CENTRAL ARIZONA SALINITY STUDY --- PHASE I

Technical Appendix F

HYDROLOGIC REPORT ON THE HARQUAHALA BASIN

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1.0 INTRODUCTION

The Central Arizona Salinity Study (CASS) is a coalition of water and wastewater agencies evaluating salinity issues in Central Arizona. The mission of CASS is to provide its members with workable alternatives for a quality, cost effective, sustainable, and reliable water supply through partnerships and cooperative efforts in regional salinity planning and management. CASS was formed in November 2001. CASS is a study group and not a legal entity.

Salinity from local and imported sources is increasing the salinity of groundwater in localized areas and the salinity of reclaimed water in Central Arizona. The magnitude of the salinity issue is unclear and water providers in Central Arizona decided to work together to assess the problem and, if necessary, develop regional strategies for managing it. Central Arizona water providers must work together to protect, preserve, and develop these shared resources and to respond to issues of: increasing water quality and water supply regulation; increasing reclaimed water utilization; increasing levels of salinity into water reclamation facilities; developing brine disposal strategies; deteriorating groundwater quality in localized areas; and managing costs.

If no workable solution is implemented, salinity increases may result in greater water and wastewater treatment costs, decreased agricultural production, and some water sources may become unsuitable for their intended uses.

- Increasing salinity levels may reduce the ability of water providers to use groundwater and reclaimed water to meet customer water demands. Some communities may not have enough supply to meet demand. Growth and development in these communities may become limited.

- Water reclamation plants may have water quality permit compliance problems. High salinity levels in reclaimed water supplies may make this resource unsuitable for some of its intended uses. Retrofitting water reclamation plants to manage salinity and dispose of brine may significantly increase wastewater treatment costs.

- Water customer complaints may increase due to increasing salinity of the drinking water supply. Retrofitting potable water treatment plants to manage salinity and dispose of brine may significantly increase water treatment costs.

The following white paper describes hydrologic conditions in the Harquahala Basin. This report is based on literature review of publicly available information, and site-specific fieldwork was not conducted as part of this study. The purpose of the report is to provide a general framework of the physical, geologic, and hydrologic aspects of the basin. The report will also discuss surface water quality and groundwater quality over time, with a primary focus on salinity.

2.0 PHYSICAL SETTING

The Harquahala Basin is located in west-central Arizona within the Sonoran Desert section of the Basin and Range physiographic province (Figure 1). The basin is adjacent to the Phoenix Active Management Area (AMA) to the east, Lower Gila Basin to the south, Ranegras Plain Basin to the west, and McMullen Valley Basin to the north. The Harquahala Basin comprises approximately 765 square miles, and precipitation in the basin averages approximately 6 inches per year (Hedley, 1990). The principal natural surface drainage feature is Centennial Wash, which enters the basin between the Harquahala and Little Harquahala Mountains in the northwest, and exits the basin between Saddle Mountain and the Gila Bend Mountains in the southeast (Figure 2). The land surface elevation ranges from 1,000 feet above mean sea level (amsl) where Centennial Wash exits the basin to over 5,000 feet amsl in the surrounding mountains. The basin supports a sparsely populated agricultural community of approximately 900 people, and the population is projected to increase slightly to 1,000 people by the year 2040 (ADWR, 1993).

3.0 GENERALIZED GEOLOGY

The Harquahala Basin is thought to have formed during the Tertiary Basin and Range Disturbance. During this disturbance, widespread extensional deformation in southern and western Arizona resulted in northwest trending mountain ranges separated by alluvial filled troughs.

3.1 BEDROCK GEOLOGY

The Harquahala Basin is bounded by the Harquahala Mountains on the north, Big Horn Mountains on the northeast, Saddle Mountain on the southeast, Gila Bend Mountains on the south, Eagletail Mountains on the southwest, and Little Harquahala Mountains on the northwest (Figure 2). The bounding mountain ranges are predominantly comprised of Precambrian granitic and metamorphic rocks, Mesozoic and Paleozoic sedimentary rocks, Jurassic to Late Cretaceous granitic rocks and volcanics, and Tertiary volcanics and basalt (Reynolds, 1988. Hedley, 1990). In general, the sedimentary and metamorphic rocks primarily occur in the north/northwest portion of the basin (Harquahala and Little Harquahala Mountains), and the granitic rocks and volcanics dominate the bedrock geology elsewhere in the basin.

3.2 BASIN GEOLOGY

The Harquahala Basin is comprised of a relatively deep, northwest trending alluvial valley that is typical of the Basin and Range physiographic province. Based on gravity modeling (Oppenheimer and Sumner, 1980), the depth to bedrock in the majority of the basin is greater than 1,600 feet below land surface (bls). The gravity modeling also suggests the deepest portion of the basin is near the center, with a depth to bedrock greater than 8,000 feet bls. Graf (1980) reported that the alluvial deposits are less than 300 feet thick near the mountains, and greater than 2,000 feet thick near the center of the basin. Hedley (1990) reported that the alluvial deposits are up to 5,000 feet thick in the center of the basin. Although differences in depth to bedrock values are noted in each study, the alluvial deposits are thickest near the center of the basin, and thin towards the bounding mountain ranges.

Based on the study by Hedley (1990), the basin fill alluvium in the Harquahala Basin is composed of heterogenous deposits of clay, silt, sand and gravel. The most prominent alluvial unit in the basin is an extensive fine-grained (clay-dominated) deposit. The approximate extent of the fine-grained deposit as modified from Graf (1980) is shown on Figure 2. The fine-grained deposit occurs in the majority of the basin, and is known to be absent only in the extreme southeastern portion of the basin. According to Graf (1980), the thickness of the fine-grained deposits increases towards the northwest, and is more than 1,000 feet thick in the center of the basin. Relatively coarse-grained sand and gravel deposits occur in the southeastern portion of the basin, and also underlie the fine-grained deposits in the majority of the basin.

4.0 HYDROGEOLOGIC CONDITIONS

4.1 GROUNDWATER OCCURRENCE AND MOVEMENT

The alluvial basin fill deposits represent the regional aquifer in the Harquahala Basin. Groundwater in the alluvial deposits is generally unconfined, although local semi-confined to confined conditions exist. Based on estimates by the Arizona Department of Water Resources (ADWR) in 1988, the Harquahala Basin contains approximately 15.5 million acre-feet of recoverable groundwater to a depth of 1,200 feet. Natural recharge to the aquifer is minimal, and is estimated at approximately 1,000 acre-feet per year (ac-ft/yr), primarily as underflow from the McMullen Valley Basin (Freethey and Anderson, 1986). Sources of man-induced groundwater recharge include irrigation seepage (varies), losses from the Central Arizona Project (CAP) canal (5,900 ac-ft/yr), and permitted recharge facilities (projected up to 100,000 ac-ft/yr). The primary sources of discharge from the aquifer are groundwater pumpage for crop irrigation (varies) and evapotranspiration (100 ac-ft/yr).

Based on predevelopment hydrologic conditions, groundwater flowed into the Harquahala Basin from the northwest (McMullen Valley Basin inflow), generally mimicked the direction of surface flow (Centennial Wash) to the southeast, and exited the basin as underflow into the Hassayampa Sub-Basin of the Phoenix AMA (Freethey and Anderson, 1986). However, major groundwater development began in the southeast portion of the basin in 1951, eventually altering the groundwater flow regime. By 1954, approximately 6,000 acres of land was being cultivated with groundwater produced from 20 wells (Stulik, 1964). Agricultural development reached its peak in 1966, totaling 39,500 acres under irrigation with approximately 120 wells supplying 200,000 ac-ft of groundwater (Denis, 1971). Due to the extensive pumping, the groundwater flow direction to the southeast reversed in the developed portion of the basin, and by 1957 the flow direction was toward the northwest (Denis, 1971). By 1966, the majority of the groundwater in the basin flowed toward a well developed cone of depression beneath the agricultural area, resulting in little to no groundwater outflow into the Hassayampa Sub-Basin (Denis, 1971. Graf, 1980).

Due to significant groundwater depletion, the Harquahala Basin was designated as an Irrigation Non-expansion Area (INA) by the Director of the ADWR in 1982. Within an INA, the irrigation of any land is prohibited unless the land was irrigated during the five years preceding the date of designation, which amounts to 38,500 acres of farmland in the Harquahala Basin (ADWR, 1993). According to Hedley (1990), groundwater levels in the agricultural portion of the basin declined up to 325 feet from 1951 to 1980. Although groundwater declines are significant, only 0.6 ft of subsidence has occurred in the basin from 1927 to 1981, and evidence of subsidence is limited to two small earth fissures (Schumann and Genualdi, 1986). With the introduction of CAP water in the mid 1980’s, groundwater pumpage decreased dramatically, and groundwater levels have risen as much as 70 feet in the southeast portion of the basin (Hedley, 1990).

4.2 GROUNDWATER QUALITY

The Arizona State Land Department conducted the initial water quality study in the Harquahala Basin, sampling 23 wells from 1952 to 1955. Based on sampling results from this study, total dissolved solids (TDS) concentrations ranged from 432 to 864 milligrams per liter (mg/l), and averaged 608 mg/l (Metzger, 1957). The relatively small range in TDS concentrations and minor groundwater development at the time suggests that the TDS values are likely representative of ambient (predevelopment) groundwater quality conditions. Metzger (1957) also noted that the TDS content represented no water quality problems in the basin with respect to potential irrigation uses. As follow up to this study, the Arizona State Land Department conducted another water quality study in 1966, which included the sampling of 21 wells. Based on sampling results from this study, TDS concentrations ranged from 429 to 810 mg/l, and averaged 616 mg/l (Denis, 1971). Although significant groundwater development occurred in the Harquahala Basin by 1966, TDS concentrations compare readily with the initial water quality study, suggesting that the regional aquifer was not impacted from salinity due to agricultural irrigation at this time.

The ADWR conducted two additional studies that included comprehensive water quality sampling in the Harquahala Basin. The study by Graf (1980) included the sampling of 61 wells from 1979 to 1980. Graf noted that TDS concentrations ranged from 438 to 2,340 mg/l, and averaged 762 mg/l. The study by Graf also indicated that an extensive perched water system had developed beneath the southeast agricultural area, due to downward percolation of irrigation water above the extensive fine-grained unit (Figure 2). The study by Hedley (1990) involved the sampling of 89 wells from 1984 to 1989, and TDS concentrations ranged from 429 to 1,800 mg/l (average 700 mg/l). Hedley also noted the extensive perched water zone beneath the southeast agricultural area, and indicated that cascading water from the perched zone was cross-contaminating the regional aquifer via wells.

A comparison of TDS concentrations over time in the Harquahala Basin, based on the previously discussed water quality studies, is presented in Table 1 and is graphically displayed on Figure 3. In general, the studies conducted by Metzger (1957) and Denis (1971) suggest that the regional aquifer was not impacted from agricultural irrigation, and that the sample results likely reflect ambient groundwater quality in the basin. By contrast, the ADWR studies noted the formation of an extensive perched water system with significantly increased TDS concentrations compared to the regional aquifer. Furthermore, cross-contamination through wells (cascading water from the perched system to the underlying regional system) has degraded water quality locally (Hedley, 1990. Graf, 1980). This is also indicated by the abrupt increase in maximum TDS concentrations noted in the ADWR studies, which compare readily to the average perched water system TDS concentrations.

TABLE 1. TDS CONCENTRATIONS IN THE HARQUAHALA BASIN

SOURCE AND SAMPLE YEARS	MINIMUM (mg/l)	MAXIMUM (mg/l)	AVERAGE (mg/l)
Arizona State Land Department (Metzger, 1957) Samples collected from 1952 to 1955	432	864	608
Arizona State Land Department (Denis, 1971) Samples collected in 1966	429	810	616
Arizona Department of Water Resources (Graf, 1980) Samples collected from 1979 to 1980	438	2,340	762 (2,421)
Arizona Department of Water Resources (Hedley, 1990) Samples collected from 1984 to 1989	429	1,800	700 (2,036)
Note: TDS concentrations represent the regional aquifer system, with the exception of TDS concentrations shown in parentheses that represent the perched water system.			

5.0 SURFACE WATER CONDITIONS

5.1 SURFACE WATER OCCURRENCE

The principal natural surface drainage feature is Centennial Wash, which enters the basin between the Harquahala and Little Harquahala Mountains in the northwest, and exits the basin between Saddle Mountain and the Gila Bend Mountains in the southeast (Figure 2). Centennial Wash and its tributaries are ephemeral, and flow only in response to local precipitation. Due to the arid climate in the basin (approximately 6 inches per year precipitation), flows in Centennial wash are extremely low, and unreliable for crop irrigation (Denis, 1971). Also, due to the extremely low flows, no United States Geological Survey (USGS) stream gauging sites are located within the basin to measure annual flow. Freethey and Anderson (1986) reported that perennial stream losses (inflow) and stream base flow (outflow) for Centennial Wash were essentially zero, and subsequently not included in the predevelopment groundwater budget for the basin. Therefore, the surface flows in Centennial Wash and its tributaries are considered to be negligible for the purposes of this study.

The only reliable surface water source in the Harquahala Basin is the CAP canal, which traverses from west to east across the basin (Figure 2). The CAP canal began delivering water for crop irrigation in the mid 1980's, substantially reducing the reliance on groundwater pumping in the basin. The relationship between groundwater pumping and CAP deliveries in the Harquahala Basin is illustrated on Figure 4. According to rates determined by the Central Arizona Water Conservation District, as reported by ADWR (1988), approximately 5,900 ac-ft/yr is recharged into the basin due to seepage along the canal.

5.2 SURFACE WATER QUALITY

Surface water quality is only available for the CAP canal in the Harquahala Basin. There are no USGS water quality stations in the basin, and therefore no publicly available water quality information for Centennial Wash and its tributaries exists. Based on previous studies in the Salt River Valley, the TDS concentration of CAP water delivered in the Harquahala Basin is assumed to be 560 mg/l.

6.0 GENERALIZED SALT BALANCE

Based on ADWR groundwater pumpage data and CAP water deliveries in the Harquahala Basin, a generalized salt balance was calculated for the Harquahala Basin. The salt balance is divided into three distinct time frames on the basis of irrigation water sources and CAP water usage. The period from 1951 to 1985 represents extensive groundwater development and pumping, almost exclusively for agricultural irrigation. By contrast, the period from 1986 to 2002 represents the introduction of CAP water for irrigation, and significant reductions in groundwater pumpage. Future conditions include the Vidler Recharge Facility in the basin and continued irrigation with CAP water. Results of the salt balance are presented in Table 2 and graphically illustrated on Figure 5. Assumptions utilized in the salt balance are listed below:

TABLE 2. GENERALIZED SALT BALANCE FOR THE HARQUAHALA BASIN

DESCRIPTION	1951 TO 1985	1986 TO 2002	FUTURE
Average salt load from agricultural irrigation (million tons per year)	0.002	0.002	0.002
Average salt load from CAP deliveries and canal seepage (million tons per year)	0	0.066	0.066
Average salt load from recharge facilities (million tons per year)	0	0.001	0.076
Average salt accumulation in the Harquahala Basin (million tons per year)	0.002	0.069	0.144

- The difference in natural recharge to the basin and groundwater outflow from the basin is negligible.
- All groundwater pumpage is utilized for agricultural irrigation.
- The TDS concentration of CAP deliveries and canal seepage is 560 mg/l.
- Wastewater (septic) infiltration and irrigation return flows are not included in the salt balance, as they originate and terminate within the basin.
- Future salt loading assumes current agricultural practices (1986 to 2002) continue into the future, and that the Vidler Recharge Facility operates at the permitted capacity (100,000 ac-ft/yr).
- The Harquahala Basin is essentially a "closed" basin, and there is no salt removal.

Prior to the introduction of CAP water, the only reliable source of water in the Harquahala Basin was groundwater from wells, and virtually all of the groundwater pumped was utilized for agricultural purposes (Graf, 1980). According to the ADWR Assessment in 1993, municipal and industrial water demands in the basin are essentially negligible (1,000 ac-ft/yr), and represent 1 percent of the average water pumpage in the basin (104,000 ac-ft/yr from 1951 to 1985). Therefore, the only significant source of salt loading in the Harquahala Basin prior to CAP water was from agricultural irrigation practices. Based on previous salt contribution calculations from irrigation in the Salt River Valley, the crop irrigation in the Harquahala Basin would result in approximately 0.002 million tons of salt per year.

Utilization of CAP water for irrigation purposes in the mid 1980's essentially replaced groundwater pumping in the basin. Compared to average pumping from 1951 to 1985 (104,000 ac-ft/yr), groundwater production decreased dramatically to approximately 8,500 ac-ft/yr from 1986 to 2002. During this time, average CAP water deliveries were approximately 81,000 ac-ft/yr. Although CAP water essentially replaced groundwater, the total amount used for irrigation did not decrease dramatically, and the salt contribution from agricultural irrigation practices is essentially the same at 0.002 million tons per year. However, CAP water represents a new water source inflow for the basin, resulting in additional salts of approximately 0.066 million tons per year. The additional salts were calculated based on the quantity of CAP deliveries (including seepage) and an average TDS concentration of 560 mg/l. Recharge facilities also represent additional inflow of CAP water into the basin. The Vidler Recharge Facility began pilot operations in 1998, and had recharged approximately 17,000 ac-ft of water by 2002 based on reported water deliveries (CAP, 2002).

Future salt loading in the Harquahala Basin was estimated for comparative purposes only. The future salt loading assumed that average irrigation demands from 1986 to 2002 would continue into the future, and that the Vidler Recharge Facility would operate at the maximum permitted capacity of 100,000 ac-ft/yr of CAP water. For the purposes of the annual salt accumulation graph (Figure 5), the year 2010 was arbitrarily chosen to represent the future. Additional sources of future salt loading in the basin could result from new recharge facilities in the basin. Decreases in future sources of salt loading could result from significant declines in agriculture, as predicted in the ADWR Assessment (1993).

The annual salt accumulation in the Harquahala Basin is relatively low (0.069 million tons per year) compared to recently completed salt balances in nearby basins. By comparison, the Gila Bend Basin averages approximately 0.5 million tons per year of salt, and the Salt River Valley averages approximately 1.1 million tons per year. Although the accumulated salts in the Harquahala Basin are relatively small, they are generally restricted to the agricultural area in the southeast portion of the basin. The agricultural area encompasses approximately 40,000 acres, and the downward percolation of irrigation water in this area has caused a perched water system to form above the fine-grained unit (Graf, 1980). The perched water system has significantly increased TDS concentrations compared to the regional aquifer, and cross-contamination through wells has degraded water quality locally (Hedley, 1990, Graf, 1980). Therefore, although the annual salt accumulation is relatively small in the basin, the applied area is also relatively small, and groundwater salinity has been impacted locally due to salt loading from agricultural irrigation practices.

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