Ambient Groundwater Quality of the San Rafael Basin: An ADEQ 2002 Baseline Study

I. Introduction

The San Rafael Groundwater Basin (SRF) is a rustic landscape composed of large cattle ranches and public lands situated along the Arizona/Mexican border between the cities of Nogales and Sierra Vista (**Figure 1**). The basin is renown for the beauty of its oak-dotted, rolling hills that contain some of the most pristine remnants of shortgrass prairie in Arizona. From a hydrology perspective, it's most noteworthy as the headwaters of the bi-national Santa Cruz River (**Figure 2**). This factsheet reports upon the results of groundwater quality investigations in the SRF and is a summary of the more extensive report produced by the Arizona Department of Environmental Quality (ADEQ).[1]

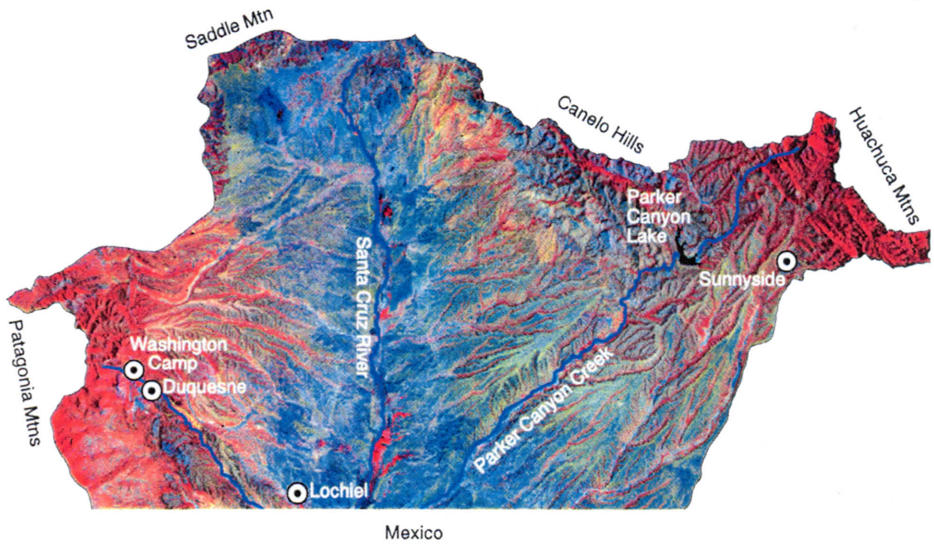

Figure 3. Infrared satellite image (June 1993) in which forested mountains appear in crimson, grasslands are in blue, and irrigated or riparian areas along the lower stretches of the Santa Cruz River are depicted in bright red. The San Rafael Basin has a very small, dispersed population. For most services, residents must travel outside the basin to Patagonia, Sonoita, or Nogales as Washington Camp, Duquesne, and Sunnyside are old mining camps with little commercial activity.

II. Background

The SRF is a small basin encompassing 172 square miles.[2] It includes the broad San Rafael Valley, the eastern slopes of the Patagonia Mountains, the southern slopes of the Canelo Hills, and portions of the western slopes of the Huachuca Mountains (**Figure 3**). To the south, the Mexican border creates an arbitrary physical boundary.

Uplands in the SRF are managed by the U.S. Forest Service while the San Rafael Valley is mostly private land. Although the majority of the basin is in Santa Cruz County, the extreme eastern portion is in Cochise County.

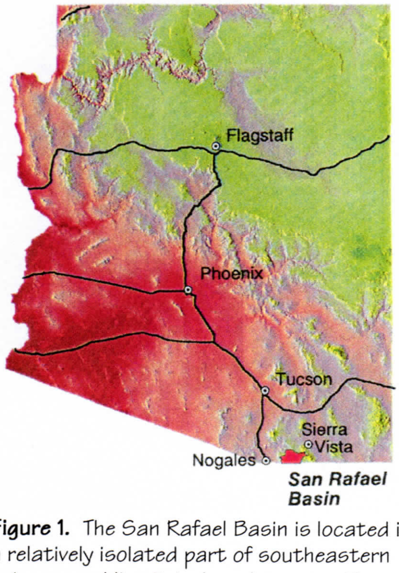

Figure 1. The San Rafael Basin is located in a relatively isolated part of southeastern Arizona enabling it to largely escape the transformations that have altered the landscape of other rural areas of the state.

Elevations in the SRF range from 7,900 feet at Peterson Peak in the Huachuca Mountains to 4,500 feet where the Santa Cruz River enters Mexico near the town of Lochiel. Vegetatively, the SRF supports 90,000 acres of shortgrass prairie as well as valuable cottonwood riparian habitat along the Santa Cruz River and its major tributaries. The surrounding uplands support an evergreen woodland ecosystem.[3]

III. Hydrology

Groundwater in the SRF is found in an *alluvial aquifer* consisting of three basic units: streambed alluvium, pediment gravels, and basin-fill alluvium.[2] The streambed alluvium consists of well-sorted silt, sand, and gravel that forms the narrow floodplain of the Santa Cruz River and its major tributaries. The pediment gravels form terraces along the valley's eastern side. The remainder of the valley consists of basin-fill alluvium composed of clay, silt, sand, and gravel deposits.[2]

> ***"Groundwater in the San Rafael Basin, particularly in areas not in proximity to historic mines in the Patagonia Mountains, appears to be largely suitable for domestic use."***

Limited groundwater occurs in *hardrock* areas that are most productive where the bedrock is fractured and faulted.[2] The SRF is predominantly sedimentary rock with basaltic rock formations in the Canelo Hills, and granitic rock outcrops in the Patagonia Mountains (**Figure 4**).

Figure 2. A bi-national watercourse, the San Rafael River begins in the SRF, flows into Mexico and turns back into the U.S. 32 miles later near the city of Nogales. From there it continues north to Tucson. The author is pictured along a perennial stretch of the river near the hamlet of Lochiel, Arizona.

Groundwater movement in the SRF is toward the Santa Cruz River and then south into Mexico. Groundwater depth is shallowest near the major waterways, averaging 10 to 25 feet below land surface (bls), increasing to over 100 feet bls in other parts of the basin.[2]

The Santa Cruz River is one of the few grassland streams in the Southwest with stretches of perennial flow. Although ephemeral in its headwaters in the Canelo Hills, it becomes perennial for a three-mile reach, five miles north of the international boundary with Mexico. Numerous springs and creeks contribute to this perennial flow. The Santa Cruz River has an average annual discharge into Mexico of 2,900 acre-feet.[2]

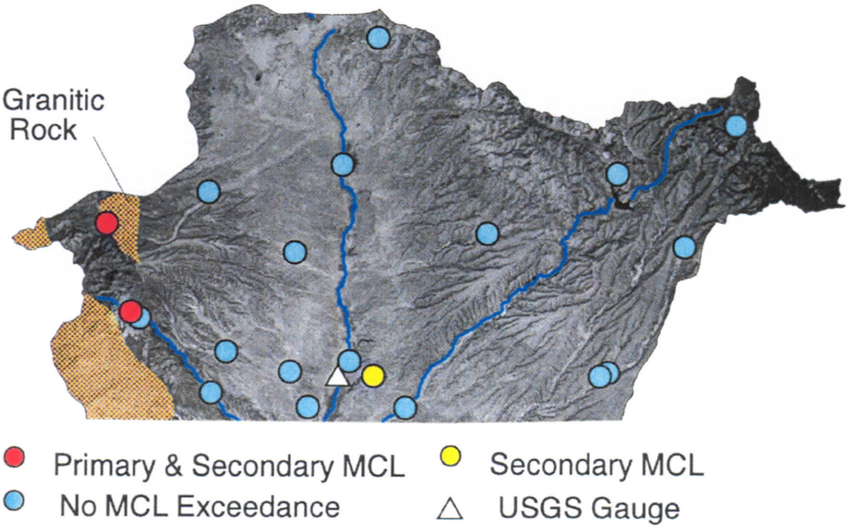

Figure 4. Locations of 20 sample sites and the U.S. Geological Survey gaging station on the Santa Cruz River are shown. Primary, health-based water quality standard exceedances (shown in red) occurred only in the Patagonia Mountains in or near areas of granitic rock.

IV. Methods of Investigation

This study was conducted by the ADEQ Ambient Groundwater Monitoring Program, as authorized by the legislative mandate in Arizona Revised Statutes §49-225. To characterize regional groundwater quality, 20 sites (15 wells and 5 springs) were sampled. Samples were collected for inorganic constituents and isotopes of hydrogen and oxygen at all sites. At selected sites, samples were also collected for radiochemistry (5 sites), radon gas (5 sites), and volatile organic compounds (2 sites) analyses.

Sampling protocol followed the *ADEQ Quality Assurance Project Plan*. Based on quality control data, the effects of sampling equipment and procedures were not considered significant.

V. Water Quality Sampling Results

The collected groundwater quality data were compared with Environmental Protection Agency (EPA) Safe Drinking Water (SDW) water quality standards.

Primary Maximum Contaminant Levels (MCLs) are enforceable, health-based water quality standards that public systems must meet when supplying water to their customers. Primary MCLs are based on a lifetime daily consumption of two liters of water.

Of the 20 sites sampled, 2 had constituent concentrations exceeding a Primary MCL (**Figure 4**). Antimony, lead, gross alpha, and uranium concentrations each exceeded Primary MCLs at one site apiece.

EPA SDW Secondary MCLs are unenforceable, aesthetics-based water quality guidelines for public water systems. Water with Secondary MCL exceedances may be unpleasant to drink and/or create unwanted cosmetic or laundry effects but is not considered a health concern.

Of the 20 sites sampled, 3 had constituent concentrations exceeding a Secondary MCL (**Figure 4**). Constituents above Secondary MCLs included total dissolved solids (TDS), sulfate, manganese (two sites apiece), and iron (one site).

Figure 5. John Russell Bartlett toured the San Rafael Valley in 1851 as part of the U.S. Boundary Commission and wrote that "this valley was covered with the most luxuriant herbage and thickly studded with live oaks; not like a forest, but rather resembling a cultivated park."[4] This description is still appropriate as shown in this photo taken near the San Rafael Ranch; the Huachuca Mountains are in the background.

VI. Groundwater Composition

Groundwater in the SRF is generally *slightly alkaline* (pH > 7 standard units), *fresh* (TDS < 1000 milligrams per liter or mg/l), and *hard* (> 150 mg/l) (**Figure 6**). At 85 percent of sites, nitrate (as nitrogen) was found at levels under 3 mg/l, which is often interpreted as representing no impact from human activities.

"SRF groundwater chemistry is generally calcium-bicarbonate which is common in Arizona and typical of recharge areas. Two sites in the Patagonia Mountains with calcium-sulfate chemistry appear to be impacted by historic mining activity."

> ***"The surface flow of the Santa Cruz River near Lochiel tends to have lower mean constituent concentrations than SRF groundwater sites. This may be explained by the dilution of the stream's base flow by direct runoff from precipitation."***

Most sample sites exhibited a *calcium-bicarbonate* chemistry, though the two sites with Primary MCL exceedances in the Patagonia Mountains had a *calcium-sulfate* chemistry. Barium, fluoride, and zinc were the only trace elements detected at more than ten percent of sites. Others such as antimony, arsenic, beryllium, boron, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, and thallium were rarely, if ever, detected.

Many significant correlations were found among concentrations of water quality constituents. Generally, levels of major ions (calcium, magnesium, sodium, chloride, and sulfate), TDS, and hardness (**Figure 7**) were positively correlated with one another (Pearson Correlation Coefficient test, $p \leq 0.05$).

The SRF appears to be an *open hydrologic system* or one in which groundwater chemistry is, in part, controlled or influenced by atmospheric gases or liquids that enter the system along flow paths subsequent to initial recharge.[6] This statement is supported by the predominant *calcium-bicarbonate* chemistry, the shallow depths to groundwater, and permeable alluvial deposits found in the SRF. These factors suggest that recharge occurs not only along mountain fronts in the basin but also along the Santa Cruz River and its major tributaries.

VII. Groundwater Quality Patterns

Groundwater quality constituent concentrations were statistically compared among SRF aquifers, watersheds, and geologic types. No significant differences were found except that sodium concentrations at sites in the Santa Cruz River watershed in the central portion of the SRF were significantly higher than at sites in the Parker Canyon watershed located in the eastern portion of the basin (Kruskal-Wallis in conjunction with the Tukey test, $p \leq 0.05$).

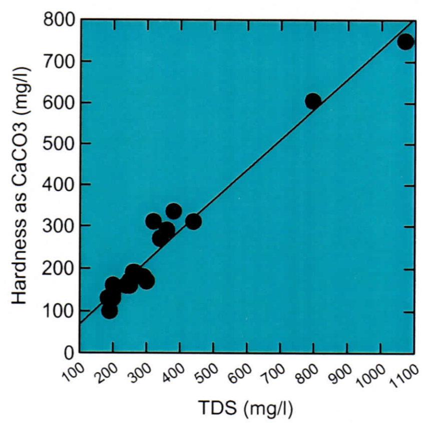

Figure 7. The significant positive correlation between TDS and hardness indicates that sodium is a relatively minor component in groundwater found in the San Rafael basin (Pearson Correlation Coefficient, $p \leq 0.01$).

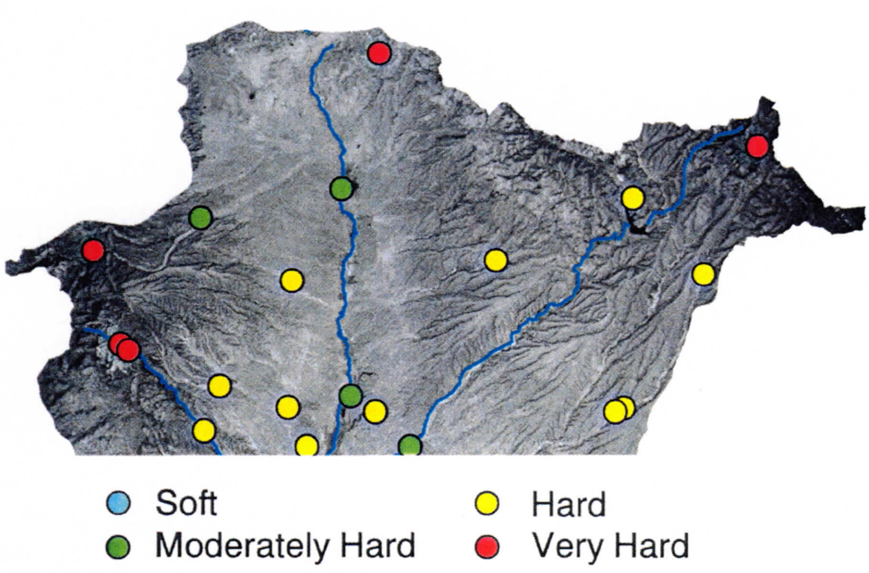

Figure 6. Groundwater in the San Rafael Basin is generally *hard* or *very hard* with the greatest levels found at high elevation sites in the surrounding mountains.

Figure 8. The San Rafael Valley contains some of the most pristine desert grasslands in the Southwest. Livestock grazing is the main land use. Pictured is the windmill, barn, and rolling grasslands of the Arizona State Park's San Rafael Ranch.

VIII. Study Conclusions

Groundwater in the SRF generally meets drinking water standards and is suitable for domestic, municipal, irrigation, and stock uses based on the analytical results of 20 sites sampled for water quality constituents.

The two sites having the majority of the water quality standard exceedances were located in the Patagonia Mountains. The elevated gross alpha and uranium at one site may be naturally occurring because of the surrounding geology. The area's granitic rock is frequently associated with elevated radiochemistry concentrations in groundwater.[5] These constituents may be further elevated by the extensive hardrock mining in the area for silver, lead, zinc, copper, manganese, and gold that increased rock surface exposure.[1]

Over 1.9 million tons of ore were extracted from about 40 large mines located in the highly-mineralized Patagonia Mountains.[3] Production commenced in the 1880s with mining activity ebbing by the 1910s although a few mines were worked into the 1960s.[3] Elevated sulfate, TDS, antimony, lead, manganese, and iron concentrations found at one or both sites also suggest impacts from historic mining activity.[3] Weathering of ore deposits often produces increased sulfate and metal concentrations in groundwater.

Figure 9. Contrary to the movie's title, much of the classic musical *Oklahoma!* was actually filmed in the San Rafael Valley in a humorous example of Hollywood inaccuracy.[3] The SRF's stunning landscapes may have been the inspiration behind such famous songs as "Oh What A Beautiful Mornin'".

Groundwater Isotope Investigation

Stable isotopes of oxygen (^{18}O) and hydrogen deuterium (D) were collected at each SRF sample site to further examine groundwater quality patterns.

This isotopic data was compared to the standard reference water or Global Meteoric Water Line (GMWL) which is based upon world-wide precipitation data not exposed to evaporation. The SRF data forms a *Local Meteoric Water Line* whose slope of 4.6 conforms to the range of slopes (3 to 6) normally found in arid environments.[6]

The most *depleted*, or isotopically lighter, samples tended to be at high elevations in the Huachuca and Patagonia Mountains and may be influenced by recent local precipitation that is less subject to evaporation than other areas of the basin.[6] In contrast, the most *enriched*, or isotopically heaviest, samples tended to be at lower elevations in the central part of the SRF. Isotopic data of these two groups were found to be significantly different (Kruskal-Wallis test, $p \leq 0.01$).

"Mercury has been found in the tissue of warm-water fish species in Parker Canyon Lake. There were no mercury detections at any of the groundwater sampling sites however, including Collins Spring located upgradient of the lake."

Health-based water quality exceedances could potentially exist anywhere in the SRF. However, based upon the results of this regional groundwater quality study, their occurrence should not be widespread.

Even with the overall acceptability of groundwater quality in the SRF, ADEQ suggests that well owners--particularly those in the Patagonia Mountains--periodically have their groundwater analyzed by certified laboratories. A list of such laboratories may be obtained from the state's Environmental Laboratory Licensure Section at (602) 255-3454.

---Douglas Towne
Maps by Larry W. Stephenson
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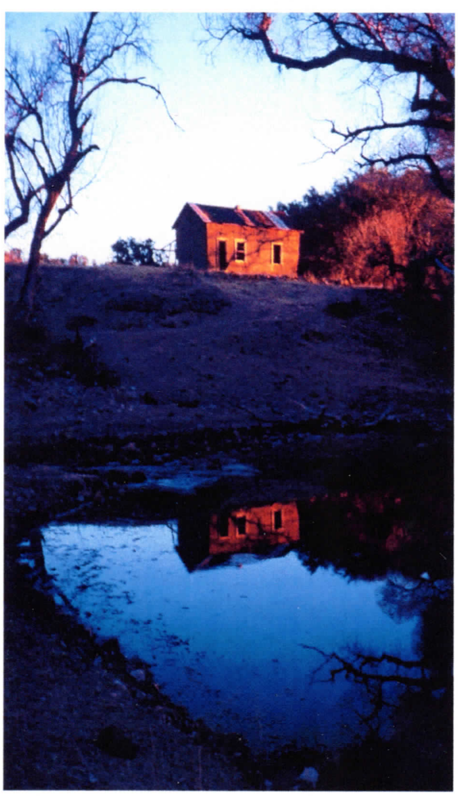

Figure 10. Overflow from Captain Spring forms a picturesque mirror image of an abandoned homestead. Considered groundwater outcrops, springs are often found at the base of a hill and are an invaluable source of groundwater information in lightly-developed basins.

Figure 11. A wildfire swept through part of the basin during the study. Saddle Mountain can be seen in the background.

References Cited

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