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Surface and Ground Water Interactions: El Paso Ciudad Juárez Region

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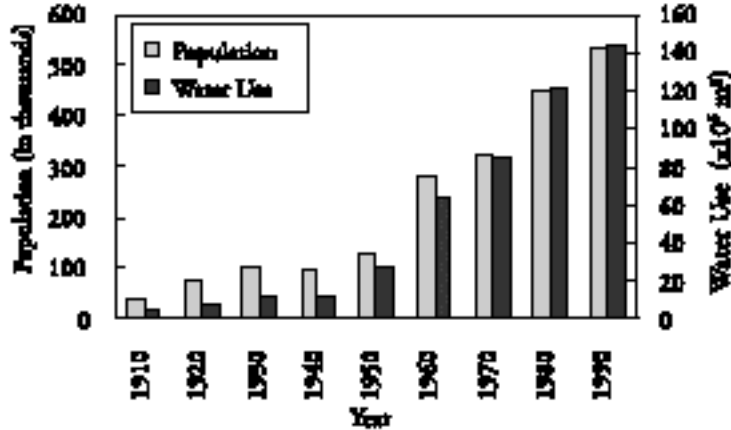
ABSTRACT

Ion concentrations and flow rates in the Rio Grande measured at El Paso reflect a strong interaction between surface and ground waters. The interaction occurs as irrigation waters are applied to fields with shallow groundwater, returning to the river in agricultural drains. Strong seasonal cycles are apparent in flow and water chemistry caused by irrigation patterns. Summer water release leads to higher flows and improved water quality. Winter flows primarily represent irrigation return flow and are of lower quality. Multiyear cycles reflecting climatic cycles are also apparent in the data. Empirical evidence is presented suggesting precipitation of calcium carbonate and calcium sulfate in fields.

INTRODUCTION

Growth of the El Paso Ciudad Juárez metropolitan area is increasing the demand on the available freshwater resources of the area. In the El Paso area, the increase in water use is directly correlated to the increase in population (Figure 1). Population pressures have increased water usage, even with the water conservation measures implemented in the 1980s. El Paso and Ciudad Juárez primarily use groundwater from intermontane-basin aquifers to supply their needs. However, during the past 10 years, El Paso has increased its usage of water from the Rio Grande. Based on 1994 data, El Paso obtained 56% of its water supply from intermontane-basin aquifers in the

Figure 1: Relationship between Population Growth and Water Use for El Paso, Texas



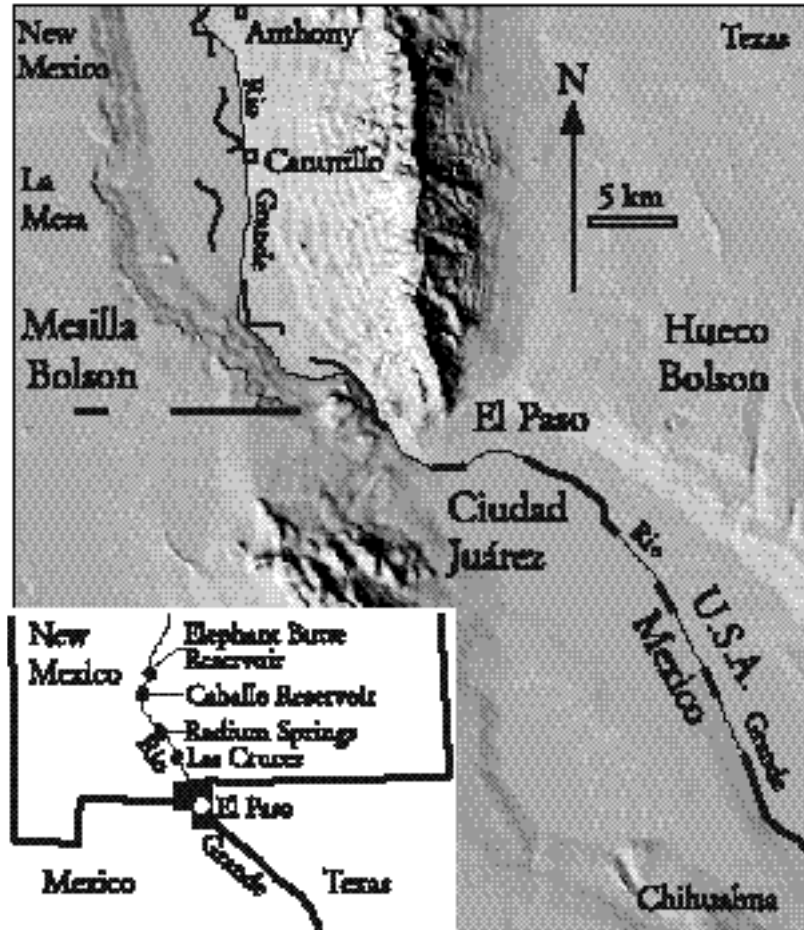
Source: Rebeck et al. (1996).

Hueco and Mesilla bolsones (Figure 2) and 44% came from the Rio Grande (Rebeck et al. 1996). Repeated usage of river water for irrigation between the headwaters and El Paso has degraded the quality of the water by increasing the salinity. During periods of high discharge, the water quality meets water standards and can be used by El Paso. However, during periods of low discharge, including the non-irrigation season (October-March) and droughts, the salinity increases to the point that the water is no longer usable for domestic purposes.

Groundwater used for municipal purposes comes from aquifers in the Mesilla and Hueco bolsones. Four aquifers, referred to as the shallow, upper and lower intermediate, and deep aquifers, are recognized in the sediments of the Mesilla Bolson (Nickerson 1989). These aquifers are recharged by the Rio Grande, irrigation canals, water spread on agricultural fields, and groundwater flow from the La Mesa, New Mexico, region. The Rio Grande is a losing stream (a zone of groundwater recharge) where it enters the north end of the Mesilla Bolson near Radium Springs (Figure 2). Traditionally, the Rio Grande was a gaining stream (a zone of groundwater discharge) where it exited the south end of the Mesilla Bolson near El Paso. This pattern has become more complex and seasonally variable because of irrigation and municipal water usage.

The quality and quantity of recharge from surface water and groundwater flow control the quality of the water in the shallow aquifer beneath the Mesilla Bolson. A strong hydraulic connection

Figure 2: Shaded Relief Map of the Area Surrounding El Paso, Texas, and Ciudad Juárez, Chihuahua (Digital Elevated



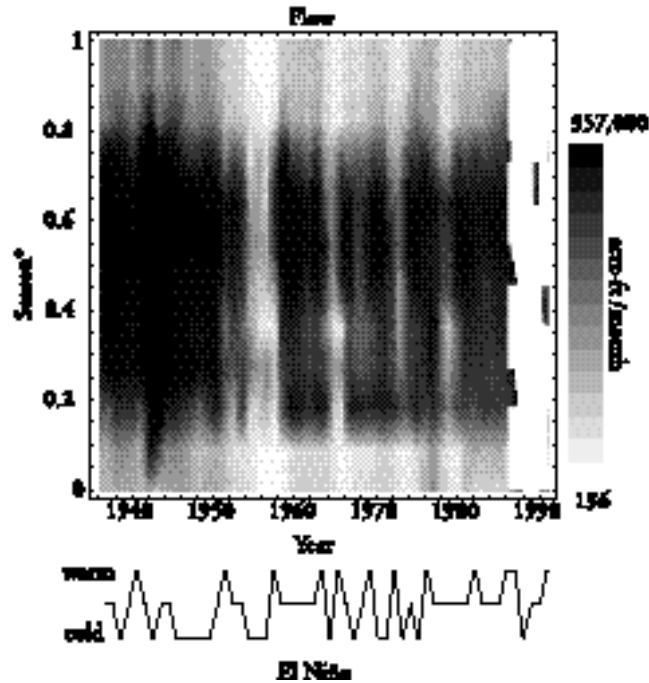
Note: The area of the shaded relief map is shown as a black box near El Paso on the inset map. The Mesilla Bolson stretches from Radium Springs, New Mexico, to El Paso, Texas.

exists between the surface water and the shallow aquifer. Water mass balances for the shallow aquifer show annual cycles of draw-down and rebound related to irrigation practices (Updegraff and Gelhar 1978). However, recharge to the shallow aquifer beneath the Mesilla Bolson appears to be keeping pace with water usage (Hernandez 1978; Peterson et al. 1984). Current water-use practices control salinity in the shallow aquifer. River water is applied to agricultural areas where the salts are concentrated by the high evapotranspira-

tion rates characteristic of this semiarid region. Additional salts are added to the water due to the weathering of minerals in the soil. The overall salinity of the shallow groundwater reflects the balance between applied irrigation water, evapotranspiration, and leakage of water from canals. Water currently leaking from irrigation canals is not wasted as is commonly believed rather, it plays an important role in reducing the salinity of groundwater in the shallow aquifer.

The brackish groundwater from the shallow aquifer is discharged into the irrigation drains and flows back into the Rio Grande. This leads to an increase in the salinity of the river water as it flows through the Mesilla and Hueco bolsones (Hernandez 1978). Additionally, pumping in the intermediate and deep Mesilla Bolson aquifers has affected groundwater flow by causing the downward migration of brackish groundwater from the shallow aquifer. The migration of this water will

Figure 3: Discharge in the Rio Grande at El Paso



*The seasons in Figures 3-6 are represented as numbers between 0 and 1, where 0 is January 1 and 1 is December 31.

Note: White regions on the right side of graph represent times when discharge data are lacking. The generalized El Niño temperature range is represented as a solid line below.

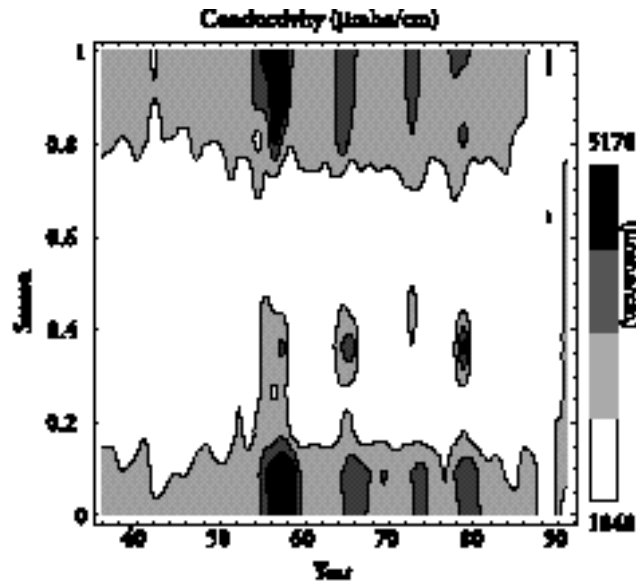
eventually cause degradation of the intermediate aquifers (Walton et al. 1999). This study documents and analyzes the relationship between the water quality, discharge, and source waters of the Rio Grande in the El Paso area.

WATER CHEMISTRY AND DISCHARGE TRENDS ON THE RIO GRANDE

The approximately 60-year record of discharge for the Rio Grande at El Paso is shown in Figure 3. Higher discharges are shown in the darker shades. Several trends emerge from the data. Discharges are generally greatest during the irrigation season when water is released from Elephant Butte and Caballo reservoirs (Figure 2). The irrigation season extends (approximately) from March to October and would have seasonal values of about 0.17 to 0.83 (Figure 3).

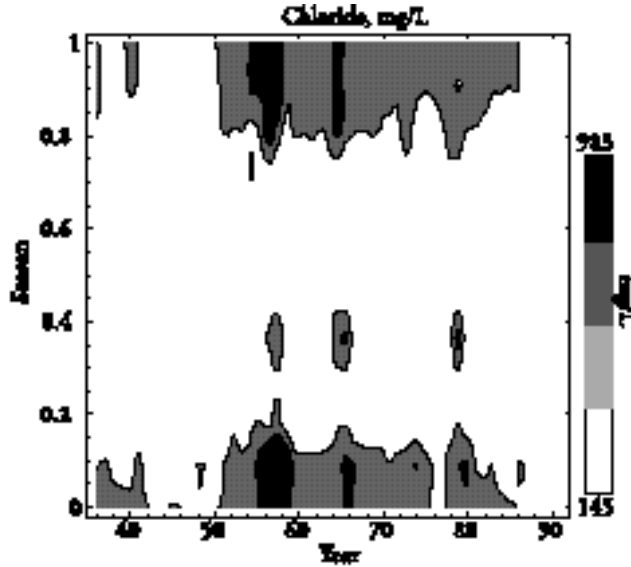
Multiyear variations in precipitation are also visible as vertical light and dark bands. Darker vertical bands represent wetter years, while lighter vertical bands represent drier years. The dark band in the early

Figure 4: Conductivity in the Rio Grande at El Paso by Year and by Season



Note: Conductivity can be used as a surrogate for salinity in the river. Higher conductivity values are related to higher salinity values.

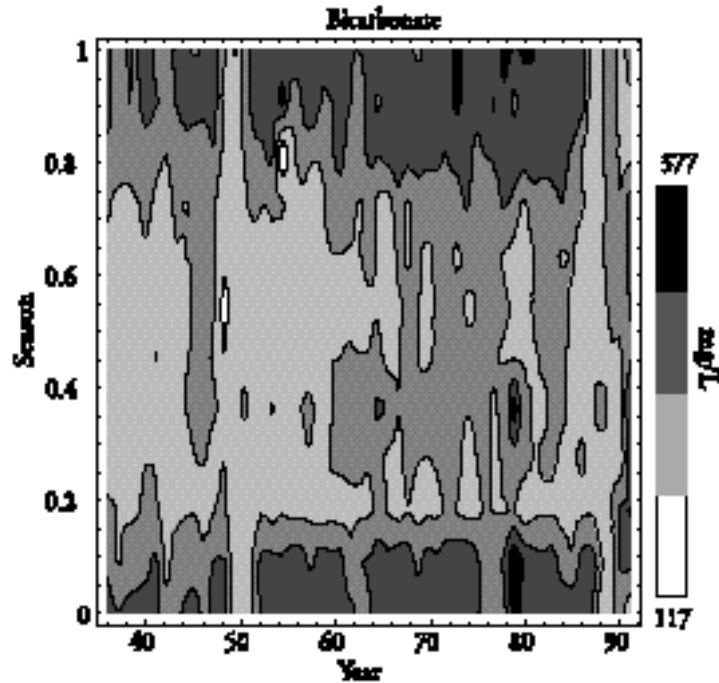
Figure 5: Chloride Concentrations in the Rio Grande at El Paso by Year and by Season



1940s represents a period of high precipitation. A severe drought is evident during the mid- to late-1950s. The droughts and wet periods shown in Figure 3 can be compared with the El Niño temperatures from the southern Pacific Ocean. El Niño temperatures are classified as warm, neutral, and cold and are shown as high, middle, and low values, respectively, as demonstrated by the line at the bottom of Figure 3. The multiyear variations of discharge appear to have complex relationships with the El Niño temperature variations. Some of the wet periods appear to follow transitions from warm to neutral or cold El Niño temperatures. Droughts tend to occur after transition from colder El Niño temperatures. However, exceptions to these patterns are observed.

Conductivity of Rio Grande water is related to the discharge of the river. Figure 4 shows the observed conductivity of the Rio Grande by season and year. Conductivity of the river water increases with the concentration of dissolved salts in the water and, as such, is an analog for salinity. Conductivity is lowest during the irrigation season and increases during the winter months. During the winter, discharge in the river consists predominantly of irrigation return flows, which are dominated by brackish groundwater from the shallow aquifer. Thus, discharge and water quality during most winters represent an integrated picture of the groundwater quantity and quality in the shallow

Figure 6: Bicarbonate in the Rio Grande at El Paso by Year and by Season

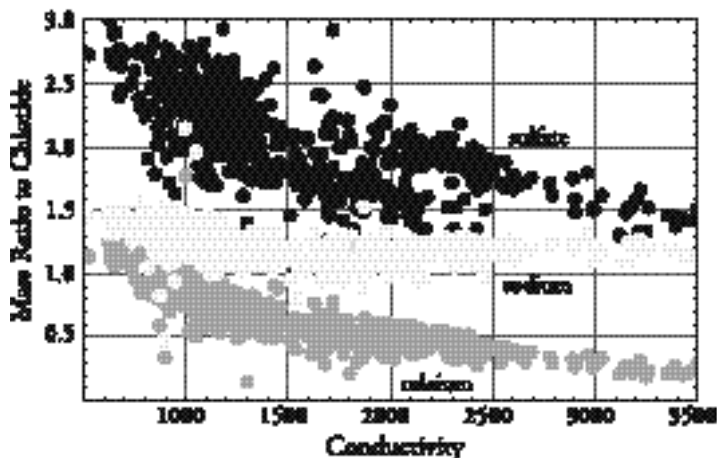


aquifer for the entire region between Elephant Butte Reservoir and El Paso. Most years the salinity of the water in the winter is too high for domestic use. The drought in the 1950s is visible as a darker vertical band and the wet period in the 1940s is visible as a lighter vertical band in Figure 4.

Chloride concentrations behave analogously to conductivity levels in the river. Figure 5 is the observed chloride concentration in Rio Grande water by season and year. Chloride concentrations are higher during the winter months and during droughts when more of the discharge in the river is from the irrigation drains. The drought in the 1950s is evident in Figure 5.

The variation in bicarbonate concentration (HCO_3^-) is more complex (Figure 6). Notice that the variability of bicarbonate is less than the variability of chloride. Seasonal variations in bicarbonate concentration are evident. Bicarbonate levels drop in February and March at the beginning of the irrigation season and increase in September and October at the end of the season. This may indicate a change in water source for the river from reservoir releases associated with irrigation to brackish groundwater discharge from the shallow aquifer.

Figure 7: Ion Mass Ratios ($\text{SO}_4:\text{Cl}$, $\text{Na}:\text{Cl}$, and $\text{Ca}:\text{Cl}$) as a Function of Conductivity



Note: Higher conductivity values indicate periods of lower discharge. Decreases in the ion mass ratio for calcium and sulfate for high conductivity values indicates the precipitation of calcite (CaCO_3) and gypsum

The multiyear variations associated with wet-dry climatic cycles are not as visible in the bicarbonate concentration data, suggesting concentrations are moderated by solubility controls.

Figure 7 plots the observed ion mass ratios for sulfate ($\text{SO}_4:\text{Cl}$), sodium ($\text{Na}:\text{Cl}$), and calcium ($\text{Ca}:\text{Cl}$) to chloride as a function of water conductivity for the recorded period. As discussed above, the higher conductivity waters are associated with periods of low discharge. In Figure 7, the higher conductivity values and, correspondingly, the lower discharge are to the right of the graph. Chloride is used as a tracer of evaporative concentration of the waters because it participates in few chemical reactions. Notice that the ratio of sodium to chloride in the waters is not heavily influenced by the conductivity of the water. In contrast, the ratio of calcium to chloride decreases by a factor of five and the ratio of sulfate to chloride decreases by a factor of two as the conductivity of the water increases in Figure 7.

The water chemistry trends suggest that calcium carbonate is precipitating in fields during periods of low discharge. Precipitation of calcium carbonate (CaCO_3) in concentrated waters (and potentially some dissolution during higher water years) would explain the observed calcium to chloride ratio and the attenuation of variation in bicarbonate ion. The sulfate trend suggests that, to a lesser extent,

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precipitation of calcium sulfate as gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) occurs in fields. Precipitation of calcium carbonate and calcium sulfate decreases the amount of calcium in solution without affecting sodium concentrations, thereby increasing the sodium adsorption ratio (Richards 1954), which is a critical factor for the quality of irrigation water. Water with high sodium absorption ratios can cause the breakdown of certain clay minerals.

DISCUSSION

A number of management decisions are likely to influence the quantity and quality of water flowing in the Rio Grande in the future. Population growth upstream from El Paso, in New Mexico and Colorado, will inevitably lead to increased water demands. Even with water reuse and (or perhaps especially with upstream water reuse) the salinity of the water flowing downstream is likely to increase with time.

El Paso is currently considering placing an impermeable lining along the base of some canals from Elephant Butte and Caballo reservoirs to the lower Mesilla Valley. This would provide a year-round source of higher quality surface water to El Paso. However, reducing the canal leakage will tend to increase the salinity of the shallow groundwater and irrigation return flows. This could further degrade the quality of the Rio Grande and eventually damage the quality of the intermediate and deep Mesilla Bolson aquifers.

Another potential water management strategy for the Mesilla Valley, which has not been attempted, would be to apply excess irrigation water during high water years at the end of the growing season. This would tend to periodically flush the salts from the shallow groundwater. The shallow groundwater is the primary source of recharge for the Mesilla Bolson aquifers used extensively for water supply by the city of El Paso. Lowering ion concentrations in the shallow aquifer would serve to protect this valuable resource into the future as well as lower downstream concentrations of ions in the Rio Grande during low water years.

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