Discovering a Geologic Salinity Source *in the Rio Grande Aquifer*

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Water resources of the Rio Grande and its alluvial aquifer downstream of El Paso are shared by many users in both the United States and Mexico. The groundwater is used primarily to supplement surface-water irrigation from the river, and is vital to sustain agriculture during periods of drought.

Groundwater in the alluvial aquifer is saline, and the quality of both groundwater and surface water deteriorates progressively downstream of El Paso. Historically, the groundwater salinization has been thought to result from irrigation practices along the Rio Grande. The postulated model is that irrigation water becomes increasingly saline through evaporative concentration. Concentrated recharge moves downgradient, or discharges into the Rio Grande, then is re-applied to crops further downstream. Evaporation of already saline water further increases salinity and accelerates the formation of salt crusts in irrigated soils. Over-irrigation causes these salts to leach into the shallow water table, increasing the groundwater salinity. Saline groundwater is later used to irrigate fields during drought, repeating the cycle of salinity enrichment.

Agricultural and Geologic Factors in Salinization

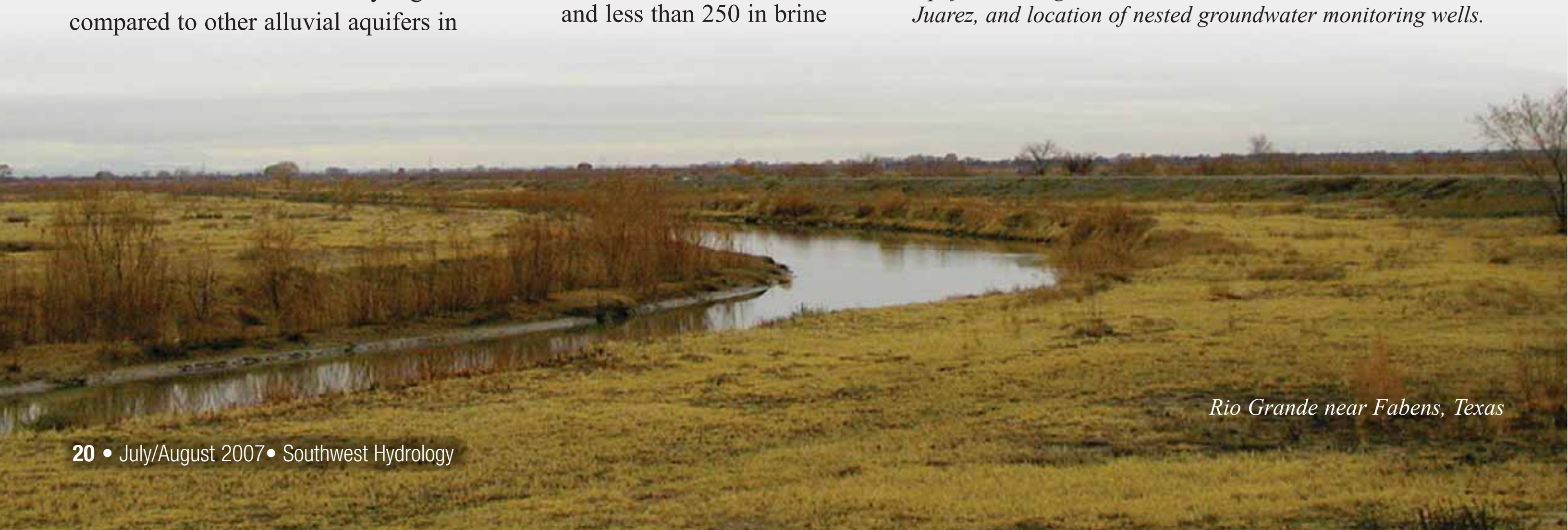
The salinity of alluvial groundwater below El Paso is uncommonly high compared to other alluvial aquifers in the Rio Grande Basin. Is this salinity due only to agricultural return flows, or could geological factors be part of the problem? Hibbs and Darling (1995) discussed potential sources of salinity in the Rio Grande aquifer, including: 1) recycling of irrigation water in heavily irrigated areas; 2) intrusion of Rio Grande water and evaporative concentration by phreatophytes; and 3) upwelling of saline waters from evaporite units in deeper strata (see diagram, opposite page). The latter source is based on a finding of high chlorine/bromine weight ratio (Cl/Br ratio) in both the river and the alluvial aquifer near Fabens, Texas, 30 miles downstream of El Paso.

Subsequently, Phillips and others (2003) and Dadakis (2004) showed that total dissolved solids, Cl/Br ratios, and chloride concentrations increase in the river and the alluvial aquifer downstream of El Paso. Because chlorine and bromine are nonreactive, their ratio is conservative and useful for identifying the origin, mixing, and evolution of groundwaters. Cl/Br ratios range from 50 to 150 in precipitation, from 300 to 600 in domestic sewage, and from 280 to 300 in marine water. They can be greater than 1,000 in waters that react with masses of halite in basin evaporites, and less than 250 in brine residues that remain after precipitation of masses of halite (Davis and others, 2001). The Cl/Br ratio can serve as a solute tracer because it can distinguish between salinization due to evaporation, in which Cl/Br ratios do not change, and subsurface geologic sources such as evaporite dissolution that increase the ratio.

Exploration for a Geologic Source of Salinity

Rio Grande aquifer waters in the Fabens area were sampled to determine salinity and Cl/Br ratios. Sampling in this intensively irrigated reach of the

Location map for Rio Grande aquifer and Hueco Bolson aquifer, showing El Paso and Fabens, Texas; Juarez, Ciudad Juarez, and location of nested groundwater monitoring wells.



Rio Grande near Fabens, Texas

floodplain aquifer identified two distinct groundwater types: one relatively dilute (1,000 to 2,000 milligrams per liter [mg/L] total dissolved solids [TDS] with Cl/Br ratios of 550 to 900), and one relatively saline (2,000 to 9,000 mg/L TDS with Cl/Br ratios of 1,200 to 3,900).

Chlorine isotopes combined with halide ratios provide compelling evidence of a geological source of salinity in the alluvial aquifer.

To determine whether an evaporite source exists beneath the Rio Grande aquifer, nested stainless steel monitoring wells were installed in the Fabens area and screened at 150 to 250 feet, 350 to 450 feet, and 650 to 750 feet below land surface. Chloride and Cl/Br ratios were low in the deepest monitoring wells, but drilling in the shallowest well detected a very saline, silty-clay, water-bearing unit 150 to 250 feet below land surface, directly beneath the Rio Grande alluvial deposits. This saline water-bearing unit contains about 15,000 mg/L Cl and Cl/Br weight ratios of about 5,800. The two deeper monitoring wells were flowing artesian wells, suggesting vertical flow from the deeper Hueco Bolson deposits into the Rio Grande alluvium.

The halide data suggest that the saline unit detected at 150 to 250 feet may be an important source of salinity in the river and alluvial aquifer in this area. This saline unit is likely a late-stage evaporite deposit that formed in a playa that developed about 1 million years ago (Hawley, 1975). The Rio Grande established its present course around 0.65 million years ago, cutting the present El Paso Valley over the older evaporite deposit.

Hypothesis Testing with Chlorine Isotopes

While the halide ratio data are compelling, other forensic tracers are required to confirm that upwelling from a shallow evaporite source is the cause of salinity. Chlorine radioisotopes were used to test this hypothesis.

Due to its half-life of approximately 300,000 years, chlorine-36 (^{36}Cl) is a useful tracer for studying slowly circulating groundwater systems, providing approximate ages between 50,000 and 2 million years (Davis and others, 2001). A potential problem with this application is that geologic sources may contribute chloride to the aquifer in addition to that which was present at the time of recharge. As a result, the age inferred is that of the geologic chloride source (typically very old), not of recharge to the aquifer. In these cases however, chlorine isotopes can be used to identify and quantify chloride sources and, in our study, to test the hypothesis that old chloride dissolved from the paleophreatic evaporite deposit is the source of salinity.

Samples for chlorine isotope analysis were collected from the end members of the Rio Grande surface water and from groundwater in the shallow evaporite unit 150 to 250 feet below land surface. Samples from a select group of wells in the alluvial aquifer define a mixing curve between these two sources and establish the evaporite unit as the source of additional salinity in the alluvial aquifer. As shown on the mixing curve (page 33), alluvial groundwater with high Cl/Br ratios (greater than 1,300) have demonstrably

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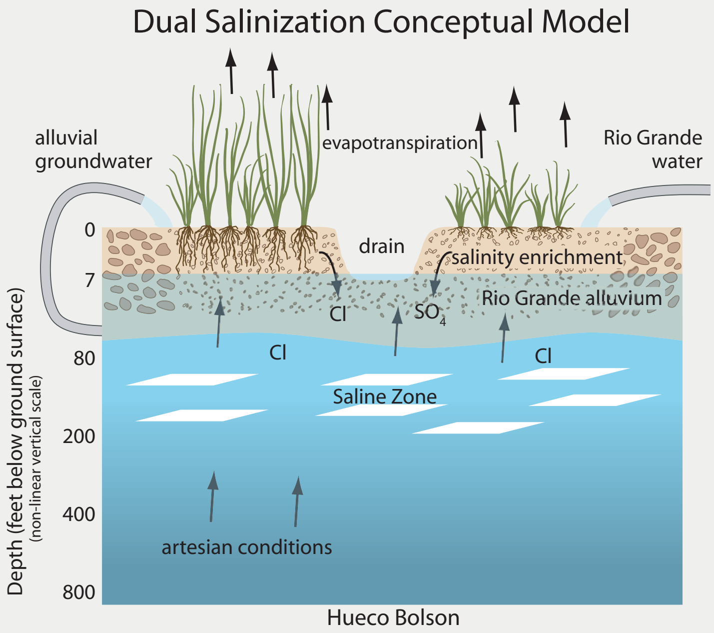

Evaporites in the Hueco Bolson react with groundwater which becomes enriched in chloride and Cl/Br ratios (modified from Lee Wilson and Associates, 1986).

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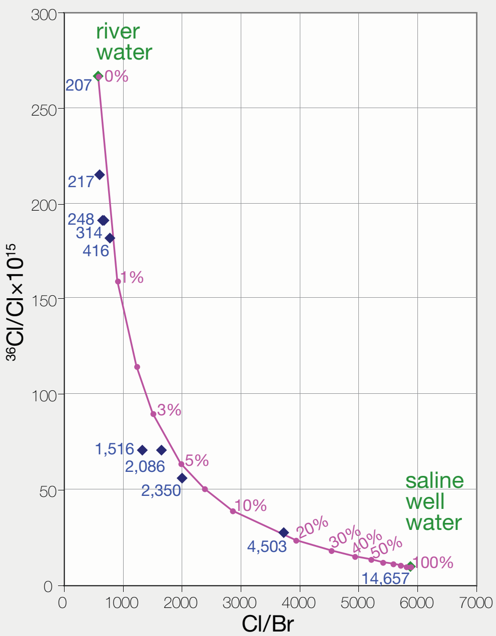
lower ^{36}Cl/Cl x 10^{15} ratios, less than 71. (^{36}Cl ratios are typically reported relative to total chloride x 10^{15} to produce whole numbers.) Alluvial groundwater with low Cl/Br ratios (less than 800) have higher ^{36}Cl/Cl x 10^{15} ratios and are closer to the values measured in Rio Grande irrigation waters. The chlorine isotopes combined with halide ratios provide compelling evidence of a geological source of salinity in the alluvial aquifer due to artesian upwelling from the Hueco Bolson. Once in the alluvial aquifer, the saline waters move into local agricultural drains and flow at various locations into the Rio Grande.

Role of Agriculture in Salinization

Our results suggest that dissolution of the buried evaporite deposit may be the primary source of salinity in the El Paso Valley. However, use of already saline alluvial groundwater for irrigation accelerates evaporative salinity enrichment of irrigation water, leading to greater potential for development of salt-encrusted soils. Steps should be taken to minimize use of saline alluvial groundwaters for irrigation in areas where evaporite dissolution signatures are identified, while using managed irrigation practices and crop management to help control salinity.



Samples from the alluvial aquifer (blue diamonds) fall close to a mixing line (pink) defined by the end members of river water and saline well water. Percent saline well water is shown next to the curve. Chloride concentrations (in blue, mg/L) show that waters with higher salinity (as expressed by chloride) also have higher Cl/Br ratios.

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