Ambient Groundwater Quality of the Lower San Pedro Basin: An ADEQ 2000 Baseline Study

Figure 1. The San Pedro River riparian ecosystem is used by a diversity of wildlife unequaled in the U.S. and has been declared one of the "Last Great Places" in the western hemisphere[2]. The San Pedro River is perennial only where the streambed intercepts hardrock or flowing springs[4].

I. Introduction

The Lower San Pedro groundwater basin (LSP) is a long, narrow, northwest-trending valley situated in southeastern Arizona. The Arizona Department of Environmental Quality (ADEQ) extensively sampled this semiarid basin in 2000, producing a comprehensive groundwater quality report[1], of which this factsheet is a summary.

II. Background

The LSP encompasses the San Pedro River (**Figure 1**) drainage basin from *the Narrows* to the confluence with the Gila River and includes the Gila River drainage basin between the towns of Winkelman and Kelvin. The Rincon, Santa Catalina, Black, Tortilla, Dripping Springs, and Galiuro mountain ranges form its boundaries (**Figure 2**).

The main communities found in the LSP include Winkelman, Oracle, Mammoth, Hayden, Kearny and San Manuel. The large copper processing and mining operations in the basin are the major economic activity. Land ownership is principally State Trust (65 percent) with private, Bureau of Land Management, and Forest Service lands each comprising about 10 percent each.

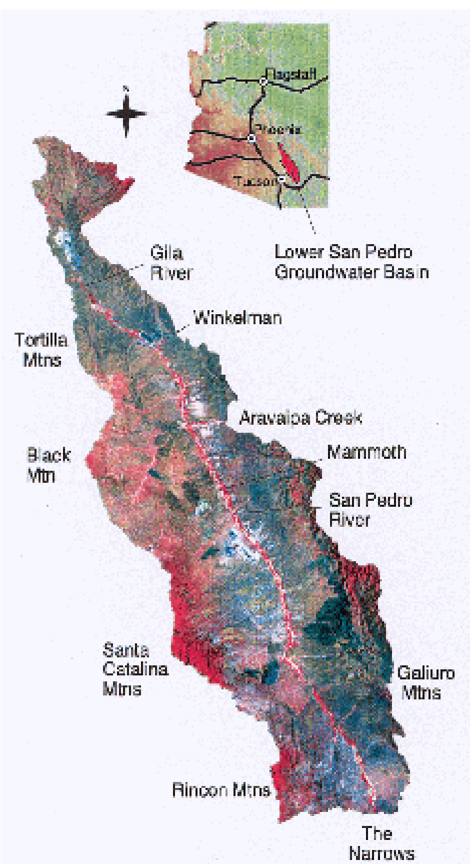

Figure 2. Infrared satellite image (June 1993) highlights (in bright red) irrigated farmland and riparian areas along the San Pedro and Gila Rivers as well as lush mountain forests and (in white and blue) major copper facilities.

III. Hydrology

Groundwater resources in the LSP are found in four principal water-bearing units (**Figure 4**): the *floodplain aquifer*, the *unconfined* and *confined* (or *artesian*) *basin-fill aquifers*, and in the fractured and faulted portions of *hardrock* mountains of the basin [3].

The most productive water-bearing unit is the *floodplain aquifer* which parallels the major waterways. This aquifer of limited extent is composed of gravel, sand, silt, and clay, and recharged primarily by surface flows of the San Pedro and Gila Rivers[4]. The *artesian aquifer* maybe encountered in wells drilled deeper than 500 feet in or near the middle section of the San Pedro River's floodplain near Mammoth[5]. Layers of fine-grained deposits restrict vertical groundwater movement in this area, creating artesian conditions.

The *unconsolidated basin-fill aquifer* exhibits highly variable hydrologic characteristics depending on the substrata. Younger and older basin-fill alluvium provides the majority of water pumped from this aquifer. In contrast, tightly-cemented basal conglomerate yields water only where cementation is weak or fractured. Recharge consists of mountain precipitation infiltrating into nearby alluvial fans[4]. The consolidated mountain *hardrock* yields only limited amounts of water where the rock is sufficiently fractured or faulted [3].

The majority of groundwater pumped in the LSP is used for mining and irrigation; lesser amounts are withdrawn for municipal, domestic, and stock purposes. Groundwater movement in the basin is from the higher mountain elevations toward the valley; little groundwater flows northwest along the riverbed [6].

"Aside from elevated fluoride concentrations in the artesian and floodplain aquifers in the central basin, groundwater in the LSP appears to be largely suitable for domestic or municipal use."

Figure 3. A turbine pump sitting 20 feet above land surface shows the erosional effects of 1993 flooding along the San Pedro River.

Groundwater readily moves from the *unconfined basin-fill aquifer* to the *floodplain aquifer*. These water table aquifers, especially the *floodplain*, may also receive water leaking upwards from the *artesian aquifer*, particularly in the Mammoth area[5].

IV. Methods of Investigation

To characterize regional groundwater quality, the ADEQ Ambient Groundwater Monitoring Program sampled 63 sites (27 in the *floodplain aquifer*, 23 in *hardrock*, 9 in the *unconfined basin-fill aquifer*, and 4 in the *artesian aquifer*).

Inorganic samples were collected at all 63 sites. Samples were also collected for Volatile Organic Compounds (VOCs) (25 sites), radiochemistry (19 sites), radon (19 sites), and pesticide (2 sites) analyses. Sampling protocol followed the *ADEQ Quality Assurance Project Plan*. Based on quality control data, the effects of sampling procedures on the results 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 water 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 63 sites sampled, 11 had constituent concentrations exceeding a Primary MCL (**Figure 5**). Site exceedances included fluoride (8), antimony and gross alpha (2 each), and arsenic and nitrate (1 each). Eleven additional sites exceeded revised arsenic standards (effective in 2006).

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 63 sites sampled, 31 had constituents exceeding a Secondary MCL (**Figure 5**). Site exceedances included total dissolved solids (TDS) (24), fluoride (16), sulfate (11), manganese (9), iron and pH (4 each), and chloride (2).

One site had VOC detections that are common by-products of chlorination. No pesticides or related degradation products on the ADEQ Groundwater Protection List were detected.

VI. Groundwater Composition

In general, groundwater in the LSP is *slightly alkaline* (pH > 7 standard units), *fresh* (TDS < 1000 milligrams per liter or mg/l) and varies widely in hardness and chemical composition.

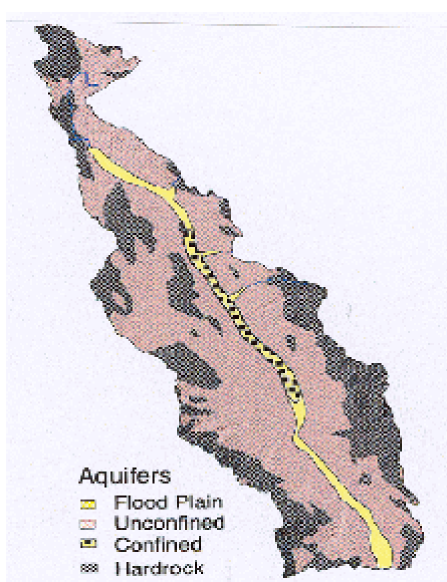

Figure 4. Approximate extent of the four main water-bearing units in the LSP.

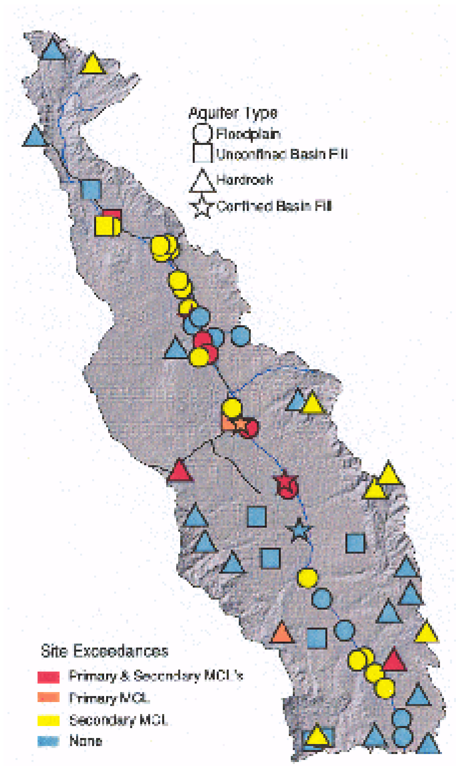

Figure 5. Locations of 63 sample sites are shown, including 11 sites exceeding health-based water quality standards and 31 sites exceeding aesthetics-based water quality guidelines.

Nutrient concentrations were generally low with only nitrate, total phosphorus, and total Kjeldahl nitrogen detected at more than 20 percent of sites. At 11 percent of sites, nitrate (as nitrogen) was detected at over 3 mg/l, which may indicate impacts from human activities.

Boron and fluoride were the only trace elements commonly detected. Most were detected at less than 20 percent of sample sites. These included antimony, arsenic, barium, beryllium, cadmium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, and thallium.

VII. Patterns Among Aquifers

Of the four water-bearing units examined, constituent concentrations were generally highest in the *artesian aquifer* and the *floodplain aquifer*. Fluoride (**Figure 6**), pH, and sodium concentrations were higher in samples from the *artesian* wells than from the other three water-bearing units.

" Of the 63 LSP sites sampled, 18 percent exceeded a health-based water quality standard and 49 percent exceeded an aesthetics-based water quality standard."

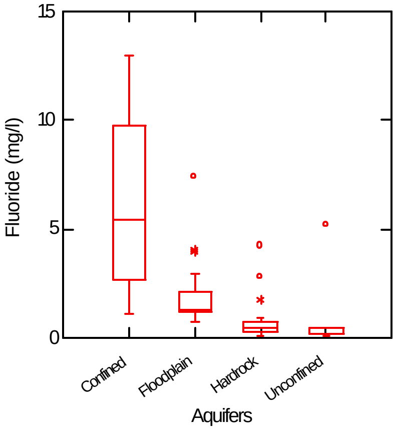

Figure 6. Fluoride concentrations are frequently elevated above water quality standards in the confined, artesian aquifer.

Figure 8. Great tasting "Mountain Water" causes individuals to kick up their heels near the town of Kearny. Water from upland areas is generally lower in salinity and more palatable than groundwater pumped from valley areas that supply the municipal tanks pictured in the background.

Other patterns include sulfate, which was lower in *hardrock* than in either the *artesian* or *floodplain aquifers*, and bicarbonate, which was lower in the *artesian aquifer* than in the *floodplain aquifer* or *hardrock* (Kruskal-Wallis and Tukey test, p # 0.05).

Data outliers occurred at many sites in the *artesian aquifer*; consequently the statistical tests were rerun without data from this aquifer (**Figure 7**). As a result, TDS, sodium, potassium, sulfate, and fluoride concentrations were higher in the *floodplain aquifer* than in *hardrock* (**Figure 8**) (Kruskal-Wallis and Tukey test, p # 0.05).

Figure 7. Soft groundwater with elevated concentrations of fluoride pours out of a 1485-foot artesian well drilled in 1934 near Mammoth.

VIII. Floodplain Aquifer Patterns

Constituent concentrations were compared for *floodplain aquifer* data collected from four watersheds. These were, upgradient to downgradient, *Redington*, *Mammoth*, *Winkelman*, and *Kearny*. Two significant patterns were found. TDS, sodium, chloride (**Figure 9**), and potassium were higher in the *Kearny watershed* than the other three watersheds. In contrast, fluoride (**Figure 10**) was higher in the *Mammoth watershed* than the other three watersheds (Kruskal-Wallis and Tukey test, p # 0.05).

IX. Groundwater Depth Patterns

Many constituent concentrations (hardness, calcium, magnesium, sodium, chloride, fluoride, and boron) tended to significantly decrease with increasing groundwater depth below land surface (bls). In contrast, pH, temperature, and bicarbonate increased with increasing groundwater depth bls. Few patterns

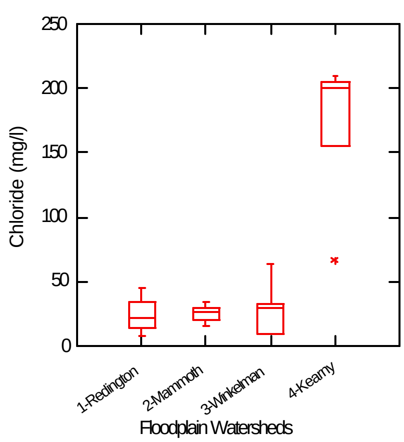

Figure 9. Chloride increases in the most downgradient watershed are probably due to recharge from the Gila River which carries a high salt load from a variety of sources.

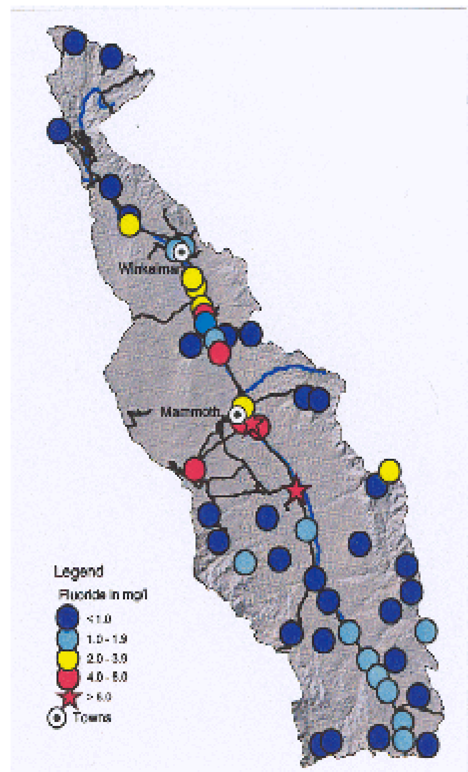

Figure 10. Fluoride concentrations are highest near the San Pedro River in the vicinity of the town of Mammoth.

existed when individual aquifers were examined. These relationships appear to be more the result of differences among aquifers with respect to constituent concentrations and groundwater depth, than with groundwater depth per se.

X. Study Conclusions

Artesian conditions are present in the *confined basin-fill aquifer* which generally is found along the central portion of the basin's axis. Water from this *artesian aquifer* is suitable for domestic and irrigation purposes at its southern boundary near Redington. However, farther north near Mammoth, the water quality deteriorates.

> ***"Sample sites in the unconfined basin-fill aquifer and hardrock areas had the most dilute groundwater with the fewest water quality standard exceedances."***

Gypsum deposit dissolutions and the associated cation exchange create groundwater with high sulfate and sodium concentrations that are elevated near Mammoth and continue to increase at the *artesian aquifer's* northern boundary near the town of Dudleyville.

This aquifer has a *chemically closed hydrologic system* which favors high pH values and depleted calcium concentrations[6]. These are factors which often produce high fluoride concentrations that exceed both aesthetics and health-based water quality standards. The increased sodium and salinity concentrations also make groundwater from the *artesian aquifer* only marginally suitable for irrigation north of Redington.

The *floodplain aquifer* is the most productive in the LSP and supplies water for mining, irrigation, and municipal uses. Found in close association with the major waterways, most of its recharge is from surface water flows[3]. As such, this aquifer is considered to be a *chemically open hydrologic system.*

Leakage from the *artesian aquifer* upwards into the *floodplain aquifer* is thought to be largely responsible for the variable salinity and fluoride concentrations that are particularly elevated near Mammoth[5]. The elevated salinity, sodium, chloride, and potassium concentrations found in the most downgradient portions of the *floodplain aquifer* appear to be connected to the high concentrations of these constituents recharged by the Gila River (**Figure 11**).

Figure 11. The commingling of waters from the San Pedro River and the Gila River during spring flow in 1995 is clearly seen here at the confluence near Winkelman. The San Pedro River, the largest free-flowing river in the Southwest[2], carries a thick, chocolate-colored silt load as the result of recent precipitation. In contrast, the Gila River, impounded approximately 25 miles upstream by Coolidge Dam, has dropped most of its silt load into San Carlos Reservoir.

Elevated sulfate concentrations found along the *floodplain aquifer* (**Figure 12**) between Mammoth and Winkelman appear to be related to both leakage from the *artesian aquifer* and recharge from the San Pedro River. The sulfate source is likely a combination of nearby gypsum deposits and mine dumps.

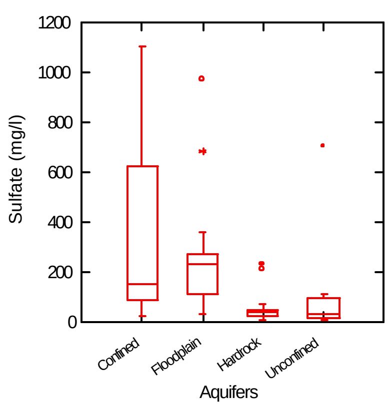

Figure 12. In comparison to the above aquifers, sulfate mean concentrations for the San Pedro River range from 106 mg/l upgradients of Mammoth to 268 mg/l downgradient near its mouth[5].

Groundwater collected from the *unconfined basin-fill aquifer* and from *hardrock* areas was the most dilute and had the fewest water quality standard exceedances. Their largely-pristine water quality appears to be related to a lower salinity recharge source (mountain precipitation) and lack of leakage from the *artesian aquifer*. However, these water-bearing units also have a more limited groundwater production potential.

Groundwater quality concerns in the *unconfined basin-fill aquifer* and *hardrock* appear largely confined to fault zones producing water from great depths and areas of granitic rock which may have elevated gross alpha levels.

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Maps by Larry W. Stephenson
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