Ambient Groundwater Quality of the Douglas Basin: An ADEQ 1995-1996 Baseline Study

I. Introduction

The Douglas Groundwater Basin (DGB) is located in southeastern Arizona (**Figure 1**). It is a picturesque broad alluvial valley surrounded by rugged mountain ranges. This factsheet is based on a study conducted in 1995-1996 by the Arizona Department of Environmental Quality (ADEQ) and summarizes a comprehensive regional groundwater quality report (1).

The DGB was chosen for study for the following reasons:

- Residents predominantly rely upon groundwater for their water needs.
- There is a history of management decrees designed to increase groundwater sustainability (2).
- The basin extends into Mexico, making groundwater issues an international concern.

II. Background

The DGB consists of the southern portion of the Sulphur Springs Valley, a northwest-southeast trending trough that extends through southeastern Arizona into Mexico. Covering 950 square miles, the DGB is roughly 15 miles wide and 35 miles long. The boundaries of the DGB include the Swisshelm (**Figure 2**), Pedregosa, and Perilla Mountains to the east, the Mule and Dragoon Mountains to the west, and a series of small ridges and buttes to the north (**Figure 1**). Although the DGB extends south hydrologically into Mexico, the international border serves as the southern groundwater divide for this report.

Figure 2. The Swisshelm Mountains stand out across the DGB's broad alluvial valley.

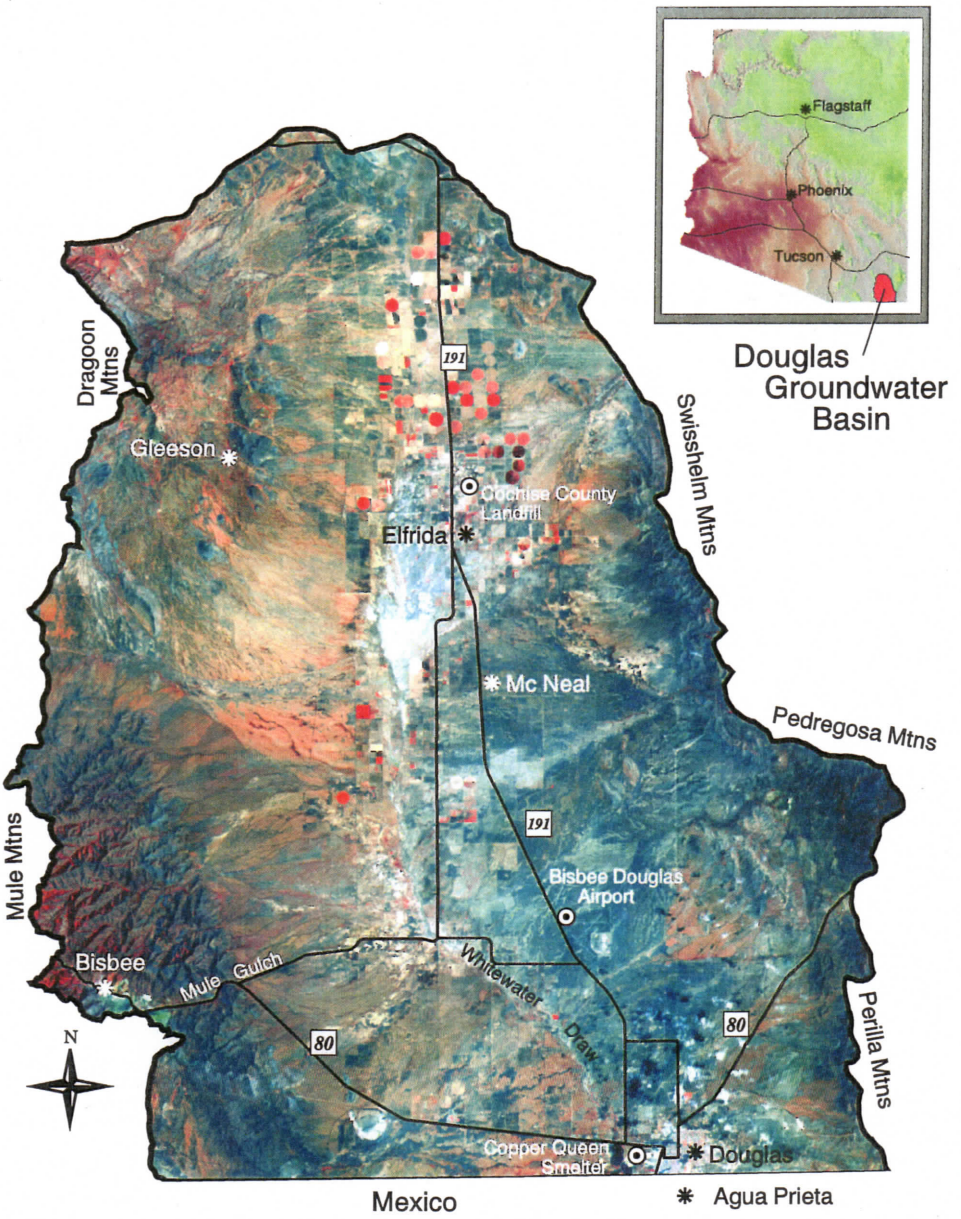

Figure 1. Infrared satellite image of the Douglas Groundwater Basin (DGB) taken in June, 1993. Irrigated farmland is shown in bright red in the central parts of the basin, grasslands and mountain areas appear in both blue and brown. The inset map shows the location of the DGB within Arizona.

The principal landowners in the DGB are private entities and the state of Arizona. Bisbee, Douglas, Elfrida, and McNeal are the major communities within the DGB. Bisbee and Douglas formerly served as copper mining and ore processing centers, respectively and currently are government, retail, and service centers. Elfrida and McNeal are agriculturally-oriented small towns located near the center of the basin.

III. Hydrology

This study examined the water quality of two aquifers: the alluvial and the hardrock. The alluvial aquifer is the DGB's principal water-bearing unit and consists of valley basin-fill deposits. The upper layer of these deposits contains unconsolidated to poorly consolidated gravel, sand, and silt. These alluvial lenses are largely interconnected to form a single aquifer; however, there are considerable spatial differences in water transmissivity, storage, and hydraulic conductivity (3).

"Study results suggest that most groundwater in the DGB is suitable for domestic purposes."

The hardrock aquifer is found in mountainous areas and includes significant expanses of sedimentary rock with lesser amounts of volcanic, granitic, and metamorphic rock (**Figure 3**). Limited amounts of groundwater are contained in the hardrock aquifer, which is most productive in fractured sedimentary and granitic rock (3).

Groundwater generally flows toward the center of the valley and then south toward Mexico (3). The main drainage is Whitewater Draw, an ephemeral watercourse that flows from the Swisshelm Mountains through the center of the valley before exiting the basin near the city of Douglas.

The majority of groundwater pumped in the DGB is used for irrigation; lesser amounts are withdrawn for municipal, domestic, stock, and mining purposes. The sustainable use of groundwater resources for irrigation has historically been a concern in the DGB. In response to annual pumping increases from 5,000 acre-feet (af) in 1938 to 110,000 af in 1964, the State designated most alluvial portions of the basin a Critical Groundwater Area (CGA) in 1965. This prohibited drilling of new irrigation wells within the CGA (2). The CGA evolved into an Irrigation Non-Expansion Area (INA) in 1980 with the passage of the Arizona Groundwater Management Act. The INA limited the acreage that could be irrigated. During the 1980s, pumping was reduced because of rising energy costs and by 1990, annual groundwater pumpage was only 43,000 af (2).

IV. Methods of Investigation

This study was conducted by ADEQ Ambient Groundwater Monitoring staff. This program is based on the legislative mandate in Arizona Revised Statutes §49-225. To characterize regional groundwater quality, 51 sites were sampled: 29 grid-based random sites and 22 targeted sites. Samples were collected at all sites for inorganic constituents (physical characteristics, general mineral parameters, nutrients, and trace elements). At selected sites, samples were also collected for Volatile Organic Compounds (VOCs)(12 sites), Groundwater Protection List (GWPL) pesticides (7 sites), and radiochemistry (6 sites) analysis. Sampling protocol followed the *ADEQ Quality Assurance Project Plan (QAPP)*. The effects of sampling equipment and procedures on data results were not considered significant according to quality control data, except for antimony contamination acquired through impurities in filters during sample processing.

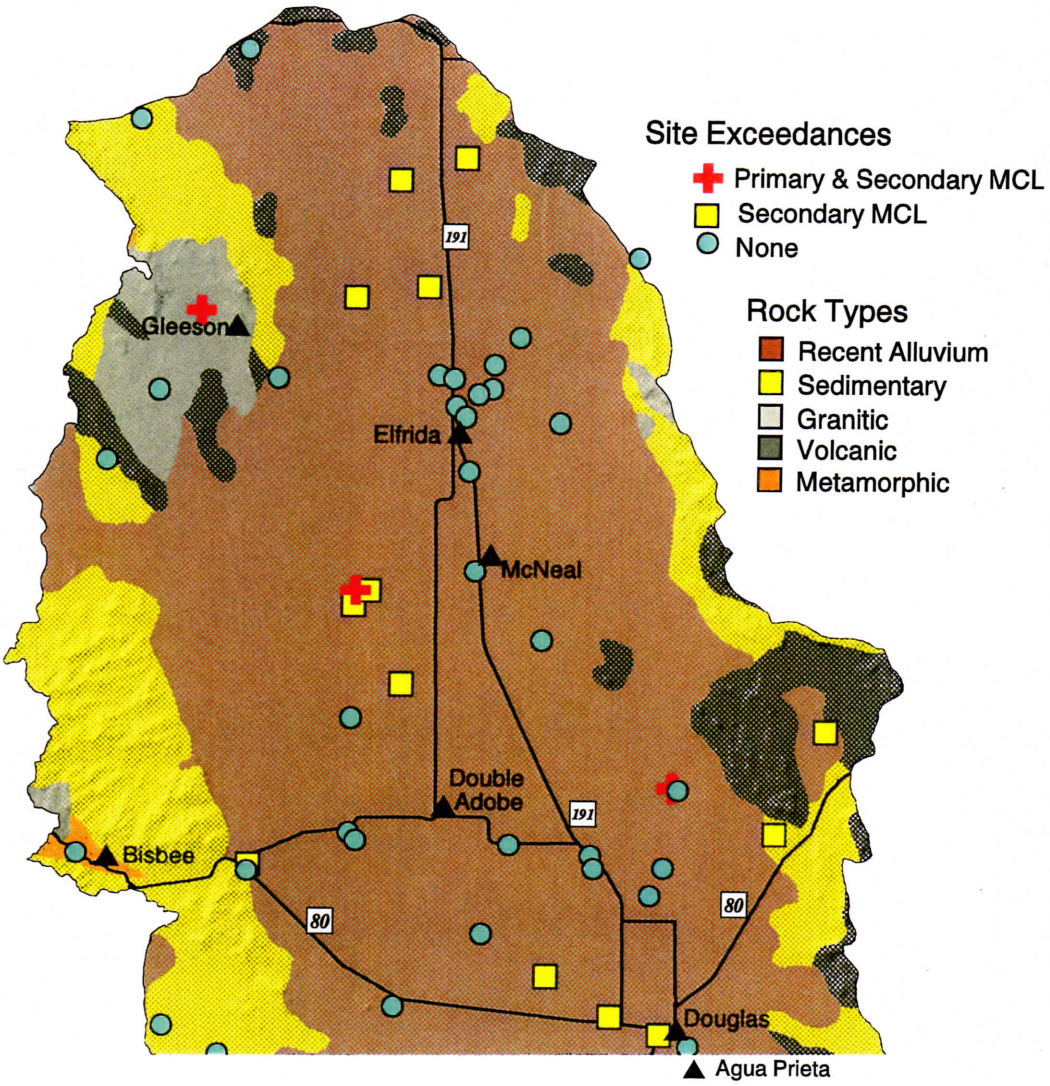

Figure 3. Locations of 51 sample sites, including 3 sites exceeding health-based water quality standards and 16 sites exceeding aesthetics-based water quality guidelines, are shown in this map.

V. Water Quality Sampling Results

The collected groundwater quality data were compared with U.S. Environmental Protection Agency (USEPA) Safe Drinking 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. Three of the 51 sites sampled had parameter levels exceeding a Primary MCL: arsenic, beryllium, and nitrate each exceeded their respective Primary MCLs at one site each (**Figure 3**).

USEPA Secondary MCLs are unenforceable, aesthetics-based water quality guidelines for public water systems. Water with parameters exceeding guidelines may be unpleasant to drink and/or create unwanted cosmetic or laundry effects, but is not considered a health concern. Sixteen of the 51 sites sampled had parameters exceeding a Secondary MCL (**Figure 3**). Exceedances included fluoride and total dissolved solids (TDS) (eight sites each), pH and sulfate (two sites each), and chloride, iron, and manganese (one site each).

None of the 152 pesticides or related degradation products on the ADEQ Groundwater Protection List were detected at the two sites sampled. One site had a VOC detection of chloroform, a common byproduct of chlorination.

These results suggest that groundwater in the DGB generally supports drinking-water uses and seems largely suitable for domestic purposes.

"Fluoride and TDS each exceeded their respective aesthetics-based water quality guidelines at 16 percent of the sample sites."

VI. Groundwater Composition

In general, the DGB has *slightly, alkaline*, *fresh* groundwater. Sample sites in both the hardrock and alluvial aquifers typically exhibited a *calcium-bicarbonate* chemistry. In the alluvial aquifer, *sodium-bicarbonate*, *sodium-sulfate*, and *calcium-sulfate* sites were also present. Groundwater was predominantly *moderately hard* and *hard*, though some sites had *soft* and *very hard* water. *Soft* water was found in the extreme northeast and south-central basin areas. *Very hard* and *hard* groundwater was found in hardrock areas and in the center of the basin near the town of McNeal.

Nitrate (as nitrogen) was found at 41 percent of sample sites at levels over 3 milligrams per liter (mg/l), which may indicate impacts from human activities. Areas with the highest nitrate levels include the intensively-farmed areas near Elfrida and in the foothills of both the Dragoon and Mule Mountains.

Most trace elements such as aluminum, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, selenium, silver, and thallium were rarely detected. Arsenic, barium, fluoride, and zinc were the only trace elements detected at more than ten percent of sites at levels above Arizona Department of Health Services Laboratory minimum reporting levels.

The association between levels of different parameters was examined. Fluoride was positively correlated with pH and negatively correlated with bicarbonate (**Figure 4**) and calcium (Pearson Correlation Coefficient test, $p \leq 0.05$). Calcium is an important control of fluoride through precipitation of the mineral fluorite. Since fluorite solubility is not often attained in groundwater, hydroxyl ion exchange is also an important fluoride control. The exchange of fluoride and hydroxyl ions typically increases downgradient as pH values rise.

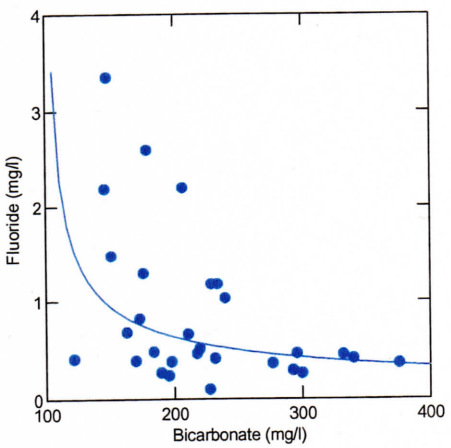

Figure 4. Fluoride levels generally decrease with increasing bicarbonate levels (Pearson Correlation Coefficient test, $p \leq 0.05$).

VII. Groundwater Quality Patterns

Levels of bicarbonate, calcium, hardness (**Figure 5**), magnesium, sulfate, and turbidity were significantly higher in the hardrock aquifer than the alluvial aquifer. The opposite trend occurred with temperature and pH (Kruskal-Wallis test, $p \leq 0.05$).

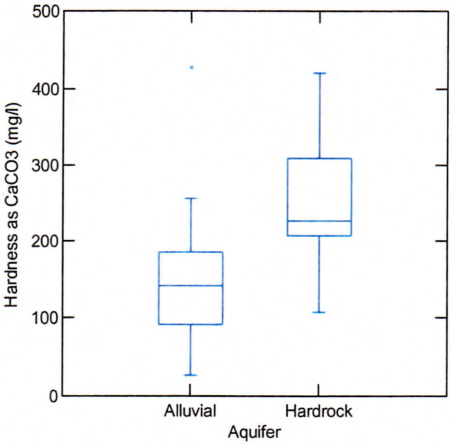

Figure 5. Hardness levels are higher in the hardrock aquifer than in the alluvial aquifer (Kruskal-Wallis, $p \leq 0.05$).

Levels of calcium, hardness, specific conductivity, sulfate, and turbidity significantly decreased with increasing groundwater depth below land surface (bls). In contrast, boron, potassium, pH, and temperature (**Figure 6**) increased with increasing groundwater depth bls (regression analysis, $p \leq 0.05$).

VIII. Targeted Sampling Results

Four areas were targeted for more intensive sampling to examine potential effects on groundwater quality from various land uses. Impacts were determined by comparing parameter levels from these targeted sites to 95 percent confidence intervals calculated from random sites in the DGB.

Targeted sampling was conducted near the town of Elfrida to examine potential impacts from the nearby Cochise County landfill. No effects from the landfill were discerned; however, six of nine targeted sites had nitrate levels exceeding the upper 95 percent confidence level. Agricultural activities and septic system discharges may be contributing to these elevated nitrate

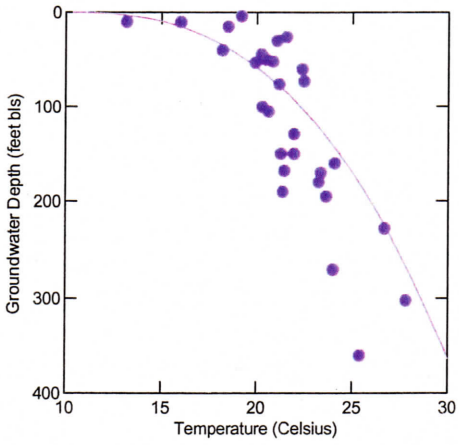

Figure 6. Temperature generally increases with increasing groundwater depth below land surface (regression analysis, $p \leq 0.01$).

levels that were all, nonetheless, below the 10 mg/l Primary MCL.

Mine tailings appear to be contributing to elevated groundwater sulfate levels found along Mule Gulch, downgradient of the town of Bisbee (**Figure 7**). Sulfides in these tailings are oxidized to yield sulfate that is soluble in water. A site near where Mule Gulch enters the alluvium of Sulphur Springs Valley had a sulfate level of 1330 mg/l, exceeding the 250 mg/l Secondary MCL. Further downgradient, sulfate levels rapidly decreased. Elevated sulfate levels due to mine activities have been found south of Bisbee near the town of Naco (4).

Figure 7. Mine tailings near Mule Gulch appear to contribute to the elevated sulfate levels found downgradient of Bisbee.

"Elevated groundwater sulfate levels, near where Mule Gulch enters the alluvium of the Sulphur Springs Valley, appear to result from the effects of mine tailings."

Six sites targeted in areas near the city of Douglas showed no impacts from either municipal activities or slag waste from the Copper Queen Smelter. In contrast, a targeted site east of the Bisbee-Douglas Airport unexpectedly showed influences from geothermal activities. Parameter levels in this 600-foot well frequently exceeded their respective upper 95 percent confidence levels by several orders of magnitude. The high temperature and elevated levels of TDS (14,000 mg/l), sulfate (5,020 mg/l), ammonia (1.09 mg/l), and iron (13.9 mg/l) suggest a reducing, geothermal environment. TDS, arsenic, chloride, iron, manganese, and sulfate each exceeded their respective water quality standards/guidelines at this site.

IX. Groundwater Changes

A time-trend analysis was conducted by comparing groundwater quality data collected from the same seven wells approximately eight years apart. The wells, sampled in 1987 by the Arizona Department of Water Resources, were resampled by ADEQ for this study (2). While many of the 12 parameters examined appear to have higher levels in 1995-1996 than in 1987, only nitrate (**Figure 10**) and potassium levels were significantly higher (Wilcoxon ranked-sum test, $p \leq 0.05$).

Figure 8. Windmill pumps water into a storage tank by the Pedregosa Mountains.

Figure 9. Farmland, irrigated by groundwater pumped by the turbine well in the foreground, lies fallow after fall harvest north of the town of Elfrida.

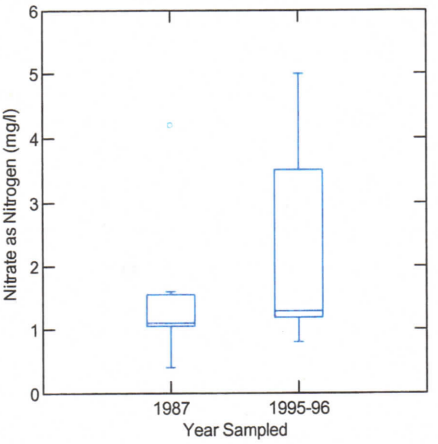

Figure 10. Nitrate levels in 1995-1996 were higher than in 1987 (Wilcoxon test, $p \leq 0.05$).

X. Study Conclusions

Although groundwater in the DGB generally met water quality standards, ADEQ suggests that well owners periodically have their groundwater analyzed by certified laboratories. Most parameters, including fluoride, appear to be controlled by natural geochemical reactions and will probably not vary significantly in the short term. In contrast, some parameters such as nitrate, sulfate, and TDS that occasionally exceed water quality standards and/or guidelines appear (at some sites) to be influenced by anthropogenic activities. The levels of these parameters may be dynamic and should be monitored for changes.

---Douglas C. Towne
Maps by Larry W. Stephenson
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