CENTRAL ARIZONA SALINITY STUDY --- PHASE I

Technical Appendix G

HYDROLOGIC REPORT ON THE PINAL ACTIVE MANAGEMENT AREA

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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 Pinal Active Management Area (AMA). This report is based on literature review of publicly available information. 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 groundwater quality and surface water quality over time, with a primary focus on salinity.

2.0 PHYSICAL SETTING

The Pinal AMA is located in south-central Arizona within the Sonoran Desert section of the Basin and Range physiographic province (Figure 1). The boundary of the Pinal AMA is generally consistent with the boundary of the Lower Santa Cruz basin. The Maricopa-Stanfield, Eloy, Vekol, Santa Rosa, and Aguirre Valley sub-basins comprise the Pinal AMA (Figure 2). Water use in the AMA has been primarily in the Maricopa-Stanfield and Eloy sub-basins in the northern portion of the AMA. Due to a lack of development, little or no data is available for the Vekol, Santa Rosa, and Aguirre Valley sub-basins (ADWR, 2003). The general focus of this study has been on the Maricopa-Stanfield and Eloy sub-basins, thus they are referred to in this report as the principal sub-basins.

The Pinal AMA is adjacent to the Phoenix AMA to the north, Donnelly Wash Basin and the Tucson AMA to the east, San Simon Wash Basin to the south, and the Gila Bend Basin to the west. The Pinal AMA comprises approximately 4,100 square miles, land surface elevation ranges from 1,000 feet to 4,000 feet above mean sea level (amsl), and precipitation averages between approximately 6.5 and 8.5 inches per year (ADWR, 2000). The average daily mean temperature at a weather station at the Casa Grande National Monument is 69.4 degrees Fahrenheit (Western Regional Climate Center, 2003).

Principal surface drainage features include the Gila and Santa Cruz Rivers. Within the principal sub-basins, these rivers are generally dry except after a significant storm event (Hammett, 1992). However, the San Carlos Project delivers Gila River water for irrigation within the Pinal AMA, and Pima County wastewater treatment plants contributes intermittent flow to a portion of the Santa Cruz River (ADWR, 1993). The Gila River enters the northeast corner of the AMA and generally extends westward into the Phoenix AMA, then re-enters the northwest corner of the Pinal AMA. The Santa Cruz River enters the east side of the AMA near Picacho Peak and extends northwest as a broad wash area that discharges into the Gila River in the northwest corner of the AMA (Figure 2).

The Central Arizona Project (CAP) aqueduct flows through the eastern portion of the Eloy Sub-basin. Since 1987, water from the CAP has been utilized for irrigation uses within the Pinal AMA (ADWR, 2000). CAP deliveries are made to the Maricopa-Stanfield Irrigation and Drainage District (MSIDD), the Central Arizona Irrigation and Drainage District (CAIDD), the Hohokam Irrigation and Drainage District (HIDD), the Ak Chin Indian Community, the City of Eloy, and Arizona Water Company in Casa Grande (ADWR, 2003).

3.0 GENERALIZED GEOLOGY

Basins within the Pinal AMA are 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 principal sub-basins of the Pinal AMA are bounded by South Mountain, Sacaton, and Santan Mountains on the north; Tortilla and Picacho Mountains on the east; Silver Bell, Sawtooth, Tat Momoli, and Tabletop Mountains on the south; and the Sierra Estrella and Palo Verde Mountains on the west (Figure 2). The mountain ranges to the south and east are predominantly comprised of Tertiary volcanic and granitoid rocks. The mountain ranges on the northern and western boundaries of the principal sub-basins are predominately Tertiary granitoid rocks and Precambrian granitoid and metamorphic rocks (Reynolds, 1988).

3.2 BASIN GEOLOGY

The Pinal AMA is comprised of north trending structural troughs that include five sub-basins separated by low mountains. Based on gravity modeling, the depth to bedrock is less than 1,600 feet below land surface (bls) in the majority of the Pinal AMA (Oppenheimer and Sumner, 1980). However, gravity modeling also suggests a deep portion in each sub-basin. The deepest sub-basins include the Maricopa-Stanfield (estimated between 6,400 and 8,000 feet deep), the Santa Rosa (between 8,000 and 9,600 feet deep), and the Eloy sub-basin (between 9,600 and 11,200 feet deep). The Aguirre sub-basin is between 3,200 and 4,800 feet deep and two small basins in the Vekol sub-basin are between 1,600 and 3,200 feet deep.

Based on the study by Hammet (1989), the alluvial deposits in the principal sub-basins are separated into three distinct units, referenced as the stream alluvium, upper basin fill, and lower basin fill. A brief summary of each unit is presented below:

- ***Stream Alluvium.*** Unconsolidated fluvial deposits that are late Pliocene to Holocene in age characterize the stream alluvium. The extent of the stream alluvium deposits is restricted to the Santa Cruz and Gila Rivers and its tributaries and washes.

- ***Upper Basin Fill.*** The upper basin fill is characterized by unconsolidated to moderately cemented gravel, sand, silt, and clay. The finest fill deposits are found near the centers of the sub-basins. The upper basin fill deposits were likely deposited in an integrated (through-flowing) drainage basin. Agriculture primarily utilizes groundwater in the Upper Basin Fill for irrigation.
- ***Lower Basin Fill.*** The lower basin fill primarily consists of conglomerate and a fine-grained unit. The fine-grained unit is predominately silt and clay near the centers of

the sub-basins. However, this fine-grained unit becomes coarser at the margins of the sub-basins and includes sand and gravel lenses that are utilized for water production.

4.0 HYDROGEOLOGIC CONDITIONS

4.1 GROUNDWATER OCCURRENCE

Based on estimates by the Arizona Department of Water Resources (ADWR, 2003), the principal sub-basins contain approximately 34 million acre-feet of recoverable groundwater to a depth of 1,200 feet. Since 1989, groundwater storage in the AMA has increased due to significant flood events and reduced groundwater reliance. The primary source of groundwater recharge (inflow) to the principal sub-basins is infiltration of irrigation water from the San Carlos and Central Arizona Projects. Additional sources of recharge include groundwater flow from adjacent sub-basins and infiltration of storm water from the Gila and Santa Cruz Rivers and its tributaries. Loss of water from the principal sub-basins is primarily a result of groundwater and surface water outflow

Based on predevelopment hydrologic condition, groundwater in the principal sub-basins of the Pinal AMA generally flowed west to northwest (Freethey and Anderson, 1986), roughly following flow directions of the Gila and Santa Cruz Rivers. The estimated pre-development volume of water stored in the principal sub-basins (to a depth of 1,200 feet) was approximately 63 million acre-feet. The groundwater system was in dynamic equilibrium with slight to non-existent vertical hydraulic gradients (Hamett, 1992). Beginning in the 1930s, major groundwater development significantly changed these conditions.

Between the 1930s and 1987, more than 47 million acre-feet of water had been pumped in the Pinal AMA (United States Geologic Survey (USGS), 1986). As a result, cones of depression formed at pumping centers near the cities of Stanfield and Eloy. By 1986, water levels in the Stanfield and Eloy areas had declined more than 550 and 350 feet, respectively (Hamett, 1992). Because of extensive pumping, approximately 120 square miles of land in the area of the pumping centers subsided, a maximum of approximately 12 feet in the Eloy area (Laney, 1978). Earth fissures formed predominately at the margins of the land subsidence zones and are extensive in the Eloy area (Schumann, 1974).

Since deliveries of CAP water began in 1987, water levels in the Stanfield and Eloy areas have increased due to decreased reliance of groundwater and implementation of efficient water-use practices. Between 1989 and 1998, water levels have risen 50 to 150 feet in the Stanfield area and 50 to 175 feet in the Eloy area (ADWR, 2003).

Based on data collected in the late 1980s, two major perched water systems are identified in the principal sub-basins, formed as a result of irrigation return flow. The perched zones are located in the Casa Grande area and in an area extending from Coolidge to between Sawtooth and Picacho Mountains (Hammett, 1992). The Casa Grande perched zone is generally the result of irrigation, however after significant storm events, the Santa Cruz River also provides recharge to the zone. Depths to water in the Casa Grande perched zones range from less than 10 feet to approximately 100 feet (ADWR, 2003). The zone extending south from Coolidge is partially perched, and depths to water range between 50 and 300 feet (Hammett, 1992)

4.2 GROUNDWATER MOVEMENT

The ADWR (2000) has identified post-development inter-basin groundwater flow with respect to the principal sub-basins of the Pinal AMA (Figure 2). Major groundwater inflow has contributed to the principal sub-basins from the west by the South Picacho Peak inflow (~29,000 acre-feet per year) and from the north by the Maricopa-Stanfield inflow (~24,600 acre-feet per year). Groundwater inflow, from Waterman Wash to the west and Aguirre Valley to the south, total approximately 3,500 acre-feet per year. Groundwater outflows include the SanTan-Sacaton and Florence outflows to the north, totaling approximately 10,500 acre-feet per year. Based on the difference between inflows and outflows, approximately 46,600 acre-feet per year of groundwater flows into the principal sub-basins.

Prior to development, groundwater inflows and outflows from the principal sub-basins were generally equal. Groundwater development, beginning in the 1930s, significantly changed this condition, especially in the northwestern portion of the principal sub-basins. Due to the cones of depression, groundwater that had previously flowed out of the basin to the northwest had reversed directions and resulted in the Maricopa-Stanfield groundwater inflow.

4.3 GROUNDWATER QUALITY

According to ADWR (2003), groundwater quality in the principal sub-basins is sufficient for agricultural, industrial, and residential uses, and no major water quality concerns were identified. Based on water level and water quality data collected in the late 1980s, Hammett (1992) identified upper and lower water zones that generally correlate to the upper and lower basin fill units. In addition, a perched water zone was identified.

Total dissolved solids (TDS) concentrations are a general measure of water quality and specific conductivity is directly related to TDS concentration. TDS concentrations can be estimated by multiplying the conductivities measured in groundwater samples by 0.60.

In the upper water zone, specific conductivities range between 1,000 and 2,000 μS/cm (approximately 600 to 1,200 mg/l TDS) in the northern portion of the Eloy sub-basin and the margins of the Maricopa-Stanfield sub-basin. Water quality generally improves in the upper zone in the southern portions of the Eloy sub-basin and in the Stanfield area where specific conductivities are generally below 1,000 μS/cm (below approximately 600 mg/l TDS). Water quality distribution throughout the lower water zone is similar to the upper water zone, except in the northern portion of the Eloy sub-basin and margins of the Maricopa-Stanfield sub-basin, where specific conductivities are between approximately 3,000 and 7,000 μS/cm (approximately 1,800 and 4,200 mg/l TDS).

The perched water system is generally the result of agricultural practices and is reflected in water quality. Specific conductivities in the perched zone located in the Casa Grande area range between 2,000 and 4,000 μS/cm (approximately 1,200 to 2,400 mg/l TDS). In the perched zone that extends south from Coolidge, specific conductivities generally range between 1,300 and 2,300 μS/cm (780 to 1,380 mg/l TDS), however values up to 4,700 μS/cm (2,820 mg/l TDS) were recorded.

4.4 INTER-BASIN GROUNDWATER FLOWS AND TDS CONCENTRATIONS

The TDS concentrations of groundwater inflow and outflow were estimated from water quality parameters recorded in wells in the general areas of the inter-basin inflows and outflows. Three to seven conductivity measurements were used to estimate an average TDS concentration for each flow (Hammett, 1989 and Reeter, 1986) and are presented in Table 1. Assumptions utilized to determine average values are listed below:

TABLE 1. AVERAGE ANNUAL INTER-BASIN GROUNDWATER FLOW AND TDS CONCENTRATIONS

DESCRIPTION	FLOW (acre-feet per year)	AVERAGE TDS CONCENTRAION (mg/l)
South Picacho Peak Groundwater Inflow	29,000	290
Maricopa-Stanfield Groundwater Inflow	24,600	2,292
Aguirre Groundwater Inflow	2,900	393
Waterman Wash Groundwater Inflow	600	580
Santan-Sacaton Groundwater Outflow	7,500	1,604
Florence Groundwater Outflow	3,000	884
Total Groundwater Inflow	46,600	

- Groundwater flow, ADWR (2000).
- Groundwater inflow and outflow and TDS concentrations remain constant.
- Average TDS concentrations based on specific conductivity values in the flow areas.

4.5 SALT ACCUMULATION DUE TO AGRICULTURE

Between 1984 and 1998, Pinal AMA agriculture utilized between 800,000 and 1,200,000 acre-feet of water per year (ADWR, 2000). For purposes of this study, an annual average of 1,000,000 acre-feet of water was utilized for irrigation in the AMA. Based on previous salt contribution calculations from irrigation in the Salt River Valley, crop irrigation in the Pinal AMA would result in approximately 0.0200 million tons of salt per year.

5.0 SURFACE WATER CONDITIONS

5.1 SURFACE WATER OCCURRENCE

Surface water features in the Pinal AMA include the Gila and Santa Cruz Rivers and the CAP aqueduct. The Gila and Santa Cruz Rivers are generally dry, except after significant storm events that result in surface water inflow and outflow from the principal sub-basins, and in areas where flow is contributed by wastewater treatment facilities. Annual surface water inflow and outflow from the principal sub-basins are shown on Figures 3 and 4.

The Gila River is generally dry due to a diversion at the eastern edge of the Eloy Sub-basin. The diversion provides irrigation water for the San Carlos Irrigation Project. Between 1934 and 1984, the San Carlos Irrigation Project has provided an average of approximately 218,000 acre-feet of Gila River water per year to the AMA, however yearly deliveries vary depending on the flow of the Gila River (ADWR, 1993). For example, between 1985 and 2000, the diversion has delivered between approximately 60,000 and 425,000 acre-feet per year (USGS, 2002). Some of this water is utilized by the Gila River Indian Community in the Phoenix AMA. However for this study, it is assumed that surface water use outside the Pinal AMA is negligible

The Santa Cruz River is generally dry in the Pinal AMA, however, inflow does occur due to the discharge of treated effluent from Pima County wastewater treatment plants. In addition, intermittent inflow and outflow generally occurs due to storm events (Figure 5). The Ina Road Waste Pollution Control Facility has been utilizing the Santa Cruz River for effluent discharge since 1978 (personal communication, 2003). The flow of the Santa Cruz River is measured by a USGS surface water station (#09486500), located approximately 22 miles upstream from the Pinal AMA. Between 1940 and 1977, an average of 26,000 acre-feet per year was recorded at this station. Flow increased to an average of 68,000 acre-feet per year (between 1978 and 2000) after construction of the Ina Road Plant. Minor diversions utilize this water in the Tucson AMA, however most of this flow evaporates or infiltrates (ADWR, 1993).

For the purposes of this study, an estimate of the amount of Santa Cruz river flow into the Pinal AMA was calculated. A USGS surface water station (#09486520) is located approximately 6 miles upstream from the Pinal AMA. Since 1996, flow at this station has been approximately 45 percent of the flow recorded upstream near the Ina Road facility. Based on the change in flow over distance between surface water stations and the border of the Pinal AMA, the flow of the Santa Cruz River to the Pinal AMA is estimated to be approximately 9 percent of the flow measured at USGS Surface Water Station #09486500. Additional inflow such as irrigation tailwater is considered negligible for this study.

The CAP aqueduct flows in the eastern portion of the Eloy Sub-basin, and began providing water to the AMA in 1987 (ADWR, 2003). Between 1989 and 1994, CAP deliveries to customers in the Pinal AMA averaged approximately 343,000 acre-feet per year (ADWR, 2003). Non-Indian irrigation districts were the predominant users of the CAP deliveries, Indian deliveries accounted for approximately 20 percent, and municipal use accounted for less than 1 percent.

5.2 SURFACE WATER QUALITY

Surface water quality data was aquired from USGS surface water stations on the Gila and Santa Cruz Rivers (USGS, 2003). Water quality data for the Gila River was obtained from a station near Kelvin, Arizona, approximately 19 miles upstream of the Pinal AMA. Gila River TDS concentrations and flow data were analyzed for the period between 1950 and 2000. Flow varied from less than 1 cubic foot per second (cfs) to 12,200 cfs, and TDS concentraions ranged between 184 and 4,330 mg/l. In general, during high river stages, TDS concentraions were low; during low-flow periods, TDS concentrainos were higher. This general relationship is shown on Figure 5 over a typical four year period. The average TDS concentration for the total Gila River flow between 1950 and 1987 was 653 mg/l. Between 1988 and 2000, the average TDS concentration was 596 mg/l.

Water quality data for the Santa Cruz river is limited in the study area. However, TDS concentration data is available from two USGS surface water stations (Figure 6). For this study, USGS Surface Water Station #09486500 (near the Ina Road Facility) represents water quality of Santa Cruz river inflow. One measurement of 335 mg/l TDS was recorded prior to completion of the Ina Road Facility and represents the TDS concentration of Santa Cruz River inflow between 1950 and 1977. The average TDS concentration of numerous samples collected in 1996 and 1997 is 527 mg/l, and this value represents the TDS concentration of Santa Cruz inflow between 1978 and 2000.

Numerous water quality samples were collected between 1976 and 1981 at USGS Surface Water Station #09489000 which was located on the Santa Cruz River, near the confluence with the Gila River in the northwest portion of the Maricopa-Stanfield sub-basin. The average TDS concentration of these samples is 362 mg/l. For purposes of this study, a TDS concentration of 362 mg/l is utilized for the surface water outflow of both the Santa Cruz and Gila Rivers.

5.3 HISTORICAL SURFACE WATER FLOWS AND TDS CONCENTRATIONS

The time period from 1950 to 2000 can be divided into two distinct intervals on the basis of annual surface water flow into the Pinal AMA. The interval from 1950 to 1987 represents the period of extensive groundwater pumping and Gila River diversions prior to major utilization of CAP water. The delivery of CAP water to the AMA is reflected in the 1988 to 2000 interval. The relationship between average annual surface flows and TDS concentrations is illustrated in Table 2, and assumptions utilized to determine average values are listed below:

TABLE 2. AVERAGE ANNUAL FLOW AND TDS CONCENTRATIONS IN SURFACE WATERS OF THE PINAL AMA

DESCRIPTION	1950 TO 1987	1988 TO 2000
Average annual Gila River diversions (acre-feet)	218,115	318,032
Average TDS concentrations in the Gila River diversions (mg/l)	653	596
Average annual Gila River outflow (acre-feet)	24,570	98,688
Average TDS concentrations in the Gila River outflow (mg/l)	362	362
Average annual Santa Cruz River inflows (acre-feet)	3,286	6,195
Average TDS concentrations in the Santa Cruz River inflow (mg/l)	391	527
Average annual Santa Cruz River outflows (acre-feet)	15,682	10,342
Average TDS concentrations in the Santa Cruz River outflow (mg/l)	362	362
Average annual CAP deliveries (acre-feet)		342,850
Average TDS concentrations of the CAP (mg/l)		640

- Gila River 1950 to 1987, average diversion between 1934 and 1984 (ADWR, 1993).
- Gila River 1988 to 200 diversions, USGS (2003).
- Entire Gila River delivery was used in the Pinal AMA.
- TDS values for the Gila River are averages of the entire flow for each interval at a USGS surface water station near Kelvin, Arizona.
- Gila River outflow, USGS Surface Water Stations Nos. 09479500 and 09479350 (2003).
- Santa Cruz outflow, USGS Surface Water Station #09489000 (2003).
- TDS concentration of Gila River outflow is equal to Santa Cruz River outflow.
- Santa Cruz inflow is estimated to be 9.1 percent of the flow measured by a USGS surface water station near the Ina Road Facility.
- TDS values for the Santa Cruz River inflow and outflow are averages of available USGS data.
- CAP deliveries, average of available data from the ADWR (2003).

The apparent increase in Gila River outflow between 1988 and 2000 is mainly due to a significant storm event in 1993 (Figure 3). The increase in Santa Cruz River inflow in the 1988 to 2000 interval is due in part to discharge from the Ina Road Facility.

6.0 GENERALIZED SALT BALANCE

Based on surface and groundwater data presented in Sections 4.0 and 5.0, a generalized salt balance was calculated for the principal sub-basins of the Pinal AMA. Results of the salt balance are presented in Table 3, and assumptions utilized in the salt balance are listed below:

TABLE 3. GENERALIZED SALT BALANCE FOR THE PRINCIPAL SUB-BASINS OF THE PINAL AMA

DESCRIPTION	1950 TO 1987	1988 TO 2000
Average salt inflow from the Gila River (millions tons per year)	0.1937	0.2578
Average salt outflow from the Gila River (millions tons per year)	0.0121	0.0486
Average salt inflow from the Santa Cruz River (millions tons per year)	0.0017	0.0044
Average salt outflow from the Santa Cruz River (millions tons per year)	0.0077	0.0051
Average salt inflow from the CAP Aqueduct (millions tons per year)		0.2984
Average salt inflow from groundwater inflow (millions tons per year)	0.0683	0.0683
Average salt inflow from agricultural practices (millions tons per year)	0.0200	0.0200
Average salt accumulation in the principal sub-basins (millions tons per year)	0.2639	0.5952

- Assumptions for Tables 1 and 2 apply to Table 3.
- Average Pinal AMA water demand of 1,000,000 acre-feet per year.

Prior to utilization of the CAP Aqueduct, the primary source of salt contribution in the principal sub-basins was from the utilization of Gila River (approximately 69 percent), followed by groundwater inflow (approximately 26 percent), and agricultural practices (approximately 8 percent). The Santa Cruz River acted as a salt sink, removing approximately 2 percent of the salt accumulated in the principal sub-basins.

CAP utilization dominates salt accumulation and accounts for approximately 50 percent of the salt accumulation between 1988 and 2000. In this time interval, Gila River utilization accounted for approximately 35 percent of salt accumulation, followed by inter-basin groundwater inflow (approximately 12 percent), and agricultural practices (approximately 3 percent). Removal of salt in surface water outflow was negligible in this time interval.

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