CENTRAL ARIZONA SALINITY STUDY—PHASE I

Technical Appendix H

Salinity in the Salt River Valley, Arizona: A Historic Perspective

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Abbreviations

Acre-feet per year – Af/Yr
AMA – Active Management Area
CAP – Central Arizona Project
CASS – Central Arizona Salinity Study
LCU – Lower Conglomerate Unit
MFGU – Middle Fine-grained Unit
mg/l – Milligrams per liter
myo – Million years old
SRP – Salt River Project
TDS – Total dissolved solids
UAU – Upper Alluvial Unit

1.0 Introduction

Salinity has been an issue in the central Arizona area since irrigated agriculture was initiated but recently an increase in overall salinity has been noted in the surface water, groundwater and reclaimed water resources in the area. Salinity is a general term for a range of minerals dissolved in water or deposited in the soils. These minerals give a salty taste to water and thus the term salinity is used to describe the conglomeration of dissolved minerals. Some of these minerals occur naturally within central Arizona and can be found in the geologic deposits or in the rivers that flow into the area. The importation of Colorado River water and use of water treatment processes such as water softening and demineralization has increased the amount of salinity in the central Arizona area. Initial assessments have verified that a large portion of the total natural and imported salinity remains in the area trapped in the groundwater or in the soils and recycled in the wastewater/reclaimed water reuse process.

The U.S. Bureau of Reclamation and a large group of stakeholders initiated the Central Arizona Salinity Study (CASS) to identify the sources of salinity, develop a salt balance, determine the economic impact on the area and to develop recommendations to reduce the salinity and the corresponding economic impacts. As a part of this study, the Bureau of Reclamation funded a series of white papers to address specific salinity issues. This white paper addresses the historic sources and patterns of salinity within the central Arizona area.

The area of investigation in this white paper includes the general central Arizona area shown on Figure 1-1. The inset map shows the location of the two Active Management Areas (AMA) in central Arizona; the Phoenix AMA and the Pinal AMA. The larger map area shows the Sub-basins within the two AMAs within this white paper study area. The entire area of the CASS study is larger than this white paper study area because it includes the Gila Bend area to the southwest and the Tucson area.

1.1 Purpose

Salinity in central Arizona has been a natural occurrence and can be traced back through geologic history. The purpose of this white paper is to present the historic perspective of salinity to assist others in evaluating the current impacts and to project future impacts. This historic perspective will discuss the geologic history of the central Arizona area and some of the natural sources of salinity. It will also discuss the changes in groundwater salinity that has occurred over time and how irrigation practices and the importation of Colorado River water has changed the historic salt balance.

2.0 Regional Geology

When viewed in the geologic perspective, the minerals that are present in the sediments, soils and groundwater in central Arizona were imported from other areas. Sources of salinity can be identified throughout the drainage areas in formations that are as much as 225 million years old (myo). A review of a geologic map of the southwest shows there are Mesozoic Era formations throughout eastern and northern Arizona (Oetking, 1967). Presumably, these formations were more extensive in the geologic past before erosion shaped them to their present configuration. Many of these formations were formed in marine environments where the sandstones, shales, siltstones and limestones deposited. The sodium, calcium, potassium, chloride and carbonate ions trapped in these formations yielded the minerals to surface water and groundwater as the formations eroded. Rivers transported the minerals into the central Arizona area. The geologic map also shows there are large areas of Tertiary Period volcanic rocks east and south of the central Arizona area. These rock units would yield a wide range of minerals including sulfate compounds to the water as the rocks eroded. These minerals were also transported to central Arizona.

The transportation of salinity into central Arizona from these geologic formations continues to the present. The early explorers were very descriptive in naming features and the Salt River was named because of its salty taste attributed to the high concentration of total dissolved solids (TDS) contained in its water when compared to other rivers in the area. The primary source of these salts is a series of salt springs on the Fort Apache Indian Reservation east of the white paper study area.

2.1 Bedrock and Structural Geology

The character of the central Arizona area seen today began to form during the middle Tertiary Period about 30 to 20 myo when tectonic forces stretched the crust and a series of faults formed the basin and range physiographic province. Portions of the bedrock moved up relative to the basins that dropped down. The surface blocks of bedrock remnants form the mountains ranges seen throughout central Arizona. The basins became repositories for the materials eroded from the local bedrock and transported from other areas by the rivers flowing into the basins. Figure 2-1 shows the physiography of the central Arizona basins and ranges.

The bedrock mountains surrounding the basins in central Arizona are predominately Precambrian Era (greater than 550 myo) granite, gneiss and schist and Tertiary Period granite and volcanic rocks (Wilson, et.al. 1957). Most granite, gneiss and schist rock units do not yield the minerals commonly associated with the TDS salinity. Some volcanic rock units can yield sulfate compounds and these can contribute to salinity.

2.2 Sedimentary Geology

The sediments eroded from the mountains surrounding the basins and transported into the basins have been divided into three regional sedimentary units; the Lower Conglomerate Unit (LCU), Middle Fine-grained Unit (MFGU) and Upper Alluvial Unit (UAU).

2.2.1 Lower Conglomerate Unit

The LCU is classified as a fanglomerate, is primarily composed of pebble to cobble sized fragments of rocks from the surrounding mountains. The LCU also contains a significant amount of sand. These sediments indicate there was a high-energy environment capable of transporting these large materials. The presence of cobbles indicates the materials were not transported great distances because they would have been broken down into smaller fragments. The lack of fine-grained sediments in most of the LCU indicates there could have been a flow through system where there was sufficient energy in the water to transport the fine-grained materials out of the basin leaving the larger and heavier sediments behind. There could have been local closed basin areas where the transportation of sediments was over a short distance and thus the sediments are coarse-grained because the period of erosion during transport was limited. The upper portion of the LCU transitions into fine-grained sediments and these indicate there was a low energy, closed basin depositional environment at that time.

The LCU can form an aquifer unit and the water quality varies from good to marginal depending on the specific local conditions. In some places the LCU groundwater has been impacted by minerals such as fluoride or arsenic due to natural processes. In other areas the LCU has high TDS groundwater because it has been impacted by percolation from overlying sediments or minerals in the fine-grained sediments. The nature of the sediments in the majority of the LCU do not indicate that a depositional environment was present that would result in the formation of materials and layers within the LCU that would yield salinity to groundwater.

2.2.2 Middle Fine-Grained Unit

The MFGU is sometimes called the Middle Alluvial Unit but that name does not describe the sedimentary character of the unity. The MFGU represents a very different depositional environment than the LCU. The MFGU sediments are primarily fine-grained clay and silt sediments deposited during the middle to late Tertiary Period and are about 10 to 5 myo. The fine-grained sediments indicate a very low energy depositional environment existed during that period. It is possible that the volcanic activity that occurred during this time period blocked the drainage paths and produced closed basins with lakes. As the lake sediments accumulated the grade of the land surface became flatter and the energy available to transport sediments was further reduced. The result was a condition that looks like the Great Salt Lake basin or Death Valley. Because drainage in the basins was cut off, the water evaporated and evaporite minerals such as halite (salt), gypsum and anhydrite were deposited in playa lake beds. These evaporite sequences dominate the lower and middle parts of the MFGU and clay layers dominate the upper part.

The MFGU overlies the LCU and due to the fine-grained nature of the MFGU, it generally forms a seal trapping groundwater in the LCU. Most of the recharge to the LCU occurs around the edges of the basins and any additions to the salinity of the groundwater in the LCU is introduced in the peripheral area or where it is in contact with the base of the MFGU sediments.

The MFGU does contain evaporite deposits that represent potential sources of groundwater salinity. There is a large salt dome in the West Salt River Valley Sub-basin that demonstrates that portion of the basin area contained a large lacustrine or playa environment for a very long period. The Luke Salt Dome will be discussed in Section 3 of this white paper. The playa lake deposits have been identified in the MFGU throughout the central Arizona area (Bureau of Reclamation, 1976).

Not all of the groundwater in the MFGU is poor quality. There are coarse-grained layers within the upper part of the MFGU that form an excellent aquifer capable of yield good quality groundwater in high rate pumping wells.

2.2.3 Upper Alluvial Unit

The youngest unit is the UAU and it overlies the MFGU throughout most of the areas of the central Arizona basins. Along the basin margins where the MFGU is absent, the UAU overlies the LCU. Deposition of the UAU began about 3 myo and continues today. The UAU is the surface unit of the basins. The UAU represents another change in the depositional environment in the central Arizona basins. The UAU contains a mixture of sediments that range in size from cobbles to clay and the layers within the UAU vary in sediment composition, thickness and areal extent.

The original groundwater within the UAU was impacted by the salinity of the Salt River and this is discussed in Section 4 of this white paper. Human activities have increased the area of the UAU impacted by salinity and this is discussed in Section 5.

2.2.4 Geologic Cross-Section

Figure 2-2 presents a generalized typical cross-section of the geology through a central Arizona basin. It shows the regional relationship of bedrock with the basin faults and the three sedimentary units. It also shows the stratigraphic position of the Luke Salt Dome.

3.0 Luke Salt Dome

The Luke Salt Dome is a massive deposit of halite (sodium chloride) located in the west Salt River Valley area near Luke Air Force Base (Figure 3-1). The Arizona Geological Survey estimated this salt body may be at least 6,000 feet thick and as much as 10,000 feet thick and contains 15 cubic miles of salt (Rauzi, 2002).

Salt is not deposited in a dome shaped form but rather in flat layers similar to what can be seen in Death Valley, California. When the salt layers are buried by additional layers of sediment and the thickness and weight of the overlying sediments increases, the salt begins to slowly flow. Salt is less dense than the sediments and once a weak spot is formed in the sediments, the salt begins to form an upward bulge. This process continues and the weight of the sediments forces the salt to form a dome. As the salt rises, the sediments above the dome also begin to bulge up. In the west Salt River Valley just west of Luke Air Force Base, there are some small hills near Dysart Road and Bethany Home Road that represent this uplift of sediments above the salt dome.

The deposition of 15 cubic miles of salt required a long period to form. Using present day information developed as a part of the CASS study a conservative time period can be estimated. The CASS data for the average year shows the following information:

- Salt River and Verde River at Granite Reef Diversion Dam – inflow 770,000 Acre-feet per year (Af/Yr) and a salinity of 480 milligrams per liter (mg/l).
- Gila River at Ashurst Hayden Dam – inflow 90,000 Af/yr and a salinity of 550 mg/l.
- Agua Fria River at Waddell Dam – 50,000 Af/Yr and a salinity of 400 mg/l.

The present day average conditions may not reflect the conditions during the Miocene when the salts were being deposited. The deposition of salts and the fine-grained sediments indicate it may have been dryer and thus the inflow rates would be less than today. However, the present day conditions can provide a general order of magnitude for this volume of salt to be deposited. These three rivers bring roughly 610,000 tons of TDS into the Phoenix valley each year. This is equal to a volume of 9 million cubic feet or 0.00006 cubic miles of salts. If the Luke Salt Dome contains at least 15 cubic miles of salt, it would have required about 250,000 years to bring that volume of salts into the valley based on current conditions. If the climate was dryer, the time for deposition would be longer. This calculation demonstrates that the importation and deposition of salt related minerals has been a long-term condition in the central Arizona area.

The Luke Salt Dome impacts some of the groundwater in the west Salt River Valley area but not the majority of the groundwater. Most of the salt is contained in the clay sediments of the MFGU and this seals it away from overlying sediments that contain groundwater. However, near the Dysart Road and Bethany Home Road area where the salt dome is a few hundred feet below the surface it does impact the groundwater and the TDS can reach 40,000 mg/l.

The Luke Salt Dome also contributes to the geologic hazards in the area, not because of the salt contamination but rather due to the structure and location of the dome. Groundwater pumping has been used in the west Salt River Valley around the Luke Air Force Base for decades and as a result the water table has declined several hundred feet and formed what is called the Luke Sink, an area of water table depression. Associated with this water table decline is land subsidence caused when alluvial sediments are dewatered and the weight of overlying sediments caused the pore spaces to collapse. The result is a regional lowering of the land surface due to subsidence. When there is a structure in the land subsidence area, like the Luke Salt Dome, compaction is not equal because the thickness of sediments above the structure is thinner than the thickness of sediments around the structure. The differential compaction can produce earth fissures and these rapidly erode into fissure gullies. There are fissures and fissure gullies around the Luke Salt Dome. This demonstrates that the impact of historic salinity in the central Arizona area are not only related to groundwater quality.

The Salt Dome does have economic benefits. Morton Thiokol operates a salt mine in Glendale. Water is pumped down into the dome where it dissolves the salt. The fluid is pumped to the surface into evaporation ponds where the salt is deposited and harvested for sale. Liquefied petroleum gas is pumped into the cavities as a part of a gas storage project.

4.0 Historic Salt River

The configuration of the historic Salt River did not always appear as it does today. During the deposition of the UAU, which began about 3 myo, the river channel changed location. The reasons for these changes are both structural and sedimentary.

The structural reason for potential changes in the Salt River channel location is documented by the terraces mapped along the rivers. Terraces formed as sediments were deposited adjacent to the historic river. Mapping shows that the terraces that formed along the Salt River, as well as the Agua Fria, New River and Queen Creek changed over time. In the Salt River Valley, the evidence is that the mountains continued to rise changing the base level of the rivers. This is a structural change. As the mountains rose, the river became unstable in the channel it had eroded and it began to erode a new channel into the terrace deposits and formed a new lower level terrace. This was not a one-time event. In the Salt River Valley a series of four historic terraces were mapped in addition to the modern floodplain (Péwé, 1978). These are from oldest to youngest; Sawik, Mesa, Blue Point, and Lehi Terraces. Each time the base level changed it provided the energy for the Salt River to cut a new channel.

Subsurface geologic investigations have verified that the depth to the bedrock of the basement of the central Arizona area varies. In areas between the mountains such as between the Phoenix Mountains and South Mountain or between the Sierra Estrellas and the White Tank Mountains, the bedrock is closer to the surface than in the center of the basins. When the UAU was being deposited, the bedrock may have formed shelves that could block the flow of the rivers. Lee (1905) proposed that the Salt River might have flowed south to join with the Gila River on the south side of South Mountain in the past. This was based on an analysis of the surface physiography and analysis of the sediments penetrated by water wells. The area between South Mountain and the San Tan Mountains is a broad flat plain while the area between the Phoenix Mountains (which includes Papago Buttes, Tempe Butte, and Camelback Mountain) and South Mountain is much narrower and the bedrock is closer to the surface. When the surface of the UAU was lower in the past because there was less sedimentary material in the valley, the Salt River could have flowed in the alternate path hypothetically shown on Figure 4-1 because the path between the Phoenix Mountains and South Mountain was blocked by the bedrock. As the sedimentary material continued to accumulate and the base level changed due to structural actions, the course of the Salt River was altered to follow the path seen today. Péwé suggested that the Salt River changed course after the Sawik and Mesa terrace periods.

Additional evidence that the Salt River may have flowed south of South Mountain is presented on Figure 4-2. The pink and purple colors on the map represent areas where the salinity ranges from 1,000 to more than 3,000 mg/l. These high TDS water areas surround South Mountain. The area of impact of the high TDS water probably is greater today than it was historically, due to the activities of man moving water away from the river for irrigation.

5.0 Groundwater Salinity

The previous sections of this white paper documented the historic salinity in the Salt River valley area before human activity changed the conditions. The primary reason for the change caused by humans was the need to divert water from the river for irrigation of crops. Abandoned Indian canals showed irrigation had occurred centuries before the Salt River Project (SRP) system of dams and canals were built. This had an effect on the pattern of salinity.

In geologic history, the high salinity areas were primarily associated with the location of the Salt River, but with the practice of irrigation the water was moved across the surface of the basins and spread over a wider area. Figure 5-1 shows salinity data plus the locations of SRP canals. This system distributes Salt River water over a wide area of the valley. Figure 5-1 shows the configuration of the SRP canals and the location of high salinity zones. The areas where the TDS ranges from 1,000 to greater than 3,000 mg/l is shown in pink and purple. In many limits of the areas with the higher TDS is generally associated with the lands irrigated by the SRP canals.

When farmers use water with a high TDS for irrigation they must apply more water than is needed to grow the crops. This extra water is used to flush or leach the salts deposited in the soil by the irrigation water to depths below the root zone of the crops. Over time, this leaching percolates down to the aquifer and increases the salinity of the groundwater below the irrigated fields. SRP water deliveries begin in the east part of the Salt River Valley and water is conveyed by the canals to the west. The water used in the east part of the SRP system is almost all surface water. SRP developed a series of wells along the canal system to supplement the available Salt River flow. Wells pump groundwater from beneath the eastern areas and add it to the canal flows. This combined flow is transported west where some of the water is used for irrigation. Again, due to leaching the recharge to the aquifer from the fields has a greater salinity than the irrigation water. Wells in this second area add water to the canals and the process is repeated until by the time the flow in the canals reaches the far western part of the SRP system a large proportion of the water is well water. This is how the water is recycled. The leaching water recharges the aquifer with water that has a greater salinity than the source irrigation water. As the water is recycled from the east to the west the salinity increases and is discussed in Section 5.4.

5.1 1905 Conditions

The earliest major report on the water supply of the central Arizona area was prepared by Lee (1905). However, by 1905, modern irrigation had been practiced in the Phoenix area for almost 40 years and historic irrigation had been practiced for centuries. Lee’s water quality data is reported as parts per 100,000 and thus all concentrations reported are multiplied by 10 to convert the data to parts per million (equivalent to mg/l) for use in this white paper. Many of the wells described by Lee were really sumps rather than wells. Pits were excavated until water was encountered, then a pump was installed. Many pits were excavated close to the Salt River or where the groundwater was very shallow and influenced by the river. This means the water quality data really reflects the surface water quality rather than groundwater quality. These wells are not used in this white paper for analyses. Some shallow wells located away from the Salt River, Gila River and Agua Fria River probably were pumping shallow groundwater and while the groundwater may have been influence by irrigation leaching, they do reflect groundwater quality. These shallow wells are used in this white paper for analyses. Some deeper wells were drilled but were less than 300 feet deep and thus constructed in the UAU. Wells did not penetrate the MFGU our LCU. These wells reflect groundwater quality and are used in this white paper analyses.

Figure 5-2 presents the groundwater salinity based on the data in the Lee report. Most of the wells with water quality information were concentrated it a few areas, thus the interpretations of regional groundwater salinity shown on Figure 5-3 is not very detailed. The figure shows areas where the TDS is less than 1,000 mg/l and the concentrations ranged from 320 to almost 1,000 mg/l. Figure 5-2 also shows where the TDS was between 1,000 and 1,500 mg/l and where it is greater than 1,500 mg/l. Some of the analytical results in the highest TDS area ranged as great as 5,000 mg/l. There was insufficient information to attempt to develop TDS contours for concentrations greater than 1,500 mg/l.

The 1905 data shows the greatest TDS concentration was located along the Salt River and the concentration decreased to the west. The area with the best quality water was located on the north side of the Salt River between the two 1,000 mg/l contour lines.

5.2 1973 Conditions

Figure 5-1 presents the salinity data for the 1973 period (Kister, 1974). There was much more information available in 1973 then in 1905 and thus the TDS areas are presented in greater detail. The figure shows that a large portion of the central Arizona area has TDS concentrations greater than 1,000 mg/l and that the groundwater with TDS concentrations less than 1,000 mg/l are located along the edges of the basins away from the Salt River. There is no indication that the salinity of the groundwater increased or the area impacted by TDS greater than 1,000 mg/l increased between 1905 and 1973 just that there was more information available in 1973.

5.3 1976 Conditions

Figure 5-3 presents the groundwater salinity in 1976 (Reclamation, 1976). This information is shown as specific conductance but is converted to mg/l on the legend to be consistent with the information shown on other figures. The information for 1976 is very consistent with the information presented for 1973. The areas of low TDS concentrations are still north and east of the SRP area. The TDS concentration increases to the west and south to more than 3,250 mg/l.

Figure 5-3 also shows the chemical nature of the TDS minerals by classifying the groundwater. The areas influenced by the Salt River, Gila River and SRP irrigation are sodium – calcium chloride waters, similar to the salt in the salt dome.

5.4 1999 to 2002 Conditions

By 1999, conditions had changed again in the Phoenix area. Central Arizona Project (CAP) water was being imported from the Colorado River and used to supplement irrigation water and as a part of the municipal supply for areas outside of the SRP boundary. CAP water averages about 650 mg/l and is a new source of salinity being imported to the central Arizona area.

The majority of CAP water is used for municipal supply. Interior use of CAP water has increased the salinity measured at the wastewater treatment plants and water reclamation plants. This may have an impact on the use of reclaimed water produced by these facilities. Exterior use of CAP water may be building salinity in the soils. Most residential irrigation is for turf and ornamental plants and the homeowners do not add the quantity of water needed for leaching as do farmers. Much of the salinity associated with CAP water may be building in the soil layers just below the plant root zones and will remain in the soil unless a wet period with high rainfall totals flushes the salinity to deeper soil zones.

The use of CAP water outside of the SRP boundary means the area of potential TDS impacts has expanded again. The first expansion from the river corridor was associated with SRP water use and the second is with CAP water use. In 1999, the average TDS of SRP water measured at Granite Reef Diversion Dam was 563 mg/l while the SRP water averaged 518 mg/l at the same location.

The information on Figure 5-4 shows the average TDS concentrations within the SRP area and this is consistent with the information presented on previous figures.

Figure 5-5 presents the TDS concentrations measured in the SRP system in 1999 (SRP, 1999). This information confirms that the salinity of SRP water generally increases from the east to the west. This is very apparent in the portion of the system south of the Salt River where the TDS increases from 518 mg/l measured in the south canal to 823 mg/l at the end of the Western Canal. Water is diverted into the Arizona Canal on the north side of the Salt River and it had a TDS concentration of 518 mg/l at Granite Reef Diversion Dam. The impacts of the higher salinity groundwater shown in Figure 5-1 are evident in this northern part of the SRP system. The Grand Canal is the southern of the two canals and much of it passes through the area where the groundwater averages 1,000 to 3,000 mg/l and thus by the time the water reaches the end of the Grand Canal the TDS concentration is 612 mg/l. The Arizona Canal is north of the Grand Canal and passes through areas where the groundwater TDS is from less than 500 mg/l to 1,000 mg/l. This higher quality groundwater results in better quality canal water and the Arizona Canal TDS averaged 503 mg/l at the Agua Fria River.

Figure 5-5 shows the concentration of three irrigation drainage system discharges, two near the Gila River and one in the east portion of the SRP system. This data shows how the concentration of SRP water is changed as it runs off irrigated fields. In the east valley the concentration of the irrigation water was 681 mg/l but the drain water TDS concentration was 1,347 mg/l. The Western Canal water averaged 823 mg/l and the drain on the south side of the Gila River averaged 888 mg/l. The Grand Canal water averaged 612 mg/l of TDS and the drain averaged 945 mg/l.

6.0 Conclusions

The information developed in this white paper confirms:

- Salinity has been imported into the central Arizona area for millions of years from geologic formations east and north of the area and is not a new problem.
- Geologic conditions in the past fostered the deposition of huge salt deposits that now form a salt dome in the West Salt River Valley. Mining the dome provides and economic benefit but the dome impacts local groundwater quality and contribute to the formation of geologic hazards.
- The Salt River probably flowed south of South Mountain to join with the Gila River but now flows north of South Mountain.
- The earliest documentation of groundwater quality was in 1905 and by then the groundwater may have been impacted by irrigation return flows. Subsequent groundwater quality analyses confirm that the poorest quality groundwater is in a zone that follows the Salt River and Gila River while the areas with the highest quality groundwater are located closer to the mountains.
- The dominant groundwater is a sodium-calcium chloride water.
- Farming activities have contributed to the spread of poor quality, high salinity water from the river corridor to throughout the irrigated area.
- Central Arizona Project water is importing additional salts into the central Arizona area and the CAP water is being used in areas where SRP water was not used. This is potentially increasing the areas impacted where salinity will be accumulating in the groundwater and soils.

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