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AN OVERVIEW OF THE HYDROGEOLOGY OF SALINE GROUND WATER IN NEW MEXICO

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INTRODUCTION

Increasing demand on limited potable ground water supplies in New Mexico has stimulated interest in saline water resources. Saline water is defined for the purpose of this paper as containing a dissolved solids concentration equal to or greater than 1,000 milligrams per liter (mg/L). Saline water resources can augment potable water supplies following treatment to reduce concentrations of dissolved solids. This treatment, known as desalination, is expected to play and increasingly important role in meeting water demand in the desert southwest and the nation. "By 2020, desalination and water purification technologies will contribute significantly to ensuring a safe, sustainable, affordable, and adequate water supply for our Nation" (U.S. Bureau of Reclamation and Sandia National Laboratories, 2003).

Purpose and Scope

Successful development of saline water resources in New Mexico will require information on the geohydrology of aquifers containing these resources. Existing information is scattered throughout the scientific literature and, in some instances, is currently available only on the internet. The purpose of this paper is to present a reconnaissance-scale overview of the saline ground water resources of New Mexico and to compile and synthesize available information on the geographic location; geohydrologic setting; extent and movement of saline ground water; and the hydraulic properties of, yields to wells from, and saline water in storage in selected ground water reservoirs in New Mexico. The discussed reservoirs include the Albuquerque Basin, San Juan Basin, Roswell Basin, Capitan aquifer, Estancia Basin, and the Tularosa-Salt Basin (Fig. 1). Kelly and others (1970) and Kelly (1974) determined these reservoirs to be potentially important sources of saline ground water in New Mexico.

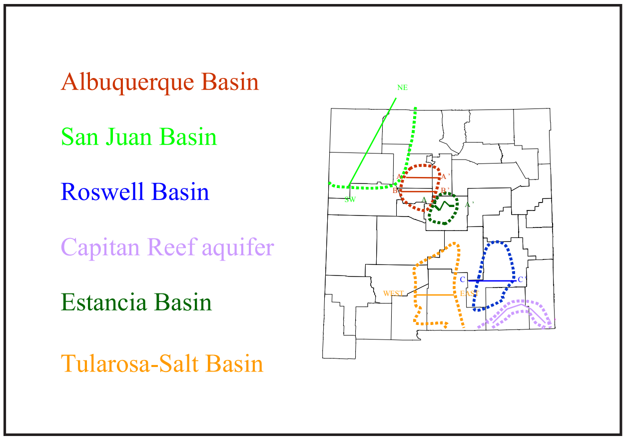

Figure 1. Generalized boundaries of selected ground water basins and aquifers in New Mexico including the locations of cross sections shown in figures 3-8.

Background

The importance of saline ground water resources is reflected in the number of studies on the results (American Hydrotherm Corporation, 1966a; 1966b; 1967) and feasibility (Morris and Prehn, 1971; Stucky and Arnwine, 1971) of desalination in New Mexico. Recently renewed interest in use of saline water resources is reflected in the works of U.S. Bureau of Reclamation and Sandia National Laboratories (2003), Whitworth and Lee (2003), and Huff (2004). A workshop was convened in 2004 by the New Mexico Office of the State Engineer, the New Mexico Water Resources Research Institute, and the U.S. Bureau of Reclamation to devise strategies for development of saline water resources in New Mexico. Results of the workshop can be viewed at http://wrri.nmsu.edu/conf/brackishworkshop/report.html.

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SALINE GROUND WATER RESOURCES

Approximately three-fourths of the ground water in New Mexico is too saline for most uses without treatment (Reynolds, 1962, p. 91). Hood and Kister (1962), Hale and others (1965), Kelly and others (1970), Kelly (1974), U.S. Bureau of Reclamation and State of New Mexico (1976), Thompson and others (1984), and Lansford and others (1986) reported results of reconnaissance scale investigations on the distribution and chemical composition of saline ground water in New Mexico. Figure 2 shows areas of New Mexico that were known to contain saline ground water resources in 1965 as described by Hale and others (1965). The rest of this paper will summarize the available information describing our current state of knowledge concerning the hydrology of and the saline ground-water resources contained within areas shown in Figure 1. Sources of information summarized include works at regional, state, and local scales.

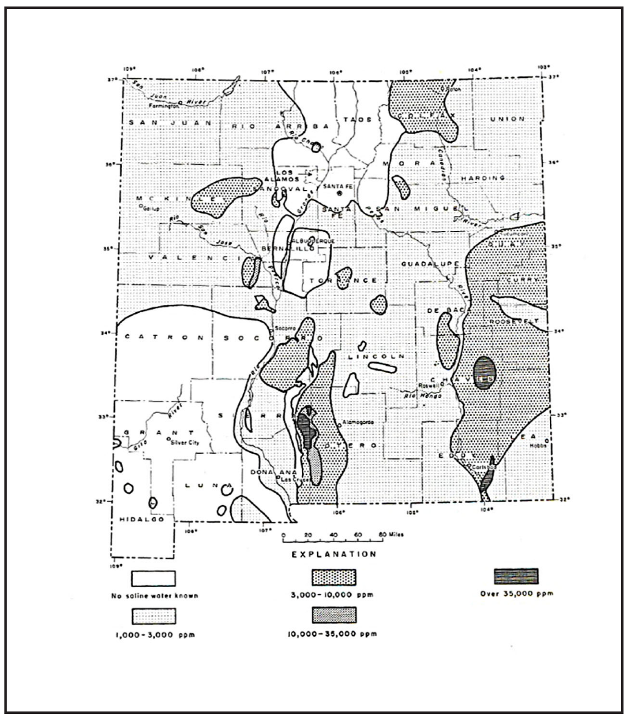

Figure 2. Generalized occurrence of saline ground water in New Mexico (from Hale and others, 1965).

Albuquerque Basin

The Albuquerque Basin covers about 2,100 square miles (mi^2) of central New Mexico (Fig.1) (Lozinsky and Hawley, 1992). Figure 3 shows geologic cross sections representative of the basin. The basin was formed by tectonic events in Pennsylvanian-Permian time, Jurassic-Cretaceous time, late Cretaceous-Tertiary time (Laramide Orogeny), and events in Oligocene-Recent time associated with opening of the Rio Grande Rift (Kelley, 1977).

The Albuquerque Basin contains geologic units of Precambrian through Quaternary age. Sedimentary rocks of Paleozoic through Cenozoic age, representing a variety of marine and non-marine depositional environments, overlie Precambrian basement (Kelley, 1977). The major aquifer in the basin is contained within the Santa Fe Group of Pliocene-Pleistocene age. The Santa Fe Group is up to 14,000 feet thick and is divided into upper, middle, and lower hydrostratigraphic units (Hawley, 1992; Lozinsky and Hawley, 1992).

Recharge enters the Santa Fe Group sediments by surface water infiltration, mountain front recharge, and as ground water flow across the northern boundary of the Albuquerque Basin. The total estimated recharge to the Santa Fe Group aquifer is about 268,000 acre-feet per year (ac-ft/yr) (Kernodle and others, 1995). Kernodle and others (1995) estimated that inflow to the Santa Fe Group aquifer and overlying sediments exceeded outflow (including ground-water withdrawal) by 920 ac-ft/yr under 1994 conditions.

Water having dissolved solids concentrations of 1,000 to 3,000 mg/L occupies the Santa Fe Group from about 3,000 to about 7,000 feet below land surface. The total volume of saline water in these sediments is estimated to be about 300 million acre-feet (Kelly, 1974).

Estimated values of hydraulic conductivity in the Santa Fe Group aquifer range from 40 to less than 0.3 feet per day (ft/d) (Kernodle and Scott, 1986; Haase and Lozinsky, 1992; Kernodle and others, 1995). Estimated values of transmissivity in the Santa Fe Group range from 7,500 to 600,000 gallons per day per foot (gpd/ft) (about 1,000 to about 80,100 square feet per day (ft^2/d)) (Bjorklund and Maxwell, 1961) with an average value near 221,000 gpd/ft (29,500 ft^2/d) (Kernodle and Scott, 1986). Hydraulic conductivity in the Santa Fe Group aquifer decreases with depth. Estimated values of hydraulic conductivity are 10-15 ft/d for the upper hydrostratigraphic unit, 4 ft/d for the middle hydrostratigraphic unit, and 2 ft/d for the lower hydrostratigraphic unit (Kernodle and others, 1995). Aquifers containing saline water in the basin may yield up to 500 gallons per minute (gpm) to wells (Kelly, 1974).

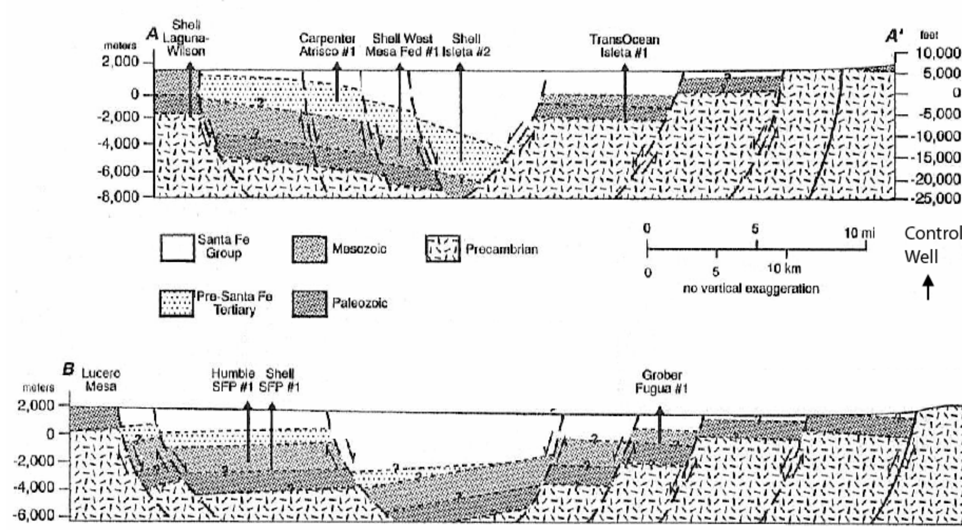

Figure 3. Geologic cross section through Albuquerque Basin (modified from Lozinsky and Hawley, 1992).

San Juan Basin

The San Juan Basin covers about 15,000 to 20,000 mi^2 of New Mexico, Colorado, Arizona, and Utah (Kelley, 1957). Figure 1 shows the area of New Mexico included in the San Juan Basin. Figure 4 shows a hydrogeologic cross section representative of the basin. The basin was formed principally by tectonic events in Late Cretaceous time (Laramide Orogeny) (Kelley, 1957).

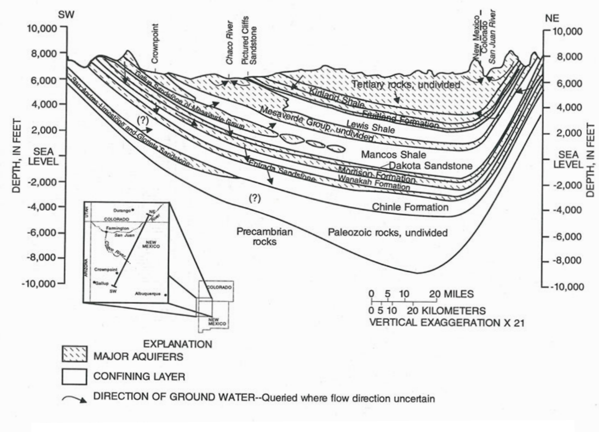

Figure 4. Hydrogeologic cross section through the San Juan Basin (modified from Dam, 1995; originally from Stone and others, 1983).

The San Juan Basin contains rocks of Precambrian through Quaternary age. Rocks of Precambrian age are overlain by maximum thicknesses of geologic units of Cambrian through Quaternary age that exceed 14,000 feet and represent a series of terrestrial and marine depositional environments (Stone and others, 1983). Geologic units that contain major aquifers within the basin include the undivided rocks of Tertiary age; the Kirtland Shale, Fruitland Formation, Pictured Cliffs Sandstone, Mesaverde Group, Gallup Sandstone, and Dakota Sandstone of Cretaceous age; The Morrison Formation and Entrada Sandstone of Jurassic age; and the San Andres Limestone and Glorietta Sandstone of Permian age (Stone and others, 1983).

Ground water recharge to the San Juan Basin takes place primarily through streambed infiltration and infiltration of precipitation in the basin-margin outcrop areas (Kernodle, 1996). Cross-formational flux in the basin is generally thought to be small (Frenzel, 1982; Dam, 1995). Total ground water recharge to the basin is about 85,700 gpm (138,300 ac-ft/yr) (Kernodle, 1996).

All the major aquifers in the basin contain areas of freshwater. All major aquifers in the basin, with the exception of the aquifer contained in the Gallup Sandstone, also contain saline water (San Juan Water Commission, 2003). Water with salinities of 3,000 to 10,000 mg/L occupies geologic units of the basin from about 500 feet to about 5,500 feet below land surface (Kelly, 1974). Water salinity typically increases basinward from outcrop areas and with increasing depth (Stone and others, 1983). Substantial areal variations in water salinity occur within the basin (Stone, 1992).

Transmissivities of aquifers in the San Juan Basin cover a wide range of values but generally lie between 5 and 4,000 ft^2/d (Stone and others, 1983; Kernodle, 1996). Reported yields to wells range between 1 and 500 gpm (Kelly, 1974; Kernodle, 1996) with locally greater yields possible (Hale and others, 1965). Aquifers containing saline water in the basin may yield from 100-500 gpm to wells (Kelly, 1974).

Roswell Basin

The areal extent of the Roswell Basin varies depending on the definition of its boundaries. The legal boundary of the Roswell Groundwater Basin includes 10,799 mi^2 of southeastern New Mexico (Pecos Valley Water Users Organization, 2001). The extent of the basin as defined by the presence of its principle aquifer (Fig. 1) is approximately 2,170 mi^2 (Welder, 1983). Additional definitions exist which yield various estimates of basin area (Welder, 1983). Figure 5 shows a hydrologic cross section representative of the basin.

The Roswell Basin has a complex history of erosion and sedimentation extending from Paleozoic through Cenozoic time. The result of this history is 4,000 to 5,000 feet of unconsolidated sediments and sedimentary rocks in the basin representing a variety of marine and non-marine depositional environments. The sedimentary rocks contain the well-developed geologic section of Permian age characteristic of much of southeastern New Mexico (Fiedler and Nye, 1933; Morgan and Sayre, 1942; Mourant, 1963; Havenor, 1968; Welder, 1983). The principle aquifer of the basin is contained in the upper part of the San Andres Limestone and the lower part of the overlying Artesia Group, both of Permian age. The principle aquifer is often referred to as the artesian aquifer. Alluvial

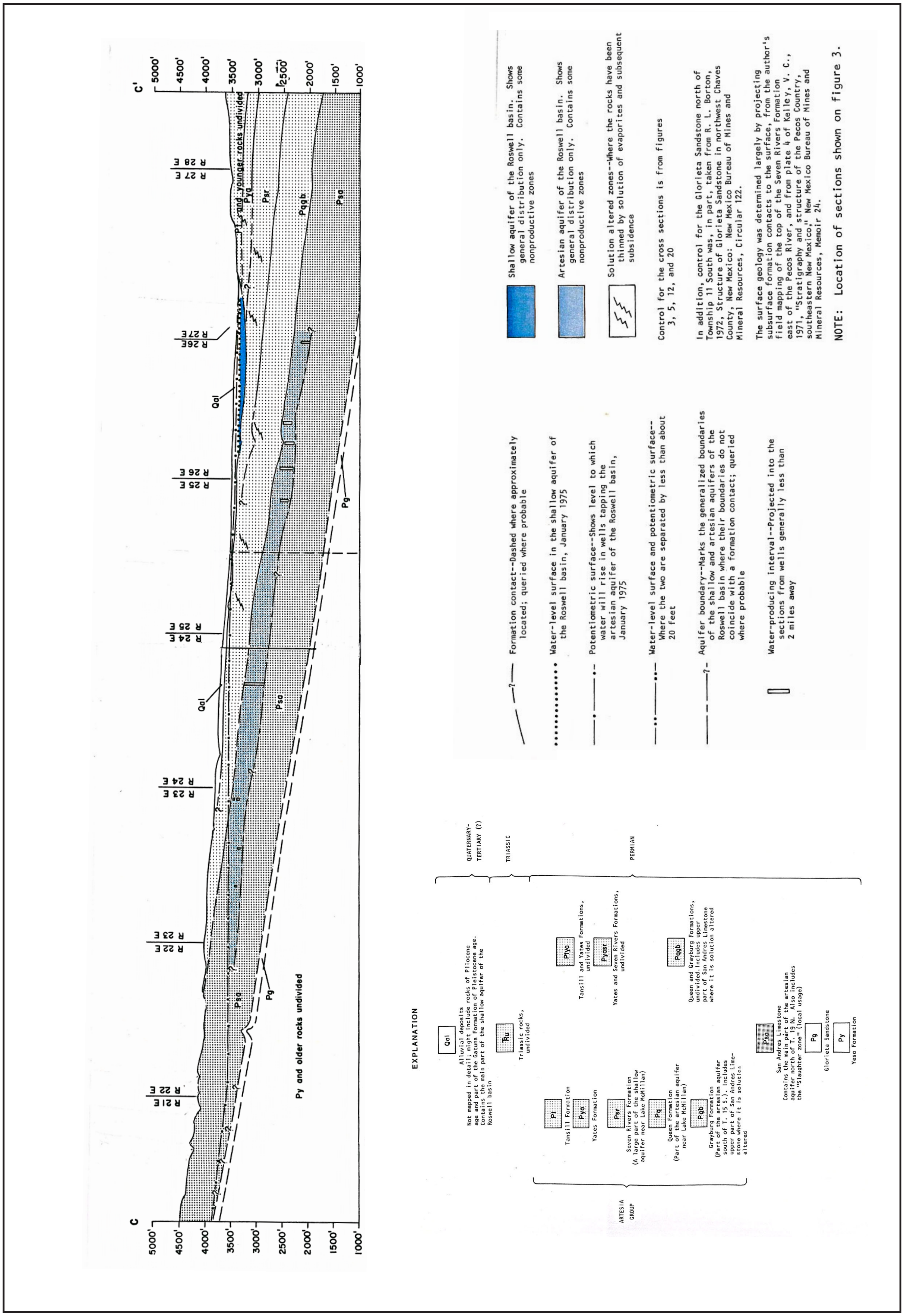

Figure 5. Hydrogeologic cross section through the Roswell Basin (modified from Welder, 1983.)

sediments of Quaternary age also contain an aquifer in the basin. The aquifers are separated by the Artesia Group that acts as a leaky confining unit (Havenor, 1968; Saleem and Jacob, 1971; Welder, 1983). The Yeso Formation and Glorietta Sandstone, both of Permian age, may also contain aquifers useable for the production of saline water.

Fisher (1906), Fiedler and Nye (1933), and Morgan (1938) completed early studies on the geohydrology of the Roswell Basin. Ground water recharge enters the aquifer contained in the alluvial deposits by direct infiltration of precipitation on the basin floor and by infiltration of surface water. Ground water recharge enters the principle aquifer from infiltration of precipitation and infiltration of surface water on the outcrop in elevated areas west of the basin (Fiedler and Nye, 1933; Theis and others, 1942; Mourant, 1963; Saleem and Jacob, 1971). Saleem and Jacob (1971) estimated average recharge to the principle aquifer to be approximately 240,000 ac-ft/yr between 1903 and 1968. Hydrologic modeling indicates that about 2 million ac-ft of water was depleted from storage in the principle aquifer between 1926 and 1968 (Saleem and Jacob, 1971).

The principle aquifer in the Roswell Basin contains both saline and fresh water. The eastern margin of the basin is marked by a facies change in the San Andres Limestone near the Pecos River from carbonate to evaporite and siliciclastic sediments (Morgan and Sayre, 1942; Welder, 1983). Ground water salinity increases in association with this facies change. Saline water has migrated westward into freshwater areas of the principal aquifer in response to hydraulic gradients created by ground water withdrawal (Hood and others, 1960; Hood, 1963). This induced lateral migration of saline water demonstrates the interconnected nature of fresh and saline ground water systems in the principle aquifer. Water having dissolved solids concentrations of 3,000 to 10,000 mg/L occupies geologic units within the basin from about 500 to 1,500 feet below land surface (Kelly, 1974). Water having dissolved solids concentrations of 10,000 to 35,000 mg/L occupies geologic units within the basin starting between about 500 and 3,000 feet below land surface and extending to about 3,500 to 6,000 feet below land surface (Kelly, 1974).

Transmissivity of the aquifer in the alluvial deposits of the Roswell Basin averages about 13,000 ft^2/d with specific yields of 0.10 to 0.20. Estimated transmissivities of the principle aquifer range between 800 and 187,000 ft^2/d (Theis, 1951; Hantush, 1957). The distribution of transmissivity in the principle aquifer is largely controlled by the distribution of dissolution-enhanced secondary porosity. Porosity enhancement took place through dissolution of carbonate rock on movement of large quantities of freshwater through the aquifer during periods of subareal exposure in Permian and Pleistocene times (Fiedler and Nye, 1933). Relatively less is known about the hydraulic characteristics of the remaining rocks of Permian age (Wasiolek, 1991). However, Kelly (1974) estimates that yields to wells of 100 to 500 gpm can be expected from saline water bearing aquifers.

Capitan Aquifer

The Capitan and Goat Seep Limestones along with the Carlsbad Facies of the Artesia Group make up an arcuate band of stacked and adjoining limestone facies that collectively form the Capitan aquifer in New Mexico (Fig. 1). The lithofacies forming the Capitan aquifer of New Mexico represent the shelf-margin facies of a carbonate shelf complex deposited during Permian time (Meissner, 1972). Figure 6 shows a hydrologic cross section representative of the Capitan aquifer. Aquifer thickness ranges from a few hundred to approximately 2,000 feet (Meissner, 1972; Hiss, 1975). The width of the aquifer varies, in part, as a function of which formations and facies are included. The width of the Capitan Limestone was reported by Dunham (1972) to be slightly less than 5 miles.

Hiss (1975) systematically studied the hydrology of the Capitan aquifer. Recharge to the Capitan aquifer in New Mexico comes from infiltration of precipitation in elevated terrain on the western side of the aquifer; from leakage from underlying, overlying, and adjoining geologic units; and infiltration of surface water (Bjorklund and Motts, 1959; Hiss, 1975; Richey and others, 1985). The dominant modern-day ground-water-flow pattern is from the west toward the Pecos River (Hiss, 1975).

Generally, freshwater occurs in the Capitan aquifer of New Mexico west of the Pecos River (Hiss, 1973; 1975; 1976). The distribution of fresh and saline water correlates with the history of fresh ground-water

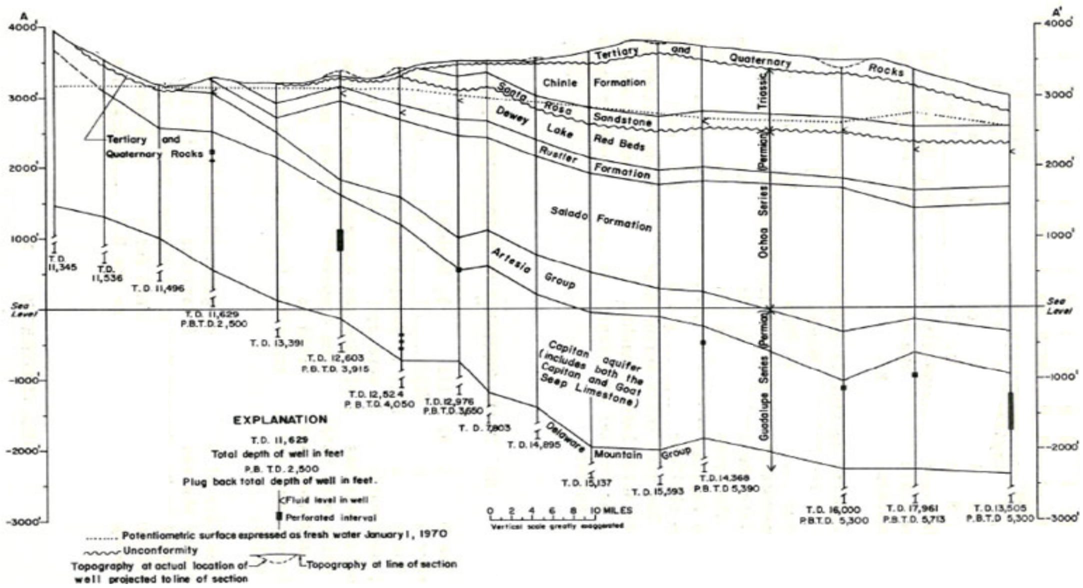

Figure 6. Hydrologic cross section through the Capitan aquifer (modified from Hiss, 1973.)

movement through the aquifer. Two major episodes of flushing of the part of the aquifer west of the Pecos River with freshwater are recognized; one in late Permian time and one in Pliocene-Pleistocene time. Periods of subareal exposure of the aquifer led to both flushing episodes. Flushing of the part of the aquifer west of the Pecos River, while removing a large amount of possibly connate saline water from the aquifer, also enhanced the porosity and permeability of the aquifer through dissolution of carbonate material (Gail, 1974; Hiss, 1975). Modern-day saline water in the aquifer west of the Pecos River could be, in part, the result of interformational leakage (Hiss, 1975; Richey and others, 1985). Extensive flushing of the aquifer with freshwater has likely not occurred in areas east of the Pecos River. Saline water in the aquifer east of the river is likely either connate or derived from interformational leakage (Hiss, 1975). Water having dissolved solids concentrations of 3,000 to 10,000 mg/L occupies the Capitan aquifer in New Mexico from between land surface and about 5,000 feet below land surface extending to about 1,200 to 6,200 feet below land surface (Kelly, 1974). The relatively lower porosity of the aquifer east of the Pecos River may limit the amount of recoverable saline water in storage in the aquifer (Leedshill-Herkenhoff and others, 2000). Depths to saline water in the aquifer east of the Pecos River range from greater than 300 to greater than 1,000 feet below land surface (Hiss, 1973).

Hydraulic conductivity of the Capitan aquifer in New Mexico ranges from 1 to 25 ft/d west of the Pecos River and averages about 5 ft/d east of the river. Transmissivities may be as much as 10,000 ft^2/d in thicker parts of the aquifer that have well–developed porosity (Hiss, 1975). The portion of the aquifer containing saline water may yield up to 500 gpm to wells (Kelly 1973). Huff (1997) summarized available porosity, permeability, and aquifer test data for the Capitan aquifer of New Mexico.

Estancia Basin

The Estancia Basin covers about 1,500 mi^2 of central New Mexico (Fig. 1). Figure 7 shows a geologic cross section representative of the basin. The basin was formed by tectonic events in late Pennsylvanian to Permian time, late Cretaceous to Eocene time (Laramide Orogeny), and Oligocene to Holocene time. The most recent tectonic event is associated with formation of the Rio Grande Rift (Barrow and Keller, 1994).

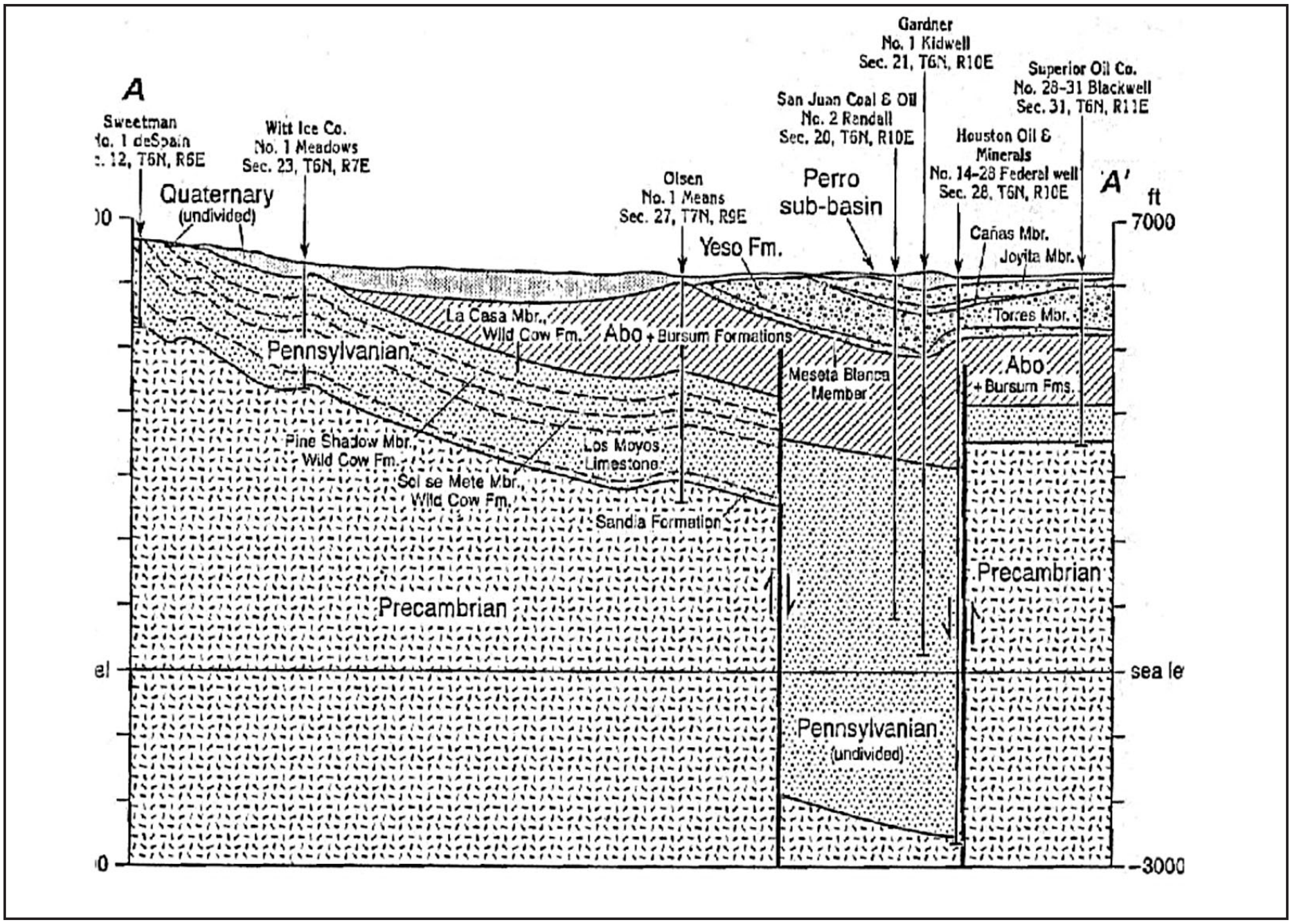

Figure 7. Geologic cross section through the Estancia Basin (modified from Broadhead, 1997).

Rocks of Precambrian age on the western side of the Estancia Basin are covered by up to 1,000 feet and on the eastern side by up to 8,500 feet of sedimentary rocks of Pennsylvanian to Permian age (Broadhead, 1997). Sedimentary rocks of Permian age in the central part of the basin are overlain by 300-400 feet of alluvial, lacustrine, and dune deposits of Tertiary to Quaternary age. The sediments of Tertiary to Quaternary age make up the valley fill deposits (Broadhead, 1997). Major aquifers within the basin are contained within geologic units of Pennsylvanian age (Madera Group), geologic units of Permian age (the Yeso Formation and the Glorietta Sandstone), and within the valley fill deposits of Tertiary to Quaternary age (White, 1994).

Meinzer (1911) initially investigated the hydrology of the Estancia Basin. Ground water recharge comes dominantly from infiltration of precipitation in mountains rimming the western side of the Estancia Basin (Titus, 1969; White, 1994). An unpublished estimate of ground-water recharge to the basin of 37,774 ac-ft/yr is cited by Shafike and Flanigan (1999). Hydrologic modeling suggests that approximately 2 million ac-ft of ground water was depleted from the basin between 1940 and 1996 (Shafike and Flanigan, 1999).

All the major aquifers in the Estancia Basin contain areas of fresh water. Generally, ground water salinity in the northern half of the basin increases as water moves basinward from the basin margins (White, 1994). Ground water salinity may follow a similar pattern in the southern half of the basin. Smith (1957) discussed the presence of saline water in geologic units of Permian age. Water with salinities of 10,000 to 35,000 mg/L occupy geologic units within the basin from land surface to about 500 feet below land surface extending to about 8,000 to 8,500 feet below land surface (Kelly, 1974). Hawley and Hernandez (2003) have begun a reevaluation of the saline water resources of the basin.

The presence of fractures and areas of dissolution-enhanced porosity largely control the hydrologic properties of aquifers in the Madera Group and the Yeso Formation (Smith, 1957; Jenkins, 1982). Estimates of transmissivity for the aquifer contained in the Madera Group range from 20 to greater than 1 million ft^2/d (Jenkins, 1982). Yields to wells have been reported as about 5 gpm from the aquifer contained in the Madera Group, 15 to 500 gpm from the aquifer contained in the Yeso Formation, greater than 1,000 gpm from the aquifer contained in the Glorietta Sandstone, and greater than 500 gpm from the aquifer contained in the valley fill deposits (White, 1994). Aquifers containing saline water may yield up to 500 gpm to wells (Kelly, 1974).

Tularosa/Salt Basin

The Tularosa and Salt basins together cover approximately 7,750 mi^2 of south central New Mexico (Fig. 1). Though hydrologically different, their proximity suggests they be discussed together as a potential source of saline ground water.

The Tularosa Basin covers approximately 6,500 mi^2 of south central New Mexico (Orr and Myers, 1986). Figure 8 shows a geologic cross section representative of the Tularosa Basin. The basin was formed by tectonic events over the last 10 million years associated with development of the Rio Grande Rift in southern New Mexico (Adams and Keller, 1994).

Consolidated rocks of Paleozoic and Mesozoic age are overlain by approximately 2,000 to 8,000 feet of sediments of Cenozoic age in the Tularosa Basin (McLean, 1970). Sediments of Cenozoic age range from coarse-grained alluvial deposits rimming the basin margin to fine-grained lacustrine deposits near the basin center. The major aquifers in the basin are contained in the basin-margin alluvial fans (McLean, 1970; Orr and Myers, 1986).

Meinzer and Hare (1915) initially investigated the hydrology of the Tularosa Basin. Ground-water recharge comes from infiltration of precipitation in the topographically elevated areas rimming the basin (Burns and Hart, 1988; Risser, 1988; Morrison, 1989; Huff, 2005). Estimates of total recharge to the basin include 143,000 meters cubed per day (m^3/d) (42,300 ac-ft/yr) (Huff, 2005) and 86,400 ac-ft/yr (Livingston Associates and John Shomaker and Associates, 2002). Hydrologic modeling indicates that approximately 101,500 m^3/d (30,000 ac-ft/yr) of ground water left the basin through evapotranspiration under 1995 conditions (Huff, 2005).

Generally, fresh ground water in the Tularosa Basin occurs only in alluvial fans that rim the basin. Ground-water salinity generally increases basinward from the basin rim and generally increases with depth (McLean, 1970; 1975; Thompson, 1984; Orr and Myers, 1986). The basin contains at least 90 million and perhaps over 400 million ac-ft of saline water having dissolved solids concentrations of 35,000 mg/L or less (McLean, 1970; Livingston Associates and John Shomaker and Associates, 2002). Only approximately 2 percent of saturated basin-fill deposits contain water

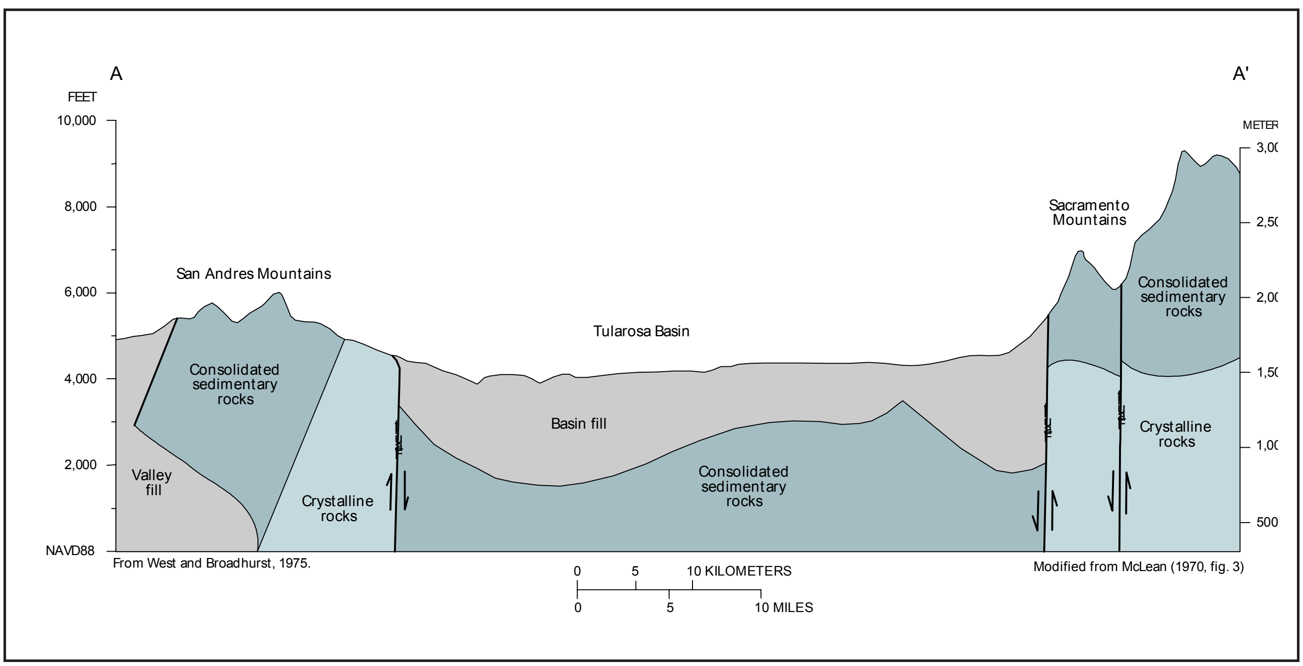

Figure 8. Geologic cross section through the Tularosa Basin (modified from West and Broadhurst, 1975; originally from McLean, 1970).

having dissolved solids concentrations of 35,000 mg/L or less (McLean, 1970). Data from Livingston Associates and John Shomaker and Associates (2002) suggest that approximately 25 percent of the water in the basin having dissolved solids of 10,000 mg/L or less may be recoverable.

Transmisivity of aquifers contained in alluvial fan deposits that rim the Tularosa Basin can exceed 10,000 ft^2/d. Transmissivity generally decreases basinward (Burns and Hart, 1988; Orr and Myers, 1986; Morrison, 1989). Typical specific yields of aquifers contained in the alluvial fan deposits range between 0.08 and 0.12 (Burns and Hart, 1988; Morrison, 1989). Parts of the aquifer containing saline water may yield up to 500 gpm to wells (Kelly, 1974).

Relatively less is known about the hydrogeology of the Salt Basin compared to the Tularosa Basin.The Salt Basin covers approximately 1,250 mi^2 of south central New Mexico. Major aquifers in the basin are contained in alluvial deposits of Quaternary age and in the 'bedrock aquifer' contained in the San Andres Limestone and the Yeso and Abo Formations, all of Permian age (Livingston Associates and John Shomaker and Associates, 2002). Ground water recharge occurs by infiltration of surface water and infiltration of precipitation (Livingston Associates and John Shomaker and Associates, 2002).

The Salt Basin contains approximately 31 million ac-ft of saline water having dissolved solids concentrations of 5,000 mg/L or less. Approximately 90 percent of this saline water is contained within the 'bedrock aquifer' which typically yields 50 gpm or less to wells (Livingston Associates and John Shomaker and Associates, 2002). Reported yields to wells from the aquifer contained in the alluvial deposits range from 10 to 3,800 gpm (Bjorklund, 1957).

SUMMARY

Increasing demand on limited potable ground water supplies in New Mexico has stimulated interest in saline water resources. Successful development of saline water resources in New Mexico will require information on the geohydrology of aquifers containing these resources. Substantial saline ground-water resources are contained within aquifers in the Albuquerque Basin, aquifers in the San Juan Basin, aquifers in the Roswell Basin, the Capitan aquifer, aquifers in the Estancia Basin, and the aquifers in the Tularosa/Salt Basin of New Mexico. Hydrogeologic characteristics of and the amount of saline water stored in these aquifers vary widely.

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