Ambient Groundwater Quality of the Prescott Active Management Area: An ADEQ 1997-1998 Baseline Study

I. Introduction

The Prescott Active Management Area (PAMA) covers approximately 485 square miles of Yavapai County in north central Arizona (**Figure 1**). This factsheet, based on a 1997-1998 study conducted by the Arizona Department of Environmental Quality (ADEQ), is a summary of a comprehensive regional groundwater quality report (1). The PAMA was selected for study for the following reasons:

- Residents predominantly rely upon groundwater for their water needs.
- It has a history of management decrees designed to achieve groundwater sustainability (2).
- Recent population growth and a subsequent increase in the number of wells provide greater access to investigate groundwater quality.

II. Background

The boundaries of the PAMA are the Black Hills to the east and north, Granite Mountain and Sullivan Buttes to the west, and the Bradshaw Mountains to the south. The surface topography consists of broad, sloping alluvial fans which extend from the surrounding mountains to the valley floor. Vegetation varies with elevation.

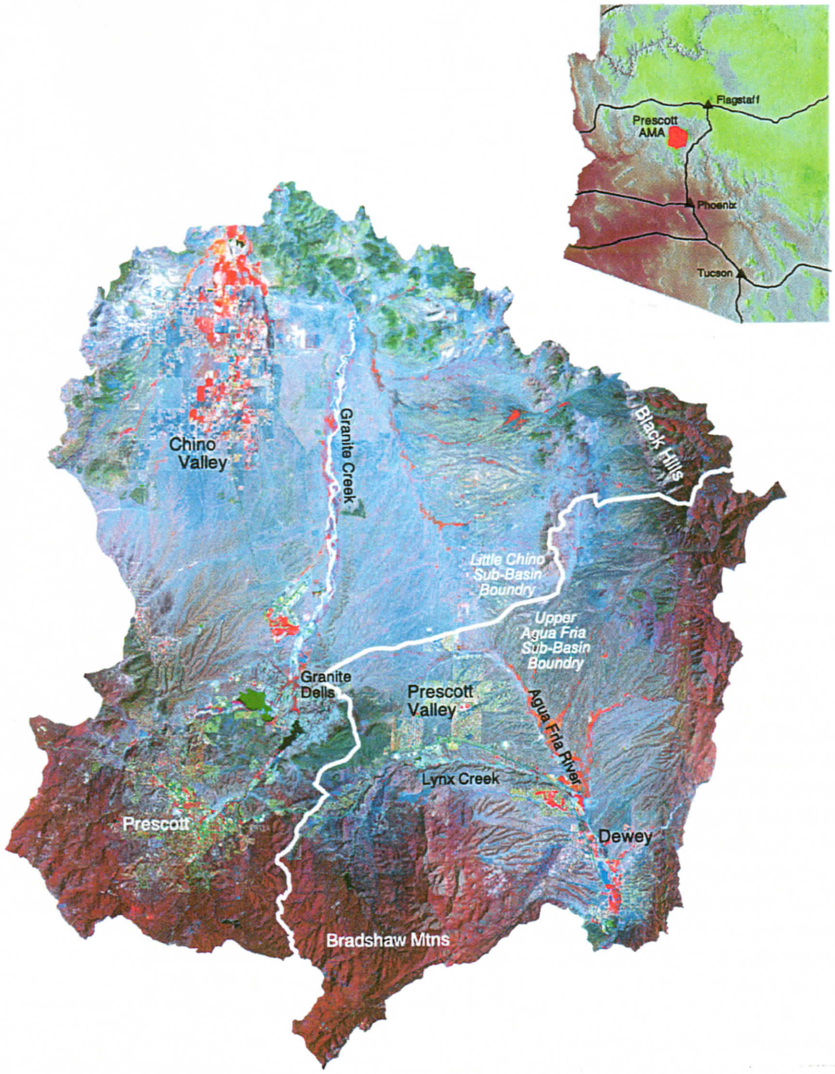

Figure 1. Infrared satellite image of the Prescott Active Management Area (PAMA) in which mountains appear as crimson, grasslands are blue, and irrigated areas and/or riparian areas are bright red. Inset map shows the location of the PAMA within Arizona.

Figure 2. The James Windmill appears as a dark silhouette over Hickey Mountain.

High desert grasslands are found in the valleys, pinion-juniper forest grows in upland areas, and ponderosa pine forest appears at the highest elevations. The principal landowners in the PAMA are private entities (55 percent), the U.S. Forest Service and the state of Arizona (21 percent apiece). Prescott, Prescott Valley, Chino Valley, Dewey, and Humboldt are the major communities within the PAMA. Groundwater is the primary source for municipal, domestic, irrigation, and livestock water uses.

III. Hydrology

The PAMA is composed of two groundwater sub-basins: the Upper Agua Fria and the Little Chino. These sub-basins are hydrologically linked to other basins which are predominantly outside the PAMA. The Upper Agua Fria sub-basin is hydrologically part of the Agua Fria groundwater basin and covers the southeastern one-third of the PAMA. The Little Chino sub-basin covers approximately two-thirds of the PAMA and is hydrologically part of the Verde groundwater basin.

Two aquifers, the regional and the hardrock, were examined in this study. The regional aquifer is generally found in valley alluvial areas and is the principal water-bearing unit in the PAMA. In the Little Chino sub-basin, the regional aquifer is composed of an

> ***"Study results suggest that most groundwater in the PAMA is suitable for domestic purposes."***

upper alluvial unit and a lower volcanic unit. In the Upper Agua Fria sub-basin, the regional aquifer is composed solely of an upper alluvial unit. The upper alluvial unit contains a mixture of sedimentary, volcanic, and younger alluvial rocks, and is the primary source of groundwater for most domestic wells. The lower volcanic unit consists of lava flows interbedded with pyroclastic and alluvial materials (3). The lower volcanic unit exhibits confined aquifer conditions and is the main source for most Little Chino sub-basin irrigation and municipal wells. The hardrock aquifer is found in mountainous areas of the PAMA and includes significant expanses of basaltic, granitic, sedimentary, and volcanic rock. Limited amounts of groundwater are found in the hardrock aquifer, which is most productive where the bedrock is highly fractured (3).

Sustainable groundwater use has historically been a concern in the PAMA. As far back as 1962, the Little Chino Valley was declared a Critical Groundwater Area (2). The PAMA was created by passage of the 1980 Groundwater Act, with the Arizona Department of Water Resources (ADWR) designated as the oversight agency. The PAMA's main objective was to achieve *safe yield* (equalizing groundwater use and recharge) by 2025 (4). However, ADWR declared in 1999 that the PAMA was no longer in a state of *safe yield* (5).

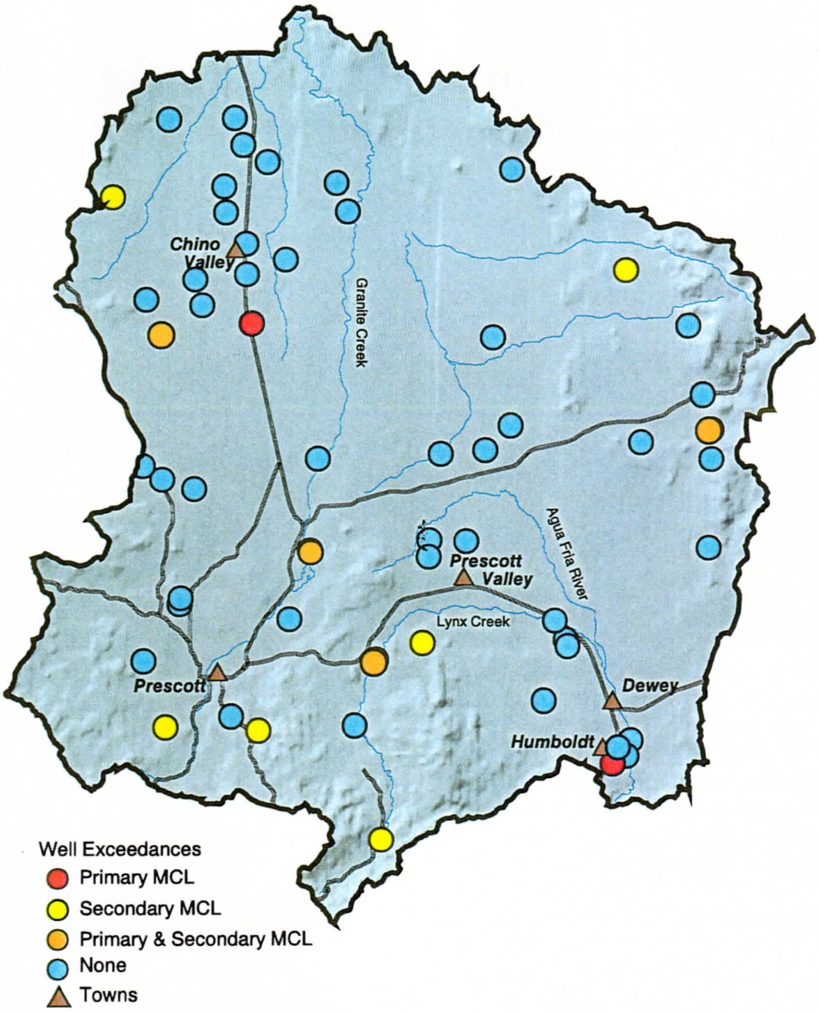

Figure 3. Locations of 58 sample sites, including 6 sites exceeding health-based water quality standards and 10 sites exceeding aesthetics-based water quality guidelines, are shown in this map.

IV. Methods of Investigation

This study was conducted by the ADEQ Ambient Groundwater Monitoring Program, which is based on the legislative mandate in Arizona Revised Statutes §49-225. To characterize regional groundwater quality, 58 sites were sampled: 41 grid-based random sites and 17 long-term index sites. Inorganic constituents were collected at all sites. Samples were also collected for radiochemistry analysis at ten sites in hardrock areas and for pesticide analysis at two sites in agricultural areas. Sampling protocol followed the *ADEQ Quality Assurance Project Plan*. The quality control data indicated that the effects of sampling equipment and laboratory procedures on the analytical results were insignificant.

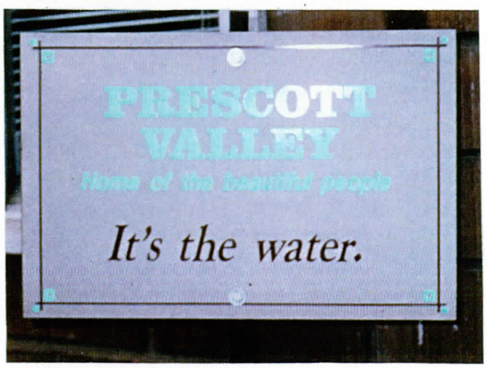

Figure 4. This water company sign illustrates the high profile this resource has in the PAMA.

V. Water Quality Sampling Results

The collected groundwater quality data were compared with U.S. Environmental Protection Agency (USEPA) 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. Six of the 58 sites sampled had parameter levels exceeding a Primary MCL (**Figure 3**). These exceedances included arsenic (four sites), fluoride (three sites), and barium, gross alpha, and nitrate (one site apiece).

USEPA 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 it is not considered a health concern. Ten of the 58 sites sampled had parameters exceeding a Secondary MCL (**Figure 3**). These exceedances included total dissolved solids (TDS) at six sites, fluoride at four sites, and iron, manganese, and sulfate at two sites apiece.

None of the 152 pesticides or related degradation products on the ADEQ Groundwater Protection List were detected at the two sites sampled.

These results suggest that groundwater in the PAMA generally supports drinking-water uses and is mostly suitable for domestic purposes. Although 19 percent of sampled sites had parameters exceeding water quality standards and/or guidelines, they were spatially scattered and did not appear to indicate extensive areas of groundwater unsuitable for domestic use.

VI. Groundwater Composition

In general, the PAMA has *neutral* to *slightly alkaline*, *fresh*, and *moderately hard* or *hard* groundwater. Most trace elements such as aluminum, antimony, beryllium, boron, cadmium, chromium, iron, lead, manganese, mercury, selenium, silver, and thallium were rarely detected. Arsenic, barium, copper, fluoride, and zinc were the only trace elements detected at more than ten percent of the sites at levels above Arizona Department of Health Services (ADHS) minimum reporting levels. Nitrate (as nitrogen) was occasionally found at levels over 3 milligrams per liter (mg/l), which may indicate impacts from various types of human activities.

The vast majority (90 percent) of PAMA sample sites exhibited a *calcium-bicarbonate* chemistry which is common in Arizona and typical of recharge areas (6). Two sites near Lynx Creek had a *calcium-sulfate* chemistry. Their sulfate levels may have been impacted by nearby historic mining activity. The calcium-dominated chemical character of the PAMA groundwater is consistent with the presence of limestone and dolomite, particularly in the Black Hills where some recharge occurs.

Four sites had a *sodium-bicarbonate* chemistry, which is typical of areas downgradient of recharge zones in Arizona (6). At these sites, calcium was probably removed from solution by precipitation of calcium carbonate and formation of smectite clays; the presence of elevated sodium appears to be the result of silicate weathering and halite dissolution in combination with minor amounts of ion exchange (7).

The association between levels of different parameters showed two general patterns that varied with the dominant cation. Calcium had positive correlations with bicarbonate, chloride, copper, magnesium, nitrate, sulfate, and total Kjeldahl nitrogen (TKN). Negative correlations occurred with fluoride, pH, and temperature. In contrast, sodium had positive correlations with arsenic, bicarbonate, boron, fluoride, potassium, and TKN (Pearson's Correlation Coefficient test, $p \leq 0.05$).

VII. Groundwater Quality Patterns

Levels of bicarbonate, calcium, hardness, magnesium, sodium, and TDS were significantly higher in the hardrock aquifer than in the regional aquifer. The opposite pattern occurred with pH and temperature levels (Kruskal-Wallis test, $p \leq 0.05$).

Groundwater derived from granitic and volcanic rock had higher bicarbonate, hardness, and TDS (**Figure 5**) levels than that from sedimentary rock or alluvial fill. In contrast, groundwater derived from alluvial fill had significantly higher pH and temperature levels than that from granitic rock (Kruskal-Wallis test, $p \leq 0.05$).

Levels of bicarbonate, sulfate, and TDS were significantly higher in the Upper Agua Fria sub-basin than in the Little Chino sub-basin. Fluoride levels exhibited the opposite pattern (Kruskal-Wallis test, $p \leq 0.05$).

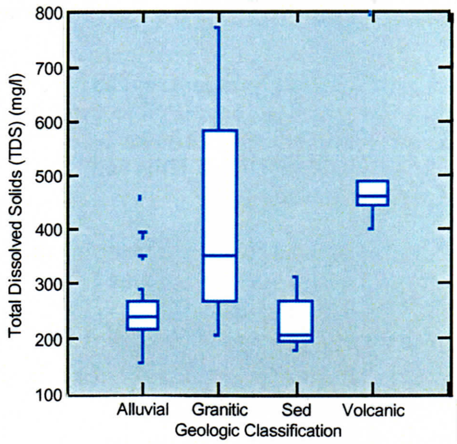

Figure 5. TDS levels in volcanic and granitic rock are significantly higher than in sedimentary rock and alluvial fill (Kruskal-Wallis test, $p \leq 0.05$).

Levels of barium, calcium, hardness (**Figure 6**), magnesium, manganese, specific conductivity (SC), TDS, and TKN decreased with increasing groundwater depth below land surface. In contrast, pH, temperature, and zinc increased with increasing groundwater depth below land surface (regression analysis, $p \leq 0.05$).

Despite these groundwater depth relationships, additional analyses seem to indicate that vertical variation is less important than spatial variation for groundwater quality in the PAMA. Groundwater depth in the regional aquifer and the Little Chino sub-basin is greater than in the hardrock aquifer and Upper Agua Fria sub-basin, respectively (Kruskal-Wallis test, $p \leq 0.05$). Thus, with parameter levels generally lower in the regional aquifer and the Little Chino sub-basin, groundwater depth patterns appear to be influenced by previously-mentioned

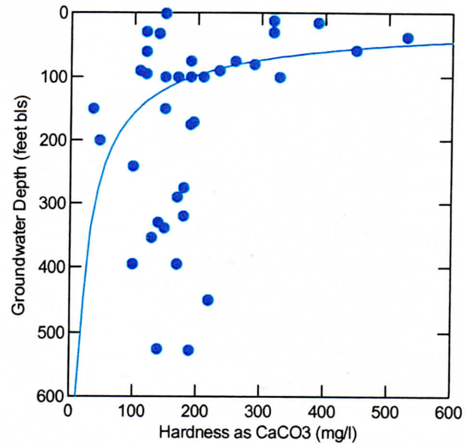

Figure 6. Hardness levels generally decrease with increasing groundwater depth below land surface (regression analysis, $p \leq 0.05$).

spatial patterns. Other sources have also indicated that in Arizona, groundwater parameter levels tend to be more a function of flow path evolution than vertical mixing (6).

A related analysis (based on very limited data) supports an earlier study in the Little Chino sub-basin that found parameter levels are generally higher in the upper alluvial unit than in the lower volcanic unit (2). Groundwater quality differences may be due to recharge to the lower volcanic unit which occurs near the PAMA's margins where there is less evaporation and concentration of salts (3). Surface water flow in the Little Chino sub-basin typically has comparatively high TDS levels during base flow periods, which only approach the quality of lower volcanic unit recharge during spring runoff from snowmelt (2).

VIII. Groundwater Changes

A time-trend analysis was conducted in the PAMA with 12 parameters collected from 17 ADEQ index wells located throughout the study area. Levels of chloride, fluoride, hardness, magnesium, nitrate, sodium, SC, sulfate, total alkalinity, TDS, and zinc did not significantly vary between 1991-1993 and 1997-1998. Only calcium levels were significantly higher in 1997-1998 (Wilcoxon rank-sum test, $p \leq 0.05$). This calcium increase may be due to flooding in 1993 which produced large volumes of recharge. It is also possible that different analytical methods for calcium used by the ADHS laboratory during each sampling period may have been a factor in the increasing calcium levels.

IX. Study Conclusions

Sites exceeding Primary MCLs for fluoride, arsenic, and gross alpha appear to be the result of naturally occurring conditions. Elevated levels of fluoride and arsenic tend to occur at sites characterized by *soft, moderately alkaline* groundwater that has been largely depleted of calcium. Calcium is an important control of fluoride levels through precipitation of the mineral fluorite (8). High fluoride levels (>5 mg/l) may occur in calcium-depleted groundwater through mineral equilibrium reactions if a source of fluoride ions is available for dissolution (8). Since fluorite solubility is not often attained in groundwater, hydroxyl ion exchange or sorption-desorption reactions appear to be additional controls on fluoride levels. Fluoride ions exchange for hydroxyl ions, with this process typically increasing downgradient as pH values rise (7). Sorption-desorption reactions are considered to be the most important control on arsenic levels (8).

A gross alpha exceedance occurred in the Granite Dells area north of Prescott. Granite rock in general, and this area specifically, has been previously cited as frequently having elevated groundwater radiochemistry levels (4). Nitrate was generally below natural background levels but was occasionally elevated, especially in the Dewey-Humboldt area. High nitrate levels in this area have been reported by other sources and may be influenced by wastewater from older septic systems and/or agricultural operations (1).

"The geochemistry of sites with naturally occurring soft groundwater makes them particularly susceptible to elevated levels of fluoride and arsenic."

Figure 8. A deep, high-capacity municipal well pumps water near the Prescott Airport.

Figure 7. A windmill pumps water from the hardrock aquifer into a storage tank in the Black Hills.

PAMA Secondary MCL exceedances involving TDS, iron, manganese, and sulfate often appear to be related to site-specific conditions such as historic mining activity in the Black Hills and Bradshaw Mountains.

Time-trend analyses show parameter levels were mostly stable during the 1990s. This indicates that most parameters are largely controlled by natural factors and would probably not vary significantly over the short term.

Groundwater in the PAMA generally meets water quality standards. Despite these encouraging results, ADEQ suggests that well owners periodically have their groundwater analyzed by certified laboratories. Of particular concern is *soft* groundwater that has been naturally depleted of calcium. The geochemistry of these groundwater sites makes them particularly susceptible to elevated levels of trace elements such as fluoride and arsenic.

---Douglas Towne and Maureen Freark
Maps by Larry W. Stephenson
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X. References Cited

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