the U.S. Geological Survey was the major institution contributing to hydrogeologic/geohydrologic investigations on a local to regional scale (e.g., Maxey 1979; Rabbitt 1989; Deming 2002, p. 8-11; Davis and Davis 2005; *cf.* Hawley and Kernodle 2008). Other early sources of information on the hydrogeology of the northwestern Rio Grande basin include reports by Hill (1891 and 1892b), Barker (1898), Follett (1898), Hill (1900), and Siebenthal (1910). Moreover, at least some alpine-glacial and periglacial features had now been identified in source highlands of the Rio Grande and Colorado River in the New Mexico-Arizona region (Stone, 1901).

Prior to Slichter's research on groundwater-flow in the Mesilla Valley-El Paso del Norte area, emphasis of work throughout the northern Rio Grande basin was on surface-water and stream-connected shallow aquifers (aka *subsurface waters*; e.g., Newell 1893, Follett 1898), and only one report dealt specifically with the Mesilla Valley (Barker 1898). Waring and Meinzer's (1947) "Bibliography and index of publications relating to ground water prepared by the Geological Survey and cooperating agencies (USGS Water-Supply Paper 992)," remains the most comprehensive document of its type on the history of groundwater-resource investigations in the United States between 1865 and 1945.

C1.1. Field-Based Research on the Rate of Movement of Underground Waters, by Charles S. Slichter (1864-1946)

Mathematician and geohydrologist Charles S. Slichter is internationally recognized for his pioneering laboratory and field investigations of "the motions of ground waters" (Slichter 1899, 1902, 1905a; Anderson 1995; Davis and Davis 2005). Moreover, in his "observations on ground waters of the Rio Grande valley (1905b)," Slichter made the first definitive quantitative analysis of inter-basin underflow discharge in the "Narrows of the Rio Grande near El Paso (**Figs C1-2a, b**; *cf.* **Fig. C1-7**)."

Slichter (1905b) introduced his work in the Paso del Norte (EPdN) area as follows:

> [p. 9] An investigation of the underflow of the Rio Grande was begun in the latter part of August, 1904, at the narrows of the Rio Grande, a few miles above El Paso, Tex., where the stream flows through a narrow gorge of limestone. At this place is the site of the proposed Mexican-American international dam [**Fig. C1-2a**]. At the surface of the water the distance between the walls of the gorge is less than 400 feet. The dam site has been investigated by the International (Water) Boundary Commission, organized by the joint action of the American and Mexican Governments, and maps and reports concerning the proposed dam will be found in the Proceedings of the International (Water) Boundary Commission [IBC], vol. 2, page 277.
>
> [p. 9] A brief reconnaissance at the site of the proposed international dam indicated that there could be no underflow of any magnitude at this point. The distance between the walls of the gorge is less than 400 feet, and the test borings made by the Mexican Commission in 1897 seemed to indicate that the maximum depth to bed rock is 86 feet. A cross section of the gorge, based upon the Mexican borings, is shown in fig. 2 [**Fig. C1-2b**]. In this diagram the vertical and horizontal scale are the same. A cross section of less than 40,000 square feet could not transmit a large volume of ground water even if other conditions were favorable. The highest velocity ever determined for ground water is about 100 feet in twenty-four hours, and assuming this maximum velocity at the above cross section, and a porosity of one-third in the water-bearing

sands and gravel, the daily discharge would be 1,333,000 cubic feet, or 15½ cubic feet per second. The gradient of the water plane at the narrows is but 3.8 feet to the mile, and all other indications point to a low rather than a high velocity. . . .

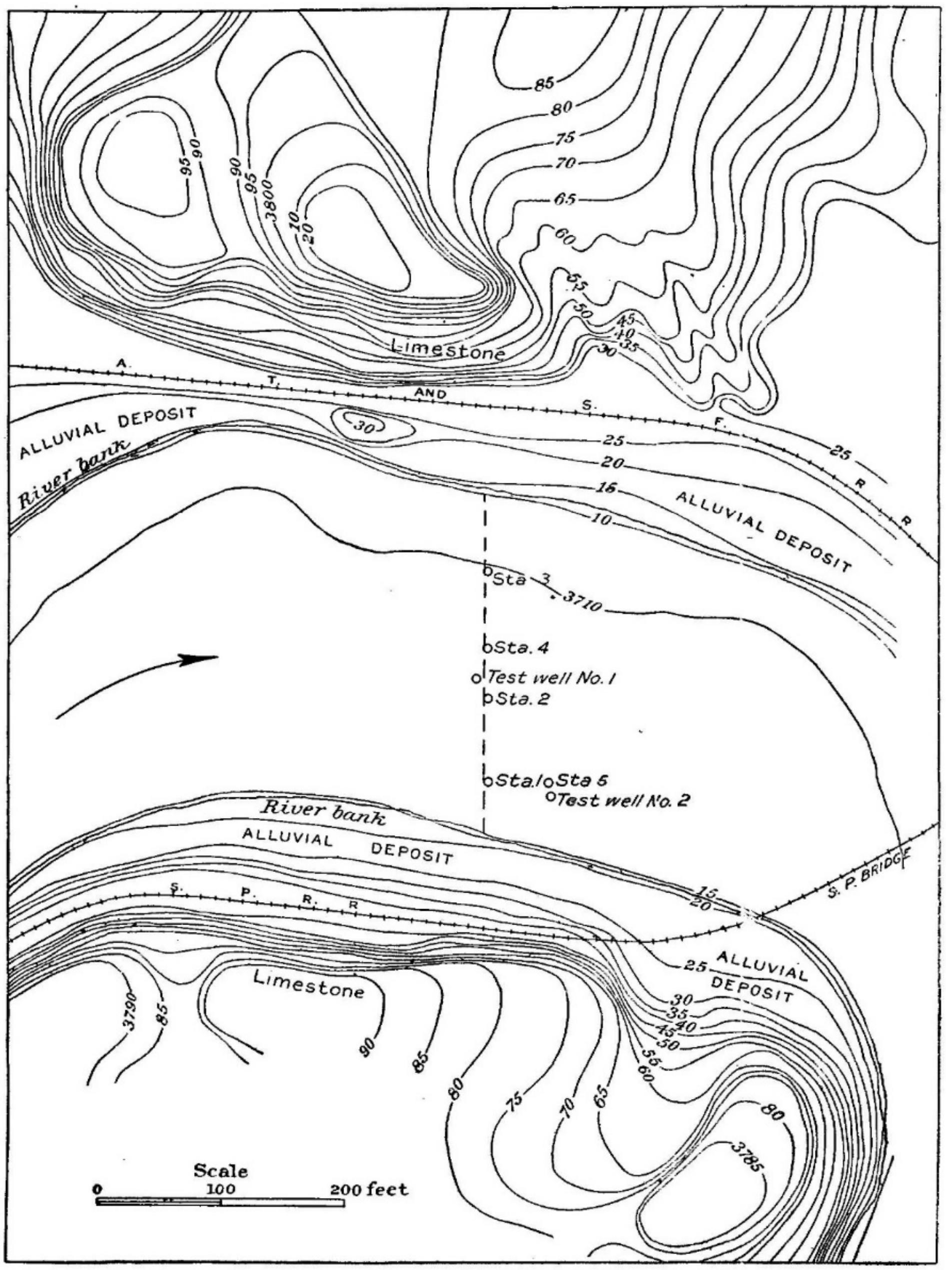

FIG. 1.—**Topographic map of the gorge of the Rio Grande above El Paso Tex., where the underflow measurements were made.**

Figure C1-2a. (Slichter 1905b, Fig. 1) First map of hydrogeologic-framework details in the "Narrows of the Rio Grande" near the northwestern end of Paso del Norte (*cf.* Part C1.2, Fig. C1-4; Darton 1933, p. 131). The north-trending dashed line shows the location of **Figure C1-2b** (Slichter 1905b, Fig. 2) and the sites of test boring for a (then) proposed "international dam (*cf.* **APNDX H5.4** [**Figs. H-2** and **H5-3**]."

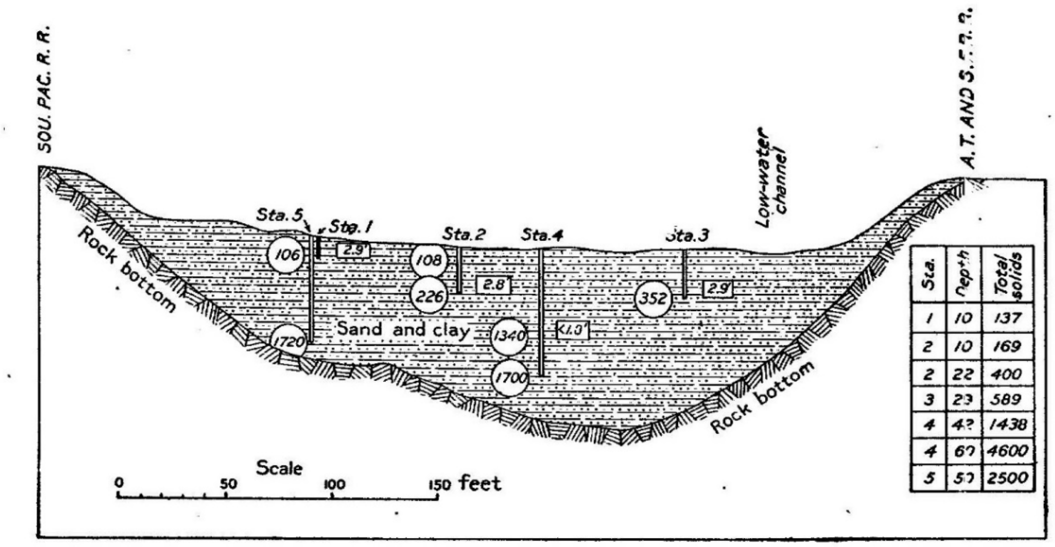

FIG. 2.—Cross section of the gorge of the Rio Grande, above El Paso, Tex., at the site of the proposed international dam.

The numbers inclosed in the rectangles give the velocity of the ground water in feet per twenty-four hours. The numbers inclosed in circles give the amount of common salt in parts per 100,000 dissolved in the ground water. The table at the right gives the depths of the test wells and the amount of total solids found in the water. The supposed rock bottom is given as determined by the Mexican borings, the vertical and horizontal scales being alike.

Figure C1-2b. (Slichter 1905b, Fig. 1) Schematic cross-section depiction of shallow-subsurface hydrogeologic and hydrochemical relationships at the Paso del Norte location shown on **Figure C1-2a**. It represents the first cartographic product of this detail to be prepared in the RG-rift region, and Meinzer (1923b, Fig. 16) used it to illustrate the basic concepts of "underflow" and "underflow corridor."

> [p. 11-12] The material in the river bed at the site of the proposed international dam consists of sand and fine gravel with occasional layers of silt. No bowlders were encountered in sinking the test wells and the borings were made with great ease. The ground waters in the sands of the gorge were found to contain a large amount of dissolved solids. At a depth of 10 feet the waters contained about 100 parts per 100,000 of common salt, and the quantity became larger as distance from the surface increased. Below a depth of 32 feet so much salt was present that it was very difficult to determine the rate of motion of the ground waters. At a depth of 42 feet the common salt in solution amounted to 1,340 parts per 100,000; at 60 feet it reached 1, 700 parts per 100,000; in a 50-foot test hole it amounted to 1, 720 parts per 100,000. The total solids dissolved in the ground water were proportionately as large as the amount of common salt, so that at a depth of 40 feet the water was about half as strong as sea water, and at a depth of 60 feet it was about 30 per cent stronger than ordinary sea water. In fig. 2 the positions of the principal test wells are shown. . . .
>
> [13] The velocities of the ground water in the tests described above are undoubtedly the maximum velocities in the narrows of the gorge, since pains were taken to make the tests in the coarsest strata encountered in the borings. Layers of fine silt were frequently met with in putting down the test wells, which probably accounts for the stagnant condition of the water below the 35-foot level. These layers of silt are undoubtedly imbricated in such a way that movement of the deeper ground waters is impossible.
>
> The total cross section in which the ground waters move is about 35 feet in depth and 325 feet in width and has an area of 11,200 square feet. If it is assumed that the porosity of the

> material is one-third and the maximum velocity of the ground water is 3 feet per day, the total discharge through the gorge does not exceed 11,200 cubic feet per twenty-four hours, or about 0.132 cubic foot per second, or about 50 gallons a minute. This amount of underflow is entirely insignificant. It is obvious that on account of the enormous quantity of dissolved solids the underflow would be worthless, no matter what its magnitude might be.

C1.2. Development of the Bolson/Semibolson Conceptual Model by Cyrus F. Tolman (1873-1942)

Stanford University Professor of Geology and Mining, Cyrus Fisher Tolman, was a pioneer in the field of hydrogeology and was author of the first textbook on *Ground Water* (Deming 2002, p. 414-415; Tolman 1937). Based on long-term field observations in the American Southwest, he (1909) was the first to make a clear geomorphic and hydrogeologic distinction between depositional systems in aggrading intermontane basins with topographic closure (*bolsons)* and those that are open in terms of both surface and subsurface flow (*semibolsons*). He recognized three basic classes of lithofacies assemblages in the continuum of closed and open basin landforms: Piedmont-slope facies (e.g., coalescent alluvial-fan) are present along the margins of both basin types, while basin floors in topographically *closed* (*endorheic*) systems include alluvial flats that grade to terminal ephemeral-lacustrine plains (e.g., *playas*, *barreals [barrials]*, and *salinas*). Floors of basins that are integrated with external (*open* or *exorheic*) surface-flow systems, in marked contrast, include alluvial flats and fluvial plains that grade to basin outlets (*cf.* Bryan 1938; **Fig. C1-8**).

The *closed* and *open*, intermontane-basin (*bolson*) landforms of the New Mexico region were major sites of definitive research on paleo-lake and ancestral-fluvial systems outside the Great Basin and Colorado River region (*cf.* Allen 2005, Connell et al. 2005, Hawley 2005). Of special importance were studies of Late Pleistocene lakes associated with USGS "Water-Supply" investigations in the Estancia, Wilcox (SE AZ), Tularosa, Animas-Cloverdale, Playas and Hachita basins (Meinzer, 1911, 1922; Meinzer and Kelton, 1912; Meinzer and Hare, 1915; Schwennesen, 1918). These pioneering studies of Late Cenozoic bolson and river-valley aquifer systems were closely linked to technological advances in deep-well drilling and the development of electric and (gas-oil) internal-combustion engines.

C1.3. Hydrogeologic Investigations in the Mesilla Basin Region by Willis T. Lee (1864-1926)

Willis Thomas Lee developed the earliest model of ancestral Rio Grande (ARG) evolution (1907b, **Fig. C1-3**), and was the first (1907a) to suggest that the Kilbourne and Hunts Hole maars (his Afton Craters) were the product of hydromagmatic-explosive processes. He (1907b) also played a key role in locating a dam at the Elephant Butte site for irrigation-water storage and flood control. Other seminal studies by Lee in New Mexico included work on evaporite-karst processes in the lower Pecos Valley (1925a), and he also led the first scientific surveys of the Carlsbad Cavern (Bat Cave) complex (1924, 1925b; Kues 2014a, p. 91-92).

The relatively advanced state of early conceptual models of Jornada (del Muerto) and Mesilla Basin hydrogeology is quite evident in the following excerpts from W.T. Lee's (1907b) Water resources of the Rio Grande Valley in New Mexico: USGS Water-Supply Paper 188 (p. 10-11, 39-40). The accuracy of Lee's interpretation of regional ancestral Rio Grande (ARG) evolution in the Mesilla Basin region is illustrated by **Figure C1-4** (Hawley et al. 2009, Fig. 9).

Figure C1-3. USGS geologist Willis T. Lee on his cutting-edge, AT&SF RR field vehicle during a Jornada del Muerto mapping expedition (*circa* 1904-1905; *cf.* Lee 1907b).

The following excerpts from "Water resources of the Rio Grande Valley in New Mexico: USGS, Water-Supply Paper 188" (p. 10-11, 39-40) illustrate the accuracy of Lee's (1907b) interpretation of hydrogeologic system evolution in the southern Rio Grande-rift region:

CENTRAL AREA—PLAINS (Lee 1907b, p. 10-11)

The second plain, locally known as "La Mesa," lies in the southern part of the Rio Grande region west of Mesilla Valley, and extends from the vicinity of Las Cruces southward into Mexico, It is similar to the Jornada in many ways. Its altitude is the same as the southern end of the Jornada, and the two formed a single plain previous to the excavation of Mesilla Valley. La Mesa has a width of 20 miles or more and is undissected by erosion and entirely wanting in lines of surface drainage. It contains several broad shallow depressions, but, unlike those of the Jornada, these do not retain storm waters for any appreciable length of time. Although inclined slightly to the south] the surface appears practically level over an area of more than 1,000 square miles.

To a depth of at least 945 feet, the depth of the deepest well, the material in La Mesa consists of clay, sand, and rounded pebbles of quartzite, argillite, and a great variety of hard igneous and metamorphic rocks, with a subordinate amount of angular, debris. The surface is notably more sandy than that of the Jornada, and wells sunk in it encounter a greater proportion of fine material than occur in the Jornada.

In the northern part of La Mesa there are gravel beds of considerable size at the surface, but these become less numerous toward the south, until near the Mexican boundary sand alone is exposed, and the surface becomes practically level. The region was not explored south of the Mexican boundary for the purposes of this report, but from the summit of the Potrillo Mountains the sandy plain appeared to continue southward unbroken as far as the eye could reach. It is probable that La Mesa is the northern extremity of the broad interior basin of northern Mexico, the lowest parts of which, containing undrained lakes, occur 25 to 50 miles south of the international boundary. At some former time this basin was probably occupied by a large lake, the northern extremity of which covered La Mesa [Bolson de Los Muertos, and Lake Cabeza de Vaca of W.S. Strain 1966 and 1971; **Figs. C1-1 and C1-4**].

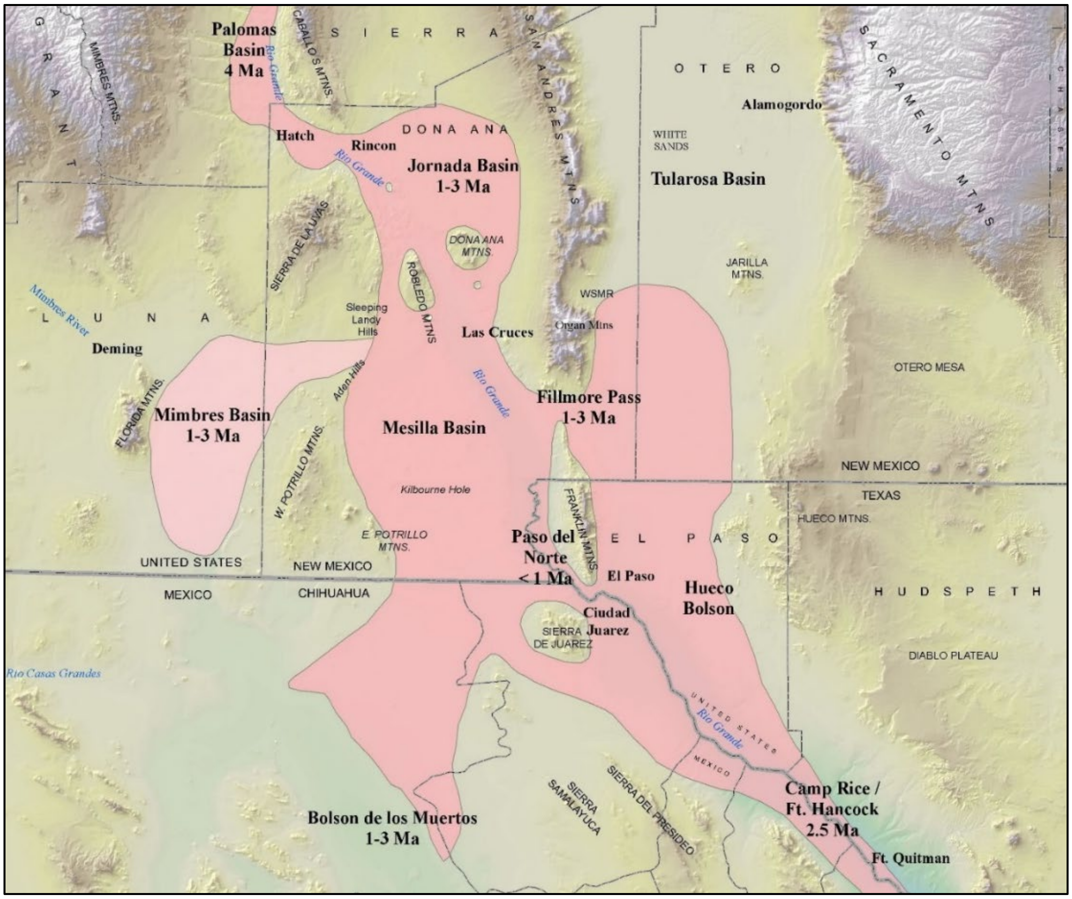

Figure C1-4. (Hawley et al. 2009, Fig. 9) Schematic depiction of Pliocene and Early Pleistocene evolution of the ancestral Rio Grande (ARG) fluvial-deltaic system in basins of the southern Rio Grande rift, with inferred age ranges. General area occupied by Upper Santa Fe Group ARG fluvial distributaries that spread out from a trunk-drainageway in the Palomas Basin above Hatch (dark pink), with a spill-out fluvial fan in eastern Mimbres Basin (light pink). ARG fluvial-plain remnants comprise the "La Mesa geomorphic surface." The inferred Bolsón de Los Muertos ARG discharge zone is also shown (*cf.* Report **Parts 3.1.4** and **3.3.2**).

Lee also inferred that "the ancient Rio Grande flowed through the Jornada and La Mesa into the interior [Los Muertos] basin of Mexico, and that in comparatively recent geologic time changes occurred which turned it out of its valley [West Mesa area] and away from the interior [Los Muertos] basin toward the Gulf of Mexico (Lee 1907b, p. 22; **Fig. C1-2b**)." His observations on the hydrogeologic framework and groundwater-flow regime of the "LA MESA DISTRICT" are equally prescient.

UNDERGROUND WATERS—LA MESA DISTRICT (Lee 1907b, p. 39-40)

La Mesa district lies in the southern part of the Rio Grande region west of Mesilla Valley. Wells have been sunk in various parts of this district, both for railroad use and for stock purposes. No solid rock was encountered in any of the wells, most of which find water in abundance, but at a considerable depth, as indicated in Table 5 [**Tbl. C1-1**]. The deepest well on La Mesa, 945 feet, was bored by the Southern Pacific Railway Company at Lanark.* The company owns two other wells at the same place, one 648 feet and one 615 feet deep, the three yielding 50 gallons of water a minute. The material penetrated is sand with small waterworn pebbles, and contains water below a depth of 380 feet.

Table C1-1. (facsimile copy of USGS Water-Supply Paper 188, Table 5—Records of bored wells in La Mesa district (Lee 1907b)). Note that three wells (Herrington, Noria, and Potrillo) are on or near the former "El Paso and S.W. Rwy." route, which is now the location of NM State Highway 9. The E.P. & S.W. and S.P. Rwy. Co. well are completed in ARG deposits (*cf.* Report **Part 3.4**).

TABLE 5.—*Records of bored wells in La Mesa district.*

Owner.	Location.	Total depth.	Depth to water.	Power used.	Material encountered.
		Feet.	*Feet.*		
Henry Brock	Sec. 30, T. 25 S., R. 2 W.	240	221	Gasoline	Sand and waterworn gravels.
Do	Sec. 7, T. 24 S., R. 1 W.	430	386	do	Do.
Do	T. 24	515			Clay.
Mr. Hawkins	5 miles west of Picacho Mountain.	218	170	Gasoline	
Robert Herrington	2 miles northwest of Noria.	435	350	do	Sand and gravel.
J. F. Kilburn	T. 27 S., R. 1 W.	[a] 478	408		Do.
Do	6 miles northwest of Lanark.	388	370	Gasoline	Sand and waterworn gravel.
S. P. Rwy. Co.	Lanark	945	380	Steam	Do.
Lewis Bros	5 miles northeast of Lanark.	365	340	Gasoline	Sand and gravel.
J. B. Stahling	10 miles west of Lanark.	[b] 460	440		
Do	6 miles west of Lanark	350	311	Gasoline	
El Paso and S. W. Rwy.	Potrillo	240	220	do	Sand and clay.
Do	Noria	438	358	do	Sand and gravel.

[a] 170 feet in bottom of crater. [b] 200 feet in bottom of crater.

Since the altitude of Lanark is 4,156 feet, the altitude of the water surface is 3,776 feet, while that at Bosque Seco, in Mesilla Valley, 15 miles northeast of Lanark, is 3,800 feet - 24 feet higher than at Lanark. At Noria, the altitude of which is 4,114 feet, the water surface, 358 feet below the surface of the land, is 3,756 feet above sea level. In the 12 miles between Lanark and Noria the water surface inclines to the south 20 feet, or at an average rate of 1.7 feet per mile. A line drawn through Bosque Seco, Lanark, and Noria would run somewhat west of the center of the old debris-filled valley of the Rio Grande for a distance of 27 miles. Along this line there is a fall of the water surface of 44 feet, or an average of 1.7 feet per mile. The gradient of the water table in Mesilla Valley between Bosque Seco (3,800 feet) and the southern end of Mesilla Valley (3,680 feet), a distance of about 32 miles, is 3.7 feet per mile. It is evident from these facts that the surface of the underground water has a regular gradient down the old channel through La Mesa, although it is less than the gradient of the river. A line of wells a few miles farther east in the center of the old valley would probably show a steeper gradient of the water plane.

The facts upon which the determination of gradient rests are not sufficiently numerous to make it conclusive. The depths to water determined and the indications that La Mesa is a part of the ancient debris-filled valley naturally leads to the inference that the course of the underflow should be southward through the detritus of La Mesa. It is possible, on the one hand, that additional data will show a gradient steeper than 1.7 feet per mile. On the other hand, it is possible that the original course of the underflow down the old channel has been reversed by reason of the down cutting of the river in Mesilla Valley and the accumulation of surface water in the gravels of La Mesa. The latter possibility is strengthened by the facts that La Mesa is nearly level and the material so porous that rain enters it without producing even temporary streams.

With respect to the future role of aerial photography in the earth sciences, and the constant need for ground truth, Lee also made these prescient observations (1922, p. 1-2):

The navigation of the air has accomplished much in many fields. Not only does it offer a new means of efficiency in [a variety of governmental], commercial and scientific pursuits. . .; but it has also opened a new world to the geographer, the photographer, and the geologist.

The ability of the camera to make instantaneous exposures and fix a clear image on a photographic plate enabled the [aerial] observer to obtain a record not only the scenes that he had viewed by also many that he might have missed . . . Immediately inventive genius was set to work to adjust the mechanisms of the camera to the demands of air photography and to prepare . . . films and sensitized paper necessary for the best results.

So satisfactory were the results and so great are the possibilities of further adaptation that there is an unfortunate tendency on the part of certain enthusiasts to make exaggerated claims that may retard progress. This is particularly true in the use of the air photograph in mapping. . . It cannot be reasonably expected to do away entirely the work of the ground surveyor. . . Observations from the air can never take the place of close examination of the ground, but it can be of great use in the location and study of land forms and geologic relations. Air photography is only an added means of obtaining information, although it promises to be a very important means.

C1.4. Early Advances in the Technology (and Art) of Drilling Deep Water Wells

Deep-well drilling in the 1890-1940 period was done very efficiently with cable-tool rigs such as the one at the Lubbock, TX National Ranch Heritage Museum shown in **Figure C1-5** (Bowman 1911; Meinzer and Hare 1915, p. 118).

Figure C1-5. Vintage cable-tool rig at the Lubbock, TX National Ranch Heritage Museum (*cf.* Bowman 1911, and Meinzer and Hare 1915, p. 118).

The following excerpt from Meinzer and Hare (1915, p. 118) illustrates the type of equipment that was used in drilling the deep wells that were required to supply the first steam railway operations throughout the binational Mesilla Basin region:

> The valley [basin] fill is easily penetrated, and, except near the mountains where bowlders are encountered, it presents few difficulties in sinking wells.
>
> Most of the domestic wells are dug a short distance below the water table and are about 3½ feet in diameter. Some shallow wells have also been bored with augers propelled by hand. Where the water level is far below the surface, however, or where sinking to considerable distances below the water level has been necessary in order to obtain larger supplies or water that is less mineralized, machines propelled by horsepower, steam, or gasoline have been used.
>
> The machine most commonly used for sinking these deeper wells is the portable standard [cable-tool] rig with percussion drill attached to a cable, the drill being withdrawn at intervals and the drillings removed by means of a bailer or sand bucket [**Fig. C1-5**; Bowman (1911) USGS WSP 257]. A machine of this type is among the most reliable for exploration work, especially where deep drilling is involved, and it is also well adapted for drilling through deposits containing bowlders or hard layers. By its use water-bearing beds are generally detected, even though their yield is not great.

C1.5. New Mexico's First "State Geologist:" N.H. Darton (1865-1948)

The field-based investigations of Nelson Horatio Darton (Kues 2014b) covered an enormous geographic and geologic-conceptual area (Darton 1899, 1905, 1914, 1916a-b, 1917, 1922, 1928a-b; Darton et al. 1916). His contributions to Late Cenozoic geology included formally naming the Ogallala Formation (1899, 1905). He was also a pioneer in the use of modern subsurface-mapping methods in his characterization of Luna County's Mimbres basin aquifer system (1916a, **Fig. C1-6**).

Darton compiled the Deming folio for the Geologic Atlas of the United States series (1917), and other examples of these visionary synoptic coverages of geology, mineral resources, water supply, and soil conditions include the El Paso and Silver City Folios, respectively by Richardson (1909) and Paige and Darton (1916). Darton's "Red Beds of New Mexico" (Darton 1928b) represents the first comprehensive map (a) and overview (b) of New Mexico geology. Of special importance in hydrogeological studies in the Mesilla Basin region (MBR), however, is his 1933 compilation of the first detailed-reconnaissance geologic map of the southern part of the Mesilla Basin and bordering mountain uplifts.

Like present-day NMGS Field Conference Guidebooks, the geologic railroad guides compiled by Darton and USGS associates (e.g., 1916, 1933) are invaluable sources of information not only on the local geologic and geomorphic setting, but also on its history and economy. Darton's 1933 "Guidebook of the Western United States—Part F. The Southern Pacific Lines (USGS Bull. 845)" covers the present Union Pacific RR route that crosses the southern Mesilla Basin from the western Hueco Bolson and El Paso del Norte to the east-central Mimbres Basin (**Fig. C1-7**).

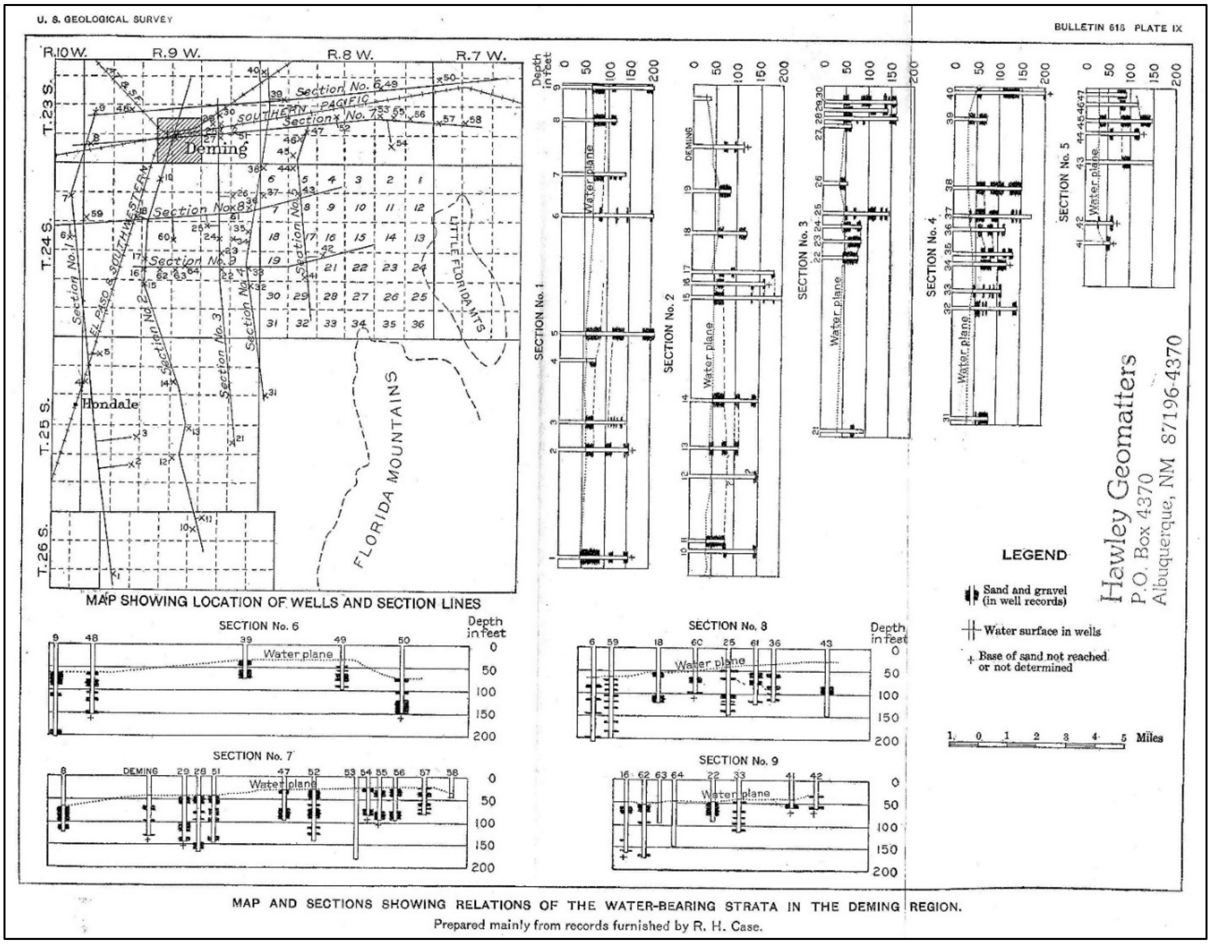

Figure C1-6. (Darton 1916b, Plate IX) First 3-D (fence-diagram) portrayal of lithofacies relationships in the shallow basin-fill aquifer system (Upper Gila Gp) in the Deming area of the central Mimbres Basin.

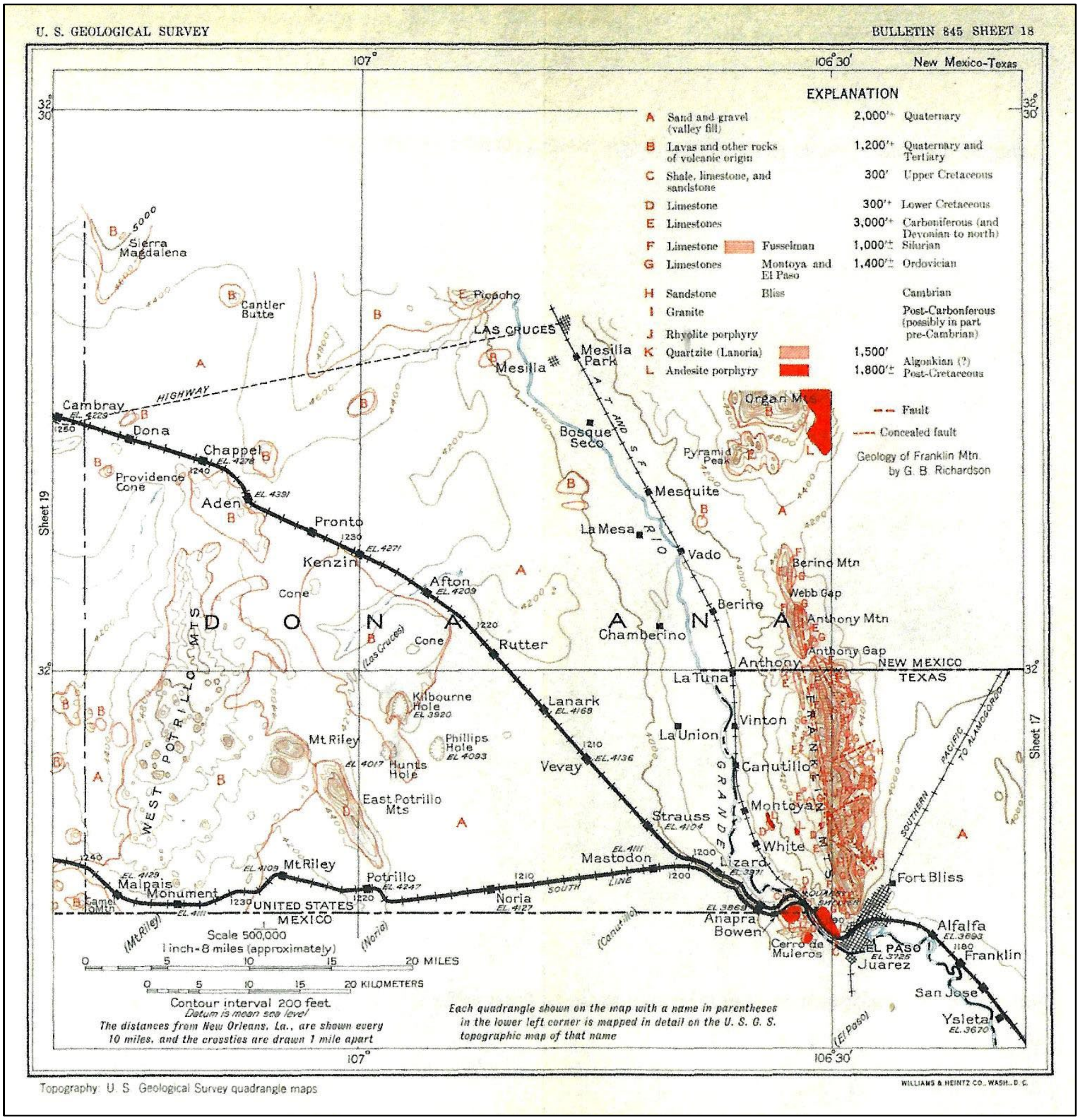

Figure C1-7. (facsimile copy of USGS Bulletin 845, SHEET 18) First reconnaissance geologic map of the Mesilla Basin region by N.H. Darton (1933). Bulletin 845 includes detailed commentary on geology and history along (1) the mainline of the Southern Pacific RR (now Union Pacific) between the El Paso, TX and Cambray, NM area, and (2) the southern (now abandoned) SPRR route between El Paso and Malpais Siding, NM (Darton 1933, p. 123-136, and p. 162-164; *cf.* Lee 1907b, Richardson 1909, Seager et al. 1987, Seager and Mack 1994, Seager 1995, Collins and Raney 2000, Hoffer 2001b).

Most descriptions of geology and hydrogeologic features in USGS Bulletin 845 retain their conceptual validity, as evidenced by the following extended passages, which start with entries on the El Paso area (elev. 3,725 ft/1,135 m; 1930 population about 131,500):

> [p. 125] In 1852 a post office, called Franklin [after local land owner Franklin Coonze] was established here, and in 1859 the name was changed to El Paso. There was no town

development until after the Civil War—. . . . A few years after hostilities ceased a triweekly schedule was established for this region. The railroad reached El Paso from the east in 1883, and in the next few years brought many immigrants to the Rio Grande Valley. Since that time the city has had rapid growth.

El Paso has long been prominent as headquarters for the mining industry, although there are no notable mines in its immediate vicinity. For many years it has had the largest custom smelter* in the United States, . . . and treating [gold, silver, copper and other] ore[s] from New Mexico, Arizona, and Texas [and Mexico]. In 1930 the Nichols copper refinery was completed on the eastern edge of the city. Just west of this refinery are the Pasotex and Texas Co. oil refineries, which receive crude oil by a long pipeline from the Winkle field in Texas. Another pipeline brings gas to El Paso. The large cement plant on the western edge of the city furnished cement for the Elephant Butte Dam; it utilizes the limestone of the [Lower Cretaceous] Comanche series. Beaumont Hospital is a large Government establishment for tubercular soldiers, and Fort Bliss, 5 miles [8 km] northeast of the center of the city, . . is the largest cavalry post in the United States. The Texas College of Mines [UTEP], a branch of the University of Texas, and Loretto College are also in El Paso. . . .

American Smelting and Refining Corporation (ASARCO) operation in El Paso del Norte (EPdN; USGS Bull. 845, PL. 18A). See discussion of environmental impacts in **APPENDIX H, Part 9.3.*

[p. 126] In New Mexico and Texas above El Paso the Rio Grande flows in a wide valley of alluvium [the Mesilla Valley], bordered by a high terrace plain [La Mesa surface]; . . . . At El Paso the valley is constricted to the narrow rock-walled pass that gives name to the city, but the bordering high terrace continues far down the valley. Below the pass the alluvial plain [El Paso/Juárez Valley floor] is a broad flat in which the river meanders widely, often changing its course by cutting new channels at time of freshets. The high terrace plain [western Hueco Bolson floor] that borders this valley terminates in bluffs and steep slopes, in places as much as 200 ft [61 m] above the bottom lands. The smooth [ARG-fluvial] plain at the top of these bluffs [La Mesa surface] extends far north as a wide bolson or desert flat between mountain ranges. Near El Paso there are several distinct benches, 3,800 to 3,950 feet above sea level, mostly in the form of mesas or projections from the base of the Franklin Mountains. These benches slope gently toward the river and are in part capped by caliche, an infiltration of calcium carbonate in the sand, which makes a material so hard that it helps preserve the tabular form and sharp edges of the mesas.

[p. 126-127] The Franklin Mountains form a high ridge on the southern prolongation of an axis of uplift which extends across central New Mexico from the Rocky Mountains. Probably this uplift is cut off to the south by a fault. The range rises abruptly about 3,000 feet [900 m] above the adjoining plains or valleys and culminates in Mount Franklin [north, alt. 7,192 ft/2,192 m]. The west side is mainly a dip slope of heavy beds of limestone with pronounced westerly dip; the east side shows many ridges, irregular lower crests, and buttes, and [is] deeply cut by canyons. The range is a typical tilted block of the basin-range type, which predominates in a large part of the Southwest.

[p. 128] . . . . The mountains to the south, in Mexico, are the Sierra Guadalupe [de Juárez] and the Cerro de Muleros [del Cristo Rey].

Wells in El Paso are to have penetrated valley fill [SFG basin fill] to a depth of 2,285 ft (696 m). Fossil bones found in Quaternary deposits have been determined as *Elephas Mammuthus] columbi*, *Equus complicatus*, and *Tapirus haysii?*, representing an elephant, an ancient horse, an a tapir, all of which have been extinct for many centuries [millennia] . . . .

[p. 128-129] The Southern Pacific [now Union Pacific] lines enter New Mexico on crossing the Rio Grande just west of El Paso, the State line being in midstream. . . .

[p.131] NORTH LINE FROM EL PASO, TEXAS TO MESCAL, ARIZONA

From El Paso westward to Tucson the Southern Pacific Railroad has two lines—one going by way of Deming and Benson [present UPRR] and the other (former El Paso & Southwestern Railroad [now abandoned]) by way of Columbus and Douglas [now route of NM Hwy. 9; **Fig. C1-7**; *cf.* Rpt. **PL. 9k**]. Leaving El Paso, the north line of the railroad follows the north [NE] bank of the Rio Grande for some distance, with Mexico in plain view on the opposite bank. In about 1 mile a large [ASARCO] smelter is passed, and in 2 miles a cement plant, near which are large quarries in limestones (of Comanche or Lower Cretaceous age) in a downfaulted block at the south end of the Franklin Mountains. It is the presence of this rock and a mass of intrusive [Campus Andesite] porphyry that cause the [EPdN] constriction of the river valley at El Paso (Spanish, the pass). At the entrance of this pass the railroad crosses the river into New Mexico and skirts the north side of Cerro de Muleros [del Cristo Rey], a high ridge which lies mostly in Mexico. . . .

[p. 131-132] The Cerro de Muleros consists of a mass of limestone, shale, and sandstone of [Lower] Cretaceous age penetrated and tilted by a large mass of [Eocene andesite] porphyry. The lower or quarry limestone in this succession is well exposed in the first railroad cut west of the river. It is overlain by nodular and slabby limestones and shales containing large numbers of Washita fossils and grading upward in to a thick mass of dark shale in which there are deep cuts extending to and beyond Brickyard siding. This shale is extensively worked for brick, hollow tile, etc., on the west bank of the river below the 2 railroad bridges. . . .

[p. 132] Just above Anapra siding [alt. 3,869 ft/1,179 m; pop. 27], where north [main SPRR] and south [now abandoned] lines are close together and joined by switches to be used in case of necessity, the railroad grade ascends the terrace of valley fill [Upper SFG], the edges of which margins the Rio Grande Valley in a long line of steep slopes. The top is attained near Strauss siding [alt. 4,110 ft/1,253 m]. Along the upgrade are many fine exposures of gravel and sand of which the terrace is composed. This material was deposited by the Rio Grande at an earlier stage of its history, when it flowed west of the Cerro de Muleros [Cristo Rey] and another high range to the south [Sierra de Juárez] and emptied into Guzman [Los Muertos] Basin in Chihuahua, Mexico. This was before its present course was developed through the "pass" at El Paso [*cf.* Lee 1907b, p. 10-11] . . . .

[p. 133] From Strauss siding the railroad goes northwest over the wide alluvial plain that extends entirely across the southwestern part of New Mexico. . . . The northerly trend of the railroad in this area is taken to avoid the large rugged area of volcanic rocks [basalt flows] of the West Potrillo Mountains and its extension to the north.

The thick body of sand and gravel underlying the plain has been drilled for water at several points along the railroad. A boring at Lanark [alt. 4,168 ft/1,270; pop. 40] passed through 950 ft (390 m) of beds, all supposed to be valley fill but possibly including some underlying Tertiary or Cretaceous strata [Lee 1907, Tbl. 5; Rpt. **TBL. 1**, no. 239]. It found water which rises approximately to the level of the Rio Grande Valley, 15 [8 mi/13 km] miles east. A boring at Kenzin [at eastern edge of Aden-Robledo Uplift], several [15 mi/24 km] miles beyond Lanark, passed through 550 feet [168 m] of clay and sand with water in its lower part and continued through [Lower Tertiary andesitic] rock 527 feet [161 m] farther.

Beyond Rutter siding great [basalt] lava fields are in sight to the southwest, and near Afton and Kenzin sidings [alt. 4,203 ft/1,281 m and 4,271 ft/1,302] the tracks skirt the edge of a fresh recent-looking [Aden/Afton] lava flow ….

[p. 134] Eight miles [13 km] southwest of Rutter siding are two large "holes" in the wide terrace plain [La Mesa surface] which have been the source of much wonderment for many years. They were originally called Los Corrales de Piedra (rock corrals). The more northerly, Kilbourne Hole, …, is 300 ft [91 m] deep and is encircled with a rim of loose material 50 to 150 feet [15 to 46 m] high, so that in places it has a total depth of 450 feet [137 m],…. Hunts Hole, 2 miles [3.2 km] to the south, is closely similar but smaller and has a rim of less height…. The material in the wall of Kilbourne Hole (*see* fig. 28 [*from* Lee 1907a]) is stratified [Upper SFG-ARG] sand similar to that which underlies the wide surrounding [La Mesa] plain, capped by a 15-foot [5 m] layer of [basalt] lava, which thins out to the southeast. The encircling rim is composed mostly of soft sandstone, strongly cross-bedded and including some cinders, fragments of pumice, and many angular blocks of lava. A remarkable fact is that much of the cross-bedding slopes toward the hole. It is believed that these two holes were caused by a volcanic explosion probably with outburst of water. Steam doubtless accumulated in sand under the lava sheet until the pressure was sufficient to cause the explosion.

In the sand penetrated by a 170-foot [52 m] boring in the Kilbourne Hole, part of the jaw of a Pleistocene horse was found at a depth of 70 feet [21 m], possibly in material that caved from the sides of the hole. At the bottom of the boring a large accumulation of warm Sulphur water was found.

[p. 134] Through Kenzin, Pronto, Aden, Chappel, and Dona sidings lava field are in sight in every direction, especially on the south side of the railroad; most of them are recent outflows of scoriaceous basalt, but some are rhyolite [and basaltic andesite] of Tertiary age.

Aden Crater, 4 miles [6 km] south of Pronto siding and 7½ miles [12 km] southeast of Aden siding, is a cone of lava undoubtedly marking the vent from which came one of the large recent lava flows skirted by the railroad in this vicinity. In its top is a deep blowhole or steam vent in the lava, in which many animal skeletons have been found, including coyotes, bobcats, and other animals of the present fauna, and a remarkable ground sloth which Lull[1] has identified as *Nothrotherium shastence*. The remains were partly buried in bat guano in a sloping chamber about 100 feet [30] below the surface. The bones of the sloth were held together by the original ligaments, and some of the periosteum, patches of skin, muscle fibers, and claws remain. Most of the hide has been devoured by fellow victims, whose teeth marks are visible on the remaining fragments. The sloth and other animals had evidently fallen into this hole, which is a natural trap in the crater rim. The time was many thousands of years ago, for the sloth is a species found also in the Rancho La Brea asphalt in Los Angeles, where it occurs with bones of middle [and late] Pleistocene age.

[1]*Lull, R.S., 1929, A remarkable ground sloth: Yale University Peabody Museum Memoir, v. 3, part 2, 21 p.*

Just south of Aden [siding, alt. 4,391 ft/1,338 m] is a prominent knob of rhyolite [Mount Aden] of the older volcanic series with a basalt flow at its foot, and 3 miles [5 km] west are other [p. 136] knobs of [Bell Top] rhyolite tuff capped by [Uvas] basalt of the older [Oligocene] succession. The volcanic area here [now in NE part of Mimbres River basin] extends so far north as to cause considerable deflection of the railroad to reach a long tangent that passes through Chappel [siding, alt. 4,279 ft/1,304 m] and extends [sub-parallel to I-10] beyond Carne [siding, elev. 4,193 ft/1,278 m].

At Chappel the lava fields are left behind, but detached igneous masses are in sight not far to the south and north. Two miles [3.2 km] south of Dona siding [near Doña Ana-Luna County Line] is the very prominent Providence Cone, rising nearly 300 feet [90 m] above the surrounding desert plain. . . . Far to the west from this place extends the level-floored Mimbres [River] Valley, which merges into the Lake Guzman [Bolsón de los Muertos] Desert, Mexico. This extensive basin has no surface outlet to the Rio Grande.

Near Cambray [alt. 4,229/1,289 m; pop. 40], the highway [now I-10] crossed the railroad; and after following the track for some distance, goes due west to Deming.

C1.6. Field-Based and Government-Administrative Contributions to Geohydrology and Hydrogeology by O.E. Meinzer (1876-1948)

Oscar Edward (O.E.) Meinzer is widely regarded as the "father of groundwater hydrology (Hackett, 1964)." His most significant contributions to hydrogeology were in two specialty areas: Basin and Range hydrologic systems, and federal-government service (Maxey 1979, Fryar 2007). Almost all of his early (1907-1912) fieldwork was done in the New Mexico region, but duties as Chief of the U.S. Geological Survey, Ground Water Division (1912 to 1946) occupied most of his professional life (Deming 2002, p. 86-87). It is important to note here that the first appointee to his 3-person staff was 24-year-old Kirk Bryan, a 1909 UNM geology graduate (*cf.* **Part C1.4**). Meinzer "connected" with the physical and cultural landscape of the New Mexico region at the very beginning of his career, so it seems reasonable to infer that many of his later contributions of national significance were strongly influenced by this early field experience. Major contributions to Basin and Range province hydrogeology are summarized in the following excerpt from Hawley (2014b, p. 117-118):

> Meinzer's first USGS publications dealt with the hydrogeology of closed intermontane basins of central New Mexico and southeastern Arizona. These "Geology and water resources" reports were released between 1911 and 1915, although most of the fieldwork was completed by 1912, and include Meinzer (1911) on the Estancia-Encino Valley area; Meinzer and Kelton (1912) on the Sulphur Springs Valley of southeastern Arizona (pluvial-Lake Cochise basin); and Meinzer and Hare (1915) on the Tularosa (pluvial-Lake Otero) Basin. They are still recognized as the seminal hydrogeologic studies on pluvial-lake basins in arid to semiarid parts of the American Southwest (Allen, 2005; Hawley, 2005; Hawley and Kernodle, 2008). Even cursory review of the many maps and photographs in these early papers shows how productive this pre-automotive era, Illinois "farm boy" could be when quality field work was facilitated by lots of equine and/or *shanks-mare* assistance.
>
> Following additional field studies in the Big Smoky Valley area of east-central Nevada, Meinzer synthesized his "pluvial-lake" research in a 1922 paper *Map of the Pleistocene lakes of the Basin and Range province and its significance*. This is the first lucid description of "the extent to which ancient lakes would be restored by lowered temperatures (Waring and Meinzer, 1947, p. 193)." He also proposed that hydrologic conditions conducive to lake formation in the cool-dry northern Great Basin region were valid modern analogs of Late Pleistocene paleohydrologic systems in the relatively warm-dry playa-lake basins of the southeastern Basin and Range province. In addition, the Meinzer and Kelton (1912) Sulphur Springs Valley report exemplifies a pioneering "integrated, joint investigation of chemical and physical hydrogeology (Meyer et al., 1988, p. 5). While the above-cited publications relate to Meinzer's direct contributions to geologic research in the New Mexico region, they also help explain his future effectiveness in federal-governmental science and administration, particularly when prior Midwestern rural-life and educational experiences are taken into account.

C1.7. Hydrogeologic Contributions by Albuquerque Native, Kirk Bryan (1888-1950)

Albuquerque native and 1909 UNM graduate, Kirk Bryan (1888-1950) is now primarily recognized for his contributions to geomorphology and geoarchaeology (Sharp 1993, Leopold 2004). From all perspectives, Bryan, his Harvard students (including Luna B. Leopold), and many professional colleagues have been major figures in the fields of geomorphology and Late Cenozoic geology since the early 1920's. He was a major contributor to the development of current models of hillslope-landform evolution, and many other aspects of physiography in both semiarid and humid regions (Bryan 1923, 1925, 1936, 1940a-b, 1941; Bryan and McCann 1937, 1938). Much of his career, however, was devoted to field investigations in Arizona and New Mexico (Hawley 2005; Hawley and Kernodle 2000, 2008; Hawley et al. 2001; Phillips 2014).

Bryan joined O.E. Meinzer's new USGS Division of Ground Water in 1912, and his important hydrogeologic contributions include development of the first synoptic conceptual model of basin-fill aquifer systems in the Rio Grande rift tectonic province. This work is summarized in the "Geology and ground-water conditions of the Rio Grande depression in Colorado and New Mexico" (Bryan 1938) for a "[US] National Resources Committee . . . Regional Planning" publication, which also included C.V. Theis' first detailed review of "ground water in the middle Rio Grande valley" (*cf.* Theis 1935a, b; 1938).

As earlier done by W.T. Lee (1907b), Bryan recognized that the river-linked series of deep structural basins, which extend from southern Colorado to Trans-Pecos Texas, form a unified geologic and geohydrologic system. This regional tectonic feature, which Bryan initially named "the Rio Grande depression," is now designated the Rio Grande rift (RG-rift; Kelley, 1952; Chapin, 1971; Chapin and Seager, 1975; Hawley 1978; Riecker 1979; Keller and Cather 1994). Bryan's (1938) major contribution to upper Rio Grande basin evolution was his observation that (p. 205): "The main body of sedimentary deposits of the Rio Grande depression, from the north end of the San Luis valley to and beyond El Paso, is considered to be the same general age and to belong to the Santa Fe formation…." In general, the basins appear to have been elongated into ovals and to be divisible into two major types: basins with a through-flowing river and basins with enclosed drainage." He also noted (p. 221) that basins of the Rio Grande depression "differ from other basins [in the B&R province] principally in being strung like beads on a string along the line of the Rio Grande."

In comparison to Tolman (1909 and 1937), Bryan's 1938 conceptual model of intermontane-basin hydrogeologic systems was developed in much greater detail and presented in a semi-quantitative format. **Figure C1-8**, adapted by Hawley and Kernodle (2008) from Bryan (1938, Figures 51 and 52), clearly demonstrates a basic understanding of integrated surface and subsurface flow regimes in "completely enclosed" and "incompletely enclosed" basins of the "Rio Grande depression," and similar geologic terranes throughout the Basin and Range province. This robust model of groundwater flow systems in a variety of *bolson* and *semibolson* hydrogeologic settings was originally used in implementing the 1938 Rio Grande Compact, and in continues to serve as a definitive, basin-scale geohydrologic model.

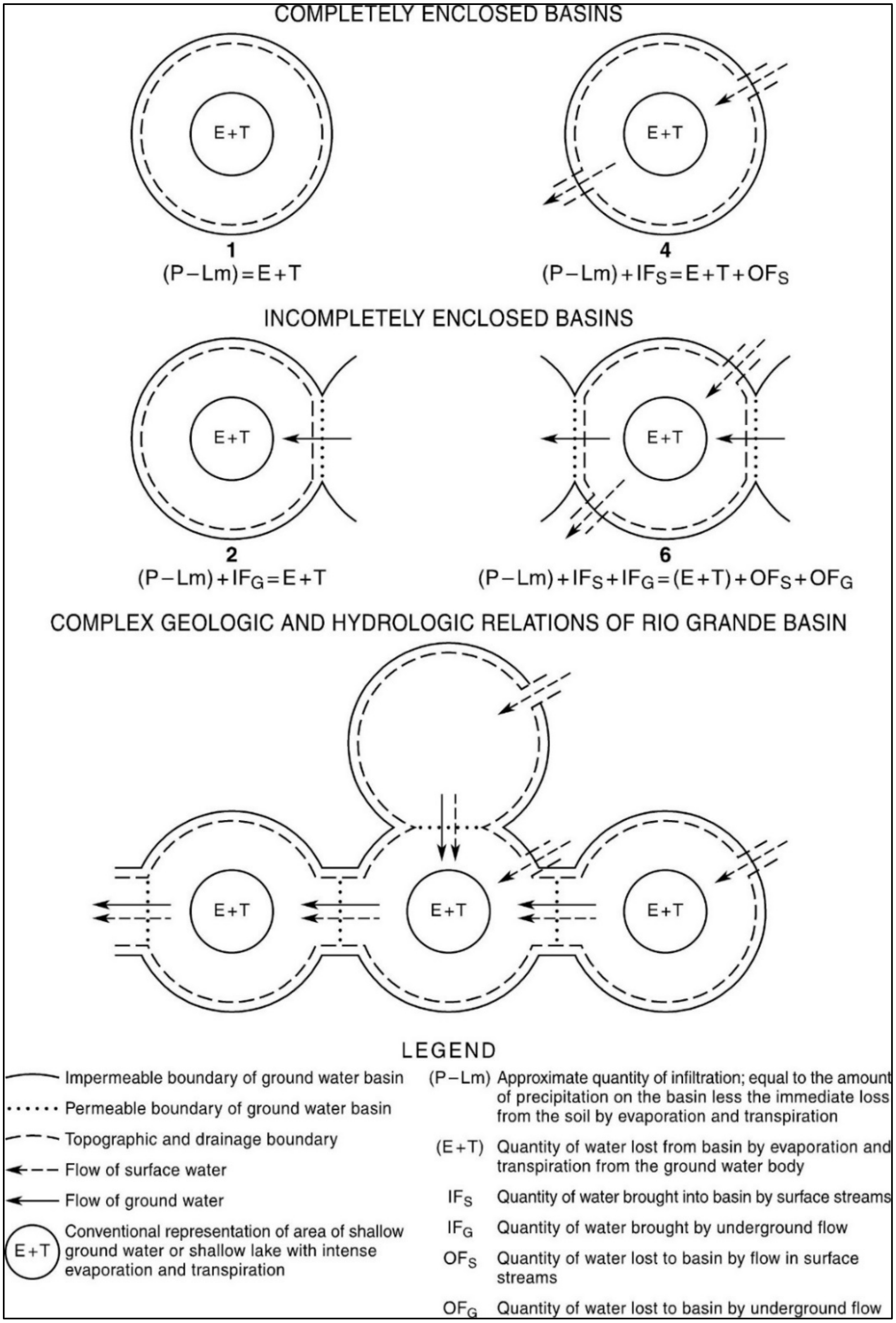

Figure C1-8. Conceptual model of geologic and hydrologic relations in intermontane basins of the Rio Grande "depression." *From* reformatted version of Bryan (1938) *in* Hawley and Kernodle 2008, Figs. 51 and 52.

C1.8. Exploration Geophysics and Hydrogeology in the El Paso Area

Notable USGS contributions to early groundwater-resources studies in the El Paso area include the pioneering work of A.N. Sayre and E.L. Stephenson (1937) on the use earth-resistivity geophysical-survey methods to locate "salt-water bodies" in local basin-fill aquifers. Another seminal "ground-water" investigation by Sayre and Penn Livingston, which was completed before World War II, was done in cooperation with the El Paso Water Board and the Texas State Board of Water Engineers. Their 1945 Water-Supply Paper (919) includes descriptions of geology, ground-water occurrence, and available water-quality information. B.J. Hibbs (2/15/2021 written communication) states that (1) the "first transboundary water table map was also generated by Sayre and Livingston (1945, Fig. 4)," and (2) it was based on data "compiled in Sayre and Livingston (1945, appendices labeled Well Logs, Records of Water Levels in Observation Wells in El Paso Area, Deep Wells Analyses of Water, and Records of Wells in the El Paso Area." He notes that: "While hydrogeologic problems from aquifer overdraft took more time to develop than predicted by Sayre and Livingston (1945), their report set in motion accelerated inventories of groundwater resources in the United States and Mexico and established beneficial data exchanges."

C2. MULTI-INSTITUTION HYDROGEOLOGIC/GEOHYDROLOGIC INVESTIGATIONS—1945 to 1971

Throughout the United States, the WW II and early post-war period witnessed the development of strong collaborative ties between geologists and hydrologists involved in groundwater investigations. In the New Mexico–Trans-Pecos Texas region, this was primarily due to the continued leadership role played by the USGS-Water Resources Division (WRD), NM Office of State Engineer, NM Bureau of Mines & Mineral Resources at NM Tech, Texas Water Commission, and (after 1964) the NM Water Resources Research Institute at NMSU (e.g., Conover 1954, Knowles and Kennedy 1958, Reeder 1957, Leggat et al. 1962, Spiegel 1962, and Spiegel and Baldwin 1963, Trauger and Doty 1965, Cliett 1969, Hawley 1969a, King et al. 1971, Trauger 1972). Report **Figure 1-4** is an index map of the Mesilla Basin Study Area that shows locations of groundwater-basins, hydrogeologic cross-sections (**A-A′** to **S-S′),** population centers, and major landscape features, including the Mesilla Valley of the Rio Grande.

C2.1. USGS Studies in the Rincon and Mesilla Valley Areas—1946 to 1954

Figure C2-1 illustrates the initial developmental stage of potentiometric-surface maps that schematically depict GW-flow trends in the United States part of the Mesilla Basin region. This 1954 map by Clyde Conover (Plate 1) shows approximate 1947 water-level contours in central and southern Doña Ana County, New Mexico. Estimated depths to water in the 300 to 400-ft and > 400 ft ranges are shown, respectively, with light greenish yellow and green dotted patterns. This and subsequent maps comprise an invaluable history of ground-water flow evolution during the past 75 years (*cf.* King et al. 1971, Wilson et al. 1981, Frenzel and Kaehler 1992, Nickerson and Myers 1993, and Teeple 2017a).

C2.2. Cooperative Investigations in Lower Mesilla Valley Area—1952 to 1962

The USGS, Texas Water Commission, and City of El Paso initiated a cooperative study in 1952 that was designed to determine the quantity and quality of groundwater available in the Lower Mesilla Valley for (1) public supply of El Paso, and (2) industrial and irrigation use (Leggat et al. 1962). The study by Edward Leggat and associates, which was completed in 1958, included a number of innovative hydrogeological, geophysical, and hydrochemical practices with respect to groundwater-resource investigations in the Mesilla Basin region:

1. Application of standard "oilfield" borehole-geophysical logging methods in ground.
2. Drill-stem hydrochemical sampling of representative hydrostratigraphic intervals in most wells.
3. Formal introduction of the Santa Fe Group (SFG) lithostratigraphic concepts to basin-fill stratigraphy.

4. Subdivision of the SFG into informal “upper, medium [middle], and lower” hydrostratigraphic categories based on drill-cutting and geophysical-log analyses from deep test- and production wells (**Figs. C2** and **C2-3a, b**).

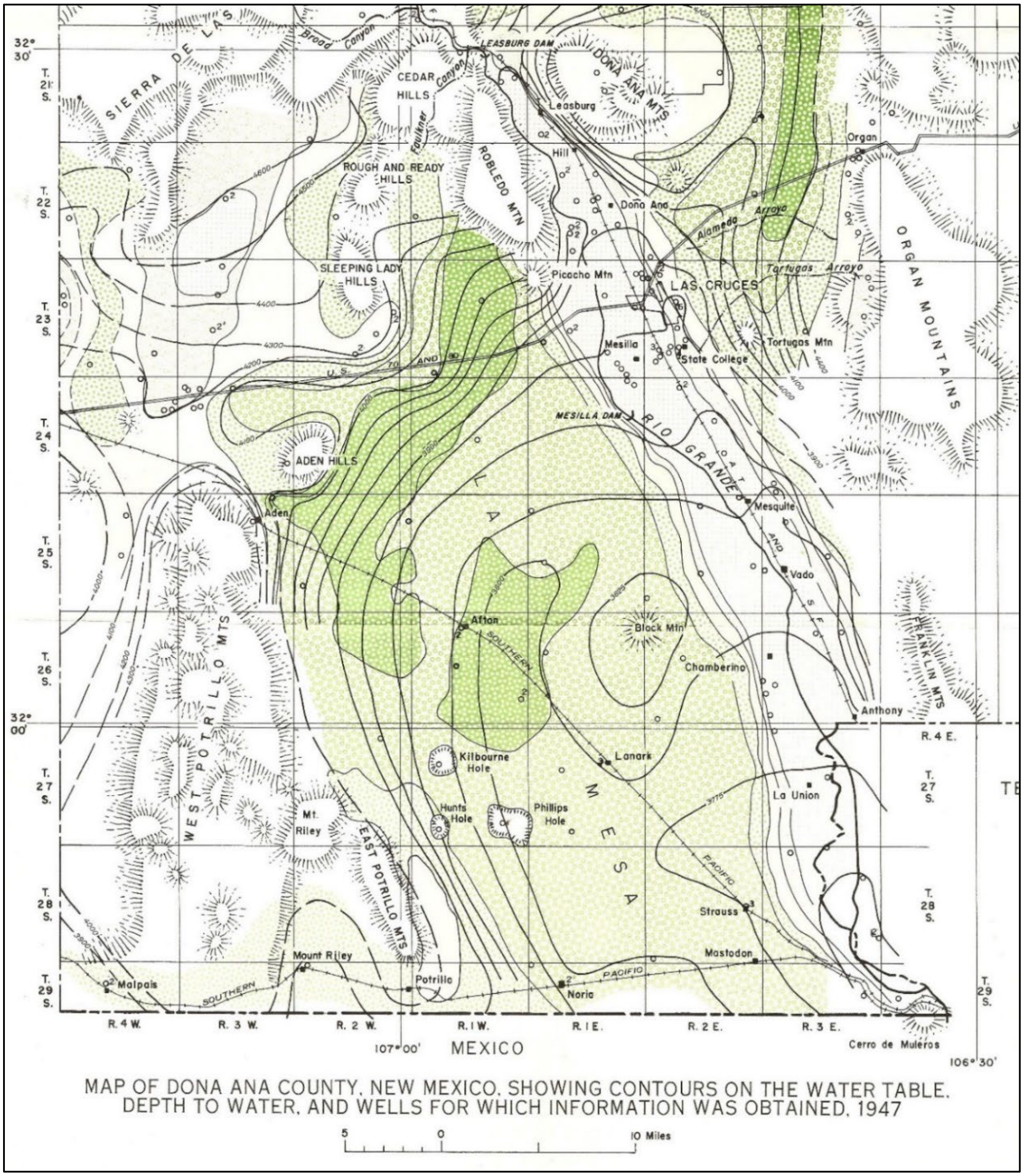

Figure C2-1. (Report **Plate 9A extract**) Facsimile copy of central and southern parts of Plate 1 *in* Conover (1954). The map shows approximate 1947 water-level contours in central and southern Doña Ana County, New Mexico. Estimated depths to water in the 300 to 400-ft and > 400 ft ranges are shown, respectively, with light greenish yellow and green dotted patterns.

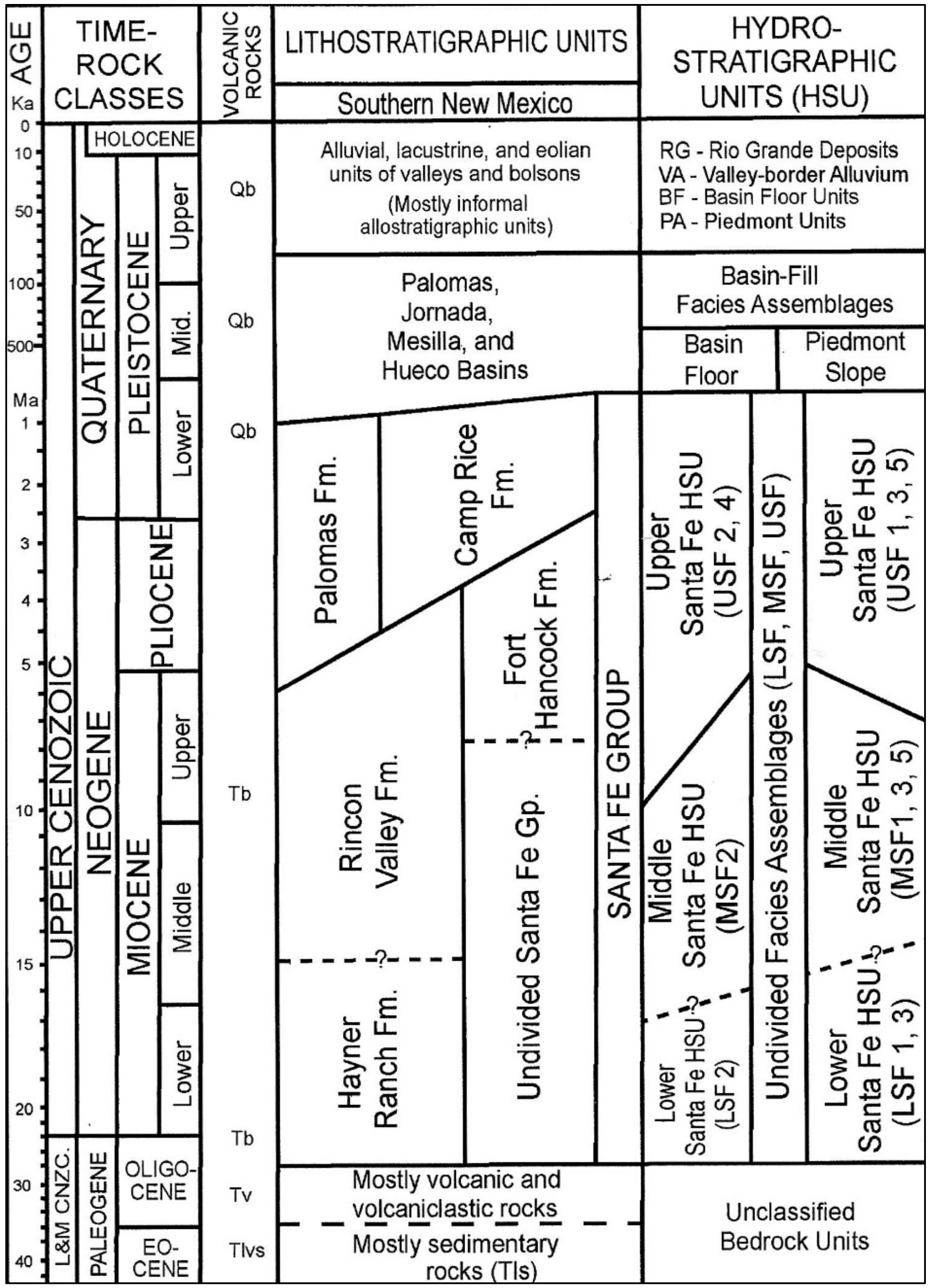

Figure C2-2. (modified from Hawley and Kernodle, 2000, Fig. 6) Correlation diagram of major Time-Rock (chronostratigraphic) classes, lithostratigraphic, allostratigraphic, and hydrostratigraphic units of Cenozoic Age in the southern RG-rift region (*cf.* NACOSN 2005; **APNDX. G**). Bedrock units: Qb–Quaternary basalt, Tb–Tertiary mafic volcanics, and Tv–older Tertiary intermediate and silicic volcanics, and associated plutonic-igneous and sedimentary rocks.

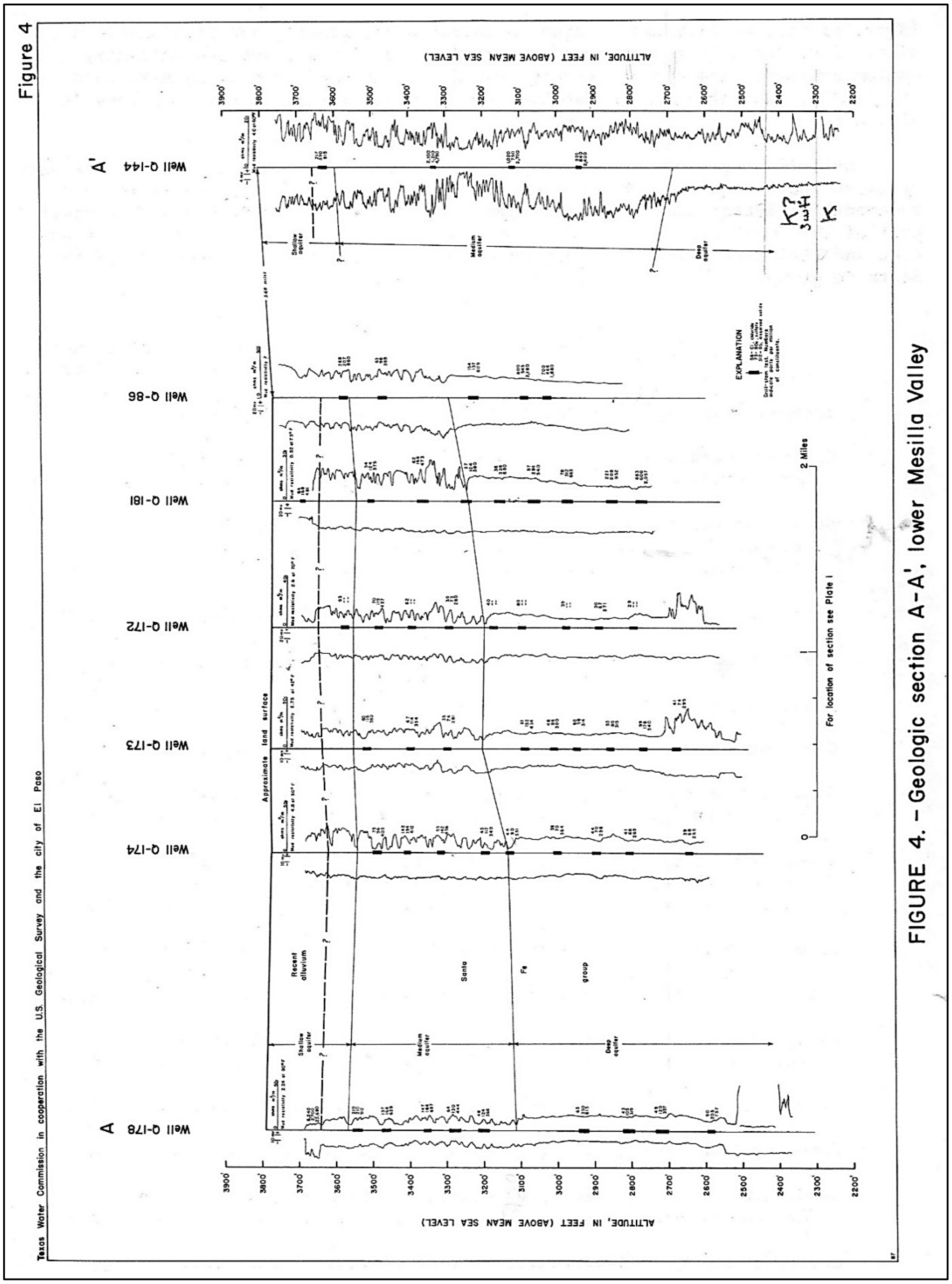

Figure C2-3a. (facsimile copy of Leggat et al. 1962, Fig. 4) Longitudinal "Geologic section A-A′, lower Mesilla Valley" between Anthony, TX and Santa Teresa, NM (btw. Sections I-I′ and K-K′; **Fig. C2-3b**). It illustrates (1) the first formal use of Santa Fe Group (SFG) lithostratigraphy in the southern Rio Grande rift region, (2) application of borehole-electric logs (SP and long-normal resistivity) in identification of informal "lower, medium [middle], and upper/shallow" SFG-hydrostratigraphic unit subdivisions, and (3) use of modern drill-stem sampling technology for hydrochemical characterization (black rectangles show sampling sites). Information on listed wells is on the **TABLE 1** spreadsheet: Q144-**no. 279**, Q174-**no. 325**, Q173-**no. 327**, Q178-**no. 328**, Q172-**no. 329**, and Q181-**no. 337**.

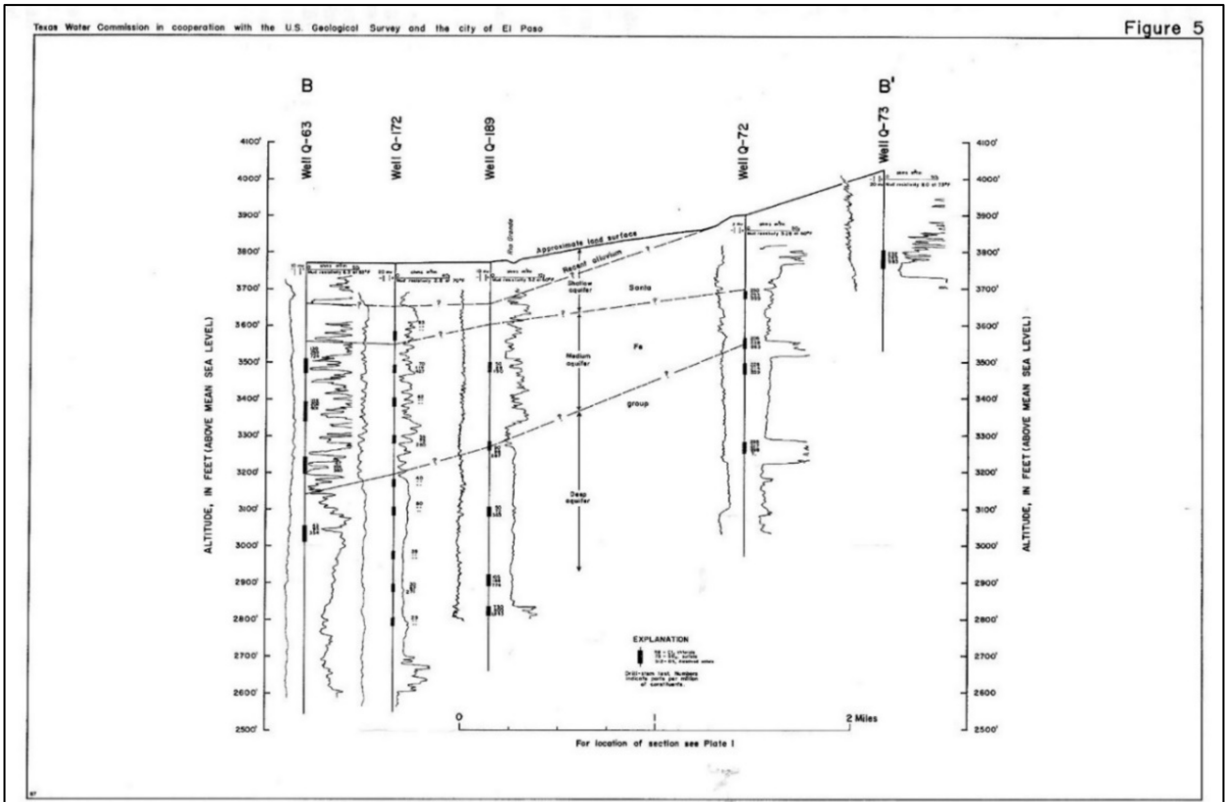

FIGURE 5. - Geologic section B-B', lower Mesilla Valley

Figure C2-3b. (facsimile copy of Leggat et al. 1962, Fig. 5) “Geologic section B-B′, lower Mesilla Valley” that is located near the eastern end of Hydrogeologic Section I-I′ (32° N latitude alignment). Information on listed wells is on the **TABLE 1** spreadsheet: Q63-**NA**, Q172-**no. 336**, Q189-**no. 335**, Q72-**no. 340**, and Q73-**no. 344** (*cf.* **Figs. C2-4** and **C2-5b**).

The following passages from the Leggat and others report (1962, p. 10-16) document the scope of this seminal contribution to the hydrogeology of the Mesilla Basin region. Detailed information on specific wells is on the Report **TABLE 1** spreadsheet (e.g., Q178-**no. 329**):

Santa Fe Group

The Santa Fe group underlies the lower Mesilla Valley and is exposed in nearly all the arroyos between the flood plain and the Franklin Mountains and in the bluffs at the east edge of La Mesa. In the uplands east of the Rio Grande, the top of the Santa Fe, mostly coarse sand and gravel containing some caliche-cemented boulders, probably is correlative with the Pleistocene cap of the Santa Fe, as defined by Spiegel and Baldwin (in preparation [1963]). A thick series of reddish to brown silty clay, fine to medium sand or poorly consolidated sandstone, and thick-bedded conglomerate underlies the coarse sediments.

Characteristic responses in electric logs of eight wells northwest of Canutillo suggest that the Santa Fe may be subdivided into two units (*See* Figures 4 and 5 [**Figs. C3-2a** and **C2-3b**]). In electric logs, the curve on the right side of the base line represents the relative resistivity of the individual beds. A deflection of the resistivity curve to the right (increase in resistance) usually is indicative of a fresh-water-bearing sand. Sand beds containing brackish or salty water have low resistance and cause little or no deflection of the resistivity curve. It is not possible to determine on the basis of available data if the units can be correlated over a large part of the valley.

The lower unit (the deep aquifer of the well field northwest of Canutillo) is composed of unconsolidated fine to medium sand; the percentage of clay is smaller than in the upper unit. The low, but uniform, resistivity response in the well field suggests that the sand in the lower unit is uniform, thick bedded, and relatively free of interbedded shale or clay [HSU-LSF, LFA 4—Rpt. **Fig. 4-3**, **Tbls. 4-1** and **4-2**]. The lower unit reaches a maximum thickness of at least 1,000 feet in well Q-178 [**no. 328**]; electric logs indicate that the lower unit thickens to the north and west. The spontaneous-potential curve (on the left side of the base line) of well Q-144 [**no. 281**] suggests that the lower unit in the south end of the valley is much thinner.

The upper unit of the Santa Fe, which contains the medium [Middle SFG] aquifer and a part of the shallow aquifer of the El Paso well field, is exposed in arroyos above the flood plain and in the bluffs of La Mesa. It consists of alternating layers of varied thickness of fine to coarse sand, gravel, and reddish-brown silty clay. Locally the sand is crossbedded, lenticular, and predominantly medium-grained. The clay is evenly bedded in many exposures along Mesa Road (U. S. 80), indicating that clay layers may extend laterally for considerable distances. In [Beneath] the flood plain, the upper unit reaches a depth of 470 feet in well Q-86 [NA], 678 feet in well Q-178 [**no. 328**], and possibly 1,100 feet in well Q-144 [**no. 281**]. According to electric logs and drillers' logs, the maximum thickness of the upper unit is at least 1,000 feet and perhaps as much as 1,400 feet.

Electric logs and drillers' logs reveal that in [beneath] the flood plain a thick-bedded limestone conglomerate underlies the lower unit but that east of the flood plain the conglomerate occurs within the Santa Fe. The conglomerate, derived from limestone that probably is of Cretaceous age (Virgil Barnes oral communication, Feb. 27, 1957), has a maximum observed thickness of 160 feet in well Q-173 [no. 327]. According to the electric and driller's logs of well Q-173 the conglomerate is underlain by clay, sand, and gravel. Although the sediments underlying the conglomerate probably are Santa Fe in age [here interpreted as pre-Santa Fe], they are not included in the lower unit. Figures 4 and 5 show that the conglomerate lies at a greater depth north and west of well Q-173 [**Figs. C2-5a** and **5b**). Well Q-178 [**no. 328**], depth 1,705 feet, did not penetrate the conglomerate. The highly resistive zone between 1,280 and 1,380 feet in well Q-178 is an igneous sill underlain by sand, shale, and clay of the lower unit of the Santa Fe. The igneous rock penetrated by well Q-178 may be associated with the series of volcanic rocks interbedded with the Santa Fe group of sediments near Las Cruces, New Mexico [interpreted as pre-Santa Fe bedrock-unit Tls herein].

The maximum thickness of the Santa Fe group in the lower Mesilla Valley is not known; unconsolidated sediments were penetrated to a depth of 1,705 feet in well Q-178 [**no. 328**]. The original thickness of the unconsolidated sediments in the area, the surface being about 300 feet lower than La Mesa, may have been about 2,000 feet. However, as the sediments thicken toward the center of the basin, it is probable that the maximum thickness of the Santa Fe is considerably greater.

The medium and deep aquifers of the Santa Fe group [SFG] are the major sources of ground water for public supply in the valley. Many wells obtain water from both the Santa Fe and the alluvium. Yields as large as 3,000 gpm of fresh water have been obtained from the Santa Fe north and northwest of Canutillo. South and southwest of Canutillo, the water in the Santa Fe is brackish or salty. Small to moderate quantities of fresh water have been obtained from the Santa Fe in the upland east of the Rio Grande, where the saturated thickness is much less.

C2.3. Digital Conversion of Borehole Geophysical and Drill-Cutting Logs—1987 to 1992

The seminal work of Leggat and others (1962), as illustrated in **Figures C2-2a** and **C2-2b**, continues to provide a robust model for the hydrostratigraphic and lithofacies interpretations of later workers. As noted in **Part C5.2**, hydrogeologic investigations between 1983 and 1997 included collaborative efforts that involved the NMBMMR Environmental Geology and NM Tech Hydrology programs, the USGS-WRD (NM), the El Paso Water Utility (EPWU), and the NMOSE. Emphasis was on: (1) manual conversion of analog data from original borehole-electric logs into digital format, (2) compilation of drill-stem-sample information on water quality, (3) detailed petrographic analyses of drill cutting, and (4) interpretation of this subsurface database as an initial step in hydrogeologic-framework characterization in the Mesilla GW basin (e.g., Hawley and Lozinsky 1992, Nickerson and Myers 1993). The examples of this work from Hawley and J. Kennedy (2004) that are presented in **Figures C2-3** to **C2-5**, illustrate the value of continuing to utilize the historic databases developed by Leggat and other (1962) and their contemporaries in the Mesilla Basin/Hueco Bolson region (*cf.* Knowles and R. Kennedy 1958).

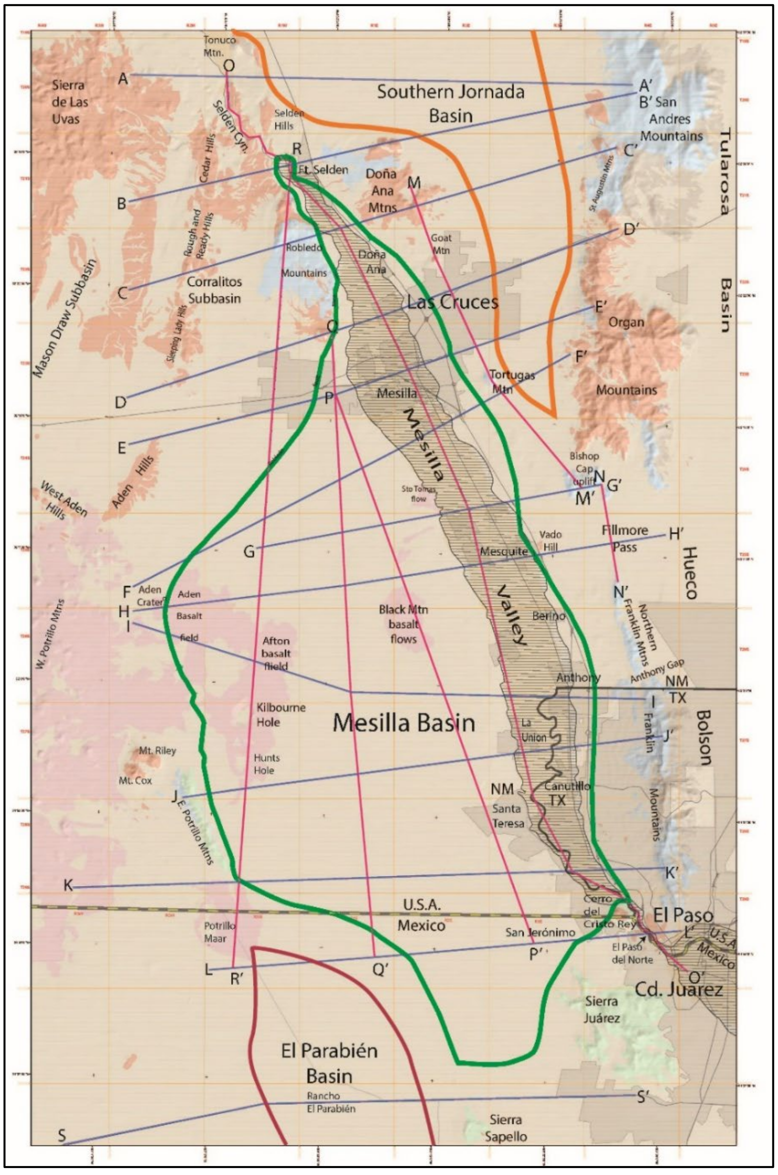

Figure C2-4. (Report **Fig. 2-3**) NM WRRI Study Area index map on a **PLATE 1** Hydrogeologic Map base. The Mesilla, Southern Jornada, and El Parabién groundwater (GW) basins (MeB, SJB and EPB) are outlined in green, orange, and red, respectively. Also shown are locations of major terrain features (including the Mesilla Valley, Selden Canyon and El Paso del Norte of the Rio Grande), hydrogeologic cross-sections **A-A′** to **S-S′**, and the El Paso/Ciudad Juárez and Las Cruces metropolitan districts.

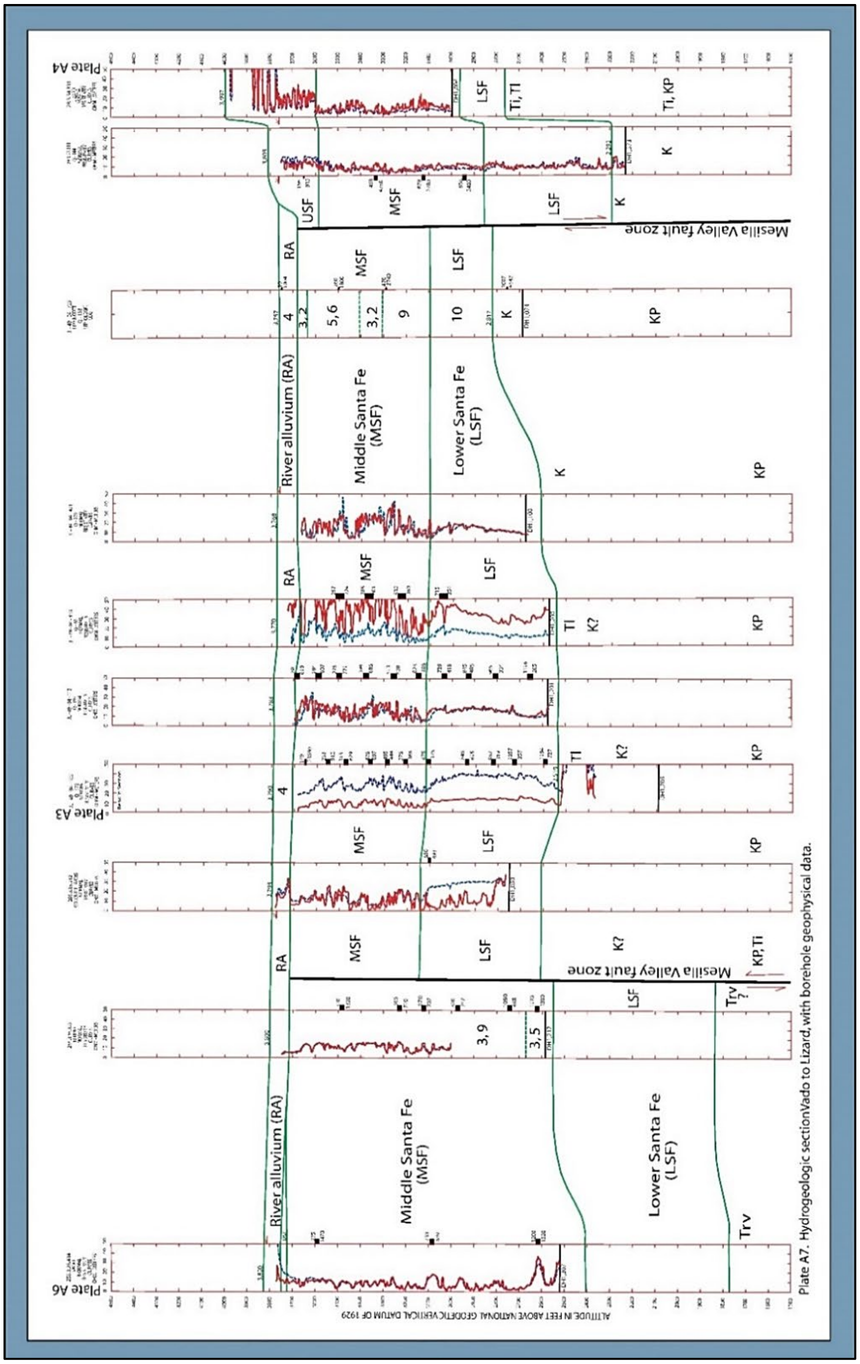

Figure C2-5a. (Hawley and Kennedy 2004-Appendix A, Plate A7) Down-valley hydrogeologic cross-section of the lower Mesilla Valley that follows the approximate trends of (1) the Section O-O'-O"-O"' series (**PL 5o**), and (2) Geologic section A-A′ in Leggat and others (1962, Fig. 4; *cf*. **Fig C2-3a** caption). Detailed information on specific wells is on the Report **TABLE 1** spreadsheet: Vado test-**no. 200**, Berino test-**no. 227**, Colquitt Farms-**no. 332**, Q178 Howell-**no. 328**, Q197-**no. 329**, Q63-NA, Q202-**no. 339**, Q144-**no. 279**, and Lizard 2-**no. 291**. Drill-stem water-sample locations are shown with black rectangles, and the upper and lower numbers show, respectively, depth to top of screen in feet and sample TDS in mg/L. Borehole resistivity-logs (red: short-normal, blue: long-normal).

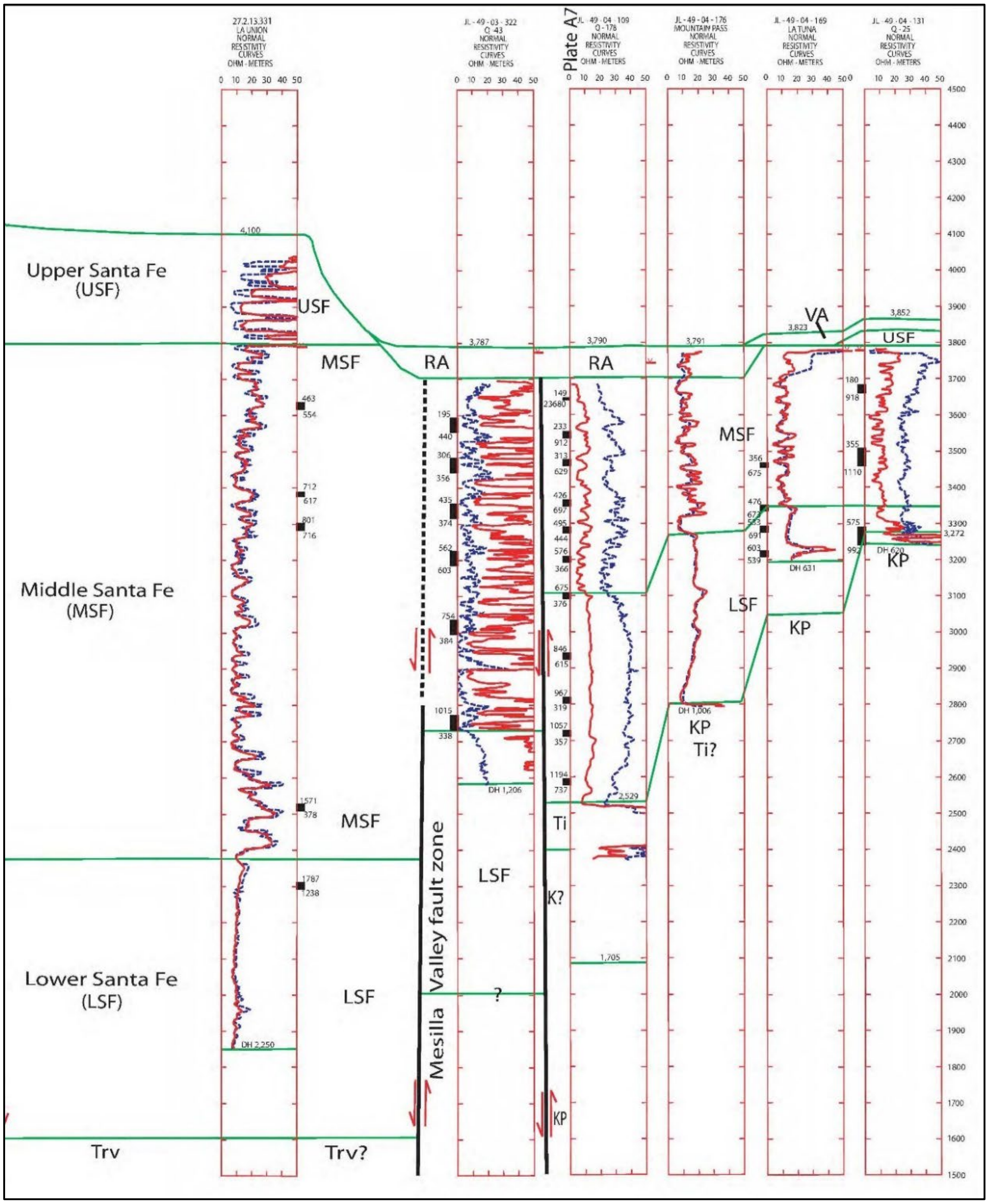

Figure C2-5b. (eastern part of Plate A3 in Hawley and Kennedy 2004-Appendix A) Transverse hydrogeologic cross-section of the lower Mesilla Valley that is located near the eastern end of Hydrogeologic Section I-I′ (near 32° N alignment; *cf.* **Fig. C2-4**). *See* **Fig. C2-3a** caption, and Report **TABLE 1** entries for additional information on specified test wells: La Union (MT-1)-**no. 242**, Q43-**no. 322**, Q178-**no. 328**, Mountain Pass-**no. 333**, La Tuna (Fed. Prison)-**no. 332**, and Q25-**no. 330**. Drill-stem water-sample locations are shown with black rectangles, and the upper and lower numbers show, respectively, depth to top of screen in feet and sample TDS in mg/L.

C2.4. Cooperative Investigations with El Paso Water Utility—1963 to 1970

The above-described Mesilla Valley investigations were primarily conducted by USGS hydro-scientists, and they temporally overlapped with studies in the Hueco Bolson of similar scope that were covered in Water Supply Paper 1426 (Knowles and Kennedy 1958). For the next four decades (through the 1990s) Thomas E. (Tom) Cliett of the El Paso Water Utility (EPWU) played a major leadership role of geology-based groundwater investigations in the Texas part of the southern Mesilla Basin and western Hueco Bolson part of the Paso del Norte region (e.g., Mattick 1967, Cliett 1969, Knorr and Cliett 1985, Cliett and Hawley 1996; *cf*. Hawley et al. 2009). Cliett (1931-2015) graduated from Texas Western College in 1958 with B.S. in geology; and he immediately began a 32-year tenure with the EPWU groundwater-geology program. It soon expanded under his leadership with innovative aquifer exploration and development methods that included borehole geophysics, hydrochemical sampling, and ultimately aquifer-storage and recovery. The following quote from Cliett (1969, p. 210-212), illustrates his early grasp of the essential hydrogeological and hydrochemical components of the GW-flow system in the lower Mesilla Valley between Anthony, NM/TX and El Paso del Norte (**Fig. C2-6**):

> Production in the Canutillo Well Field, which supplies the City of El Paso with a large portion of its water, is derived from three zones known as the shallow, intermediate, and deep which probably constitute only a two-aquifer system. Most of the shallow zone is made up of coarse sand, gravel, silt and clay and probably does not exceed 90 feet in thickness when referring to Recent alluvium, but the production zone itself extends to an average depth of about 150 feet. There is often no distinct lithologic break (as indicated by well cuttings) between the Recent [Late Quaternary] alluvium and the underlying Santa Fe Group basin fill within the shallow aquifer zone, and the two rock-stratigraphic units are hydraulically connected. The separation of the shallow and intermediate zones is based primarily on groundwater quality changes even though static levels in the intermediate average about 40 feet from the ground surface and only 10 feet in the shallow. There are no known continuous barriers between the two, but overlapping clay lenses possibly create a partial barrier to vertical components of groundwater movements.
>
> The differing qualities of groundwater in the various zones may be noted in Figures 6 and 7 [e.g., **Figs. C2-7** and **C2-8**] and are characteristic of the Canutillo Well Field. However, the quality of the groundwater in the shallow zone becomes much better to the north and west of the field.
>
> The deep aquifer is a fine-grained homogenous body of unconsolidated sand with superior quality groundwater and an artesian head of about 440 feet (190 psi). The aquifer is encountered at an average depth of about 500 feet which places the existing piezometric surface at 60 feet below the surface of the ground. Its average thickness is about 500 feet and its only known occurrence is in the Canutillo Well Field. An equally extraordinary anomaly, besides its excellent quality, is the temperature of the water of 98° F. [36.7°C].
>
> The aquifer may represent a fluvial environment of an isolated nature where the ancestral Rio Grande acquired stream velocity magnitudes great enough to carry silts and clays to other points of deposition, leaving the fine-grained sand in its present locale.
>
> King and others (1969) have speculated that the aquifer may represent deposition in a deltaic environment. It is also possible that the unit is basically an aeolian deposit analogous to the Medanos de Samalayuca dune complex in north-central Chihuahua (John Hawley, personal communication, July, 1969). In any case, the aquifer has rapid communication with a recharge zone of a highly permeable nature which is indicated by its water quality, and the recharge is directed through a zone with a high geothermal gradient.
>
> Much more subsurface data are needed to make more accurate assumptions but undoubtedly future test drilling will prove a more extensive occurrence of the deep aquifer zone.

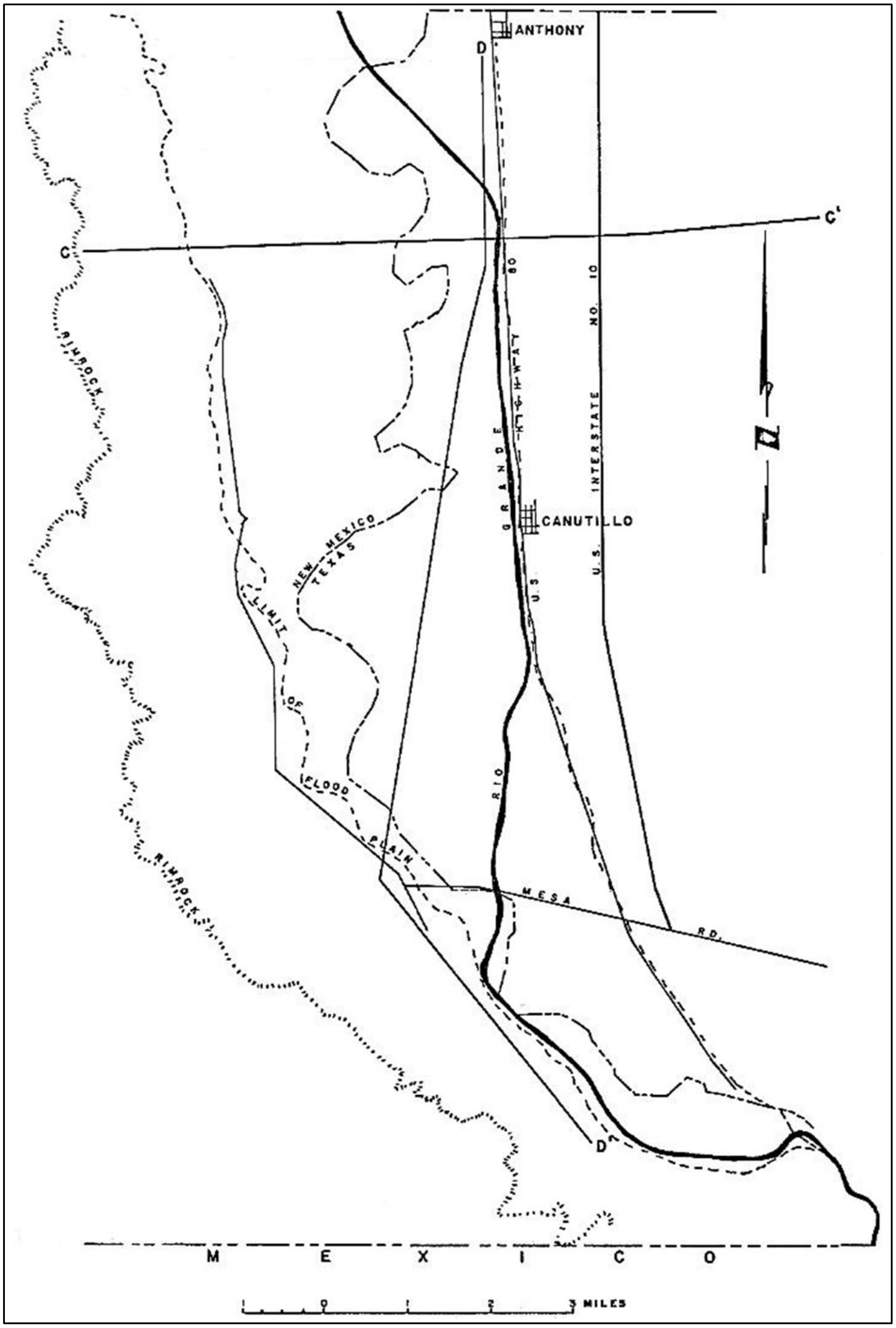

Figure C2-6. (facsimile copy of Cliett 1969, Fig. 5; reproduced with New Mexico Geological Society, Inc. permission) Index map of the lower Mesilla Valley showing locations of local geomorphic and cultural features, and hydrogeologic cross-sections C-C′ and D-D′ (**Figs. C2-7** and **C2-8**, respectively). "RIMROCK" delineates the Mesilla Valley-West Mesa (La Mesa surface) boundary and the constructional top of Upper Santa Fe Group fluvial-facies (ARG) deposits (USF-HSU2/LFA2&1).

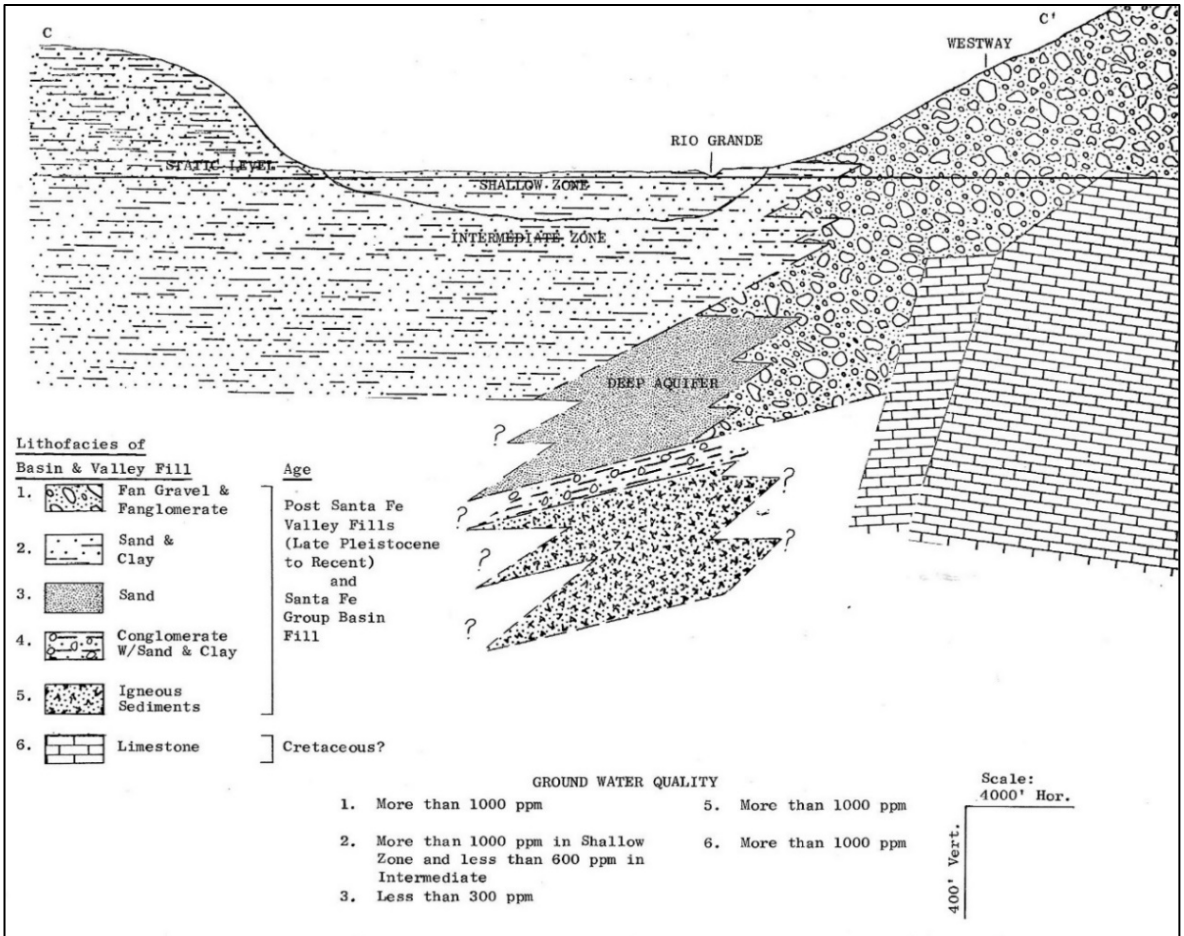

FIGURE 6.
Generalized geology and groundwater occurrence in Canutillo Well Field.

Figure C2-7. (facsimile copy of Cliett 1969, Fig. 6; reproduced with New Mexico Geological Society, Inc. permission) Transverse “Generalized” geologic section C-C′, lower Mesilla Valley” that is located near the eastern segment of cross-section J-J′ (**Fig. C2-6, PL. 5j**).

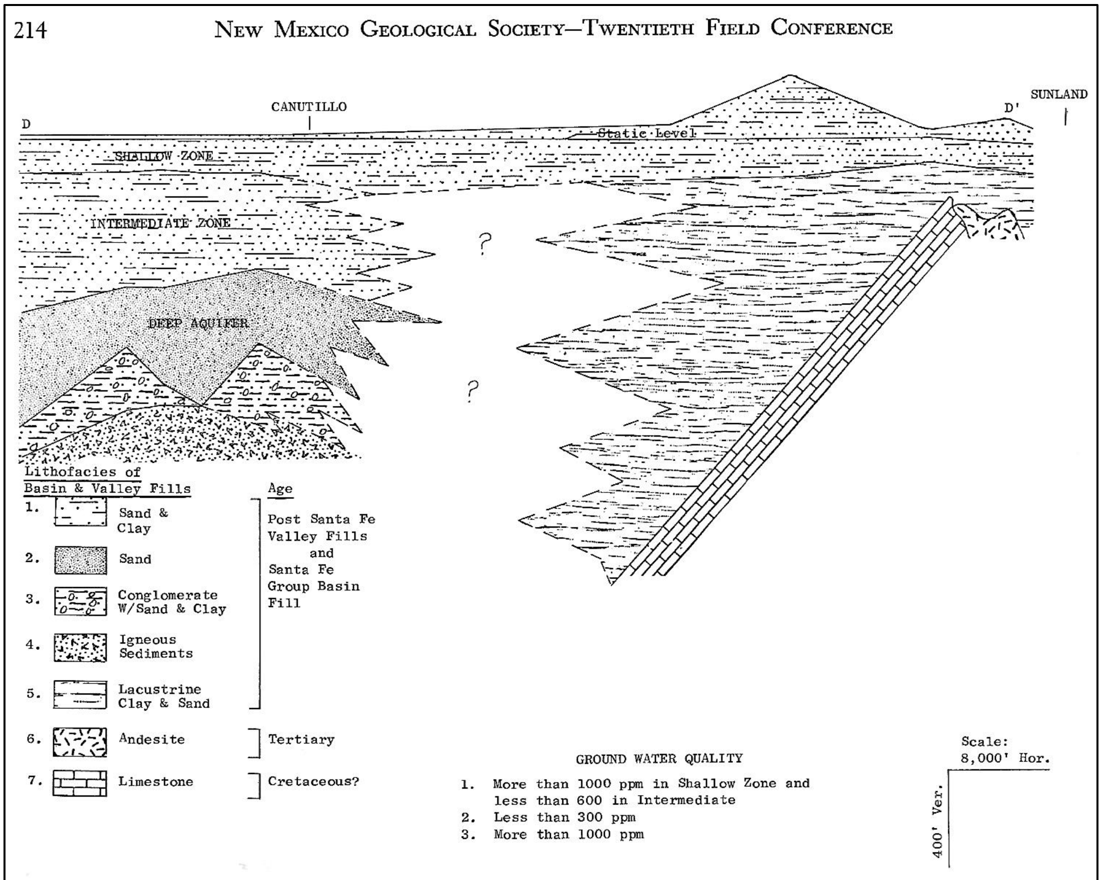

FIGURE 7.
Generalized geology and groundwater occurrence, lower Mesilla Valley to El Paso Canyon.

Figure C2-8. (facsimile copy of Cliett 1969, Fig. 7; reproduced with New Mexico Geological Society, Inc. permission) Longitudinal hydrogeologic section D-D′ of the lower Mesilla Valley between Anthony, TX and Sunland Park, NM. Cross-section location (**Fig. C2-6**) also approximates that of section A-A′ in Leggat and others (1962, Fig. 4; **Fig. C2-3a**) and Plate A7 in Hawley and Kennedy 2004-Appendix A (**Fig. C2-5a**). Sedimentary units that underlie the "DEEP AQUIFER and intertonguing conglomeratic deposits of the Lower SFG hydrostratigraphic unit (HSU-LSF) are here correlated with the pre-Santa Fe (Tls) bedrock sequence of Early to Middle(?) Tertiary Age (Report **TABLE 2**). "INTERMEDIATE ZONE" deposits are primarily part of the Middle Santa Fe HSU, while the SHALLOW ZONE comprises Upper SFG basin fill with a thin (<100-ft, 30-m) cover of river-valley alluvial fill beneath the Rio Grande floodplain and bordering valley sideslopes.

For more than a decade following his retirement, Tom Cliett was still actively involved as a private consultant in groundwater exploration and well/wellfield design. Throughout his career he was an enthusiastic collaborator in all phases of aquifer-system characterization throughout the binational Hueco Bolson-Mesilla region, especially in the planning and implementation of USGS-NM OSE-NM Bureau of Mines collaborative studies completed in the early 1990s (**Part C2.3**). The following excerpt and diagrams from Cliett (1969, p. 210-214) illustrates some of the contributions of a consummate public servant, who devoted a lifetime to getting a sound grasp on the applied hydrogeology of the Paso del Norte region (**Figs. C2-5** to **C2-7**). A cross-section diagram from Cliett and Hawley (1996, Fig. 5; **Fig. C2-9**) is also included to better illustrate Tom Cliett's significant contributions in the areas of groundwater chemistry, and hydrogeologic-framework characterization:

The geology of the Mesilla bolson is similar to that of the Hueco bolson and the basin fills are contemporaneous. By early Pleistocene (Kansan time) basin filling in the El Paso and Lower Mesilla Valley areas reached its climax (Kottlowski, 1958a; Hawley, et al. 1969; King, et al. 1969). The ancestral Rio Grande entered the Hueco bolson through Fillmore Gap [Pass] between the Organ and Franklin Mountains and was diverted to its present course in late mid-Pleistocene time (Strain, 1966).

Groundwater produced for irrigation and municipal purposes in the Lower Mesilla Valley occurs principally in deposits of the Santa Fe Group with many shallow wells completed in Recent [Late Quaternary] river alluvium.

Tom Cliett and John W. Hawley

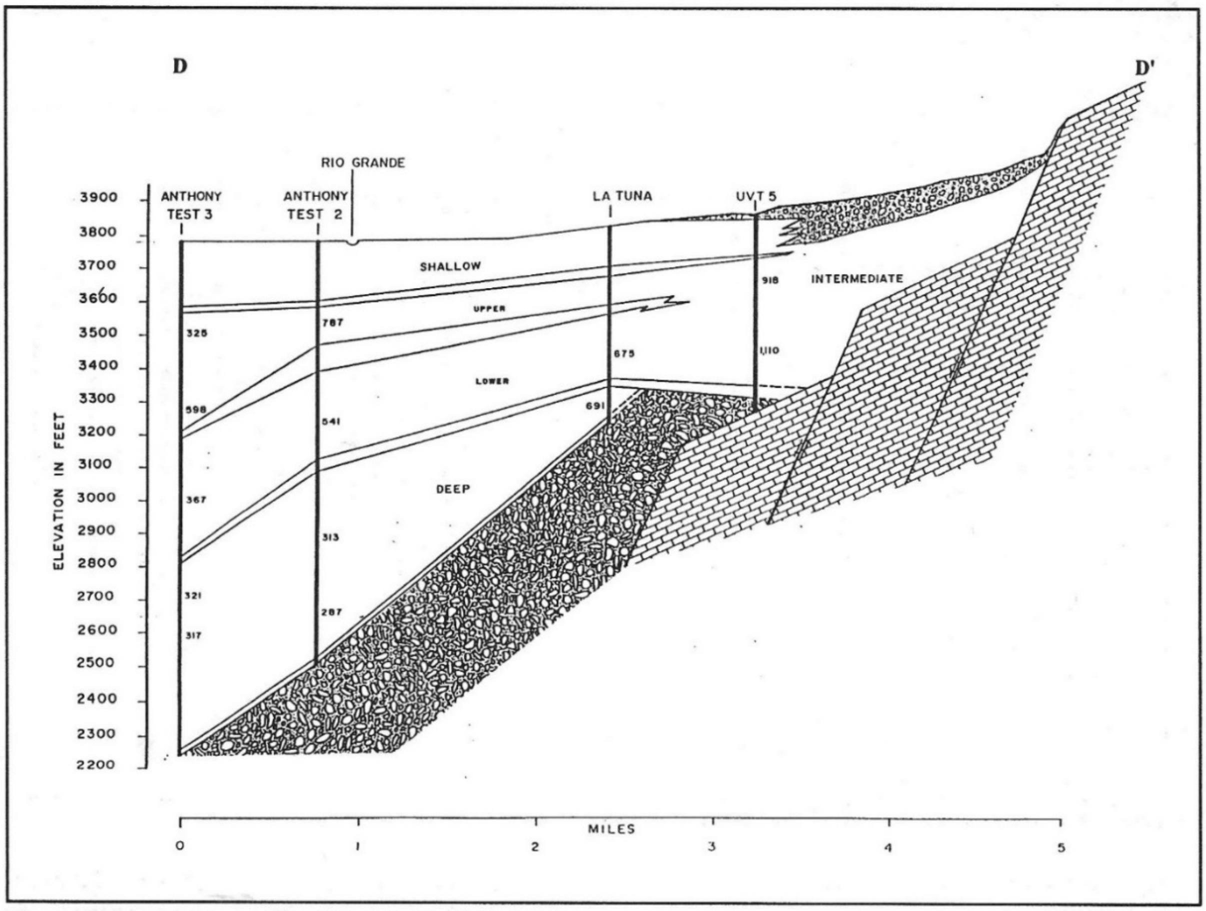

Figure 5. Groundwater quality of the Mesilla Valley system.

Figure C2-9. (facsimile copy of Cliett and Hawley 1996, Fig. 5) Transverse hydro-chemical/stratigraphic cross-section D-D′ is located near the eastern end of Hydrogeologic Section I-I′ (32° N alignment, **Fig. C2-3**). "DEEP and INTERMEDIATE" SFG aquifer zones are, respectively, approximate equivalents of the Lower and Middle Santa Fe Hydrostratigraphic Units (LSF and MSF—**Fig. C2-2b**), Numbers to right of well symbols are water-quality values in mg/L tds. Detailed information on the following wells is on the Report **TABLE 1** spreadsheet: Anthony Test 3-**no. 324**, UTV 5 (Q25)-**no. 330**, La Tuna (Fed. Prison)-**no. 332**, and Anthony Test 2-**no. 351**. Note that the Anthony Test Wells are near Q178 (Howell)-**no. 328** (**Figs. 2-8a**).

C3. USDA-SCS SOIL SURVEY INVESTIGATIONS DIVISION, NMSU (NM WRRI AND EARTH SCIENCE DEPT.) and NM TECH (NM BUREAU OF MINES & MINERAL RESOURCE DIV.) COLLABORATIONS —1964 to 1977

C3.1. Research Related to the USDA-SCS Desert Soil-Geomorphology Project

From October 1962 to May 1977, Hawley's geology-related activities in the New Mexico-West Texas region were performed as an employee of the Soil Survey Investigations Division of the USDA Soil Conservation Service, with administrative headquarters in Washington D.C. (Hawley 2005, p. 15-16). Until June 1971, most work was done from a field headquarters based at NMSU-Las Cruces, and during the following four years, field research was based at Texas Tech-Lubbock (1971-1974), and NM Tech-Socorro (1974-1975). Soil-geomorphic and hydrogeologic studies in Chihuahua were completed in 1968 and 1969 in cooperation with Mexican federal agencies (**APPENDIX D, Parts D2** and **D3**; and **APPENDIX H**). The scope of geology-related work in the binational Mesilla Basin region (**Figs. C1-1**) is described in the following excerpt from the 26th NMGS Field Conference "Guidebook to the Las Cruces Country" (Hawley 1975b, p. 183):

> The Desert Soil-Geomorphology Project refers to a Soil Conservation Service [USDA-SCS] investigation, between 1957 and 1972, of landscape evolution and soil development in a 400 sq. mi. area of Dona Ana County, New Mexico (Fig. 1 [**Fig. C-14**]). Its primary purpose was to gather basic information on soil-geomorphic relationships that would lead to increased accuracy and efficiency of the Soil Survey program in arid and semi-arid regions of the western states. A team of soil scientists and geologists from the S.C.S. Soil Survey Investigations Division . . . staffed the project. Research geologist R. V. Ruhe conducted initial geologic-geomorphic field studies from 1957 to 1960 and headed the project from 1957 to 1965 [*cf.* Ruhe 1962, 1964, 1967]. F. F. Peterson and J.W. Hawley were responsible for geomorphic and geologic research from 1960 to 1962 and 1962 to 1972, respectively. L. H. Gile was in charge of soils investigations for the duration of the project. Field research involved close collaboration with the Soil Survey Laboratory staff, particularly the Lincoln, Nebraska unit headed by R. B. Grossman. Work was done cooperatively with the New Mexico State University College of Agriculture, and Departments of Biology and Earth Sciences, and the New Mexico Bureau of Mines and Mineral Resources. The NMSU Agricultural Experiment Station and Department of Agronomy provided office and laboratory space, and numerous other supporting services for the 15-year period [*cf.* Monger et al. 2009].
>
> The project area is typical of large parts of west-central North America, and results of investigations can be applied in many other warm-arid regions, particularly those with basin and range topography [**Fig. C-14**]. The area comprises the northern Mesilla Valley segment of the Rio Grande, parts of two internally-drained intermontane basins [Jornada del Muerto and Mesilla], and several mountain masses. Because of striking differences in rock units exposed in source watersheds in local mountains and the upper Rio Grande basin (e.g. rhyolite, monzonite, limestone, and mixed-[composition ARG] fluvial deposits), it has been possible to study effects of various bedrock and alluvial parent materials on desert soil development [Gile 1961; Gile and Grossman 1979; Gile et al. 1965, 1966; 1981].
>
> Field investigations in the project area included mapping of geomorphic surfaces, geologic units, and soils at scales ranging from 1:8,000 to 1:24,000. Detailed studies were also made in the Rincon Valley area of northern Dona Ana County [Gile et al. 1996], and reconnaissance investigations were conducted at a number of sites elsewhere in the Basin and Range province. Geologic studies emphasized late Cenozoic stratigraphy, geomorphic surface mapping, and sedimentology and hydrogeology of basin and valley fills [e.g., Hawley and Gile 1966; Hawley 1969b, 1970, 1972, 1975a and b; Hawley and Kottlowski 1969; Hawley et al. 1969; King et al. 1969, 1971; Seager and Hawley 1973; Seager et al. 1971, 1975; King and Hawley 1975]. Pedologic

investigations [by Gile, Grossman, Peterson et al. 1965, 1966] were concerned with the [mineralogy,] morphology, genesis, and classification of desert soils, and soil-geomorphic relationships [e.g., Gile 1961; Gile and Hawley 1966, 1968, 1972; Gile and Grossman 1968; Gile et al. 1965, 1966, 1981*, 1995; Vanden Heuvel 1966; Monger et al. 2009; Hawley 2014a].

**Recipient of the 1983 Geological Society of America - Kirk Bryan Award: for paper of distinction advancing the science of geomorphology (cf. Birkeland 1984).*

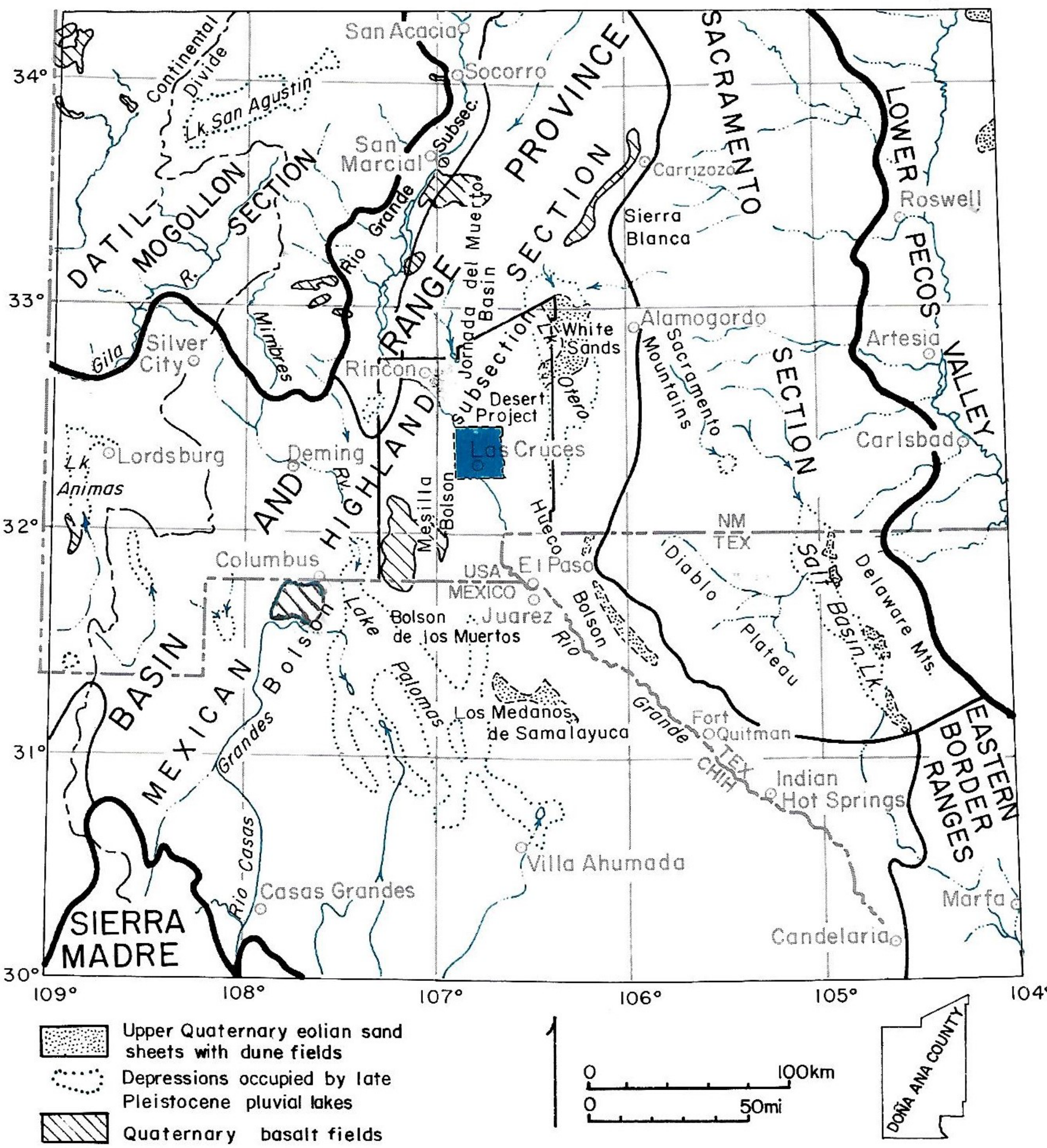

FIGURE 1—PHYSIOGRAPHIC SUBDIVISIONS OF THE DESERT PROJECT REGION, New Mexico, Texas, and Chihuahua, showing major stream systems, pluvial-lake basins, dune fields, and basalt terranes (adapted from Hawley, 1975, fig. 1).

Figure C3-1. (Gile et al. 1981, FIG. 1) Index map of physiographic subdivisions and major landforms in southeastern Basin and Range province region of New Mexico, Trans-Pecos Texas, and Chihuahua. The Study Area (Fig. 1-2) covers most of Doña Ana County and includes the USDA-SCS Soil Survey Investigations Div. (1957-1977) Desert Soil-Geomorphology Project area—blue rectangle.

C3.2. Research Collaborations Related to the NM Water Research Institute Program

Early hydrogeologic phases of Desert Project studies involved collaboration with the USGS-WRD in locating water-supply wells for the new NASA-Apollo Project White Sands Test Facility (Doty 1963). Formal collaboration with water-resources research programs at NMSU was initiated when Hawley was invited to be a Charter Member of the newly established NM Water Resources Research Institute by Director, Dr. H.R. Stucky, in October 1964 (**Fig. C3-2**).

NEW MEXICO STATE UNIVERSITY
COLLEGE OF AGRICULTURE AND HOME ECONOMICS
EXPERIMENT STATION • EXTENSION SERVICE • RESIDENT INSTRUCTION

Department of
Agricultural Economics and Agricultural Business
Water Resources Research Institute

UNIVERSITY PARK, NEW MEXICO
88070

October 15, 1964

Dr. John W. Hawley
Geologist, USDA
Campus

Dear John:

A procedure was recently adopted for the administration of the Water Resources Research Institute at New Mexico State University. In accordance with the procedure, I am naming as Charter Members of the Institute all staff members who are actually engaged in water resources research as indicated by the listing in the publication, A Compilation of Water Resources Research Projects, Engineering Experiment Station, Report No. 17, February 1964.

You have been actively engaged in water resources research and we are pleased to name you as a Charter Member of the Institute. All of these appointments have the concurrence of President Corbett, Director Leyendecker and Director Bromilow.

There will be a meeting of the Institute members at 3:30 p.m. Friday, October 23, in room 297, Agriculture Building, for the purpose of outlining the position of the Institute to date.

Also, a meeting will be held on Monday, October 26, with Dr. John C. Calhoun, Director, Office of Water Research, Department of Interior, Washington, D. C., who is planning to spend October 26 on our campus. The time and place of that meeting will be announced at the meeting on Friday.

Best wishes to you in your water resources research work.

Sincerely yours,

H.R. Stucky

H. R. Stucky
Director, Water Resources Research Institute

hh

Figure C3-2. Facsimile copy of letter of 10/15/1964 from NM WRRI Director H.R. Stucky to John Hawley concerning the latter's appointment as an Institute "Charter Member."

Initiation of NM Water Resources Research Institute programs in 1964 reinforced the pressing need for a fully accredited geology department at NMSU. In this respect, one of Dr. Ralph Stucky's earliest contributions to groundwater science in the southern New Mexico area was the result of his forceful advocacy with the NMSU Board of Regents for formation of an undergraduate-major program in the combined earth-science fields of geology and geography. This activity's early success was exemplified in the 1964 appointment of Dr. William E. (Bill) King (1925-2014, a former Mobil-Oil Senior Geologist) as Chairman of a new NMSU Earth Science & Astronomy Department. The following excerpt from the introduction to an early NM WRRI report (No. 6) on the "Hydrogeology of the Rio Grande Valley and adjacent intermontane areas of southern New Mexico" illustrates the substantial contributions to the understanding of the Mesilla Basin region in the first five years of NM WRRI's existence (King et al. 1969, p. 5):

> In 1964, the Water Resources Research Act was passed by the United States Congress, and the Water Resources Research Institute of New Mexico, under the direction of H. R. Stucky, was established soon thereafter. The present investigation was among the first to be funded by the institute. The field and laboratory work was begun in February 1965 and terminated in August 1968.
>
> The principal investigator, W. E. King, professor of geology at New Mexico State University, spent one quarter of his time through each academic year and three full months each summer on the investigation. He was responsible for supervision of the investigation and is accountable for many of the conclusions. Andrew M. Taylor [Taylor 1967] served as a graduate assistant on the project from its inception through August 1967 and did much of the well logging and surface geology. Richard P. Wilson spent one year as a student assistant and is largely responsible for the drafting as well as much of the thought expressed in the water-table contour map (Pl. 1).
>
> John W. Hawley, areal geologist with the Soil Conservation Service, of the U.S. Department of Agriculture, suggested the investigation and cooperated in the study throughout [*cf.* King and others (1971) p. 9-24}.*
>
> **Part C8a** *is a special Appendix Addendum that comprises a reformatted copy of the section by J. W. Hawley on the "Geology and its relation to the hydrologic system" in King, W.E. and others, 1971, Geology and ground-water resources of central and western Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Hydrologic Report 1, p. 9-24.*

C4. USGS-WATER RESOURCES DIVISION INVESTIGATIONS IN THE DOÑA ANA COUNTY, NM AREA: THE CLYDE A. WILSON ERA—1971 to 1980

C4.1. Background

Reports by Clyde A. Wilson and USGS Water-Resources Division (WRD) associates, which were published by the NM OSE and the USGS, remain the most comprehensive accounts of geo-hydrological investigations in the area of Mesilla Basin and Rincon Valley/Palomas Basin between Caballo Dam and the International Boundary (**Fig. C4-1**; Wilson et al. 1981, Wilson and White 1984; *cf.* Gates and Stanley 1976 [Report **Part 3.7.3**, **Fig, 3-16**]). Due to Wilson's unanticipated death in October 1980, only a fraction of his impressive geohydrologic and geophysical work was ever published. However, with full support of the USGS-WRD New Mexico and Texas Districts, Hawley and NM Tech colleagues were able to acquire a nearly complete set of Wilson's detailed, handwritten notes on a large number of deep test-well installations, many of which were supplemented by borehole-sample and geophysical logs. This subsurface database has been of immeasurable value in all subsequent hydrogeologic investigations in the Mesilla Basin region (e.g., Khaleel et al. 1983, Peterson et al. 1984, Hawley and Lozinsky 1992, Nickerson and Myers 1993, Hawley and Kennedy 2004, and Hawley et al. 2005). Additional information on Wilson's seminal contributions is included in **Parts C4.3** and **4.4**.

PROJECT PROPOSAL* FOR A COMPREHENSIVE STUDY OF THE WATER RESOURCES OF THE SOUTHERN RIO GRANDE VALLEY AREA, NEW MEXICO

C. A. Wilson

UNITED STATES DEPARTMENT OF THE INTERIOR, GEOLOGICAL SURVEY
Albuquerque, New Mexico, May 1972

****Part C8b** is a special Appendix Addendum that comprises a reformatted copy of the heretofore unpublished "Project Proposal" by C.A. Wilson (5/1972).*

INTRODUCTION [p. 2-3]

The water supply of the lower Rio Grande Valley and adjacent uplands is derived from surface water from the Rio Grande and ground water from sediments of the intermontane basin. Neglecting the short-term effects, the surface and ground-water units function as one system, due to the hydraulic connection between the river and the aquifers. Planning the orderly development of water resources of the valley requires current factual data followed by complete and reliable analyses.

The purpose of this proposal is to aid in planning, organization, and preparation of a comprehensive study plan of the southern Rio Grande Valley in New Mexico, to evaluate data presently available, and to determine data that will need to be collected (*cf.* **Fig. C4-2**).

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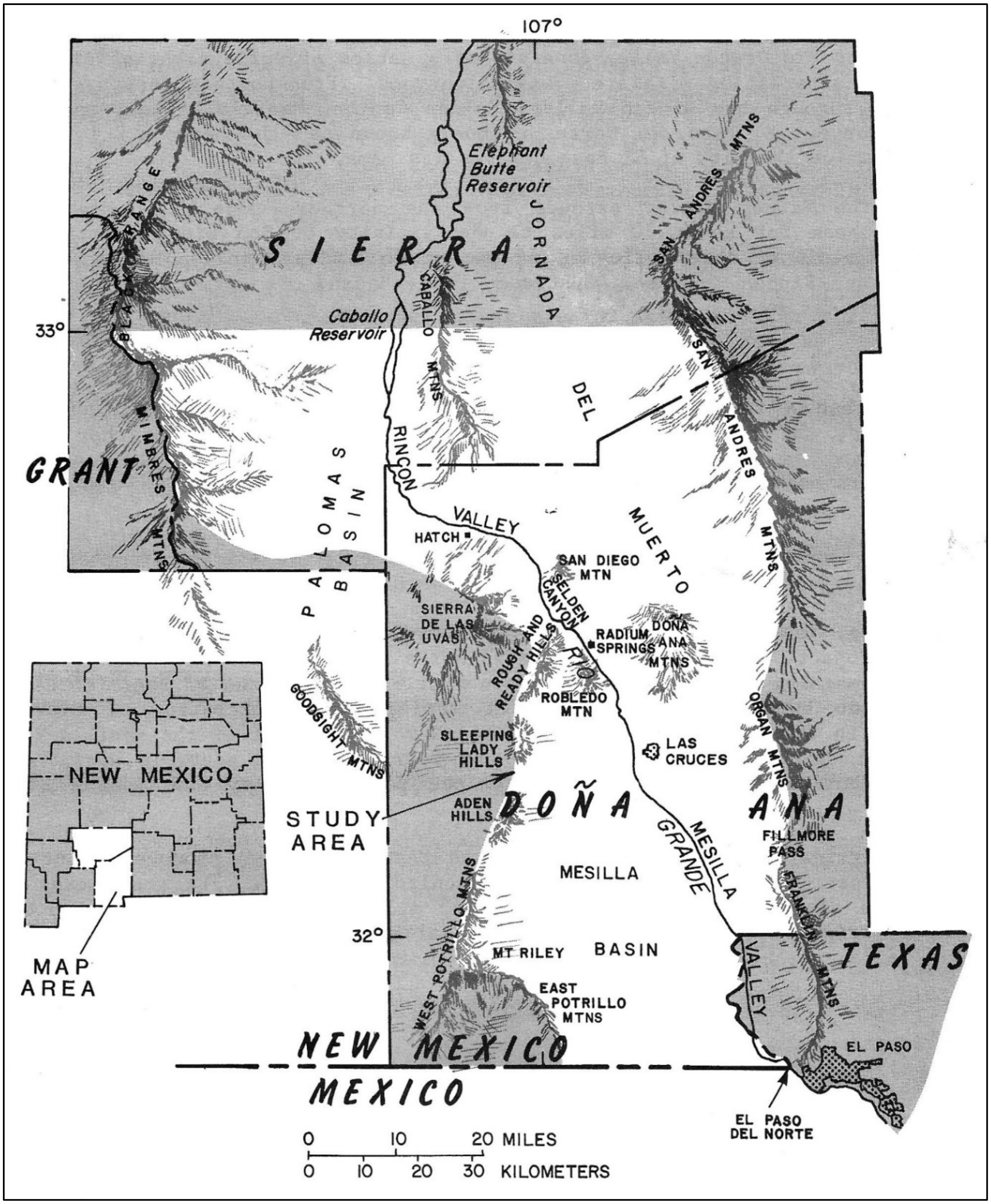


Figure C4-1. Facsimile copy of Figure 1. "Location of study area" from Wilson and others (1981, p. 5).

United States Department of the Interior

GEOLOGICAL SURVEY
Water Resources Division
P.O. Box 4198
El Paso, Texas 79914

August 14, 1972

Dr. John W. Hawley
U. S. Soil Conservation Service
1616 19th St.
Lubbock, Texas 79403

Dear John:

As you probably know from talking to Clyde Wilson and Jim Smith, we are beginning an evaluation of ground water in several areas in West Texas. One area we will concentrate on is the Mesilla Valley, where we plan to run several earth-resistivity profiles this fall and drill 2-3 deep test holes next year in an attempt to better define the potential of the Santa Fe aquifers. I am rounding up references on the Cenozoic geology of the area, and would like to obtain a copy of your 1966 Friends of the Pleistocene guidebook. Could you tell me if they are still available and how to get one?

You probably won't recall, but we met briefly on a Friends of the Pleistocene trip at Promontory Point, Utah in 1958 or 1959. The trip was to look at the Lake Bonneville deposits exposed by excavation for the SP causeway. As I recall you came over from Nevada with George Maxey. Sometime when you're in Las Cruces, we would appreciate your taking a day and showing us some of the pertinent features of the Mesilla Valley.

Sincerely

For: Bonnie Fry

Joseph S. Gates
Hydrologist

JSG: bf

Figure C4-2. Facsimile copy of 8/14/1972 letter from Joseph S. Gates (USGS-WRD) on Proposed Earth-Resistivity Surveys and Test Drilling in the El Paso area of the Southern Mesilla Basin (*cf.* Gates and Stanley 1976, Jackson 1976, Zohdy et al. 1976, Wilson et al. 1981).

C4.2. Major Contributions by C.A. Wilson to the Understanding of Regional Hydrogeology *in* Water Resources of the Rincon and Mesilla Valleys and Adjacent Areas in New Mexico: New Mexico State Engineer Technical Report 43 (Wilson et al. 1981)

The scope of investigations directed by C.A. Wilson and colleagues and their major contributions to the current understanding of the basic hydrogeologic-framework components in the Mesilla Basin region is illustrated in the following selections from parts of the "Methods of investigation" section in Wilson and others (1981, p. 13-16):

1. Well inventory

During the study, about 1,530 water wells were inventoried for such information as total depth, static and pumping depth-to-water, yield, and the specific conductance and temperature of the pumped water. . . .

2. Test drilling

Test holes ranging in depth from 135 to 2,470 feet were drilled at 27 locations in the study area. Hole diameters ranged from about 6 to 8 inches. Drill cutting samples from each test hole were used to compile a geologic log. This log was later revised on the basis of microscopic examination of cuttings and examination of available geophysical logs. Borehole geophysical logs, including natural gamma-ray, spontaneous potential, and resistivity logs, were made in 25 of the holes. Neutron, gamma-gamma (density), and caliper logs also were recorded in selected deep holes. . . .

3. Geophysical studies

Geophysical studies, which included surface electrical-resistivity soundings, permitted the estimation of critical hydrologic data from depths below the limits of existing wells. Vertical electrical-resistivity soundings (VES) made on the land surface permitted estimates of subsurface rock properties and ground-water salinity and allowed coverage of large areas in a short time and at a reasonable cost. . . .

Electrical-resistivity sounding were made at 150 sites in the Rincon and Mesilla Valleys and adjacent areas (plates 1 and 2*****). The initial set of 50 soundings was made during 1973 by Geoterrex, Ltd., Tucson, Arizona. The remaining 100 sounding were made by the U.S. Geological Survey (Jackson, 1976). Sites were selected so that results from the soundings could be integrated with borehole logs and chemical analyses of water from test holes and water wells in order to improve the geophysical log interpretation. . . . [*cf.* Jackson 1976, Jackson and Bisdorf 1975, Zohdy et al. 1976].*****

****Note:** VES-survey and borehole-log hydrogeologic interpretations are illustrated in 14 "Hydrologic sections" of basin-fill deposits in the Rincon and Mesilla Valley areas (respectively, A-A' and B-B' and C-C' to N-N'). Section-base elevation is 4,000 ft (1,219 m) below msl (Wilson et al. 1981, plates 1, 2, and 8).*

With regards to current estimates of the amount of fresh and slightly saline groundwater stored in basin-fill aquifers of the Mesilla Basin's RG Valley and "West Mesa" area, the following selections from Wilson and others (1981, p. 58-59) are of special relevance:

The approximate thickness of sediments saturated with freshwater ranges from less than 400 feet in the northern and southern ends of the valley to more than 2,400 feet in the central valley (plate 15). The thickest part of the freshwater zone generally follows the present course of the Rio Grande.

In the part of the Mesilla Valley north of Anthony, the volume of sediments containing freshwater is estimated to be approximately 215 million acre-feet. If the average sediment porosity is assumed to be 30 percent, about 64 million acre-feet of freshwater are in storage. Assuming that all recharge to the aquifer stops, that pumpage continues for a very long time, that average effective porosity is 15 percent, and that 60 percent of the sediments are sand and gravel, approximately 20 million acre-feet of fresh-water may be available for withdrawal by wells. Any recharge from applied irrigation water, river or canal seepage, inflow from other areas, precipitation, and water that moves from clay units into sands in the aquifer increases the volume of freshwater available for pumping.

In the part of the Mesilla Valley south of Anthony, much less freshwater is present. Leggat, Lowry, and Hood (1962, p. 38-39) estimated that about 980,000 acre-feet of freshwater are in storage in the basin fill of the New Mexico part of the Mesilla Valley that is south of Anthony and east of the western edge of the flood-plain alluvium. They defined freshwater as water that contains less than 250 parts per million chloride. Gates, White, Stanley, and Ackermann (1978 [1980]) prepared a map of the Mesilla Valley south of Anthony showing the approximate thickness of basin fill containing freshwater. They (1978 [1980], p. 108) estimated that 820,000 acre-feet of freshwater are in storage beneath the Texas part of the Mesilla Valley and the adjacent mesa to the east. .

Adding the estimates of freshwater in storage north of Anthony (64 million acre-feet) and south of Anthony (1.8 million acre-feet) gives a total of about 66 million acre-feet. The saturated thickness of sediments containing freshwater beneath the West Mesa ranges from less than 400 to more than 2,400 feet (plate 15). The greater thickness occurs near the Mesilla Valley.

The volume of saturated sediments in the freshwater zone beneath the West Mesa is estimated to be 380 million acre-feet. Assuming an average porosity of 30 percent, about 114 million acre-feet of freshwater may be in storage. Not all of this water would be available to wells. Assuming that the specific yield of the sand layers is 15 percent and that 60 percent of the freshwater zone is sand, about 34 million acre-feet of freshwater theoretically could be pumped in the West Mesa. Additional water may be derived from the clay units in the aquifer. The very large volume of slightly saline water [SSL] that lies beneath the freshwater zone is not considered in these calculations although this water may be suitable for some purposes. . . .

The upper SSW zone is thinnest on the west side of the Mesilla Valley and thickens to the east where it unites with the slightly saline water that underlies the freshwater zone (plate 8, sections C-C' through N-N'). In the Mesilla Valley area extending south to Anthony, the volume of sediments containing slightly saline water that lies above the zone of freshwater is estimated to be 17 million acre-feet. Assuming a porosity of 30 percent, there are about 5.1 million acre-feet of slightly saline water in storage. The upper SSW zone is generally under unconfined conditions. Assuming 80 percent of the zone is sand and gravel and the average specific yield of the sand and gravel is 20 percent, about 2.7 million acre-feet of slightly saline water theoretically would be available to shallow wells in the Mesilla Valley north of Anthony. This upper SSW zone furnishes much of the water to the valley's irrigation wells.

C4.3. Memorials to Clyde A. Wilson (1932-1980)

C4.3.1. Memorial to Clyde Wilson *in* Wilson and others (1981, p. ii)

Clyde A. Wilson, the senior author of this report, died on October 11, 1980, in the Gila National Forest in southern New Mexico. Only through his guidance and expertise was this study possible.

C4.3.2. Memorial to Clyde Wilson in the NM WRRI *The Divining Rod*:

Clyde Wilson Dies at Age 48 (Mackichan, 1980, *The Divining Rod*, no. 80-3. p. 1, 3):

Clyde Wilson, U.S. Geological Survey hydrologist at Las Cruces, New Mexico, died Saturday, October 11, 1980, while on a family hunting trip. He had been chief of the Las Cruces field office since 1971. Clyde was born in Morenci, Arizona in 1932. After graduating from Carlsbad High School in 1950, he first attended New Mexico School of Mines, Socorro. He then enlisted in the Air Force and received his commission and wings in March 1954. Wilson served as a navigator-bombardier in Korea, and an Air Force police officer at Hurlbut Field, Florida until March, 1957, when he left the service with the rank of First Lieutenant.

Returning to college, Clyde received his B.S. in geology from Texas Technological College, Lubbock, and his M.S. in geology from the University of Arizona. He later earned a second Master’s degree in hydrology from the University of Arizona. Wilson had been employed by the U.S. Geological Survey since 1962. He had worked as a geologist on several Texas projects, and later was assigned to the Permian Basin Project in Austin, Texas, as a hydrologist. Clyde came to Las Cruces from Lubbock, Texas, where he was involved in a study of the Ogallala Aquifer.

When Clyde first came to Las Cruces, he developed a proposal for a groundwater study of the lower Rio Grande [NM] area [**Part C7.2**]. In July, 1972, the formal study began with the Office of State Engineer . . ., the City of Las Cruces, and the Bureau of Reclamation for the Elephant Butte Irrigation District as cooperators. It was at this time that the USGS moved its office into Stucky Hall with the WRRI on the NMSU campus. . . ,

C5. MULTI-INSTITUTIONAL COOPERATIVE INVESTIGATIONS—1980 to 2000

C5.1. Beginning of the "Administratively Closed Groundwater-Basin" Era

C5.1.1. Management of Shared-Water Resources—Progress and Pitfalls

The following excerpt from Harris (2012, p. 249) serves as a very appropriate introduction to the following discussion:

On Sept. 5, 1980, El Paso took the first step along a legal route it hoped would lead to a plentiful and free water supply from New Mexico. On that Friday after Labor Day, the city of El Paso, through the Public Service Board, filed suit in US. District Court in Albuquerque against Steve Reynolds individually as the New Mexico state engineer, and also New Mexico Attorney General Jeff Bingaman and the New Mexico district attorney for Doña Ana County. The city sought to overturn New Mexico's embargo statute as violating the Commerce Clause of the US. Constitution. The embargo statute, enacted in 1953, prevents anyone from drilling wells in New Mexico and transporting the water outside the state.

By September 12, New Mexico State Engineer Steve Reynolds "declared" both the Mesilla Basin and the Hueco Bolson under state authority. El Paso responded quickly by filing well applications for 246,000 acre-feet a year in the Mesilla Basin* and for 50,000 acre-feet a year in the Hueco Bolson.

**USGS hydrologist Clyde A. Wilson, the leading expert on Mesilla Basin and Lower Rio Grande Valley water-resource matters, died unexpectedly on October 11, 1980 . . . .*

The state engineer denied all of El Paso's applications on grounds that New Mexico statute prohibited the transfer of water across the state line. El Paso took its case before US. District Court Judge Howard Bratton in January 1982. In July of that year the US. Supreme Court ruled that groundwater was to be considered an article of commerce and as such its transfer across state lines could not be restricted. In January 1983, Bratton ruled in favor of El Paso on all accounts, writing that New Mexico's embargo violated the Commerce Clause of the US. Constitution because it promoted New Mexico's economic advantage.

C5.1.2. Hydrogeologic Framework Characterization for Numerical Modeling

Hydrogeologic investigations between 1983 and 1997 included collaborative efforts involving the NMBMMR and NM Tech (Hawley and Rick Lozinsky), USGS-WRD (Mike Kernodle and Ken Stevens), NMOSE (Francis West) and EPWU (Tom Cliett [**Part C-2b**]). Emphasis was on compilation and interpretation of subsurface geologic, geophysical and geochemical data (e.g., Hawley and Lozinsky 1992, Nickerson and Myers 1993, Cliett and Hawley 1996). The focus of most hydrogeologic-research activities was on development of framework characterizations of basin-fill aquifer systems of the Mesilla Basin region that were compatible with emerging numerical groundwater-flow modeling, computer-platforms, and GIS technologies.

Much of the basic information compiled for studies initiated after 1982 had already been collected during early stages of geohydrologic and hydrogeologic research projects jointly sponsored by the USGS-WRD, NMBMMR, NM Mexico Tech Research Division, NM WRRI, and NMSU-Energy Institute (**Parts C2** to **C4**). In addition to published sources, available unpublished, subsurface data (primarily drilling, and borehole-sample and geophysical logs) was obtained from USGS-WRD and

NMBMMR files. Emphasis was on development of a lithofacies classification scheme for use in precursor (quasi-3D) groundwater-flow models of basin-fill (alluvial) aquifer systems (e.g., Khaleel et al. 1983, Hawley 1984, Peterson et al. 1984; *cf.* **APNDX A**).

Published-information sources utilized in those studies came from three complementary earth-science disciplines:

1. "Traditional" field geology and geophysics exemplified by work synthesized by Hawley and others (1969), Hawley (1975a, 1978), Seager and Morgan (1979), Seager (1981), Gross and Icerman (1983), Icerman and Lohse (1983), Seager and others (1987), Keller and others (1990), Seager and Mack (1994), Mack and others (1998), and Seager (1995). *See* **CHAPTER 3** and **APPENDIX H**.
2. Integrated soil-science and Quaternary geology/geomorphology studies, notably work by Gile and Hawley (1966 and 1968), Gile and Grossman (1979), and Gile and others (1981, 1995). *See* Monger and others (2009) and **APPENDIX D**.
3. Integrated geohydrologic and hydrogeologic studies by Conover (1954), Knowles and Kennedy (1958), Leggat and others (1962), King and others (1971), Wilson and others (1981), Wilson and White (1984), Frenzel and Kaehler (1992), and Nickerson and Myers (1993).

Key sources of borehole data were identified and located on available geologic maps of the Mesilla Basin (scales 1:24,000 and 1:100,000) for use as control points. These included borehole geophysical and sample logs, geothermal data, and geochemical analyses. Six new test wells drilled by the USGS-WRD and EPWU provided supplemental information. The Afton, Lanark, La Union, and Noria test wells were drilled in the basin area west of Mesilla Valley (MT 1 to 4; Well nos. 175, 236, 242, and 253 *in* Report **TABLE 1**). The other two wells (CWF1D, CWF4D; JL-49-04-481 and 469; Report **TABLE 1** nos. 343 and 341) are located in the Canutillo Well Field area on the Rio Grande floodplain west of Vinton, Texas (Frenzel and Kaehler 1992, Hawley and Lozinsky 1992; Nickerson 1989, 1995; Nickerson and Myers 1993).

Drill-cutting analysis and driller-log data (Report **TABLE 1**) were supplemented by detailed seismic reflection profiles made at two sites near the Canutillo Well Field (C.B. Reynolds and Associates 1986, 1987 *unpublished*). The subsurface database also included water-chemistry analyses from one or more sampling intervals in most of the key wells (Hawley and Lozinsky 1992, Table 4; Appendix—Tables A1, A2, A3).

C5.2. USGS-WRD Regional Aquifer-Systems Analysis (RASA): Southwest Alluvial Basins (SWAB) Program

The USGS-WRD Regional Aquifer-Systems Analysis (RASA)—Southwest Alluvial Basins (SWAB) Program has had a major impact on development of new-generation conceptual and digital models of intermontane-basin hydrogeologic systems throughout the eastern Basin and Range and Rio Grande-rift provinces (*cf.* Gates et al. 1984**,** Freethey et al. 1986). The following selections from Frenzel and Kaehler (1992, p. iii), and (Wilkins 1986, p. 2) summarize the program's purpose and scope:

> **THE REGIONAL AQUIFER-SYSTEM ANALYSIS PROGRAM**
>
> The Regional Aquifer-System Analysis (RASA) program was started in 1978 after a congressional mandate to develop quantitative appraisals of the major ground-water systems of the United States. The RASA program represents a systematic effort to study a number of the Nation's most important aquifer systems that, in aggregate, underlie much of the country and that represent important components of the Nation's total water supply. In general, the boundaries-of these studies are identified by the hydrologic extent of each system and accordingly transcend the political subdivisions to which investigations have often arbitrarily

been limited in the past. The broad objective for each study is to assemble geologic, hydrologic, and geochemical information; to analyze and develop an understanding of the system; and to develop predictive capabilities that will contribute to the effective management of the system. The use of computer simulation is an important element of the RASA studies, both to develop an understanding of the natural, undisturbed hydrologic system and any changes brought about by human activities as well as to provide a means of predicting the regional effects of future pumping or other stresses. . . .

The objectives of Regional Aquifer-Systems Analysis (RASA) are: (1) to describe the water-resource system, (2) to analyze changes in the system, (3) to develop a data base from existing information, and (4) to simulate the hydrologic system using mathematical models.

Hydrologic data, geologic descriptions of basin boundaries, and aquifer properties presented in this report were compiled from the many previous studies completed in the regional study area. Regional interpretations resulting from analysis of existing data are also presented in this report.

The study area encompasses parts of Colorado, New Mexico, and Texas and is structurally and hydrologically divided into 22 surface-water open and closed basins [**Fig. C5-1**]. The Rio Grande is the primary hydrologic connection through the open basins of southern Colorado, New Mexico, and western Texas. Closed basins in southwestern New Mexico and western Texas make up the rest of the area. . . .

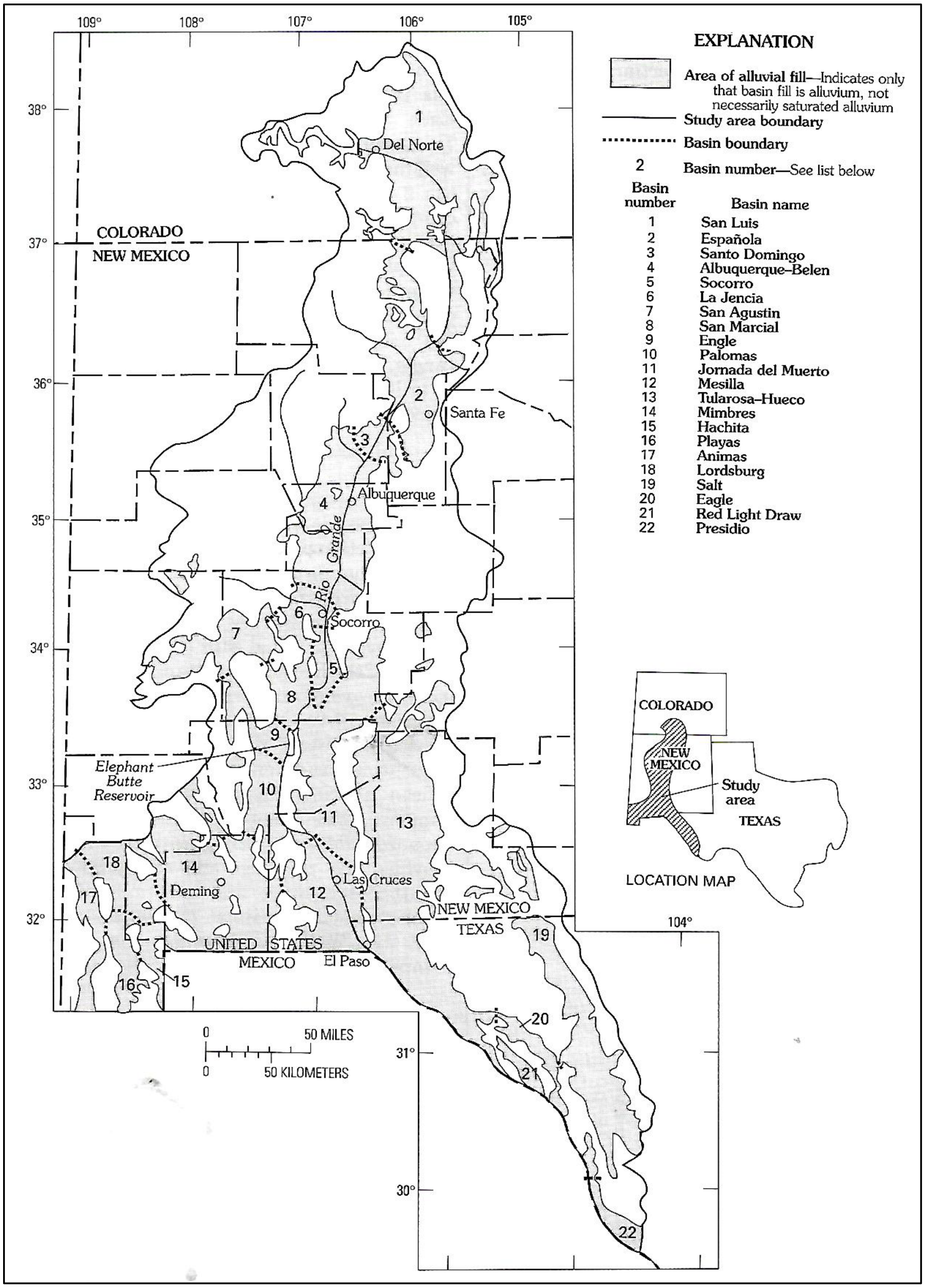


Figure C5-1. Location of the Mesilla Basin (12) within the RASA "Southwest Alluvial Basin Regional Aquifer-System Analysis (SWAB)" area of the United States (from Frenzel and Kaehler 1992, Fig. 1; *cf.* Wilkins 1986, 1998). Major basins of the Rio Grande rift (RG-rift tectonic province: 1-10, east 14, and 19-22; with other contiguous Basin and Range physiographic-province basins: 14-18). Besides the Mesilla Basins, the Study Area includes parts of the following groundwater basins: Southern Jornada, and western Tularosa-Hueco (13).

In addition to Frenzel and Kaehler (1990, 1992), the following reports are representative of the substantial contribution made by SWAB-Program investigations to NM WRRI-sponsored hydrogeologic research in the Mesilla Basin region:

Anderholm, S.K., 1985, Clay-size fraction and powdered whole-rock X-ray analyses of alluvial basin deposits in central and southern New Mexico: U.S. Geological Survey Open-File Report 85-163, 18 p.

Freethey, G.W., Pool, D.R., Anderson, T.W., and Tucci, P., 1986, Description and generalized description of aquifer materials in alluvial basin of Arizona and adjacent parts of California and New Mexico: U.S. Geological Survey Hydrologic Investigations Atlas HA-664, 4 sheets, scale 1:500,000.

Hanson, R.T., McLean, J.S., and Miller, R.S., 1994, Hydrogeologic framework and preliminary simulation of ground-water flow in the Mimbres Basin, southwestern New Mexico: U.S. Geological Survey Water-Resources Investigations Report 94-4011, 118 p.

Kernodle, J.M., 1992a, Results of simulations by a preliminary numerical model of land subsidence in the El Paso, Texas, area: U.S. Geological Survey Water-Resources Investigations Report 92-4037, 35 p.

Kernodle, J.M., 1992b, Summary of U.S. Geological Survey ground-water-flow models of basin-fill aquifers in the southwestern alluvial basins region, Colorado, New Mexico, and Texas: U.S. Geological Survey Open-File Report 90-361, 81 p.

Myers, R.G., and Orr, B.R., 1986, Geohydrology of the aquifer in the Santa Fe Group, northern West Mesa of the Mesilla Basin near Las Cruces, New Mexico: U.S. Geological Survey Water-Resources Investigations Report 84-4190, 37 p.

Nickerson, E.L., and Myers, R.G., 1993, Geohydrology of the Mesilla ground-water basin, Doña Ana County, New Mexico, and El Paso County, Texas: U.S. Geological Survey Water-Resources Investigations Report 92-4156, 89 p.

Orr, B.R., and Risser, D.W., 1992, Geohydrology and potential effects of development of freshwater resources in the northern part of the Hueco Bolson, Doña Ana and Otero Counties, New Mexico, and El Paso County, Texas: U.S. Geological Survey Water-Resources Investigations Report 91-4082, 92 p.

A significant contribution of the first major RASA-SWAB Project completed in New Mexico (Frenzel and Kaehler 1990, 1992) involved making a formal distinction between the deep, structural, Mesilla "groundwater basin (MeB)," and the areally more-extensive, physiographic- and hydrographic-basin categories, with the latter being defined, respectively, in terms of Basin and Range topography and surface-watershed divides (**Figure C5-2**). The MeB boundaries selected by USGS hydrologists Peter Frenzel and Charles Kaehler were specifically designed for an initial-phase "digital model of the Mesilla Basin ground-water flow system (1992, p. C2, Fig. 4 [1990, p. 9-10])." Except for its southern extension into Chihuahua, these boundaries closely match mapped positions of the Study Area's major Basin and Range/RG-rift basin-border fault zones (e.g., L. Woodward et al. 1978, Seager et al. 1987, and Seager 1995). Accordingly, MeB boundary locations in all subsequent digital hydrogeologic-framework characterizations and derivative GW flow-models in the USA part of Mesilla Basin region remain in close agreement with those defined by Frenzel and Kaehler (1990, 1992; Report **PLATES 1** to **5**; *cf.* Hawley and Lozinsky 1992, Nickerson and Myers, 1993, Hamilton and Maddock 1993, Hawley and Kennedy 2004, Sweetkind 2017).

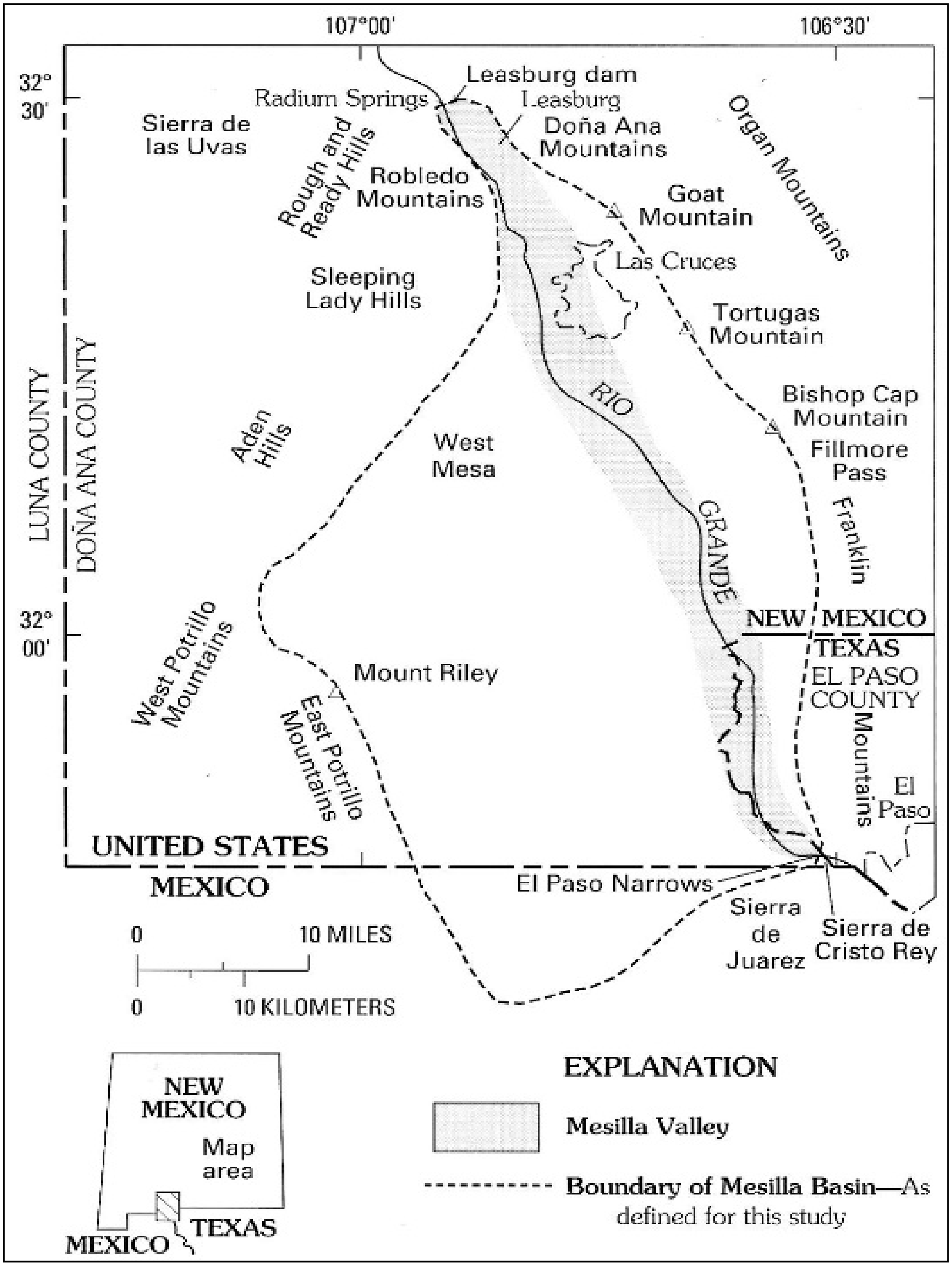
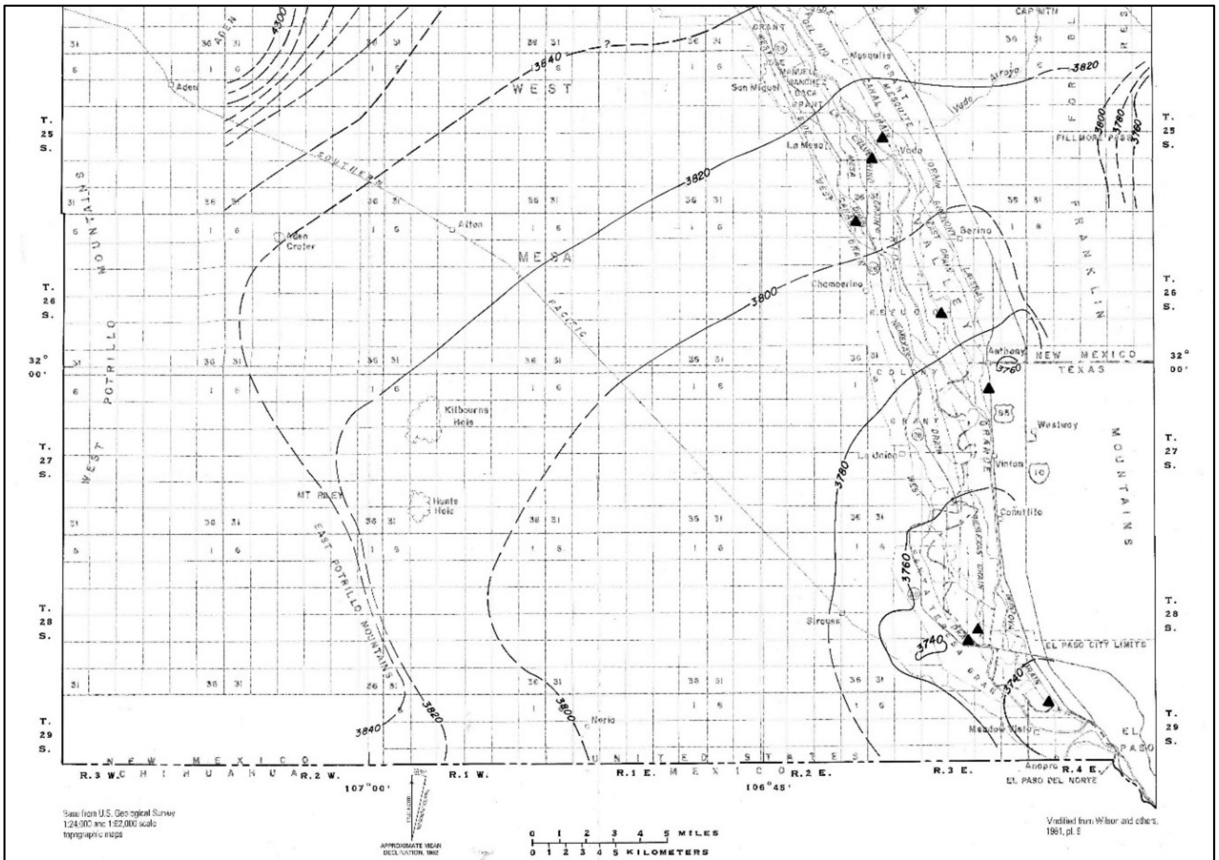


Figure C5-2. Map showing locations of the Mesilla Basin, Mesilla Valley, and bounding bedrock uplifts in the Doña Ana County area of south-central New Mexico. Dashed line shows boundary of the Mesilla "groundwater basin [MeB]" as defined by P.F. Frenzel and C.A. Kaehler (1990, Fig. 4; 1992, Fig. 4).

While none of the above-cited reports included information on potentiometric-surface elevation or regional groundwater-flow direction south of the International Boundary, invaluable interpretations on approximate predevelopment water levels are presented in maps compiled by Conover (1954), King and others (1971), Wilson and others (1981), and Nickerson and Myers (1993) for the 1946 to 1985 interval (*see* Report **CHPT. 7**). All, however, show a regional GW-flow component that is subparallel to binational-border zone with a focused-outflow discharge area in the southernmost Mesilla Valley area between Canutillo and Sunland Park (*cf.* **Parts C2.1** and **C2.2**, **Figs. C2-1** and **C5-3**). Moreover, most also indicate that a substantial flow component had a recharge source in north-central Chihuahua's "Zona Hidrogeológica de Conejos Médanos" (Conover 1954, Plate. 1 [**PLATE 9A**]; King et al. 1971, Plate. 1 [**PLATE 9B**]; Wilson et al. 1981, Pl. 9; Nickerson and Myers 1993, Fig. 9). **Figure C5-3** (south part of **PLATE 9C**) shows the approximate pre-development water-level contours in the southwestern Mesilla Basin. **Figure C5-4** (from **PLATE 4**) is included to illustrate the remaining degree of uncertainty on the nature of the GW-flow regime in parts of the Study Area in Chihuahua.



MAP SHOWING APPROXIMATE WATER–LEVEL CONTOURS AND GAGING STATIONS ON DRAINS, MESILLA BASIN, NEW MEXICO AND TEXAS

Figure C5-3. (**Plate 9C extract**) Map showing approximate water-level contours and gaging stations on drains, Mesilla Basin, New Mexico, and Texas (Lower part of Plate 1 *in* Frenzel and Kaehler 1992 [**Plate 9C**]; modified from Wilson et al. 1981 [Plate 9]—1976 water-level compilation) (*cf.* **Figure C5-4** and **PL. 4**).

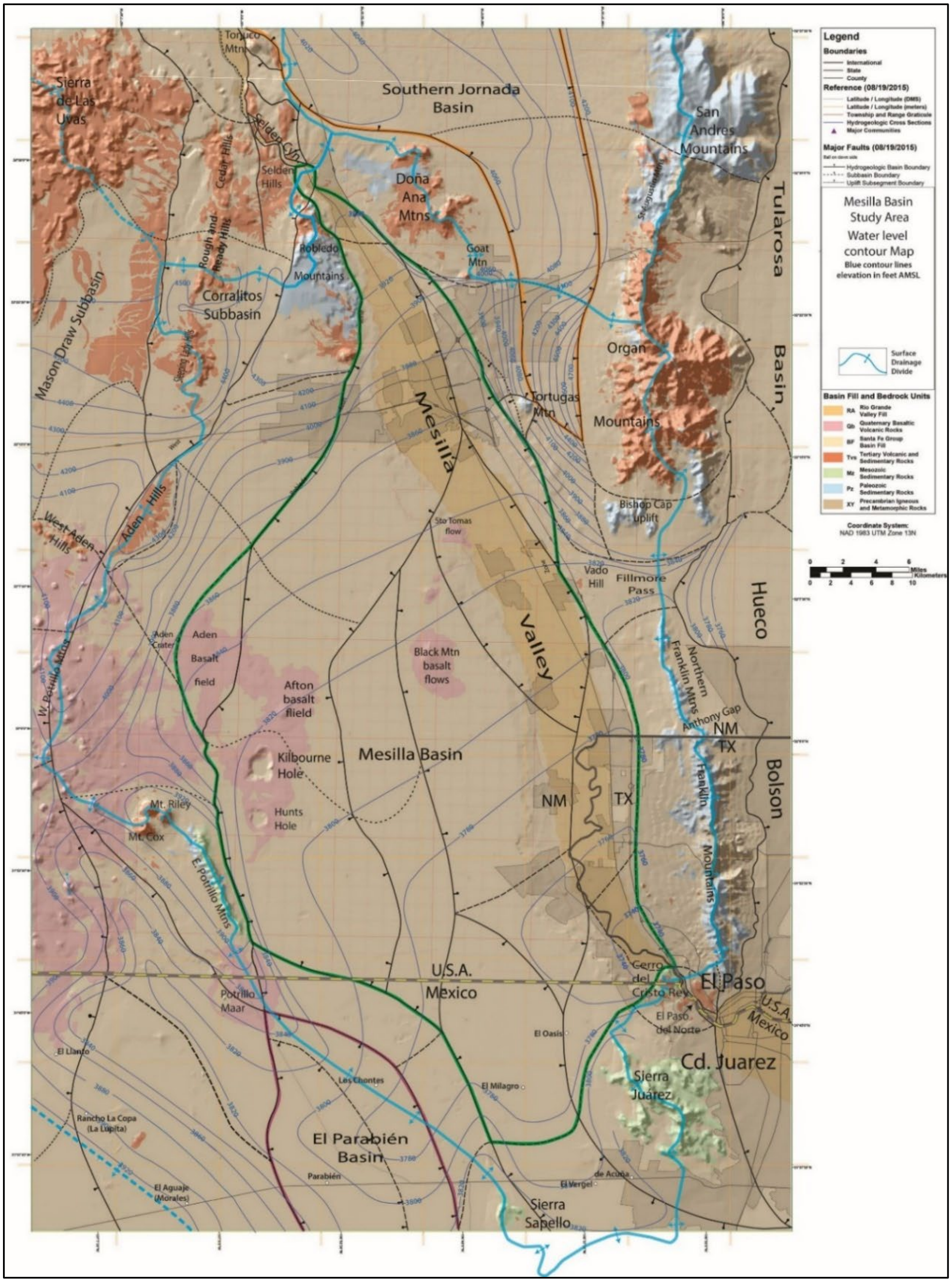


Figure C5-4. (page-size **PLATE 4**) Index map of major hydrographic and geohydrologic features of the Study Area. Surface-watershed boundaries—heavy-blue lines. Pre-development potentiometric-surface elevation approximation (10-ft contour interval) in central-basin areas—light-blue lines. The dashed-blue in the map's SW corner shows the approximate position of the GW-flow divide between lower Mesilla Valley directed flow and Los Muertos Basin/El Barreal-directed flow. Swanson Geoscience, LLC compilation on a **PLATE 1** hydrogeologic map base (1:100,000 compilation scale).

C5.3. USGS-State Cooperative Studies of Geology and Hydrology in the Basin and Range Province Related to Selection of Sites for the Disposal of High-Level Radioactive Waste

Throughout the 1980s, USGS-State collaborative studies of the Basin and Range province relative to the disposal of high-level radioactive waste also had a significant impact on the development of present generation of hydrogeologic-framework models of the Mesilla Basin region, particularly with respect to groundwater-flow regimes in interlinked rift-basin interiors and inter-basin bedrock uplifts (Bedinger et al. 1984, 1989a-c). The following selections from the "INTRODUCTION" to USGS Professional Paper 1370-A describe the program's "background and purpose" (Bedinger, Sargent, and four others, 1989, p. A-2):

> A study by the U.S. Geological Survey to evaluate potential hydrogeologic environments for isolation of high-level radioactive waste in the Basin and Range physiographic province was begun in May 1981, with the introduction of the study to the Governors of eight Basin and Range States-Arizona, California, Idaho, Nevada, New Mexico, Oregon, Texas, and Utah-and to Indian tribes in those States. Accordingly, these States were invited to participate in the study by designating an earth scientist to serve on a Province Working Group with the U.S. Geological Survey-membership of the working group is shown following the title page. State representatives have provided consultation in selecting guidelines, assembling geologic and hydrologic data, and assessing such information to identify environments that meet the guidelines for further study….
>
> The regions were selected [for further evaluation during first-phase studies] on the basis of the adopted guidelines and of information obtained from available sources on: (1) The distribution of rock types that may be host media for radioactive waste; (2) characteristics of the province related to tectonic stability-seismicity, late Cenozoic volcanism, Quaternary faulting, late Cenozoic regional uplift, and heat flow; and (3) the hydrology of ground-water flow systems.
>
> This report, Chapter A of Professional Paper 1370, is one of a series of eight chapters (A through H) that describe the evaluation of potential hydrogeologic environments for the isolation of high-level radioactive waste in the Basin and Range physiographic province. These chapters present the results of the second phase of study. The titles of chapters in this series are:
>
> A Basis of characterization and evaluation
> B Characterization of the Trans-Pecos region, Texas
> C Characterization of the Rio Grande region, New Mexico and Texas
> D Characterization of the Sonoran region, Arizona
> E Characterization of the Sonoran region, California
> F Characterization of the Death Valley region, Nevada and California
> G Characterization of the Bonneville region, Utah and Nevada
> H Evaluation of the regions
>
> . . . . Resources and time did not permit study in the present, second, phase of all potential regions identified in the first phase of study. . . . The regions selected for study and revised subdivisions are shown in figure 2 (**Fig. C5-5**).

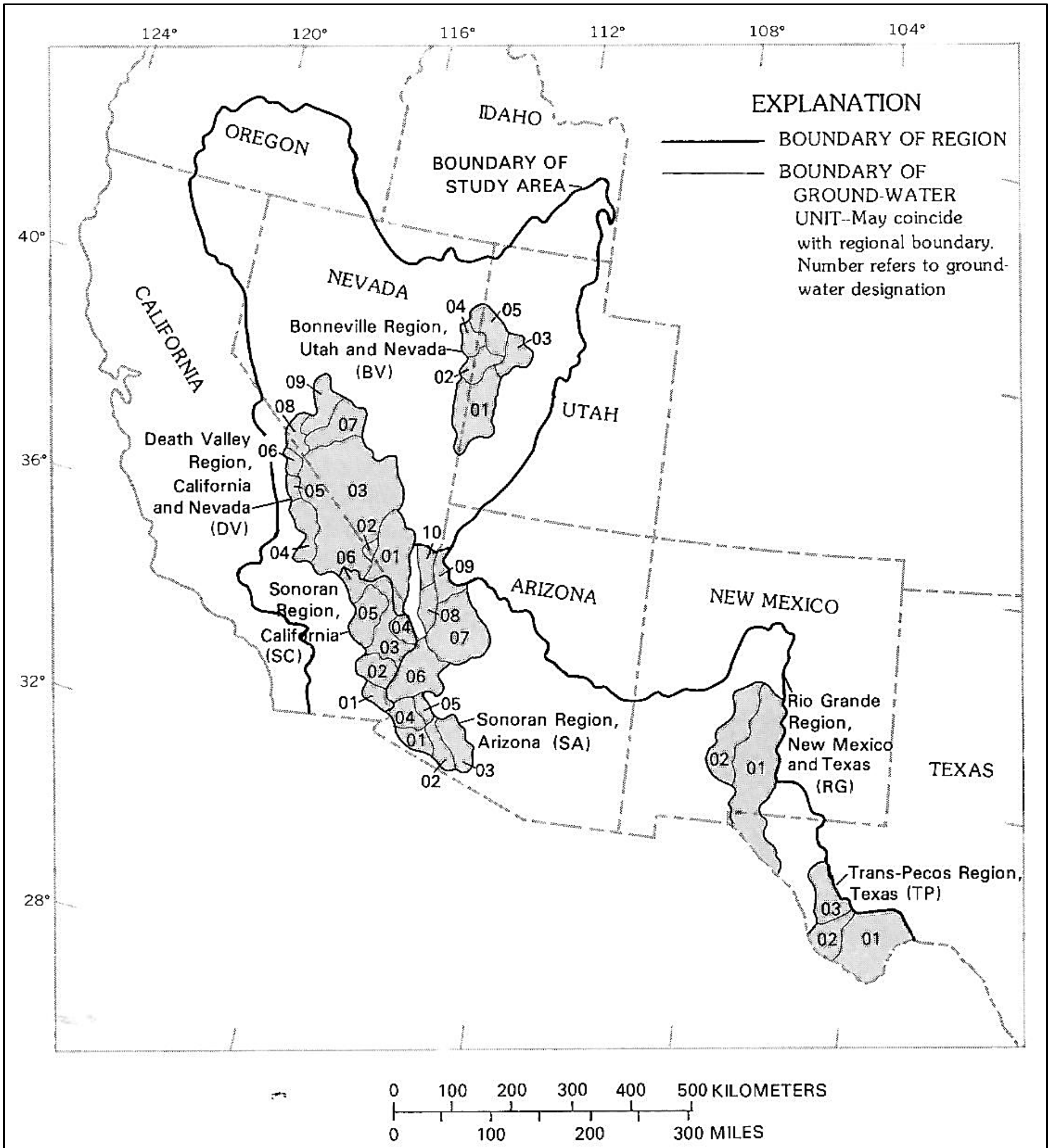


FIGURE 2.—Regions (shaded) selected for study.

Figure C5-5. (Bedinger et al. 1989a, Fig. 2) Map of regions (shaded) in the Basin and Range physiographic province selected for evaluation of "potential hydrogeologic environments for isolation of high-level radioactive waste." "Rio Grande Region (RG):" Tularosa Basin and Hueco Bolson-01, and Central and Northern Jornada (del Muerto) Basin-02 (Bedinger et al. 1989b, Johnson et al. 1989, and Sargent et al. 1989).

C6. CONCLUDING REMARKS

The following selection from Nickerson (2006, p. 2) represents the first formal USGS recognition of the hydrogeologic-framework model that was developed by Hawley and Lozinsky (1992) for use throughout the Mesilla Basin region (*cf.* Hawley et al. 2009, Sweetkind 2017, Sweetkind et al. 2017, Teeple 2017a, Hanson et al. 2018):

> The lower Mesilla Valley ground-water system consists primarily of a basin-fill aquifer with two main geologic units: the Santa Fe Group of Quaternary and Tertiary age and the Rio Grande flood-plain alluvium of Quaternary age (King and others, 1971). The Santa Fe Group is an intermontane basin-fill unit that extends throughout the Mesilla Basin and includes alluvial, eolian, and lacustrine deposits (Hawley and Lozinsky, 1992, p. 4). These clay, silt, sand, and gravel deposits can reach depths of more than 2,000 feet in the lower Mesilla Valley. The Rio Grande flood-plain alluvium overlies the Santa Fe Group in the Mesilla Valley and consists of channel and flood-plain deposits of clay, silt, sand, and gravel that generally are less than 125 feet thick (Wilson and others, 1981, p. 27).
>
> The hydrogeologic framework of the Mesilla Basin was established in Hawley and Lozinsky (1992). Their basinwide conceptual model delineated three hydrogeologic features: (1) bedrock and structural boundaries, (2) lithofacies assemblages, and (3) hydrostratigraphic units. Santa Fe Group basin fill is divided into the informal upper, middle, and lower hydrostratigraphic units based on depositional environment and age. The upper Santa Fe hydrostratigraphic unit (USF) consists primarily of ancestral Rio Grande deposits of medium to coarse sand and [pebble] gravel. The USF includes the Camp Rice and upper Fort Hancock Formations. The middle Santa Fe hydrostratigraphic unit (MSF) consists primarily of alluvial deposits with eolian and playa-lake facies.
>
> Basin-floor sediments of interbedded sand and silty clay are common. The MSF includes the Fort Hancock and Rincon Valley Formations. The lower Santa Fe hydrostratigraphic unit (LSF) consists primarily of eolian, playa-lake, and alluvial facies. Basin-floor sediments include thick-bedded dune sand. The LSF includes the Hayner Ranch and the lower Rincon Valley Formations. Detailed descriptions of the hydrostratigraphic units and associated lithofacies can be found in Hawley and Lozinsky (1992). The Mesilla Basin hydrogeologic framework was recently updated and integrated into a digital format by Hawley and Kennedy (2004).

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C7.2. Chronology of Notable Contributions to the Understanding of the Binational Mesilla Basin Region's Hydrogeology and Geohydrology (1890-2006)

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C7.2.4. 1996 to 2010

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C7.3. Topic/Subtopic Categories, with Alphanumeric Cross-Reference Codes (Appendix B)

A. Bibliographies, Dictionaries, Glossaries, Biographies, Reviews, and News Items
- A1. Bibliographies, Dictionaries, and Glossaries
- A2. Biographies and Reviews
- A3. News Items

B. Time: Geologic, Prehistoric, and Historic
- B1. Geologic and Prehistoric Time
- B2. Prehistoric Perspective: US Southwest and Northern Mexico
- B3. Historic Perspective: US Southwest and Northern Mexico

C. Environmental, Physiographic, and Geologic Setting
- C1. Climatic, Hydrographic, Ecologic, and Paleoenvironmental Setting
- C2. Geologic and Geomorphic Setting
  - C2a. Geologic and Geomorphic Setting: Pre-1990
  - C2b. Geologic and Geomorphic Setting: Post-1989
- C3. Soil-Geomorphic Relationships and Soil Surveys
- C4. Geophysical/Geochemical Data and Interpretations

D. Basic Hydrogeologic Concepts
- D1. Conceptual Models, Definitions, and Regional Overviews
- D2. Groundwater-Flow Systems, Including Recharge

E. GIS/Remote Sensing and GW-Resource Management/Planning
- E1. GIS/Remote Sensing
- E2. Resource Management/Planning
  - E2a. Desalination
  - E2b. Recharge and Recovery
  - E2c. Groundwater-Quality Projection and Waste Management
- E3. Legal and Environmental Issues and Constraints

F. Transboundary Regional Hydrogeology and Geohydrology
- F1. Binational
- F2. USA
- F3. México

G. Early Documents on Mesilla Basin Regional Aquifer Systems (1858-1970)
- G1. 1858 to 1935
- G2. 1935 to 1970

H. Contemporary Documents on Mesilla Basin Regional Aquifer Systems
- H1. Hydrogeology
- H2. Hydrochemistry
- H3. Flow Models

I. Paleohydrology: Ancestral Fluvial and Pluvial Lake Systems
- I1. Regional Overviews
- I2. Transboundary Region Paleohydrologic Systems
- I3. Evolution of the Rio Grande Fluvial System

C8a. SPECIAL ADDENDUM 1—HAWLEY, J.W., 1971, GEOLOGY AND ITS RELATION TO THE HYDROLOGIC SYSTEM (W.E. King et al.; Reformatted) * **

**Contribution approved for publication by the Director, Soil Conservation Service, U.S. Department of Agriculture.*

*******In* W.E. King and others, 1971, Geology and ground-water resources of central and western Doña Ana County, New Mexico: N.M. Bureau of Mines and Mineral Resources, Hydrologic Report 1

GEOMORPHIC FEATURES

The area under discussion (Fig. 4) is in the Mexican Highland section of the Basin and Range physiographic province (Fenneman, 1931; Thornbury, 1965). It includes a number of mountain uplifts, parts of four major intermontane basins, and the valley of the Rio Grande. The area is bounded on the west by the Mimbres River basin, the Goodsight Mountains, and the Hillsboro-Animas uplift. The San Andres-Organ-Franklin Mountain chain forms the eastern boundary. The intermontane basins extend southward into northern Chihuahua and northward into central New Mexico.

The geomorphology of the region has been discussed in detail by Ruhe (1962, 1964, 1967), Kottlowski (1958), Kelley and Silver (1952), and Hawley (1965; Hawley and Gile, 1966; Hawley and Kottlowski, 1969). The succeeding discussion will emphasize features considered to be of hydrogeologic significance.

MOUNTAINS

With some major exceptions, the mountains in the Rio Grande region of southern New Mexico consist of fault-block uplifts with a general north-south trend (Kottlowski, 1958). Other mountain types include broad domal uplifts and remnants of igneous intrusive bodies. Only the low-lying West Potrillo Mountains (maximum elevation, 5,473 ft), in southwest Doña Ana County, reflect the primary form of the basaltic volcanic cones and flows that underlie that particular upland area.

The highest peak in the region, Organ Needle (elevation, 9,012 ft) is part of the jagged crest of a mass of Tertiary [igneous] intrusive rocks (monzonites) that comprises the central Organ Mountains. The San Andres range and the Franklin and southern Organ Mountains generally have the form of strongly tilted fault blocks, which are bounded on the west by dip slopes on Paleozoic to Tertiary beds (dominantly marine carbonate rocks), and on the east by escarpments that cut across Paleozoic strata into Precambrian rocks. Alluvial fan and pediment gravels on the upper piedmont slopes of the western Hueco and Tularosa Basins are cut by faults that are closely aligned with the eastward-facing escarpments. The Caballo Mountains, which extend into the north-central part of the area of investigation, are similar in form to the San Andres-Franklin range, with the exception that they consist of several eastward-tilted fault blocks.

The Robledo Mountains also consist of a tilted fault-block uplift, but in this case, the mountains have the form of a wedge-shaped horst that is bounded on the east and west by faults and is tilted gently toward the south. The peaks and high ridges of the Robledo, Caballo, San Andres, and Franklin Mountains are in most places underlain by thick-bedded carbonate rocks of Paleozoic age.

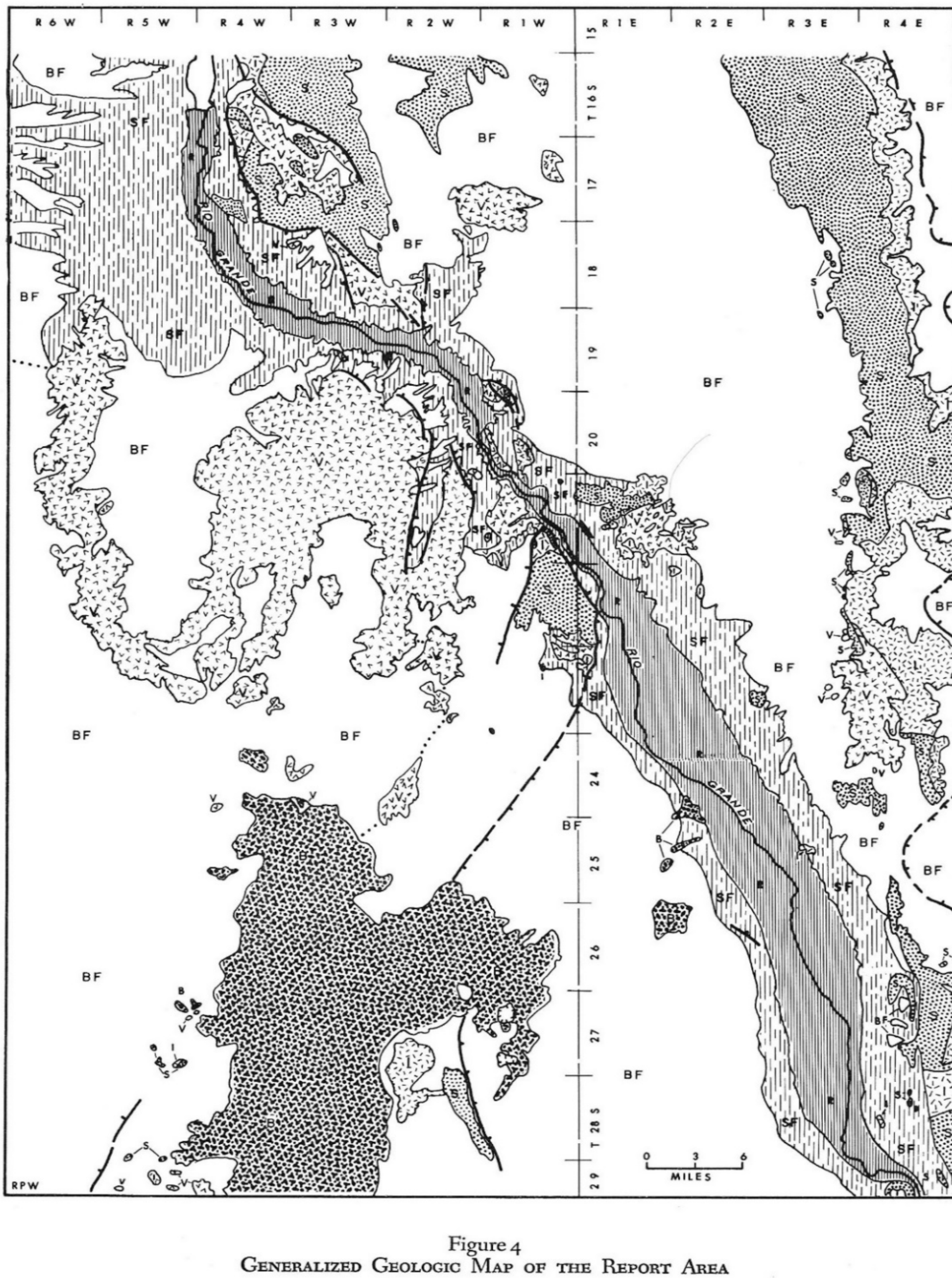

Figure 4
Generalized Geologic Map of the Report Area

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R	Valley-fill alluvium; Lake Quaternary; clay to gravel, less than 80 feet thick.
B	Olivine basalt flows and volcanic cones; Quaternary, generally post date the Santa Fe Group.
BF	Basin-fill surface. Santa Fe Group, with discontinuous overlay (generally less than 25 feet thick) of younger alluvial, eolian and minor lacustrine deposits.
SF	Santa Fe Group basin fill; Miocene to Middle-Pleistocene; clay to gravel, locally as much as 4,000 feet thick. Also discontinuous overlay (generally less than 100 feet thick) younger valley slope deposits.
V	Volcanic rocks, and associated clastic sedimentary rocks, undifferentiated; Middle Tertiary.
S	Sedimentary rocks, undifferentiated; Paleozoic, Cretaceous and Early Tertiary.
I	Intrusive rocks, undifferentiated, and associated metamorphics; Precambrian and Tertiary.
......	Santa Fe—Gila Group Boundary.
┬┬	Faults involving significant displacements of Basin Fill.

GEOLOGIC MAP LEGEND

The two other major upland areas, the Doña Ana Mountains and the Sierra de Las Uvas, are domal uplifts composed mainly of Tertiary igneous rocks. Monzonite intrusive rocks form the high peaks of the Doña Ana Mountains, and thick basaltic andesite flows and rhyolitic welded tuffs hold up high mesas, cuestas, and buttes in the Sierra de Las Uvas. The west flanks of the Uvas uplift make up the east limb of a large northward-plunging syncline. The Tertiary volcanics cropping out in the nose and west limb of this syncline form the arcuate Goodsight Mountains.

A number of small, isolated upland areas occur throughout the region. Many are aligned along definite trends and appear to be associated with buried extensions of major positive structures. Small fault-block uplifts include the Rincon Hills, Tonuco-Selden Hills uplift, Tortugas Mountain, and Bishop Cap. Small peaks formed by erosional remnants of Tertiary igneous intrusive bodies include Goat Mountain, Picacho Peak, Vado Hill, Mount Riley, and Cerro de Muleros [Cristo Rey]: The Aden, Sleeping Lady, and Rough and Ready Hills consist of a belt of small peaks, ridges, buttes, and elongated mesas underlain by Tertiary volcanic rocks. The hills appear to be remnants of a former cover of andesites, basalts, rhyolite tuffs, and associated sedimentary rocks that had been disrupted by a combination of erosion, faulting, and warping. Point of Rocks, between the southern Caballo and San Andres ranges, is another group of hills of this type.

BASINS

The major intermontane basins (fig. 3) represent structurally depressed units that have been displaced downward with respect to the mountain uplifts. Relative displacement of mountains and basins has been achieved by block faulting, warping, and a combination of the two. The basins include the southeastern Mimbres Basin and Mesilla Bolson (Hill, 1900), which are separated by the Rough and Ready-Sleeping Lady-Aden Hills and the West Potrillo Mountains; and the southern Jornada del Muerto and Palomas Basins, which are separated by the Caballo Mountains and the Sierra de Las Uvas. The Goodsight Mountains and the Sierra de Las Uvas separate the Mimbres Basin from the southern Palomas Basin. There is no distinct positive surface boundary between the Mesilla Bolson and the Jornada del Muerto, but, for the purposes of this report, the two basins are separated along a line extending eastward from the northern Robledo Mountains to the central Doña Ana Mountains and then to the central Organ Mountains via Tortugas Mountain.

Only a part of each of the four basins is included in the area of study. Each basin is highly elongated in a north-south direction and can be subdivided into two or more distinct subbasins in terms of surface-water hydrology. Each basin has two basic landscape components: basin floor and piedmont slope. The basin floors generally have a slight gradient toward the south (> 0.5%) and are nearly level transversely; they range in width from less than 1 mile to more than 20 miles; and they are locally marked by shallow, closed depressions….

The piedmont slopes, which gradually rise from the basin floors to the abrupt break in slope at the mountain fronts (gradients from less than 1% to about 10%) include two basic types of surfaces: constructional, alluvial-fan, and coalescent-fan surfaces; and erosional surfaces, cut both on hard rocks adjacent to the mountain fronts (pediments) and on older basin fill deposits.

The range in age of the basin surfaces is considerable. Large areas of the basin floors of the Mesilla Bolson and the southern Jornada del Muerto are remnants of a middle Pleistocene basin landscape that formed prior to initial cutting of the Rio Grande valley. A few remnants of this landscape are also preserved in the southern Palomas Basin, which is now largely occupied by the valleys of the Rio Grande and tributary arroyos. In early to middle Pleistocene times, these basin floors were the sites of aggrading channels of the ancestral Rio Grande [ARG], which emptied into lake basins in what is now northern Chihuahua and westernmost Trans-Pecos Texas. Subsequent to valley entrenchment, only the basinfloor areas adjacent to piedmont slopes and the scattered closed depressions that are subject to episodic flooding have been sites of active sedimentation.

In contrast to the basin floors, large areas of the piedmont slopes have been the sites of repeated episodes of erosion and deposition in middle and late Quaternary time (Gile and Hawley, 1966). Remnants of the piedmont-slope component of the ancient basin landscape are preserved only in dissected areas near the mountain fronts and adjacent to the valleys of the Rio Grande and tributary arroyos.

Formal geomorphic surface names have been given to parts of the basin landscape that pre-date initial cutting of the present valley system. The basin floors underlain by sand and rounded gravel deposits of mixed composition and middle Pleistocene age have been designated the La Mesa surface (Ruhe, 1964, 1967; Hawley and Kottlowski, 1969). A piedmont-slope surface of roughly equivalent age has been named the Doña Ana surface (Ruhe, 1964, 1967), and a slightly younger piedmont-slope and basin-floor surface has been designated the Jornada surface (Ruhe, 1964, 1967; Hawley and Gile, 1966; Hawley and Kottlowski, 1969). In the Rincon to Caballo Reservoir area, the names "Jornada," "Palomas," and "Rincon," have been applied to a complex of basin surfaces ranging from early(?) to middle Pleistocene age (Kelley and Silver, 1952; Kottlowski, 1953; Hawley, 1965). Late Quaternary piedmont-slope and basin-floor surfaces include the late-Pleistocene Jornada II and Petts Tank surfaces and the Holocene Organ surface (Hawley and Gile, 1966; Gile and Hawley, 1968).

VALLEY OF THE RIO GRANDE

The evolution of the basically erosional Rio Grande valley system in southern New Mexico has been discussed in considerable detail by Kottlowski (1958), Ruhe, (1962, 1964, 1967), Hawley (1965), Metcalf (1967), and Hawley and Kottlowski (1969).

The morphology of the Rio Grande valley, which crosses the area from northwest to southeast, reflects (1) the nature of the materials in which the valley is cut, (2) the control exerted by deep-seated structural movements, and (3) the episodic nature of valley incision since integration of the upper and lower Rio Grande systems and development of through drainage to the Gulf of Mexico in middle Pleistocene time.

The present flood-plain surface ranges from about 250 to 500 feet below the ancient basin surfaces. Evidence of former episodes of valley entrenchment and aggradation is preserved in the form of rock-defended river terraces and valley-slope remnants of geomorphic surfaces that were graded to former, higher river base levels. These relict surfaces extend into the drainage basins of tributary arroyos. Levels of ancestral flood-plain stability can be reconstructed at elevations of about 130 feet, 70 feet, and less than 30 feet above the present valley floor.. The two higher levels, listed in order of decreasing age and elevation, correspond with the Tortugas and Picacho valley-slope surfaces of middle to late Pleistocene age (Dunham, 1935; Kottlowski, 1953, 1960; Rube, 1962, 1964, 1967; Hawley, 1965; Hawley and Kottlowski, 1969). The Leasburg and Fillmore (Fort Selden Group) surfaces comprise latest Pleistocene and Holocene terraces and valley slopes associated with local base levels no more than 30 feet above the present Hood-plain surface (Ruhe, 1962, 1967; Hawley, 1965; Hawley and Kottlowski, 1969). Maximum entrenchment of the ancestral Rio Grande occurred in latest Pleistocene time (probably between 11,000 and 22,000 years ago). This stage of valley cutting is represented by an erosion surface, cut in basin fill and older rocks, about 80 feet below the present valley floor (Hawley, 1965; Hawley and Kottlowski, 1969; Davie and Spiegel, 1967).

Local evidence of fault movements and downwarping along the Rio Grande valley margins in Quaternary time indicates that the general valley position is structurally controlled and that some of the relief between the basin surfaces and valley floors is a product of tectonic movements (Ruhe, 1964; Hawley and Kottlowski, 1969). However, the major valley border surfaces in the study area can be correlated with similar stepped sequences of geomorphic surfaces up and down the Rio Grande valley (Ruhe, 1964; Hawley, 1965). It thus appears that the geomorphic development of the valley system since middle Pleistocene time has been basically controlled by the hydrology of the upper Rio Grande system. Marked changes in river and arroyo discharge, erosion and sediment production, and character of vegetative cover have occurred periodically and were related to the waxing and waning of Quaternary glacial-pluvial stages (Hawley and Gile, 1966; Metcalf, 1967; Schumm, 1965).

The Rio Grande erosional valley is wide where it is cut into the poorly consolidated fills of the intermontane basins and narrow where it crosses the rock cores of mountain uplifts. The valley has been subdivided into five major segments in the Caballo-El Paso reach (Hawley, 1965). The northern segment, the Palomas Valley, comprises the river valley and the valleys of major tributary arroyos (such as Placitas, Thurman, Crow, Green, and Berrenda) from Caballo Reservoir to the town of Hatch. Rincon Valley designates the area between Hatch and Selden Canyon and includes the valley of Rincon Arroyo and several other arroyo valleys heading in the Sierra de Las Uvas. Selden Canyon extends from the valley constriction southwest of San Diego Mountain to the Radium Springs-Fort Selden area of Mesilla Valley, the major valley area, extends about 50 miles from Fort Selden to northwest El Paso. El Paso Canyon, the final valley constriction, is in the southeastern corner of the area at the Texas-New Mexico-Chihuahua boundary juncture.

The present flood plain ranges in width from about 0.25 mile in narrower canyon areas to 5 miles in parts of the Mesilla Valley. The gradient of the floor plain is about 4 to 5 feet per mile in the Caballo Dam-El Paso reach. The gradient of the present, straightened river channel approaches that of the flood-plain slope, but the sinuous channel that characterized the reach prior to the 1860's had a gradient as low as 1.5 feet per mile (U.S. Reclamation Service, 1914). Maximum river discharge since Elephant Butte Dam closed in 1915 has been generally less than 8,000 cubic feet per second (cfs). However, in 1904 and 1905, peak discharges in the San Marcial-El Paso reach attained magnitudes ranging from about 24,000 (El Paso, 6/12/1905) to 50,000 cfs (San Marcial, 10/11/1904; U.S. Geological Survey, 1961; Patterson, 1965).

SOILS

Soils form an integral part of the landscape discussed above. The early soil surveys of Nelson and Holmes (1914) and Sweet and Poulson (1930) have been updated during the past two decades by relatively detailed surveys of the U.S. Soil Conservation Service. Detailed soils maps covering parts of Doña Ana County and a new soil associations map for New Mexico are available for inspection at the Las Cruces and University Park offices of the Soil Conservation Service . . . . Published soil maps and other significant information on soil-geomorphic relationships are included in reports by Gile and others (Gile, 1961, 1966, 1967, 1970; Gile, Peter son, and Grossman, 1965, 1966; Gile and Hawley, 1966, 1968; Gile, Hawley and Grossman, 1970) and by Maker et al. (1960). Publication of additional soil maps is scheduled for the near future.

The two [major] soil-resource areas include (1) the Rio Grande flood plain and the alluvial-fan surfaces that form the lower parts of valley slopes, and (2) the extensive, undissected plains in basins adjacent to the river valley. The former area is under intensive cultivation, while the latter area is utilized primarily as rangeland.

Soils of the flood-plain and adjacent valley slopes are associated with very young, constructional geomorphic surfaces. The soils show little profile development. They primarily reflect the composition of recently deposited alluvium and the addition of small amounts of organic matter and calcium and sodium salts. Dominant great groups in these areas are torrifluvents, torripsamments and torriorthents in the new soil survey classification system (Soil Survey Staff, 1960, 1967).

Soils of the basin surfaces reflect the great age range of geomorphic surfaces and variations in geologic parent materials, as well as orographic and topographic effects. Soils associated with very young basin surfaces are weakly developed compared to soils of older basin surfaces. Torrifluvents, torripsamments, torriorthents, weak calciorthids, and weak haplargids are the dominant great groups. Soils associated with Pleistocene basin surfaces have much stronger horizons of clay or carbonate accumulation, or both, with the strongest horizons of accumulation generally associated with soils of the older Pleistocene landscapes. Haplargids, paleargids, calciorthids, and paleorthids are dominant great groups. The paleorthids and paleargids with indurated horizons of carbonate accumulation within 40 inches of the ground surface are particularly important from a hydrologic standpoint. Shallow horizons plugged with carbonate inhibit deep movement of soil moisture, thereby retaining the limited amounts of water for plant use (Bailey,1967) and preventing downward percolation into the thick interzone of unsaturated basin fill.

Rocks and Unconsolidated Deposits: Stratigraphy, Lithology, and Water-Bearing Characteristics

CONSOLIDATED ROCKS

The primary hydrologic role played by consolidated rocks in the area of study is that of a barrier to the movement of water. The consolidated rocks also serve as the source of many of the dissolved solids found in the ground and surface waters of the area. The geohydrologic properties of various bedrock units that occur in the area have been summarized by Dinwiddie (1967) and Titus (1967). On the geologic map (fig. 4) the consolidated rocks are subdivided into four groups on the basis of both geologic and water-bearing characteristics: (1) Precambrian Tertiary metamorphic and igneous intrusive rocks; (2) Paleozoic, Mesozoic, and early Tertiary sedimentary rocks, (3) Tertiary volcanics and associated sedimentary rocks, and (4) late Cenozoic basalts. Groups 1, 2, and 3, comprise the bedrock exposed in the mountain uplifts and buried by fills of variable thickness in the intermontane basins (Dunham, 1935; Kelley and Silver, 1952; Kottlowski, 1953, 1960; Kottlowski et al., 1956; Dane and Bachman, 1961). These rocks will be discussed in the following paragraphs. The late Cenozoic olivine basalts are either interbedded with or cover the basin-fill deposits and will be described in the section dealing with those materials.

IGNEOUS INTRUSIVE AND METAMORPHIC ROCKS

Deep-seated igneous intrusive bodies of granitic to porphyritic texture and of Precambrian and Tertiary age make up the cores of the San Andres-Organ-Franklin Mountain chain and the Doña Ana and Caballo Mountains. Smaller uplifts with igneous intrusive centers include the Tonuco (San Diego Mountain) uplift, Goat Mountain, Vado Hill, Picacho Peak, Cerro de Muleros [Cristo Rey], and Mount Riley. The Precambrian intrusives are intimately associated with complexes of metamorphic rocks.

All the rocks in the intrusive-metamorphic group are effective barriers to ground-water movement and yield only small quantities of water in local weathered or fractured zones. Quality of water derived from intrusive-metamorphic terrains is usually good, but may be exceptionally poor in mineralized areas.

SEDIMENTARY ROCKS OF PALEOZOIC TO EARLY TERTIARY AGE

For the purposes of this report, the sedimentary rocks of Paleozoic, Cretaceous, and early Tertiary age are discussed as one hydrogeologic unit. All these rocks are well consolidated and have been locally subjected to tectonic deformation. The rocks of Paleozoic age dominantly limestones and dolomites, with the exception of a basal Cambrian-Ordovician quartzite to quartzite conglomerate, a Devonian shale sequence, and intertonguing bodies of gypsum and redbed sandstone to siltstone in the Upper Pennsylvanian to Permian part of the section. Paleozoic rocks make up the bulk of the bedrock in the San Andres, Franklin, Caballo, and Robledo Mountains. Relatively complete stratigraphic sections ranging from Cambrian/ Ordovician to Permian in age are exposed in each of the uplifts. Cretaceous rocks include shales and limestones that crop out in the southern Franklin, Cerro de Muleros, and East Potrillo uplifts, and shales to sandstones exposed along the flanks of the Caballo and San Andres Mountains. The early Tertiary sedimentary rocks consist of conglomerates, sandstones, and minor shales that crop out in a few areas along the east flanks of the Caballo Mountains and the west flanks of the San Andres and Organ Mountains.

Primary porosity is low in all the rock units. The major effective porosity is along joints, fissures, and faults. Solution cavities in carbonate and gypsiferous rocks appear to be uncommon in this area. Yields from the few wells penetrating the sedimentary rocks are low, rarely exceeding a few gallons per minute (gpm). Two Apollo Project test wells (Doty, 1963, wells D, G; table 4, wells 20.3E.12.332, 20.3E.15.442) respectively, penetrated about 1,150 and 350 feet of rocks below the water table that are interpreted as Cretaceous and early Tertiary shales, sandstones, and conglomerates. Although the wells were regarded as “dry” holes, enough water for stock or domestic purposes might be available, and the term “damp holes” (Lehr, 1968) would be a more accurate designation. Large water yields have been reported from the Torpedo Bennett fault zone along the northwest base of the Organ Mountains (Dunham, 1935). Water produced from the sedimentary-rock group often has a high content of dissolved solids, particularly in areas of hydrothermal mineralization or where gypsum is present.

TERTIARY VOLCANIC AND SEDIMENTARY ROCKS

The third major bedrock group comprises Tertiary volcanics and thick sequences of interbedded elastic sedimentary rocks. These rocks are mainly of Eocene to Miocene age. They comprise the major bedrock units in the Sierra de las Uvas, Goodsight, Doña Ana, and southern Organ Mountains, and the Rincon, Selden, Rough and Ready, Sleeping Lady, and Aden Hills.

There is a great range in consolidation of these materials. Rhyolite, andesite-latite, and basaltic andesite flows and rhyolitic welded tuffs are generally hard and dense; on the other hand, unwelded tuffs of rhyolitic to andesitic composition and the interbedded sedimentary rocks are moderately well to poorly consolidated. These rocks generally have low permeability. Even the poorly consolidated volcanics and associated sediments consist of well-graded mixtures including a wide range of particle sizes (from boulders to clay); thus, the primary porosity of these materials is very low. As is the case with the older rocks, effective porosity is provided by fractures. Since the joints, faults, and fissures in the bedrock tend to be sites of mineralization, water in zones of intense fracturing at many places has a high content of dissolved solids and [is] commonly non-potable. Two Apollo Project test wells were also drilled into Tertiary volcanics (Doty, 1963, wells C, H; table 4, wells 21.3E-4-211, 20.3E.16.233), well C, which penetrated about 550 feet of rhyolite and interbedded sediments below the water table, produced less than 40 gpm; well H, which penetrated about 1,150 feet of andesitic volcanics, was regarded as a “dry (damp) hole.”

DISCUSSION

An important point that should be considered here is the influence of the various bedrock units exposed in the mountain uplifts upon the textural and geochemical characteristics of the basin fills. The latter deposits are described in the next section, but it should be noted here that the types of material deposited in the basins, particularly in the piedmont-slope areas, directly reflect the way the different bedrock lithologies behave as they are affected by the various agents of weathering, entrainment, and transport. For example, monzonite and other granitic-textured rocks generally break down into fragments ranging in size from very coarse sand to clay during weathering and transportation. Limestones and calcareous sandstones and siltstones (such as those cropping out in the San Andres, Caballo, Robledo, and Franklin Mountains) tend to break down either into gravel or fine sand to silt-sized particles. The more massive, very hard rocks, such as metaquartzites and some rhyolites (e.g., the Soledad Rhyolite in the southern Organ Mountains) tend to break down into gravel-sized clasts. The shape and the size of the gravel is in great part controlled by spacing of fractures in the bedrock outcrop. Poorly-consolidated tuffs and tuffaceous sedimentary rocks of middle Tertiary age, older shales and mudstones, and the clayey B [argillic] horizons of some upland soils have been source materials for much of the fine-grained material in the basin fills. Of particular importance to the geochemistry of ground water are the prominent gypsite beds occurring in the Upper Pennsylvanian and/or Permian section in parts of the San Andres and Franklin Mountains. These rocks have been the source beds for locally thick secondary gypsum deposits in the fills of adjacent basin areas.

UNCONSOLIDATED TO MODERATELY CONSOLIDATED DEPOSITS

This category of geologic materials includes the two major water-bearing units in the region: The Santa Fe Group basin fill of Miocene(?) to middle Pleistocene age, and the Rio Grande and tributary arroyo valley fills of late Quaternary age. The stratigraphy and general composition of these units has been described by Hawley et al. (1969). This section of the report will emphasize the hydrogeology of the basin and valley fills at places where semiquantitative information is available in the form of well data. Table 6 of this report contains a number of sample and drillers’ logs that include specific notations on the stratigraphic and lithologic units penetrated by water wells and oil tests.

BASIN FILL—THE SANTA FE GROUP AND THE GILA CONGLOMERATE

The Santa Fe Group is a rock-stratigraphic unit comprising a complex sequence of unconsolidated to moderately consolidated sedimentary deposits, and some basalts, that partly fill the intermontane basins along and adjacent to the Rio Grande depression [rift] from the San Luis Valley of Colorado to the lower El Paso Valley of Texas and Chihuahua. The lower limit of the Santa Fe Group in the area of investigation is placed above the volcanic and associated sedimentary rocks of middle Tertiary age, which are well exposed in the Rincon Valley-Selden Canyon area. The upper limit of the group is the surface of the youngest basin-fill deposits predating initial entrenchment of the present Rio Grande valley system in middle Pleistocene time. The Jornada, La Mesa, Doña Ana, and Palomas geomorphic surfaces and associated soils commonly mark the upper boundary of the Santa Fe Group in southern New Mexico.

Studies of lithologic variations in the basin-fill deposits (both in outcrop and in subsurface), carried out in conjunction with investigations of basin geomorphology and basinfill stratigraphy, demonstrate that Santa Fe Group deposition occurred in both closed and open intermontane basin environments (Bryan, 1938; Spiegel, 1962; Strain, 1966; Lambert, 1968; Hawley et al., 1969). The former type, the classic bolson environment (Tolman, 1909; Thornbury, 1969), prevailed during early stages of basin filling, whereas later stages were marked by coalescence of the floors of contiguous basins and development of a regional system of through drainage (the ancestral Rio Grande system of Bryan, 1938; Spiegel, 1962). Locally derived piedmont-slope alluvium, characterized by wide textural variation and including alluvial-fan, coalescent-fan, and pediment deposits, is a typical facies in both closed and open basin environments. In closed systems, piedmont-slope alluvium grades into or intertongues with fine-grained, lacustrine and alluvial basin-floor deposits. In open systems, the basin-floor facies included medium- to coarse-grained fluvial deposits, with fine-grained materials making up a relatively small proportion of the basin-fill sequence.

By arbitrary decision, the boundary with the Santa Fe Group's southwestern New Mexico analog, the Gila Conglomerate, has been placed along the eastern drainage divide of the Mimbres Basin (Dane and Bachman, 1961; Hawley et al., 1969). Therefore, the older fills of the Mimbres-Mason Draw Basin, an area subjected to only cursory study in this investigation, are classified as Gila Conglomerate.

The Santa Fe Group is the major ground-water reservoir in the region. Aquifers in the Santa Fe produce most of the water used in metropolitan and industrial centers, as well as a significant proportion of ground water used to supplement surface irrigation supplies (Conover, 1954; Leggat, Lowry, and Hood, 1962; Dinwiddie et al., 1966; Dinwiddie, 1967). From the preceding discussion, however, it can be seen that the group is not a single hydrologic unit. Water-bearing properties of the basin fill and quality of the ground water reflect the variety of depositional environments in both open- and closed-basin systems. Thus, the Santa Fe Group includes a number of aquifers as well as major zones that are relatively impermeable. Obviously, the quantity of water needed for a particular purpose at a certain place determines an individual's concept of what an aquifer is. Highly productive domestic and stock wells are often referred to as "dry holes" when [they are] considered as producers of water for irrigation or industrial uses.

THE SANTA FE GROUP IN THE PALOMAS BASIN

Much of the upper Santa Fe Group fill of the Palomas Basin has been removed during episodes of valley entrenchment by the Rio Grande and its tributaries since middle Pleistocene time. The only extensive remnants of the original or slightly modified basin-fill surface are preserved north of Caballo Dam and in the undissected Uvas-Goodsight Basin (Nutt-Hockett Basin of New Mexico State Engineer Reports).

Subsurface information (Kelley and Silver, 1952; Davie and Spiegel, 1967) shows that as much as 1,165 feet of Santa Fe sediments was deposited in Palomas Basin in late Cenozoic time. The basin is asymmetric with its axis located in the eastern part of the basin at the foot of the Caballo structural block. Piedmont slopes rising to the Animas-Hillsboro uplift on the west are long and gentle, whereas slopes rising to the Caballo Mountains are short and steep. Studies by Davie and Spiegel (1967, p. 9) in the Animas Creek area (T. 15 S., Rs. 4-6 W.) northwest of Caballo Dam show that the Santa Fe Group is composed of three facies: (1) an alluvial-fan facies composed of gravel to clay derived from bordering uplands on the east and west; (2) "a clay facies, possibly representing the distal ...beds of alluvial-fan facies"; and (3) "an axial-river facies (in this report designated the fluvial facies)" consisting of well-sorted sand and gravel containing well-rounded quartzite pebbles, probably derived from northern New

Mexico and Colorado. Geologic studies in areas to the south (Strain, 1966; Hawley et al., 1969) indicate that the clay facies (which also includes beds of silt and sand) was deposited in large part in playa-lake and/or perennial lake basins.

Near Caballo Reservoir, the exposed sections of Santa Fe deposits are generally medium- to very coarse-grained, reflecting alluvial-fan (extensive) and fluvial (limited) environments of deposition. The clay and fluvial facies occur mainly in subsurface, in the central parts of the basin (Davie and Spiegel, 1967, pl. 3).

In the Hatch area, at the south end of the basin, the clay and fluvial facies are well exposed in valley walls. West of Hatch, a 400-foot section of silt, bentonitic clay, sand, and sandstone is exposed below a high-level basin-floor remnant correlated with the older parts of La Mesa geomorphic subsurface (Hawley and Kottlowski, 1965, p. 25).

The fluvial facies in the Palomas Basin, as well as in basins to the south and east, typically occupies a position in central areas immediately below the ancient basin floors and crops out on the slopes of the Rio Grande valley. This lithologic unit is primarily composed of cross-bedded, clean sand and gravel that may be cemented with calcite locally. The gravel fraction consists of subangular to rounded, pebble to cobble gravel of obvious local origin, and of rounded to well-rounded pebbles (and some cobbles) of rock types foreign to the local drainage basin. The latter types include hard siliceous rocks, such as quartzite, quartz, chert, granite, and obsidian, and coarse fragments of basalt scoria and rhyolite pumice.

Water-well tests near Hatch indicate that the clay facies of the Santa Fe Group extends as much as 2,000 feet below the valley floor. In the Palomas Valley segment south of Caballo Dam, the fluvial facies is above the water table and the major basin-fill facies in the zone of saturation consists of clay, which does not yield significant quantities of water to wells. Ground-water production is from the late Quaternary valley-fill aquifer. The north to south change from relatively coarse-grained to fine-grained facies in the saturated part of the Santa Fe Group is apparently due to large-scale structural movements. This point is discussed further in the next section.

The Uvas-Goodsight (Nutt-Hockett) ground-water basin at the extreme south end of the Palomas Basin is just outside the area discussed in this report. In this subbasin, which is currently being studied by the New Mexico State Engineer, large quantities of ground water are produced from a coarse-grained alluvial facies of the Santa Fe Group.

THE SANTA FE GROUP IN THE SOUTHERN JORNADA DEL MUERTO BASIN AND SELDEN CANYON

Reconnaissance studies in the southern Caballo Mountains northern Sierra de Las Uvas area by Seager and Hawley (unpublished data) indicate that the Rio Grande valley between Caballo Dam and Rincon crosses an upwarped and faulted basin-fill area extending from the Southwestern Hills (Kelley and Silver, 1952) and southern Caballo Mountains to the Sierra de Las Uvas and Tonuco-Selden Canyon uplifts. This positive trend marks the poorly defined boundary between the Jornada del Muerto and southern Palomas Basins. In addition to the clay facies, an intertonguing and underlying fanglomerate facies is upwarped in this area. This gravelly unit generally has a fine-grained, compact matrix and yields only small quantities of water to wells. The fluvial facies of the Santa Fe Group, which is the major water producer in the Mesilla Valley area, appears to be entirely above the water table in most parts of the Rincon Valley, excluding the eastern slopes between the Rincon Hills and San Diego (Tonuco) Mountain. In Selden Canyon, south of Rincon Valley, tectonic uplift has raised the lower fanglomerate facies of the Santa Fe Group above the water table and late Quaternary valley fills rest directly on andesitic to rhyolitic volcanics.

The main part of the structural basin that forms the southern Jornada del Muerto lies east of a line extending through the crests of the southern Caballo Mountains, Rincon Hills, Tonuco uplift, Selden Hills, Doña Ana Mountains, Goat Mountain, and Tortugas Mountain. Point of Rocks and the Doña Ana-Sierra County line mark the northern limit of the basin; and a line extending from Tortugas Mountain to the Fillmore Canyon area of the central Organ Mountains forms the approximate southern boundary of the Jornada basin system.

The central Jornada del Muerto Basin, which occupies the area north of Point of Rocks and between the Caballo-Fra Cristobal and San Andres Mountains, is also a distinct structural unit. It is north of the area of investigation and is only briefly discussed. This basin segment was not subjected to the intense down-faulting, relative to the adjacent uplifts, that was so prominent in parts of the Jornada del Muerto to the south and north during the period of Santa Fe Group deposition. Thus basin-fill deposits are relatively thin, and Tertiary and late Cretaceous bedrock crops out or is only shallowly buried along the axis of the basin. There is no surface or shallow subsurface evidence that an ancestral Rio Grande ever flowed through the central Jornada del Muerto Basin between the San Marcial basalt flow and Point of Rocks (Kelley and Silver, 1952; Hawley et al., 1969).

The basin south of Point of Rocks contrasts markedly with the area to the north. North of the Doña Ana Mountains, the basin floor, which is as much as 12 miles wide, is a constructional plain underlain by as much as 350 feet of fluvial facies sand and gravel that rest in tum on a thick clay to fan-gravel sequence. Studies of samples from a group of seismic shot holes drilled in an 8-mile line from NW cor. sec. 21, T. 16 S., R. 1 E., NE cor. sec. 33, T. 18 S., R.2 E., demonstrate that the fill in that area is more than 325 feet thick. Unconfirmed reports on the results of seismic testing and deeper drilling indicate that the fill is at least 1,000 feet thick. Southeast of San Diego Mountain, a lower Santa Fe Group sequence of gypsiferous silt and clay over partly consolidated, gravelly fan alluvium is more than 3,100 feet thick (measured section in Hawley et al., 1969; Seager et al., in press [1971]). This sequence underlies more than 200 feet of sand and gravel of the fluvial facies. Vertebrate fossils recovered from the fluvial facies near San Diego Mountain indicate that the ancestral Rio Grande was established in the area in early to middle Pleistocene time. There is no evidence of a Pliocene Rio Grande in the region.

The broad piedmont slope rising to the San Andres Mountains and the narrower slopes rising to the Doña Ana Mountains consist mainly of coalescent alluvial-fan surfaces, which locally bear evidence of as much as 30 feet of deposition in middle to late Quaternary time (post-Santa Fe deposition). Underlying fan alluvium of the upper Santa Fe Group appears to intertongue with pebbly sand to clay of the fluvial facies that is partly impregnated with gypsum. The zone of facies change occurs approximately below the break in slope at the piedmont slope-basin floor juncture. Still older fan deposits definitely predate the fluvial facies and appear to interfinger, below the present basin floors, with extensive fine-grained deposits that may be partly of lacustrine origin.

In the northwest part of the southern Jornada basin (the area between the Doña Ana Mountains and Point of Rocks), the lowermost part of the fluvial sand and gravel facies probably extends into the zone of saturation. Elsewhere in the basin, the fluvial facies is usually above the water table, and the zone of saturation is either in older alluvial-fan deposits or in the fine-grained units of the clay facies.

The only large ground-water development in the southern Jornada del Muerto Basin is in sec. 36, T. 20 S., R. 2 E., and secs. 30, 31, T. 20 S., R. 3 E., on the lower slopes of the large alluvial fan spreading out from the mouth of Bear Canyon in the San Andres Mountains. Four water wells in the area are capable of producing from 500 to 1,500 gpm. The western two wells are used for irrigation, and the eastern two are production wells for the NASA Apollo Test Site 5 miles to the east. Doty (1963) has reported on the water-supply development for the Apollo Site. The two Apollo wells each penetrate more than1,000 feet of unconsolidated Santa Fe Group fan alluvium that contains thick, very gravelly zones (limestone, sandstone, chert, and some rhyolite clasts). The static water level in the area ranges from 300 to 350 feet below the ground surface, and the coefficient of transmissibility for the 400 to 500 feet of saturated sediments tested ranges from 48,000 to 80,000 gpm/ft.

Moderate amounts of ground water are produced at the southern end of the Jornada Basin along U.S. Highway 70 between Interstate Highway 25 and Organ. The relatively large quantity of subsurface hydrogeologic information available for this area (including drillers' logs, notes on well cuttings, geophysical data, and water-table configuration) is summarized in Figure 5, a cross-section extending from La Mesa, west of the Mesilla Valley, to San Augustin Pass, east of Organ.

Ground-water production in the U.S. Highway 70 area is again from the alluvial-fan facies of the Santa Fe Group. Basin fill in the area was deposited in an environment of coalescing alluvial fans that spread out from several canyons in the central and northern Organ Mountains. The fan deposits are fine textured in comparison with the coarse fan gravels that were penetrated by the Apollo wells. Intergranular spaces between coarser clasts are largely plugged with compact, well-graded mixtures of fine sand, silt, and clay. Common lithologic types noted in well cuttings include primarily monzonite-derived sand and very fine-grained pebble gravel, originally from the northern Organ Mountains, and some andesite pebble gravel derived from outcrops on the banks of the northern Organs, mixed with pebbles of rhyolite and andesite derived from the Fillmore Canyon area of the central part of the mountains (Dunham, 1935). The Fillmore Canyon watershed was the primary source for much of the fan alluvium in the Santa Fe Group in a 45-square-mile area, including the southwest part of T. 22 S., R.3 E., the southeast part of T. 22 S., R. 2 E., the northeast part of T. 23 S., R.2 E., and the northwest part of T. 23 S., R. 3 E.

The major bedrock unit in Fillmore Canyon is the Soledad Rhyolite (Dunham, 1935). Ruhe (1962, 1964, 1967) noted the widespread occurrence of Soledad Rhyolite clasts, derived originally from Fillmore Canyon and other watersheds in the southern Organ Mountains, in surficial fan gravels of the area. He used this information to map out ancient drainage and sediment distribution patterns. Taylor (1967) noted the occurrence of several other distinctive volcanic rock types in Fillmore Canyon, and he showed that these types, along with the Soledad Rhyolite, can be used locally as indicators of the source and depositional environment of certain basin-fill deposits found in the subsurface in the Las Cruces area. This point is elaborated upon in a later section of this report.

Production from wells along U.S. Highway 70 ranges from about 20 to 250 gpm depending on the thickness of saturated materials penetrated and the type of well construction. Specific capacities of wells are less than 5 gpm per foot of drawdown. Depth to the water table . . . ranges from about 300 feet to 575 feet, and the maximum thickness of saturated basin fill penetrated by any well is about 400 feet (tables 4, 6).

South of the Doña Ana Mountains, there is no distinct surface divide between the southernmost part of the Jornada del Muerto Basin and the northeastern Mesilla Bolson. Surface and subsurface studies between the Doña Anas and Tortugas Mountain demonstrate that the two basins aggraded as a single unit during the deposition of at least the final 200 to 300 feet of basin filling. However, subsurface information from wells and gravity surveys demonstrates that the southern Jornada is a well-defined structural basin separated from the Mesilla Bolson by a buried bedrock high extending from the Doña Ana Mountains to Tortugas Mountain (wells 22.2E.15.143, 22.2E.21.444, 22.2E.23. 111, 22.2E.29-.444). Samples recovered from these four different wells indicate that Tertiary volcanic rocks make up the high. The geologic cross section along U.S. Highway 70 (fig. 5) shows the general position of this barrier and illustrates the marked effect it has on the water-table configuration.

East of the bedrock high, the basin fill thickens markedly, and a gravity survey by Bear Creek Exploration Company indicates that the depth to bedrock is about 2,500 feet along a belt about 2.5 miles west of Organ and extending several miles north of U.S. Highway 70. Recent test drilling in secs. 16 and 34, T. 21 S., R. 3 E., indicates that the Santa Fe Group basin fill is about 1,900 feet thick in those areas.

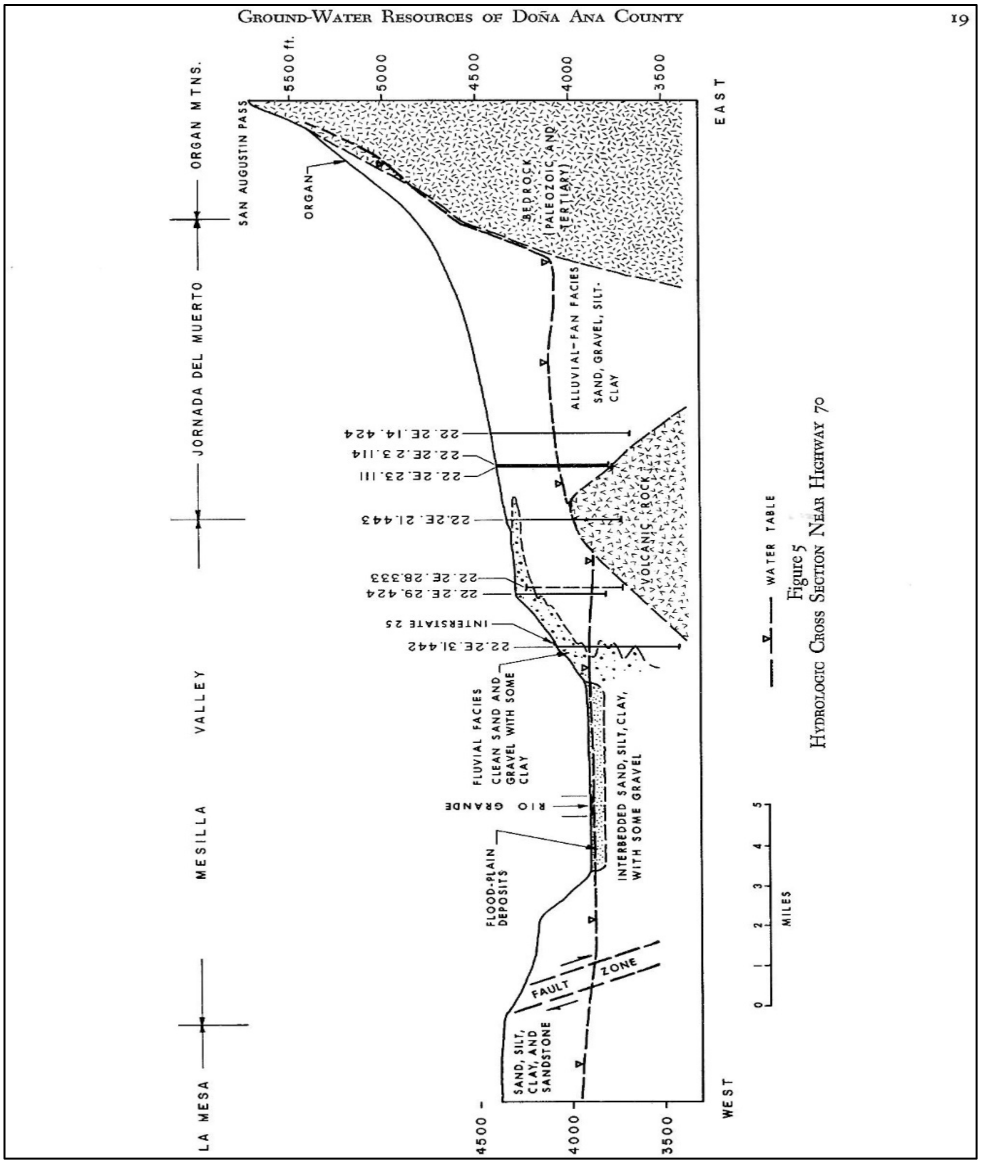

Figure 5. Hydrologic Cross Section Near US-Highway 70 (North is to the Left).

No wells have been drilled on the main part of the Fillmore Canyon fan between Tortugas Mountain and U.S. Highway 70. A test well drilled in 1966, halfway between Tortugas Mountain and the Organ Mountain front (23.3E.20.222) possibly penetrated dense volcanic rock at 285 feet after penetrating about 10 feet of younger basin alluvium and 275 feet of Santa Fe Group fan gravel. This “rock” could be a large rhyolite boulder, but, if bedrock was actually encountered, the deep basin shown in Figure 5 ends rather abruptly within a distance of no more than 6 miles south of U.S. Highway 70.

THE SANTA FE GROUP IN THE MESILLA BOLSON [BASIN]

The quantity of water produced from the Santa Fe Group basin fill in the Mesilla Bolson is many times greater than the combined production from all other basins discussed. Average daily pumpage from basin-fill aquifers in the City of El Paso’s Canutillo well field exceeds 10 million gpd, and Las Cruces City wells completed in the Santa Fe Group produce on an average more than 8 million gpd (Dinwiddie, Mourant, and Basler, 1966). Many of the supplemental irrigation wells in the Mesilla Valley tap, not only the late Quaternary valley fill (which is discussed below), but also the upper Santa Fe Group. All irrigation wells on the Mesilla Valley slopes are finished in the basin fill.

Because the wells drilled in the Santa Fe Group are primarily concentrated in the area of the Mesilla Bolson occupied by the Mesilla Valley, most of the succeeding discussion is concerned with that area.

The Santa Fe Group exposed in side slopes of the Mesilla Valley consists of two facies that in various places intertongue or are gradational with each other. In the northern and southern parts of the valley that are opposite the Doña Ana, Robledo, and Franklin Mountains, the alluvial-fan facies is the dominant Santa Fe facies cropping out in the valley slopes and the walls of the deep tributary arroyo valleys. Essentially continuous outcrops of the fluvial sand and gravel facies occur in two valley-border areas: (1) the east valley slope, between Doña Ana and Berino, that ascends to scattered remnants of Jornada and La Mesa geomorphic surfaces; and (2) the west valley slope, between Picacho Peak and the Cerro de Muleros, that ascends to the main part of the Mesilla Bolson floor and La Mesa geomorphic surface. (Refer to geologic maps by Kottlowski, 1953, 1960, and Ruhe, 1967, as well as to section descriptions in Ruhe, 1962, and Sayre and Livingston, 1945). Due to the general unconsolidated nature of the upper Santa Fe beds, exposures are poor, particularly on the lower slopes.

Intertonguing of the two facies can be observed locally in the walls of the deep valleys of several arroyos that extend from the Organ Mountains across the northeastern part of the Mesilla Bolson and into the Mesilla Valley (Hawley and Kottlowski, 1969, fig. 2). Figure 5 shows diagrammatically the intertonguing relationships between the fluvial facies and the alluvial-fan facies along U.S. Highway 70 east of Las Cruces. The results of surface mapping along Alameda Arroyo, and the sample and drillers' logs of four key wells (22.2E.21.444, 22.2E.28.3334, 22.2E.29.424, 22.2E.31.444) were used in construction of the part of the cross section extending from the crest of the buried bedrock high to the Mesilla Valley floor.

Distinct lithologic differences between the mixed-rounded gravels of the fluvial facies and the more angular, locally derived gravels of the fan facies enabled Taylor (1967) to distinguish the two facies in the basin fill penetrated by Las Cruces city wells 23 and 24. The distinctive suite of volcanic rock clasts derived from Fillmore Canyon in the Organ Mountains, mentioned previously . . . , appeared in the fan facies in both city wells at depths considerably below the top of the intervening buried bedrock high shown in Figure 5. This observation indicates that the buried uplift is locally breached in the area east of Interstate Highway 25, between U.S. Highway 70 and Tortugas Mountain, and that it is not a continuous barrier to water movement in the Santa Fe Group basin fill. Taylor's (1967) detailed studies of the gravel lithologies in cuttings from city wells 23 and 24 (22.2E.31.444, 23.2E.16.133) also enabled the writers to determine that the ground-water production of the east Las Cruces well field comes from a zone of the Santa Fe Group characterized by intertonguing of sand and gravel (with only minor amounts of silt and clay) of the alluvial-fan and fluvial facies. These wells, which are 650 feet deep (up to 430 feet of saturated fill), are capable of producing large quantities (on the order of 1,000 gpm) of good quality water (table 5).

The comments of the previous paragraphs also generally apply to the New Mexico State University Campus area. The University has an independent water-supply system tapping both the fan facies (23.2E.22.331) and the fluvial facies (23.2E.28.331). Well 22.331 is one of the few wells in the area that has had its hydraulic capabilities adequately tested. Records of a step-drawdown well-performance test shows a relatively low coefficient of transmissibility of about 6,000 gpd/ft (about 150 feet of saturated basin fill tested), which is probably a near-maximum figure for wells tapping only the alluvial-fan facies on the east side of the Mesilla Bolson.

A small area of domestic ground-water production from the alluvial-fan facies, 2 miles southeast of the university, is of particular interest because of the high temperature of water (90 to 110°F) produced from a zone about 350 to 450 feet below the surface (sec. 34, T. 23 S., R. 2 E.). A high geothermal gradient associated with a fault zone bounding the Tortugas Mountain block may be the cause of this temperature anomaly. The geochemistry of thermal waters in the area is currently being studied by W.K. Summers of the New Mexico Institute of Mining and Technology.

A final area of interest in the Mesilla Bolson east of the Rio Grande valley proper is Fillmore Pass. The pass is a 4-mile-wide gap between the Bishop Cap outlier of the Organ Mountains and the Franklin Mountains and connects the Mesilla and Hueco Bolsons. Test drilling in Fillmore Pass (Knowles and Kennedy, 1958), indicates unconsolidated basin fill locally as much as 970 feet thick and the absence of a bedrock barrier that would impede the flow of ground water between the two bolsons. Strain (1966, p. 11) suggested that, after initial coalescence of basin fill through the pass, the Mesilla and Hueco Bolsons "continued to aggrade with a common level" during the deposition of at least the last [uppermost] 500 feet of basin filling. The present floor of the pass represents the constructional La Mesa surface formed on middle Pleistocene sand and gravel of the Santa Fe Group fluvial facies. The thickness of this facies is not definitely known, but, according to Thomas Cliett, geologist for the El Paso Water Utilities Board (personal communication, 1968), it could be as much as 400 feet.

In the part of the Mesilla Bolson occupied by the Mesilla Valley, subsurface information on the nature of the Santa Fe Group below the Rio Grande flood plain is incomplete because the majority of the wells penetrate less than 300 feet below the valley floor. Deep drilling in the New Mexico part of the valley area has been confined to a few scattered test holes that are no more than 620 feet deep. However, a number of wells have been drilled to depths exceeding 1,000 feet in the Texas part of the valley, some of which have completely penetrated the Santa Fe Group (Leggat, Lowry, and Hood, 1962).

The late Quaternary river-valley fill, which is discussed in a later section, appears to be no more than 80 feet thick. Many shallow irrigation wells extend through the valley fill and into the uppermost beds of the underlying Santa Fe Group basin fill. Because there is no legal requirement in this part of New Mexico for submission of well logs or well construction data to the state engineer [**Part C5.1**], it has been impossible to determine from the information available the relative amounts of water produced from the two units.

The Santa Fe strata penetrated below the valley fill in the New Mexico part of the valley generally consist of alternating layers of fine to coarse sand, and clay to sandy clay (well 25.3E.32.421). However, wells on the east side of the valley near Las Cruces also encounter some beds of gravel in the upper 200 to 300 feet of basin fill (well 24.2E.9.132). Earlier workers assumed that the Santa Fe Group below the Mesilla Valley floor was nongravelly and erroneously attributed some deep gravel-bearing strata to post-Santa Fe valley-fill deposits (Conover, 1954; Leggat, Lowry, and Hood, 1962).

The basin-fill facies classification used up to this point does not adequately characterize the sequence of alternating medium- and fine-grained beds described in the preceding paragraph. This sequence comprises a large part of the "subvalley" Santa Fe section and extends to depths as much as 600 feet below the surface in the area south of Las Cruces. The alternating sand and clay unit extends southward into Texas, where Leggat, Lowry, and Hood (1962) referred to it as the "medium (Santa Fe Group) aquifer." Well cuttings from the sand to sand and gravel zones are identical to cuttings from the fluvial facies elsewhere in the area. Samples from the clay to sandy clay beds appear identical to clay facies material from the Palomas and Rincon Valleys.

Strain (1966, 1969) postulated that a large lake, Lake Cabeza de Vaca, periodically occupied the floor of Hueco Bolson in early Pleistocene time, prior to the extension of ancestral Rio Grande deposits into that basin. He also considered it likely that higher stands of this lake extended into the Mesilla Bolson via basins in northern Chihuahua, the El Paso narrows, and possibly Fillmore Pass, and that clayey beds exposed in the lower parts of the southern Mesilla Valley walls might represent lacustrine strata. With this hypothesis in mind, it appears quite possible that the alternating clay and sand sequence represents basin-fill deposition in a deltaic area near the mouth of the ancestral Rio Grande, with the lithologic variations being controlled by rising and falling levels of ancient Lake Cabeza de Vaca.

Deep wells drilled for the City of El Paso south of Anthony, Texas-New Mexico, in the east half of T.27 S., R 3 E. (projected township and range lines) encountered a thick unit of clean, well-sorted fine to medium sand (<1 mm maximum grain size) between 600 and 1,300 feet below the flood-plain surface (Leggat, Lowry, and Hood, 1962). Several wells have penetrated below this unit, which has been designated the "deep (Santa Fe Group) aquifer," one into a tongue of lower Santa Fe fanglomerate, and one into pre-Santa Fe volcanic rock and underlying older Tertiary sedimentary deposits. The resistivity curves on electric logs for City of El Paso test wells show the striking contrast between the upper, alternating sand and clay unit and the lower, thick sand unit, as well as the general improvement in water quality with depth (Leggat, Lowry, and Hood, 1962).

The origin and distribution of the thick sand unit comprising the deep aquifer is an important and unsolved hydrogeologic question. As the sand has been encountered only in the subsurface, sedimentary structures cannot be observed. In the Anthony-Canutillo area, the unit is about 450 to 1,150 feet below the elevation of the bedrock lip in the El Paso Canyon (Slichter, 1905). One possible hypothesis is that the unit is a fluvial to deltaic facies of ancestral Rio Grande alluvium deposited in a subsiding structural basin, now occupied in part by the lower Mesilla Valley. How far the unit extends up the valley and to the west is unknown. Thomas Cliett, geologist for El Paso Water Utilities, is working on the problem at the present time.

The aquifers described above can produce copious quantities of water if care is taken in installation of properly sized gravel-pack and well-screen combinations. Wells completed in the Santa Fe Group (medium and deep aquifers) in the Texas section of the southern Mesilla Valley commonly produce between 1,000 and 3,000 gpm (Leggat, Lowry, and Hood, 1962). Measured coefficients of transmissibility range from 34,000 to 73,000 gpd/ft and average about 50,000. Permeabilities range from 128 to 150 gpd/ft2 and average about 140. Local flowing wells and low measured storage-coefficient values demonstrate that artesian ground-water conditions exist. This might be expected because of the presence of thick clay beds in the upper 500 to 600 feet of the Santa Fe section. Wells drilled in the Anapra, New Mexico, section of the lower Mesilla Valley (Leggat, Lowry, and Hood, 1962); wells (28.3E.34.331, 29.3E.3.243) have encountered Tertiary intrusive bedrock at relatively shallow depths (less than 300 feet), and have thus demonstrated that the Santa Fe Group abruptly wedges out at the south end of the valley. Groundwater quality deteriorates at all depths in the extreme southern part of the valley.

The Santa Fe Group appears to extend westward under the floor of the Mesilla Bolson (La Mesa geomorphic surface) without any appreciable decrease in thickness between the Las Cruces Municipal Airport area, north of U.S. Highway 70, and the International Boundary. The basin fill definitely wedges out against the East Potrillo Mountains, Mount Riley, and the Aden-Sleeping Lady Hills. To the north, Santa Fe Group fluvial and older fanglomerate facies extend through the Corralitos subbasin (T. 22 S., Rs. 1 [and] 2 W.) between the Rough and Ready Hills and the Robledo Mountains into the Selden Canyon area. To the south, the Santa Fe Group extends an unknown distance into the Lake Palomas Basin (Reeves, 1965) of northern Chihuahua, probably at least 75 miles. Outcrops of the fluvial facies (sand and rounded-gravel unit) have been examined in caliche borrow pits below La Mesa surface along Chihuahua State Highway 10, 20 miles south of the International Boundary and due south of T. 29 S., R. 1W. and 1E. The fine-grained (in part lacustrine) facies of the Santa Fe Group should be expected in the subsurface below the extensive bolson plains of northern Chihuahua.

No more than 60 wells have been drilled in the 725-square-mile area of the Mesilla Bolson west of the Rio Grande. Most are stock wells for which no logs have been kept. Logs of eight railroad wells (Conover, 1954), one test well for a radar site, and three oil tests provide the only relatively good subsurface information for the area. Well cuttings from two of the three oil tests in the area were available for study by the authors and have provided a limited amount of information on the subsurface geology. Unfortunately, the physical properties of the basin-fill deposits are not of primary interest to the well-owners. Thus, the size and quality of the samples available left something to be desired from the standpoint of obtaining the maximum information on hydrogeologic properties of the Santa Fe Group.

The Picacho Oil and Gas Syndicate test well (Conover, 1954, Kottlowski et al., 1956) is the northernmost deep well in the bolson. This wildcat, drilled in [sec. 15.211, T. 23 S., R. 1 W.], penetrated only 165 feet of Santa Fe basin fill (fluvial, clay, and fanglomerate facies), which in turn rested on a sequence of andesitic volcanics and early Tertiary sedimentary rocks at least 2,175 feet thick. The hole ended in Permian sedimentary rocks at 3,196 feet.

The driller and electric logs of a “dry test hole” (well 23.1W.31.440) at the radar site 4.5 miles southwest of the Picacho oil test indicate that basin-fill sediments extend to a depth of at least 440 feet in the immediate area of the well. Surface outcrops of two basalt “necks” near the well site, as well as flow (?) rocks reported in the upper part of the section penetrated, demonstrate that Quaternary volcanics locally intrude and possibly intertongue with the upper Santa Fe Group near the radar site.

The northernmost of two recently drilled oil tests (Boles 1 Federal [24 S. 1 E. sec. 7.440]) is in the north-central part of the bolson, about 4 miles west of Mesilla Dam. This well, drilled in 1962, appears to have penetrated 3,790 feet of sandy to gravelly Santa Fe Group basin-fill, with some interbedded clays, before encountering Tertiary volcanic rocks. Drillers’ records are not clear as to whether or not the well finished in Paleozoic carbonate rocks at about 5,180 feet.

The best subsurface information on the basin-fill and underlying volcanics is provided by an oil test well (S.H. Weaver 1 Federal; T. 26 S. 1E. sec. 35.332) about 12 miles west of Anthony. A relatively good sample set and an electric log (partial penetration) are available for this well. Study of well cuttings and the electric log indicates that medium- and fine-grained beds constitute the bulk of the Santa Fe Group at the site. Gravelly to conglomeratic beds are also present at the top and base of the fill sequence, which extends to about 2,020 feet and rests on Tertiary volcanics and associated sedimentary rocks. The well was finished in Tertiary rocks at 6,600 feet. The interpretation of this subsurface data was difficult because electric logging was not done below 2,432 feet. It is possible that the above interpretation may be incorrect and that Santa Fe beds may extend below 2,020 feet. Wells drilled at former watering stops along the two Southern Pacific Railroad rights-of-way west and northwest of Anapra provide the only subsurface information for the southern half of the bolson (Conover, 1954). The wells penetrated 950 feet of basin-fill at Lanark (sec. 11, T. 27 S., R. 1E.), 1,330 feet at Strauss (sec. 24, T. 28 S., R. 2 E.), and 565 feet at Noria (sec. 8, T. 29 S., R. 1 E.). In each area the fill consisted of alternating layers of sand and clay. Gravel-sized materials reported in some drillers’ logs probably represent calcareous concretions that formed in place after sediment deposition.

The general textural trend for the upper 1,330 feet of bolson fill, revealed by the well logs, is one of progressive decrease in average grain size from north to south. Coarse gravelly zones are uncommon even beneath the northern part of the Mesilla Bolson floor.

THE WEST POTRILLO MOUNTAINS AND QUATERNARY VOLCANISM IN THE MESILLA [BASIN] AREA

Olivine basalt flows and cinder cones are prominent surface features in the Mesilla Bolson-Potrillo area southwest of Las Cruces (fig. 3). Flows cover an area of at least 350 square miles. The West Potrillo Mountains form the largest single volcanic field and include at least 85 cinder cones (Hawley and Kottlowski, 1969). Six smaller volcanic centers occur on the Mesilla Bolson floor (La Mesa geomorphic surface) between the Potrillo Mountains and the Mesilla Valley. The oldest basalts, such as at the radar site (sec. 31, T. 23 S., R. 1 W.), appear to intertongue with basin-floor sediments of the upper Santa Fe Group. However, the bulk of the basalts east of the West Potrillo field, and perhaps in that field as well, postdate development of La Mesa geomorphic surface in middle Pleistocene time (Rube, 1962; Hawley and Kottlowski, 1969; DeHon, 1965; Kottlowski, 1960). Two basalt flows that spilled into the Mesilla Valley during an early stage of valley entrenchment are preserved in the west-central part of the valley near San Miguel and Santo Tomas. The minimum age of the youngest group of flows, the Aden, or Qb3, basalt of Kottlowski (1960) is definitely established. Remains of a ground sloth in a lava tunnel on Aden Volcano date the youngest eruption at more than 11,000 years before the present (Simons and Alexander, 1964). Potassium-argon dating of La Mesa basalts has been attempted, but there are still problems in obtaining accurate dates (Hawley and Kottlowski, 1969). In all cases the Quaternary basalts of the central Mesilla Bolson appear to be thin and well above the water table.

Three huge, rimmed depressions of volcanic origin are near the western edge of Mesilla Bolson, 26, 29, and 39 miles south-southwest of Las Cruces (pl. 1). From north to south, they are Kilbourne Hole, Hunt's Hole, and Potrillo Maar. These explosion features, termed *maare* by DeHon (1965), formed after initial extrusion of basalts on La Mesa geomorphic surface. The largest of the three, Kilbourne Hole, is about 2 miles in diameter. Its floor is about 280 feet below and its rim as much as 170 feet above La Mesa surface. Excellent exposures in the southeast wall of the "hole" show a thick section of rim ejecta resting on a thin basalt flow that in turn, rests on Santa Fe Group beds ranging from sands (with scattered, rounded, siliceous pebbles) to clayey silts. A strong soil profile, with a prominent indurated horizon of carbonate accumulation (caliche) was developed in the uppermost part of the Santa Fe section. It marks the buried La Mesa surface.

A fourth large depression, Phillip's Hole, 3 miles east of Hunt's Hole, is also from 1 to 2 miles in diameter, but it is shallower than the others and lacks a rim. DeHon (1965, p. 208) stated that "Phillip's Hole may be a maar which, lacking a buried basalt to control erosion, has engulfed the rim deposits by backwasting." The four depressions, while postdating La Mesa geomorphic surface, may not all be of the same age. They may each represent a distinct set of volcanic eruptions. The maare-forming events may have been spread over a long span of middle to late Pleistocene time.

The West Potrillo Mountains, which bound the west-central part of the Mesilla Bolson, form a mountain upland that is unique in the region. That is, the relief in all the other mountains flanking the Rio Grande valley and adjacent basins is the result of differential uplift of segments of the Earth's crust relative to adjoining segments. A considerable part of the relief of the West Potrillos is due to constructional processes–the piling up of volcanic ejecta around vents to form cinder cones and the simple building up of layer upon layer of olivine basalt flows in Quaternary time. Due to the fact that there has been no subsurface geologic or geophysical logging of wells in the central part of the Potrillo volcanic field, it is not known whether the basalts are underlain by a thick section of basin-fill deposits or by Tertiary and older bedrock units. Isolated exposures of middle Tertiary volcanic rocks and older sedimentary rocks on the flank of the West Potrillo Mountains do indicate that the latter alternative is probably more likely.

RIO GRANDE VALLEY-FILL DEPOSITS

Three major alluvial-fill sequences that postdate deposition of the Santa Fe Group basin fill are present in the Rio Grande valley. The youngest of the three, comprising the late Quaternary flood-plain and channel deposits of the Rio Grande and interfingering of alluvial-fan deposits of tributary arroyos, is the only group of valley-fill deposits that makes up an important aquifer unit (table 6). This is due to the fact that the older valley fills, associated with constructional parts of the Tortugas and Picacho surfaces (Hawley and Kottlowski, 1969), appear in all cases to be above the water table.

In latest Pleistocene time, probably during the last major Wisconsinan glacial-pluvial substage (between 22,000 and 13,000 years ago) when the discharge of the ancestral Rio Grande was considerably greater than present, the floor of the river valley was eroded down to a level about 80 feet below the present flood-plain surface (Kottlowski, 1958; Hawley, 1965; Davie and Spiegel, 1967). Subsequent to the time of maximum degradation, a thick channel gravel and sand deposit was laid down on the erosion surface, which appears in most cases to have been cut into ancient basin-fill of the Santa Fe Group, or, in the case of El Paso and Selden Canyon areas, locally into older rocks. Carbon-14 dating of Holocene valley fills (Hawley and Gile, 1966; A.L. Metcalf, University of Texas, El Paso, Biology Dept., personal communication, October 1968) in the Mesilla and Palomas Valleys indicates that early back filling of the inner valley was relatively fast, with aggradation of the valley floor being essentially completed by 10,000 years B.P. (before present). The upper group of floor-plain deposits are finer grained than the basal gravelly unit and consist mainly of sand to clay. The [C]arbon-14 dating indicates that at least one halt in valley aggradation, perhaps accompanied by minor valley cutting and back filling, also occurred sometime between 5,000 and 10,000 years ago.

As mentioned in the section on the Santa Fe Group in the Mesilla Valley, the shallower wells in valley-floor areas (generally less than 200 feet deep) are commonly finished in both the younger valley fill and the underlying Santa Fe beds. A good example of this practice is the "shallow aquifer" of Leggat, Lowry, and Hood (1962) in the Mesilla Valley south of the 32nd parallel. This aquifer designation includes both late Quaternary flood-plain deposits and middle Pleistocene and older basin fill. Furthermore, it appears to be a meaningful hydrologic unit in a large part of the Mesilla Valley area because in terms of physical aquifer characteristics and water-quality problems, the profound geologic unconformity about 80 feet below the flood-plain surface does not seem to play and important role in most places.

In general, the quantity of water production from wells penetrating the shallow-valley and basin-fill deposits is not a problem. Wells developed in buried channel gravel and sand deposits below the river flood plain are capable of producing 1,000 to 3,000 gpm. Specific capacities are usually high, many ranging from 70 to 100 gpm per foot of drawdown, with coefficients of transmissibility commonly in the 100,000 to 150,000 gallons per day per foot range (Conover, 1954; Leggat, Lowry, and Hood, 1962).

Quality of ground water in the shallow deposits tends to vary from place to place and at a single point it often varies with depth (Leggat, Lowry, and Hood, 1962; Conover, 1954; current studies by the U.S. Geological Survey in cooperation with the New Mexico State Engineer Office). Although quantitative studies of water quality are beyond the scope of this report, it appears that two major geologic features associated with flood-plain depositional environments are important in influencing the quality of water stored and moving through the valley-fill deposits. First, the late Quaternary valley fill contains local lenses of concentrated organic matter ranging in size from microscopic particles to large fragments of rotten wood. Such materials probably represent deposition in ancient ox-bow lake and slough environments. Besides organic compounds, hydrogen sulfide and iron concentrations are common features of these zones and have a deleterious effect on ground-water quality. Second, concentrations of soluble salts were locally built up in poorly drained, fine textured, floodplain sediments. Although this phenomenon is particularly noticeable at the present time due to irrigation practices since inception of the Elephant Butte Irrigation Project, it is also a natural geologic process that has taken place during the progressive filling of the valley in latest Quaternary time. With local exceptions, the salt problem seems to increase progressively southward in the Mesilla Valley (Conover, 1954; Leggat, Lowry, and Hood, 1962). Apparent upward movement of deep circulating ground water and discharge by evaporation and transpiration at the extreme south end of the valley is a probable cause for the poor quality of the ground water in that area, in both the younger valley fill and the Santa Fe Group.

In the Palomas and Rincon Valleys and in Selden Canyon, the late Quaternary valley fill for all practical purposes is the only source for reliable supplies of ground water of relatively good quality. As mentioned previously, the Santa Fe Group in those areas is clayey or otherwise very compact and impermeable. The same can be said for the older Tertiary volcanic and sedimentary rocks that locally underlie the valley fill alluvium in Selden Canyon. As in the Mesilla Valley, the late Quaternary fill generally grades upward from very gravelly at the base to sandy at the top, and it rarely exceeds 80 feet in thickness (table 6).

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C8b. SPECIAL ADDENDUM 2—PROJECT PROPOSAL FOR A COMPREHENSIVE STUDY OF THE WATER RESOURCES OF THE SOUTHERN RIO GRANDE VALLEY AREA, NEW MEXICO (C.A. Wilson, May 1972; Reformatted)

PROJECT PROPOSAL FOR A COMPREHENSIVE STUDY OF THE WATER RESOURCES OF THE SOUTHERN RIO GRANDE VALLEY AREA, NEW MEXICO

C.A. Wilson

UNITED STATES DEPARTMENT OF THE INTERIOR, GEOLOGICAL SURVEY
Albuquerque, New Mexico, May 1972

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INTRODUCTION [p. 4-7]

The water supply of the lower Rio Grande Valley and adjacent uplands is derived from surface water from the Rio Grande and ground water from sediments of the intermontane basin. Neglecting the short-term effects the surface and ground-water units function as one system due to hydraulic connection between the river and the aquifers. Planning the orderly development of the water resources of the valley requires current factual data followed by complete and reliable analyses.

The purpose of this proposal is to aid in the planning, organization, and preparation of a comprehensive study plan of the water resources of the southern Rio Grande Valley in New Mexico, to evaluate data presently available, and to determine additional data that will need to be collected.

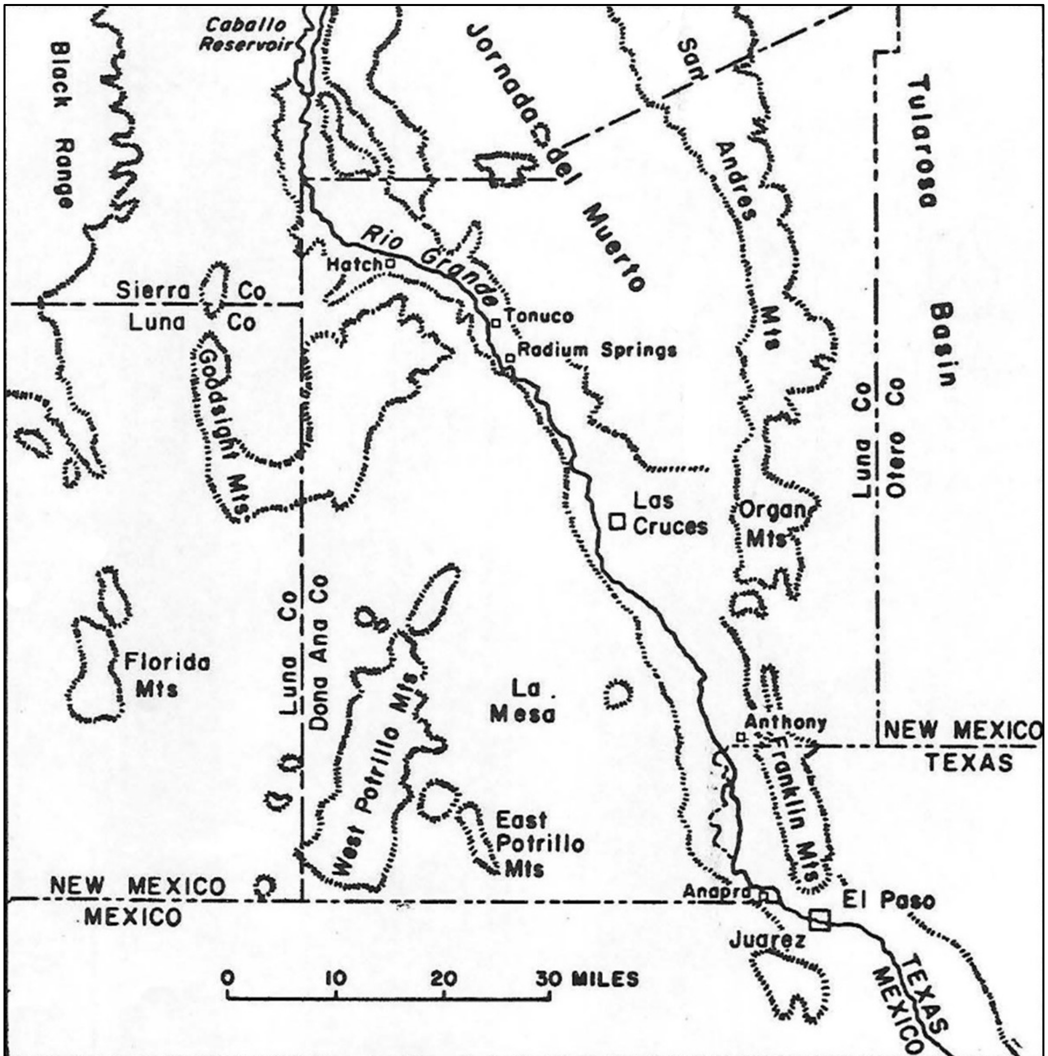

Figure 1.--Lower Rio Grande Valley area in New Mexico.

[p. 5] The following agencies might be cooperators with the U.S. Geological Survey for the proposed study:

State Engineer of New Mexico
City of Las Cruces
Elephant Butte Irrigation District
New Mexico Water Resources Research Institute

The New Mexico Water Resources Research Institute has furnished office space to the Geological Survey since the project began in October 1971 and has extended this privilege for the duration of the project.

The lower Rio Grande Valley is in the basin and range province of southwestern New Mexico, mostly in Dona Ana and Sierra Counties (fig. 1 [p.6]). The western boundary of the basin is formed by the East Potrillo, West Potrillo, Goodsight Mountains, and the Black Range; the eastern boundary by the Franklin, Organ, and San Andres Mountains.

The Rio Grande Irrigation Project of the Bureau of Reclamation encompasses the river and adjacent flood plain downstream from Caballo Reservoir to below EL Paso, Tex. The upper part is referred to as the Rincon Valley; it extends from Caballo Reservoir, in Sierra County, southward to the narrowing of the flood plain, near Tonuco in Dona Ana County. The Mesilla Valley extends from near Radium Springs, Dona Ana County, to the "narrows" at El Paso. About 180,000 acres are served with irrigation water by the Project. About 100,000 irrigated acres are in Rincon and Mesilla Valleys.

[p. 7] The largest use of water within the valley is for irrigation (mostly surface water with supplemental supplies from ground water). During periods of drought, ground water is the major source of irrigation water. Ground water is the municipal supply, for Las Cruces Anthony, Hatch, and most of the supply (over 85 percent) for El Paso. Most rural areas use ground water for domestic and stock needs; and industry depends heavily on ground-water supplies.

On May 4, 1971 the Governors of New Mexico and Texas gave support to a proposed areal resource study, the "Rio Grande Regional Environmental Study." Elephant Butte Reservoir, New Mexico--Fort Quitman, Texas. The overall purpose of this large study is to enhance 'the social, economic, and environmental conditions of the valley, through inventory, study, and planned use of the total resources available to the area, especially the surface and ground-water supplies. The study should evaluate resource development and management plans using multipurpose approaches to the resource problems. The major resource problems to be dealt with by the Environmental Study are water resources and supply.

NEED FOR THE STUDY [p. 8-12]

The needs for a study of the water resources in the southern Rio Grande Valley, New Mexico may be categorized into three general Groups:

(1) the need for information on the general hydrology over the entire area, with emphasis on the occurrence, availability and quality of the ground water,
(2) greater detailed information is needed by the city of Las Cruces for planning and developing municipal supplies for the future,
(3) evaluation of the availability, quantity, quality, and uses of ground water in the flood-plain alluvium, and adjacent units along the Rio Grande, and recommendations or considerations in the design and operation of combined ground- and surface-water system for year-round irrigation

[p. 9] Recent studies have defined the geologic framework for the occurrence of ground water in the Rio Grande Valley (*see* References). These studies need to be expanded and knowledge increased on the general hydrologic situation, especially the availability, quantity, and chemical quality of the ground water, and the aquifer characteristics of the intermontane valley fill. In many areas of the basin, basic data on ground water are scarce. Some investigators feel that large quantities of potable water are present in La Mesa bolson; others believe the quantity is limited. Little basic data are available on ground water in the southern part of the Jornada del Muerto. The connection, if any, between the aquifers which furnish water to Las Cruces and to El Paso's Canutillo well field is known. The connection and extent of subsurface boundaries need to be defined throughout the basin, little is known about ground-water conditions below depths of a few hundred feet. It is felt that additional hydrologic studies would give information and may provide answers to these problems.

A port of entry from Mexico into New Mexico is being proposed for Anapra, located about 10 miles west of downtown El Paso. This gateway to Mexico would cause industrial and agricultural requirements for water to increase greatly in that area. However, ground-water conditions are not known in the vicinity of Anapra. Water resources should be determined during the earliest planning phase of planning the port of entry.

[p. 10] The city of Las Cruces has developed its water supply from about 18 wells finished in sand and gravel units of the Santa Fe Group (one of these wells taps the Rio Grande flood-plain alluvium). The wells are located within the city limits, some exceeding 750 ft in depth. Some increase in the dissolved-solids content of the water has been noticed in recent years. Also, recent maps showing the altitude of the water table in the vicinity of Las Cruces indicate that ground water of higher dissolved-solids content may be moving downgradient from the river and flood-plain alluvium into the cone of depression created by pumping wells in the city well field.

King, and others (1969, p. 18-20) discuss the subsurface occurrence of nearly impermeable igneous intrusive barriers to ground-water movement in the vicinity of the well field. These intrusives tend to limit expansion into adjoining areas without detailed exploration to insure that new wells will encounter sufficient saturated thickness and permeable sediments.

City officials need detailed information on the extent and volume of fresh-water supplies in the vicinity of Las Cruces, delineation of areas where new wells should be drilled, and recommendations for development so as to recover the fresh water most effectively. Also, the city needs to know what changes in chemical quality may occur in the future due to pumpage. Development of the fresh-water zones must take into account and suggest ways to prevent or limit the possible encroachment of underlying and/or overlying more saline water.

[p. 11] Irrigation uses and reuses the largest amount of water in the Rincon and Mesilla Valleys. Often the supply of surface water in the river is deficient, and supplemental irrigation using ground water from the adjacent shallow (±80 feet) flood-plain alluvium is needed. The ground water pumped is replenished later during subsequent irrigation by surface water in years of above-normal supply, Early hydrologic studies of this irrigation system indicated that any substantial ground-water pumpage would result in much lower drain return flow and hence less availability of surface water downstream in the next 3 or 4 years. However, ground-water pumpage during the droughts of the early and mid-1950s and again in the mid-1960s did not appear to cause the predicted later severe decreases in surface-water supplies downstream. Overall, the effect of ground-water pumpage on the river needs further study. Quantities in the field need to be measured as much of the early work was based on estimated values and/or calculation.

The chemical quality of the water in the alluvium is variable; in general, the water is more highly mineralized than water in the river, or in the upper aquifers of the adjacent Santa Fe Group. This mineralization is probably caused by use and reuse of water for irrigation. Definition is needed on the quality of this shallow alluvium water, its circulation patterns, the depth to which fresher and more saline water may occur in the underlying aquifers, and changes in water-quality which occur. Sources of possible water pollution need to be delineated and monitored.

[p. 12] Basic needs other than to the surface-ground water irrigation system in the lower Rio Grande Valley would include, (1) the capability for year-round irrigation from a firm supply of water; (2) improvement in the quality of irrigation water applied in the fields, and improvement in the quantity and quality of return flow which is used to meet downstream demands; and (3) the reduction of water losses in the current delivery system. In order to meet these needs, the Elephant Butte Irrigation District is planning revisions to the physical layout and construction of the irrigation network that will involve a combined surface-ground water system. These revisions will require hydrologic information to aid in design and modification of facilities, and to allow predictions of water quality and quantity changes due to different demands or stresses which may be applied in the course of managing the irrigation system. The ground-water reservoir must be defined in order to best meet these needs and techniques developed to allow management of the whole hydrologic system.

In addition to the southern Rio Grande Valley area, New Mexico, the Mimbres River Basin and Tularosa Valley areas may be of importance to the Regional Environmental Project. At present, water-resources studies are being done in these areas, and information from the studies are available.

PREVIOUS STUDIES AND DATA AVAILABILITY [p. 13-17]

Many geologic and hydrologic studies have been made in the lower Rio Grande Valley since the first work in 1905. Many references to these published studies and some open-file reports of various governmental agencies are included in the Reference section of this proposal.

The first ground-water study in the valley was by Slichter (1905). By use of observation wells he demonstrated the connection between the river and the alluvium aquifer, and calculated the underflow of the river at the "narrows" near El Paso. He conducted some aquifer tests on wells and described well construction and pump design.

Keyes (1905) recorded the geology and ground-water conditions in the Jornada del Muerto. The report is elaborate in its descriptions of the desolation of this area. Keyes subdivided the area into general geologic units and outlined structural relations. Data are given on the occurrence of ground water and some wells are described.

Lee (1907) reported on the water resources of the entire Rio Grande Valley of New Mexico. He noted the large discharge of ground water by evaporation in the va1ley and speculated that the flow of ground water in La Mesa was toward the Rio Grande.

The geology of Dona Ana County was studied by Dunham (1935). He recognized the basin-fill deposits as belonging to the Santa Fe Group and outlined the formation of the Mesilla Valley.

[p. 14] The most extensive ground-water investigation in the entire basin area was by Conover (1954). The main purpose was to study possibilities of pumping ground water for supplemental irrigation when surface-water supplies were deficient, and the effects of this pumpage on later flow in drains and the river. Conover concluded, through use of gross water-budget calculations, that only a fixed amount of water was available in the Rincon and Mesilla Valleys, and that heavy ground-water pumpage over a period of several years would cause less return flows to be available for reuse downstream by other irrigators in the succeeding 3 to 4 years because of replacing the water pumped from storage. His report contains records for 108 wells in the flood-plain area, 147 wells on the uplands, 44 chemical analyses of well water, and 45 driller’s logs. He estimated that the river alluvium had an average transmissivity of about 75,000 gpd/ft (gallons per day per foot) and that the upland parts of the Santa Fe Group had an average transmissivity of about 30,000 gpd/ft. These estimates were based on seven aquifer tests and seven calculations of transmissivity based on drain discharges and water-table gradients. His report also contains a map showing the altitude of the water table over most of the basin area.

Gunaji (written communication 1961) differed with some previous investigators on the effect of ground-water pumpage on return flows into the river. He showed that aquifer recover from the heavy ground-water pumpage of 1954-1956 was more rapid than others would have predicted. He felt that ground water should be used as supplemental supply during years of short surface supplies. Gunaji’s report contains no additional field data that is not in previous reports.

[p. 15] Three aquifers (shallow, medium. and deep) were described by Leggat, Lowry, and Hood (1962) in the Canutillo well field south of Anthony. Detailed data on the lower Mesilla Valley area of New Mexico and Texas shows leakage between the three aquifers and changes in flow patterns due to changes in pumpage from the different aquifers. Their report showed the quick recovery in 1958 of water levels in the alluvial aquifer from previous heavy pumpage during years of drought. Occurrences of fresh water at depths over 1,200 feet were noted. Some estimates on water-availability are calculated. The report contains records of 219 wells and 76 driller's logs, and about 350 chemical analyses of water; most wells and test holes are located in Texas.

Hawley (1965), and Hawley and Gile (1966) discuss the geomorphic surfaces and the recent geologic formation of the lower Rio Grande Valley area. These reports are quite detailed and show the chronological development of the basin and deposition of the Santa Fe Group from Paleocene to the present.

The most recent hydrogeology investigation is by King, Hawley, Taylor and Wilson (1969). This report pertains to ground-water conditions in the Santa Fe Group and includes a map showing the altitude of the water table throughout much of the basin. The report describes and relates the occurrence of ground water to geology. The report contains records for 219 wells and test holes, 39 chemical analyses, and driller's logs or lithologic descriptions of samples from 52 wells and test holes. Some of these well records are updated measurements of wells listed by Conover (1964).

[p. 16] Some unpublished sources of hydrologic information on the lower Rio Grande Valley include reports by Basler and Alary (1968), Doty (1969), Meyer and Gordon (1971), and Richardson (1971). The purpose of the report by Basler and Alary was to determine the quality of the shallow ground water in the alluvium of the flood plain in Rincon and Mesilla as an aid in planning a comprehensive study of ground water in the valley of the Rio Grande. Forty wells were sampled by Basler and Alary. Doty (1969) reported on development of the water supply for the NASA site in eastern Dona Ana County. Meyer and Gordon (1971) is the most current progress report (covers the period 1963-70) on the development of ground water in the El Paso district, Texas. The report updates information on development, well locations, and pumpage; it also discusses the rapid recovery of ground-water levels in the alluvium after the heavy pumpage of 1964. The report contains the water budget for 1968 of the lower valley area (the Rio Grande Valley below E1 Paso). Inflow from surface water, ground water, and precipitation amounted to 348,700 acre-feet; outflow as surface-water flow, ground-water movement, consumptive use, evaporation, and changes in storage amounted to 314,100 acre-feet. The imbalance, about 10 percent or 34,600 acre-feet, may represent such things as use or flow into Mexico, errors in measurements or estimates, and pumpage out of the river.

[p. 17] Richardson (1971) constructed a mathematical model of the Mesilla Valley based on a model program written by Dr. William Brutsaert of New Mexico Institute of Mining and Technology. Basic data used in the model were taken from published and unpublished sources. Model calibration was by changing the value of the storage coefficient (ranged from 15 to 25 percent best fit using 20 percent). Model verification was by comparing the average of monthly water-level measurements for 1962 and 1964 in 21 selected observation wells, with the average of computed water-level values in the same grid nodes as the observation wells.

Some data are available in the files of various government agencies, however, much may have been published. The Geological Survey files (New Mexico District) for Dona Ana County contain about 350 well Schedules, 225 chemical analyses (some wells may have several analyses), 8 borehole geophysical logs, 7 aquifer-test results, and 65 driller's logs. The Geological Survey files (Texas District) contains about 250 well schedules for wells located below Anthony in the lower Mesilla Valley of Texas and New Mexico. About 170 well schedules, 150 chemical analyses, no borehole geophysical logs, 38 aquifer tests, and 10 driller’s logs are available for Sierra County.

Records of stream flow and flow in canals and drains are available in published and unpublished records of the Bureau of Reclamation, International Boundary and Water Commission, Elephant Butte Irrigation District, and the U.S. Geological Survey.

OBJECTIVES AND PLAN OF STUDY [p.18-21]

The boundaries of the proposed water-resources study of the southern Rio Grande Valley are the latitude of Caballo Reservoir on the north, the San Andres, Organ, and Franklin Mountain ranges on the east, the “narrows” near El Paso, Tex., and the Mexican border on the south, and the Mimbres-Rio

Grande watershed boundary (approximates the East and West Potrillo, and Goodsight Mountain ranges) on the west (fig. 1).

[p. 19] The objectives of the general hydrology study of the entire area would include, but not be limited to, the study and determination of the following:

(1) thickness of the river flood-plain alluvium; thickness of the Santa Fe Group; delineation of major aquifers; and/or water-quality zones,
(2) water quality and variations in quality with areal extent and depth, and if possible, the base of the fresh and slightly saline water zones (water containing 1,000 mg/l, milligrams per liter, or less and 1,000 to 3,000 mg/l respectively of dissolved solids),
(3) the altitude of the water table and/or potentiometric surface, and the general flow patterns of the ground water in the different aquifers,
(4) the thickness of the fresh and slightly saline water zones, and the total saturated thickness of the alluvium and the Santa Fe Group,
(5) the amount of ground water in storage in the various aquifers or zones,
(6) areas, sources, and estimates of the amount of recharge to, and discharge from, the various aquifer,
(7) depth to water throughout the area,
(8) aquifer properties, such as transmissivity, storage, capacity, lithology, and structure,
(9) availability of fresh and slightly saline water, and estimates of the potential yield of wells.

[p. 20] A detailed and well-planned program of data acquisition is necessary to meet the objectives of the general hydrology study. Several deep test holes are needed (about 8 holes to depths of approximately 1,500 feet) at selected locations throughout the study area. Several types of borehole geophysical logs would be run in the holes. Four types of data could be collected at selected depth intervals in each hole: (1) water-quality samples, (2) aquifer permeability, (3) hydrostatic pressure, and (4) aquifer lithology. If possible, the test holes should be converted and equipped as permanent observation wells so that changes in water quality and hydrostatic pressure with time can be recorded.

Magnetic, gravity, and seismic geophysical surveys, borehole geophysical logs, and selected driller's logs would be used to define the thickness of the Santa Fe Group and aquifer zones within the group. Information on water-quality zones would be obtained from water sampling at selected depths in test holes and in some wells, interpretation of borehole geophysical logs, and possibly by use of earth-resistivity measurements. The top of the water table and potentiometric surface would be based on water-level measurements in wells and test holes. Flow pattern can be outlined from vertical flow-meter tests and by head measurements at selected depths in test hole. Surface geological mapping may show areas of natural recharge and aquifer lithology. Data on aquifer properties, ground-water availability, and potential yield would be obtained by making aquifer tests (pump tests involving drawdown-yield measurements) on wells and test holes. The results of the general hydrologic study would be prepared as a comprehensive report for publication by the State or by the Geological Survey.

[p. 21] Specific areas in the lower Rio Grande Valley may require more detailed hydrologic work. For example, a study of ground-water resources in the vicinity of the proposed port of entry at Anapra needs to be done in as much detail as possible. This study should include the drilling of test holes to investigate water quality and aquifer yields.

WATER RESOURCES IN THE VICINITY OF LAS CRUCES [p. 22-23]

In the vicinity of Las Cruces the study would be expanded and done in greater detail. Special attention would be given to delineation of geologic trends and the location of subsurface barriers to flow within the aquifers so that areas favorable for future exploration for fresh water can be outlined. The relationship of the aquifers from which Las Cruces, Anthony, and EI Paso (Canutillo well field) produce water would be investigated. The decline of the water table around Las Cruces may cause water of inferior quality that moves downgradient in the river alluvium to enter the aquifer tapped by city wells. The extent of this decline, potential chemical-quality problems in the well field, and recommendations to relieve the problems would be studied.

The city of Las Cruces has information on most of the city water wells. Additional information is available on wells at New Mexico State University and in the files of various governmental and private institutions. It is planned to drill two or three of the eight proposed deep test boles in the vicinity of Las Cruces and several shallower test holes in the area between the river alluvium and the city well field. Gravity and seismic surveys would be done in greater detail around the city so that subsurface features can be delineated. Borehole geophysical-logs could be made in used or abandoned wells and test holes.

[p. 23] An open-file report on the water resources in the vicinity of Las Cruces would be prepared upon completion of that part of the study. The detailed report will contain maps and/or discussion of objectives 1 through 9 of the general hydrology study of the entire area.

WATER RESOURCES IN THE RINCON AND MESILLA VALLEYS [p. 24-29]

The third area of need water-resources study involves the surface-ground water system of the Rio Grande and associated irrigation network, and ground water in the surrounding flood-plain alluvium. Broad general objectives required to fulfill the needs discussed previously would involve collecting and analyzing sufficient basic data to define the hydrologic system in the valley area and then using this information to construct models which can predict reaction to desired management practices.

Specific objectives sought in relation to defining the hydrologic system include:

(1) Evaluation of the usefulness of the mathematical model constructed by Richardson (1971). This can be done with data now in the report, and should show if the model could form the basis for future use in design, operation and management of the system. The model may also indicate areas of concentration in collecting basic data.

(2) Determine quantities and discuss components of the water budget of the river and ground-water system in the valleys. Water-budget amounts for the Mesilla Valley were calculated for 1962 and 1964 for use in Richardson's model. Refinement of budget factors is needed, especially where values such as streamflow or ground-water pumpage can be measured.

(3) Based on field measurements, delineate in detail and use maps when possible, the following items for both the flood-plain alluvium and adjacent parts of the Santa Fe Group [p. 24]:
   a. Altitude of the base of the alluvial aquifer and effective hydrologic boundaries of adjoining aquifers.
   b. Altitude of the water table and/or potentiometric surface.
   c. Saturated thickness of the alluvium and the saturated thickness in other aquifers that are affected by large-scale pumpage.
   d. Degree and areal extent of hydraulic connection between aquifers.
   e. Water-quality zones within the aquifers.
   f. Aquifer properties such as transmissivity and storage capacity.
   g. Amount of ground-water pumpage.

(4) Discuss and illustrate the relationship, hydraulic connection, and flow pattern of the ground water in the alluvium and in the Santa Fe Group.

(5) Determine areas and quantities of better quality water in the alluvium and in nearby parts of the Santa Fe Group. Factors affecting and controlling the quality should be found and related to changes which may have occurred in recent years in water quality.

[p.26] Once the hydrologic system is defined (items 1-5), the remaining, but most important objective is to determine future changes in quantities and chemical quality of the irrigation water due to management manipulation of the system. It is suggested that a digital or combination analog-digital model be constructed and used to meet this objective. Many recommendations for operation of the system can be made in the course of analyzing the basic data collected (such as areas and zones of the better quality water, quality of water in surrounding aquifers, well spacing, and needed pumpage during selected times). However, modeling the aquifer permits quantitative predictions, such as effect on ground-water levels due to limited surface-water irrigation in an area, effect on drain flows and river flow by ground-water pumpage, or optimum location of canals, wells, and drains in design of a system. It should be realized that modeling requires good basic-data input time to construct and verify the model, and realization of its limitations.

Studies by Conover (1954), Gunaji (1961), and Richardson (1971) along with streamflow measurements and chemical-quality analyses in the files of various agencies will provide some background information on ground water in the alluvium. The Bureau of Reclamation has records of monthly water-level measurements in 50 observation test holes located throughout the valleys. Richardson's digital model may be very useful in planning a basic-data collection program and even in later phases of the study as a management tool for operation of the irrigation system.

[p. 27] Components of the water-budget study are measured quantities of surface-water inflow, outflow, and precipitation; and calculated values of ground-water inflow, outflow, consumptive use by crops and phreatophytes, free-surface evaporation, and changes in storage.

In order to define quantities and quality of water a detailed program of basic-data collection and test-hole drilling will be necessary. The program would include such field work as well inventory, streamflow measurements of selected canals and drains, water-sampling of wells and surface flows for chemical analysis, and conducting aquifer tests and power-yield tests on selected wells. Some surface and borehole geophysical data may be collected.

A test-hole drilling program is needed to define the various quality-of-water zones laterally, and in depth. In addition to existing test holes and wells, as many as 25 additional shallow and cased test holes (±80 foot depth) may be needed in order to sample the ground water in otherwise inaccessible locations.

At 15 or more sites throughout the Rincon and Mesilla Valleys it is recommended that "nests" of shallow, small-diameter sampling wells be installed in order to observe changes in the water-quality profile with time. These wells should be constructed as permanent observation and sampling test wells. Each "nest" would consist of 3 to 7 individually cased holes with depths ranging from about 10 to as much as 200 feet.

[p. 28] Two or three test holes (±1,500 feet) should be drilled near the irrigated valleys in order to determine water quality and aquifer properties at depths below that which are normally encountered in wells. The exact location of test holes should be chosen after the well inventory is completed. These three deep test holes would be part of the recommended eight holes to be drilled and tested as part of the general study. Testing would include geophysical logging, water sampling, permeability tests, and hydrostatic-head measurements.

Using the basic data collected in the aforementioned programs, the hydrologic system can be analyzed and described in a preliminary written report. Based on the report a digital or combined analog-digital model would be constructed (or modified from an existing model). The model's purpose would be as a management tool, to show the hydrologic response to a given stress or imposed conditions on the irrigation system. It permits rapid calculation of quantitative effects of water-management practice[s].

The model would include river and flood-plain alluvium, as well as adjacent parts of the Santa Fe aquifer where heavy pumpage is affecting water in the alluvium (such as the Las Cruces well field). The model should be sensitive enough to duplicate changes in hydrologic conditions (such as water levels) and small area of a few [sq. mi.] sections. Also, the model must be flexible enough to allow for large-scale modifications and changes in the present irrigation network.

[p. 29] Along with predicting changes in the quantities of water available at a particular location and time, the need is to predict the chemical quality of the water resulting from a management decision. It appears this second objective may also be solved by digital computer. The model may not have the sensitivity of the quantity model, but should show changes in ion concentration and loads over an area of several square miles during periods of a few years.

An open-file report would be written upon completion of the data gathering and defining of the system. Later, the modeling phase of the project, with supporting data, would be described in another report.

MAJOR ITEMS OF WORK [p. 30-33]

1. General collection of hydrologic data.
    - a. Well inventory - Inventory all wells in the upland area. Locate all large capacity wells in the flood-plain alluvium (estimated 2,000 wells) and inventory 40 percent or more on a selective basis. Inventory selected test holes: Take water samples of selected inventoried wells.
    - b. River, canal, and drain-flow measurements - The water-budget study will require frequent flow measurements and water sampling (weekly to monthly) of river, canal, and drain discharges at selected locations. The budget should follow the water year and continue over a 2- or 3-year period.
    - c. Aquifer tests - Pumping test and specific capacity measurements will be made whenever practical.
    - d. Pumpage inventory - Power-yield measurements need to be on wells in selected areas where acreage, irrigation quantities, and rainfall amounts are known. About 10 percent of the inventoried irrigation wells should be measured for the inventory.
    - e. Computer - formats will be used in data collection. Previously gathered material should be transferred to the format, and all format data put on punched cards and entered into a data file.
2. [p. 31] Quality-of-water work – Collect samples from 25 percent of all upland wells inventoried. Make specific-conductance measurements whenever possible. Sample, at selected depths, water from the deep test holes, and at intervals of time, water from the shallow test holes and observation wells. Later it may be desirable to install water-quality monitors on a few test holes.
3. Surface geophysics - a survey will be made of commercial sources, and if possible the data obtained. If desirable data are not available, a gravity survey of the area will be made by the Geological Survey. Minimum work would consist of five east-west gravity profiles distributed across the area, average length of 50 miles, using 1- mile station spacing. Altitudes of stations would be surveyed to an accuracy of 1 foot or less. In the vicinity of Las Cruces, more detailed gravity work is needed (estimated 75 additional stations). Based on analyses of the gravity survey, about 90 miles of seismic refraction profiles may be made at selected locations. Earth resistivity studies will be conducted in the Texas area of the Rio Grande Environmental Project area. If these studies prove successful, the seismic work may be replaced by resistivity studies.
4. [p. 32] Deep test drilling - Deep test drilling would be contracted to commercial drillers. Two or three holes are planned in the vicinity of Las Cruces, one ±10 miles south of Las Cruces, two in the La Mesa bolson, two in the La Mesa bolson, one 10 to 20 miles west of Las Cruces; and one or two north of Las Cruces on the Jornada del Muerto. Location of these holes should depend on results of' the geophysical surveys and well inventory. Each hole would be about 1,500 feet deep.Tests will be conducted at selected depth intervals in each hole to

determine (1) quality of water in that zone, (2) hydrostatic pressure, (3) aquifer permeability, and (4) lithology of the formation. If possible, in areas of high stress, each deep test hole will be cased and equipped so as to construct a permanent observation well where one or more separate intervals in the aquifers can be tested to monitor changes in water quality and hydrostatic pressure with time.

5. [p. 33] Shallow test-hole drilling - Drill about 25 shallow test holes in the alluvium as supplemental observation wells. At 15 other sites throughout the alluvium of the lower Rio Grande Valley, "nests" of observation wells would be installed. Depths of installation range from 10 to 200 feet, with depths of 10 to 80 feet being most common. These "nest" wells would be cased, perforated, and equipped as permanent observation wells. Two or three of the "nests" should be installed between the river alluvium and the city well field in order to monitor chemical changes with continuous city pumpage.
6. Borehole geophysical logging - borehole geophysical logs would be made in the eight deep test holes. All available logs on previously drilled wells and test holes would be purchased. The New Mexico District logger would make logs in shallow test holes, and in unused or abandoned deep test holes and wells. Also, some logging may be done by arrangement with commercial drillers.
7. Models - A digital or combined analog-digital model would be constructed for the area containing the flood-plain alluvium and Rio Grande. Also adjacent areas where heavy pumpage occurs would be included in the model. Exact planning on the models should await evaluation of the digital model used by Richardson (1971).

SCHEDULE OF WORK, TIME, AND COSTS [p. 34-39]

First Fiscal Year, October 1971 – June

	Schedule Item	Project Time In man-months	Costs
1.	Project Planning		$ 1,000
2.	Well Inventory		3,000
3.	Water-Use Data		2,000
4.	Water-Sample Collection		1,000
5.	Data Sources		4,000
6.	Water-Sample Analysis		2,000
7.	Report Preparation		4,000
8.	Report Review		1,200
9.	Overhead Charge		1,800
Totals		9	$20,000

Second fiscal year, July 1972-June 1973

Schedule item	Project time in man-months	Costs
1. Begin inventory and sampling of wells. Put data on punch cards. (Estimated 2,800 wells in valley, inventory ±1,300 wells and sample 390 wells.)	13	$ 53,690
2. Buy or do complete gravity geophysical survey.	1	8,200
3. Aerial magnetic geophysical survey.	-	6,000
4. Begin earth resistivity measurements or seismic profiling.	2	20,000
5. Plan and begin river, canal, and drain-flow measurements at selected sites. Begin water-budget calculations. Collect water samples for analyses.	5	17,500
6. Begin series of power-yield tests.	2	5,800
7. Drill, test, and equip shallow test holes in or near alluvium. About 25 single test holes (80' depth) and 15 "nests" of observation wells (10 to 200' depths). Work by USGS Hydrologic Laboratory, Denver. Sample wells bimonthly.	7	70,050
8. Anapra special report.	1	2,900
9. Aquifer tests on wells (pumping tests and specific capacity).	2	5,800
10. Prepare preliminary maps on geologic structure of base of Santa Fe Group and locate subsurface barriers.	1	2,900
11. Plan drilling of deep and shallow test holes.	1	2,900
12. Equipment to establish office.	-	3,000
13. Move allowance for 2 employees (or per diem).	-	3,000
14. Data analysis, progress reports, and project administration.	3	8,700
15. Drill 1 deep test hole (1,500').	1	40,300
TOTALS	39	$250,740

Third fiscal year, July 1973-June 1974

Schedule item	Project time in man-months	Costs
1. Complete well inventory and sampling. Punch data.	4½	$ 18,610
2. Complete earth resistivity and seismic work.	2	19,000
3. Measure and sample observation wells.	2½	21,880
4. Inventory new wells and update.	1	2,900
5. Make river, canal, and drain-flow measurements at selected sites. Collect and analyze water samples.	5	20,750
6. Continue aquifer tests.	3	8,700
7. Continue power-yield tests.	2	5,800
8. Drill 3 deep test holes (1,500') and test.	3	120,900
9. Begin detailed analysis of system, mainly in vicinity of Las Cruces. Prepare preliminary maps as possible, showing:		
a. Base of Santa Fe Group and subsurface structures and barriers.		
b. Major aquifers and/or water-quality zones.		
c. Altitude of water table.		
d. Base of alluvium and saturated thickness.		
e. Saturated sand thickness of different water-quality zones.		
f. Cross-sectional views of valley.	4	11,600
10. Assemble and review water budget.	3	7,900
11. Assemble and complete computer output of basic well data.	2	5,800
12. Data analysis, progress reports, and project administration.	4	11,600
TOTALS	36	$255,440

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Fourth fiscal year, July 1974–June 1975

Schedule item	Project time in man-months	Costs
1. Drill 4 deep test holes (1,500'). Analyse drilling results.	6	$167,000
2. Measure and sample observation wells.	2½	21,880
3. Inventory and update for new wells.	2	5,800
4. Make river, canal, and drain-flow measurements at selected sites. Collect and analyze water samples.	5	20,750
5. Continue aquifer tests.	2	5,800
6. Continue power-yield tests.	2	5,800
7. Borehole geophysical logging with District logger.	1	6,900
8. Outline contents of final reports. Plan digital models.	5	14,500
9. Continue intensive analysis of system. Refine water budget; complete maps started before; define geologic framework; begin water-quality budget.	4	11,600
10. Begin preparation of final reports and maps.	3½	10,150
11. Project administration, progress report, half-time secretary for ½ of year.	3 + 3 secretary	9,800
TOTALS	36 + 3 secretary	$279,980

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Fifth fiscal year, July 1975–June 1976

Schedule item	Project time in man-months	Costs
1. Complete river, canal, and drain-flow measurements and sampling.	2	$ 12,050
2. Measure and sample observation wells.	2	19,190
3. Complete power-yield tests and pumpage inventory.	1	2,900
4. Complete aquifer test program.	1	2,900
5. Inventory selected new wells and verify data.	2	8,260
6. Complete 2 open-file reports.	13	37,700
7. Complete digital model of ground water in alluvium.	4	11,600
8. Complete final report.	5	14,500
9. Secretary and project administration.	3 + 6 secretary	14,700
10. Effort on digital or analog-digital quality-of-water model.	3	8,700
TOTALS	36 + 6 secretary	$132,500

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[p. 39] A breakdown of expenses by year and cooperator is given below. It is assumed that the city of Las Cruces and Elephant Butte Irrigation District will share equal expenses throughout the last four years of the project. The Water Resources Research Institute furnishes office space to the project on a non-matching cooperative basis.

Costs					
State Engineer	City of Las Cruces	Elephant Butte Irrigation District	Anapra study	U.S. Geological Survey	Total
$5,000	$5,000			$10,000	$20,000
5,000	58,185	$58,185	$4,000	125,370	250,740
5,000	61,560	61,560	-	123,120	256,240
5,000	67,495	67,495		139,990	279,980
5,000	30,625	30,625		66,250	132,500
$25,000	$222,865	$217,865	$4,000	$469,730	$939,460

REPORTS [p. 40-41]

Progress reports would be made at the end of the second, third, and fourth fiscal years to all cooperators. Also at the end of the fourth fiscal year, a computer printout: of basic data such as a table of well records, results of chemical analyses, streamflow records and selected lithologic logs should be available. By January 1973, an open-file letter report with accompanying maps should be available on the general hydrologic conditions in the vicinity of the proposed port of entry at Anapra.

Two open-file reports, including maps and tables, would be prepared by about March 1976. One report would describe in detail the ground-water situation in the vicinity of Las Cruces. The other report would describe ground-water conditions in the flood-plain alluvium and adjacent aquifers of the Rio Grande Valley from Caballo Reservoir, New Mexico to EI Paso, Tex. Some results of the quantitative model study should be included.

A comprehensive report to be completed by June 1976 would describe the general hydrologic situation of the southern Rio Grande Valley area, New Mexico. It is planned that this report would be published as a State Engineer Technical Report or as a Geological Survey Water-Supply Paper.

[p. 41] The final report from this project would contain results of the model studies on the flood-plain alluvium aquifer. This Report would describe the model and associated data used, verification, and the results obtained in using the model for design, planning, and operation of the surface-ground water system for irrigation in the Rincon and Mesilla Valleys. The date and type of report would depend on the results of the models. The completion date would be decided on later in the study.

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