Surface and Ground Water Interactions: El Paso – Juarez Region

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Introduction

Growth of the El Paso, Texas, USA—Ciudad Juarez, Chihuahua, Mexico 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. Primarily, El Paso and Ciudad Juarez use ground water 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 Hueco and Mesilla Bolson (Figure 2) and 44% came from the

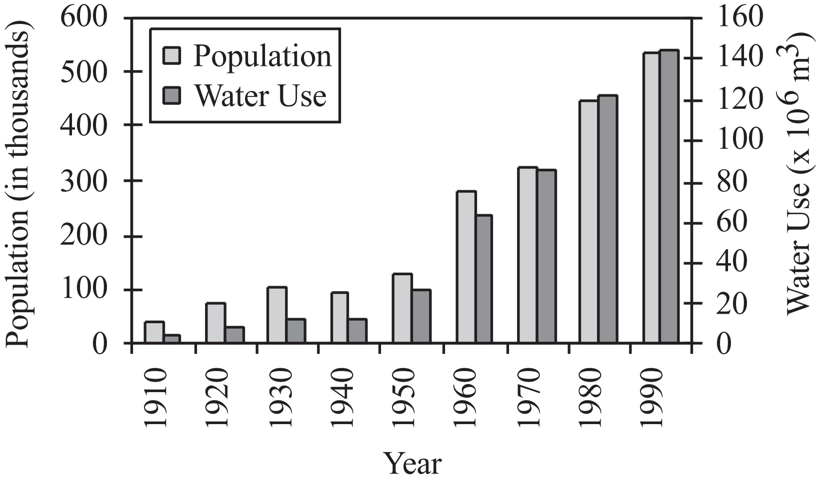

Figure 1. Graph showing the relationship between population growth and water use for El Paso, Texas.

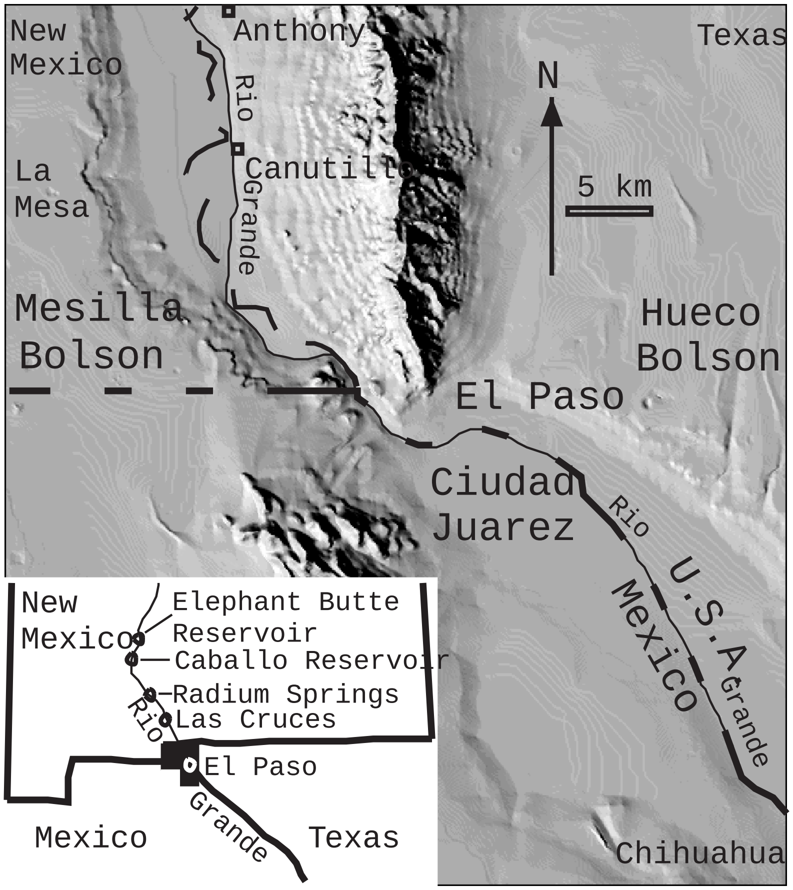

Figure 2. Shaded relief map of the area surrounding El Paso, Texas and Ciudad Juarez, Chihuahua from a digital elevation model. The area of the shaded relief map is shown as a black box near El Paso on the inset map (lower left corner). The Mesilla Bolson stretches from Radium Springs, New Mexico to El Paso, Texas.

Rio Grande (Rebuk 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 El Paso can use the water. 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.

Ground water used for municipal purposes comes from aquifers in the Mesilla and Hueco Bolson. 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, the irrigation canals, water spread on agricultural fields, and ground-water flow from the La Mesa, New Mexico, region. The Rio Grande is a losing stream (a zone of ground-water 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 ground-water 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.

Quality and amount of recharge from surface water and ground-water flow control the quality of the water in the shallow aquifer beneath the Mesilla Bolson. A strong hydraulic connection exists between the surface water and the shallow aquifer. Water mass balances for the shallow aquifer show annual cycles of drawdown and rebound related to irrigation practices (Updegraff and Gelher, 1977). 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 evapotranspiration rates characteristic of this semi-arid region. Additional salts are added to the water due to the weathering of minerals in the soil. The overall salinity of the shallow ground water 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 is reducing the salinity of ground water in the shallow aquifer.

The brackish ground water from the shallow aquifer is discharged into the irrigation drains and flows back into the Rio Grande. This is leads to an increase in salinity of the river water as it flows through the Mesilla and Hueco Bolsons (Hernandez, 1978). Additionally, pumping in the intermediate and deep Mesilla Bolson aquifers has affected ground-water flow by causing the downward migration of brackish ground water from the shallow aquifer. The migration of this water will eventually cause degradation of the intermediate aquifers (Walton et. al., in press). 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. Black areas near the right side of the graph represent time periods with no available data. Several trends emerge from the data. Discharges are

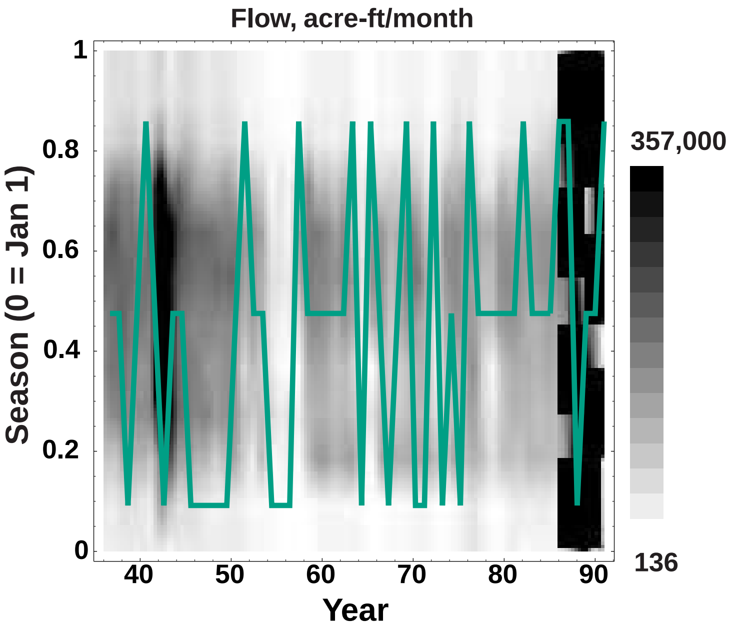

Figure 3. Graph showing discharge in the Rio Grande at El Paso. Black squares on the right side of graph represent times were discharge data is lacking. The seasons are represented as numbers between 0 and 1 where 0 is January 1 and 1 is December 31. The generalized El Nino temperature ranges are represented as a solid line on the graph. Upward spikes represent warm El Nino years,

generally greatest during the irrigation season when water is released from Elephant Butte and Caballo reservoirs (Figure 2). The irrigation season extends from March to October and would have season values of 0.2 to 0.8 in Figure 3. In a normal year, the majority of the rainfall in the upper Rio Grande Valley falls between July and October, season values of 0.5-0.8. These trends are visible in Figure 3.

Multi-year variations in precipitation are also visible. Darker vertical bands represent wetter years where lighter vertical bands represent dry years. The dark band in the early 1940s represents a period of high precipitation. A severe drought is evident during the middle to late 1950s. The droughts and wet periods determined from Figure 3 can be compared with the El Nino temperatures from the southern Pacific Ocean. El Nino temperatures are classified as warm, neutral, and cold and are shown as high, moderate (0.5), and low values, respectively, of the line in the Figure 3. The multi-year variations of discharge appear to have complex relationships with the El Nino temperature variations. Some of the wet periods appear to follow transitions from warm to neutral or cold El Nino temperatures. Droughts tend to occur after transition from colder El Nino 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

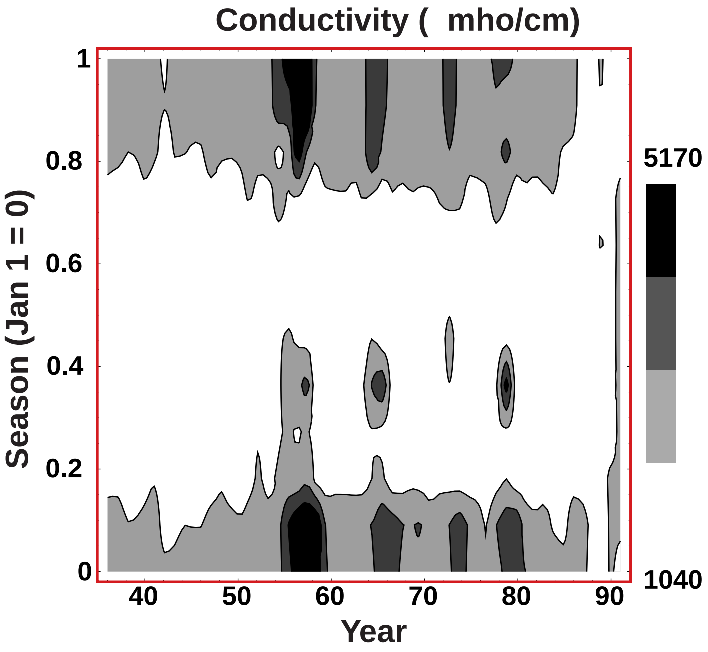

Figure 4. Graph showing conductivity in the Rio Grande at El Paso by year and season. Conductivity can be used as a surrogate for salinity in the river. Higher conductivity values are related to higher salinity values. The seasons are represented as numbers between 0 and 1 where 0 is January 1 and 1 is December 31.

observed conductivity of 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 ground water from the shallow aquifer. Thus, discharge and water quality during most winters represents an integrated picture of the ground-water quantity and quality in the shallow 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 droughts when more of the discharge in the river is from the irrigation drains. The drought in the 1950s is evident in Figure 5.

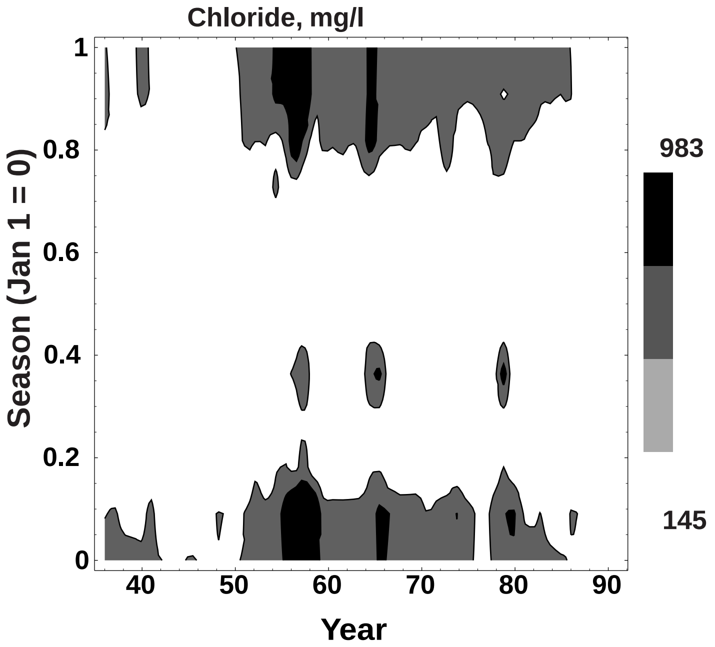

Figure 5. Graph showing the chloride concentration in the Rio Grande at El Paso by year and season. The seasons are represented as numbers between 0 and 1 where 0 is January 1 and 1 is December 31.

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 irrigation. This may indicate a change in water source for the river from reservoir releases associated with irrigation to brackish ground-water discharge from the shallow aquifer. The multiyear variations associated with wet/dry climatic cycles are not as visible in the bicarbonate concentration data.

Figure 7 plots the observed ion mass ratios for sulfate (SO_4:Cl), sodium (Na:Cl), and calcium (Ca:Cl) to chloride as a function of water conductivity for the period of record. 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 5 and the ratio of sulfate to chloride decreases by a factor of 2 as the conductivity of the water increases in Figure 7.

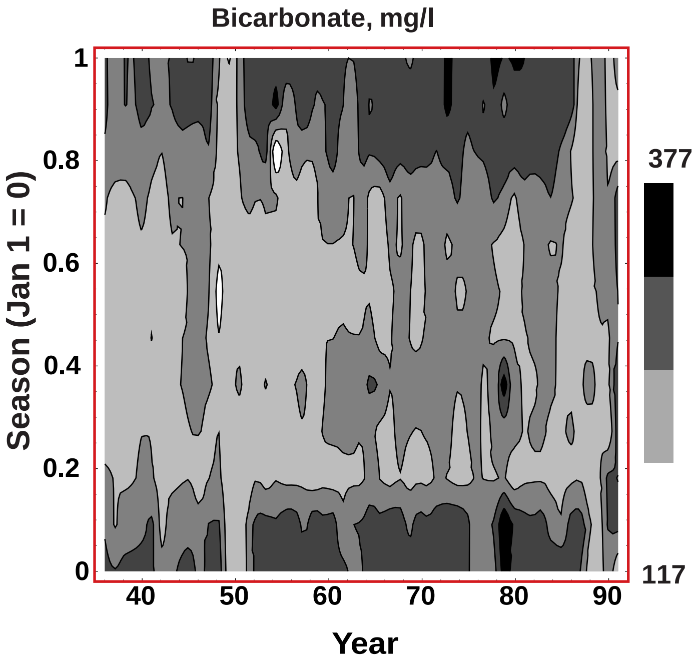

Figure 6. Graph showing bicarbonate in the Rio Grande at El Paso by year and season. The seasons are represented as numbers between 0 and 1 where 0 is January 1 and 1 is December 31.

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, precipitation of calcium sulfate as gypsum ($CaSO_4 \cdot 2H_2O$) 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.

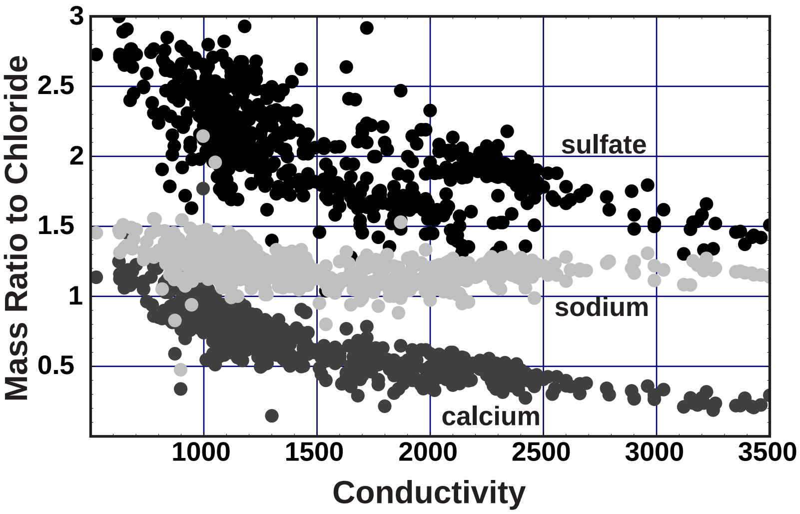

Figure 7. Graph showing ion mass ratios (SO_4:Cl, Na:Cl, & Ca:Cl) as a function of conductivity. Higher conductivity values indicate periods of lower discharge. Decreases in the ion mass ratio for calcium and sulfate for high conductivity values indicates the precipitation of calcite ($CaCO_3$) and gypsum ($CaSO_4 \cdot 2H_2O$) in the soils.

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 ground water 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 ground water. The shallow ground water 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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