



Review of Knowledge on the Occurrence, Chemical Composition, and Potential Use for Desalination of Saline Ground Water in Arizona, New Mexico, and Texas with a Discussion of Potential Future Study Needs

By G.F. Huff

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
Length		
gallon (gal)	3.785	liter (L)
acre-foot (acre-ft)	1,233	cubic meter (m ³)
gallon per minute (gal/min)	0.06309	liter per second (L/s)

Review of Knowledge on the Occurrence, Chemical Composition, and Potential Use for Desalination of Saline Ground Water in Arizona, New Mexico, and Texas with a Discussion of Potential Future Study Needs

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ABSTRACT

Increasing demand on the limited supplies of freshwater in the desert Southwest, as well as other parts of the United States, has increased the level of interest in saline-water resources. Saline ground water has long been recognized as a potentially important contributor to water supply in the Southwest, as demonstrated by the number of hydrologic, geologic, and engineering studies on the distribution of saline water and the feasibility of desalination.

Potential future study needs include investigating and documenting the three-dimensional distribution of salinity and chemical composition of saline-water resources and the hydraulic properties of aquifers containing these saline-water resources, assessing the chemical suitability of saline water for use with existing and anticipated desalination technologies, simulating the effect of withdrawal of saline ground water on water levels and water composition in saline and adjoining or overlying freshwater aquifers, and determining the suitability of target geologic formations for injection of desalination-generated waste.

INTRODUCTION

Increasing demand on limited supplies of freshwater in the desert Southwest, as well as other parts of the United States, has increased the level of interest in saline-water resources. Saline water is defined as containing 1,000 milligrams per liter (mg/L) or greater dissolved solids. Saline ground water has long been recognized as a potentially important contributor to water supply in the Southwest, as demonstrated by the number of hydrologic, geologic, and engineering studies on the distribution of saline water and the feasibility of desalination (American Hydrotherm Corporation, 1966a, 1966b, 1967; Southwest Research Institute and Texas Water Development Board, 1966, 1967; Ralph M. Parsons Company and Texas Water Development Board, 1967; Schultz and others, 1967; Morris and Prehn, 1971; and Stucky and Arnwine, 1971). Desalination is expected to play an increasingly important role in meeting water demand in the 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).

Potential future study needs that could enhance the use of saline-water resources for desalination include:

- Investigating and documenting the three-dimensional distribution of salinity and chemical composition of saline-water resources and the hydraulic properties of aquifers containing these saline-water resources,

- Assessing the chemical suitability of saline water for use with existing and anticipated desalination technologies,
- Simulating the effect of withdrawal of saline ground water on water levels and water composition in saline and adjoining or overlying freshwater aquifers, and
- Determining the suitability of target geologic formations for injection of desalination-generated waste. Similar problems in using saline water resources have been identified by Kelly (1974) and Alley (2003).

Purpose and Scope

This report documents the state of knowledge and future needs on the occurrence and chemical composition of saline-water resources, the hydrogeologic properties of aquifers containing saline-water resources, the chemical suitability of saline water for use in desalination, and the effect of withdrawal of saline ground water on water levels and water composition in saline and adjoining or overlying freshwater aquifers. The report also discusses formations that have been evaluated as target intervals for deep-well injection of desalination-generated waste. The geographic scope of the report includes Arizona, New Mexico, and Texas.

Background

Early large-scale inventories of saline-water resources of the United States include those of Krieger and others (1957) and Feth and others (1965). In general, less is known about the hydraulic properties of saline-water aquifers than their freshwater counterparts. This is attributable to the relatively small number of wells, aquifer tests, and hydrogeologic studies completed about saline-water aquifers or saline parts of otherwise freshwater aquifers.

Black and Veatch Consulting Engineers (1967) and, more recently, Hooley and others (1993) discussed the importance of input-water composition in desalination. The tendency of input water to form scale deposits during the desalination process is a primary concern regarding the economic feasibility of desalination for water supply. Scale decreases the efficiency of and increases the maintenance costs associated with desalination. Common scale-forming solids include calcite, gypsum, and amorphous silica. Methods to quantify the chemical suitability of saline water for use in desalination based on the tendency of input water to form scale have focused on solubility data (Langelier, 1936; Ryznar, 1944; Stiff and Davis, 1952), chemical characteristics of input water (El-Manharawy and Hafez, 2001a, 2001b; Hadi, 2002), and thermodynamic modeling (Hamrouni and Dhahbi, 2001; Huff, 2004). To date (2004), no systematic effort has been undertaken to evaluate the scale-forming tendencies of saline ground water in the Southwest.

The literature has only recently begun to address how salinity of ground water used for desalination input may change with time and withdrawal rate (Al-Zubari, 2003). Simulations and observations of the movement of saline ground water resulting from freshwater withdrawal in Arizona, New Mexico, and Texas are local to regional in scale and are addressed in following sections.

Desalination produces a lower salinity water (permeate) from which most dissolved solids have been removed and a higher salinity waste water (concentrate) in which much of the dissolved solids present in input water has been concentrated. Coastal desalination operations typically dispose of concentrate at sea. Inland desalination operations commonly dispose of concentrate using evaporation ponds (Morris and Prehn, 1971; Stucky and Arnwine, 1971) or deep-well injection (Ralph M. Parsons Company and Texas Water Development Board, 1967; Boegly and others, 1969; LeGros and others, 1969, 1970; U.S. Bureau of Reclamation, 1998). The hydrogeologic characteristics required for a target formation to be used for deep-well injection of concentrate, as synthesized from Boegly and others (1969), LeGros and others (1969), and U.S. Bureau of Reclamation (1998), include:

- Adequate capacity, based on area of extent, thickness, and porosity, to accept the anticipated volume of injected concentrate,
- Effective confining units above and below the target formation to restrict the vertical movement of injected concentrate,
- A depth below the deepest usable ground water in an area and an initial water composition of 10,000 mg/L or greater dissolved solids,
- Sufficient permeability to accept a reasonable rate of concentrate injection without the buildup of excessive pore pressures,

- Absence of faults or other wells penetrating the target formation in the anticipated area of injection that would provide preferential pathways for the vertical movement of injected concentrate or, for injection near faults, would increase the likelihood of significant seismic activity, and
- Chemical compatibility of the injected concentrate with the native water in and mineralogy of the target formation that would lessen the permeability or porosity of the target formation by precipitation of solid phases on reaction of the concentrate with the native water or target formation matrix.

Wilson (1971) discussed the theoretical aspects of controlling water chemistry in the target formation during concentrate injection. Kharaka and others (1996, 1997) presented recent work on geochemical modeling of target formation/concentrate compatibility.

ARIZONA

Saline ground water exists on a regional scale near Wilcox, Case Grande, Tucson, Coolidge, and Phoenix (Kister and Hardt, 1966; Kister, 1974a, 1974b; Davidson, 1979). Saline ground water also occurs in alluvial deposits of the Gila, Salt, and Colorado Rivers (Davidson, 1979; Thompson and others, 1984a; Robertson, 1991). Davidson (1979) estimated a 30- to 100-year supply of saline ground water in the alluvial aquifers of the Basin and Range Province in Arizona. Information on the distribution of saline to moderately saline ground water in southern Arizona is contained in Kister (1973) and Robson and Banta (1995). Sulfate or chloride is the dominant anion in most saline ground water in the Basin and Range Province in Arizona (Thompson and others, 1984a).

Available literature does not discuss the specific hydrogeologic characteristics of aquifers containing saline water. However, Davidson (1979) reported that large-diameter wells in Colorado River alluvial deposits can yield as much as 2,500 gal/min.

Also not discussed in the available literature are the potential effects of withdrawal of saline water on water levels in saline or adjoining or overlying freshwater aquifers. The interconnectedness of adjoining saline and freshwater aquifers has been demonstrated by saline-water movement in response to freshwater withdrawal in western Pinal County and near the Gila River Indian Reservation (Kister and Hardt, 1966; Thomsen and Baldys, 1985). A study of the feasibility of concentrate disposal in the Tucson area found no suitable target formations for deep-well injection (U.S. Bureau of Reclamation, 1998).

NEW MEXICO

Approximately three-quarters of the ground water in New Mexico is saline and requires treatment prior to most uses (Reynolds, 1962, p. 91). The potential saline ground-water resources in New Mexico total approximately 15 billion acre-ft (U.S. Bureau of Reclamation and State of New Mexico, 1976). The potential contribution of desalination to water supply in New Mexico has been discussed by Morris and Prehn (1971) and Stucky and Arnwine (1971). Hood and Kister (1962) presented detailed information on the distribution and potential yield from saline-water aquifers contained in rocks of Pennsylvanian to Holocene age in New Mexico. Moderate (100 gal/min) or larger yields of saline water are available, in order of decreasing age, from aquifers contained in:

- Undifferentiated rocks of Pennsylvanian age on the flanks of the southern Rocky Mountains,
- The Yeso Formation of Permian age in the eastern Basin and Range Province,
- The San Andres Limestone of Permian age in the Pecos Valley and near the Zuni Uplift,
- The Capitan Limestone of Permian age near Carlsbad,
- The Ogallala Formation of Tertiary age in the southern High Plains Province,
- The Santa Fe Formation of Tertiary age in the Basin and Range Province, and
- Areas within the alluvium of Quaternary to Tertiary age associated with the Pecos River and the Rio Grande (Hood and Kister, 1962).

Hale and others (1965a, 1965b) presented a map showing the general occurrence of saline ground water in New Mexico. Maps presented by Lansford and others (1986) show the approximate thickness of aquifers containing slightly saline ground water (1,000 to 3,000 mg/L dissolved solids), moderately saline ground water (3,000 to 10,000 mg/L dissolved solids), and very saline ground water (10,000 to 35,000 mg/L dissolved solids) to brine (greater than 35,000 mg/L dissolved solids).

Kelly and others (1970) and Kelly (1974) presented detailed maps showing the extent and thickness of aquifers in the Rio Grande Basin of Colorado, New Mexico, and Texas that contain slightly saline ground water, moderately saline ground water, very saline ground water, and brine. Saline resources that have been identified by Kelly and others (1970) and Kelly (1974) as being most suitable for development include:

- Slightly saline water of the Albuquerque Basin,
- Moderately saline water from the San Juan and Roswell Basins and the Capitan Limestone,
- Highly saline water from the Roswell, Jornada del Muerto, and Estancia Basins, and
- Brine from the Tularosa Basin.

McLean (1970, 1975) presented detailed information on the hydrologic characteristics and distribution of saline-water resources in rocks of Pennsylvanian through Holocene age in the Tularosa Basin with emphasis on the basin-fill aquifer, which is composed primarily of Santa Fe Formation sediments of Tertiary age. Products of this study include maps showing the extent and depth of occurrence of slightly, moderately, and very saline water in the basin-fill aquifer. Salinity of water in the basin-fill aquifer of the Tularosa Basin generally increases and yield to wells decreases moving basinward from the surrounding mountains. The greatest ground-water salinities and smallest yields are associated with playa deposits near the basin center. The basin-fill aquifer of the Tularosa Basin contains approximately 140 million acre-ft of water with dissolved-solids concentrations between 1,000 and 35,000 mg/L (Stucky and Arnwine, 1971). Under 1971 conditions, Stucky and Arnwine (1971) estimated that one million gal/day of saline water could be produced from the Tularosa Basin without unacceptable interference with then-current users. Orr and Myers (1986) presented additional information on saline ground water on the eastern side of the Tularosa Basin.

Witcher and others (2004) presented an updated geohydrologic framework of the Mesilla Basin and concluded that dissolved salts are accumulating within the basin. Discharge of saline water from deep aquifers and discharge of saline geothermal water from shallow bedrock are the dominant mechanisms introducing dissolved salts into the aquifer contained in the Santa Fe Group sediments of Tertiary age within the Mesilla Basin. Products of this study include hydrologic cross sections of the Mesilla Basin and extensive tabulations of chemical and isotopic data for ground and surface waters.

Hood and others (1960) presented a detailed study of the occurrence and movement of saline ground-water resources near Roswell in aquifers contained in rocks of Permian age, including the Yeso Formation, the Glorieta Sandstone, the San Andres Limestone, and the Chalk Bluff Formation. Hood (1963) provided additional details on the occurrence and movement of saline ground-water resources in the San Andres Limestone aquifer of the Roswell Basin approximately between Roswell and Artesia, New Mexico. Products of Hood and others (1960) and Hood (1963) include maps showing the distribution of dissolved chloride and the generalized direction of movement of saline water in the San Andres Limestone aquifer. Withdrawal of freshwater from the San Andres Limestone aquifer is cited by Hood and others (1960) and Hood (1963) as the cause of migration of saline water toward areas of withdrawal from the San Andres Limestone aquifer.

Hiss (1975, 1977) presented information on the chloride content and saline/freshwater interface in aquifers in rocks of the Guadalupe Series of Permian age in southeastern New Mexico. Hibbs and others (2000) discussed the movement and chemical evolution of slightly saline water in the Animas Basin system of extreme southwestern New Mexico and identified gypsum dissolution, cation exchange, and evaporation as the primary processes responsible for the chemical evolution of saline ground water. Information presented by Stone and others (1983) indicates that aquifers contained in the Entrada Sandstone and the Morrison Formation, both of Cretaceous age, may be useful reservoirs of saline ground water.

Sulfate or chloride is the dominant anion in most saline ground water in the Basin and Range Province of New Mexico (Thompson and others, 1984b). Hood and Kister (1962), Kelly and others (1970), and Kelly (1974) provided chemical analyses from selected areas throughout New Mexico that could be used to determine the suitability of saline ground water for desalination. Chemical analyses presented by McLean (1970) and Hood and

others (1960) could be used to determine the suitability for desalination of saline ground-water resources from the basin-fill aquifer of the Tularosa Basin and from aquifers in rocks of Permian age near Roswell, respectively. Available literature does not discuss the potential effects of withdrawal of saline water on water levels or water movement in saline or adjoining or overlying freshwater aquifers in New Mexico.

Boegly and others (1969) concluded that the potential for deep-well injection of concentrate into geologic formations of Mesozoic or older age in the Basin and Range Province of New Mexico was small because of small formation permeability. However, LeGros and others (1970) recommended the Abo Formation of Permian age near Gallup as a suitable target formation for deep-well injection of concentrate. The statewide summary of geologic and hydrologic properties for formations of Paleozoic through Quaternary age presented by Hood and Kister (1962) could be used to select potential target formations for localized study of their suitability for deep-well injection of concentrate. Information provided in McLean (1970) could be used to select potential target formations in the Tularosa Basin for localized study.

TEXAS

The potential contribution of desalination to water supply in Texas has been discussed by the Southwest Research Institute and Texas Water Development Board (1966, 1967) and Ralph M. Parsons Company and Texas Water Development Board (1967). Information on the area of extent, lithology, and saline resources of the Bone Spring- Victoria Peak, Blaine, Capitan Reef, and Rustler aquifers in rocks of Permian age in western Texas is provided in Ralph M. Parsons Company and Texas Water Development Board (1967).

Winslow and Kister (1956) published detailed information on the distribution of and yield to wells from saline-water aquifers in rocks of Cambrian through Quaternary age in Texas. Moderate (200 gal/min) or larger yields of saline ground water to wells are available, in order of decreasing age, from aquifers contained in:

The Hickory Sandstone of the Riley Formation of Cambrian age in parts of central Texas,

The Quartermaster Formation of Permian age in the Osage Plains region,

The Rustler Limestone of Permian age in the Pecos Valley,

The Dockum Group of Triassic age in parts of western Texas,

The Navarro Group of Tertiary age and the Nacatock Sand of Tertiary age in western Texas,

- The Wilcox Group of Tertiary age and the Carrizo Sand of Tertiary age in the western Gulf of Mexico Coastal Plain,
- The Sparta Sand of Tertiary age in eastern Texas,
- The Catahoula and Oakville Sandstones of Tertiary age in the western Gulf of Mexico Coastal Plain,
- The Ogallala Formation of Tertiary age in the High Plains region,
- The Goliad Sand of Tertiary age, the Willis Sand of Quaternary and Tertiary age, and the Lissie Formation and the Beaumont Clay of Quaternary age in the Gulf of Mexico Coastal Plain, and
- Alluvial deposits of Quaternary to Tertiary age in the Pecos and lower Rio Grande Valleys (Winslow and Kister, 1956).

An exhaustive and detailed description of saline ground-water resources in Texas was presented in a series of volumes prepared by Core Laboratories, Inc. for the Texas Water Development Board. Core Laboratories, Inc. (1972a) contains extensive geologic cross sections through, as well as structure, thickness, and water-salinity maps for, 25 aquifer systems that contain saline-water resources. These aquifers occur in rocks that range from Cambrian to Ordovician through Tertiary in age. Information on the age, lithology, and net non-clay thickness of rocks containing each aquifer is tabulated. Texas aquifer systems discussed by Core Laboratories, Inc. (1972a), in order of decreasing age, include:

- The Ellenbruger aquifer in rocks of Cambrian to Ordovician age in the western, central, and Panhandle areas,
- The Simpson aquifer in rocks of Ordovician age in the western, central, and Panhandle areas,

- The Montoya aquifer in rocks of Ordovician age in the western and Panhandle areas,
- The aquifer in rocks of Silurian to Devonian age in the western and Panhandle areas,
- The aquifer in rocks of Mississippian age in the western and Panhandle areas,
- The aquifer (undifferentiated) in rocks of Pennsylvanian age in the western and Panhandle areas,
- The aquifer system in rocks of Pennsylvanian age in the central area,
- The Wolfcamp aquifer in rocks of Permian age in the western, central, and Panhandle areas,
- The Leonard aquifer in rocks of Permian age in the western area,
- The San Andres aquifer in rocks of Permian age in the western area,
- The Upper Guadalupe aquifer in rocks of Permian age in the western area,
- The Upper Permian (undifferentiated) aquifer in rocks of Permian age in the central area,
- The Rustler aquifer in rocks of Permian age in the western area,
- The aquifer in rocks of Triassic age in the western area,
- The Trans-Pecos aquifer in rocks of Cambrian through Pennsylvanian age and in rocks of Permian through Quaternary age between El Paso and the Pecos River,
- The Smackover aquifer in rocks of Jurassic age in the eastern area,
- The Pettet-Travis Peak aquifer in rocks of Jurassic and Cretaceous age in the eastern area,
- The Edwards and Glen Rose aquifers in rocks of Cretaceous age in the southern and southwestern areas,
- The Lower Glen Rose aquifer in rocks of Cretaceous age in the eastern area,
- The Paluxy aquifer in rocks of Cretaceous age in the eastern area,
- The Woodbine aquifer in rocks of Cretaceous age in the eastern area,
- The Eagle Ford aquifer in rocks of Cretaceous age in the eastern area,
- The Navarro-Taylor aquifer system in rocks of Cretaceous age between Bowie and Hunt Counties and extending southwestward to the Mexican border,
- The Carrizo-Wilcox aquifer in rocks of Tertiary age in the Gulf Coast area, and
- The Gulf Coast aquifer system in rocks of Tertiary age in the Gulf Coast area.

LBG-Guyton Associates and NRS Consulting Engineers (2003) recently compiled information about the extent, geology, hydrology, and available saline-water resources in major aquifer systems in Texas contained in rocks of Quaternary to Cretaceous in age. These rocks include:

- The Trinity Group of Cretaceous age,
- The Wilcox Group of Tertiary age,
- The Ogallala Formation of Tertiary age,
- The Chicot, Evangeline, Jasper, and Catahoula Formations of Quaternary to Tertiary age, and
- Bolson-fill and alluvial deposits of Quaternary to Tertiary age.

LBG-Guyton Associates and NRS Consulting Engineers (2003) also includes information on minor aquifer systems and an extensive tabulation of references to literature on ground-water resources in Texas.

Extensive tabulations exist of chemical analyses of water from (Core Laboratories, Inc., 1972c) and permeability and porosity data for (Core Laboratories, Inc., 1972b) saline-water aquifers of Texas. Subsurface geologic data including formation depth, thickness, and lithology are tabulated for western Texas (Core Laboratories, Inc., 1972h), the Texas Panhandle (Core Laboratories, Inc., 1972g), central Texas (Core Laboratories, Inc., 1972d), eastern Texas (Core Laboratories, Inc., 1972e), and the Texas Gulf Coast Region (Core Laboratories, Inc., 1972f). The database used by Core Laboratories, Inc. was generated during the long history of oil and gas exploration and production in Texas.

Sulfate or chloride is typically the dominant anion in saline ground water in the Basin and Range Province of Texas (Thompson and Nuter, 1984). Winslow and Kister (1956) presented chemical analyses of saline water from selected areas throughout Texas that could be used to determine the suitability of saline ground water for desalination. The extensive tabulation of chemical analyses of saline ground water by Core Laboratories, Inc. (1972c) does not include data on the concentration of silica, which somewhat limits the use of this data set in determining the chemical suitability of saline ground water for desalination.

Numerical simulations of aquifer systems that include saline water, such as those of the Hueco Bolson (Groschen, 1994) and the Ogallala aquifer (Mehta and others, 2000), have focused on the movement of saline water

in response to the withdrawal of freshwater in adjoining or overlying aquifers. In principal, these types of simulation could be used to project the response of freshwater/saline-water interfaces to withdrawal of saline water.

Boegly and others (1969) concluded that the overall potential for deep-well injection of concentrate into geologic formations of Mesozoic or older age in the Basin and Range Province of Texas is small because of small formation permeability. Target formations in Texas that have been recommended for deep-well injection of concentrate include the San Andres Sandstone near Midland (LeGros and others, 1969, 1970); the Capitan Reef near Midland (LeGros and others, 1969); the Hueco Bolson near El Paso; the Bell Canyon Formation in the area of Reeves, Ward, and Winkler Counties; the Yates Formation, San Andres Sandstone, and Bell Canyon Formations in the Ector-Midland region; the San Andres Sandstone in the Crane-Regan-Upton Counties area; the Tannehill Formation in Taylor County; and the Cisco Group in the Childress-Hardeman-Vernon area (Ralph M. Parsons Company and Texas Water Development Board, 1967).

FUTURE NEEDS

The generalized mapping of saline ground-water resources in the southwestern United States has largely been accomplished. However, the distribution of salinity in ground water is typically mapped in two dimensions when, in fact, the distribution of subsurface salinity is often three-dimensional in nature. Three-dimensional representations of subsurface salinity could be made using ARC/INFO or similar software. Information on the three-dimensional distribution of subsurface salinity could be gathered from existing well and electric-log data in addition to new and existing geophysical surveys. A discretized three-dimensional representation of subsurface salinity, and other chemical and physical characteristics of subsurface water or aquifers, could allow more accurate estimations of changes in described properties with depth and volumes of saline resources available. Accurate three-dimensional representations of salinity would also aid in establishing more comprehensive and accurate initial and boundary conditions for flow and transport modeling in saline and variable-density systems.

Relatively little is known about the specific hydraulic characteristics of saline-water-yielding aquifers because of a general lack of wells completed in saline water. A program of exploration that includes drilling and pump testing saline aquifers would refine expectations of how these aquifers respond to ground-water withdrawal. The potential effects of withdrawal from saline-water aquifers on adjoining or overlying freshwater resources are largely uninvestigated. Additionally, changes over time in the salinity and chemical composition of water from a saline-water production well could affect the suitability of that water for desalination. Both the movement of and changes in composition over time of saline water resources could be addressed through variable- density and solute-transport modeling studies.

The importance of input-water composition to the desalination process is well known. However, relatively little has been done to develop accurate techniques to quantify the behavior of saline ground water, particularly regarding scale-forming potential, in desalination systems. Present or future techniques to quantify scale-forming potential applied to existing chemical analyses of saline waters could aid in assessing which saline resources are more suitable for use in desalination.

Commonly used concentrate-disposal methods include evaporation ponds and deep-well injection. Successful deep-well injection requires a target formation that meets certain geologic, hydrologic, and compositional criteria. Acquiring detailed information on deep formations by drilling, logging, pump testing, and recovering materials from deep wells is expensive. Therefore, large amounts of data on deep formations may be available only from the records of oil and gas exploration and production activities. The long history of oil and gas exploration and production in the Permian and Delaware Basins of southeastern New Mexico, in addition to the extensive subsurface database tabulated for Texas, could provide sufficient data for studies of the feasibility of deep-well injection of concentrate.

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