MOJAVE RIVER TRANSITION ZONE RECHARGE PROJECT

PHASE I REPORT
TRANSITION ZONE HYDROGEOLOGY

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EXECUTIVE SUMMARY

This report is the culmination of Phase I of the Mojave River Transition Zone Recharge Project. Phase I, Transition Zone (TZ) Hydrogeology, entails describing the interrelationship of hydrogeologic conditions governing the TZ water bridge concept. The TZ water bridge is the physical and natural means by which surface and groundwater are conveyed to the Centro Subarea through the TZ from the upper Alto Subarea. Phase I also entails evaluating the potential for artificial recharge programs based on these interrelating hydrogeologic concepts. The four phases of the Mojave River TZ Recharge Project identified by Mojave Water Agency are:

Phase I	Define Transition Zone Hydrogeology,
Phase II	Assess Current Supply and Demand & Project Future Demand,
Phase III	Perform Candidate Recharge Site Analysis, and
Phase IV	Assess Current Regulatory Environment in Relation to the Proposed Recharge Activity and Prepare Environmental Documentation.

GEOLOGY

The TZ consists of complex fault and erosion controlled bedrock depressions that are partially filled with consolidated sedimentary materials, which in turn are covered with unconsolidated sediments. Sedimentary units include Tertiary-age consolidated sediments, Quaternary-age Older and Younger Alluvium, and Quaternary-age fluvial deposits. The Tertiary-age consolidated sediments are overlain by Older Alluvium of the age-equivalent Victorville Fan deposits. Bedrock occurs at depths up to 3,000 feet. The Tertiary deposits range in thickness between 600 and 1,600 feet and the Quaternary deposits range in thickness between 800 and 1,200 feet. The paleo Mojave River channel, eroded into the Older Alluvial deposits, has been partially backfilled with Mojave River fluvial deposits consisting of interbedded sand, gravel, boulders, silt, and clay.

HYDROGEOLOGY

TZ formations can be grouped into three hydrogeologic units: 1) nonwater-bearing units composed of bedrock and consolidated sediments, 2) the Regional aquifer composed of Older Alluvium, and 3) the Floodplain aquifer composed of Mojave River fluvial deposits. Nonwater-bearing units that underlie the Regional aquifer form the effective base of the groundwater system. The Regional aquifer is generally located between exposed bedrock outcrops and underlies the Floodplain aquifer. The Regional aquifer generally is up to 1,200 feet thick in the center of the TZ. Beneath the Floodplain aquifer, the Regional aquifer ranges between 150 and 840 feet thick. The Regional aquifer contains locally perched groundwater. The Floodplain aquifer is generally between 250 and 300 feet thick. In the Floodplain aquifer, shallow and deep zones can be distinguished through the central TZ. The shallow zone generally corresponds with areas of dense riparian vegetation. The Floodplain aquifer is generally as wide as the Mojave River channel between eroded bluffs. The Floodplain aquifer has a much higher transmissivity than the Regional aquifer. The Floodplain aquifer forebay occurs between the Lower Narrows and Oro Grande south of the shallow and deep zone separation.

A downward hydraulic gradient occurs in the forebay towards the underlying Regional aquifer indicating the Regional aquifer may receive recharge from the Floodplain aquifer in this area. An afterbay exists in the Floodplain aquifer near the Helendale fault north of the distinction of the shallow and deep zones. North of the forebay, the vertical gradient between Floodplain and Regional aquifer slowly reverses as the width of the Regional aquifer narrows at the latitude of Bryman. As the Regional aquifer widens north of Bryman, the vertical gradient again gradually reverses to a slight downward gradient from the Floodplain aquifer to the Regional aquifer. North of the distinction of the Floodplain aquifer shallow and deep zones, an afterbay exists in the Floodplain aquifer. The Floodplain aquifer afterbay, located immediately up stream of the Helendale fault, has a small vertical groundwater gradient from the Floodplain to the Regional aquifer, indicating a potential for recharge from the Floodplain aquifer to the Regional aquifer in this area.

GROUNDWATER FLOW

Groundwater flows generally northward in both the Regional and Floodplain aquifers. Flow paths in the Floodplain aquifer follow the course of the river channel from south to north. Flow paths in the Regional aquifer are generally from south to north but are controlled by the extents of the aquifer. Constriction of the Regional aquifer in the central TZ causes water levels in the Regional aquifer to rise in this area relative those observed in the Floodplain aquifer, and may cause the Floodplain aquifer to receive some recharge from the Regional aquifer in this area. Groundwater elevations in the Regional aquifer range from about 2850 feet MSL in southwestern TZ to less than 2400 feet at the Helendale fault. Groundwater elevations in the Floodplain aquifer range from about 2625 feet MSL in the southern TZ to 2400 feet MSL in the northern TZ. Depending on relative groundwater elevations, groundwater can flow between the Regional and Floodplain aquifers.

WATER QUALITY

TZ groundwater is generally of good quality with some notable concerns. Arsenic, iron, and fluoride concentrations in excess of State Drinking Water Standards occur in some wells within both the Floodplain and Regional aquifers. Arsenic, Iron and Fluoride concentrations in excess of State Standards are not observed in surface water or VVWRA discharge. Locally perched groundwater beneath the former George AFB contains dissolved jet fuel and chlorinated solvents. From approximately 35 years of historical surface water data collected at the Lower Narrows, basin objectives set by the RWQCB Lahontan Region have recently been exceeded for TDS and sulfate. Since 2001, sulfate concentrations have occasionally exceeded basin objectives set by the RWQCB Lahontan Region. Since 2001, TDS concentrations have consistently exceeded basin objectives by 10 to 100 mg/L. These sulfate and TDS concentrations are within the historically range of values measured since 1965. Comparison of contemporaneous data indicates Upper Narrows surface water quality may not be a good indicator of Lower Narrows surface water quality. In the southern TZ Floodplain aquifer, groundwater quality resembles that of Mojave River surface water at the Lower Narrows. Along the Mojave River, groundwater quality in the Floodplain aquifer shallow zone increases in TDS likely to due evapotranspiration effects. The groundwater quality of the Floodplain aquifer deep zone is more similar to the Regional aquifer. Groundwater in the Floodplain aquifer shallow zone is similar to VVWRA discharges.

KEY WELL HYDROGRAPHS

Key well hydrographs show TZ water levels have seasonal variations, but have not changed significantly on an annual basis over the past 10 years. Depth to water during winter has changed little over the period of record, while depth to water during summer has increased over the past few years, particularly in the southern TZ. Increasing seasonal groundwater fluctuations will results in greater summer pumping lifts and potentially threaten seasonal water supply to riparian vegetation. Within the TZ, seasonal water level fluctuations decrease in magnitude from south to north. In the period immediately prior to and since the Judgment, annual water level changes from 1990 to 2001 are relatively small in magnitude. Long-term water levels are rising in some locations and falling in others, likely due to changes in water use and recharge throughout the TZ.

SOURCES AND SINKS

The annual TZ water budget is essentially balanced based on representative long-term average conditions. The water budget indicates that under recent conditions, the TZ has an average annual water inflow of approximately 61,150 AFY and average annual water outflow of 61,336 AFY. The difference is within the estimating precision of the data. The annual balance is supported by long-term stability of annual water elevations shown by the Key Well Hydrographs presented in this report. The water budget does not provide an indication of seasonal balance as would be required to judge water supply conditions for riparian vegetation.

VOLUME CALCULATIONS

The total saturated thickness of the TZ, groundwater storage estimates for the Regional and Floodplain aquifers are 6.6 million AF and 700 thousand AF, respectively. Using only the upper 100 feet of aquifer, TZ groundwater storage is estimated at approximately 1.1 million AF and 280,000 AF in the Regional aquifer and Floodplain aquifers, respectively. Pumping this quantity of water without annual replacement would severely impact the TZ water bridge function.

THE TZ WATER BRIDGE

As indicated by long-term hydrographs, a generally balanced TZ water budget, and relatively constant groundwater storage, the TZ water bridge has been maintained since implementation of the Judgment for the purposes of groundwater flow to the Centro Subarea. The water bridge function of the TZ to maintain riparian vegetation is jeopardized in the southern TZ due to recent increased depth to water during summer months. Although the water levels recover during the winter, riparian vegetation can be affected without a year round supply of water.

POTENTIAL RECHARGE PROGRAMS

Artificial groundwater recharge is feasible in the TZ. Potential program objectives should be considered when selecting recharge locations and methods. Water level data show available storage exists predominately in the Regional aquifer and to a lesser extent in the southern portion of the Floodplain aquifer. Conversely, aquifer properties and demand support recharge to the Floodplain aquifer rather than the Regional aquifer. Artificial recharge to the Floodplain aquifer would be most effective in the aquifer forebay, which is the Mojave River channel between the

Lower Narrows and Oro Grande. The southern TZ area would be preferable to supplement the Section 30 well field used largely by the City of Adelanto and the SCLA. Potential surface recharge of the Floodplain aquifer between Oro Grande and Bryman would recharge the shallow zone and be useful to support surface flows and water for riparian vegetation. Recharge of the Regional aquifer should consider the occurrence of local perched conditions when selecting recharge mechanisms. The southern area would be preferable to store water or supplement groundwater in the Adelanto area. The northern area would be preferable to store water in the Regional aquifer west of Helendale or to enhance subsurface outflow towards the Centro Subarea.

DATA GAPS

The most significant data gaps include sparse groundwater elevation data in areas of the Regional aquifer, and lack of multi-depth groundwater elevations from certain areas of the Floodplain aquifer. Additional monitoring wells in inflow and outflow areas of the Regional aquifer will allow more accurate monitoring of groundwater gradients, especially where existing wells are separated by faults and gradients are subjective. A total of four additional single casing monitoring wells would assist in evaluating subsurface flow in the Regional aquifer. Two additional multi-depth monitoring wells would assist in monitoring groundwater recharge of the Floodplain aquifer and water levels in areas of riparian vegetation. Reevaluation of existing geophysical (gravity) data could provide additional insight into TZ hydrogeology specifically along the perimeter of the TZ where faults control groundwater flow into and out of the TZ. Evaluation of the data set could refine the locations of future well, including both production and monitoring wells.

INTRODUCTION

Increasing demand for limited surface water and groundwater resources along the Mojave River has led to adjudication of the Mojave Basin Area (City of Barstow et. al. vs. City of Adelanto et. al., Case No. 208568) (Riverside County Superior Court, 1996). The adjudication is commonly referred to as the Judgment. The court appointed Mojave Water Agency (MWA) as Watermaster to administer the provisions of the Judgment. Groundwater management practices (the "physical solution") enforced through the Judgment are conducted in five hydrologic subareas of the Mojave River Basin. The five subareas are the Alto, Este, Oeste, Centro, and Baja Subareas. The northern portion of the Alto Subarea has been designated the Transition Zone (TZ) and is the subject of the Phase I evaluation. For the remainder of this report, the portion of the Alto Subarea that excludes the TZ will be referred to as the upper Alto Subarea. The boundaries of the MWA, the five Subareas, and the TZ are shown on Figure 1. The term "Mojave River Basin" is used in this report to refer to the surface drainage area of the Mojave River. The term "Mojave Basin Area" is used in this report to refer to the area within the limits of the Judgment, namely the MWA jurisdiction within the Mojave River, Lucerne Valley and El Mirage Basins. As can be ascertained from Figure 1, the Mojave Basin Area is more restrictive in size than the Mojave River Basin.

The Judgment declared the Mojave Basin Area and each of the five subareas to be in overdraft and established base annual production rights (BAP) for groundwater producers within each subarea. Each year the Watermaster set a subarea's Free Production Allowance (FPA) as a percentage of the BAP. With FPA ramp down, the Judgment should ultimately end overdraft conditions. The Judgment also established minimum subarea flow obligations from each subarea to each downstream subarea. The hydrologic subareas are interrelated, and receive at least some of their annual water supply from outflow of an up-gradient adjoining subarea. For the Alto Subarea producers, the Judgment established an initial subsurface flow obligation of 2,000 acre-feet per year (AFY), and a base flow obligation of 21,000 AFY from the Alto Subarea to the Centro Subarea. The combined minimum Alto Subarea obligation of 23,000 AFY is measured entering the TZ. The Judgment requires MWA to develop data to improve the estimates of subsurface flow between subareas, including flow from the Alto to the Centro Subarea across the Helendale fault. The obligation location was dictated by the presence and historical record of a steam gage at the Mojave River Lower Narrows, where the Mojave River enters the TZ. There is no current stream gage at the boundary between the Alto and Centro Subareas and historically it has been very difficult to maintain one in the wide sandy river channel found near Helendale. The Judgment also requires water level data development (installation and selection of key wells) and collection within the TZ to allow the Watermaster to recommend minimum TZ water levels to the Court. Maintenance of the selected minimum groundwater elevations would subsequently guide the process of determining where replacement water is recharged within the Alto Subarea.

Since the initial drafting of the Judgement, the TZ has historically been referred to as a "water bridge". Although the term “water bridge” was not used in the final language of Judgment, the term is still commonly used to describe the function of the TZ to transmit water from the upper Alto Subarea to the Centro Subarea. In the Judgment, the physical solution includes an interim assumption that if the Alto Subarea obligation to the TZ were met, and groundwater producers within the TZ did not exceed their FPA (as determined by their BAP), the TZ would remain in balance and sufficient water would flow to the Centro Subarea from the Alto Subarea through the TZ. This concept is the concept of the water bridge.

MWA was created in 1960 by a special act of the State Legislature to secure future groundwater supplies in the Mojave River Basin. California State Water Code (1959) states MWA is “*to do any and every act necessary . . . so that sufficient water may be available for any present or future beneficial use of the lands and inhabitants of the agency*”. Under State law, MWA is obligated to provide adequate water supplies to residents within its boundaries and thus, has a responsibility to investigate potential solutions to offset overdraft of the Mojave Basin Area and its respective subareas. With this mandate and in order to meet the terms of the Judgment, MWA was prompted by declining annual Mojave River base flows entering the TZ to access hydrogeologic conditions of the TZ and to consider using artificial recharge to supplement river and groundwater flows to the TZ and through it to the Centro Subarea.

MWA has defined a four-phase approach to assess the potential for recharge within the TZ. Each phase depends on successful completion and findings of previous phases, thus creating an incremental approach to first investigate the need for additional recharge and then to take the necessary steps toward establishing recharge facilities.

The four phases of the Mojave River TZ Recharge Project identified by MWA are:

Phase I	Define Transition Zone Hydrogeology,
Phase II	Assess Current Supply and Demand & Project Future Demand,
Phase III	Perform Candidate Recharge Site Analysis, and
Phase IV	Assess Current Regulatory Environment in Relation to the Proposed Recharge Activity and Prepare Environmental Documentation.

This report is the culmination of Phase I, which entails describing the interrelationship of hydrogeologic conditions, water supply, and water demand, all of which govern the TZ water bridge concept. Phase I also entails evaluating the potential for artificial recharge programs based on these interrelating concepts. The Phase I report is intended to be a document that would set the stage for future project phases and be a reference for future TZ work.

MWA defined the tasks completed under the Phase I scope. The specific tasks are listed in Appendix A. In general, the tasks included:

1. Compiling and summarizing existing data and technical reports,
2. Summarizing existing water sources and sinks to create a TZ-specific water budget,
3. Performing groundwater storage volumetric calculations,
4. Compiling and summarizing existing groundwater level and water quality data,
5. Preparing a basic hydrogeologic interpretation of TZ area stratigraphic formations,
6. Preparing four geologic cross sections,
7. Selecting key wells and summarizing key well hydrographs,
8. Preparing a potentiometric map,
9. Preparing an interpretation of hydrogeologic conditions of the water bridge,
10. Estimating average annual water supply,
11. Identifying gaps in existing data, and
12. Preparing this report.

PHYSIOGRAPHY

This section describes the physiography of the TZ, including its boundaries, topography, drainage patterns, climate, and land use. Important elements of the TZ physiography are shown on Figure 2.

BOUNDARIES

The TZ comprises an approximately 296-mile^2 area within the northernmost portion of the Alto Subarea. The TZ boundaries are shown on all maps used in this report and are described in the following paragraphs starting at the Lower Narrows stream gage and traveling counter-clockwise. As described, the administrative TZ boundaries do not always coincide with hydrologic boundaries. Hydrologic boundaries are defined as boundaries that influence the flow of both groundwater and surface water. This means that groundwater and/or surface may flow readily across administrative boundaries, such as those defined by Township and Range lines.

Southeast Boundary

From the Lower Narrows stream gage, the TZ boundary heads in a straight line in a northeasterly direction to the low peak of Turtle Mountain. This line is not a hydrologic boundary as surface runoff can flow southerly across the boundary line out of the TZ, into the Mojave River below the Upper Narrows, and return to the TZ across the Lower Narrows. This boundary is an internal boundary within the Alto Subarea.

Eastern Boundary

From Turtle Mountain, the TZ boundary heads in a northerly direction winding along a topographic divide towards the peak of Silver Mountain and then subsequently towards the Helendale fault directly north of Helendale Peak. The eastern boundary is a hydrologic boundary as the divide occurs in bedrock and separates surface drainage between the TZ and the Centro Subarea.

Northeastern Boundary

The northeastern TZ boundary coincides with a branch of the Helendale fault from the topographic divide of the eastern boundary to the northern boundary. This boundary is also a hydrologic boundary, as the fault is known to partially impede groundwater flow from the TZ to the Centro Subarea. Northeast of this boundary is the Centro Subarea.

Northern Boundary

From the Helendale fault just north of Silver Lakes and Helendale, the TZ boundary follows the east-west line between Townships 8 and 9 North, San Bernardino Base Line and Meridian (SBB&M) to the topographic divide separating drainages of the Mojave River and El Mirage Valley. This east-west line is an administrative boundary rather than a hydrologic boundary as surface water can flow south across it into the TZ and groundwater can flow across it toward the Helendale fault. Buckthorn Wash is the major drainage that crosses the northern boundary of the TZ. Buckthorn Wash originates west of Kramer Hills, northwest of the TZ. North of this boundary is the Centro Subarea.

Western Boundary

From the northeast corner of Section 3 of Township 8 North, Range 7 West SBB&M, the TZ boundary heads southerly along a topographic divide separating surface drainages of the Mojave River and El Mirage Valley. The divide traverses low-lying alluvial hills and the Shadow Mountains. The western boundary is also a hydrologic boundary as it separates surface drainages between the TZ and the Oeste Subarea. West of this boundary is the Oeste Subarea.

Southern Boundary

The southern TZ boundary heads east from western boundary along the east-west line separating Townships 5 and 6 North, SBB&M. At the southeast corner of Township 6 North, Range 5 West, SBB&M, the southern TZ boundary joins the southeastern TZ boundary near the Lower Narrows stream gage. The southern boundary is not a hydrologic boundary as groundwater and surface water can flow across it into the TZ. The southern boundary is an internal administrative boundary within the Alto Subarea.

TOPOGRAPHY

The topography of the TZ is shown on Plate 1 in feet above mean sea level (MSL). The TZ is bounded to the east and west by several mountain ranges. Along the eastern boundary lie the Quartzite and Silver Mountains. Quartzite Mountain, the farther south of the two, rises 1,300 feet above the Mojave River channel over a distance of about 2 miles to an elevation of 3900 feet MSL. Silver Mountain rises 1,700 feet above the Mojave River channel over a distance of about 4 miles to an elevation of 4251 feet MSL. Along the western TZ boundary, the Shadow Mountains lie 8 to 10 miles west of the Mojave River channel and rise to a maximum elevation of 4120 feet MSL.

Between the mountains along the eastern and western boundaries, the TZ is an alluvial plain sloping gently northeast towards the Mojave River. Along the southern TZ boundary, the alluvial plain lies at an elevation of 2900 feet MSL at the former George Air Force Base (AFB). At the northern and northeastern TZ boundaries, the alluvial plain is at an elevation of about 2600 feet MSL. From the base of the Shadow Mountains, the alluvial surface slopes toward the Mojave River channel at about 150 feet per mile or 2.8 percent. At the Mojave River channel, the alluvial surface is abruptly truncated at bluffs that in some locations stand 200 feet or more above the channel bottom.

DRAINAGE PATTERNS

The alluvial plain is incised by drainages of the Mojave River, Fremont Wash, and Buckthorn Wash. Within the TZ, the Mojave River follows a broad arc-shaped path to the northwest and then northeast from the Lower Narrows where it enters from the upper Alto Subarea to the Helendale fault where it exits to the Centro Subarea.

The Mojave River originates outside the TZ about 20 miles to the south on north-facing slopes of the San Bernardino Mountains (Figures 1 and 2). The Mojave River headwaters originate at an elevation between 5500 and 6000 feet MSL. From the base of the San Bernardino Mountains, the Mojave River channel heads north, skirting the eastern toe of the Victorville Fan towards Victorville and the Upper Narrows. At the Upper Narrows, the river channel passes through a bedrock outcrop, which narrows the Mojave River channel forcing groundwater and underflow to the surface of the normally dry channel.

Approximately 4 miles downstream of the Upper Narrows, a second bedrock outcrop constricts the river channel at the Lower Narrows. The Lower Narrows mark the entrance of the Mojave River into the TZ at an elevation of approximately 2660 feet MSL. USGS constructed a stream gage at the Lower Narrows in the early 1900s. The location of the Lower Narrows gage is shown on Figure 2. Within the TZ, the Mojave River is contained within an incised, broad, alluvial channel along the foothills of Quartzite and Silver Mountains. Through the TZ, the Mojave River channel slopes at approximately 17 feet per mile or about 0.3 percent. The Mojave River channel trends north through the TZ, past the communities of Oro Grande, La Delta, Bryman, and Helendale (Plate 1). Approximately 16 miles down stream of the Lower Narrows, the Mojave River leaves the TZ crossing the Helendale fault at an elevation of approximately 2390 feet MSL.

Two large washes drain the TZ alluvial plain towards the Mojave River channel. From south to north, these washes are the Fremont and Buckthorn Washes. These washes are both located west of the Mojave River. Fremont Wash, located near the southern extent of the Shadow Mountains, collects several small unnamed washes originating in the foothills of the San Gabriel Mountains 20 miles or more southwest of the TZ. Within the TZ, Fremont Wash collects runoff from the southern Shadow Mountains and drains northeasterly into the Mojave River channel at the community of Silver Lakes. Buckthorn Wash originates in the Kramer Hills approximately 6 miles northwest of the TZ and enters the TZ across the northern administrative boundary 3 miles east of Highway 395. Buckthorn Wash collects runoff from the southern slopes of the Kramer Hills and the northern portion of the Shadow Mountains then drains southeast into the Mojave River channel at the community of Silver Lakes.

East of the Mojave River channel, Oro Grande Canyon and several small unnamed washes drain the eastern foothills of the TZ toward the Mojave River. Oro Grande Canyon drains the north slope of Quartzite Mountain and the south slope of Sparkhule Mountain into the Mojave River channel. Approximately six west-draining unnamed washes occur between Sparkhule Mountain and Helendale Peak. These washes drain the western slopes of Silver Mountain and other unnamed peaks between Silver Mountain and Helendale Peak.

CLIMATE

The TZ climate is that of the western Mojave Desert, a typical rain-shadow desert. Precipitation in the TZ and western Mojave Desert is limited by the rain shadow of the San Bernardino, San Gabriel, and Sierra Nevada mountains ranges, which are partial barriers to storms originating along the California coast. Consequently, the TZ and western Mojave Desert are arid and experience long, hot summers and relatively short, mild winters. Daily summer temperatures commonly exceed 100° F, while daily winter temperatures can be below 30° F. The average annual high and low temperatures in Victorville are 77.1° and 44.2°F, respectively (Desert Research Institute, 2002). Although areas in the San Bernardino and San Gabriel Mountains can receive up to 40 inches precipitation per year (MWA, 1992b), average annual precipitation the desert can be as low as 3.5 inches per year in some areas.

Much of the precipitation received throughout the western Mojave Desert and the TZ occurs in the months of November through April. Commonly, these months are as dry as other months of the year with the exception of a few strong storms that contribute much or all of the precipitation for the year. Based on a 62-year precipitation record obtained from the National Oceanic Atmospheric Administration (NOAA, 2002) for the Victorville Pumping Plant No. 4, the TZ receives approximately 5.6 inches of precipitation per year. Victorville Pumping Plant is located approximately 3.5 miles upstream of the Lower Narrows and is the closest rain gage to the TZ with a significant historical record**.** An isohyetal map of MWA indicates that annual precipitation ranges from approximately 4.5 to 5.0 inches in the central low-lying areas of the TZ (MWA, 1992b). Precipitation may be somewhat higher in the surrounding hills; however; rain gage data do not exist in those areas. The MWA isohyetal map was compiled using average rainfall data from rain gages outside the TZ and located at Stoddard Valley, Victorville, Kramer Junction, and Barstow.

Pan evaporation rates far exceed measured precipitation in the hot and arid western Mojave Desert. East of the TZ, evaporation rates as high as 160 inches per year have been measured in some of the lower elevation basins of the Mojave Desert (MWA, 1992b). Evaporation estimates for the TZ, however, are not as high. NOAA (1982) estimated evaporation rates along the Mojave River range between 60 and 85 inches per year. For lakes and aquaculture ponds, the Judgment uses a “consumptive use” (surface evaporation) of 7 feet (84 inches) per year (Riverside County Superior Court, 1996).

USGS (1996c) estimated evaporation rates in the TZ range between 60 and 75 inches per year. Because the (USGS, 1996c) values represent the most detailed TZ-specific research available on the subject, the mean of the estimated USGS evaporation range (67.5 inches per year) are used later in the Phase I report for water budget calculations.

LAND USE

Principal land uses within the TZ include urban development, industrial, freight transport, a closed military base redeveloped for civilian uses, agriculture, ranching, mining, transportation, and undeveloped private land. The Federal government administers some undeveloped portions of the TZ through the Bureau of Land Management (BLM). Historically, people have been drawn to the Mojave Desert by opportunities in mining, ranching, and agriculture. More recently, people have been drawn to the TZ and surrounding desert communities as these areas have developed into alternatives to the more densely populated urban communities of San Bernardino and Los Angeles Counties.

Urban

With a population of approximately 18,130 (U.S. Census Bureau, 2002) the City of Adelanto has the largest population center within in the TZ. Historically, the City of Adelanto grew to support the George AFB, now utilized as the Southern California Logistics Airport (SCLA). The SCLA is owned and controlled by the City of Victorville, which also has incorporated areas within the TZ along the bluffs on the west side of the Mojave River and north of the SCLA. Adelanto has grown around the intersection of Highway 395 and Air Base Road. Several small, unincorporated communities also exist within the TZ, namely Oro Grande, La Delta, Bryman, Silver Lakes, and Helendale and are located adjacent to the Mojave River channel. The Silver Lakes Association is located along the west bank of the Mojave River and falls within the community of Helendale. The 2000 census indicates that Helendale had a population of 4,936 and Oro Grande had a population of 895 (U.S. Census Bureau, 2002). The populations of Bryman and La Delta are included in the Oro Grande census track population estimate.

Victor Valley Wastewater Reclamation Authority (VVWRA) operates a wastewater reclamation plant on the west bank of the Mojave River across from Oro Grande. From the plant, VVWRA recharges treated wastewater into infiltration basins and the Mojave

River channel. From 1994 to 2000, an average of 8,857 AFY of treated wastewater has been released or infiltrated (MWA, 1995, 1996c, 1997b, 1998b, 1999a, 2000b). Other wastewater treatment plants within the TZ include one operated west of the SCLA by the City of Adelanto Public Utility Authority having a 1.5 million gallons per day (mgd) design capacity and another operated near Helendale by San Bernardino County Services Area No. 70 having a 0.4 mgd design capacity.

The TZ includes large tracts of undeveloped land, the majority of which are located on the alluvial plain between the Shadow Mountains and the Mojave River channel. The undeveloped desert areas are typically private lands with a few residences located great distances from one another. Some of the undeveloped land is used for grazing and ranching. Very little of the Mojave River bottomlands have undergone urban development. Only a few single-family dwellings are located adjacent the bottomlands on either side of the river channel.

Industrial

In the southern TZ, the former George AFB has been deactivated as a military base and has been turned over to the City of Victorville-sponsored Southern California Logistics Airport Authority. The former George AFB is now the SCLA, and is now home to several growing industries including an airliner refurbishment and scrapping business, the High Desert Power Project, a road to air cargo transfer point, and a proposed rail intermodal facility.

The High Desert Power Project is a combined cycle power plant rated at 700 megawatts currently under construction on 25 acres in the northeast corner of the SCLA (High Desert Power Project Fact Sheet 97-AFC-1, California Energy Commission). Although the HDPP is being constructed within the TZ, cooling water for the plant will be provided by State Water Project water (up to 4,000 AFY) transported through the California Aqueduct and the Mojave River pipeline (power-technology.com, 2002). The Victor Valley Water District will provide potable water to the project. Some of the purchased State Water Project will be treated to drinking water standards and injected in the upper Alto Subarea a few miles south of the TZ for subsequent recovery by HDPP when backup water is needed. As much as 13,000 acre feet (AF) is required to be stored in the Regional aquifer and may be withdrawn for the HDPP when water is not available from the Mojave River Pipeline (power-technology.com, 2002). The injected water will be stored in the Regional aquifer and withdrawn by up to seven wells currently being constructed a few miles south of the TZ. As the HDPP will be supplied with imported water, the project will not increase TZ water demand.

Portions of the SCLA are currently used as a transfer point for cargo moving between road and air modes of transportation. A rail intermodal facility has been proposed for the site and would expand the cargo transfer capabilities between truck, rail and air transport. It is anticipated that the intermodal facility will occupy 700 acres, may create 200 jobs (The Business Press, 2002), which may contribute to economic development with the Victor Valley and increased TZ water usage.

Agriculture and Ranching

Agriculture in the TZ has been limited to and is the dominant land use of the fertile Mojave River bottom adjacent the channel of the intermittent river. These fertile and easily irrigated lands are what attracted some the earliest settlers to the region. Much of the Mojave River bottomlands is or has been at one time under cultivation with alfalfa or other crops. Portions of the bottomlands are currently maintained as pasture or are fallow. These and slightly higher elevation areas have been used as pasture or to support livestock. Within the entire Alto Subarea (including the TZ), Albert A. Webb Associates (Webb, 2000) estimated 2,607 acres of land are used for agricultural purposes. Webb does not estimate how much of this land is specifically located within the TZ. However, from the Webb estimate, it can be assumed that there is no more than 2,607 acres under cultivation in the TZ. Undeveloped lands, west of the Mojave River channel are mostly privately owned, and are used at least on an intermittent basis for grazing sheep.

Mining

The largest mining land use in the TZ supports cement manufacturing. Limestone and aggregate are mined on Quartzite Mountain and are transported to the Riverside Cement Company plant located in the community of Oro Grande. Cement has been produced by a succession of companies at this location since the early 1900s. Cement is exported from the TZ to non-local markets using the transportation corridors of the Union Pacific Railroad and National Trails Highway. The Shadow Mountains contain major crystalline limestone reserves similar to those near Oro Grande (Gray and Brown, 1980). Most of these are claimed by the cement companies in Oro Grande and Victorville and are on private land with moderate relief.

Pipelines

Major water and gas lines are located within the TZ. West of the Mojave River, MWA operates the Mojave River Pipeline, a buried high-capacity water pipeline that carries imported water from the California Aqueduct. The pipeline travels through the TZ (Figure 2) northward from the California aqueduct, east along Colusa Road, and generally northwest along Helendale Road and the Mojave River into the Centro Subarea. The pipeline is used by MWA to supplement groundwater recharge along the Mojave River. Two natural gas transmission lines traverse the Silver Mountains towards Brisbane Valley. The Kimber Morgan Company operates the “Cal Nev” gasoline pipeline that passes through eastern Adelanto to Colusa Road and from Colusa Road, turns to follow the Mojave River channel into Barstow. The “Cal Nev” pipeline carries gasoline from San Bernardino, California to Las Vegas, Nevada. Southern California Gas Company operates two major natural gas pipelines along Highway 395 between Adelanto and Kramer Junction.

Transportation

Transportation has been an important land use within the TZ. In the mid 1880s, railroad tracks were laid along the Mojave River to connect San Bernardino with Barstow (Upland Savings & Loan Association, 1973). Since then, the railroad industry has continued to play a major part in the TZ economy by providing transportation to market for mined materials and cement manufactured in Oro Grande.

National Trails Highway (formerly Route 66) follows the railroad route through the TZ. Route 66 was constructed in the late 1920 and 1930s, connecting Los Angeles, San Bernardino, Barstow, and other rural communities by highway to Chicago, Illinois (National Historic Route 66 Federation, 1995). Service stations, repair shops, and motels appeared beside the new highway through the TZ. Most of these roadside establishments disappeared following development of the national interstate highway system in the late 1950s. Route 66 traffic in the TZ was largely taken up by Interstate 15, located several miles to the east. In the western TZ, Highway 395 is a major north-south transportation corridor connecting the desert communities of Victorville, Adelanto, Boron, Ridgecrest, and eastern California communities within Owens Valley. Airbase Road and Shadow Mountain Road are the only through-going east-west roads within the TZ. Airbase Road connects National Trails Highway with Highway 395 in the southern TZ. Shadow Mountain Road connects the Silver Lakes with Highway 395 in the northern TZ.

PREVIOUS INVESTIGATIONS

The search for water resources in the Mojave Desert dates back to the earliest inhabitants of the region. The nature of that search has changed in modern times from one of travel and exploration to one of science. Accordingly, over the past 80 years, a number of works have been produced ranging from reconnaissance level to detailed scientific examinations of aquifer properties and water use trends. Appendix B contains a brief summary of previous Mojave River Basin investigations with either historical significance or specific emphasis on the area now known as the TZ. Appendix C is a matrix of documents reviewed during this investigation correlated with general informational and data categories found within each document. The matrix serves as a quick reference to locate specific information. Documents listed in Appendix C that are specifically cited in the current TZ evaluation are listed in the References Cited section.

GEOLOGY

REGIONAL GEOLOGY

The TZ lies within the Mojave Desert geomorphic province. The Mojave Desert is a wedge-shaped 25,000-square mile area of southern California bounded by the Transverse Range province to the southwest and the southern Sierra Nevada and southwestern Basin and Range provinces to the north (Norris and Webb, 1990). The Nevada state line and the Colorado River forms an arbitrary eastern limit of the Mojave Desert in California. Bounding ranges of the Transverse Ranges are the San Bernardino and San Gabriel Mountains.

The TZ lies approximately 55 miles south of the Garlock fault and approximately 90 miles east of the intersection of the Garlock and San Andreas faults, the western tip of the Mojave Desert. The San Andreas fault runs southeast along the northern foothills of San Gabriel Mountains and crosses through Cajon Pass to the southern foothills of the San Bernardino Mountains. The Garlock fault zones marks the northwest and northern limits of the Mojave Desert. The Garlock fault is a left-lateral strike-slip fault with a mapped length of nearly 160 miles.

Internally, the Mojave Desert consists of small mountain ranges and individual mountains composed largely of Mesozoic plutonic and metavolcanic rocks with lesser occurrences of metasedimentary rocks. These ranges are separated by Tertiary and Quaternary sediment-filled basins and occasional volcanic flows. The Mojave is considered by some researchers to be a coherent block that is undergoing differential clockwise and counterclockwise rotation taken up by numerous sub-parallel northwest-trending right-lateral faults.

The geologic evolution of the Mojave Desert is long and complex. Appendix G contains a synopsis of the Mojave Desert geologic origin distilled from several chapters of *The Cordilleran Orogen: Conterminous U.S.* (Burchfiel, et al., 1992), which represents a vast collection of research synthesized into a geologic history of the western margin of the North American continent.

LOCAL GEOLOGY

The geology of the TZ is similar to the regional geology of the Mojave Desert, as detailed in Appendix G. As the primary purpose of the Phase I evaluation is groundwater resources, the local geology is focused on those rock units and structures that control the presence and movement of groundwater. The mountains bounding the TZ contain bedrock units ranging from Paleozoic metasediments to Mesozoic intrusives. These units are discussed in brief as they are essentially nonwater-bearing rocks. The core of the TZ is composed of Tertiary and Quaternary sediments and structures. These units are discussed in more or less detail depending on their ability to contain or control groundwater or define the shape and limits of aquifers systems. Local geologic features expressed at the surface are shown on Figure 3a, which is a geologic map of the TZ and surrounding areas, modified from the Geologic Map of California, San Bernardino Sheet (California Division Of Mines And Geology (CDMG), 1986). Figures 3b and 3c are the explanation to the geologic map.

Paleozoic And Mesozoic Bedrock

Bedrock outcrops exposed in the mountains surrounding the TZ are comprised of igneous, metavolcanic, and metasedimentary units ranging in age from Cambrian to Cretaceous. These units are referred to throughout this report as bedrock or as bedrock complex.

Along the eastern TZ boundary, the southern two thirds of the Quartzite Mountains are composed predominantly of quartz monzonite (Cretaceous or Jurassic). These rocks outcrop at the Lower Narrows. The northern third of the Quartzite Mountains, directly east of Oro Grande is composed of Cambrian crystalline limestone, Cambrian quartzite, and Mesozoic metavolcanics. Also along the eastern TZ boundary, Silver Mountain is composed predominately Mesozoic metavolcanics. The southern margin of Silver Mountain contains outcrops of Paleozoic limestone and Mesozoic limestone, sandstone, and siltstone (Fairview Valley Formation). North of Silver Mountain, quartz monzonite (Cretaceous or Jurassic) shares the landscape with the metavolcanic rock outcrops.

Along the northwestern corner of the TZ boundary, bedrock outcrops of quartz monzonite (Cretaceous or Jurassic) occur as relatively flat areas. Some hills within this area are shown on the geologic map (Figure 3a) as Red Buttes, Rabbit Hill, and Haystack Butte. Red Buttes lies along the TZ boundary and is composed of Miocene shallow intrusive volcanics (basalt). North of the TZ, the Kramer Hills form the northern extent of the Buckthorn Wash drainage that flows into the TZ. Although not within the administrative TZ boundary, the Kramer Hills contribute surface drainage into the TZ. The Kramer Hills consist of bedrock outcrops of quartz monzonite (Cretaceous or Jurassic) and Miocene shallow intrusive volcanics (unspecified).

Along the western TZ boundary, the Shadow Mountains are composed of quartz monzonite (Cretaceous or Jurassic), Mesozoic metasediments, and Paleozoic limestone. Within the Shadow Mountains, quartz monzonite bedrock occurs predominately along the northwest and southwest slopes (outside the TZ). Metasediments and limestone occur predominately along the eastern slopes (inside the TZ). Along the eastern foothills of the Shadow Mountains, alluvial deposits surround outliers of metasediments and limestone bedrock. Two small outliers of quartz monzonite occur in Fremont Wash several miles from the Shadow Mountains. These islands of bedrock protruding from the alluvial deposits indicate relatively shallow bedrock in these areas.

Cenozoic Faulting And Deposition

Tectonism defining the current landscape of the Mojave Desert can generally be divided into normal faulting and strike-slip faulting. Normal faulting shaped the Tertiary landscape and was subsequently imprinted with strike-slip faulting from the Miocene to present. Tertiary and Quaternary deposition of continental sediments between the surrounding ranges has obscured many of these faults except in exposed bedrock areas.

<u>Normal Faulting</u>

Throughout the Mojave, early Cenozoic (post-Mesozoic subduction) extensional forces produced normal faulting and created ranges separated by broad sediment filled basins. Normal faulting in the TZ is not apparent from the predominately northwest-trending strike-slip faults mapped on Figure 3a. High angle normal faulting would likely have occurred during Oligocene and Miocene extension and would now be long inactive. Significant erosion and deposition of sediments from surrounding mountains and through-going fluvial systems obscure such faults. The broad valley between the Shadow and Quartzite Mountains probably originated through normal faulting processes and has been modified by subsequent erosion, deposition, and strike-slip faulting.

Deep bedrock depressions have been identified by gravity data and are evidence of past normal faulting in the TZ. Figure 4 is a map showing depth to bedrock as interpreted for MWA by Subsurface Surveys, Inc. (SSI, 1990). Although the gravity data provide a general sense of the depth to bedrock, caution should be exercised in making a conceptual model based solely on interpretation of broad-based regional gravity data. Gravity data can be used in some instances to estimate bedrock depth and buried bedrock fault locations. As alluvial sediments are less dense than bedrock, sedimentary basins can be identified from areas having relatively lower gravity values. The difference in gravity measured over one of these basins from surrounding area measurements can be modeled to indicate the sediment depth.

The deep bedrock depressions within the TZ have been labeled the George, Bryman, Fremont, and Astley Basins (SSI, 1990). As discussed later, these basins are partially filled with nonwater-bearing sediments and do not coincide with distinct groundwater basins. Based on the URS seismic work, bedrock depths shown on Figure 4 (SSI, 1990) are underestimated in the area of the former George AFB. The seismic line conducted as part of the Phase I evaluation is discussed in Appendix D. This Appendix also briefly evaluates in part the precision of the presented gravity data depth interpretations in comparison with a deep seismic refraction profile.

Bedrock depressions beneath the TZ likely formed during normal faulting as bedrock dropped down between normal faults. With a land surface elevation of approximately 2500 feet MSL and basement depths of over 3,000 feet, the bottoms of the George and Astley Basins are below sea level. As seen on Figure 4, these bedrock depressions have steep sides. Basement depths below sea level coupled with steep sides indicates these bedrock depressions are not erosional in nature but have formed from tectonic process such as normal faulting (Dr. Shawn Biehler, personal. communication, 2002). The Bryman Basin is a steep-sided closed basin and is likely tectonic in origin. Erosion processes also control bedrock topography, such as in the shallower, less steep areas shown on Figure 4. The opening of the Fremont Basin into the George Basin and may be erosional in origin.

Mapped northwest-trending strike-slip faults, conjugate with northeast-trending faults, most likely originated as normal faults and later changed their sense of motion. The change would have occurred during the Miocene as tectonic stresses changed from extension to right-lateral shear. The locations of such buried, inactive, normal faults cannot be precisely located without more detail gravity or other geophysical data.

Strike-Slip Faulting

At the surface, several faults have been mapped in bedrock outcrops in the mountains surrounding the TZ. Several of these faults have been projected into the alluvium (CDMG 1986, DWR 1960, and SSI 1990) based on geomorphic indicators (CDMG, 1987). These faults are predominately northwest-trending, right-lateral strike-slip faults. As shown on Plate 1 and/or Figure 3a, from north to south, these faults are the Helendale fault along the northeast TZ boundary, the Kramer Hills, Airport, and Leumen faults along the southern foothills of the Kramer Hills, an unnamed fault in Buckthorn Wash, Blake Ranch fault north of the Shadow Mountains, and Mirage Valley fault south of the Shadow Mountains. Although these faults show remarkable parallelism with the strike-slip San Andreas, vertical displacement has occurred on the Blake Ranch and Mirage Valley faults (Norris and Webb, 1990). Within the TZ, only the Helendale fault is considered recently active (CDMG, 1994).

With additional gravity data, some of these and other faults could possibly be projected further into the TZ. Near the southern TZ boundary USGS (2001a) infers two faults, the Shadow Mountains fault and the Adelanto fault. The Shadow Mountains fault is likely a strike-slip fault based on its northwest orientation. The Adelanto fault is likely an inactive normal fault based on its northeast orientation. These faults bracket the southern margin of an apparent groundwater depression beneath the City of Adelanto. These faults help explain the deeper groundwater elevations north of the faults as the faults are partial groundwater flow boundaries which slow northward groundwater flow into the southern TZ.

The Helendale fault is a right lateral, strike-slip fault trending northwest and forms the northeastern boundary of the TZ. Several other northwest oriented, right lateral strike-slip faults have been mapped outside of, but adjacent to, the TZ. The northwest-trending strike-slip faults most likely originated as normal faults and later experienced right lateral movement. The change would have occurred during the Miocene as tectonic stresses changed from extension to right-lateral shear.

Deposition

As the surrounding ranges were being uplifted, deposition from a highland area north of the TZ deposited non-marine conglomerate and sandstone of the Tertiary-age (middle Miocene) Punchbowl Formation. One of the oldest formations within the Mojave River Basin, the Punchbowl Formation is exposed in Cajon Pass and at other uplifted locations along the southern margin of the Mojave Desert. The extent of the formation in the Mojave River Basin as a whole is unknown. Above the Punchbowl Formation is the Miocene-age Crowder Formation, which consists of non-marine granitic sandstone, siltstone, and conglomerate. Comprising a large portion of the Tertiary basin fill, the Crowder Formation was deposited by a southward draining river and may be as thick as 3,200 feet (USGS, 2000b). From two deep exploration boreholes in the Buckthorn Wash area (08N/06W-12B01 and 08N/05W-07F01, Plate 2D), sandstone, conglomerate, shale, and siltstone formations have been identified below a depth of 1,200 feet to as deep as 4,100 feet. Sediments of this composition and depth suggest these deposits deep below Buckthorn Wash are correlative with the Punchbowl and Crowder Formations. As these older deposits are significantly compacted, they would likely yield little to no groundwater to wells.

With uplift along the southern Mojave, the direction of sediment deposition in the Alto Subarea gradually reversed. Approximately 3.8 million years ago in the late Tertiary (middle Pliocene), the Mojave River began flowing north from the ancestral Transverse Ranges and began depositing sediments over existing southward deposited Tertiary sediments. These deposits include the Quaternary-age (early Pleistocene) Phelan Peak Formation composed of a succession of sand, silt, and gravel deposited from both the north and south (USGS, 2000b). The Phelan Peak Formation unconformably overlies the Tertiary-age Crowder Formation. The Mojave River gradually progressed to the north about 22 miles to the latitude of George AFB where a south facing alluvial slope stopped the river. At that location, a lake formed and the river began depositing sediments over the Phelan Peak and other exposed contemporary deposits. Sediment deposition by the river gradually raised the river grade, and the river topped the alluvial dam to continue northward towards Pleistocene Harper Lake. As the river cut down through the south facing alluvial slope, it uncovered and occupied a bedrock channel in the Upper and Lower Narrows areas that had been cut by an ancestral river flowing south from northern highlands (USGS, 2000b). The Mojave River, representing a depositional system of greater sustained energy, eroded through the Older Alluvium cutting a channel that may have been as much as 300 feet deep in areas.

Older Alluvial Units

South of the TZ, Victorville Fan deposits cap the sedimentary sequence now exposed in the Cajon Pass. Formations of the Quaternary-age Victorville Fan include from oldest to youngest the Harold Formation, the Shoemaker Gravel, and Older Alluvium. Equivalent-age sediments were deposited in the TZ. Based on clast lithology, all three formations were derived from basement rocks of the San Gabriel Mountains. Some of the clasts found in these formations were derived from the Pelona Schist and Lowe Granodiorite.

The Harold Formation is a gray silty sandstone with lenses of conglomerate and occasional thin beds of clayey silt (DWR, 1967). Although USGS (2000b) defines the entire Victorville Fan sequence as 650 feet thick, DWR defines the formation as up to 1,300 feet thick. It is likely that DWR (1967) has grouped the Harold formation with other coeval formations throughout the Mojave River Basin. CDMG (1986) has mapped the Harold Formation at the surface for a distance of several miles from the Cajon Pass. The Harold Formation is the base of potential water-bearing formations in the Mojave River Basin (DWR, 1967). The Shoemaker Gravel overlies the Harold Formation and is as much as 300 feet thick (DWR, 1967). The Shoemaker Gravel is characterized by poorly-sorted, sub-angular gravel with lenses of silt.

Older Alluvium ranges in thickness from a few inches to about 1,000 feet and is composed of moderately consolidated deposits of interbedded gravel, sand, silt, and clay with cementation in the form of caliche (DWR, 1967). With the exception of the Mojave River and bedrock areas, this formation underlies the entire TZ. In northern portions of the TZ west of the Mojave River channel, Older Alluvium is broadly exposed with no younger alluvial cover. Older Alluvium consists of sediments shed from mountains east and west of the TZ and the San Gabriel Mountains to the south.

Younger Alluvial Units

Younger Alluvium occurs as a veneer overlying large areas of Older Alluvium. Areas of Younger Alluvium are most extensive in the southern half of the TZ, west of the Mojave River channel. In the northern TZ, west of the river channel, Younger Alluvium typically occupies washes incised into the Older Alluvium. Younger Alluvium east of the Mojave River is limited to incised channels in deeply dissected Older Alluvial fans. Younger Alluvium sediments range in size from clay to large boulders and include unweathered sands, silts, and gravel. Thickness ranges from a few inches to approximately 100 feet

(DWR, 1967). Younger Alluvium is typically undifferentiated material shed from the surrounding mountains during the Holocene. Younger alluvium includes the Mojave River fluvial deposits, or River Deposits as named by DWR (1967), which consist of sand, gravel, boulders and silt with interbedded clay. The Younger Alluvium partially fills the channel cut into the Older Alluvium.

HYDROGEOLOGY

This section addresses aquifer systems, groundwater flow, groundwater water quality, cross sections, and groundwater storage within the TZ. Together, these features provide the foundation of the TZ water bridge concept.

AQUIFER SYSTEMS

The rock units and formations within the TZ constitute two nonwater-bearing units and two water-bearing units. The nonwater-bearing units include the Paleozoic and Mesozoic-age bedrock and the Tertiary-age consolidated deposits. Quaternary-age sediments overly the nonwater-bearing units and are considered water bearing. Two major recognized aquifers exist within the Quaternary Sediments, the Regional aquifer and the Floodplain aquifer. Both of these aquifers exist outside the TZ in both the upper Alto and Centro Subareas. The Regional aquifer consists of upper and lower zones with the upper zone locally containing perched groundwater. This report shows that the Floodplain aquifer can be subdivided into shallow and deep zones in the TZ. Both the Regional and Floodplain aquifers play important roles in groundwater supply of the TZ. The physical relationships between these aquifers are shown in cross section on Plates 2A through 2D. The cross sections are described in more detail later in this report.

The lateral extents of the Regional and Floodplain aquifers are defined by areas of saturated older and younger alluvial sediments, respectively. Areas outside the aquifer limits are either nonwater-bearing rocks or alluvium where depth to groundwater exceeds depth to nonwater-bearing rocks. Nonwater-bearing rocks are those that may contain water, but do not readily yield water. Aquifer depths were estimated from several sources, including borehole logs, gravity survey data, seismic survey data, and/or well hydrographs.

The lateral extents of both the Regional and Floodplain aquifers within the TZ are shown on Figure 5 as estimated by the Phase I evaluation and as previously shown by USGS (1971) and USGS (2001a). Differences between these boundaries are described in the following paragraphs. Areas within the TZ yet outside the aquifer boundaries are essentially nonwater bearing. The two USGS aquifer boundaries, which differ from each other, are both reproduced from their original sources in Appendix E. The USGS (1971) boundaries are the limits of mapped transmissivity values. The USGS (2001a) boundaries are the limits in the TZ of Mojave River "groundwater basin" as defined and modeled by USGS. Differences in these three boundaries are discussed below for the Regional aquifer.

Nonwater-Bearing Units

Nonwater-bearing units include Paleozoic and Mesozoic-age bedrock and Tertiary consolidated deposits (Punchbowl and Crowder Formations). Paleozoic and Mesozoic-age bedrock comprise the majority of surface outcrops within the hills and mountains surrounding the TZ. Surface outcrops of the nonwater-bearing units are shown on Plate 1 as "bc" for bedrock complex and on Figures 3 and 5 as granitic, volcanic, and metasedimentary units. In the mountain and hill areas, these rocks yield little water to wells, but can be a source of water on a limited basis. Wells completed in fracture zones within these formations have the potential of producing some water; however due to the arid climate and limited extent of most fracture systems, they offer little storage, have low transmissivity, and can dewater quickly. DWR (1967) found that yields from wells completed in the bedrock complex are typically less than 50 gpm. For purposes of the Phase I evaluation, these rocks are not considered significant as groundwater aquifers, and are not part of the aquifer systems discussed in this report. As a whole, the nonwater-bearing units act as barriers to groundwater flow.

The Paleozoic and Mesozoic-age bedrock units generally comprise the nonwater-bearing units of the surrounding mountains and beneath the alluvial foothills. Where historical faulting has deepened the sedimentary basins to depths greater than approximately 1,200 feet, Tertiary consolidated deposits form the lower limits of the water-bearing sediments. Tertiary consolidated deposits do not outcrop in the TZ, but have been identified at similar elevations in two exploration boreholes in the Buckthorn Wash area and in the seismic refraction line conduced north of the former George AFB during the Phase I evaluation (Appendix D). Based on seismic velocity data, these deposits may contain minor quantities of water in pore spaces, but would be too consolidated or may be partially cemented and would not yield water freely to wells.

Tertiary consolidated deposits exposed south of the TZ in Cajon pass include the Punchbowl, Crowder, Phelan, and Harold Formations. The Phelan and Harold formations are early Pleistocene (Quaternary) in age, but are lumped with the Tertiary-age formations due to their limited extent and consolidated nature. The Harold

Formation is the deepest and oldest formation of the upward coarsening Victorville Fan sequence. The Harold Formation is relatively consolidated, has a fine-grained texture and thus reduced water-bearing capacity. DWR (1967) states wells completed in the Harold Formation typically produce less than 20 gpm. Although it is unlikely that Victorville Fan deposits extend into the TZ, the stated well yields of the Harold Formation are likely similar to the underlying Tertiary consolidated deposits.

Regional Aquifer

Regional aquifer is primarily composed of Older Alluvium and represents a significant storage volume of groundwater in the TZ and Mojave River Basin as a whole. Older Alluvium, first identified by Noble (1954) and mapped by CDMG (1986) overlies the Harold Formation and Shoemaker Gravel in the Victorville area and extends throughout the Mojave River Basin. DWR (1967) characterized this formation as one that freely yields water to wells. Although hydraulic properties of Older Alluvium vary throughout the basin, some wells constructed in Older Alluvium have been known to produce as much as 2,000 gpm (DWR, 1967). The saturated thickness of the Regional aquifer varies between approximately 100 and 1,000 feet depending of the controlling structure of the nonwater-bearing units and groundwater elevations. The Regional aquifer underlies the Mojave River fluvial deposits that constitute the Floodplain aquifer. USGS (2001b) estimated Regional aquifer transmissivity values range from 50 to 2,500 feet^2 per day and a storage coefficient value of 12 percent.

The extents of the Regional aquifer within the TZ (Figure 5) cover an area of approximately 165 mile^2. The Regional aquifer extends from the southern to the northern TZ administrative boundary between bedrock outcrops of the Shadow Mountains to the west and Quartzite and Silver Mountain the east. Counter clockwise from the southern tip of the Shadow Mountains, the Regional aquifer boundaries within the TZ (Figure 5) follows the alluvial divide of the western TZ boundary, east along the southern TZ boundary and the southeastern TZ boundary to the Lower Narrows, northward along the bedrock-alluvium interface to the Helendale fault, northeast along the Helendale fault and the northwest TZ boundary to the northern TZ boundary, west along the northern TZ boundary to the bedrock-alluvium interface at Red Buttes, southwest along the bedrock-alluvium interface to the Blake Ranch fault, southeast along the Blake Ranch fault and its projection towards exposed bedrock outcrops in Fremont Wash, and southwest around these outcrops along Fremont Wash, and then along the bedrock-alluvium interface of the eastern Shadow Mountains.

The extents of the Regional aquifer identified in the Phase I evaluation differ from two previous USGS reports, which in turn differ from each other. These differences are understandable given the different purposes and from data available to each report. The area of the Regional aquifer used in the Phase I evaluation is essentially the same as used by the USGS in the southern TZ. In the eastern TZ near Bryman, the Regional aquifer boundary lies between the locations used by the two USGS reports. Based on the projection of water elevations to a buried bedrock slope, the USGS (2001a) boundary near Bryman is too close to the nonwater-bearing bedrock and the USGS (1971) boundary is not close enough. Near Helendale both USGS references include a triangle-shape area of older alluvium east of the Mojave River. This small area is not included within the Regional aquifer by the Phase I evaluation due to the occurrence of various islands of bedrock complex outcropping within it. These outcrops are observed on both Plate 1 and Figure 3a, and indicate shallow bedrock. In the northwest TZ, the Phase I evaluation and (USGS, 1971) use a Regional aquifer boundary along the alluvium-bedrock contact near Red Buttes. This more western boundary is appropriate, as groundwater would come near the steep buried bedrock slope in this location (Figure 4). In the northwest TZ, USGS (2001a) excludes much of this area from their regional model. Excluding this area may be appropriate for the regional groundwater flow modeling purpose of the USGS, but not appropriate when estimating groundwater storage in the TZ.

The representations of the Regional aquifer boundary near Highway 395 east of the Shadow Mountains varies significantly between the Phase I evaluation, USGS (1971), and USGS (2001a). USGS (2001a) uses a close approximation of the bedrock-alluvium contact. USGS (1971) uses a more broad approximation of the bedrock-alluvium contact. The Phase I evaluation draws the boundary northeast around outlying bedrock outcrops in Fremont Wash and turns it northwest towards the northern extent of Shadow Mountains and the Blake Ranch fault. An area of shallow bedrock (Figure 4) lies between the Regional aquifer boundaries that are indicated by the Phase I evaluation and by USGS (2001a). Projections of groundwater elevations into this region would be lower than the bedrock elevations, thus precluding this region from the Regional aquifer.

The Regional aquifer extents overlap the area of the Floodplain aquifer. The Regional aquifer underlies the Floodplain aquifer where the Floodplain aquifer bottom is shallower than bedrock. Near Adelanto, the Regional aquifer is about 8 miles wide and narrows to about 6 miles wide a few miles south of Silver Lakes. Northeast of Silver Lakes, the Regional aquifer widens again at the Buckthorn Wash area. The Regional aquifer occurs in the upper portion of the deep sedimentary basins identified from interpretation of gravity data. Existing exploration boreholes and the seismic line conducted as part of the Phase I evaluation limit the saturated thickness of Older Alluvium and thus the Regional aquifer to about 1,000 feet in the center of the TZ. The area covered by Older Alluvium, to the northwest of the two small bedrock outcrops in Fremont Wash, is not considered part of the Regional aquifer because shallow bedrock in this area is higher in elevation than surrounding groundwater elevations.

Groundwater flow in the Regional aquifer is influenced by the Shadow Mountains and Helendale faults (USGS, 2001a), both of which are northwest-trending strike-slip faults. The effects of other mapped strike-slip faults on groundwater flow in the basin is not known due to the lack of water level data near these other faults. Near Astley Ranch, a short unnamed fault crossing Highway 395 may affect groundwater flow based on the relatively higher elevation of groundwater in a single well at the Ranch. Alternatively, water levels in this area may be perched in the upper unit of the Regional aquifer. Groundwater elevations northwest of Adelanto may also be perched in the upper unit of the Regional aquifer.

Two small areas of the Regional aquifer outside the TZ administrative boundaries are important to the Phase I evaluation. The first area is that south of the TZ, but north of the Adelanto and Shadow Mountains faults. Groundwater in this portion of the upper Alto Subarea has crossed the partial barriers to groundwater formed by these faults (USGS, 2001a) and may thus be affected by groundwater management practices within the TZ. Groundwater in this approximately 5-mile^2 area can originate either outside the TZ in the Alto-Subarea from flow across these faults or within the TZ and be made to flow out of it by potential pumping south of the SCLA. The second area is in the Centro Subarea, north of the TZ and southeast of the Kramer Hills. Surface water in this approximately 18-mile^2 area drains southerly into the TZ. Groundwater flow from this area is at a low northeast gradient towards the partial groundwater barrier formed by the Helendale fault. As the groundwater surface in this area is flat and impeded by the partial flow barrier, this area is more likely affected by groundwater management practices in the TZ than in the Centro Subarea.

Floodplain Aquifer

In the Mojave River Basin, the Floodplain aquifer extends from a location near the headwaters of the Mojave River in the San Bernardino Mountains, 90 miles northward along the course of the Mojave River to the downstream extent of the Mojave Basin Area at Afton Canyon. Within the TZ, the Floodplain aquifer occurs beneath the lowland along the Mojave River channel from the Lower Narrows to the Helendale fault. The Floodplain aquifer is composed of Quaternary fluvial deposits and younger fan deposits which have partially back filled the channel cut through Older Alluvium by an ancestral Mojave River. The extents of the Floodplain aquifer within the TZ (Figure 5) are approximated along the Mojave River channel by areas mapped as younger Quaternary alluvium. Based on the distribution of wells within the Floodplain aquifer, the entire area of younger alluvium is considered saturated. As shown on Figure 5, the Floodplain aquifer within the TZ covers an area of approximately 22 $mile^2$.

The Floodplain aquifer ranges in width from about 100 feet at the Lower Narrows to 10,000 feet near Helendale, and in thickness from about 70 feet at the Lower Narrows to as much as 300 feet near Helendale. A seismic reflection survey conducted 2 miles downstream from the Lower Narrows (USGS, 2000c) indicates the Floodplain aquifer is approximately 200 feet thick at that location. Other than at the margins of the back filled channel in the older alluvium, the thickness of the Floodplain aquifer does not vary significantly from east to west. The bottom of the Floodplain aquifer is indicated on the hydrogeologic cross sections shown on Plate 2.

Wells completed in the Floodplain aquifer have been documented to yield between 500 and 1,600 gpm (DWR, 1967). USGS (2001a) estimated transmissivity values to range from 1,000 to 60,000 $feet^2$ per day, and a storage coefficient value of 25 percent for the Floodplain aquifer. In contrast with the Regional aquifer, the Floodplain aquifer has a much higher transmissivity and storage coefficient.

Groundwater in the Floodplain aquifer generally flows from south to north along the path of the Mojave River. Groundwater flow in the Floodplain aquifer is not impeded by any known faults within the TZ, including the Helendale fault, located at the northern extent of the TZ. Recharge to the Floodplain aquifer occurs from surface flows in the Mojave River and from the Regional aquifer in the central TZ near Bryman. The Floodplain aquifer recharges the Regional aquifer in both the southern TZ and to a lesser extent in the northern TZ. In the central TZ near Bryman, where water levels in the Regional aquifer can be higher than those in the Floodplain aquifer, the Regional aquifer may provide recharge to the Floodplain aquifer.

Starting about 1 mile below the Lower Narrows in the southern TZ, and extending to the Bryman area, the Floodplain aquifer can be divided into separate but interrelated shallow and deep zones. These zones, shown on Cross Section A-A’ (Plate 2A), are separated by clay layers interbedded with sand and gravel. The interbedded clay and sand layers are approximately 50-to 100 feet thick. Discontinuities in the clay layer allow the shallow and deep zones to be in hydrologic communication with one another. In some areas groundwater above the shallower clay layers may not be impacted by deeper water level fluctuations. The interbedded clay exhibits greater discontinuity north of Bryman. The shallow and deep zones are not distinguished in the northern TZ due to the absence of these clays. The extent to which the clay lenses act to create a confined or semiconfined aquifer in this stretch of the river is not currently known. Appendix F1 shows the extents of the clay lenses and the interrelationship of these clay lenses with infiltration of surface flows and the density of riparian vegetation along the Mojave River channel below the Lower Narrows.

The shallow zone of the Floodplain aquifer ranges in thickness from about 60 to 100 feet. The deep zone ranges in thickness from about 100 to 150 feet. North of Oro Grande, the interbedded clay boundary between the shallow and deep zones may slow surface water recharge to the deep zone. As discussed later in the water quality section, where distinguished, the shallow and deep zones may differ in water quality.

AQUIFER PARAMETERS

Aquifer parameters characterize the ability of an aquifer to transmit and store water and are typically determined through pumping tests or physical analysis of aquifer materials in a laboratory. Existing maps of aquifer transmissivity, specific yield, and production distribution are reproduced in part as figures in Appendix E. Transmissivity values provide a quantitative measure of the ability of an aquifer to transmit water based on the aquifers thickness and average hydraulic conductivity. Storativity values can be used to estimate the volume of water in storage. Aquifer properties for the TZ were first summarized by USGS during the development of several groundwater flow models prepared to simulate groundwater flow in the larger Mojave River Basin. The TZ portions of the USGS (1971) and USGS (2001a) transmissivity maps are reproduced in Appendix E, Figures E-1 and E-2, respectively. Care should be taken in comparison of these two maps as they are presented in different units. The 1971 map has units of 1,000s of gallons per day per foot, while the 2001 map has units of $feet^2$ per day. The USGS (1971) map also shows several storativity (or storage coefficient) values. In unconfined aquifers storativity is the same as specific yield, or the percentage of water by weight that can be drained by gravity from a saturated material.

USGS (1971) prepared an electric analog model of groundwater flow in the Mojave River Basin. This model was one of the first groundwater models published of the Mojave River Basin. The values established for aquifer properties in this model were cited and used again by USGS (1974) in preparing a mathematical model of flood recharge in the Mojave River channel. While preparing a MODFLOW-based groundwater flow model of the Mojave River Basin, USGS (2001a) reviewed aquifer property values originally used by USGS (1971) and found them to be generally representative of conditions in the basin.

Transmissivity values are greater along the center of each aquifer and lower along the margins as transmissivity values vary with aquifer thickness. For the Regional aquifer, USGS (2001a) estimated transmissivity values to range between 50 and 2,500 $feet^2$ per day. USGS (1971) shows three storage coefficient values through the Regional aquifer (3, 5, and 12 percent). For the Floodplain aquifer, USGS estimated transmissivity values to range between 1,000 and 60,000 $feet^2$ per day and a specific yield (storage coefficient) from 20 to 25 percent. Although the Floodplain aquifer has localized areas that can be semiconfined, both the Regional and Floodplain aquifers are unconfined aquifers. As a rule of thumb, unconfined aquifers have storage coefficients greater than 0.001 (Kruseman and de Ridder, 1994).

No new aquifer pump tests or laboratory analyses of formation materials were performed under the Phase I evaluation. Aquifer thickness data were obtained from a 2-mile long seismic refraction line conducted during the Phase I evaluation (described in Appendix D). Generally aquifer property data can be inferred from the seismic data. The seismic data indicate that in the area just north of the former George AFB, the saturated thickness of older alluvium is approximately 1,000 feet under approximately 250 feet of unsaturated alluvium. More than 1,200 feet of rocks underlying the older Alluvium have seismic velocities consistent with consolidated sedimentary rocks and/or volcanic rocks that would not readily yield water to wells.

As discussed later for the TZ water budget, groundwater production in the TZ averaged approximately 14,641 AFY during the 1994 through 2001 Water Years. The distribution of groundwater production in the TZ is predominately from wells located adjacent the Mojave River. These wells produce from either or both the Floodplain aquifer and the Regional aquifer depending on the well screen depths. Appendix E reproduces maps of the TZ area showing the 1994 distribution of groundwater production (USGS, 2001a) and the 2001 verified groundwater production (MWA, 2002).

GROUNDWATER FLOW

Groundwater flow in the Regional and Floodplain aquifers was evaluated using groundwater elevations maps for both aquifers. Groundwater elevation contours for the Regional aquifer and Floodplain aquifer are shown Figure 6 and Figure 7, respectively. In addition to groundwater elevation contours, these Figures show arrows indicating approximate groundwater flow directions. The set of groundwater elevation contours provides important information and insight regarding the relationships between pumping, groundwater levels, and surface water flows in the TZ. Later in this evaluation, the groundwater elevations contours are used to estimate groundwater in storage.

The water level data contoured are from the spring of 1998. Spring data were chosen as they reflect conditions in the basin with minimal pumping. Summer pumping water level data can distort the contours from year to year as pumping conditions shift from agriculture to municipal uses. The year 1998 was used for several reasons. USGS contoured 1992 and 1998 data for the entire Mojave River Basin, making no distinction between data from the Regional and Floodplain aquifers. The 1998 USGS water level map is a refinement on the 1992 USGS water level map, as the later represents more data and increased understanding of groundwater conditions. The current TZ evaluation advances USGS concepts from 1998 and 2000a publications and thus reevaluating the 1998 data helps highlight the water bridge function of the TZ. The 1997-98 Water Year was also an El Niño year. As such, groundwater conditions in 1998 should reflect recharge from that year’s storms. As observed later in the discussion of key well hydrographs, the 1997-98 El Niño rains raised water levels 1 to 2 feet in most areas along the Mojave River within the TZ. Water elevations during 1998 are also fairly consistent with elevations for other years during the recent 10-year period of 1991 to 2001. Thus no other years represents significantly different conditions. The 1998 data also represent conditions 2 years following the 1996 Judgment. The 1998 data allow groundwater elevations to be contoured at 25-foot intervals in the Floodplain aquifer and at 100-foot and occasionally 50-foot intervals in the Regional aquifer.

Regional Aquifer

Groundwater elevations within the Regional aquifer (Figure 6) range from a high of approximately 2875 feet MSL in the southwest corner of the TZ near the groundwater divide with the Centro Subarea to a low of 2390 feet MSL near Helendale fault. Groundwater flows northward into the TZ across the 12-mile long southern boundary after first crossing the Shadow Mountains and Adelanto faults. These faults are partial barriers to groundwater flow as evidenced by groundwater elevations approximately 100 to 150 feet lower to the north. Groundwater flow paths into the TZ across the southern boundary generally converge in the Adelanto area. Along the base of the Shadow Mountains, groundwater elevations do not show as large a change across the Shadow Mountains fault. This may be due to the base of the Regional aquifer being higher in elevation and forming an elevated bedrock shelf northwest of Adelanto. Alternatively, groundwater may be perched in an upper unit of the Regional aquifer. The groundwater gradient beneath the SCLA is relatively flat at 0.0015, decreasing 50 feet in elevation over a distance of 6.2 miles.

East of the SCLA, groundwater entering the TZ in the Floodplain aquifer infiltrates the Regional aquifer producing a small mound in the Regional aquifer at Oro Grande. At the VVWRA treatment plant downstream of Oro Grande, approximately 1,680 AFY of secondary treated wastewater are percolated using ponds constructed in sediments above the Regional aquifer. Also at the VVWRA Plant, approximately 7,177 AFY of tertiary treated wastewater are discharged to the Mojave River above the sediments of the Floodplain aquifer shallow zone. Based on available data and the contour interval used for the map, a groundwater mound at the treatment plant is not discernible within the Regional or Floodplain aquifers. As indicated by the flow arrows on Figure 6, Regional aquifer groundwater sourced at the treatment plant recharge basins would flow north-

northeast in the Regional aquifer and join the Floodplain aquifer depending on the groundwater gradient between the two aquifers.

From the SCLA, groundwater flow continues to the north and enters an east-west constriction in the Regional aquifer. The Regional aquifer narrows to about 6.5 miles wide near La Delta and 5.5 miles wide a couple miles north of Bryman. The flat gradient beneath the SCLA may represent a build up of groundwater south of this constriction. Between La Delta and a couple miles north of Bryman, the groundwater gradient more than doubles to 0.0034 by changing 100 feet in elevation over a distance of 5.5 miles. Over this same portion of the TZ, groundwater elevations in the Regional aquifer are 5 to 15 feet higher than in the Floodplain aquifer perhaps due to the build up of groundwater elevations to flow through the constriction in the Regional aquifer. The Regional aquifer may recharge the Floodplain aquifer in this constricted area as can be inferred by the differences in groundwater elevation and near Bryman by the northward bends in the respective 2500-foot groundwater elevation contours in the two aquifers (compare Figures 6 and 7). The difference in groundwater elevation within the Regional aquifer from the east bank to west bank of the Mojave River is approximately 80 feet. The northward deflection of the 2500-foot contour may also indicate a groundwater flow barrier in the deeper depths of the Regional aquifer.

Beneath the Mojave River channel, groundwater flow paths in the Regional aquifer do not parallel the flow paths or boundaries of the Floodplain aquifer, but move across the Floodplain aquifer as the Regional aquifer changes orientation and shape. Groundwater in the Regional aquifer turns slightly to the northwest as the aquifer widens into Buckthorn Wash area. Along the Mojave River channel near Buckthorn Wash, groundwater elevations in the Regional aquifer revert to being slightly deeper than in the Floodplain aquifer. Groundwater elevation measurements in the Buckthorn Wash area present a significant data gap. Groundwater elevation contours in this large area were inferred from two data points along the western periphery of the Regional aquifer and several points along the Mojave River.

Groundwater contours in the Buckthorn Wash area were constructed with the assumption that the majority of groundwater in this area originates from the southern TZ through the constricted portion of the Regional aquifer. In the Buckthorn Wash area, the groundwater gradient decreases as the Regional aquifer widens into the basin, remaining greater near the Mojave River channel and lessening to the northwest. From the 2450-

foot groundwater elevation along the river channel to the Helendale fault, groundwater has a gradient of 0.0029 decreasing 70 feet over 4.5 miles. From the 2450-foot groundwater elevation near Fremont Wash to the Helendale fault, groundwater has a gradient of 0.0013 decreasing 70 feet over 10.5 miles. Groundwater in the Regional aquifer exits the TZ across the Helendale fault, which acts as partial barrier to groundwater flow. Groundwater elevation differences across the Helendale fault are 100 feet near the Mojave River and as much as 300 feet near Red Buttes.

Groundwater elevations measured in wells 08N/06W-15J1 and 08N/06W-27H1 near Highway 395 are higher than would be expected without being perched or without a groundwater flow barrier occurring between the well and other wells near the Helendale fault. Without such conditions, groundwater elevations would suggest a significant inflow from the northwestern corner of the TZ. An unnamed northwest-trending fault located on Plate 1 may act as a significant barrier to groundwater flow. As shown on Figure 6, groundwater elevations differ by approximately 200 feet across this fault. Any groundwater flowing across this fault would next flow north and northeast with groundwater sourced from the southern TZ.

North of the Helendale fault in the Centro Subarea, Figure 6 shows non-aquifer specific groundwater elevations. In this area groundwater elevations along the Mojave River can be inferred to be for Floodplain aquifer while elevations away from the river can be inferred to be Regional aquifer. These contours indicate that as groundwater crosses from the TZ into the Centro Subarea, it generally continues to flow in the area of the Floodplain aquifer towards Barstow and turns continues to flow in the area of the Regional aquifer towards Harper Lake. Flow rates towards these areas are relatively quicker in the Floodplain aquifer than in the Regional aquifer due to relative differences in aquifer properties.

Floodplain Aquifer

Groundwater in the Floodplain aquifer flows generally to the north along the course of the Mojave River channel. North of the Lower Narrows, the Floodplain aquifer width and thickness through the TZ does not change significantly, thus the groundwater gradient should not vary significantly unless affected by changes in formation material or groundwater recharge. As shown on Figure 7, groundwater elevations in the Floodplain aquifer range from a high of approximately 2625 feet MSL near Oro Grande to 2380 feet

MSL at the Helendale fault. The elevation contours represent groundwater levels in the Floodplain aquifer deep zone. Between Oro Grande (from Wells 06N/05W-12H2 & 12H1) and Bryman (nested well 07N/05W-24R5-8), Floodplain aquifer shallow zone groundwater elevations are 5 to 25 feet higher than in the deep zone. The difference in groundwater elevations between the two zones is likely created by relatively greater volume of production in the deep zone.

From Oro Grande to Bryman, groundwater within the Floodplain aquifer has a gradient of 0.0037 changing 125 feet in elevation over a distance of 6.4 miles. Adjacent the VVWRA treatment plant, groundwater elevations in the Floodplain aquifer (see elevation contour 2575 feet MSL on Figure 7) are slightly higher along the west side of the Mojave River due to recharge operations at the plant. From Bryman to Helendale, the groundwater has a gradient of 0.0027 changing 75 feet in elevation over a distance of 5.3 miles. Near Bryman, groundwater elevations in the Floodplain aquifer are 5 to 15 feet lower than in the Regional aquifer. The flatter gradient along this portion of the Floodplain aquifer may be due to both upward recharge from the Regional aquifer into the Floodplain aquifer along the constricted portion of the Regional aquifer and/or from infiltration of discharge from the VVWRA treatment plant placed in the Mojave River channel.

From the community of Helendale to the Helendale fault, groundwater elevations in the Floodplain aquifer are a couple feet higher than in the Regional aquifer. Groundwater in the Floodplain aquifer between Helendale and the Helendale fault has a gradient of 0.0039 changing 35 feet in elevation over a distance of 1.7 miles. The steepening of the gradient along this portion of the Floodplain aquifer may be due to groundwater exiting the TZ unhindered by the Helendale fault and then subsequently recharging the Regional aquifer in the Centro Subarea. The groundwater gradient in the Floodplain aquifer directly across the Helendale fault in the Centro Subarea is also 0.0039 decreasing 55 feet in elevation over a distance of 2.7 miles.

HISTORICAL HYDROGRAPHS

Historical groundwater levels provide a perspective to which long-term and short-term water levels of the key wells can be compared. Historical groundwater levels from several wells are graphed on Figure 8. Many wells in the TZ have water level data from the 1940s and 1950s, but do not extend into more recent decades. Two wells of significance have water level records from 1930s through 1970 and from the 1990s through 2000. These two wells, 08N/04W-31R1 and 07N/04W-30C1, represent groundwater elevations in the Floodplain aquifer near Silver Lakes and Oro Grande, respectively. Three other wells are shown on Figure 8 and represent historical groundwater levels in the Regional aquifer near Adelanto. Two of the Regional aquifer wells have water levels from the 1940s and 1950s and can be used to compare historical water level trends in the Floodplain aquifer. The third Regional aquifer well (06N/05W-19J2) fills a gap in the water level record between 1978 and 1988.

In general, historical Floodplain aquifer water levels show a downward trend of 5 to 10 feet over the past 50 years. Within this historical period, shorter length cycles of rising and falling water levels occur. Figure 8 shows historical water levels in the Floodplain aquifer near Silver Lakes (Well 08N/04W-31R1) deepen by 15 feet from the early 1950s through the mid 1960s. By 1970, Floodplain aquifer water levels at this location had rebounded to within 5 feet below pre-1950s levels. Between 1970 and 1990, depth to water in the Floodplain aquifer near Silver Lakes again increased to 15 feet below pre-1950 levels. However, over the past 10 years, depth to water in the Floodplain aquifer near Silver Lakes shallowed to within 10 feet below pre-1950 levels. Historical depths to water in the Floodplain aquifer near Oro Grande show a 5-foot increasing depth trend between 1950 and 2000. From the available data, the trend has been steady and does not rise and fall as in Well 08N/04W-31R1. Current water levels in the Floodplain aquifer are similar to historical water levels in the 1960s.

Regional aquifer historical water levels in wells near Adelanto have varied historical trends and can increase or decrease during the same time period. As shown on Figure 8, a falling water level may occur in one well while another well experiences rising water levels. Water levels from Well 06N/05W-08F1 shows little variation during the 1950s and early 1960s, but are about 5 to 10 feet deep in the late 1960s. The deepening occurs as water levels are rising 5 feet in Well 06N/05W-29H1 and in the Floodplain aquifer Well 08N/04W-31R1. The depth to water on the hydrograph of Well 06N/05W-29H1 decreased by 7 feet from the late 1950s to the early 1970s. This record also includes several pumping water levels. The hydrograph of Well 06N/05W-19J2 illustrates a slight increasing depth trend of about 0.5 foot over the period 1982 to 1989.

WATER QUALITY

Groundwater and surface water quality data were reviewed both to describe variations in water quality and to identify parameters in excess of drinking water standards. Water quality data described here are summarized from both MWA and USGS on-line database (http://waterdata.usgs.gov/nwis/qw). MWA provided groundwater data only. USGS database contained both groundwater and surface water data. Inorganic and organic data were available for both groundwater and surface water. The adjacent chart summarizes the types, quantities, and dates of water quality data available for review. Groundwater data quality used in this report are included in Table 1.

Groundwater	Inorganic		Organic	
Database	Dates	Number of Samples	Dates	Number of Samples
MWA	1987-2001	325	1985-2001	210
USGS	1987-2000	155	1997-2000	3

Surface Water	Inorganic		Organic	
Database	Dates	Number of Samples	Dates	Number of Samples
MWA	none	none	none	none
USGS	1966-1982 & 1992-1997	200	1966-1982 & 1992-1997	195

Groundwater and surface water quality data were evaluated for variations over time and location using both Piper and Stiff diagrams. A Piper diagram is a graphical representation of the major ion ratios that can be used to distinguish similar water quality types within parameter fields. Dissimilar samples will appear scattered within the diagram fields, while similar samples will be clustered. Differences can be time dependent for samples collected from the same location or they can be location dependent for samples collected at two locations on similar dates. A Stiff diagram is a graphical representation of ion concentrations represented by a closed polygon. Variations in the shapes and sizes of the polygons represent variation of water chemistry between samples.

Piper and Stiff diagrams allow quick comparison of multiple parameters for multiple samples. Piper and Stiff diagrams require a full compliment of major cations (potassium, sodium, calcium, and magnesium) and anions (bicarbonate, carbonate, chloride, and sulfate). Of the available surface water data, approximately 100 samples collected at the Lower Narrows between 1966 and 1978 meet these criteria. Of the available groundwater data, 35 samples collected between 1990 and 2001 meet these criteria. Dissolved iron, arsenic, and fluoride were also specifically evaluated in both groundwater and surface water, as they are known parameters of concern in the TZ. In addition to the evaluation of ion ratios, time-series data for surface water were evaluated for total dissolved solids (TDS), specific conductance, chloride, and sulfate.

Surface Water

From 1966 to 1996, TDS of surface water samples has ranged from 110 to 567 mg/L. In its Water Quality Control Plan, the State California Regional Water Quality Control Board (RWQCB) Lahontan Region objective for TDS of the Mojave River at the Lower Narrows is 312 mg/L (RWQCB, 1994). Seasonal variations of TDS are evident; generally, higher values are observed in the summer and lower values are observed in the winter. Water from the VVWRA outflow near Oro Grande demonstrated a TDS ranging from 400 to 411 mg/L in 1996.

A series of samples collected at several locations between the Lower Narrows and Bryman in March 1996 and again in July 1996 shows a gradual increase in specific conductance both seasonally and along the river between these two locations. Between the Lower Narrows and Bryman sample locations, the difference between samples collected in the same month was approximately 85 microSeimens/cm (μS/cm). The differences between samples collected in March and July were different by approximately 188 μS/cm. The ratio of TDS to EC at the Lower Narrows averages about 0.62. Consequently, TDS of surface water at Lower Narrows can be estimated to have increased by 53 mg/L (0.62 x 85 μS/cm) by the time it reaches Bryman. The cause of the increase may be due to evapotranspiration; contributions from VVWRA, and/or irrigation pumping return flow. Likewise, TDS of surface water at the same sample location can vary seasonally as much as by 117 mg/L (0.62 x 188 μS/cm). The cause of the increase may be due to increased evapotranspiration during summer months.

The Piper diagram, shown on Figure 9, represents approximately 100 surface water samples collected at the Lower Narrows between 1966 and 1978. The diagram indicates a generally consistent water character of the calcium-sodium bicarbonate type. Stiff diagrams shown on Figure 10 represent selected surface water samples collected at the Lower Narrows. The nearly 100 surface water analyses were pared down to show only the spring and fall samples for each year of the record. The Stiff diagrams show little variation over the 10-year period, indicating a relatively consistent surface water quality over the period of record. Some spring sample Stiff diagrams are smaller in size, indicating a lower TDS, likely due to the influence of storm flow.

Several inorganic parameters of concern, namely arsenic, iron, and fluoride are detectable in surface water at the Lower Narrows and along the Mojave River, but occur in concentrations that are below State Drinking Water Standards. Dissolved arsenic concentrations in the surface water samples range from nondetect to 7 µg/L. Dissolved arsenic is also found in discharge from the VVWRA plant at about 4 µg/L. The United States Environmental Protection Agency (2001) published a final rule revising the existing primary drinking water standard arsenic from 50 µg/L) to 10 µg/L, with a compliance date of January 23, 2006. Dissolved iron concentrations in the surface water samples range from nondetect to 190 µg/L. Dissolved iron is also found in discharge from the VVWRA plant at about 40 to 80 µg/L. The Secondary Drinking Water Standard for iron is 300 µg/L. Dissolved fluoride concentrations in the surface water samples range from nondetect to 0.8 mg/L. Dissolved fluoride is also found in discharge from the VVWRA plant up to 0.6 mg/L. The average-temperature-dependent Secondary Drinking Water Standard for fluoride applicable to the TZ is 1.4 mg/L. Surface water samples do not show any consistent parameters in excess of Primary Drinking Water Standards.

The potential for degradation of surface water quality within the Mojave River due to basin overdraft, water reclamation, and water reuse in the upper Alto Subarea is a concern of MWA. To evaluate this potential, available time-series data of surface water at the Lower Narrows were reviewed. Variations in concentrations of sulfate, chloride, and TDS are specific surface water components of interest to MWA. The Basin Plan for these three parameters as measured at the Lower Narrows is 312 mg/L for TDS, 75 mg/L for chloride, and 40 mg/L for sulfate (RWQCB, 1994). Using a conversion factor of TDS=0.62xEC the TDS objective can be expressed as an EC objective of 503 µS/cm. The Basin Plan for the Mojave Hydrologic Unit also has objectives for boron, fluoride, nitrate, total nitrogen, and orthophosphate (RWQCB, 1994).

For the three parameters of interest to MWA, data exist predominately for the period 1967 to 1983 with a few data points in the mid 1990s, and the years 2000 and 2001. These data are graphed on Figure 11 and listed in Table 1. During this period, sulfate concentrations have generally ranged from 30 to 60 mg/L, chloride concentrations have generally ranged from 20 to 50 mg/L, and EC concentrations have generally ranged from 400 to 700 mg/L. These data show seasonal variations with lower concentrations during storm flows. In addition to data collected at the Lower Narrows, Table 1 also contains contemporary data collected in 2000 and 2001 at the Upper Narrows. Although the Upper Narrows data are not graphed on Figure 11, comparison with the contemporaneous Lower Narrows data indicates the Upper Narrows data are consistently higher in concentration for these three parameters. As such, Upper Narrows surface water quality may not be a good indicator of Lower Narrows surface water quality.

A long-term decrease in all three constituent concentrations is exhibited between 1965 and 1983. From 1968 to 1975, the concentrations of sulfate, chloride, and EC showed slight increasing trends. Between 1975 and 1983, the concentrations of sulfate, chloride, and EC all show a moderate decrease in concentration to the lowest concentrations available for non-storm flow data. The relatively few values for chloride and sulfate concentration since the mid 1990s show no distinct trend, but are generally within the historical range of values measured from 1967 to 1983. The chloride data reviewed have not historically exceeded the basin objectives. The sulfate concentration data reviewed show no definite degrading trend since the early 1990s, but occasionally exceed the basin objective set by the Lahontan RWQCB. The seven values for EC since the mid 1990s are generally in the upper range of values measured from 1967 to 1983. The EC concentration data reviewed show no definite degrading trend since the early 1990s, but have over the last couple years have consistently exceeded (by 10 to 100 mg/L) the basin objective set by the RWQCB Lahontan Region. The EC (TDS) and sulfate data reviewed have historically varied both above and below the basin objectives, and are below the objectives during seasonally high flows. As degradation of water quality with respect to these constituents would be expressed both as significant concentration increases and concentrations consistently exceeding basin objectives, the data do not show surface water quality degradation for chloride. In 2001, sulfate concentration exceeded basin objectives, but are within the concentration range observed between the years 1965 and 2001. For TDS (expressed as EC), seven consistent concentrations since 2001 indicate a slight degradation of water quality with respect to this constituent.

Groundwater

The Piper diagram, shown on Figure 12, depicts the major ion chemistry of groundwater samples from the TZ. Most of the waters depicted are of a calcium-sodium bicarbonate and calcium-sodium mixed-anion character. The calcium-sodium ratio in the groundwater samples is similar to that observed in surface water samples collected from the Mojave River. The mixed-anion type waters are generally bicarbonate-chloride or bicarbonate-sulfate. The anion variations observed between groundwater and surface water samples are likely due to groundwater interaction with formation material. TDS concentrations of groundwater samples range from 230 to 2,190 mg/L. North and west of the City of Adelanto, data from wells (06N/05W-8F01 and 06N/05W-03Q02) indicate that groundwater in the Regional aquifer has a TDS of about 300 mg/L. TDS values are generally greater in wells nearer the Mojave River. The samples exhibiting TDS higher than about 600 mg/L have concentrations that are generally higher than those observed for historical surface water and may reflect connate water, water concentrated by evaporation, water impacted by subsurface minerals, and/or water influenced by surface activities.

Stiff diagrams, shown on Figure 13, were constructed for groundwater samples collected from 15 wells. These 15 wells are the source of the 35 samples that can be graphed as Stiff and Piper diagrams. The spatial variation in water quality in the TZ is indicated by the locations of the Stiff diagrams on the hydrologic map of Plate 1 and the cross sections of Plate 2. Several groundwater Stiff diagrams are similar in shape to those of surface water. These likely reflect the recharge of groundwater with surface water. Several groundwater Stiff diagrams are noticeably different from those of surface water. The groundwater in two wells (08N/04W-31G01 and 08N/04W-29D03) located along the river near Silver Lakes have relatively higher ratios of sodium and chloride then the other groundwater along the river. This may indicate that this groundwater has experienced some evaporative concentration or has been in contact with evaporite minerals in the subsurface. Groundwater samples from wells 06N/05W-03Q02 and 06N/05W-08F05 are of a noticeably different character than the other groundwater samples. These two Stiff diagrams are smaller (lower TDS) and have relatively lower calcium and chloride concentration. These two Stiff diagrams represent the water chemistry in the Regional aquifer west of Adelanto. The remaining groundwater samples are from wells located along the Mojave River. Minor differences in these Floodplain aquifer groundwater samples are likely due to mixing with surface water and/or groundwater from various sample depths.

Groundwater quality in the Floodplain aquifer shallow zone more closely resembles that of rapidly recharged surface water from the Mojave River and from VVWRA discharges. Groundwater quality of the deep zone may be impacted more by slower migration of groundwater through that zone and by potential mixing with groundwater from the

Regional aquifer. Several historical samples and depth specific samples collected during the Phase I evaluation are shown as Stiff diagrams on Cross Section A-A' (Plate 2A).

The Stiff diagrams from nested monitoring well 07N/05W-24R5-R8 (near Bryman) show groundwater at 50 feet (shallow zone) to be slightly higher in chloride, sulfate, and calcium than those at 153 feet and deeper (deep zone). This shallow sample is also dissimilar from the VVWRA sample. The groundwater sample at 153 feet (Floodplain aquifer deep zone) is very similar to the VVWRA effluent. Deeper samples at this well are similar to those found in the Regional aquifer near Adelanto. The Regional aquifer and Floodplain aquifer deep zone samples near Bryman from well 07N/05W-24R5-R8 appear similar, but a have slightly different calcium and sulfate concentrations. Depth specific samples from well, 08N/04W-21M1-M4 near Helendale do not show significant concentration differences with depth, likely because there are no significant aquitards in this portion of the TZ to separate the Floodplain aquifer deep and shallow zones and the Regional aquifer.

<u>TDS</u>

The majority of available TDS data are fom wells in the Floodplain aquifer. TDS concentrations for groundwater in these wells vary from 220 to 2,210 mg/L. Most of the groundwater samples have TDS of 600 mg/L or less. A few wells along the Mojave River have groundwater having TDS concentrations in excess of 1,000 mg/L, the lower threshold for water considered brackish. These samples may reflect groundwater that has experienced some evaporative concentration or has been in contact with evaporite minerals in the subsurface. Available records for wells located in the Regional aquifer show TDS concentrations between 300 and 400 mg/L.

<u>Arsenic</u>

Arsenic concentrations in groundwater vary from nondetect to 110 µg/L. Approximately 20 wells have groundwater analyses demonstrating arsenic concentrations in excess of the proposed Primary Drinking Water Standard (10 µg/L). These wells are located along the Mojave River from the Lower Narrows to Helendale. Wells in the Regional aquifer have arsenic concentrations below the proposed standard. The higher arsenic concentrations likely originate from water flowing through deposits within the Floodplain aquifer as Floodplain aquifer recharge source waters (surface water at the Lower Narrows and groundwater in the Regional aquifer away from the river) have arsenic concentrations below 10 µg/L. Arsenic in groundwater is typically associated with weathered volcanic deposits.

Iron

Iron concentrations in groundwater vary from nondetect to 4,600 µg/L. Approximately 14 wells have groundwater analyses demonstrating iron concentrations in excess of the Secondary Drinking Water Standard (300 µg/L). These wells are found predominantly along the Mojave River from the Lower Narrows to Helendale. Wells constructed in the Regional aquifer and some wells along the river have iron levels below the standard. The higher iron concentrations likely originate from water flowing through deposits within the Floodplain aquifer as Floodplain aquifer recharge source waters (surface water at the Lower Narrows and groundwater in the Regional aquifer away from the river) have iron concentrations below 300 µg/L.

Fluoride

Fluoride concentrations in groundwater vary from nondetect to 7.7 mg/L. Approximately 14 wells have groundwater analyses demonstrating fluoride concentrations in excess of the Primary Drinking Water Standard (1.4 mg/L). These 14 wells are located along the Mojave River from the Lower Narrows to Helendale and in the Regional aquifer near the former George AFB. Fluoride levels below the standard are also observed in wells along the river and in the Regional aquifer. Fluoride is common in many desert groundwater basins containing granitic bedrock. The higher fluoride concentrations likely originate from bedrock in contact within the Regional and Floodplain aquifers.

Boron

In arid regions, Boron can accumulate in soils and water to levels that are toxic to plants. Economical borate deposits exist in Miocene-age deposits and are mined from an open pit located 30 miles northwest of the TZ and the Kramer Hills. As agriculture is an important land use in the TZ, the concentration of boron in groundwater and surface water samples was evaluated. A boron concentration greater than 5 mg/L is considered excessive or toxic to some plants (Dohahue, et al, 1983). There are no Primary or Secondary Drinking Water Standards for Boron. Boron concentration in groundwater wells range from nondetect to 3.5 mg/L. Boron in surface water is less than 0.3 mg/L. Boron concentrations in groundwater and surface water sampled in the TZ do not exceed excessive levels.

Organic Constituents

Jet fuel and solvent plumes within the groundwater beneath the former George AFB are the largest source of groundwater contamination to the TZ. While active, various maintenance and operation activities at George AFB resulted in the release of jet fuel and trichloroethane (TCE) into the groundwater. Since the base closure, the U.S. Environmental Protection Agency has assumed responsibility for cleanup oversight and has identified three Operable Units (OU-1 through OU-3). OU-1 is located beneath the northeast corner of the base and was established to control and remediate a TCE plume in that area. OU-2 is located on the southwest side of the former base and was established to control and remediate a jet fuel plume emanating from the base fuel storage and distribution system. OU-3 consists of several landfill and pond sites located throughout the former base. The locations of the operable units (Bechtel Corporation, 1995) are shown collectively on Plate 1. The TCE plume, located beneath the northeastern extent of the former base, extends northward beyond the base for distance of approximately 4,000 feet. The plume exists adjacent the VVWRA treatment plant to the west and southwest. Both TCE and jet fuel contamination primarily affects shallow (0 to 130 feet bgs) soil and perched groundwater beneath the former base. The contamination is kept from deeper sediments of the Regional aquifer by a clay aquitard that creates perched groundwater conditions (USGS, 2001b). The Air Force extracts groundwater from both the Regional and Floodplain aquifers to contain and remediate the OU-1 plume.

The RWQCB Lahontan Region reports two undefined TCE plumes in or near the TZ (Mr. Jehiel Cass, RWQCB Lahontan Region, written communication to MWA, 2003). An undefined plume of TCE is present in the Regional aquifer in the vicinity of the closed Adelanto landfill north of Adelanto and west of Highway 395. RWQCB Lahontan Region staff believe the plume is fairly small and has not impacted any groundwater users. An undefined plume of TCE is present in the upper Alto Subarea in the Floodplain aquifer near downtown Victorville, and is known as the “D Street Plume”. At this time, there is no evidence that this plume has migrated past the Lower Narrows.

At Silver Lakes, two sites with leaking underground petroleum storage tanks exist that have affected the Floodplain aquifer (Mr. Jehiel Cass, RWQCB Lahontan Region, written communication to MWA, 2003). These sites are under the oversight of the San Bernardino County Fire Department, hazardous materials Division.

The presence of the pesticide Dieldrin at low concentration in the Regional and Floodplain aquifer (yet above the State Drinking Water Action Level) beneath the Desert Willows Golf Course is being investigated by the Air Force (Mr. Jehiel Cass, RWQCB Lahontan Region, written communication to MWA, 2003).

Other Contaminants

Groundwater polluted with hexavalent chromium is located at the Riverside Cement plant near Oro Grande. This plume does not appear to threaten the Floodplain aquifer at this time (Mr. Jehiel Cass, RWQCB Lahontan Region, written communication to MWA, 2003).

HYDROGEOLOGIC CROSS SECTIONS

Four hydrogeologic cross sections were constructed through the TZ using available well data, water level data, geologic maps, and geophysical investigations. The cross section locations are shown on Plate 1. The cross section profiles, shown on Plate 2, illustrate the relationships between sedimentary units, aquifer units, recharge, production, and groundwater elevations. Cross Section A-A' follows the generally northward path of the Mojave River channel from the Lower Narrows to the Helendale fault and is intersected by east-west Cross Sections B-B', C-C', and D-D', from south to north, respectively. The cross sections also form a basis for groundwater storage calculations. The relationship of bedrock and nonwater-bearing deposits were estimated from geophysical investigations and are intended to define the limits of the aquifer system not regional tectonic relationships. Groundwater elevations on the cross sections are from 1998 data. To show details of the Floodplain aquifer, the vertical exaggeration is larger for Cross Section A-A' (20 horizontal to 1 vertical) than for the other three cross sections (5 to 1).

CROSS SECTION A-A'

Cross Section A-A', shown on Plate 2A, follows the generally northward path of the Mojave River channel from the Lower Narrows to the Helendale fault and depicts both the Regional and Floodplain aquifers. From south to north along the groundwater flow paths, the younger alluvial deposits of the Floodplain aquifer vary in thickness and depth. Near the southeast TZ boundary, the Mojave River crosses shallow bedrock at the Lower Narrows. Directly north of the Lower Narrows, a USGS seismic reflection profile indicated a bedrock depth of approximately 75 meters (245 feet) (USGS, 2000c). In the central TZ, near Oro Grande, bedrock has deepened due to faulting and erosion. Older alluvial deposits of the Regional aquifer are present between the Floodplain aquifer and nonwater-bearing units.

Between the Lower Narrows and Oro Grande, the absence of significant clay lenses in the subsurface creates a hydraulic opening between shallow and deep zones of the Floodplain aquifer. The stretch of the river is termed the Forebay as it allows for deep infiltration and recharge of surface flows. Appendix F1 demonstrates that surface infiltration in the Forebay is approximately 1.6 cfs per 1,000 feet of river channel below the Lower Narrows and is several times that of the downstream channel reaches within the TZ. Between Oro Grande and Bryman, clay and silt layers are interbedded with sand and gravel deposits and roughly define shallow and deep zones in the Floodplain aquifer at a depth of approximately 75 to 100 feet. The lateral extent of the low permeability layers between the shallow and deep zones corresponds with the areas of dense (71 to 100 percent) riparian vegetation as mapped by USGS (1996c). Appendix F1 shows the lateral extent of these clay lenses along the river below the Lower Narrows, and correlates their occurrence with areas of dense riparian vegetation and surface water infiltration. Riparian vegetation depend in part on recharge to the shallow zone of the Floodplain aquifer above these clay lenses. North of Bryman, towards Helendale, clay and silt deposits are less common making the shallow and deep zones less distinct and intern, resulting in slightly higher surface infiltration rates. Near Silver Lakes and up gradient of the Helendale fault, the Floodplain aquifer is predominately sand and gravel at all depths. The base of the Floodplain aquifer generally lies at a depth of 300 feet along the cross section as estimated from borehole lithology and water level data. Floodplain aquifer deposits were distinguished from Regional aquifer deposits from logs indicating compact or harder sedimentary units and the predominance of gravel in the Regional aquifer.

The older alluvial sediments of the Regional aquifer are deposited directly on top of nonwater-bearing units including Tertiary continental deposits and bedrock. The Regional aquifer varies in thickness along the Mojave River due to an irregular lower surface created by faulting and erosion of nonwater-bearing units. The Regional aquifer is approximately 700 to 800 feet thick between Oro Grande and La Delta and is thinned to 300 and 200 feet thick near Bryman and Helendale, respectively. Well 07N/05W-24R5-R8 (near Bryman) and Helendale No. 4, shown projected onto the Floodplain aquifer of Cross Section A-A', are completed in the older alluvium of the Regional aquifer adjacent the river channel. These two wells are projected onto the cross sections because they are multi-depth key wells and are the source of important groundwater elevation data.

Groundwater elevations in the Floodplain and Regional aquifers vary along Cross Section A-A' due to basin configuration, interbedded sediments, pumping, and recharge sources. Immediately down gradient from the Lower Narrows, groundwater elevations in the Floodplain aquifer are greater than in the Regional aquifer due to recharge of inflow passing the Lower Narrows. Pumping from the deep zone of the Floodplain aquifer may locally lower groundwater elevations below that in the adjacent Regional aquifer. Near

Bryman, the Regional aquifer water elevations are greater than in the Floodplain aquifer in part due to constriction of the Regional aquifer shape between bedrock outcrops. North of Bryman in the area up gradient of the Helendale fault, the Regional aquifer widens and exhibits groundwater elevations similar to those observed in the Floodplain aquifer, with groundwater elevations in the Floodplain aquifer being slightly higher.

Groundwater elevations in the shallow zone of the Floodplain aquifer below the Lower Narrows and below the VVWRA treatment plant are maintained by recharge from surface waters. Three major well fields extract groundwater from the Floodplain aquifer and are shown on Cross Section A-A'. The City of Adelanto well field is located in the southern TZ, between the Lower Narrows and Oro Grande. The Silver Lakes and County of San Bernardino Helendale well fields are located in the northern TZ, between Silver Lakes and the Helendale fault. Groundwater production centers are shown on Figure E-4 and Figure E-5 in Appendix E.

CROSS SECTION B-B'

Cross Section B-B', shown on Plate 2B, follows a generally west to east line from the Shadow Mountains to southern foothills of Quartzite Mountain. The cross section trace passes approximately 1 mile north of the City of Adelanto and crosses the former George AFB and the Mojave River approximately 2 miles south of the VVWRA treatment plant. Along the trace of Cross Section B-B', the TZ can be divided into three distinct regions between bedrock outcrops: 1) the area west of Highway 395, 2) the area at the former George AFB, and 3) the area of the Mojave River.

West of Highway 395, depth to bedrock is relatively shallow ranging from 0 to approximately 500 feet. Depth to water in the Regional aquifer in this area is approximately 100 feet. East of Highway 395, Tertiary normal faulting has deepened bedrock beneath the former George AFB. This bedrock depression has been termed the George Basin (SSI, 1990). Beneath this area, the bottom of the Regional aquifer is at a depth of approximately 1,200 feet and rests on nonwater-bearing Tertiary consolidated sediments. Bedrock lies much deeper at a depth of approximately 2,500 feet. These depths are determined from the seismic refraction profile conducted by URS as described in Appendix D. Just south of this cross section, depth to water in the Adelanto area is approximately 330 feet. The difference in depth to water between the areas west of Highway 395 and the George AFB area may be related to northeast-moving groundwater inflow to the TZ across the Shadow Mountains fault and the relative difference in thickness of the Regional aquifer in these two locations. Between the former George AFB and the Mojave River, the Regional aquifer thins, as does depth to bedrock.

In the Mojave River area, both the older and younger alluvium units exist, as do both the Floodplain and Regional aquifers. On Cross Section B-B', the Floodplain aquifer is shown to be approximately 170 feet thick. The shallow and deep zones of the Floodplain aquifer occur in the area of Cross Section B-B', but are better observed at the larger scale of Cross Section A-A'. Groundwater elevations in the Mojave River along Cross Section B-B' are higher in the Floodplain aquifer than in the Regional aquifer both directly beneath it and to the west. Based on the difference in groundwater elevations, the Floodplain aquifer may recharge the Regional aquifer at this latitude.

CROSS SECTION C-C'

Cross Section C-C', shown on Plate 2C, follows a generally west to east line from Silver Peak (north of the Shadow Mountains) to the northern foothills of Silver Mountain. The cross section crosses Highway 395, Fremont Wash, and the Mojave River 1 mile north of Bryman. Along the trace of Cross Section C-C', the TZ can be divided into four distinct regions between bedrock outcrops: 1) the alluvial area west of Fremont Wash, 2) the area between Fremont Wash and the Mojave River 3) the area of the Mojave River, and 4) the areas east of the Mojave River.

Beneath the alluvial area west of Fremont Wash, bedrock is relatively shallow (less than 200 feet deep) and is higher in elevation than surrounding groundwater. The USGS on-line water level database (http://waterdata.usgs.gov/nwis/gwlevels) does not contain water levels for the two wells in this area shown on Plate 1 near Highway 395. This portion of the TZ is considered outside the limits of the Regional aquifer as shown on Figure 5.

Beneath the Fremont Wash and Mojave River areas are approximately 500 feet of older alluvium. Thicker sediments occur on either side of a northwest-trending bedrock ridge (generally parallel the cross section) between two bedrock depression termed the Fremont and George Basins (SSI, 1990). From the centers of the George and Fremont bedrock depression to the south, the older alluvium and Regional aquifer thin northward toward the bedrock ridge. The Older Alluvium and Regional aquifer are significantly thicker north of the bedrock ridge in the Buckthorn Wash area. Depth to water along this ridge is approximately 280 feet in the Regional aquifer.

Where Cross Section C-C’ crosses the Mojave River, both older and younger alluvium units exist as do both the Floodplain and Regional aquifers. In Cross Section C-C’, the Floodplain aquifer is shown to be approximately 300 feet thick. The shallow and deep zones of the Floodplain aquifer both occur in this area but are less distinct than in areas south due to less interbedded clay lenses. The relationship between the shallow and deep zones is better observed at the greater vertical exaggeration of Cross Section A-A’. Groundwater elevations in the Mojave River at Cross Section C-C’ are slightly higher in the Regional aquifer than in the Floodplain aquifer. Higher groundwater elevations in the Regional aquifer relative to the Floodplain aquifer represents a change from conditions observed in the southern TZ. The change in relative groundwater elevations occurs about midway between Cross Sections B-B’ and C-C’. The higher groundwater elevations in the Regional aquifer are likely due to the thinning and narrowing of the aquifer northward as it passes from the George AFB area into the Buckthorn Wash area. Based on the difference in groundwater elevations, the Regional aquifer may recharge the Floodplain aquifer at the latitude of Cross Section C-C’.

West of the Mojave River, Older Alluvium and the Regional aquifer are present to a depth of approximately 800 feet. East of the Mojave River, alluvial sediments near Bryman may be over 1,500 feet deep just south of the cross section line. Groundwater elevations in the Bryman area are projected from wells along the Mojave River. The extend of the Regional aquifer is limited to the east as groundwater encounters a steep bedrock slope beneath alluvial fans originating from Silver Mountain.

CROSS SECTION D-D’

Cross Section D-D’, shown on Plate 2D, follows a generally west to east line from Red Buttes, across Highway 395 at the northern TZ boundary, parallels Buckthorn Wash to Silver Lakes, continues across the Mojave River, and towards Helendale Peak in the mountains along the eastern TZ boundary. Along Cross Section D-D’, the TZ can be divided into two distinct regions between bedrock outcrops: 1) the alluvial area along Buckthorn Wash and 2) the area of the Mojave River.

Beneath the Buckthorn Wash area, bedrock lies at depths as great as 4,000 feet (SSI, 1990). Tertiary and Quaternary deposits fill this bedrock depression, referred to by SSI as the Astley Basin. As bedrock in this area lies below sea level, it has been deepened by historical normal faulting. Tertiary continental deposits are found in this area at depths below 1,300 feet as indicated by sandstone and shale lithologic descriptions from two borehole logs and by northward projection of data from the URS seismic refraction line. These Tertiary deposits form the base of the Regional aquifer. Older alluvium deposits overlie the nonwater-bearing Tertiary deposits. Where groundwater occurs in these alluvial deposits, they constitute the Regional aquifer. Depth to groundwater in this area is approximately 400 feet. The Regional aquifer likely receives little to no recharge from the Buckthorn wash watershed. Quaternary strike-slip faults are mapped and projected through the Astley Basin. The extent to which these strike-slip faults create barriers to groundwater flow is unknown. The Key Well located along Highway 395 at the Astley Ranch lies about half way between Cross Sections C-C' and D-D'. Water levels in this well are higher in elevation than expected and likely represent either perched conditions or groundwater held behind a flow barrier fault.

In the area of the Mojave River, both the older and younger alluvium units exist, as do both the Floodplain and Regional aquifers. In Cross Section D-D', the Floodplain aquifer is shown to a depth of approximately 300 feet. The Floodplain aquifer in this area is predominately sand and gravel lenses and the shallow and deep zones are not differentiated. Depth to bedrock along the river is approximately 500 feet and is slightly shallower than observed beneath the river in Cross Section C-C' to the south. Groundwater elevations in the Mojave River at Cross Section D-D' are nearly equal in both the Regional and Floodplain aquifers. In Cross Section D-D', water levels in the Floodplain aquifer are a fraction of a foot higher than in the Regional aquifer. This change in relative position occurs about 1 mile north of Cross Section C-C'. The lower water levels in the Regional aquifer are likely due to the Regional aquifer widening into the Buckthorn Wash area. It is also likely that flow in the Regional aquifer across the lateral constriction near Bryman reaches equilibrium with flow from the Regional aquifer across the Helendale fault.

KEY WELLS

Hydrographs can be used to identify cycles and trends in groundwater levels, including long-term and seasonal responses to groundwater pumping and recharge. Comparison of hydrographs from different aquifers and from different areas can be useful for evaluation and management of the groundwater resource. Such comparisons can be used to identify how water levels have responded to historical conditions and management practices. Regions that are important to understanding groundwater basin dynamics are "key areas". Hydrographs of wells within the key areas that are important to understanding the groundwater basin dynamics are "key well hydrographs". The key wells selected and used in the Phase I evaluation were chosen in part because they represent long-term water level conditions within the TZ. They are considered key wells for the purposes of the Phase I evaluation and are not intended in this context to fulfill the obligation placed on MWA to establish "key wells" to monitor groundwater levels in the TZ as stated in Exhibit G Section 2 of the Judgment (Riverside County Superior Court, 1996). These wells are however suitable for this purpose should the Watermaster choose to use them. From the Phase I evaluation, additional water level monitoring wells are recommended at key locations, and are discussed in the Data Gaps section of this report.

The key well hydrographs for the TZ were selected to meet objectives of the hydrogeologic evaluation, which include identifying:

- Long-term water level trends across the TZ,
- Relationships between the Floodplain aquifer and the Regional aquifer, and
- Relationships between shallow and deep zones of the Floodplain aquifer.
- Floodplain aquifer shallow zone water levels in areas of riparian vegetation

Key well areas include locations of groundwater inflow and discharge. Inflow areas include natural recharge areas along the Mojave River directly up stream of the Lower Narrows, artificial recharge areas along the Mojave River adjacent the VVWRA treatment plant, and groundwater inflow along the southern TZ boundary and the Shadow Mountains fault. Discharge areas include production areas near the City of Adelanto and the community of Silver Lakes, and groundwater outflow across the Helendale fault.

Accordingly, key wells have been selected based on geographic distribution, aquifers screened, and the length and quality of the water level record. Well locations, construction, and water level data were reviewed from Annual Water Level Monitoring Reports (MWA, 1999, and 2000). These data were supplemented with water level data from the USGS on-line database (http://waterdata.usgs.gov/nwis/gwlevels). Areas key to the management of TZ groundwater resources may change as management practices change and areas develop. Consequently, the number of key wells required in the future may change.

The key wells selected for use in this evaluation are listed in Table 2 by key area and aquifer represented. For monitoring wells screened in multiple aquifers, the casing number is listed. Key well locations and key well hydrographs are shown on Plate 3 and where appropriate the well construction details are projected onto the hydrogeologic cross sections (Plate 2). Plate 3 contains individual key well hydrographs. Figure 14 shows all key well hydrographs together using a common elevation y-axis. Water levels presented on the hydrographs are discussed in his report in terms of depth to water for single wells or nested well casings have the same surface elevation and in terms of elevation for separate wells having differing surface elevations. The period of time shown on the key well hydrographs is the 1990-91 to 2001-02 Water Year, and represents water level conditions both prior and since to enactment of the Judgment. This 10-year period is referred to here as "long term" as opposed to "historical", which would refer a period much longer than 10 years. The period since the Judgment in 1996 is referred to here as "short-term".

KEY WELL CONSTRUCTION AND DATA

The following are descriptions of the construction and data record for each key well. Following these descriptions is a section discussing the significance of each hydrograph.

Mojave River Area Up Gradient From The TZ

Water levels in the Mojave River directly up gradient of the TZ are key to understanding basin conditions that contribute surface water to the Mojave River and ultimately to the TZ. Water levels in the Upper Narrows Well (05N/04W-14D1, D2, D3, & D4) represent conditions in the Floodplain and Regional aquifers along the Mojave River directly up gradient of the TZ. The Upper Narrows Well is a nested monitoring well consisting of four individual casings in one borehole. In order of depth, casings D4, D3, D2, and D1 are screened at depths of 30 to 50 feet, 80 to 100 feet, 180 to 200 feet, and 320 to 340 feet respectively. The water level in casing D1 and D2 represents conditions in the Regional aquifer. Water levels in casings D3 and D4 represent conditions in the Floodplain aquifer. The Upper Narrows Well hydrograph is shown on Plate 3.

Prior to 1999, depth to water at the Upper Narrows Well within the Floodplain aquifer varied from 11 feet bgs in the winter to 18 feet bgs in the summer. During the same period, depth to water in the Regional aquifer (casing D2) varied from 3 feet above ground in the winter to 20 feet bgs in the summer. Since 1999, the summer depth to groundwater in the Floodplain aquifer has deepened about 2 feet to approximately 20 feet bgs. Prior to 1999, depth to water in the Regional aquifer varied from 0 feet bgs in the winter to 20 feet bgs in the summer. Since 1999, summer water levels in the Regional aquifer have deepened to between 30 and 70 feet bgs. However, winter water levels still rebound to near or above ground surface. The large seasonal variations in the Regional aquifer indicate the aquifer may be confined at this location. Despite these recent deeper summer water levels at the Upper Narrows Well, winter water levels recovered to levels observed in previous years. The long-term and short-term trend in annual water levels is no change.

Directly up gradient from the TZ, an upward groundwater flow component exists from the Regional into the Floodplain aquifer. In the winter, the vertical gradient is upwards from the Regional aquifer through the Floodplain aquifer shallow zone. In the summer, the vertical gradient is towards the Floodplain aquifer deep zone both upwards from the Regional aquifer and downwards from the Floodplain aquifer shallow zone. The vertical flow component indicates rising groundwater from the deeper aquifers of the Victorville area into the shallower aquifers and ultimately to the Mojave River to flow into the TZ.

Mojave River Area Down Gradient From The Lower Narrows

Water levels in the Mojave River area down gradient of the Lower Narrows are indicative of conditions in the Floodplain aquifer within the southern TZ. Water levels in the Riverside Cement Well (06N/04W-30J05) represent conditions in the Floodplain aquifer shallow zone down gradient of the Lower Narrows. The Riverside Cement Well is located in the Mojave River floodplain, about one half mile down gradient from the Lower Narrows. The Riverside Cement Well has a single casing completed to 40 feet bgs and is screened from 24 to 40 feet bgs. The water level record for the Riverside Cement Well begins in January 1996 and continues through 2002. The Riverside Cement Well hydrograph is shown on Plate 3.

In the Riverside Cement Well, depth to water varies from 8 feet bgs in the winter to greater than 40 feet bgs in the summer. Water levels in this area dropped below 40 feet bgs during the summer of 2000 and 2001. Prior to 2000, summer water levels in the Floodplain aquifer shallow zone were not lower than 24 feet bgs. Despite these recent deeper summer water levels, winter water levels have recovered to water levels observed during previous winters. The long-term and short-term trend in annual water levels is no change.

Down gradient of the Lower Narrows, the shallow zone of the Floodplain aquifer is significantly influenced by annual winter recharge. The summer water levels also appear to be influenced by seasonal pumping from other wells located nearby in Section 30. Depth to water in this area is important as the area acts to transport water downstream to areas of dense riparian vegetation to the north.

Shadow Mountains Fault - Up Gradient Area

Water levels up gradient of the Shadow Mountains fault represent conditions in the western TZ and the Regional aquifer. The El Mirage Well (06N/06W-21J02) has a single casing completed at a depth of 200 feet bgs and is screened from 110 to 200 feet bgs. This well is located south of El Mirage Road and near the head of Fremont Wash at the southern end of the Shadow Mountains. Water levels in the El Mirage Well have been recorded annually since January 1987. The El Mirage Well hydrograph is shown on Plate 3.

Because El Mirage Well water levels have been measured only on an annual basis, insufficient data exist to allow evaluation of seasonal variations in the Regional aquifer at this location. Annual depth to water measurements at the El Mirage Well varied from 133 feet bgs in 1991 to 128 feet bgs in 2002. Depth to water shows a shallowing trend from 1987 to 1997 of approximately 0.6 feet per year. Since 1997 the depth to water in the Regional aquifer at this location has stabilized at approximately 129 feet bgs.

Adelanto Area

Groundwater levels in the Adelanto area are key to understanding the Regional aquifer in this area of groundwater production. Well 06N/05W-34F01 has a single casing. The depth and screened interval of this well are not available. This well is located in the center of Section 34 approximately 1 mile southeast of the Adelanto and 0.5 mile south of Air Base Road. The well is also located down gradient from the Adelanto and Shadow Mountains faults. Water levels in the well have been recorded in the spring biannually since 1996. The 06N/05W-34F01 hydrograph is shown on Plate 3. This well may not be suitable as a key well as defined by the Judgment due to its unknown construction and its scheduled abandonment by the Air Force in 2003. It does however allow evaluation of groundwater elevations in the Adelanto area since 1990.

Because water levels have only been measured every 2 years, not enough data exist for the well to evaluate seasonal variations in the Regional aquifer at this location. During the period of record, the depth to water at Well 06N/05W-34F01 varied from 330 to 332 feet bgs. With the limited data and small annual variation, it is difficult at this time to determine a long-term water level trend from this well. However, existing data do show the depth to water at Well 06N/05W-13R01 was relatively consistent at 330 feet bgs from 1995 to 1998 and increased only slightly to 332 and 331 feet bgs, respectively in 2000 and 2002. The 1-foot to 2-foot deepening of water levels is consistent in timing with depth to water increase at other wells for the period 1999 to current.

Mojave River Area Adjacent The VVWRA Treatment Plant

Water levels in the Mojave River area adjacent the VVWRA treatment plant are key to understanding the effect on the Floodplain aquifer from recharge of plant discharges and the water supply for areas of riparian vegetation in this area. Two adjacent wells, Oro Grande Wells (06N/05W-12H2 and 12H1) represent groundwater levels in the Floodplain aquifer shallow and deep zones. Well 12H2 is completed in the shallow zone to a depth of 25 feet bgs. Well 12H1 is completed in the deep zone to a depth of 150 feet bgs. The screen lengths on these two wells are unknown. The wells are located in the Mojave River channel west of the VVWRA treatment plant. Water levels in the Wells 12H2 and 12H1 have been recorded annually since 1997 and 1987, respectively. The hydrographs of these two wells are shown on Plate 3. Only an elevation scale is shown for this key well hydrograph as the two Oro Grande wells are at slightly difference elevations and would thus not show comparable water depths.

Depth to water in the Floodplain aquifer adjacent the VVWRA treatment plant was approximately 14 to 15 feet bgs from 1990 to 1992. From 1993 to 2001, depth to water increased to approximately 18 to 22 feet bgs. Water levels in the two wells varied approximately 2 feet between deeper summer and shallower winter levels. Water levels are approximately 1 foot higher in the 25-foot deep well than in the 150-foot deep well indicating a slight downward gradient at this location. Following a 7-foot water level decline in 1993, water levels have steadily shallowed by 3 feet from 1993 to 2000. Between 1993 and 2001, water levels have shallowed approximately 2 feet due in part to VVWRA discharge and the 1997-98 Water Year being an El Niño year.

Central TZ Mojave River Area

Water levels in the Central TZ Mojave River area are key to understanding conditions in the Floodplain and Regional aquifers downstream of production by the City of Adelanto and recharge at the VVWRA treatment plant. Water levels in the Well 07N/05W-24R5, R6, R7, and R8 represent conditions in the Floodplain and Regional aquifers at the Mojave River in the Central TZ near Bryman. This key well is approximately 4 miles down stream of the VVWRA percolation ponds. Water levels in the shallow zone of the Floodplain aquifer are key to monitoring groundwater supply to riparian vegetation in this area. In this area, agriculture is the dominant land use with irrigation water originating from groundwater pumped predominately from the Floodplain aquifer.

Well 07N/05W-24R5-R8 is a nested monitoring well consisting of four individual casings constructed in one borehole. In order of increasing depth, casings R8, R7, R6, and R5 are located at depths of 50 feet, 144 feet, 285 feet, and 550 feet, respectively. Water levels in casings R8 and R7 represent conditions in the Floodplain aquifer shallow and deep zones, respectively. Water level in casing R6 and R5 represent conditions in the Regional aquifer. The hydrograph for Well 07N/05W-24R5-R8 is shown on Plate 3.

At this location, depth to water in casing R8 within the Floodplain aquifer shallow zone has varied from 8 to 14 feet bgs with a 2-foot difference between deeper summer and shallower winter water levels. Winter water levels in casing R8 have been consistently about 25 feet shallower than in the Floodplain aquifer deep zone casing R7 indicating that a semiconfining clay still exists in the Floodplain aquifer at this location. Depth to water in casing R7 within the Floodplain aquifer deep zone has varied between 26 and 41 feet bgs with about a 9-foot difference between deeper summer and shallower winter water levels. Depth to water in casings R6 and R5 within the Regional aquifer have been nearly the same with those in R5 being about 3 foot deeper than in R6. Depth to water in the Regional aquifer at this location has varied between 65 and 85 feet bgs with about a 12-foot difference between deeper summer and shallower winter water levels. The seasonal variation in the Regional aquifer is larger than observed in other areas of the TZ.

During the period of record at Well 07N/05W-24R5- R8, depth to water in the Regional aquifer have consistently been about 30 feet deeper than depth to water in the Floodplain aquifer, indicating a downward gradient from the Floodplain aquifer to the Regional aquifer. Between 1991 and 1997, seasonal peak water levels were relatively steady. Following 1997 and continuing to 2001, seasonal peaks have deepened by about 2 feet in the Floodplain aquifer shallow zone and shallowed by about 1 foot in the Regional aquifer. Although relatively small, these long and short-term trends are apparent on the hydrograph.

Central TZ Highway 395 Area

Water levels in the Central TZ, Highway 395 area, represent conditions in the Regional aquifer west of the Mojave River. Well 08N/06W-15J1 is located approximately 0.25 miles west of Highway 395 and 2.5 miles south of the northern TZ boundary. The well is located approximately 0.5 miles west of an unnamed concealed fault (DWR, 1960). Well 08N/06W-15J1 has a single casing completed at a depth of 294 feet bgs. The screened interval is not known. Water levels in this well have been recorded approximately biannually since 1992. The Well 08N/06W-15J1 hydrograph is shown on Plate 3.

Because water levels have only been measured every two years, not enough data exist for Well 08N/06W-15J1 to evaluate seasonal variations in the Regional aquifer at this location. Depth to water in Well 08N/06W-15J1 has varied from 158 feet bgs to 164 feet bgs over the period of record. In this well, the long-term water level trend is no change.

Water levels in Well 08N/06W-15J1 are higher than would be expected compared to Regional aquifer water levels along the Mojave River. These shallower depths to water may indicate either locally perched groundwater conditions or the presence of a hydraulic barrier to the east. The concealed fault mapped on Plate 1 east of the well could create such a barrier.

Helendale Area Up Gradient From The Helendale Fault

Water levels in the Helendale and Silver Lakes area up gradient from the Helendale fault represent groundwater conditions in this production area near the northeast TZ boundary. This area is key to monitoring water levels that control subsurface out flow from the TZ to the Centro Subarea. For this key area, Helendale Well No. 2 and No. 4 hydrographs represent groundwater levels the Floodplain and Regional aquifers, respectively. Helendale No. 2 and No. 4 hydrographs are shown on Plate 3 with only selected casings shown to increase clarity.

Helendale No. 2

Helendale well No. 2 (08N/04W-19Q7, through Q12) is located within the Mojave River channel just south and up gradient from the Helendale fault. This well represents conditions in the Floodplain aquifer where groundwater crosses the Helendale fault into the Centro Subarea. The Helendale fault only acts as a partial groundwater barrier within the Regional aquifer and does not impede flow in the Floodplain aquifer. Water level records for the well span the period of time from January 1994 to December 2000. The Helendale No. 2 hydrograph is shown on Plate 3.

Helendale No. 2 is a nested monitoring well consisting of six casings constructed in one borehole. From shallow to deep, casing Q11 is screened from 30 to 50 feet bgs, Q12 is screened from 100 to 140 feet bgs, Q10 is screened from 140 to 160 feet bgs, Q9 is screened from 250 to 270 feet bgs, Q8 is screened from 330 to 350 feet bgs, and Q07 is screened from 440 to 460 feet bgs. Water levels in Casings Q11, Q10, and Q12 represent the Floodplain aquifer shallow zone. As water levels from these casings are nearly identical, data from Q11 and Q12 have been left off the hydrograph for clarity. Deep and shallow zones of the Floodplain aquifer are not distinguished in this key area. Although Casings Q9, Q8, and Q7 are constructed in buried ridge of fractured bedrock (see Cross Section A-A', Plate 2), they are representative of conditions in the adjacent Regional aquifer. As water levels from these casings are nearly identical, data from Q9 have been left off the hydrograph for clarity. The Regional aquifer does not exist at the well site, but occurs south and west of the well site where bedrock is deeper.

Water levels in the five casings are all within 1 foot of each other and follow nearly identical seasonal trends. Water levels are highest in April and lowest in September. During the period of record, depth to water in the Floodplain aquifer ranged from approximately 4 to 12 feet bgs, while depth to water in the Regional aquifer ranged from 6 to 13 feet bgs. Seasonal variations were similar in both the Floodplain aquifer and fractured bedrock (Regional aquifer).

Depth to water in the shallow zone of the Floodplain aquifer is generally less than in the Floodplain aquifer deep zone, but not as a rule. The winter recovery in the shallowest portion of the shallow zone lags behind the deeper casings and has equal or slightly greater depths to water during recovery. This is likely due to upstream recharge having a greater impact on deeper zones. From 1998 to 2001, water levels in the shallowest casing (Q11) were the deepest of the nested well, where as previously it has been the highest water level in Floodplain aquifer water level.

From spring 1996 to summer 1998, depth to water in all aquifers in this key area gradually increased about 2.5 feet. From 1998 to 1999, depth to water in both aquifers recovered to 1996 levels. The recovery is likely due to the 1997-98 Water Year being an El Niño year. In the year 2000, depth to water in both aquifers again began to deepen slightly; however, the typical spring low depth did not occur in 2000. Instead, depth to water remained at the 1999 fall level, perhaps due to atypical winter pumping in 1999.

<u>Helendale No. 4</u>

Helendale well No. 4 (08N/04W-19G1-G4) is located immediately up gradient from the Helendale fault about 1 mile west of the Mojave River channel. Helendale No. 4 is a nested monitoring well consisting of four individual casings constructed in the same borehole. From shallow to deep, casing G4 is screened from 80 to 100 feet bgs, G3 is screened from 150 to 170 feet bgs, G2 is screened from 220 to 240 feet bgs, and G1 is screened from 295 to 315 feet bgs. Casing G1 has the longest water level record of the four casings. Casing G1 is installed in fractured bedrock. Casing G2 is installed in the Regional aquifer. Casing G3 and G4 are installed in the Floodplain aquifer. Water level records for casing G1 began in January 1995 and May 1998 for the other three casings. Due to similarities in water levels between casings G1 and G2 and also G3 an G4, only the water levels for casing G1 and G4 are shown on the Helendale No. 4 hydrograph on Plate 3 to increase clarity.

Between 1995 and 1998, depths to water in the Regional aquifer (casing G1) varied from 70 to 72 feet bgs exhibiting small winter to summer water level fluctuations. Following May 1998, seasonal fluctuations are muted to nonexistent (casings G1 and G2) as depth to water decreased steadily to 68 feet bgs by March 2000. Over the same period, depths to water in shallower casings G3 and G4 show a similar lack of seasonal fluctuation while decreasing from 69 to 67 feet bgs. The recovery is likely due to the 1997-98 Water Year being an El Niño year. From March 2000 to March 2002, depths to water in all casings gradually deepened by about 1 foot, but continued to show little to no seasonal fluctuations.

At this location, water levels measured in the two Floodplain aquifer casings are nearly identical differing only by hundredths of a foot. Water levels measured in the two deeper casings are also nearly identical except for the monthly measurements in June and July 1998 when they are different by approximately 3 feet and 2 feet respectively. Since the water levels in these casings have been nearly equal for years, this difference is likely due to a field measurement or data entry error rather than local pumping effects.

At Helendale No. 4, water levels in the Floodplain aquifer are approximately 0.5 feet higher than in the Regional aquifer indicating a slight downward groundwater gradient in the Floodplain aquifer at this location. This is important as it indicates groundwater is still be able recharge into the Regional aquifer at this location rather than groundwater rising out of and into the Floodplain aquifer due to the partial groundwater flow barrier created in the Regional aquifer by the Helendale fault.

Mojave River area Down Gradient From The TZ

Water levels in the Mojave River area down gradient of the TZ directly across the Helendale fault are key to understanding the basin conditions in the Centro Subarea in comparison with conditions and management practices in the TZ. Water levels in two wells (08N/04W-12Q1 and 12C1) represent conditions in the Floodplain aquifer about 3 miles down gradient from the Helendale fault within the 1-mile wide bedrock gap south of the Iron Mountain. As indicated by water level contours on Plate 3, groundwater at this Centro Subarea location flows northeast in the Floodplain aquifer towards Barstow and not northwest in the Regional aquifer towards Harper Dry Lake. Wells 08N/04W-12Q1 and 12C1 are separate single casing wells completed to 49 and 150 feet bgs, respectively. The available water level records for Wells 08N/04W-12Q1 and 12C1 begin in 1931 and 1991, respectively, and continue intermittently through 2000. The hydrograph of Wells 08N/04W-12Q1 and 12C1 is shown on Plate 3.

Groundwater elevations in both Wells 08N/04W-12Q1 and 12C1 are very similar. However, depth to water in 12C1 is about 20 feet deeper than in 12Q1 due to 12C1 being at a higher surface elevation. Long-term depth to water in 12Q1 varies from 12 to 40 feet bgs with short-term depth to water ranging from 12 to 24 feet bgs. Water level measurements from these wells number about two per year and thus preclude comment on seasonal fluctuations.

Groundwater elevation in this area rose 30 feet steadily between the summer of 1991 and the summer of 1993 and then held fairly constant until the summer of 1996. During the summers of 1996 and 1997, groundwater elevation decreased steadily by 10 feet. In the spring of 1998, groundwater elevations increased 10 feet and then began a 5-foot steady decrease through the spring of 2000. The long-term and short-term trends in groundwater elevation at this location are an increase of 20 feet over 10 years and a decrease of 5 feet over the past 5 years, respectively.

KEY WELL HYDROGRAPH SIGNIFICANCE

Seasonal Water Level Changes

Generally, TZ water levels are lowest in fall at the beginning of the water year and rise winter through spring. From their shallowest depths in late spring, depths to water increase through summer and fall. In comparison to the Upper Narrows Well hydrograph, seasonal water level fluctuations in the TZ are small relative to those in the upper Alto Subarea. In the Upper Narrows area, larger seasonal fluctuations are likely due to greater pumping. The upper Alto Subarea Upper Narrows Well shows 30 to 65 foot seasonal fluctuations. Within the TZ, seasonal water fluctuations decrease in magnitude from south to north. In the Floodplain aquifer, the largest seasonal TZ water level fluctuations are approximately 30 feet down at wells down gradient from the Lower Narrows, 4 feet at wells adjacent the VVWRA treatment plant, 10 feet at wells near Bryman, and less than 2 feet at wells near Silver Lakes. Near Bryman, seasonal water level fluctuations are similar in the Floodplain aquifer deep zone and in the Regional aquifer. Near Bryman, Floodplain aquifer shallow zone water level changes are likely muted by discharges to the river channel from VVWRA. Not enough data exist to describe seasonal fluctuations in the Regional aquifer away from the Mojave River in the Adelanto and Highway 395 areas. In the areas up and down gradient from the Lower Narrows, summer water levels in both the Floodplain and Regional aquifers were deeper in 1999, 2000, and 2001 than in previous years. However, during the following winters, water levels recovered to levels similar to those observed during previous winters.

Long-term Water Level Changes

The key well hydrographs indicate only very subtle long-term changes in water levels in both the Regional and Floodplain aquifers. In the Regional aquifer, a very slight long-term shallowing of groundwater levels by approximately 5 feet is observable up gradient from the Shadow Mountains fault while a very slight long-term deepening of approximately 1 foot is observable down gradient from the Shadow Mounts fault near Adelanto. No long-term change was observed in the Regional aquifer in the central TZ near Highway 395. Along the Mojave River down gradient from the Lower Narrows no long-term change in water levels was observed in the Floodplain aquifer. Adjacent the VVWRA plant, a slight shallowing of groundwater by approximately 1 foot was observed in the Floodplain aquifer at the two Oro Grande area wells. Near Bryman, the Floodplain aquifer shallow zone exhibits a long-term deepening of about 1-foot and the deep zone exhibits no long-term change. Near Bryman, the Regional aquifer exhibits a 3-foot long-term shallowing in groundwater levels that occurred essentially in the spring of 1998. Along the Mojave River near Silver Lakes, a 1- to 2-foot shallowing of long-term depth to water has occurred in both the Regional and Floodplain aquifers.

Water-Level Changes In Relationship To The Judgment

Following implementation of the Judgment in 1996, groundwater production in the Mojave Basin Area became regulated and has undergone step-wise mandatory decreases. Beginning in 1997, small magnitude, short-term shallowing of groundwater levels has been observed in the Oro Grande, Silver Lakes, and Shadow Mountains fault areas. The shallowing may be in part due to declining groundwater production since implementation of the Judgment. Shifting of production and use from agricultural to municipal well fields may also cause decreased water levels in some areas with corresponding increases in others. Small magnitude, short-term deepening of water levels has been observed in the Adelanto area.

Vertical Groundwater Gradients

Groundwater elevations generally decreased from south to north, indicating a generally northward groundwater flow in both the Floodplain and Regional aquifers. Vertical components to the northerly gradient also exist within and between the Floodplain and Regional aquifers. Directly up stream of the TZ, groundwater in the Regional aquifer is at a higher pressure than groundwater in the Floodplain aquifer. This is caused in part by the thinning of both aquifers towards the Lower Narrows and results in upward groundwater flow towards the surface. Down stream from the Lower Narrows, surface water is able to infiltrate through the river channel into the Floodplain aquifer and subsequently the Regional aquifer. At the Riverside Cement Well, the Floodplain aquifer shallow zone responds readily to seasonal pumping and recharge influences. Near the VVWRA plant, a downward gradient is evident within the Floodplain aquifer as indicated by the key well hydrographs of two Oro Grande area wells.

The water levels in the Regional aquifer gradually built up as groundwater flows south in the Regional aquifer through the restriction in the Regional aquifer thickness and width. The constriction of the Regional aquifer is shown on Cross Section A-A' (Plate 2). The reduced width of the Regional aquifer is evident from Figure 5, which shows of the lateral extents of the Regional aquifer. North of these vertical and lateral constrictions, groundwater elevations in the Floodplain aquifer and Regional aquifer are nearly identical, with only a slightly higher pressure in the Floodplain aquifer.

If water levels in the Floodplain aquifer were increased to predevelopment levels through a floodplain recharge programs, the very small vertical downward gradient from the Floodplain aquifer to the Regional aquifer would become greater assuming water levels in the Regional aquifer did not increase as readily. Groundwater elevations in the Regional aquifer would likely respond more slowly to recharge in the Floodplain aquifer as the Regional aquifer is less transmissive.

SOURCES AND SINKS

The inflow (sources) and outflow (sinks) of surface water and groundwater within the TZ are identified for the purpose of understanding the dynamics of the TZ and to develop a water budget. A balanced water budget will give an indication of basin surplus or overdraft and verify the magnitude of budget components. The TZ-specific water budget developed for this report represents recent average conditions, but not seasonal variations in water supply.

Past studies have generally been conducted to identify, characterize, and manage water resources in the Mojave River Basin as a whole or by subarea. Although few studies provide data specific to the TZ, several address specific water resources of the entire Alto Subarea from which TZ specific data can be gleaned. The following are significant reports having TZ-specific data that were used in identifying sources and sinks:

- Albert A. Webb Associates, 2000, *Consumptive Water Use Study and Update of Production Safe Yield Calculations for the Mojave Basin Area* (Webb, 2000),
- USGS, 2001a, S*imulation of Groundwater Flow in the Mojave River Basin, California*,
- USGS, 1996c, *Riparian Vegetation and its Water Use During 1995 Along the Mojave River, Southern California,* and
- *Annual Report of the Mojave Basin Area Watermaster* (MWA Watermaster, 1995-2001).

Inflow and Outflow components of the TZ-specific water budget assembled as part of the Phase I evaluation are described in the following paragraphs. Values tabulated in this water budget are summarized in Table 3.

SURFACE WATER INFLOW

Surface water inflow to the TZ comes from the following sources: Mojave River base flow, Mojave River storm flow, VVWRA discharge, precipitation, ungaged tributaries and pumped water return flows. Currently, VVWRA discharge is the only imported water released in the TZ.

Mojave River Base Flow and Storm Flow

At the Lower Narrows, USGS records daily total flow values of the Mojave River as it enters the TZ. Total stream flow consists of combined base flow and storm flow. Each year, the Office of the Mojave Basin Area Watermaster separates, or "scalps", the storm flow value from the total flow value, resulting in a base flow value. The scalping method is set forth in Exhibit C of the Judgment. Historical base flow and storm flow at the Lower Narrows is shown in Figure 15. As described in the following paragraphs, the Mojave River base flow and storm flow values used in the TZ water budget are 8,142 AF and 33,107 AF, respectively.

The 8,142 AF base flow value used in the water budget is the average of base flow values for the 1991 through 2001 Water Years. Although the Watermaster has calculated base flow and storm flow values for the 1931 through 2001 Water Years, a longer term average was not used because the recorded base flows at the Lower Narrows have decreased significantly since about 1950. Consequently, the average base flow value for the entire period of record is higher than would be expected of an average year under current conditions. The period 1991 to 2001 better reflects groundwater conditions immediately prior to, and following the Judgment.

The 33,107 AF storm flow value used in the water budget is the average of storm flow values for the 1931 through 2001 Water Years, the entire period of record for data provided by the Watermaster. An average of scalped storm flows for the entire period of record is used because storm flow is related more closely to precipitation than groundwater use. No long-term climatic trends have been documented which would preclude long-term precipitation and corresponding storm flows from being representative of current average conditions.

River Gain / Loss

The Mojave River is an intermittent river flowing through one of the more arid regions of Southern California. Perennial water occurs only in a few locations where it is forced to the surface by shallow bedrock such as the Mojave Narrows. A stream gage exists at the Lower Narrows, the upstream limit of the TZ, but no gage exists in the Helendale fault area, the downstream limit of the TZ. With no surface water flow data for the Helendale fault area, the amount of surface flow leaving the TZ must be estimated. Webb (2000) estimated surface water flow across the Helendale fault and did not suggest any increase in base flow relative to base flow recorded at the Lower Narrows gage. None of stream gages on the Mojave River have recorded increases in flow relative to the next upstream gage.

If the Mojave River were to gain base flow within the TZ, it would be accounted for in the total surface water outflow at the Helendale fault. However, since there is not perennial flow at the Helendale fault, any river gain must be lost again to evaporation, riparian transpiration, or infiltration to groundwater. The river gain/loss is estimated at 0 AFY.

Reclaimed Water

Within the TZ, VVWRA operates a wastewater treatment plant located on the west bank of the Mojave River channel about half a mile north of the former George AFB. Most of the wastewater treated at the VVWRA plant originates from cities outside the TZ (Hesperia, Victorville and Apple Valley). The VVWRA plant discharges secondary treated effluent to percolation ponds and tertiary treated effluent to the Mojave River channel. Although the treated wastewater is discharged to ponds and to the river, it percolates prior to reaching the downstream limit of the TZ, VVWRA discharge is included as a surface water source in the water budget because it originates as surface discharges.

Between the 1994 and 2001 Water Years, the total VVWRA surface water discharge to the TZ averages approximately 8,659 AFY (MWA Watermaster, 1994 through 2002). Approximately 6.4 mgd or 7,177 AFY of tertiary effluent are discharged to the Mojave River channel. Approximately 1.5 mgd or 1,680 AFY of secondary effluent are discharged through percolation ponds that have a combined surface area of approximately 52 acres. The standard practice of VVWRA is to rotate discharge of reclaimed wastewater to about half the pond area, ideally allowing the other half to dry between discharge cycles. As discussed in the following paragraphs, the contribution of VVWRA discharge is adjusted for evaporation losses and precipitation gains, for the purposes of the water budget.

The 1994 to 2001 period for VVWRA discharge was chosen for the water budget as it reflects the period tabulated by the Watermaster and corresponds to the period of verified groundwater production. Total discharge from VVWRA has increased an average of 219

AFY from 1994 and 2001. Discharge from VVWRA is expected to increase in the future, as most new construction will be connected to the sewer system rather than septic systems. Court proceedings have been initiated by VVWRA to allow them to limit future discharge to the river channel to current levels and allow future increases to be diverted for sale and use elsewhere (Mr. Norm Caouette, MWA Assistant General Manager, personal communication, December 2002). The anticipated increase in discharge from VVWRA if discharged for use within the TZ would still apply directly toward the groundwater supply component of the TZ water budget. The diversion of new VVWRA discharges away from the river may either meet a new demand or reducing an existing pumping demand.

Precipitation

The Mojave River Basin receives a relatively small volume of precipitation and much of what is received is lost to evaporation or transpiration. With the exception of surface runoff, direct precipitation does not recharge groundwater under normal conditions (USGS, 1996c). Long-term precipitation data (1939 through 2001) indicate that an average of 5.61 inches falls at the Victorville Pumping Plant (NOAA, 2002). The Victorville Pumping Plant is located approximately 3 miles upstream from the Lower Narrows and half a mile west of the Mojave River channel.

Despite the large losses of precipitation to evaporation, precipitation falling on open water bodies is assumed to add to the water budget through direct percolation or percolation of runoff. Three major surface water bodies that exist in the TZ are the lakes at Silver Lakes, the VVWRA percolation ponds, and areas of perennial flow in the Mojave River channel. As described in the following paragraph, the TZ water budget contribution from precipitation falling on open bodies of water is approximately 96 AFY.

Silver Lakes are lined and groundwater pumped to fill them is assumed to represent a sink (outflow) from the water budget. Consequently, precipitation falling on the Silver Lakes does not enter into the water budget. During operation, the VVWRA percolation ponds as described above provide approximately 26 acres of surface water area. Based on this area and average rainfall, direct precipitation on these ponds contributes approximately 12 AFY to the TZ water budget. Although the Mojave River is dry for much of its length, several areas of the river in the TZ have perennial surface water. USGS (1996c) estimated that approximately 200 acres of surface water occur in the TZ and of that area about 10 percent (20 acres) is heavily vegetated, leaving 180 acres of open surface water. Based on this area and average rainfall, direct precipitation on areas of perennial surface water contributes approximately 84 AFY to the TZ water budget. This estimate assumes that direct rainfall on the open bodies of water in the Mojave River channel during periods of storm flow are not accumulated with the storm flow and removed from the TZ as surface flow.

Ungaged Tributaries

Several ephemeral washes contribute surface water flow to the TZ. Webb (2000) used USGS (1996a) data to estimate that approximately 320 AFY of surface water flow are contributed to the TZ by ungaged tributaries from the upper Alto Subarea. As these flows originate from storm events, it is assumed for the TZ water budget that none of these flows are lost to evaporation and that 100 percent is recharged either in the tributary or in the Mojave River.

Pumping Return Flow

Water pumped from the TZ will be consumed by evaporation to the atmosphere, transpiration by vegetation, by people and animals, or return to groundwater as infiltration. Pumping return flows occur through infiltration of irrigation and septic system water. USGS (1971) assumes 40 to 45 percent return flows from total pumping and 55 to 60 percent return flows from water pumped for irrigation. USGS (2001a) assumes that improvements to irrigation techniques since 1971 have reduced irrigation return flows to approximately 46 percent. Pumping return flows also include recharge of reclaimed wastewater by the City of Adelanto west of the SCLA and by the San Bernardino County near Silver Lakes. Pumping return flows do not include direct infiltration the lakes at Silver Lakes as are lined and are maintains for recreational and aesthetic purposes.

Webb (2000) performed a detailed consumptive use study of the Mojave Basin Area based on the 1996-97 Water Year. A maximum irrigation consumptive use of 65 percent (35 percent return) was assumed when groundwater production exceeded crop requirements. Otherwise, irrigation consumption was assumed to be equal to the crop-specific consumptive use values. A 50 percent consumption (50 percent return) value was assumed for urbanized areas (domestic and municipal production) and 100 percent consumption (no return) for industrial processes. Based on these consumption and return numbers, Webb (2000), calculated a TZ consumptive use value of 10,390 AF for the 1996-97 Water Year. This is equal to approximately 60 percent of the total verified production in the TZ for the 1996-97 Water Year of 17,199 AF. Thus Webb (2000) estimated an average return flow of 40 percent on all of the groundwater production within the TZ. The annual pumping return flow value used in the water budget represents a 40 percent return flow of the total 1994 through 2001 TZ pumping as reported by the Watermaster (2001).

GROUNDWATER INFLOW

Groundwater inflow across the southern TZ boundary occurs in the Regional aquifer. Webb (2000) used 1998 USGS water level and transmissivity data to calculate that 4,590 AFY of groundwater flow across three linear segments of southern TZ boundary. Groundwater flowing across the southern TZ boundary originates in the upper Alto Subarea. Groundwater flow across the southern boundary of the TZ is affected by faults, which occur directly south of the former George AFB and Adelanto. These faults, the Adelanto and Shadow Mountains, trend northeast to southwest, and northwest to southwest, respectively. The faults likely constitute partial barriers to groundwater flow, resulting in the steep groundwater gradient south of the former George AFB. Groundwater must flow across these partial hydraulic barriers prior to entering the TZ. These barriers are significant in that they limit the natural flow of groundwater into the TZ. Because of these faults, groundwater management practices that affect the Regional aquifer in the upper Alto Subarea up gradient of the TZ may have limited impacts on Regional aquifer groundwater conditions in the TZ. The Judgment assumes 2000 AFY of groundwater inflow into the TZ.

The gradient used by Webb (2000) to estimate groundwater flow across the southern TZ boundary, may change as groundwater pumping from the Regional aquifer changes in the Adelanto area. However, no significant long-term change in groundwater inflow to the TZ would likely occur due to the groundwater flow barriers directly south of the southern TZ boundary.

Webb (2000) also calculated flow from the Oeste Subarea to the TZ and found that no appreciable groundwater flows between the Oeste Subarea and the TZ. Low groundwater gradients between the Oeste Subarea and the western TZ combined with groundwater use characteristics of these areas preclude any significant flow contribution to the regional aquifer of the TZ.

Under the Phase I evaluation, URS estimated subsurface flow into the southern TZ by means of Darcy's Law, using published transmissivity values and 1998 water levels. The water levels were contoured specifically for the TZ evaluation using an updated conceptual understanding of the TZ hydrogeology. The calculations indicate that values determined by Webb (2000), USGS (2001a) and URS are essentially equivalent given existing parameter variability. A summary of the three subsurface flow estimates is presented in Appendix H. Of the three values, the value determined by URS (4,900 AFY) for subsurface flow into the southern TZ was used for the current TZ evaluation.

SURFACE WATER OUTFLOW

Surface water outflows from the TZ include evaporation, riparian transpiration, and surface flow across the Helendale fault.

Evaporation

Free surface water evaporation in the TZ is limited by the scarcity of open bodies of water. As described previously for Precipitation Inflow, three major water bodies occur in the TZ, Silver Lakes, VVWRA percolation ponds, and areas of perennial flow in the Mojave River channel. Water pumped to fill Silver Lakes is excluded from the calculation of evaporation loss because water used to fill these lined lakes is counted as an outflow from the system as pumped groundwater. Additional outflow of that water due to evaporation is not necessary as the water is already out of the budget.

USGS (1996c) states that evaporation along the Mojave River in the Alto Subarea ranges from 60 to 75 inches per year. Evaporation outflow for the water budget is estimated at 1,159 AFY by applying the midpoint of this range, 67.5 inches, to the surface area of the remaining two surface water bodies (206 acres).

Transpiration

In the TZ, xerophytes, irrigated crops, landscape vegetation, and phreatophytes remove significant amounts of water from the system through transpiration. Although a significant portion of the TZ is vegetated only with xerophytes (e.g. creosote), transpiration from xerophytes is accounted for by the exclusion of the limited precipitation falling on those areas from the water budget. The water budget only accounts for direct transpiration from crops, landscape vegetation, and phreatophytes.

Webb (2000) estimated transpiration from crops by performing a detailed consumptive use study that sought to establish the amount of surface water flowing across the Helendale fault. The consumptive use value determined by Webb was compared to the total pumping reported by the Watermaster for the TZ for that water year, and a gross percentage value for return flow was obtained, as described above under the Pumped Water Return Flow heading. Water pumped for irrigation of crops and landscape vegetation that is not part of the consumptive use of the crop is accounted for as a return flow of total pumping. Consequently, no additional crop specific or plant specific transpiration accounting is made under the Phase I evaluation.

USGS (1996c) conducted a detailed study of riparian water use in the TZ that included a detailed accounting of the acreage vegetated by specific riparian flora. Normal riparian vegetation have root zones depths of between 8 and 14 feet. USGS multiplied the riparian acreage by established plant-specific, transpiration values to determine the amount of water consumed to transpiration in the TZ. USGS (1996c) estimated 6,000 AFY consumed by riparian transpiration in the TZ. Because transpiration by crops and landscape vegetation is accounted for as described above, riparian transpiration as estimated by USGS is the only transpiration itemized in the Phase I water budget.

River Losses / Groundwater Gain

As described previously, the Mojave River is an intermittent river with perennial water occurring in only a few locations where it is forced to the surface by shallow bedrock and an incised channel. Except during storm flow, surface flows do not generally occur in the Mojave River at the Helendale fault, the northern TZ boundary. Because of the lack of surface water flow, no stream gage exists in the Helendale fault area, and without surface water flow data in the Helendale fault area, the amount of flow crossing the fault and leaving the TZ can only be estimated.

Webb (2000) estimated surface water flow across the Helendale fault as described below and suggested that ungaged surface flow across the fault is less than gaged surface water inflow at the Lower Narrows. From the Webb (2000) estimate of surface water flow across the Helendale fault, it is evident that the Mojave River base flow decreases significantly within the TZ. Decreases in base flow are due to surface water evaporation, plant transpiration, and infiltration to groundwater. Infiltration occurs to replace groundwater removed by a combination of pumping, evapotranspiration, and subsurface groundwater outflow across the Helendale fault.

Surface Outflow Across The Helendale Fault

The Helendale fault at the Mojave River is the downstream limit the Alto Subarea and the TZ. Surface water flowing across the fault enters the Centro Subarea. Because the Helendale fault is the boundary between these subareas, an understanding of surface and groundwater water flow across the fault is important to managing water resources within the TZ and between subareas.

Perennial flow does not generally occur in the Mojave River at the Helendale fault. Faulting has not disturbed the Floodplain aquifer enough to create a groundwater flow barrier within that aquifer. Although the Helendale fault does create a partial groundwater barrier in the Regional aquifer, the barrier is not sufficient to produce sustained surface flow across the fault.

Because there is no stream gage station on the Mojave River at or near the Helendale fault surface water flow across the fault can only be estimated. Webb (2000) undertook a detailed accounting of water flux at the fault for the 1996-97 Water Year and estimated surface water flow across the Helendale fault. In the Webb accounting, all measured and estimated sources of water inflow to the TZ were totaled and then all measured consumption of water within the TZ was subtracted. The remaining water was assumed to leave the TZ as surface water flow across the Helendale fault. Webb (2000) estimated that approximately 34,720 AFY of surface flow crosses the fault. This value is equivalent to approximately 105% of the long-term average storm flow for the base period used by Webb (2000). This factor was applied to the long-term average storm flow for the period used in the Phase I evaluation. The resulting surface outflow (34,762 AF) is used in the TZ-specific water budget.

GROUNDWATER OUTFLOW

The only significant groundwater outflow from the TZ occurs across Helendale fault at the northern TZ boundary and to direct groundwater pumping. Groundwater outflow through bedrock areas is considered to be insignificant.

Subsurface Outflows Across The Helendale Fault

The Judgment assumes that 2,000 AFY (Table C-1, Superior Court of the State of California, 1996) of groundwater flow across the Helendale fault from the TZ to the Centro Subarea. This assumption is carried forward based on the results of a Darcian flow solution calculated by DWR and published in Bulletin 84 (DWR, 1967). To calculate this flow solution, DWR used water levels observed on either side of the Helendale fault, local permeability data and selected a cross sectional area of the Flood Plain aquifer above the Helendale fault.

Gregory Mendez of the USGS (cited as personal communication in USGS, 2001a) estimated that significantly more than 2,000 AFY of groundwater cross the Helendale fault as subsurface flow. From water levels and hydraulic properties of the Floodplain and Regional aquifers, Mendez (USGS, 2001a) estimated as much as 5,000 to 6,000 AFY of groundwater flows across the Helendale fault in the Floodplain aquifer with a component of 1,200 AFY in the Regional aquifer. The model presented in USGS (2001a) has simulated approximately 1,566 AFY groundwater flow across the Helendale fault under average historical conditions.

Under the current TZ evaluation, URS estimated subsurface flow across the Helendale fault from the northern TZ into the Centro Subarea using Darcy's Law, 1998 groundwater elevations, and published transmissivity values. The estimate performed by URS produced a number closer to that of Mendez reported by USGS (2001a) than that produced by the USGS model (USGS, 2001a). The values determined by Mendez and URS are essentially equivalent given existing parameter variability. The value representing subsurface flow across the Helendale fault as simulated by USGS (2001a) is significantly less than those of Mendez and URS. The difference may be due to the transmissivity values used by each estimate. The difference between Regional aquifer transmissivity values of USGS (1971) and (2001a) shown in Appendix E are significant and may reflect variation used to calibrate the USGS regional flow model. Of these values, the one determined by URS under the Phase I evaluation was selected for use throughout this report because it was estimated using the current understanding of the TZ, and the estimating method is documented in Appendix H. For Subsurface Outflow of groundwater across the Helendale fault, the water budget uses the value of 4,600 AFY based on calculations performed by the current TZ evaluation. As tabulated in Appendix H, approximately two thirds of this outflow occurs in the Floodplain aquifer and one third in the Regional aquifer. Both existing and current subsurface flow estimates are presented in Appendix H of this report.

Groundwater Production

Groundwater production within the TZ can be estimated for large producers and small producers. The Mojave Water Agency (Mr. Victor Jackowich, personal communication, 2002) estimates that there may be as many as 177 minimal groundwater producers (producing less than 10 AFY each) in the TZ. The minimal producers are show on a map in Appendix E. The majority of the minimal producers, pump for domestic water uses. Average domestic water consumption is typically about 1 AFY. For the purposes of the Phase I evaluation it is assumed that all of the minimal groundwater producers pump 1 AFY for domestic uses. Using this assumption total minimal producer extraction from the TZ is 177 AFY.

The Watermaster has verified groundwater pumping throughout the Mojave Water Agency area beginning in 1994. Verified pumping values, broken down by use category are listed in the water budget. Groundwater production from large producers in the TZ averaged 14,641 AFY during the 1994 through 2001 Water Years. Annual production during this period is listed by water use category in Table 4. The values for municipal water use are slightly lower than values reported by producer in the Watermaster Annual Reports. The Watermaster Annual Reports address the entire Mojave Basin Area and tabulate water production by producer rather than by well location. The City of Adelanto produces water from both the TZ and the upper Alto Subarea. As a result, water production values reported in the Watermaster Annual Reports are greater than the amount produced by the City of Adelanto from within the TZ. Only City of Adelanto production from within the TZ is included in the water budget.

Much of the City of Adelanto groundwater production comes from a well field located in the southern TZ in Section 30 of Township 06N, Range 04W. Between 1996 and 2001, average groundwater production from this well field has been increasing at a rate of approximately 170 AFY. As the City of Adelanto continues to grow, both industrial and residential developments will continue to expand, and in turn will cause demand for City water to grow. For each acre-foot increase in production by the City of Adelanto, approximately 0.60 AF will be removed from the TZ water supply based on assumptions associated with the water budget prepared during the Phase I evaluation. The remaining 0.40 AF returns to the Regional aquifer through irrigation return flow, septic systems, and percolation basins. Adelanto is not part of VVWRA and operates a treatment plant that discharges to the Regional aquifer west of the SCLA.

WATER BUDGET

Inflow and outflow components described in the previous paragraphs were compiled into a TZ specific water budget shown in Table 3. Total annual inflow to the TZ is estimated to be 61,150 AFY in an average year. This value is a sum of base flow at the Lower Narrows, storm flow at the Lower Narrows, precipitation on open bodies of water, VVWRA discharge to ponds and the river channel, surface flow and infiltration from ungaged tributaries, pumping return flows and subsurface groundwater flow. The assumptions and conditions associated with each of these inflow components have been described in the preceding section.

Total annual outflow from the TZ is estimated to be 61,336 AFY in an average year, a difference of approximately 186 AFY from annual inflow. Outflow is a sum of; surface water evaporation, riparian transpiration, surface outflow across Helendale fault, subsurface outflow across Helendale fault, and municipal, domestic, agricultural, industrial, Silver Lakes Association and minimal producer groundwater production. Domestic groundwater producers are those that pump greater than 10 AFY. Minimal producers pump primarily for domestic uses and produce less than 10 AFY. The difference between total inflow and total outflow, although insignificant compared with the variability of the given data, may be accounted for by a change in storage.

Historical groundwater elevations from key wells within the TZ show annual water table stability although seasonal fluctuations are observed in the southern portion of the TZ. With annual inflow and outflow in balance, and with groundwater elevations within the TZ being annually consistent, the water budget is concluded to generally be in balance on an annual basis. While the annual water supply, annual water demand, and annual water elevations indicate a balance, seasonal groundwater fluctuations exist that can impact riparian vegetation and pumping lifts. This is especially true within the Floodplain aquifer in the southern TZ when during recent years summer-time water levels have been deeper than in previous years, only to recover by the following spring.

GROUNDWATER STORAGE

The volume of groundwater storage was estimated for both the Regional and Floodplain aquifers within the administrative TZ boundary. For the Regional aquifer, additional estimates were also made for two areas outside the administrative boundary that may be influenced by groundwater management practices within the TZ. These two areas were defined in the Aquifer Systems Section. The first area is north of the northern TZ administrative boundary but south of the Helendale fault. The second area is south of the southern TZ administrative boundary, but north of partial groundwater barriers formed by the Adelanto and Shadow Mountains faults.

Groundwater storage was estimated for both the Floodplain and the Regional aquifers by calculating the volume of water between the base of each aquifer and 1998 groundwater elevations. The base of the Regional aquifer is composed of bedrock along the basin margins and consolidated continental deposits along the basin central axis. From La Delta to Helendale, the base of the Floodplain aquifer was estimated to range from 280 to 300 feet bgs. From the Lower Narrows to La Delta, the base of the Floodplain aquifer was estimated to range from 75 to 280 feet bgs. 1998 groundwater elevations (Figure 6 and Figure 7) were used for both the Regional and Floodplain aquifers.

The first step of estimating storage was to divide the lateral extents of the Regional and Floodplain aquifers (shown on Figure 5) into grids and assign top and bottom elevations to each grid cell. This simplifies the storage calculation by allowing the irregular top and bottom surfaces to be represented by multiple parallel surfaces. In three dimensions, each grid cell becomes a column with a volume calculated by multiplying length, width, and height. The volume of the aquifer material is then estimated by totaling all the column volumes. Grid cell size for the Regional and Floodplain aquifers were 1/4-mile^2 and 1/16-mile^2, respectively. For the Regional and Floodplain aquifers, the grid cells generally correspond to a subdivision of each square-mile Township and Range Section into quarter sections (160 acres) and sixteenth sections (40 acres), respectively. A finer grid was used for the Floodplain aquifer to better define its relatively smaller area and provide a slightly more accurate estimate than the coarser grid could provide.

Based on their location in the TZ, the grid cells for each aquifer were next assigned values for water level elevation and aquifer bottom elevation. The difference between the two values multiplied by the area of the grid cell provided the volume of saturated sediments within each grid cell. Summing the volumes for all grids provided an estimate of the total volume of saturated sediments in each aquifer. As the base of the Floodplain aquifer is locally the top of the Regional aquifer, it is necessary to remove the volume of the Floodplain aquifer from the volume from the Regional aquifer. If not, this removed volume would be counted twice. Next, total volumes of each aquifer were multiplied by an average specific yield value to provide an estimate of groundwater in storage. For the Floodplain and Regional aquifers, specific yield values of 20 percent and 10 percent were used, respectively. The 20-percent value is the lower end of the USGS (2001a) specific yield range of 20 to 23 percent. The 10-percent value is a weighted average of the two values used in by USGS (2001a). Within the TZ, USGS (2001a) shows about 25 percent of the area at 5 percent specific yield and 75 percent of the area at 12 percent specific yield. Locally these values may be higher or lower, but are considered aquifer averages.

Groundwater in storage in the TZ and the two additional areas are listed in Table 5. Based on these estimation methods, the Regional and Floodplain aquifers within the TZ contain approximately 6.6 million AF and 710,000 AF of groundwater storage, respectively. The total groundwater in storage in both the Floodplain and Regional aquifers is approximately 7.3 million AF. These values are for 1998 conditions and may change slightly as the TZ population develops, additional water is produced, and as basin management practices change. A large portion of the water stored in the Regional aquifer may be unavailable for use due reasons associated with pumping water from deeper and older aquifers. Such reasons include lower yields and larger drawdowns in the more consolidated deeper aquifers, greater energy requirements needed to lift the water over larger drawdowns, and potentially poorer quality water from older more consolidated formations. Bookman-Edmonston (1994) estimated that the entire Mojave River Basin contains approximately 5 million AF of usable groundwater in storage. That estimate assumed water levels were drawn down 100 feet from the 1930s groundwater elevations. For the Phase I evaluation, using a similar drawdown assumption and the aquifer extents presented previously, the TZ aquifers contain 1.4 million AF of usable groundwater. That level of drawdown and extraction of this quantity of groundwater without replenishment would have serious impacts to the use of the TZ as a water bridge.

THE TZ WATER BRIDGE

The TZ water bridge is the physical and natural means by which surface and groundwater are conveyed to the Centro Subarea through the TZ from the upper Alto Subarea. The function of the TZ as a water bridge is controlled mainly by regional precipitation patterns, subsurface hydrogeologic conditions, and balanced water use (sources equal sinks). Regional precipitation patterns control the frequency, intensity, and volume of storm flow, which on average comprise the largest inflow component of the water budget. Storm flows also supply recharge to the upper Alto Subarea, which helps maintain water levels there and support future base flows to the TZ. Hydrogeologic conditions controlling TZ inflow and outflow include groundwater flow barriers (faults), differences in relative aquifer properties, variations in surface infiltration rates, and local pumping pattern. Favorable hydrogeological conditions have historically influenced the location of groundwater production centers along the Mojave River.

Balanced water use in both the upper Alto Subarea and in the TZ controls whether surface water and groundwater inflow replaces groundwater outflow or whether water inflow is passed through to the Centro Subarea. Conveyance of flow across the TZ water bridge is maintained when inflow is in balance with outflow (the TZ water budget) and when long-term water levels within the Floodplain and Regional aquifers are maintained. As outlined in the water budget discussion, the TZ annual water budget is on average in balance, but may experience seasonal groundwater fluctuations that can impact riparian vegetation and pumping lifts. This is especially true within the Floodplain aquifer in the southern TZ when during recent years summer-time water levels have been deeper than in previous years, only to recover by the following spring.

Groundwater production in the TZ has averaged 14,641 AFY over the period of verified production, 1994 to the 2001 Water Year (Watermaster, 1996 to 2002). Available storage created by pumping from the Floodplain aquifer can be recharge by surface water and/or inflow from the Regional aquifer. A significant portion of groundwater production occurs along the Mojave River up stream of Oro Grande. Due to the location of pumping and limited aquitards, a significant potential exists for surface water to recharge at this location. A short distance downstream of Oro Grande, clay lenses within the Floodplain aquifer separate shallow and deep zones. Groundwater in the shallow zone experiences less seasonal fluctuations from pumping. As surface flows past Oro

Grande and infiltrate above these clay layers, these waters would be less accessible to deeper pumping and would progress farther down stream towards the Centro Subarea. The existence of riparian vegetation in the TZ requires surface water and groundwater to maintain water levels above the basal clays of the upper zone of the Floodplain aquifer.

Groundwater inflow to the TZ occurs predominately in the Regional aquifer. Groundwater in the Floodplain aquifer occurs largely through the recharge of surface water in the Mojave River channel. The Mojave River channel is the effective top of the Floodplain aquifer. Although the Regional aquifer is larger and more extensive than the Floodplain aquifer, the Floodplain aquifer is able to transmit groundwater more readily. At a depth of 75 to 100 feet, the Floodplain aquifer can be subdivided into shallow and deep zones separated by interbedded sand and clay lenses. These zones occur directly down stream from the recharge forebay between the Lower Narrows and Oro Grande and continue a couple miles past Bryman. At the surface, the Floodplain aquifer shallow zone coincides with the approximate area of dense riparian vegetation in the Mojave River channel. North of this point, the Floodplain aquifer is mostly comprised of sand and gravel and is an afterbay where groundwater has the potential to flow upward from the deep to the shallow zone.

The Regional aquifer and Floodplain aquifer are in hydraulic communication. The direction of groundwater flow from one aquifer to the other varies. The Floodplain aquifer and Regional aquifer can gain water from or lose water to each other depending on relative differences in groundwater elevations. In the southern TZ, a downward gradient exists for groundwater to flow from the Floodplain aquifer to the Regional aquifer. As the width of the Regional aquifer constricts from 12 miles along the southern border to approximately 6 miles near Bryman, groundwater elevations in the Regional aquifer rise relative to those in the Floodplain aquifer. As water levels in the two aquifers become similar, the gradient and potential for groundwater to flow from one to the other diminishes. In the northern TZ, the Regional aquifer widens again, yet groundwater elevations in both the Regional aquifer and Floodplain aquifer remain similar. The Helendale fault acts to slow groundwater leaving the TZ and thus helps to maintain water level equilibrium.

Movement of water through the TZ depends on the demand not exceeding the supply, but also on the fullness of each aquifer. The fuller the Floodplain aquifer, the more likely it will be not to induce flow and storage from the Regional aquifer, and the more likely it will be that groundwater gradients will be maintained to supply the subsurface outflow component of the obligation. Likewise, the fuller the Floodplain aquifer is the more likely it is that surface water components of the obligation (base flow and current VVWRA discharges) will be transmitted through the TZ. On average, the annual water budget for the TZ is in balance with annual inflow (sources) approximately equaling annual outflow (sinks). However, the water budget may have seasonal imbalances that produce water level drawdown in areas of concentrated seasonal pumping that could impact riparian vegetation.

Historical (post 1930) water levels show a 5- to 10-foot decline in water levels in the Floodplain aquifer. Water levels in the Regional aquifer show lesser historical declines. Based on key well hydrographs, water levels in the TZ aquifers since 1990 are generally consistent from year to year. Short-term water levels show a slight increase, perhaps due to recent wet years. Since implementation of the Judgment, the TZ water bridge function has been maintained on an annual basis to transmit water though it to the Centro Subarea. This is supported by stability of long-term hydrographs, a generally balanced TZ water budget, and relatively constant groundwater storage. On a seasonal level, the timing, location, and concentration of pumping in the Floodplain aquifer in the southern TZ can produce seasonal instability in the water bridge than can affect pumping lifts and groundwater availability to riparian vegetation.

ARTIFICIAL GROUNDWATER RECHARGE POTENTIAL

Although water level data show available groundwater storage exists predominately in the Regional aquifer and to a lesser extent in the southern portion of the Floodplain aquifer, the objective of artificial groundwater recharge should be considered when selecting locations for potential recharge programs. Recharge objectives of MWA may include:

- Supplying water to riparian vegetation,
- Replenishing groundwater production,
- Banking or storing groundwater for short or long-terms,
- Meeting the minimal subarea obligation, and
- Maintaining water levels in TZ outflow areas.

Artificial groundwater recharge in the Floodplain and Regional aquifers can best occur where unsaturated aquifer material exists near ground surface and vertical hydraulic gradients have a downward component, essentially the aquifer forebay. Based on these criteria, artificial recharge to the Floodplain aquifer would be most effective in the Mojave River channel between the Riverside Cement Well and the VVWRA plant. Further north, the water levels in the Floodplain aquifer are shallower and have little or no downward vertical gradient between aquifers. Depending on the recharge program objectives, artificial recharge to the Regional aquifer would be effective in either the area north or south of the mapped constriction in the Regional aquifer extents. The southern areas would be preferable if the objective was to supplement production or store water in the Adelanto area. The northern area would be preferable if the objective was to store water in the Silver Lakes or Buckthorn Wash areas or maintain water elevations to provide subsurface flow toward the Centro Subarea.

Based on flow lines generated from 1998 Groundwater elevations, artificial recharge to the Regional aquifer would be best conducted near the Mojave River channel, or east of the Mojave River channel. In these areas, recharge water would flow to the Floodplain aquifer and flow towards Barstow area rather than toward the Harper Lake area once it crosses the Helendale fault. Barstow represents a larger groundwater demand than the Harper Lake area.

DATA GAPS

In the course of the current TZ evaluation, several data gaps have been identified. Data gaps are areas or subjects with insufficient data coverage to allow complete analysis. Several data gaps were filled during the course of the evaluation such as water quality sampling and analysis. Existing data gaps include; lack of surface water flow data at the Helendale fault area, sparse groundwater elevation data in areas of the Regional aquifer, and lack of groundwater elevations from certain key locations.

STREAM GAGE

No stream gauging station exists on the Mojave River at the Helendale fault. Webb (2000) performed an analysis of water resources within the TZ for the purpose of estimating the average annual flow across the Helendale fault. Although the work done was highly detailed, it is still only an estimate of average surface water flow across the fault. Most surface water crossing the fault occurs during storm flows. A gage at the fault would provide data for non-storm periods. According to MWA staff, potential construction of a gage at the Helendale fault has been explored with the USGS, but was rejected due to poor river channel cross-section characteristics at the fault.

MONITORING WELLS

Subsurface flow into and out of the TZ has been estimated using groundwater gradients and long-standing transmissivity data. Because the groundwater gradients into and out of the TZ occur at faults and where water level data are lacking, the gradients are subject to interpretation. For maintaining groundwater flow through the TZ, water levels in the out flow areas are more significant than maintaining water levels in inflow areas. Inflow areas can fluctuate annually or seasonally without a contemporary impact on outflow area water levels.

Accurate calculation of groundwater gradients requires elevations for at least three wells. Additional monitoring wells in inflow and outflow areas will allow more accurate monitoring of groundwater gradients, especially where existing wells are separated by faults and gradients are subjective. Rather than small diameter nested wells, new monitoring wells can be constructed as 4-inch diameter single casing wells that can also be used to conduct pump tests to refine transmissivity estimates.

Outflow Areas

Two additional monitoring wells would assist in evaluating subsurface outflow from the Regional aquifer. One well should be located about 2 miles northwest of the river between Buckthorn Wash and the Helendale fault and the other should be about 3 miles west of the river at Silver Lakes. Boreholes for the new wells if drilled to the base of water-bearing rocks, could be used to verify basin thickness in these areas . The new monitoring wells would be used with existing wells near the river to monitor Regional aquifer groundwater elevations, which account for one third of the estimated outflow from the TZ. The new wells could also be used during future aquifer pump tests to verify aquifer properties in these areas.

Inflow Areas

An additional two monitoring wells would assist in evaluating subsurface inflow from the upper Alto Subarea across the Adelanto and Shadow Mountains faults. The wells should be located on the down gradient side of the fault along the southern TZ boundary. The new monitoring wells would be used with existing wells near the SCLA and Oro Grande to monitor Regional aquifer groundwater elevations, which account for nearly all of the subsurface inflow to the TZ. Reevaluation of existing geophysical data sets can be used to focus these well locations to make sure they are placed on the correct sides of the Adelanto and Shallow Mountains faults.

Areas of Riparian Vegetation and Surface Water Recharge

Water level monitoring in areas of riparian vegetation is required by the Judgment. Significant areas of riparian vegetation occur directly downstream of the Lower Narrows just north of the Floodplain aquifer forebay. Areas of riparian vegetation continue down stream past Bryman and are supported by recharge to the shallow zone of the Floodplain aquifer. Recharge of base flow in the forebay can flow both to the deep or shallow zones of the Floodplain aquifer depending of flow rates and forebay groundwater elevations. Groundwater in the deep zone supports local groundwater production.

A multi-depth monitoring well located between Oro Grande and the VVWRA treatment plant would assist both to track groundwater flow and quality through the Floodplain aquifer forebay, and also to monitoring groundwater elevations in both the deep and shallow zones of the Floodplain aquifer. A multi-depth well at this location should completed in the shallow and deeps zones of the Floodplain aquifer, the Regional aquifer, and also in the first encountered nonwater-bearing rock. This well should be considered as a Key Well for monitoring water levels for riparian vegetation. A new multi-depth well in the floodplain between Oro Grande the VVWRA Treatment plant would also aid in understanding the complex vertical gradients between the Regional and Floodplain aquifers south of Bryman.

A second multi-depth monitoring well in the floodplain upstream of the VVWRA treatment plant near La Delta would assist both in evaluating recharge of treatment plant discharges, water levels in riparian vegetation, and in evaluating vertical gradients. Such a well would also assist in further delineating the shallow and deep zones of the Floodplain aquifer. This well would be located near discontinuity in the clay lenses separating the Floodplain aquifer deep and shallow zones. A pump test of a nearby well screened in the deep zone of the Floodplain aquifer using these two new multi-depth wells for monitoring would provide the degree of confinement of the deep zone.

GROUNDWATER CONTOURING

With the new monitoring well elevations, groundwater gradients in the inflow and outflow areas should be contoured and used to reevaluate groundwater flow. Historical estimates of subsurface inflow by USGS and others consultants range from 3,500 to 4,800 AFY. Estimates of groundwater outflow flow across the Helendale fault range from approximately 1,600 to 6,000 AFY. Although these values are published, a detailed basis for these values has not been published. Appendix H of this report provides some rationale for these estimates and provides a newer estimate based on the latest hydrogeologic understanding of the TZ. Sufficient wells exist in the Floodplain aquifer near the Helendale fault to estimate groundwater flow in the Floodplain aquifer. With new wells in the Regional aquifer and new water elevation data to contour away from the river, a detailed estimate of subsurface flows using both the Regional and Floodplain aquifer should be developed under peer review and published such that all assumptions and methods are document. These new values would provide a reasonable estimate that could be used for basin management purposes.

The USGS has produced groundwater elevation contour maps of the Mojave River Basin for 1992, 1996 and 1998 groundwater conditions and is in the process of producing a contour map for 2000 conditions. Portions of the northern and western TZ are not contoured on these maps. In particular, the area north of the Shadow Mountains and west of Highway 395, and the area between Silver Lakes and Highway 395, has few groundwater measurements. Groundwater elevation data from these areas would help define groundwater flow patterns and may offer an indication of how faults that control bedrock structure in the area may affect groundwater flow. Understanding how these faults affect groundwater flow may have an impact on aquifer volumetric calculations and estimates of water supply in the TZ. Groundwater elevation data may be obtained from these areas by adding existing wells to the groundwater level monitoring program, or constructing new wells in a few key locations.

Annual groundwater contours maps of the Mojave Basin and particularly the TZ should be constructed using contouring techniques and similar concepts of how groundwater moves through the aquifers. Comparison of the 1992, 1996, and 1998 elevation maps shows differences in elevation and shape without significant differences in water level data. These differences may have resulted from an improved understanding of the aquifer systems over time. Using the existing maps, subtle differences in contouring yield storage changes that do not match the raw water elevation data. With two successive and similarly contoured maps, a change in aquifer storage map could be produced.

GEOPHYSICAL SURVEYING

SSI (1990) produced a significant gravity data set for MWA. Through the Phase I evaluation, URS made a concerted yet unsuccessful effort to locate these data through SSI and Dr. Shawn Biehler of UC Riverside. To duplicate the effort made by SSI in 1990 would today cost between $100,000 and $200,000. If these data can be located in MWA or governmental archives, they could be used to better define subsurface bedrock structures and depths as well as alluvial units having significant differences in density. Such differences include degree of groundwater saturation and degree of consolidation. The data shown in SSI can be evaluated at a much finer resolution than was conducted by SSI, especially with new bedrock depth data from recently completed USGS wells and the URS seismic refraction survey. Reevaluation of these data could provide additional insight into where groundwater exists along the perimeter of the TZ and how faults control groundwater flow into and out of the TZ. Evaluation of the data set could refine the locations of future well, including both production and monitoring wells.

FINDINGS

Summarized below are the findings of the Transition hydrogeologic evaluation.

GEOLOGY

The TZ consists of complex fault and erosion controlled bedrock depressions that are partially filled with consolidated sedimentary materials, which in turn are covered with unconsolidated sediments. Sedimentary units include Tertiary-age consolidated sediments, Quaternary-age Older and Younger Alluvium, and Quaternary-age fluvial deposits of the Mojave River. The Tertiary-age consolidated sediments include the Punchbowl and Crowder equivalent formations. The Tertiary-age consolidated sediments are overlain by Older Alluvium of the age-equivalent Victorville Fan deposits. Based on seismic data acquired during the Phase I evaluation, the Tertiary deposits range in thickness between 600 and 1,600 feet and the Quaternary deposits range in thickness between 800 and 1,200 feet. Bedrock occurs at depths up to 3,000 feet. Normal faults can be inferred in the Tertiary and older units based on the below sea level bedrock elevations and the steep bedrock basin sides indicated by the gravity data. A series of northwest trending strike-slip faults have been mapped in all rock units. The Mojave River channel, eroded into the Older Alluvial deposits beginning in the middle Pliocene, has been partially backfilled with Mojave River fluvial deposits consisting of interbedded sand, gravel, boulders, silt, and clay.

HYDROGEOLOGY

Aquifer Systems

The formations of the TZ can be grouped into three hydrogeologic units: 1) nonwater-bearing units composed of bedrock and consolidated sediments, 2) the Regional aquifer composed of Older Alluvium, and 3) the Floodplain aquifer composed of Mojave River fluvial deposits. In the Floodplain aquifer, shallow and deep zones can be distinguished between the Oro Grande and Bryman areas.

Nonwater-bearing units that underlie the Regional and Floodplain aquifers form the effective base of the groundwater system. Within the TZ, the Regional aquifer extends from alluvial deposits between the bedrock outcrops of Quartzite and Silver Mountain to the bedrock outcrops of the eastern Shadow Mountains. Areas of alluvium can be excluded from the Regional aquifer where groundwater is within bedrock below the base of the water-bearing deposits. Within the TZ, the Regional aquifer ranges in width from about 12 miles along the southern TZ boundary, 8 miles near Adelanto, about 6 miles near Bryman, then widens again to the north in the Buckthorn Wash area. In the area of the Mojave River channel, the regional aquifer underlies the Floodplain aquifer. The Regional aquifer generally ranges in thickness from a few inches along the aquifer margins to about 1,200 feet in the center. Beneath the Floodplain aquifer, the Regional aquifer ranges between 150 and 840 feet thick.

Within the TZ, the Floodplain aquifer is generally as wide as the Mojave River channel between eroded bluffs. The Floodplain aquifer has a much higher transmissivity than the Regional aquifer. At a depth of 75 to 100 feet, a 50 to 100-foot thick zone of interbedded clay and sand layers separates the shallow and deep zones of the Floodplain aquifer from approximately 1.5 miles down stream from the Lower Narrows to midway through the TZ in the Bryman area. From Bryman northward, the clay lenses are sufficiently discontinuous or absent as to make a distinction between the shallow and deep zones of the Floodplain aquifer. The shallow zone ranges in thickness from 70 to 100 feet. The deep zone of the Floodplain aquifer ranges in thickness between 120 and 160 feet. Where zones are not distinguished, the Floodplain aquifer is between 250 and 300 feet thick.

The Floodplain aquifer forebay occurs south of the shallow and deep zone separation. A downward hydraulic gradient occurs in the forebay towards the underlying Regional aquifer indicating the Regional aquifer may receive recharge from the Floodplain aquifer in this area. North of the forebay, the vertical gradient between Floodplain and Regional aquifer slowly reverses as the width of the Regional aquifer narrows at the latitude of Bryman. As the Regional aquifer widens north of Bryman, the vertical gradient again gradually reverses to a slight downward gradient from the Floodplain aquifer to the Regional aquifer. North of the distinction of the Floodplain aquifer shallow and deep zones, an afterbay exists in the Floodplain aquifer. The Floodplain aquifer afterbay is located immediately up gradient of the Helendale fault. The afterbay area has a small groundwater gradient from the Floodplain to the Regional aquifer, indicating the potential for the Floodplain aquifer to recharge the Regional aquifer in this area. This potential downward gradient would likely increase with any future increase in Floodplain aquifer water elevations

Groundwater Flow

Groundwater flows generally northward in both the Regional and Floodplain aquifers. Groundwater flow paths in the Floodplain aquifer follow the course of the river channel from south to north. Groundwater flow paths in the Regional aquifer are generally from south to north but are controlled by the extents of the aquifer. In the southern TZ, the Regional aquifer is approximately 12 miles wide in the area of the former George AFB, and narrows to approximately 6 miles wide in the Bryman area. Constriction of the Regional aquifer in the central TZ causes water levels to rise in the Regional aquifer relative those observed in the Floodplain aquifer, and may cause the Floodplain aquifer to receive some recharge from the Regional aquifer in this area. North of Bryman, the Regional aquifer widens again and groundwater elevations are nearly the same in both the Regional and Floodplain aquifers. Groundwater elevations in the Regional aquifer range from about 2850 feet MSL in southwestern TZ to less than 2400 feet at the Helendale fault. Higher groundwater elevations in the Regional aquifer northwest of Adelanto and Highway 395 near Astley Ranch may be impacted by faulting or perching conditions. Groundwater elevations in the Floodplain aquifer range from about 2625 feet MSL in the southern TZ to 2400 feet MSL in the northern TZ.

Water Quality

Groundwater in the TZ is generally of good quality with some notable concerns. Arsenic concentrations in excess of State Primary Drinking Water Standards have been observed in samples collected from 20 wells constructed within the Floodplain aquifer between the Lower Narrows and the Helendale fault. Iron concentrations in excess of state secondary drinking water standards have been observed in samples collected from 14 wells constructed predominantly within the Floodplain aquifer and to a lesser extent the Regional aquifer between the Lower Narrows and the Helendale fault. Fluoride concentrations in excess of state primary drinking water standards have been observed in samples collected from 14 wells constructed within the Floodplain and Regional aquifers between the Lower Narrows and the Helendale fault. Arsenic, Iron and Fluoride concentrations in excess of State Standards are not observed in surface water or VVWRA discharge. Locally perched groundwater beneath the former George AFB is contaminated with jet fuel and chlorinated solvents.

From approximately 35 years of historical surface water data collected in the Mojave River at the Lower Narrows, basin objectives set by the RWQCB Lahontan Region have recently been exceeded for TDS and sulfate. Since 2001, sulfate concentrations have occasionally exceeded basin objectives set by the RWQCB Lahontan Region. Since 2001, TDS concentrations have consistently exceeded basin objectives by 10 to 100 mg/L. These sulfate and TDS concentrations are however within the historically range of values measured since 1965. Comparison of contemporaneous data indicates Upper Narrows surface water quality may not be a good indicator of Lower Narrows surface water quality.

Groundwater in the TZ reflects its source. In the southern TZ Floodplain aquifer, groundwater quality resembles that of Mojave River surface water at the Lower Narrows. Along the Mojave River, groundwater quality in the Floodplain aquifer shallow zone increases in TDS likely to due evapotranspiration effects. The groundwater quality of the Floodplain aquifer deep zone is more similar to the Regional aquifer. Groundwater in the Floodplain aquifer shallow zone is similar to VVWRA discharges. As groundwater leaves the TZ, its quality represents a blend of sources and impacts. The character of surface water at the Lower Narrows has been relatively consistent over the 25-year period of record. Groundwater in the Regional aquifer near Adelanto has lower TDS than is observed in surface water or Floodplain aquifer groundwater, except at times when surface water is affected by storm flows. The Regional aquifer does exhibit localized high TDS.

Key Well Hydrographs

Key well hydrographs show TZ water levels have seasonal variations, but have not changed significantly on an annual basis over the past 10 years. In the Floodplain aquifer, water levels are shallowest in winter and spring and deeper in summer and fall months. Seasonal fluctuations are greatest in the southern TZ and are subdued in the northern TZ. Generally, depth to water during winter has changed very little over the period of record, while depth to water during summer has increased over the past few years, particularly in the southern TZ.

Increasing seasonal groundwater elevation fluctuations will results in greater summer pumping lifts and potentially threaten seasonal water supply to riparian vegetation. Within the TZ, seasonal water fluctuations decrease in magnitude from south to north. In the Floodplain aquifer, the largest seasonal TZ water level fluctuations are greater than 30 feet down gradient from the Lower Narrows, 4 feet adjacent the VVWRA treatment plant, 10 feet near Bryman, and less than 2 feet near Silver Lakes. In the areas up and down gradient from the Lower Narrows, summer water levels in both the Floodplain and Regional aquifers were deeper in 1999, 2000, and 2001 than in previous years. However, during the following winters, water levels recovered to levels similar to those observed during previous winters.

In the period immediately prior to and since the Judgment, long-term annual water level changes (1990-2001) are relatively small in magnitude. Long-term water levels are rising in some locations and falling in others, likely due to changes in water use and recharge throughout the TZ. Following implementation of the Judgment in 1996, groundwater production in the Mojave Basin Area became regulated and free production allowances have undergone step-wise mandatory decreases. Beginning in 1997, small magnitude (approximately 1 to 2 feet), short-term shallowing of groundwater levels has been observed in the Oro Grande, Silver Lakes, and Shadow Mountains fault areas. Shifting of production and use from agricultural to municipal well fields may cause decreased water levels in some areas with corresponding increases in others. Small magnitude (approximately 1 foot), short-term deepening of water levels has been observed in the Adelanto area.

SOURCES AND SINKS

The annual TZ water budget is essentially balanced based on representative long-term average conditions. The water budget prepared for the Phase I evaluation indicates that under recent conditions, the TZ has an average annual water inflow of 61,150 AFY and average annual water outflow of 61,336 AFY. The approximate difference of 186 AFY is within the variability and estimating precision of the data. This finding is supported by long-term stability of annual water elevations shown by the Key Well Hydrographs. The water budget does not provide an indication of seasonal balance as would be required to judge the water supply for riparian vegetation. In order to evaluate annual and seasonal availability of water supply for riparian vegetation, near surface water elevations in the shallow zone of the Floodplain aquifer in areas of riparian vegetation should be investigated.

VOLUME CALCULATIONS

The total groundwater storage is approximately 1.4 million AF is by proportion roughly comparable with the storage estimate of the Regional Water Management Plan. The Regional Water Management plan (Bookman-Edmonston, 1994) cites a useable groundwater storage value of approximately 5 million AF within the entire Mojave River Basin. The 1994 estimate assumes that useable groundwater supplies consist of 100 feet of aquifer thickness below 1930 groundwater levels. Using this assumption, useable groundwater storage within the TZ is estimated at approximately 1.1 million AF and 280,000 AF in the Regional aquifer and Floodplain aquifers, respectively. Pumping of this quantity of water without annual replacement would severely impact the water bridge function of the TZ. Within the total saturated thickness of the TZ, groundwater storage estimates for the Regional and Floodplain aquifers are 6.6 million AF and 700 thousand AF, respectively.

THE TZ WATER BRIDGE

As indicated by long-term hydrographs, a generally balanced TZ water budget, and relatively constant groundwater storage, the TZ water bridge has been maintained since implementation of the Judgment for the purposes of groundwater flow to the Centro Subarea. Movement of water through the TZ depends on the demand not exceeding the supply, but also on the fullness of each aquifer. Balanced water use in both the upper Alto Subarea and in the TZ controls whether surface water and groundwater inflow replaces groundwater storage deficits or whether the inflow is passed through to the Centro Subarea.

The water bridge function of the TZ to maintain riparian vegetation is jeopardized in the southern TZ due to recent increased depth to water during summer months. Although the water levels recover during the winter, riparian vegetation can be affected without a year round supply of water. Future monitoring for riparian vegetation should utilize wells screened in the shallow zone of the Floodplain aquifer.

POTENTIAL RECHARGE PROGRAMS

Artificial groundwater recharge is feasible in the TZ and potential programs objectives should be considered when selecting recharge locations and methods. Water level data show available storage exists predominately in the Regional aquifer and to a lesser extent in the southern portion of the Floodplain aquifer. Conversely, aquifer properties and demand support recharge to the Floodplain aquifer rather than the Regional aquifer.

Artificial recharge to the Floodplain aquifer would be most effective in the Mojave River channel between the Lower Narrows and Oro Grande. The southern TZ area would be preferable if the objective was to supplement the Section 30 well field used largely by the City of Adelanto and the SCLA. Further north, water levels in the Floodplain aquifer are shallower and have only a small downward vertical gradient between aquifers. Potential surface recharge of the Floodplain aquifer in this area between Oro Grande and Bryman would supply the shallow zone and would be useful both as underflow to support surface flows and water for riparian vegetation habitat. Increase channel infiltration rates near La Delta should be considered when using the river channel as an infiltration mechanism.

Artificial recharge of the Regional aquifer would be more effective in the areas north or south of the mapped constriction in the Regional aquifer. Recharge of the Regional aquifer should consider the occurrence of local perched conditions when selecting recharge mechanisms. The southern area would be preferable if the objective was to store water or supplement groundwater in the Adelanto area. The northern area would be preferable if the objective was to store water in the Regional aquifer west of Silver Lakes or to enhance subsurface outflow towards the Centro Subarea. For Regional aquifer recharged water to flow towards the Barstow area artificial recharge would be most effective near the Mojave River channel, or east of the Mojave River channel as indicated by groundwater flow lines.

DATA GAPS

The most significant data gaps include sparse groundwater elevation data in areas of the Regional aquifer, and lack of multi-depth groundwater elevations from certain areas of the Floodplain aquifer. Sufficient wells exist in the Floodplain aquifer near the Helendale fault to estimate groundwater flow in the Floodplain aquifer.

Additional monitoring wells in inflow and outflow areas will allow more accurate monitoring of groundwater gradients, especially where existing wells are separated by faults and gradients are subjective. Two additional single casing monitoring well would assist in evaluating subsurface outflow from the Regional aquifer. An additional two monitoring wells in the Regional aquifer would assist in evaluating subsurface inflow from the upper Alto Subarea across the Adelanto and Shadow Mountains faults. With the new monitoring well elevations, groundwater gradients in the inflow and outflow areas should be contoured and used to reevaluate groundwater flow. These new values would provide a reasonable estimate that could be used for basin management purposes.

Reevaluation of existing geophysical (gravity) data could provide additional insight into TZ hydrogeology specifically where groundwater exists along the perimeter of the TZ and how faults control groundwater flow into and out of the TZ. Evaluation of the data set could refine the locations of future wells, including both production and monitoring wells.

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