Final Report

Conceptual Hydrogeologic Model

and

Assessment of Water Supply and Demand

for the

Centro and Baja Management Subareas
Mojave River Groundwater Basin

July 2013

Todd Engineers
with
Kennedy/Jenks Consultants

Mojave Water Agency

FINAL REPORT

Conceptual Hydrogeologic Model and Assessment of Water Supply and Demand for the Centro and Baja Management Subareas Mojave River Groundwater Basin

July 2013

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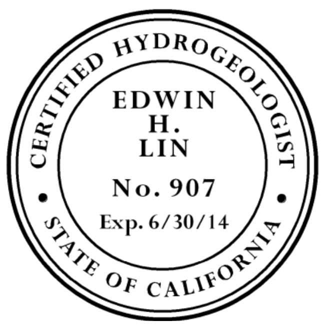

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LIST OF ACRONYMS AND ABBREVIATIONS

AFY	Acre-feet per year
AVEK	Antelope Valley-East Kern Water Agency
AWAC	Alliance for Water Awareness and Conservation
BAP	Base Annual Production
BLM	(United States) Bureau of Land Management
BNSF	Burlington Northern Santa Fe
BTEX	benzene, toluene, ethylbenzene, and xylenes
CDPH	California Department of Public Health
CEC	California Energy Commission
CII	Commercial Industrial and Institutional
CMD	Cumulative mean departure
CSD	Community Services District
CSUF	California State University Fullerton
CIWMP	California Interagency Watershed Mapping Committee
Cr-III	Trivalent chromium
Cr-VI	Hexavalent chromium
CY	Calendar Year (January 1 to December 31)
DEM	Digital Elevation Model
DOC	Dissolved organic content
DoD	(United States) Department of Defense
DRR	Delivery Reliability Reports
DWR	California Department of Water Resources
ET	Evapotranspiration
feet-bgs	Feet below ground surface
feet/day	Feet per day
feet msl	Feet above mean sea level
FPA	Free Production Allowance
GPCD	Gallons per capita per day
gpd/ft	Gallons per day per foot

gpm/ft of dd	Gallons per minute per foot of drawdown
GSA	Geological Society of America
GSWC	Golden State Water Company (Barstow)
H&SC	California Health and Safety Code
IRWMP	Integrated Regional Water Management Plan
Ka	Thousand years ago
LGS	Layne GeoSciences
LIDAR	Light Detection and Ranging
LUST	leaking underground storage tank
Ma	Million years ago
MBA	Mojave Basin Area
MCLB	Marine Corps Logistics Base
meq/L	milliequivalents per liter
MFR	Multiple Family Residential
MGD	Million gallons per day
mg/L	milligrams per liter
MBAS	methylene blue active substances
MCL	Maximum contaminant limit
MSP	Mojave Solar Project
MTBE	Methyl tert-butyl ether
MW	Megawatt
MWA	Mojave Water Agency
NWIS	USGS National Water Information System
OEHHA	California Office of Environmental Health Hazard Assessment
OU	Operable Unit
PCB	Polychlorinated biphenyls
PCE	Tetrachlorethylene
PG&E	Pacific Gas and Electric
PHG	Public Health Goal
PRISM	Parameter-elevation Regressions on Independent Slopes Model

PSY	Production Safe Yield
PUC	California Public Utilities Commission
PWSS	Public Water System Statistics
R-Cubed	(Upper Mojave River Groundwater) Regional Recharge and Recovery Project
RTP	Regional Transportation Plan
RWQCB	California Regional Water Quality Control Board, Lahontan Region
SAC	Subarea Advisory Committee
SBX7-7	Senate Bill 7 of Special Extended Session 7
SCAG	Southern California Association of Governments
SCG	Southern California Gas
SEGS	Solar energy generating systems
SFR	Single Family Residential
SNMP	Salt and Nutrient Management Plan
SWP	State Water Project
S value	(Aquifer) Storativity
TCE	Trichloroethene
TDS	Total Dissolved Solids
T value	(Aquifer) Transmissivity
μg/L	Micrograms per liter
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USU	Utah State University
UWMP	Urban Water Management Plan
VOC	Volatile organic compound
VVWRA	Victor Valley Wastewater Resources Agency
WRCC	Western Regional Climate Center
WWTP	Wastewater Treatment Plant
WY	Water Year (October 1 to September 30)
W&G	Wagner and Bonsignore

EXECUTIVE SUMMARY

The Mojave Water Agency (MWA) is responsible for managing the water resources of the High Desert in San Bernardino County to ensure a sustainable water supply for current and future beneficial uses. A primary goal of MWA is to conjunctively manage groundwater and imported water in the Mojave Basin Area while maintaining reliance on local water supplies. To support future management decisions, a focused evaluation of the Centro and Baja subareas has been conducted.

Introduction

The Mojave River Groundwater Basin (Basin) represents the predominant source of water supply in the region, relied upon for agricultural, domestic, and urban uses. Expansion of agriculture and urban growth resulted in overdraft by the 1950s, which led to the 1996 adjudication of the Basin and appointment of MWA as the Mojave Basin Area Watermaster (MBA Watermaster). The Mojave River surface water drainage basin within MWA's jurisdiction was divided into five management subareas: Este, Oeste, Alto (including the Alto Transition Zone), Centro, and Baja as shown on the following map. This study focuses on the Centro and Baja subareas.

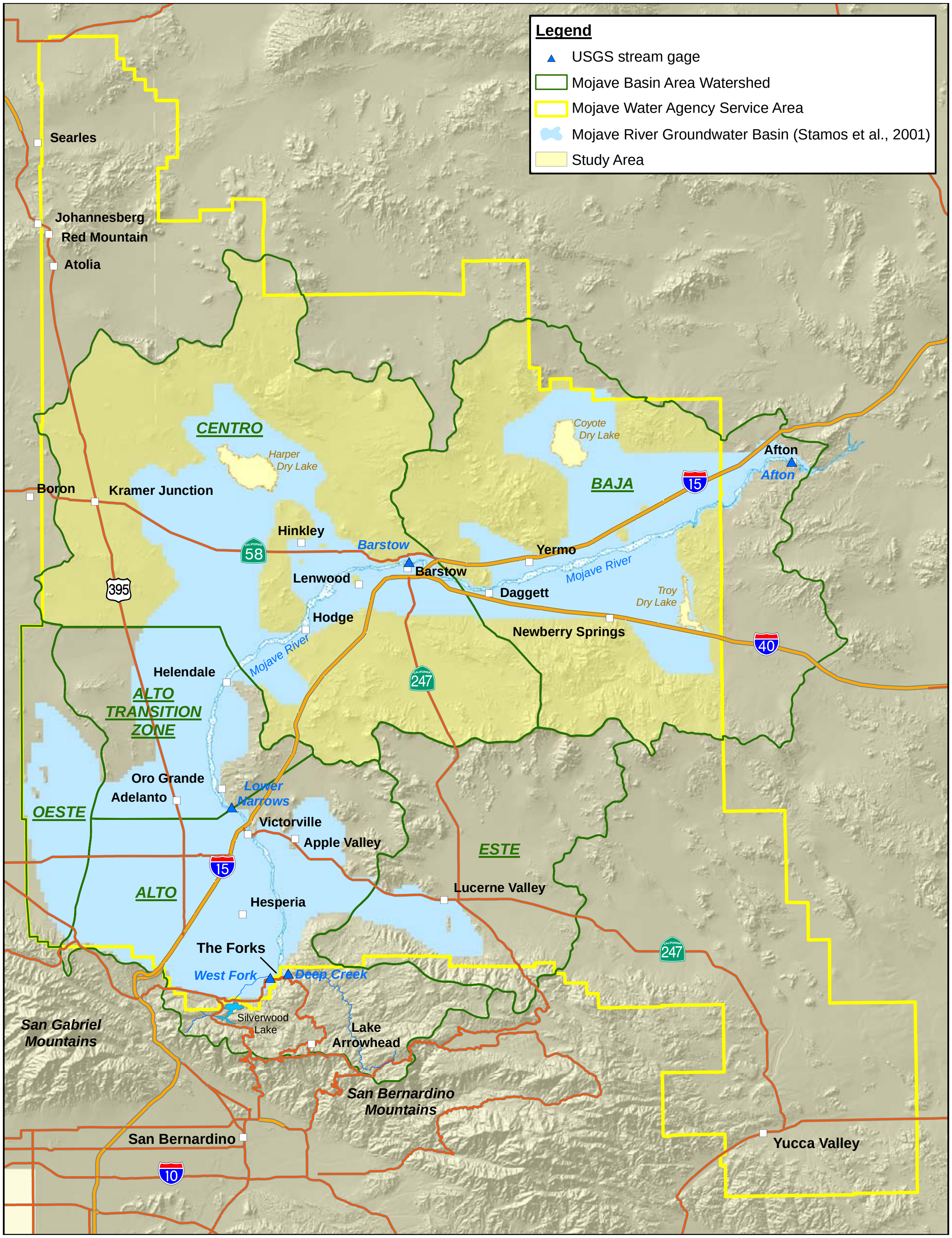
The current understanding of the Centro and Baja subareas has evolved from decades of monitoring, data collection, and scientific study, which has resulted in a substantial body of knowledge. The objectives of this report are to:

- Integrate the historical body of knowledge with recent evaluations using current information
- Develop coherent conceptual hydrogeologic models of the Centro and Baja subareas
- Summarize current and future subarea water supply and demand conditions
- Identify critical knowledge gaps and data needs
- Provide a comprehensive document as a foundation for management decisions in the Centro and Baja subareas.

> The goal of this report is provision of an integrated understanding of the hydrogeology and water supply and demand conditions of the Centro and Baja subareas to support basin management.

This report is organized into seven sections, followed by a list of references and nine appendices that provide selected reference summaries, data tables, and several specific studies.

- **Section 1** provides a summary of the project, objectives, scope, and data
- **Section 2** summarizes MWA's water management framework
- **Section 3** provides information on the physical setting and land and water uses through time
- **Sections 4 and 5** present the conceptual hydrogeologic models for the Centro and Baja subareas
- **Section 6** summarizes water supply and demand
- **Section 7** presents final conclusions and recommendations.



MWA Service Area and Study Area

Water Management Programs, Policies, and Institutional and Infrastructure Configurations

MWA manages water resources in the Mojave River Basin by means of a framework composed of water management policies, goals, and programs, plus institutional and infrastructure configurations.

Key Documents

A key overarching document is the **MWA Strategic Plan** which presents six primary goals that encourage:

1) Development of sound fiscal and organizational policies
2) Conjunctive management of local and imported water
3) Protection of water quality
4) Public outreach
5) Advancement of scientific understanding of the region's water resources
6) Water conservation

> The *MWA Strategic Plan* presents the vision and mission of MWA, while the *IRWMP* is the master planning document for MWA water management

The **Integrated Regional Water Management Plan** (IRWMP) is the master planning document for MWA water management activities. The IRWMP describes water supply and demand issues, including groundwater overdraft, and identifies projects and management actions.

The **Urban Water Management Plan** documents urban water supplies, including recycled water; quantifies existing and future demands; addresses drought and other shortages; and documents and encourages water conservation.

The **Salt and Nutrient Management Plan** evaluates the potential for increases of salt and nutrients in groundwater and provides a management plan to protect beneficial uses of groundwater.

The **Mojave Basin Area Judgment** provides the institutional framework to allocate equitably the right to produce water from the available natural water supply and to provide equitable sharing of costs for supplemental water.

Infrastructure

Section 2 also describes the local water infrastructure. MWA imports water from the State Water Project (SWP) to recharge the groundwater basin from which local water companies, municipalities, and other well owners pump for beneficial uses. MWA owns and operates two major pipelines (Mojave River Pipeline and Morongo Basin Pipeline) and associated infrastructure that convey imported SWP water to augment local groundwater supplies.

The newly completed Regional Recharge and Recovery Project (R-Cubed) project will deliver SWP water for recharge along the Mojave River (Alto Subarea), subsequent recovery through planned MWA-owned production wells, and delivery to retail water agencies. While the project is not within the Centro or Baja subareas, the project will provide MWA with increased operational flexibility.

MWA also operates enhanced recharge facilities, including two in the Centro Subarea (Hodge and Lenwood) and two in the Baja Subarea (Daggett and Newberry Springs), each of which are supplied by the Mojave River Pipeline.

Monitoring Programs and Other Collaboration

As part of its role as Watermaster, MWA maintains records of producers, production wells, and annual production from parties to the Judgment. Partnering with other agencies, MWA is actively engaged in extensive monitoring of climatic conditions, streams, groundwater levels, and water quality. MWA also has constructed numerous groundwater monitoring wells, and has provided funding and technical support of hydrogeological studies and field investigations to characterize hydrogeologic conditions and to site and monitor enhanced recharge facilities.

MWA has also entered into numerous partnerships with other organizations to develop programs that support urban and agricultural water conservation.

Basin Conceptual Model Development

A hydrogeologic conceptual model integrates all of the information from previous studies, field investigations and monitoring programs to provide a scientific foundation for groundwater management. This background information, presented in Section 3, addresses the local geology, land use and water use, climate, and hydrologic conditions of the Mojave River region through time.

Geology

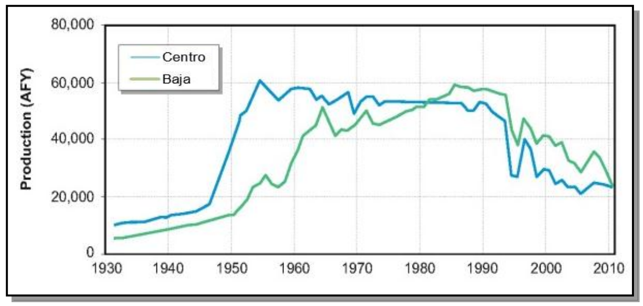
The Centro and Baja subareas are located in the lower portion of the Mojave River Basin. The valley floor along the river is surrounded by local hills and mountains.

The geology is characterized by sedimentary alluvial basins bordered by igneous and metamorphic mountain ranges and uplands. Numerous geologic faults cross the subareas variously affecting groundwater flow and quality; these are discussed in greater depth in the sections addressing the Centro and Baja subareas. The alluvial deposits associated with the modern Mojave River represent the principal aquifer system; the generally deeper Regional Aquifer consists of older alluvial deposits while the Floodplain Aquifer consists of more recent, permeable unconsolidated sand and gravel deposits.

Other significant sedimentary deposits include lake deposits and aeolian (wind-blown) sand deposits. The lake deposits (thick silts and clays) were formed when the ancestral Mojave River drained into a series of large lakes, including the ancestral Manix Lake in the Baja Subarea. Within the 270-mi^2 area once occupied by Lake Manix, the Manix Beds separate the groundwater system into shallow unconfined and deeper confined aquifers and limit recharge to the deeper aquifer system.

Land Use and Water Use

The High Desert consists of a mix of urban, agricultural, and undeveloped (mostly Federal) land. Agriculture (e.g., alfalfa) has historically been the primary land use in both subareas and continues to be the main land use in the Baja Subarea. Currently, agricultural pumping accounts for roughly 50 percent and 80 percent of the total pumping in Centro and Baja, respectively. The City of Barstow, the largest population center, is a hub of railroad and highway transportation. Other centers of activity include mining operations, military bases, power generation facilities, and recreational lakes.



Groundwater is pumped from the Floodplain Aquifer and Regional Aquifer for municipal, industrial, and agricultural supply. Pumping increased dramatically in Centro in the 1940s and 1950s and in Baja in the 1950s and 1960s. Total production in the Mojave River Basin peaked in 1989 at about 240,000 AFY, at which time combined production in Centro and Baja was about 110,000 AFY. Since the Judgment, pumping has declined significantly; production in the Centro and Baja subareas in WY 2009-10 represents about 40 percent of their respective historical peak annual production.

Perennial flows and shallow groundwater conditions along the Mojave River in Centro and Baja have historically supported riparian vegetation. However, declining groundwater levels have contributed to riparian vegetation loss. The Judgment defines protected riparian areas to be maintained; while not inclusive of all riparian vegetation in the Study Area, the Judgment specifically identifies the Camp Cady Wildlife Area in the Baja Subarea. For a variety of reasons, the density and distribution of riparian habitat at Camp Cady has declined significantly since the late 1980s/early 1990s. In response, an engineered solution (involving re-planting and irrigation with local groundwater) currently is being evaluated to restore lost riparian habitat. Another engineered wetland/marsh supported by groundwater in the southwestern corner of Harper Dry Lake in Centro provides habitat for resident wildlife and migratory waterfowl, shorebirds and wading birds.

Shallow groundwater also historically supported vegetation that anchors aeolian deposits (sand dunes). Major aeolian deposits occur near Harper Dry Lake in Centro, along the Mojave River near Barstow, near Coyote and Troy dry lakes, and in central Baja. However, anchoring vegetation has been lost because of declining groundwater levels, scouring during flood events, wildfires, and agricultural clearing. As a result of these combined factors, large quantities of exposed sand have been mobilized. In the future, the destabilized dune sands are expected to continue to migrate eastward (downwind), and sand storms are likely to increase.

Climate

Rainfall data from eleven climate stations have been evaluated to better understand the contribution of runoff from precipitation in the Mojave River headwaters, local mountains, and valley floor. Average annual precipitation in the San Bernardino Mountain headwaters averages 40.53 inches, while average annual precipitation on the valley floor averages 4.71 inches. Annual precipitation is variable; for the headwater stations, annual precipitation has been as high as 98 inches and in recent years, as low as 6 inches. Precipitation on the valley floor is more consistent. No climate gages are located in the local desert mountains; accordingly, the precise orographic effect of the local mountains on precipitation patterns is uncertain. Review of available isohyetal (rainfall distribution) maps indicates that estimated average annual precipitation likely reaches up to 10 inches/year in the local mountains.

Hydrology

The defining surface feature in the Basin is the Mojave River, an ephemeral stream fed primarily by storm runoff from the northern slopes of the San Bernardino Mountains. Other sources of flow in the river include localized groundwater inflow, direct discharges of treated effluent, and ungaged local storm runoff from ephemeral desert washes (which is quantified in this study). Streamflow losses from the river represent the primary source of groundwater recharge in the Basin; these have varied in response to both physical and human factors over time.

Because the Centro and Baja subareas are located in the downstream portion of the Basin and are subject to physical conditions and activities that occur upstream, the complete Mojave River hydrologic system was evaluated. The objective of this evaluation was to document the changing patterns of river discharge and of streamflow losses that represent recharge to the Basin along the river. This evaluation addressed streamflow data for four points along the river—The Forks, Lower Narrows, Barstow and Afton—and compared trends for two main periods, the historical base period used in the Judgment (Water Year (WY) 1930-31 through WY 1989-90 and a current period from WY 1990-91 through WY 2009-10.

The principal factors controlling the frequency and magnitude of downstream flows in the Mojave River are the frequency, magnitude, and duration of runoff in the San Bernardino Mountains and the absorption capacity of the river channel. These factors are complex and inter-related; the absorption capacity of the channel is a function of the characteristics of the unsaturated zone sediments along the channel and, at any given time, the depth to the water table, local and regional hydraulic gradients in the shallow aquifer system, and amount of water held in the unsaturated zone (i.e., from antecedent floods). Consequently, it is difficult to apportion the historical variability in downstream flows to climatic factors versus human-related activities. Nonetheless, the evaluation resulted in the following conclusions regarding Mojave River discharge and net stream recharge to groundwater in the Basin:

- Average annual discharge at the downstream gages (relative to the discharge at The Forks) has generally declined over the period of record with larger declines occurring in the downstream direction.
- Since 1990, discharge at The Forks has been above its base-period average, while discharges at the three downstream gages have been below their respective base-period averages, with larger declines occurring in the downstream direction.
- Since 1990, the average annual net stream recharge for the upper reach (The Forks to Lower Narrows) has more than tripled compared to its base-period average. As a consequence, the net stream recharge in the middle reach (Lower Narrows to Barstow) and lower reach (Barstow to Afton) have decreased relative to their respective base-period averages.
- The proportion of the discharge at The Forks that (net) recharges the groundwater system within the upper reach has increased since the 1950s. Similarly, the proportion of the discharge at Lower Narrows that recharges the groundwater system within the middle reach has increased since the 1950s.
- In contrast to the upper and middle reaches, the proportion of discharge at Barstow that recharges the groundwater system within the lower reach has not changed measurably since the 1930s. The variability in net recharge in the lower reach is thus primarily dependent on the amount of discharge reaching the Barstow gage.

Another hydrologic issue concerns the potential impact of **Cedar Springs Dam and Mojave River Dam**, two dams located in the headwaters of the Mojave River, on downstream flows and recharge. To address this question, a focused evaluation was conducted; this evaluation concludes that the construction and operation of the two dams have likely resulted in little to no impact on the volume of flows reaching downstream areas of the basin.

Groundwater recharge from storm runoff originating in the local mountains surrounding the Centro and Baja subareas has historically been ungaged. A focused evaluation of local runoff was conducted for this study incorporating previous investigations and the most current hydrologic data available. Refined estimates of average annual recharge from local runoff are presented in this report.

Centro Subarea – Basin Conceptual Model

The Centro Subarea encompasses 1,242 square miles of surface drainage area traversed by the Mojave River. It is situated generally downstream of the Alto/Transition Zone Subarea and upstream of the Baja Subarea. Groundwater occurs in a complex geologic setting. While groundwater storage change has stabilized in recent decades, groundwater storage, levels, and flow have been influenced significantly over time by local and upstream pumping. Groundwater quality also is influenced by the local geology and human activities.

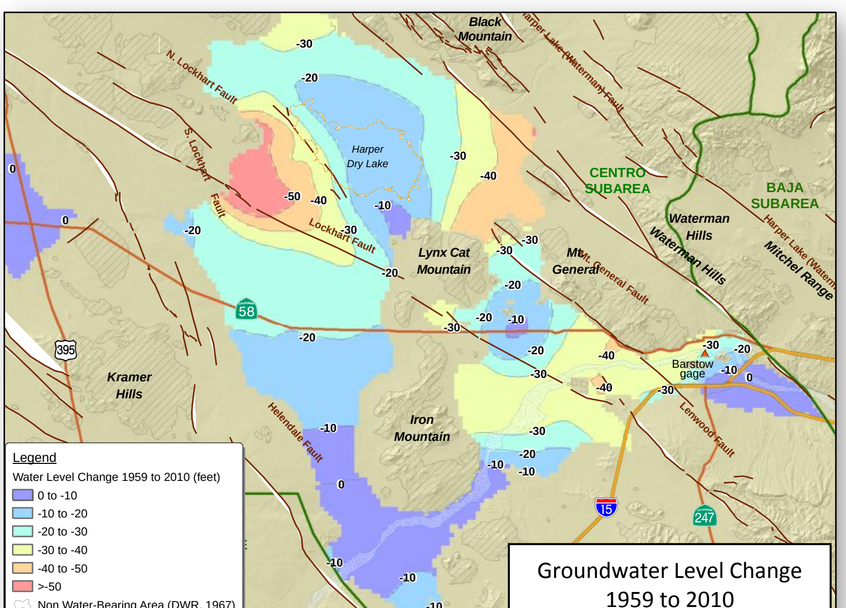
Centro Geology

Major geologic structures in the Centro Subarea include the Helendale, Iron Mountain, Lockhart, Mt. General, and Harper Lake-Camp Rock (Waterman) faults. Previous studies have identified these faults as partial barriers to groundwater flow. For example, the Helendale Fault (the boundary between the Alto Transition Zone and Centro subareas) acts as a partial barrier to groundwater flow and causes water to move upward towards the land surface, which helps sustain phreatophytes upstream of the fault.

As a result of faulting, the elevation of the base of unconsolidated sediments is highly variable across the Centro Subarea. Deep broad basins occur west and northeast of Iron Mountain and under Harper Dry Lake; the Mojave River traverses a series of small, deep basins filled with sediments and intervening areas with shallow bedrock. Accounting for the depth of sediments below the water table (as of 2010) and applying a storativity value (i.e., the volume of water contained in an equal volume of sediments), the estimated volume of groundwater in storage is estimated at 5,429,000 acre-feet for the Centro Subarea. This value represents the amount of stored groundwater that theoretically could be pumped with wells (albeit without consideration of long-term sustainability, economic or environmental factors).

Centro Groundwater Levels and Storage

Groundwater level data from the MWA database were examined to assess groundwater levels and flow over time. Numerous groundwater level hydrographs are presented, as are maps showing groundwater levels in 1959 and in 2010. Comparison of historical 1959 conditions to 2010 current conditions results in the change map reproduced below. Overall, the comparison indicates that groundwater conditions in 1959 were relatively similar to those in 2010, and that groundwater flow patterns have not changed significantly from 1959 to 2010. Groundwater level declines have been greatest west of Harper Dry Lake, and locally exceeded 50 feet. These declines are associated with historical agricultural pumping; however, since the Judgment, local agricultural land has been gradually converted to industrial land uses, groundwater production has declined, and groundwater levels have recovered slightly over the past 20 years.



Groundwater Level Change
1959 to 2010

A water budget for the Centro Subarea—summarizing groundwater inflows, outflows, and change in storage from 1931 to 1999—had been developed by the United States Geological Survey (USGS) as part of a groundwater flow model. This study documents the annual USGS model water budgets for four regions within the Centro Subarea – Centro, South Harper Valley, South Harper Lake, and North Harper Lake. The USGS water budgets indicate that groundwater storage across the Centro Subarea declined more than 760,000 AF from 1931 to 1999, with most of the storage losses occurring between 1950 and the late 1970s. In each of the four model subareas within Centro, groundwater storage losses occurred over the base period (1931 to 1990) and transient simulation period (1931 to 1999). In contrast, from the late 1970s to the end of the transient simulation period, groundwater inflows and outflows for the entire Centro Subarea were generally in balance. The USGS water budgets indicate that groundwater level and storage trends are affected directly by local pumping within the subarea and indirectly by upstream regional pumping. Based on simulations with the USGS model, upper basin pumping was the major factor in historical groundwater storage declines in the Centro model subarea.

Since the development of the numerical model, groundwater use has changed considerably in response to production rampdown mandated by the Judgment. The understanding of surface water flows across key faults and consumptive use and return flow estimates has also improved. To better understand water budget conditions since the Judgment, water budgets for the four model subareas within Centro from WY 1993-94 through WY 2009-10 were developed incorporating improved annual estimates of groundwater production, consumptive use, and return flows from Watermaster and revised estimates of ungaged local mountain runoff. This allows examination of changes in the subarea water budget relative to changes in groundwater management. Since the implementation of the Judgment, the Centro Subarea has been in operational balance as a result of large storm recharge events and production rampdown. From WY 1993-94 through WY 2009-10, groundwater storage increased by 54,515 AF in the Centro Subarea. Positive gains in the Centro model subarea are primarily the result of three large storm recharge events.

Centro Groundwater Quality

Numerous studies have characterized groundwater quality in the Centro Subarea. Despite local groundwater quality degradation in Barstow and variability elsewhere, these studies generally confirmed the suitability of groundwater for beneficial uses in the region. For this study, groundwater quality data were evaluated to identify sources of recharge and examine geochemical changes along groundwater flowpaths. General mineral quality is affected by the barrier effects of the Helendale and Waterman faults, leaching from evaporative lake deposits (and other geochemical processes) and effluent discharges from the Barstow WWTP.

> Groundwater quality in the Centro and Baja subareas is generally suitable for beneficial uses.

Additionally, maximum groundwater concentrations measured over the past 10 to 20 years were plotted for selected inorganic constituents (including TDS, arsenic, boron, chromium, fluoride, nitrate, and perchlorate) to identify areas that are potentially degraded by common naturally-occurring and anthropogenic contaminants. Areas of degraded groundwater quality in terms of TDS occur near Barstow and the Harper Lake area. A map is provided of regulated environmental contamination sites, including the Barstow Slug, Barstow WWTP, Burlington Northern Santa Fe Barstow Railway Yard, MCLB Barstow, and PG&E Hinkley; each of these is an active cleanup site.

Baja Subarea – Basin Conceptual Model

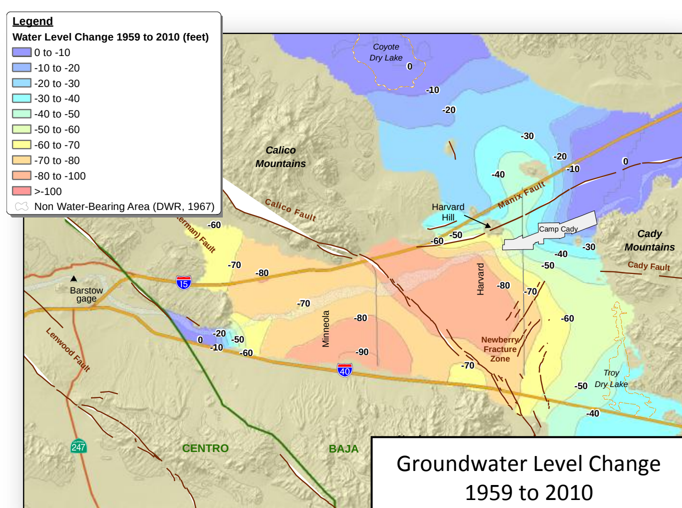
The Baja Subarea encompasses 1,075 square miles of surface drainage area traversed by the Mojave River. It is situated generally downstream of the Centro Subarea with its eastern boundary near Afton Canyon, just 20 miles from the terminus of the Mojave River at Soda Lake. Like Centro, groundwater in the Baja Subarea occurs in a complex geologic setting. Baja groundwater storage, levels, and flow have been influenced significantly over time by local and upstream pumping. Groundwater quality has been influenced by the local geology and human activities.

Baja Geology

Major geologic structures in the Baja Subarea include the Camp Rock-Harper Lake (Waterman) Fault, the Calico Fault (and associated Newberry Fracture Zone), Manix Fault, and (inferred) Baja Fault. Previous researchers have identified these structures as partial barriers to groundwater flow. The Waterman Fault represents the boundary between the Centro and Baja subareas.

Because of faulting, the elevation of the base of unconsolidated sediments is highly variable across the Baja Subarea. The Baja Subarea is characterized by a deep broad basin that extends eastward from the Waterman Fault to the Cady Mountains, with a southern extension to Troy Dry Lake. Another deep basin underlies Coyote Dry Lake. Accounting for the depth of saturated sediments (as of 2010) and applying storativity values (i.e., the volume of water contained in an equal volume of sediments), the estimated volume of groundwater in storage is estimated at 8,781,000 acre-feet for the Baja Subarea. This value represents the stored groundwater that theoretically could be pumped, albeit without considering long-term sustainability, economic or environmental factors.

Baja Groundwater Levels and Storage



Groundwater Level Change 1959 to 2010

Numerous groundwater level hydrographs are presented in Section 5 to show groundwater level trends over time and to discern the effects of upstream changes, historical local pumping, and post-Judgment rampdown. Groundwater level responses in various wells differ, ranging from persisting declines to stabilization and partial recovery. Groundwater level data also were used to prepare groundwater level contour maps representing historical 1959 conditions and current 2010 conditions. Comparison of 1959 and 2010 groundwater levels reveals that groundwater levels in the central portion of the basin have declined by as much as 80 feet. West of Camp Cady, groundwater levels have declined by about 60 feet over the past 50 years, resulting in a reduction in regional groundwater flow towards the Camp

Cady Wildlife Area. In the Coyote Lake and Afton areas, groundwater levels have been relatively stable over time.

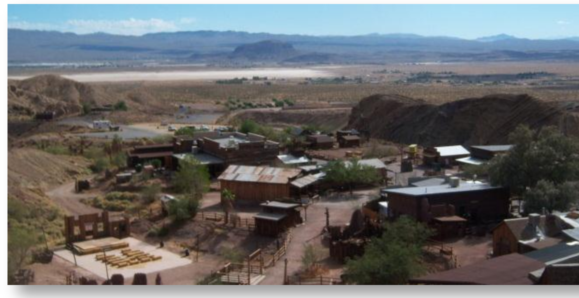
A water budget for the Baja Subarea—summarizing groundwater inflows, outflows, and change in storage from 1931 to 1999—had been developed by the United States Geological Survey (USGS) as part of the groundwater flow model. This study documents the annual USGS model water budget for three regions within the Baja Subarea – Baja, Coyote, and Afton. The USGS water budgets indicate that groundwater storage in the adjudicated portion of the Baja Subarea (not including Afton) declined by over 1,060,000 AF from 1931 to 1999 (or -15,365 AFY), with relatively consistent storage losses observed from 1950 through 1999. Evaluation of the groundwater level data and water budgets indicate that groundwater level trends are affected directly by local pumping within the subarea and indirectly by upstream regional pumping. Based on simulations with the USGS model, upper basin pumping (not including Centro) was estimated to account for about 21 percent of groundwater lost from storage in the Baja Subarea over the base period (1931 to 1990). The USGS did not simulate the effect of upstream pumping in Centro on stream discharge and recharge in Baja.

A water budget for the adjudicated portion of the Baja Subarea from WY 1993-94 through WY 2009-10 was also developed incorporating improved annual estimates of groundwater production, consumptive use, and return flows from Watermaster and revised estimates of ungaged local mountain runoff. Over the 17-year period, the estimated rate of groundwater storage decline in the Baja Subarea was slightly higher than historical declines, averaging -18,116 AFY for a cumulative storage loss of -307,979 AF. The increased rate of storage loss was a result of two factors: 1) average annual production in the Baja Subarea exceeding the natural water supply over this period despite recent decreases in production in response to rampdown; and 2) below-average recharge from Mojave River leakage as a result of the continued effect of upstream regional production reducing Mojave River flows entering the Baja Subarea.

Baja Groundwater Quality

Groundwater quality varies across the Baja Subarea but is generally suitable for beneficial uses. Groundwater from most wells located along the Mojave River has a signature similar to that of Mojave River water. For this study, groundwater quality data were evaluated to identify sources of recharge and examine geochemical changes along groundwater flowpaths. In Baja, general mineral quality is influenced by leaching from evaporative lake deposits and geochemical changes as groundwater flows toward dry lakes. In addition, maximum groundwater concentrations measured over the past 10 to 20 years were plotted for selected inorganic constituents (including TDS, arsenic, boron, chromium, fluoride, nitrate, and perchlorate) to identify areas that are potentially degraded by common naturally-occurring and anthropogenic contaminants. Areas of degraded groundwater quality (high TDS) occur near Yermo and near Troy Dry Lake. A map is provided of actively regulated environmental contamination sites in Baja, including cleanup programs (MCLB Yermo Annex, CALNEV Barstow Terminal, Yermo railyard, and Barstow-Daggett Airport), land disposal sites (SEGS I-II and Coolwater Generating Station), a clay processing plant, landfill, and gas compressor station.

Assessment of Water Supply and Demand



Historical and projected water demands are documented for the Centro and Baja Subareas, based primarily on the recent MWA 2010 UWMP but also including recent revisions. Projected water demands are based largely on population growth. However, water uses are analyzed in 11 categories (single family residential, multi-family residential, industrial, commercial/industrial/industrial, recreational lakes, unaccounted, minimal producers, golf courses, other, landscape irrigation, agriculture) to allow different assumptions about each type of water use for future years**.**

Water supplies for the 25-year period 2010-2035 are documented for MWA in general and specifically for the Baja and Centro Subareas. Water supply is accounted in terms of imported SWP water and local supplies, including natural supply, agricultural depletion from storage, return flow, and wastewater import. Of these, the major sources are imported SWP water and natural supply.

Imported water supplies are available to MWA from the SWP. MWA's maximum annual entitlement from the SWP is 82,800 AFY from 2010 to 2014 but increases to 89,800 AFY from 2020 to 2035. The amount of SWP water actually allocated to SWP contractors each year depends on a number of factors and can vary significantly. The primary factors include hydrology, the amount of water in SWP storage at the start of the year, regulatory and operational constraints, and the total amount of water requested by SWP contractors. DWR estimates the long-term average delivery reliability for each SWP contractors; for MWA, the average reliability has been 60 percent and will increase to 61 percent in 2029.

MWA has an average natural supply of 59,973 AFY, including surface water and groundwater in the five subareas of the Mojave Basin Area and in the Morongo Basin/ Johnson Valley Area. The natural supply estimates for the Mojave Basin Area are derived by the MBA Watermaster. Consistent with the Judgment, the MBA Watermaster uses these estimates to calculate annual yield for each of the subareas and to define the water quantities that each stipulating party can produce without incurring replenishment obligations. Groundwater production in the Baja Subarea is being ramped down to address continuing overdraft.

> In Centro, water supplies are greater than existing and future demands.
>
> In Baja, supply and demand are balanced; however, this is based in part on groundwater storage depletion and on return flows from groundwater pumping (which is being ramped down).

As summarized below, comparison of water demand and supply in the Centro Subarea indicates that supplies are greater than existing and future demands. In the Baja Subarea, comparison of water demand and supply indicates a balance of supply and demand; however, this is based in part on depletion of groundwater storage and return flows from pumping (which is being ramped down).

Centro Subarea
Current and Planned Water Supplies (AFY)

Water Supply Source	2010	2015	2020	2025	2030	2035
Total Existing Supplies	28,762	29,327	29,724	30,127	30,531	30,934
Projected Demands	24,320	25,414	26,205	27,009	27,813	28,617

Baja Subarea
Current and Planned Water Supplies (AFY)

Water Supply Source	2010	2015	2020	2025	2030	2035
Total Existing Supplies	23,151	23,847	24,204	24,521	24,822	25,108
Projected Demands	23,151	23,847	24,204	24,521	24,822	25,108

Note: total existing supplies in Baja include depletion of groundwater storage

Conclusions

The following are study findings that are critical to future groundwater management.

- The Centro and Baja subareas are the two largest subareas in the Mojave River Basin Management Area and account for 50 percent of the Mojave River Basin.
- Groundwater production in the Centro and Baja subareas increased into the early 1990s and has subsequently decreased because of land use changes and the Judgment mandates.
- Agriculture accounts for 50 and 80 percent of total pumping in Centro and Baja, respectively.
- The Mojave River is fed primarily by storm runoff from the San Bernardino Mountains.
- Streamflow losses from the Mojave River represent the primary source of recharge in the Basin.
- Mojave River flows—and consequently recharge from river leakage—have declined in the lower portions of the Basin since the 1950s because recharge along the upper reach (The Forks to Lower Narrows) is absorbing available stream flows.
- Two upstream dams—Cedar Springs Dam and Mojave River Dam—have a minimal effect on the Mojave River flows reaching downstream areas of the Basin.
- Groundwater storage is the amount of stored groundwater that theoretically could be pumped with wells, albeit without consideration of any consequences. The estimated groundwater storage in the Centro and Baja subareas is 5,429,000 AF and 8,781,000 AF, respectively.
- Groundwater level trends are affected directly by local pumping within the subarea and indirectly by upstream regional pumping. Based on model simulations, upper basin pumping is the major factor in historical groundwater storage declines in the Centro model subarea and accounts for about 21 percent of groundwater lost from storage in the Baja model subarea.
- Groundwater storage in the Centro Subarea declined more than 760,000 AF from 1931 to 1999, with most of the storage losses occurring between 1950 and the late 1970s. Groundwater storage increased by 54,515 AF in the Centro Subarea from WY 1993-94 through WY 2009-10.
- Groundwater storage in the adjudicated portion of the Baja Subarea declined by over 1,060,000 AF from 1931 to 1999, with relatively consistent storage losses from 1950 through 1999. Groundwater storage losses continued at a higher rate from WY 1993-94 through WY 2009-10.
- Groundwater quality varies across the Study Area but is generally suitable for beneficial uses in the region. All known contamination sites are undergoing active review and/or remediation.
- In the Centro Subarea, water supplies are greater than existing and future demands.
- In the Baja Subarea, the balance of water supply and demand is based in part on depletion of groundwater storage and return flows from groundwater pumping (which is being decreased).
- Knowledge gaps identified in this report concern the distribution and pattern of rainfall in local mountains, basin depth and hydraulic properties of deep sediments in portions of the study area, amount of reduction in stream discharge and recharge in Baja as a result of pumping along the Mojave River in Centro, effect of historical upstream flood protection measures on downstream discharge and recharge, and the lag-time of irrigation return flows to groundwater.

1. INTRODUCTION

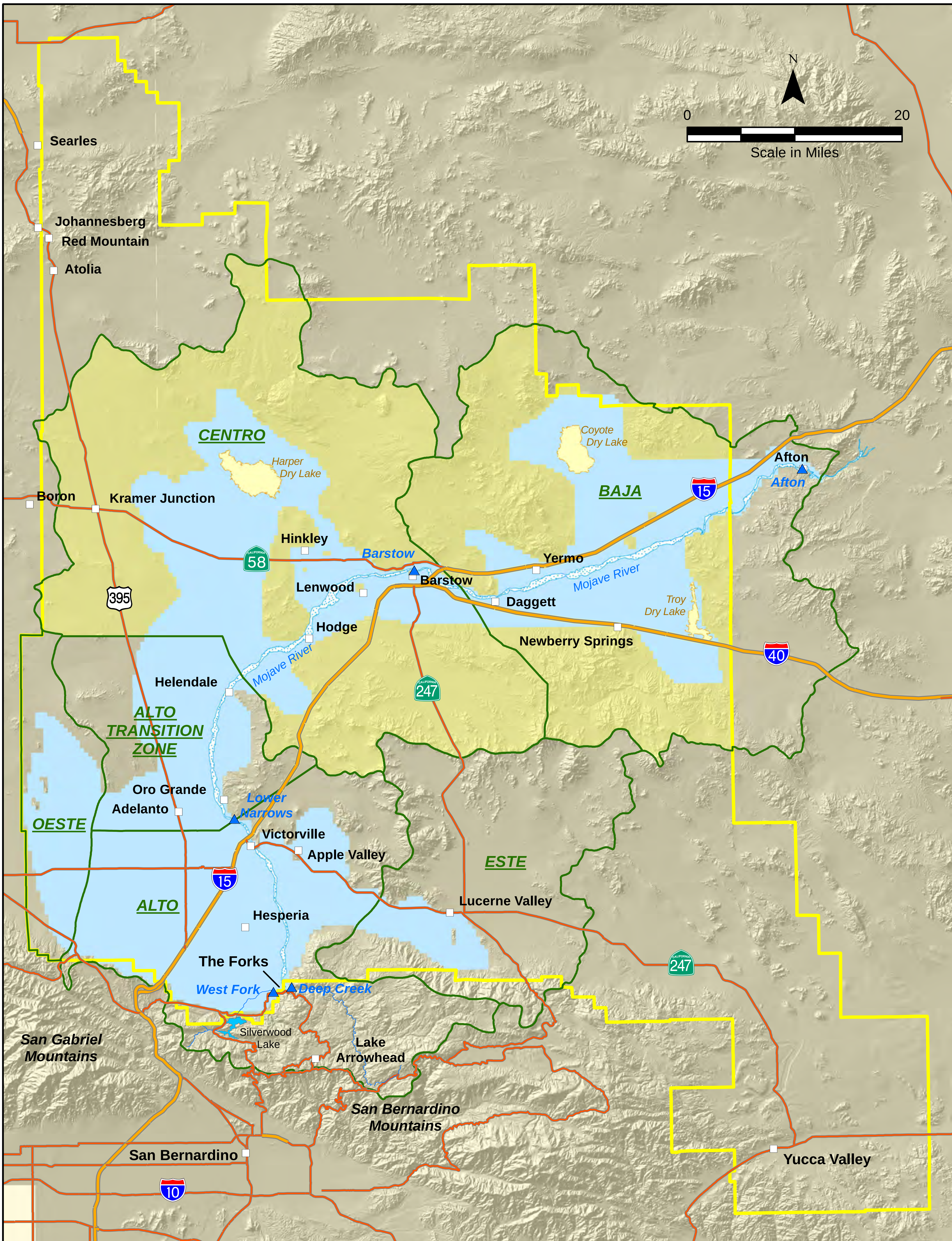
Since its establishment in 1960, the Mojave Water Agency (MWA) has been responsible for managing the water resources of the High Desert in San Bernardino County to ensure a sustainable water supply for current and future beneficial uses.

The Mojave River Groundwater Basin (Basin) represents the predominant source of water supply in the region, relied upon since the 1800s. Expansion of agriculture (beginning in the early 1900s) accompanied by urban growth dramatically increased water demands in the Basin. By the 1950s, the Basin was observed to be in overdraft as evidenced by significant regional groundwater level declines. Continued overpumping in the Basin formed the basis for early adjudication efforts in the 1960s and formal adjudication of the Basin in 1996. As mandated in the Final Judgment on the Mojave Basin Area Adjudication (Judgment), MWA was appointed as the Mojave Basin Area Watermaster (MBA Watermaster) and tasked with the responsibility of securing and delivering supplemental water to ensure sustainable and equitable use of water supplies in the Basin.

One of the primary goals of MWA is to conjunctively manage groundwater and imported water in the Basin while maintaining primary reliance on local water supplies during periods of water shortage. As one of twenty-nine State Water Contractors, MWA has access to State Water Project (SWP) water; MWA owns and maintains two major water pipelines, numerous recharge facilities, and other related infrastructure to effectively deliver SWP water and thereby balance competing uses for available water in the Basin.

As defined in the Judgment, the Mojave River surface water drainage basin within MWA's jurisdiction was divided into five management subareas: Este, Oeste, Alto, Centro, and Baja (**Figure 1.1**). The Alto Subarea was subsequently further divided to create the Alto Transition Zone (Transition Zone), a sub-management unit used to better assess water flows from Alto to Centro. Each subarea is comprised of a unique set of hydrologic and hydrogeologic conditions and land use and water demand profiles. The subareas are also hydraulically inter-related to varying degrees based on their respective location to the Mojave River and the distribution of water use in the Basin.

This study focuses on the Centro and Baja subareas, which together represent about one-half of the Mojave River Basin area. The current understanding of the Centro and Baja subareas has evolved from decades of scientific study by MWA, the U.S. Geological Survey (USGS), California Department of Water Resources (DWR), and others. In addition, MWA, in partnership with the USGS and other agencies, actively manages a basin-wide groundwater, surface water, and climatic monitoring program and maintains a comprehensive water database containing well construction and production, geologic, aquifer testing, water level, surface water and groundwater quality data. These data are used to support the ongoing implementation of the Judgment and improve the understanding of the dynamic relationship between surface water, groundwater, and water use in the Basin.



Legend
- USGS stream gage
- Mojave Basin Area Watershed
- Mojave Water Agency Service Area
- Mojave River Groundwater Basin (Stamos et al., 2001)
- Study Area

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Figure 1.1
Study Area

The first objective of this study is to integrate the historical body of knowledge gathered from previous studies with results of additional focused evaluations using current datasets and information. The second objective is to 1) develop coherent conceptual hydrogeologic models of the Centro and Baja subareas, 2) summarize current and future subarea water supply and demand conditions, 3) identify critical knowledge gaps and data needs, and 4) produce one comprehensive document to be a foundation for future management decisions in the Centro and Baja subareas.

1.1 Mojave River Groundwater Basin and Study Area

The Mojave River Groundwater Basin (Basin) is located in the High Desert of San Bernardino County. The Basin is located within the Mojave Basin Area surface water drainage basin (watershed). The generalized boundaries of the Basin were defined by the USGS initially by Hardt (1971) and then later refined by Stamos, et al. (2001) (**Figure 1.1**). The Basin covers approximately 1,400 square miles (mi^2), while the total watershed covers about 3,900 mi^2. As shown in **Figure 1.1**, the Study Area includes the Baja and Centro subareas and their associated watersheds within the MWA service area.

Table 1.1 summarizes the size of each subarea as defined by its respective contributing watershed and the adjudicated portion located within MWA's service area.

Table 1.1
Mojave Basin Area Management Subareas

Management Subarea	Surface Water Drainage Basin			Adjudicated Portion[a]		
	mi^2	acres	% Total	mi^2	acres	% Total
Oeste	164	105,054	4%	164	105,054	5%
Este	476	304,380	12%	443	283,625	13%
Alto	661	422,825	17%	465	297,446	14%
Transition[b]	301	192,881	8%	301	192,881	9%
Centro	1,242	794,775	32%	1,229	786,298	36%
Baja	1,075	688,127	27%	805	515,136	24%
Total	**3,919**	**2,508,042**	**100%**	**3,407**	**2,180,440**	**100%**

[a] Portion located within MWA's service area
[b] Alto Transition Zone is a sub-management unit

The Centro and Baja subareas are located farthest downstream in the Basin with respect to the flow direction of the Mojave River. Together, the Centro and Baja watersheds cover approximately 2,300 mi^2, of which more than 2,000 mi^2 are located within MWA's service area. The Centro and Baja subareas are the largest MWA management subareas, covering approximately 60 percent of the Mojave Basin Area watershed. Approximately 50 percent of the Basin is located within the Centro and Baja subareas. While the entire Centro watershed is effectively included within the MWA service area, 270 mi^2 of land in the eastern and northeastern portions of the Baja watershed are located outside of the MWA service area.

While this study concentrates on the adjudicated portion of the Centro and Baja subareas, information was also considered for areas within the overall Centro and Baja watersheds and within MWA's service area north of the Centro Subarea.

The Centro and Baja subareas are located within the South Lahontan Hydrologic Region as defined by DWR and overlie and include several DWR groundwater basins (or portions thereof) as defined in the 2003 update of Bulletin No. 118: California's Groundwater (DWR, 2003). The relationship between the Centro and Baja subareas and the 2003 DWR basins is shown in **Figure 1.2** and summarized in **Table 1.2**.

The Centro Subarea generally overlies three DWR basins as defined in the 2003 update of Bulletin No. 118, including the Middle Mojave River Valley (6-41), Harper Valley (6-47), and the western portion of Lower Mojave River Valley (6-40) basins. Also included in the Centro Subarea are small portions of Cuddeback Valley (6-50) and Superior Valley (6-49) basins; these basins are generally separated from the Centro Subarea by crystalline bedrock forming the watershed boundary but are included in the MWA service area. Additional information on the Cuddeback Valley area is provided in **Appendix G**.

The Baja Subarea generally overlies four DWR basins as defined in the 2003 update of Bulletin No. 118, including the Lower Mojave River Valley (6-40), Kane Wash Area (6-89), Coyote Lake Valley (6-37), and Caves Canyon Valley (6-38) basins. Also included in the Baja Subarea are small portions of the Langford Valley Basin (Langford Well Lake Subbasin [6-36.01]).

In general, DWR divides the Study Area into more subbasins that cover a larger area than the USGS groundwater basin boundary (compare **Figures 1.1 and 1.2**). However, many of the DWR basins contain areas of very thin, and likely unsaturated alluvial deposits that contribute little to the main groundwater basin. In addition, several subbasins cross watershed divides that coincide with MWA Subarea boundaries and are not likely as hydraulically connected as indicated (e.g., Lavic Valley in the southwest or the extension of Harper Valley to the northwest).

Also shown on **Figure 1.2** are hydrologic units/subunits that delineate watersheds as mapped by DWR. These watershed boundaries were included in a 1967 DWR evaluation of groundwater resources in the Mojave River region, titled Bulletin No. 84: Mojave River Ground-Water Basins Investigation (DWR, 1967[1]). The 1967 DWR hydrologic units/subunits are listed on **Table 1.2**.

While the nomenclature differs, the DWR (1967) hydrologic units generally resemble watershed boundaries (version 2.2.1) defined by the California Interagency Watershed Mapping Committee (referred to as the CalWater watersheds) (CIWMP, 2011). Similar to the convention used by DWR, the CalWater watershed boundaries are divided into hydrologic units, subunits, and subareas. The CalWater watershed boundaries are shown on **Figure 1.3** along with the boundaries used by DWR (1967). Notable differences between the DWR and CalWater watershed boundaries include 1) the exclusion of a portion of the CalWater Harper Valley Subarea in the 1967 Harper Subunit in the southwest, and 2) the further division of the 1967 Harper Subunit area to create the CalWater Grass Valley Subarea. Additionally, the boundary separating the Centro and Baja subareas as defined in the Judgment is located east of both the CalWater and DWR watershed boundaries between the Middle Mojave and Lower Mojave subunits.

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[1] Hydrologic units and subunits were incorporated into Bulletin No. 84 from a previous study (DWR, 1964b).

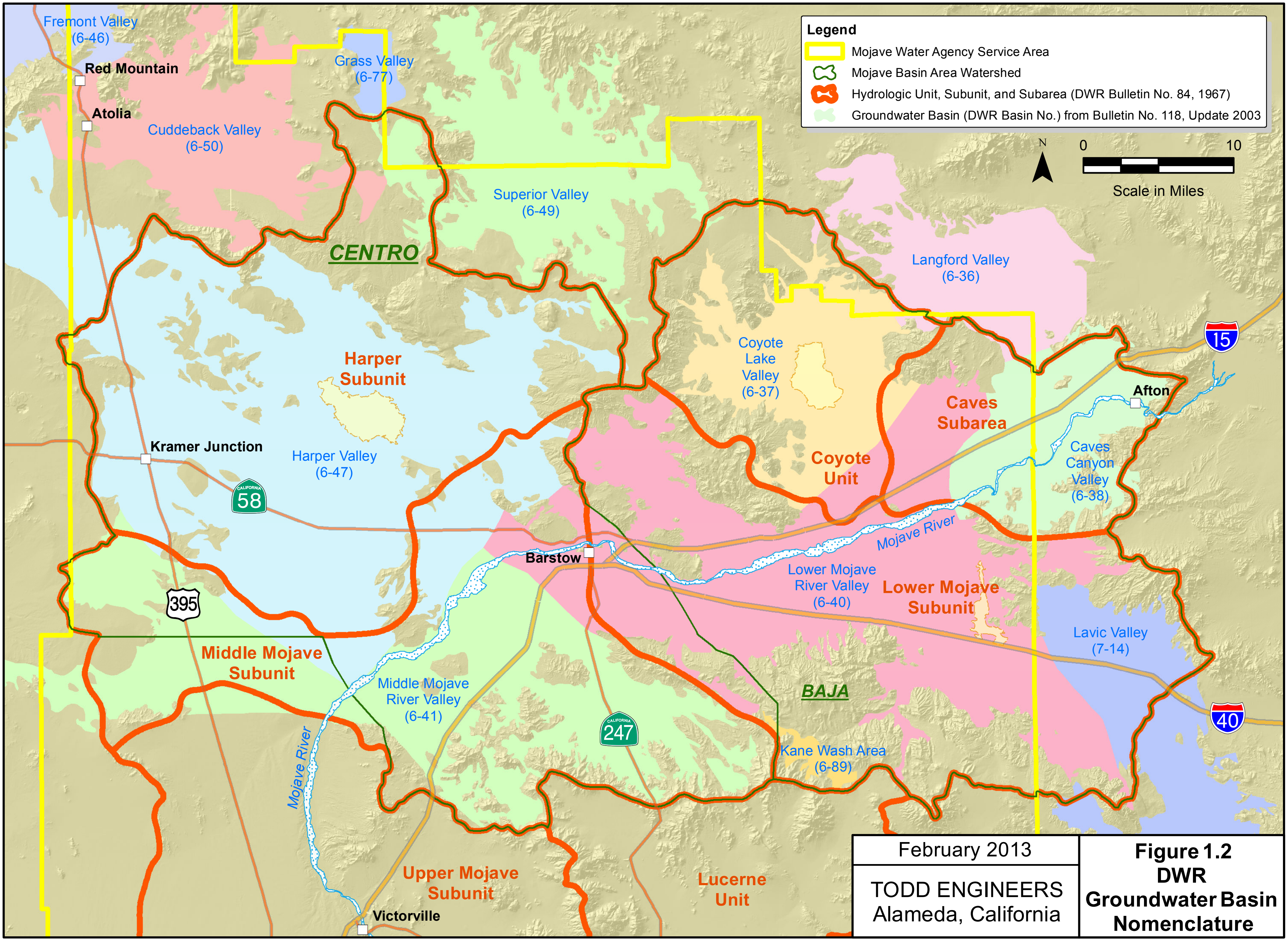

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Figure 1.2
DWR Groundwater Basin Nomenclature

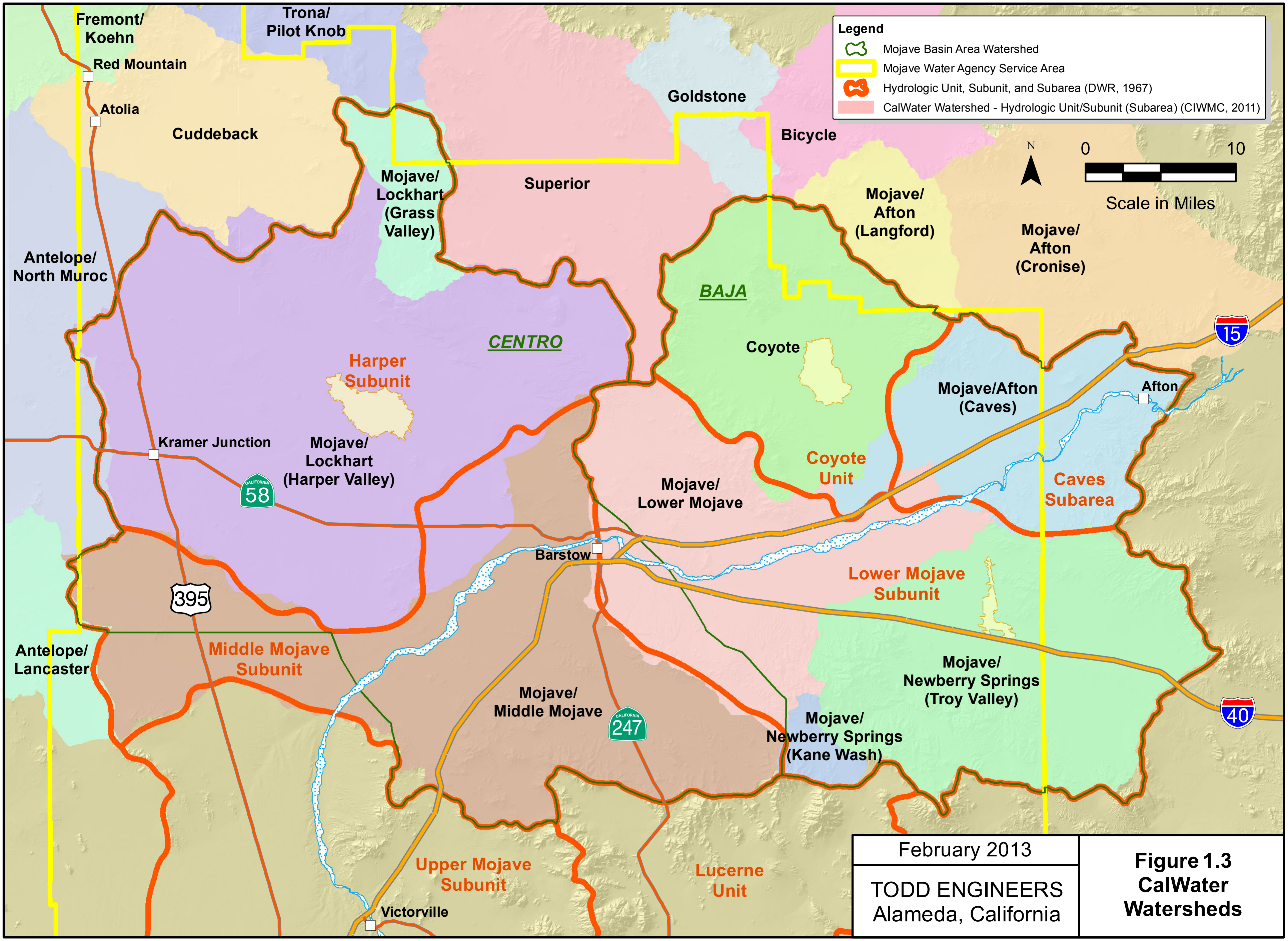

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Figure 1.3
CalWater Watersheds

Table 1.2
MWA Subarea, DWR Groundwater Basin, and Watershed Nomenclature

<table>
<tr><th>MWA Water Management Subarea</th><th>DWR Bulletin 118, update 2003[a]
Groundwater Basin / Subbasin (No.)</th><th>DWR, 1967[b]
Hydrologic Unit / Subunit (Subarea)</th><th>CalWater, 2004[c]
Hydrologic Unit / Subunit (Subarea)</th></tr>
<tr><td rowspan="6">Centro Subarea</td><td>Middle Mojave River Valley (6-41)</td><td>Mojave / Middle Mojave</td><td>Mojave / Middle Mojave</td></tr>
<tr><td>Lower Mojave River Valley (6-40)</td><td>Mojave / Lower Mojave</td><td>Mojave / Lower Mojave</td></tr>
<tr><td>Harper Valley[1] (6-47)</td><td>Mojave / Harper[1]</td><td>Mojave / Lockhart (Harper Valley)</td></tr>
<tr><td>Cuddeback Valley (6-50)[2]</td><td rowspan="2">Not included in Study Area</td><td>See footnote[4]</td></tr>
<tr><td>Superior Valley (6-49)[2]</td><td>See footnote[4]</td></tr>
<tr><td>No associated area</td><td>Not included in Study Area</td><td>Mojave / Lockhart (Grass Valley)</td></tr>
<tr><td rowspan="7">Baja Subarea</td><td rowspan="2">Lower Mojave River Valley (6-40)[3]</td><td rowspan="3">Mojave / Lower Mojave[3]</td><td>Mojave / Lower Mojave</td></tr>
<tr><td>Mojave / Newberry Springs (Troy Valley)</td></tr>
<tr><td>Kane Wash Area (6-89)</td><td>Mojave / Newberry Springs (Kane Wash)</td></tr>
<tr><td>Coyote Lake Valley (6-37)</td><td>Coyote</td><td>Coyote</td></tr>
<tr><td>Caves Canyon Valley (6-38)</td><td>Mojave / Afton (Caves)</td><td>Mojave / Afton (Caves)</td></tr>
<tr><td>Langford Valley (6-36)[2]</td><td rowspan="2">Not included in Study Area</td><td rowspan="2">See footnote[4]</td></tr>
<tr><td>Langford Well Lake (6-36.01)[2]</td></tr>
</table>

Other 2003 DWR Basins not included in table that are located within MWA service area adjacent to but outside Centro and Baja Subarea surface water drainage basins include: Goldstone Valley (6-48), Grass Valley (6-77), Searles Valley (6-52), Salt Wells Valley (6-53), Indian Wells Valley (6-54), Fremont Valley (6-46), Cronise Valley (6-35)

Lavic Valley (7-14) is located within Baja Subarea surface water drainage basin but outside of MWA service area

[a] DWR, California's Groundwater, Bulletin 118, update 2003

[b] DWR, Bulletin No. 84: Mojave River Ground-Water Basins Investigation, Middle Mojave Basin

[c] California Interagency Watershed Mapping Committee (CALWATER version 2.2.1) updated May 2004, All Hydrologic Area

[1] Approximately 90 mi^2 of the 640-mi^2 Harper Valley Basin (6-47) extend northwest into Kern County outside of the Centro Subarea. In the previous DWR Bulletin No. 118 (DWR, 1975), the surface area of Harper Valley Basin was 514-mi^2. The larger surface area of the 2003-updated Harper Valley Basin is attributable to:
1) the inclusion of alluvial areas east of the drainage/alluvial divide extending from Helendale through Iron Mountain and Lynx Cat mountains to the Kramer Hills
2) further extension of the Harper Valley Basin into Kern County

[2] Represents a small percentage (less than 1 to 2 percent) of surface water drainage basin

[3] Includes previous Troy Valley Groundwater Basin (6-39) identified in Bulletin Nos. 106-1 (DWR, 1964a), 118-75 (DWR, 1975), and 118-80 (DWR,1980)

[4] Cuddeback Hydrologic Unit, Superior Hydrologic Unit, and Mojave / Afton (Langford) Subarea located outside of Centro and Baja surface water drainage basin

1.2 Project Objectives

The goal of this study is to assimilate data and previous evaluations of the Centro and Baja subareas into a document that provides the technical foundation on which management decisions can be based. In order to support this goal, the following project objectives have been developed that are pertinent to both subareas:

- Describe subsurface basin geometry, geology, and aquifer hydraulic properties
- Evaluate groundwater occurrence and flow
- Assess water level trends in relation to historical production and enhanced recharge operations
- Estimate groundwater in storage
- Develop a comprehensive water budget accounting for historical and present land use and water use conditions
- Characterize groundwater quality with respect to source water characterization, constituent-specific groundwater quality concerns, and impacts from anthropogenic activities
- Document existing groundwater use
- Assess current and future water demand and compare against future management strategies to balance water supply

1.3 Scope of Work

To support project objectives, the study has been divided into two inter-related components: the development of a conceptual hydrogeologic model that describes the physical and hydraulic conditions for each groundwater basin and the analysis of water supply and demand that include projections of future water use through 2035. The combination of these two components provides the scientific and engineering basis for informed water management decisions.

Specific tasks developed for the scope of work include the following:

Task 1: Develop a hydrogeologic conceptual model for each subarea that identifies the extent and character of basin fill deposits, occurrence and movement of groundwater, location and influence of geologic faults on groundwater flow, chemical quality of groundwater, and water budget accounting for the unique set of hydrologic and hydrogeologic conditions and changes in land use and water demand in each subarea over time.

Task 2: Assess current water supply and demand in the Centro and Baja subareas and forecast water supply and water demand conditions through 2035.

Task 3: Participate in public meetings with the Subarea Advisory Committees (SACs) for Centro and Baja to present preliminary findings and to hear questions and concerns from local stakeholders.

Task 4: Prepare a technical report documenting the basin conceptual models and assessment of water supply and demand.

Task 5: Manage the project, adhering to contract schedules and budgets, participate in scheduled conference calls, and prepare project status reports.

1.4 Data Sources

Most of the information used for this study was compiled by MWA and made available on a website-based repository through the MWA file transfer protocol (ftp) site. Data included published articles and reports, hydrogeologic data collected from cooperating water and other governmental agencies, geographic information system (GIS) shapefiles, maps, aerial photographs, and various water-related databases. Additional data, including stream gage and climatic data, were obtained online from the USGS National Water Information System (NWIS) and Western Regional Climate Center (WRCC) sites, respectively. Key documents and data used in this study are identified on the reference list at the end of this report.

More than 8,000 wells have been drilled in the Study Area. General lithology, well construction, and aquifer testing data contained in driller's logs and compiled in MWA databases were used to confirm the hydraulic character of sediments, aquifer boundaries, and overall geometry of the Basin within the Study Area.

Water level and water quality data in the MWA water database were made available for production wells of major water providers and key monitoring wells in the area. Monitoring wells included those actively sampled by MWA and USGS as part of their cooperative groundwater monitoring program and include variable-depth piezometers along the Mojave River and dedicated monitoring wells in the vicinity of active MWA enhanced recharge facilities.

Historical SWP water delivery records and recharge estimates for facilities within the Study Area were also made available by MWA.

Historical groundwater pumping and consumptive use estimates for Stipulated Parties and Minimal Producers in the Judgment were gathered from Watermaster annual reports supplemented by additional information from the MBA Watermaster Engineer (Wagner and Bonsignore). Water demand information and data presented in the 2010 Urban Water Management Plan (UWMP) were used directly with minor revisions to reflect revised estimates by MWA.

Insofar as possible, annual values (e.g., annual production) are compiled and reported in terms of water year (WY), beginning October 1 and ending September 30, described for example as WY 2009-2010 or abbreviated as WY 2010.

1.5 Project Considerations

Hundreds of technical reports, studies, plans, and documents related to the Study Area have been generated, providing a wealth of information on basin hydrogeology and water supply. This document attempts to compile and summarize as much relevant data as possible to provide the understanding and background for developing the conceptual hydrogeologic models. While this document is intended to be a reference and summary document, its purpose is not only to look back over the data generated to date but to look forward to address current and upcoming issues and support future management.

The technical information presented herein is intended to complement and support other water supply management plans and programs by MWA, including the Integrated Regional Water Management Plan (IRWMP), UWMP, and Salt and Nutrient Management Plan (SNMP) as well as MWA's ongoing evaluation of future potential conjunctive use strategies. This study also naturally addresses key water budget components pertinent to the implementation of Judgment. Accordingly, specific technical questions critical to the development of future groundwater management strategies and the ongoing implementation of the Judgment were used to focus the basin conceptual models. Additionally, care was taken to ensure that the same basic hydrologic and hydrogeologic data used by Watermaster were used for additional focused evaluations in this study to prevent confusion stemming from data source differences.

1.6 Report Organization

Section 1 of this report provides a summary of the project, objectives, scope, and data.

Section 2 summarizes the overall framework within which MWA manages water resources in the Mojave River Basin as it relates to the Centro and Baja subareas, including MWA water management policies, goals, programs, and institutional and infrastructure configurations.

Section 3 provides information on the physical setting, historical land uses and associated water use in the Study Area. The Physical Setting introduces the geology, paleodepositional history of the Basin, climate, and hydrology and provides background information for the Study Area. The section on Groundwater Use provides summary information on historical and current groundwater pumping in the Study Area.

Sections 4 and 5 present the conceptual hydrogeologic models for the Centro Subarea and Baja subareas, respectively. Each of the sections contains subarea-specific information on faults and hydraulic barriers, basin geometry, basin fill deposits and aquifer parameters, groundwater occurrence and flow, groundwater level trends, groundwater storage, transient subarea groundwater budget, and groundwater quality.

Section 6 summarizes the water supply and demand information from the basin conceptual model water balances and considers additional water supply from imported SWP water conveyed through the Mojave River Pipeline. These data on water supply are compared to current and projected water demands for each subarea.

Section 7 presents final conclusions and recommendations.

A list of references is included at the end of the report. Appendices have been prepared to provide selected reference summaries and data tables. Several appendices also address specific topics of interest that have been identified by MWA and/or the SACs for the Centro and Baja subareas. A summary of Appendices is provided below.

In reviewing the numerous studies, investigations, and manuals covering the various components of the conceptual hydrogeologic models, it became apparent that future investigators and interested individuals would benefit from understanding the chronological history of studies related to the hydrologic characteristics of the Mojave River as well as matters specific to the Centro and Baja subareas. Accordingly, four subject-specific document timelines were developed and are included in **Appendix A**.

Despite previous studies that have directly or indirectly addressed the issue, questions remain as to the potential effect of two dams located in the headwaters of the Mojave River on downstream flows and groundwater recharge. A focused evaluation of the potential impacts from the Cedar Springs Dam and Mojave River Dam (constructed in the headwaters of the Mojave River in 1971) on downstream Mojave River flows and groundwater recharge is presented in **Appendix B**.

While storm runoff from the San Bernardino Mountains represents the primary source of recharge in the Mojave River Basin, previous studies have determined that local storm runoff from desert mountains also contributes to surface water flows in the Mojave River and directly recharge the groundwater system along the margins of the Basin. Previous findings have relied on varying data sources and analytical methods to estimate the contribution of local runoff. A focused evaluation of local mountain runoff is presented in **Appendix C**.

In 2012 and 2013, a hydrogeologic investigation of the Camp Cady Wildlife Area in the eastern Baja Subarea was completed by Todd Engineers (2013). The purpose of the investigation was to 1) develop a comprehensive understanding of surface water and groundwater dynamics and determine their relationship to the health of riparian vegetation at Camp Cady, and 2) evaluate the feasibility of developing groundwater resources to re-establish native riparian habitat at Camp Cady. A complete copy of the final report is presented in **Appendix D**. (Note: The original table and figure numbers from the Camp Cady Investigation report were left unchanged to maintain consistency between the stand-alone report and Appendix D and to preclude editing of table and figure references in the report text.)

Well construction and pumping test information contained in available water well driller's logs were reviewed and used to estimate aquifer hydraulic properties across the Centro and Baja subareas. This information is tabulated and presented in **Appendix E**.

Annual water budget tables for the Centro and Baja subareas extracted from the USGS groundwater flow model of the Mojave River Basin developed by Stamos et al. (2001) are provided in **Appendix F**.

A summary of hydrogeologic conditions and historical mining operations northwest of the Centro Subarea in the Randsburg, Red Mountain, and Atolia area is presented in **Appendix G**.

In order to calculate the surface water flows into the Centro subarea for recent years, a water budget for the Alto Transition Zone from Water Years (WYs) 1993-94 to 2009-10 was prepared by the MBA Watermaster and is presented in **Appendix H**.

Finally, demand projections for high and low conservation assumptions in the MWA water demand forecast model are presented in **Appendix I**.

1.7 Acknowledgements

This report benefited greatly from the cooperation, contributions, and support of numerous entities and individuals. In particular, Todd Engineers would like to thank the technical staff of Mojave Water Agency for providing numerous documents and data sets compiled from decades of hydrogeologic studies and monitoring programs. In addition, we thank the MBA Watermaster Engineer for sharing and explaining data and previous analyses; his institutional knowledge was also valuable to this study.

Todd Engineers would also like to acknowledge and thank George Kenline (mining geologist formerly with the Mining and Environment Section of the San Bernardino County Land Use Services Department) for compiling important references documenting historical hydrological conditions and water use along the Mojave River by mining operations in the late 1800s/early 1900s. Mr. Kenline also provided valuable personal insights and knowledge of past mining practices and water use in the Study Area. We thank Dr. Julie Laity, Professor of Geography at California State University, Northridge, for discussing issues and sand migration and providing key references.

Todd Engineers also acknowledges and thanks Consulting Hydrologist Tom Bilhorn, who provided technical review and oversight for the California Department of Fish and Game on the 2011-2013 Camp Cady hydrogeologic investigation. Much of our work was based on his previous contributions and hydrologic expertise in the area. Special thanks also go to Bruce Kenyon (Quail Unlimited) for his daily assistance onsite through the duration of the 2011-2013 Camp Cady field investigation and for providing historical photographs of flood conditions at Camp Cady.

We would also like to acknowledge Walt Brock (Fundamental Christian Endeavors) for taking time to provide photographs and personal accounts of historical riparian conditions at Camp Cady. Mr. Brock graciously hosted an onsite tour of hydrologic and hydrogeologic features on his property. Finally, we would like to acknowledge key contributions from the Centro and Baja Subarea Advisory Committees (SACs). We thank them for hosting local meetings, submitting questions, challenging assumptions, and sharing personal insights on key local groundwater management issues.

2. WATER MANAGEMENT PROGRAMS, POLICIES, AND INSTITUTIONAL AND INFRASTRUCTURE CONFIGURATIONS

MWA manages water resources in the Mojave River Basin by means of a framework composed of water management policies, goals, and programs, plus institutional and infrastructure configurations.

Key documents include the MWA Strategic Plan, Integrated Regional Water Management Plan (IRWMP), and Urban Water Management Plan (UWMP), Mojave Basin Area Judgment (Judgment), and various inter-agency agreements. Collectively, these documents describe the:

- mission, goals and objectives of MWA as a public water agency
- authorities granted to and responsibilities of MWA as MBA Watermaster
- rights and obligations defined in the Judgment
- annual SWP water entitlements
- imported water-related infrastructure
- relevant groundwater monitoring and water conservation programs.

2.1 MWA Strategic Plan

The MWA Strategic Plan (MWA, 2006) presents the vision and mission of MWA, which are distilled into six primary goals that encourage:

7) development of sound fiscal and organizational policies
8) management of local water resources conjunctively with imported SWP water
9) protection of water quality
10) public outreach
11) advancement of scientific understanding of the region's water resources
12) water conservation.

These goals help to guide MWA to fulfill its legislative mandate, identify and prioritize measurable objectives, and define and implement "key elements" (including plans and programs) to fulfill its mission. The Strategic Plan is updated every five to ten years to incorporate current MWA water management goals and objectives.

2.2 Integrated Regional Water Management Plan (IRWMP)

The IRWMP is the master planning document for MWA water management activities. The IRWMP promotes the effective use of technical information and scientific data to provide a strategic, comprehensive approach for long-term management of the region's water supplies. The IRWMP describes the magnitude of groundwater overdraft issues and identifies a wide variety of projects and management actions to meet present and future water demands. The IRWMP also provides an estimate of the existing and projected water supply and demand for the various water management areas within MWA's jurisdiction.

The goals of The IRWMP are to balance future water demands with available supplies and maximize the overall beneficial use of water throughout MWA's service area. Accordingly, MWA has designed its IRWMP to meet the various requirements set forth in Senate Bill (SB) 221, SB 610, and SB 1938, and Assembly Bill (AB) 901 for an IRWMP, Groundwater Management Plan (GWMP), and UWMP.

Preparation of the first MWA IRWMP began in December 1991 and was completed in June 1994 (Bookman-Edmonston Engineering, Inc., 1994). An update of the original IRWMP was completed in September 2004 (SWS, 2004) and formally adopted by MWA in February 2005. MWA is currently in the process of updating the 2004 IRWMP, which is scheduled for completion in 2014. In addition to those requirements satisfied in the 2004 IRWMP, the updated IRWMP will satisfy additional requirements set forth in the State Recycled Water Policy related to basin-wide salt and nutrient management, which is presented in more detail in Section 2.2.2.

2.2.1 Urban Water Management Plan (UWMP)

As an Urban Water Supplier, MWA is required to prepare and submit a UWMP to DWR every five years to satisfy requirements set forth in the California Urban Water Management Planning Act (Act). At a minimum, the UWMP must contain information that 1) addresses water supply planning over a 20-year period in five-year increments; 2) identifies and quantifies adequate water supplies, including recycled water, for existing and future demands, in normal, single-dry, and multiple-dry years; and 3) implements conservation and efficient use of urban water supplies. Significant new requirements for quantified demand reductions have been added by the enactment of Senate Bill 7 of Special Extended Session 7 (SBX7-7), which amends the Act. MWA and the retail water providers within its service area have exceeded the requirements of the Act by developing a plan that spans 25 years.

As the region's water wholesaler, MWA and its UWMP serve as a primary component of information for many of the retailer's Plans as defined in the California Water Code. Currently, 47 water retailers exist within MWA boundaries, seven of which prepared a separate UWMP in 2005. MWA prepared and adopted its initial UWMP in 2005 and has since completed its 2010 update. The UWMP update incorporates the state mandated 20x2020 water conservation component. The 2010 UWMP update incorporates a spreadsheet model to quantify water use from 2000 to the present, to project future water demands, and to identify the supply-demand balance to 2035. The 2010 UWMP update also incorporates the recently updated DWR State Water Project Delivery Reliability report (2009c), a key component of the water supply analysis. The 2010 UWMP update (Kennedy/Jenks Consultants, 2011) was completed and adopted by MWA in June 2011.

2.2.2 Salt and Nutrient Management Plan (SNMP)

As part of The IRWMP update, MWA, in cooperation with other local stakeholders, is in the process of developing a Salt and Nutrient Management Plan (SNMP) to satisfy requirements set forth in the State Recycled Water Policy (SWRCB, 2009) and Anti-degradation Policy (State Water Board Resolution No. 68-16). The purpose of the SNMP is to evaluate the potential for increases of salt and nutrients in groundwater and to develop a management plan that protects groundwater from salt and nutrient concentrations that may limit its beneficial uses. The SNMP will be adopted as an amendment to the Basin Plan for the Regional Water Quality Control Board - Lahontan Region (Regional Board). The Regional Board will regulate waste discharges in a manner consistent with the SNMP.

Specific objectives of the SNMP include the following:

1) integrate available water quality data to support evaluation of existing surface water and groundwater quality at a watershed and sub-watershed level
2) identify natural and anthropogenic sources of salt and nutrients and quantify their respective loads
3) estimate the assimilative capacity of groundwater in each subbasin
4) develop a monitoring and reporting plan that evaluates the impacts to groundwater quality resulting from past, current, and future land uses
5) identify and recommend appropriate methods and best management practices for reducing and/or maintaining salt and nutrient loadings
6) identify the agencies responsible for managing current and future anthropogenic salt and nutrient loads and the responsibilities of each agency in managing local entities to achieve the water quality specified in the plan

To evaluate salt and nutrient loading in the basin, MWA plans to audit and leverage the technical components within its 2007 water quality model (Schlumberger Water Services, 2007), which was developed using the STELLA modeling system (STELLA Model). The STELLA Model was originally constructed to characterize baseline groundwater quality in twenty-two management zones within MWA's service area and to forecast the regional impacts of specific land uses (e.g., agriculture, urban, and industrial) and water management activities (e.g., enhanced recharge facilities) on the concentrations of salt in each management zone. Results of the groundwater quality modeling will be used to identify additional data needs and support the development of a groundwater monitoring program tailored to meet the requirements of the SNMP. Parallel with The IRWMP, the SNMP is scheduled for completion in 2014.

2.3 Mojave Basin Area Adjudication

The Adjudication of the Mojave River Area provides the institutional framework to allocate equitably the right to produce water from the available natural water supply and to provide equitable sharing of costs for supplemental water. Until MWA initiated the adjudication and the Court issued the Judgment in January 1996 (Judgment), water production rights and obligations had not been defined in the Basin. For management and implementation of the Judgment, MWA defined the five management subareas—Alto, Baja, Centro, Este, and Oeste—plus the (Alto) Transition Zone sub-management unit.

In the Mojave Basin Area, Base Annual Production (BAP) rights were assigned in the Judgment to each Major Producer (defined as a person or entity using 10 acre-feet per year [AFY] or more) based on historical production. Other Minimal Producers (person or entity producing less than 10 AFY) are recognized in the Judgment as one entity and are not subject to the Judgment. BAP is defined as the producer's highest annual use verified for the five-year base period from 1986 to 1990. The MBA Watermaster assigns to each Party of the Judgment a variable Free Production Allowance (FPA), which represents a percentage of BAP set for each subarea for each year. The allocated FPA represents each producer's share of the water supply available for that subarea. The Judgment mandates that the FPA be reduced or "ramped-down" over time until total FPA for each subarea comes into balance with available supplies.

Production Safe Yield (PSY) is also determined for each subarea for each year. The PSY in each subarea represents the average net natural water supply plus the expected return flow from the previous year's water production under a representative land use condition. Since WY 2000-01, the estimated water supply and consumptive use estimates for WY 1996-97 determined by Webb and Associates (2000) have formed the basis for estimating the PSY for each of the management subareas. Currently, the Watermaster is in the process of updating water supply, consumptive use, and PSY estimates to reflect WY 2009-10 land use conditions for the Baja Subarea.

Exhibit H of the Judgment requires that in the event the FPA exceeds the estimated PSY by five percent or more of BAP, Watermaster may recommend a reduction in FPA equal to, but not more than, a full five percent of the aggregate subarea BAP. Any Major Producer that pumps more than their respective FPA in any year is required to buy "Replacement Water" equal to the amount of production in excess of the FPA. Replacement Obligations can be satisfied either by paying the Watermaster to purchase imported water from MWA or by temporarily transferring unused FPA within that subarea from another party to the Judgment. All Replacement and Makeup Water Assessments collected by the Watermaster are used to acquire supplemental SWP water from MWA to the extent that SWP water is available.

Within the Centro Subarea, the Judgment restricts the transfers of FPA between the Harper Lake Area and other areas in Centro. Specifically, use of FPA from the Harper Lake Area to support a project outside of the Harper Lake Area is not allowed. Similarly, the use of FPA from outside of Harper Lake to support a Harper Lake project is also not allowed (MBA Judgment, 1996).

Specific responsibilities of MWA as Watermaster include verifying water production of all Stipulated Parties to the Judgment and estimating production of Minimal Producers, maintaining streamflow, precipitation and other hydrologic data, and maintaining accounts of water rights transfers, the Biological Resources Trust Fund, and other storage agreements. Additionally, because the physical solution incorporated in the Judgment requires the construction of physical facilities to deliver supplemental water to specific regions and enhanced understanding of the region's hydrogeologic conditions, MWA supports the Judgment through implementation of water-related capital improvement projects and sponsorship of regional groundwater monitoring programs and focused hydrogeologic studies and field investigations.

2.4 Imported Water and Related MWA Infrastructure

2.4.1 State Water Project (SWP) Water

MWA is one of twenty-nine State Water Contractors with access to State Water Project (SWP) water from the California Aqueduct. MWA currently has an annual Table "A" Amount of up to 82,800 AFY of

SWP water. Since 1991, MWA has been regularly importing water from the California Aqueduct to recharge the groundwater basin from which local water companies, municipalities, and other well owners pump for beneficial uses.

As stated in the Judgment, MWA is required to acquire or construct conveyance facilities for the importation and equitable distribution of supplemental water to the respective water management subareas. To accomplish this, MWA has actively secured several federal and state grants and loans to finance imported water-related infrastructure, including the Mojave River and Morongo Basin pipelines, storage reservoirs, and in-stream and off-stream recharge facilities across its service area.

2.4.2 MWA Pipelines and Supporting Infrastructure

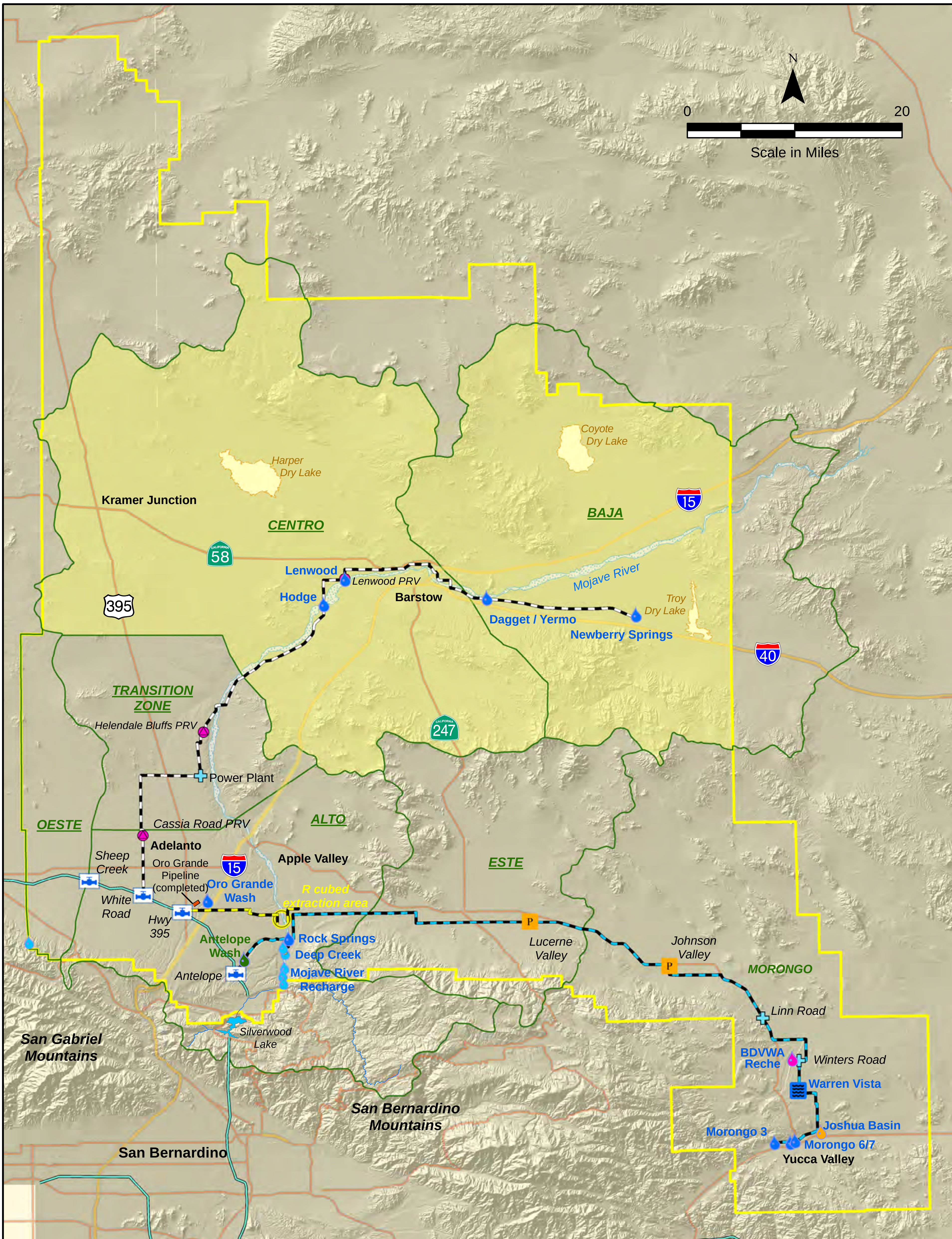
MWA owns and operates two major pipelines (Mojave River Pipeline and Morongo Basin Pipeline) and associated infrastructure that convey imported SWP water to augment local groundwater supplies within the Mojave River Basin and MWA's service area. **Figure 2.1** shows the locations of MWA's current and future conveyance and recharge features.

The Morongo Basin Pipeline is a 71-mile underground pipeline completed in 1994 that begins at the Antelope Siphon turnout of the California Aqueduct and extends east-southeast through Lucerne Valley (Este Subarea) and the Morongo Groundwater Basin, terminating at percolation ponds owned by the Hi-Desert Water District in Yucca Valley. Within the Mojave River Basin, the Morongo Basin Pipeline has historically delivered SWP water to the Rocks Springs and Deep Creek recharge facilities (Alto Subarea) in south Apple Valley.

The Mojave River Pipeline is a 24-inch diameter, underground pipeline that stretches 76 miles from the White Road Turnout of the California Aqueduct near Adelanto through the Alto, Transition Zone, Centro, and Baja subareas, terminating at the Newberry Springs recharge site in Newberry Springs. The pipeline was constructed by MWA to replenish groundwater resources in the Mojave River Basin with SWP water. The pipeline was constructed in three phases from 1997 to 2006. As shown in the figure, the pipeline roughly parallels the Mojave River and National Trails Highway, also known as Old Route 66, from the California Aqueduct through Barstow. From the Daggett Recharge site in the western portion of the Baja Subarea, the pipeline travels along the Burlington Northern Santa Fe (BNSF) railway alignment to Hidden Springs Road, then approximately 8 miles east to Newberry Road, where the pipeline turns south and travels 0.5 miles to the Newberry Springs Recharge Facility. The pipeline has a capacity to recharge 45,600 AFY.

2.4.3 Regional Recharge and Recovery (R-cubed) Project

MWA is currently embarking on a new project known as the Upper Mojave River Groundwater Regional Recharge and Recovery Project (R-Cubed). When completed, R-Cubed will deliver SWP water from the California Aqueduct in Hesperia to recharge sites in the Floodplain Aquifer along the Mojave River in Hesperia and southern Apple Valley (Alto Subarea). Planned MWA-owned production wells on either side of the Mojave River located immediately downstream of the recharge area will then recover and deliver the stored water through new pipelines directly to retail water agencies (see **Figure 2.1**). While the project is not within the Centro or Baja subareas, the project will provide MWA with increased



Legend

Planned and Under-Construction MWA Facilities

Antelope Wash

Proposed Recharge

Joshua Basin

Proposed Recharge

BDVWA Reche Basin

Proposed Recharge

Existing MWA Facilities

Recharge Site

River Recharge

Reservoir

Pressure relief valve

Pump

Aqueduct Turnout

Turnout

Morongo Basin Pipeline

Mojave River Pipeline

R-Cubed Pipeline

R-Cubed Extraction Wells

California Aqueduct

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Figure 2.1
MWA Facilities

operational flexibility by providing a new source of supply for major water providers to address historical overpumping and groundwater level declines in the upper portions of the Basin. The project is being completed in two phases. Phase I (which provides 15,000 AFY of water supply) was recently completed in 2013; Phase II (which would provide additional water supply over 15,000 AFY) is planned for completion after 2015.

2.4.4 Groundwater Recharge Facilities

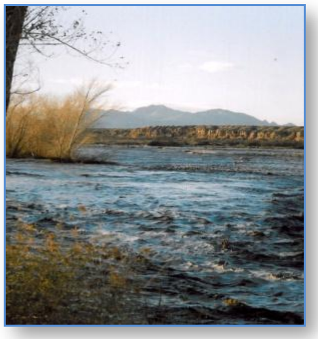
MWA operates multiple enhanced recharge facilities in its service area. Of the recharge facilities in the Mojave River Basin, two facilities are located in the Centro Subarea (Hodge and Lenwood) and two facilities are located in the Baja Subarea (Daggett and Newberry Springs) (see **Figure 2.1**). MWA has been recharging at the Hodge and Lenwood sites since 1999 and in Daggett and Newberry Springs since 2003 and 2006, respectively. Through WY 2009-10, MWA has recharged a total of about 37,000 AFY of SWP water through these four recharge facilities. MWA monitors local groundwater level response to enhanced recharge in dedicated multiple-completion (nested) monitoring wells.

2.5 Water Monitoring Programs and Other Collaboration

As part of its role as Watermaster, MWA maintains records of producers, production wells, and annual production from Stipulated Parties within the basin and strives to assemble the technical information needed to better understand the dynamic interaction between surface water and groundwater flows in the Basin. Partnering with the USGS, DWR, and other water agencies, MWA has been actively engaged in numerous groundwater management activities in the Basin, including:

- Construction of numerous groundwater monitoring wells.
- Routine measurement of groundwater levels and water quality in about 850 monitoring wells in its service area, of which about 670 wells are located in the Mojave River Basin.
- Funding and technical support of hydrogeological studies and field investigations to characterize hydrogeologic conditions and to site and monitor enhanced recharge facilities. Recent work has involved surface and borehole geophysics, well drilling, groundwater flow and water quality modeling, and geochemical analysis.
- Co-funding of the cooperative stream monitoring program with USGS and DWR.
- Maintenance of a network of weather stations to monitor rainfall, temperature, and evaporation.
- Assignment of state well numbers to new monitoring and production wells.

MWA has also entered into numerous cooperative partnerships with water agencies, cities, educational institutions, and other public and private entities to develop programs that encourage and educate users on topics related to both urban and agricultural water conservation.



3. BASIN CONCEPTUAL MODEL DEVELOPMENT

Over the past 50 years, substantial geologic, hydrologic, and hydrogeologic work has been accomplished in the Mojave River region based on datasets spanning more than 100 years. A primary objective of this report is to assimilate this available information and to develop comprehensive *conceptual hydrogeologic models* for the Centro and Baja subareas.

These conceptual models are intended to provide a foundation of knowledge that can guide and support science-based groundwater management. This section presents background information on the physical environment of the Study Area, including descriptions of the local geology, paleohistory, climate, and hydrologic conditions of the Mojave River over time. Information on historical land uses and associated water use is also presented. In combination with the institutional framework described in Section 2, information on the physical setting and land and water use sets the stage for development of the basin conceptual models.

3.1 Physical Setting

The Centro and Baja subareas are located in the lower portion of the Mojave River Groundwater Basin (Basin). The elevation of the Mojave River in the Study Area ranges from approximately 2,400 feet above mean sea level (feet msl) at its upstream boundary near the town of Helendale to about 1,600 feet msl at its downstream boundary, coincident with the eastern MWA service area boundary. The valley floor is surrounded by local hills and mountains with peak elevations ranging from 4,000 to 6,000 feet msl (**Figure 3.1**).

Mountains in the Centro Subarea include the Gravel Hills, The Buttes, and Kramer Hills in the west, Black Mountain and Mud Hills in the north, Waterman Hills and Mitchel Range to the east, Newberry Mountains to the southeast, and Stoddard Ridge and Ord Mountains in the south. Other defining physical features within the Centro Subarea include Iron Mountain, Lynx Cat Mountain, Red Hill, Mt. General, and Harper Dry Lake (**Figure 3.1**).

Mountains in the Baja Subarea include the Calico Mountains in the northwest, Alvord Mountains to the north/northeast, Cady Mountains to the east, and Newberry and Rodman mountains in the south. Other defining land features within the Baja Subarea include Elephant Mountain, Harvard Hill, and Coyote and Troy dry lakes.

There are numerous ephemeral desert washes located across the Study Area. These washes, most of which are ungaged, are fed by intermittent storm runoff from the local desert mountains. As mapped by Lines (1996), the discharge points of eleven dry washes tributary to the Mojave River are shown on **Figure 3.1** (diamond symbols along the river). Other desert washes that do not contribute directly to

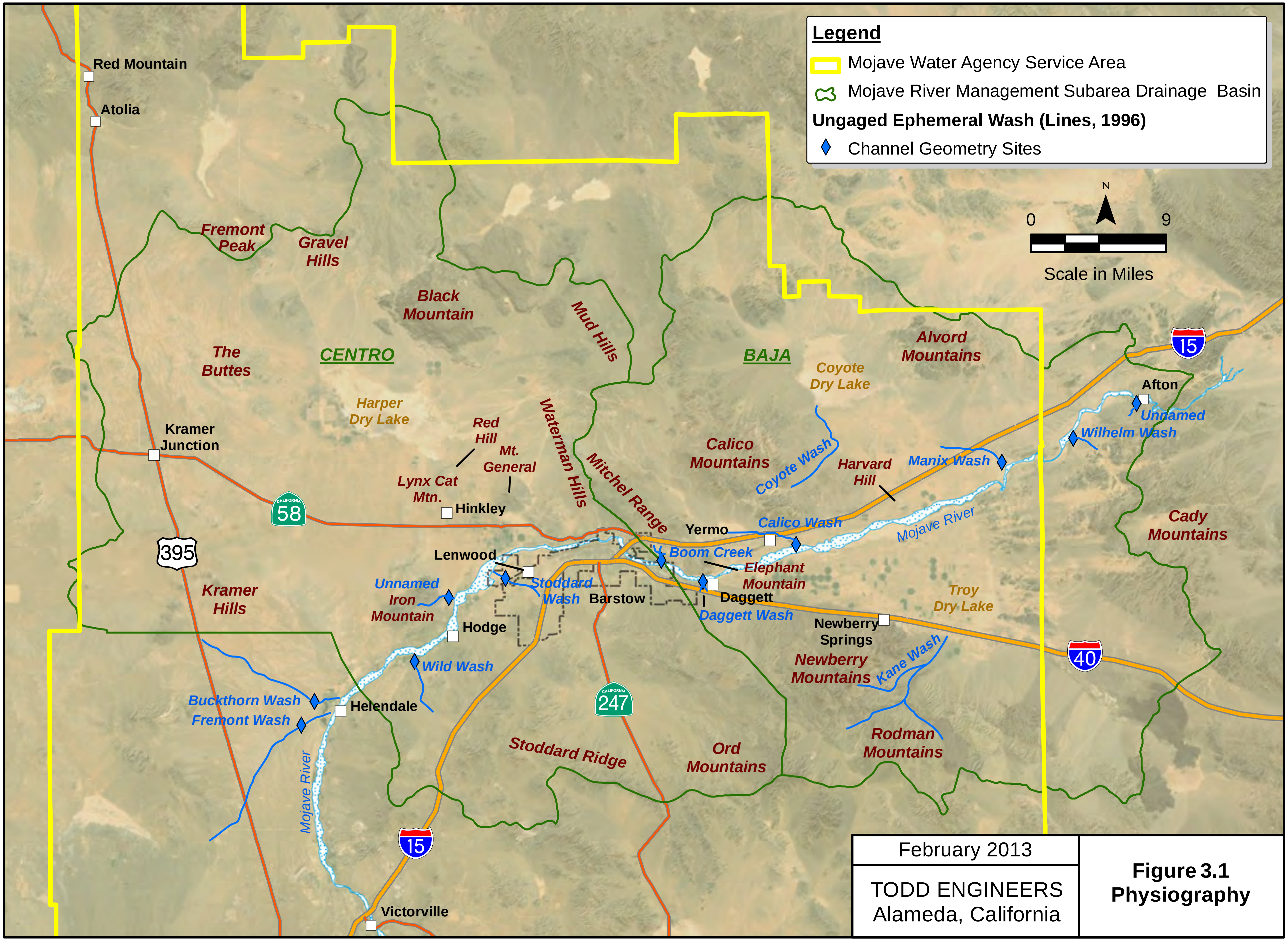


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Figure 3.1
Physiography

Mojave River flows include Coyote Wash and Kane Wash in the Baja Subarea. These two washes, labeled on **Figure 3.1**, terminate into the Baja Subarea dry lakes.

3.2 Geology

The Mojave Desert was formed in the Tertiary Period from movement along the San Andreas Fault to the south and the Garlock Fault to the north, creating the Mojave structural block (Norris and Webb, 1990). Tectonic activity associated with the Mojave structural block was superimposed onto the previously-formed Basin and Range province, which was characterized by normal faulting. The San Andreas and related faults created a horst-like block, uplifting the San Bernardino Mountains south of the Study Area.

The regional geology of the Mojave River area has been described in previous studies (DWR, 1963; DWR, 1967; Hardt, 1971; Stamos, et al., 2001). Additionally, the local geology has been investigated and mapped in detail for the Harper Lake Area (CM Engineering Associates and Leroy Crandall and Associates, Inc., 1983; The Mark Group, 1989; LGS, 2009; CSUF, 2010) and in the vicinity of Barstow and the U.S. Marine Corps Logistics Base (MCLB) – Nebo and Yermo annexes (Dibblee, 1970; Cox and Wilshire, 1993 and 1994; Densmore et al., 1997).

A map showing the generalized surficial geology within the Study Area is provided on **Figure 3.2**. As shown on the figure, the geology is characterized by sedimentary alluvial basins bordered by igneous and metamorphic mountain ranges and uplands. The basement complex is composed of Paleozoic and Mesozoic (pre-Tertiary) crystalline igneous and metamorphic rocks (pTb) and consolidated Tertiary volcanic and sedimentary rocks (Tv and Ts, respectively). These rocks (along with Quaternary basalt [Qv]) are considered non-water bearing (DWR, 1967). The crystalline complex and Tertiary deposits exposed in the local mountains and hills also underlie the valley floor but are overlain by Quaternary deposits that generally comprise water-bearing formations (DWR, 1967).

Quaternary deposits include older alluvial fans (Qoa), which are exposed irregularly across the Study Area but generally occur near the flanks of upland areas. These deposits are comprised of poorly sorted ancestral alluvial fan, braided-stream, or playa deposits and in many places are highly weathered and cemented. Accordingly, these deposits yield small quantities of water.

More recent Quaternary deposits include younger and recent fluvial/alluvial deposits associated with the modern Mojave River (Qya and Qra). These deposits represent the principal aquifer system in the Study Area and consist of boulders, gravel, sand, and silt with interbeds of clay within the river channel and associated fluvial depositional environments. Other significant recent Quaternary deposits include lake deposits (Ql) and aeolian (wind-blown) sand deposits (Qs). Undifferentiated alluvial deposits (Qal) also occur throughout the Study Area forming a thin veneer over older deposits. These undifferentiated alluvial deposits primarily occur above the water table and thus are only partially saturated.

The surficial geologic map does not show the thickness or extent of older alluvial deposits associated with the ancestral Mojave River and underlying Pliocene age alluvial deposits (identified as QToa and QTu, respectively [Stamos et al., 2001]). The ancestral Mojave River deposits are comprised of interbedded alluvial sand, silt and clay and paleolake and lakeshore sediments. Their distribution across

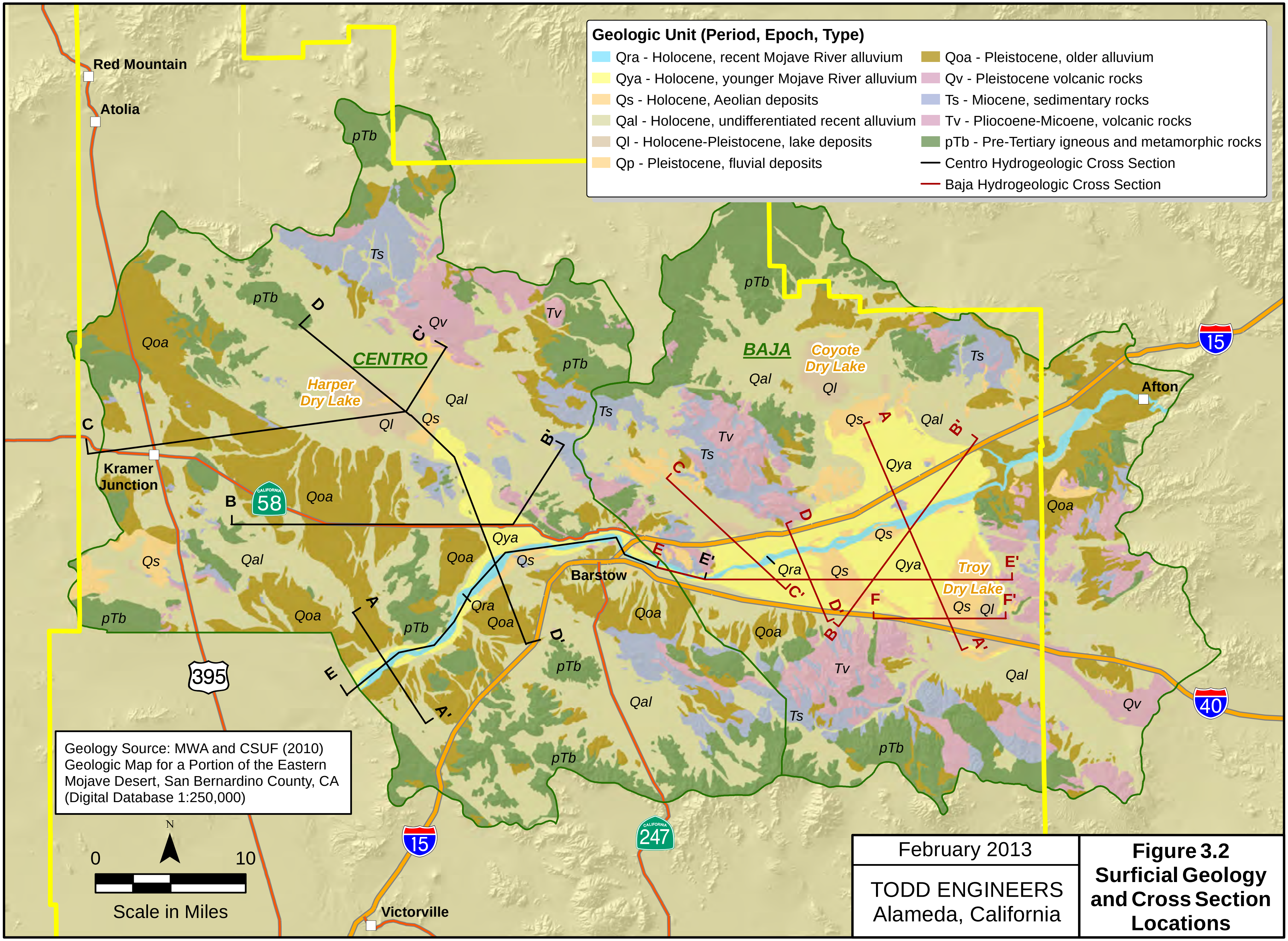


Figure 3.2
Surficial Geology and Cross Section Locations

the Study Area was controlled by the complex historical flowpaths of the ancestral Mojave River, which is described in detail in Section 3.3.

For the basin conceptual models, ten hydrogeologic cross sections (five in Centro and five in Baja) were developed to illustrate the relationship between consolidated and unconsolidated sediments, aquifer hydraulic characteristics, and groundwater levels across the Study Area over time. The locations of the cross sections (labeled A-A' through E-E' for both subareas) are shown on **Figure 3.2**. Cross sections are presented in the conceptual hydrogeologic models (Sections 4 and 5).

3.3 Faults and Hydraulic Barriers

Numerous geologic faults cross the Study Area, reflecting its complex tectonic history (**Figure 3.3**). As shown on the figure, the structural style consists predominantly of northwest-southeast trending faults, several of which impact groundwater flow and are used to define basin subarea boundaries. The trace of the Helendale Fault was used to define the boundary between the Transition Zone and Centro subareas, and represents the area of groundwater and surface water flow into the Study Area. The Camp Rock-Harper Lake (Waterman) Fault defines most of the boundary between the Centro and Baja subareas.

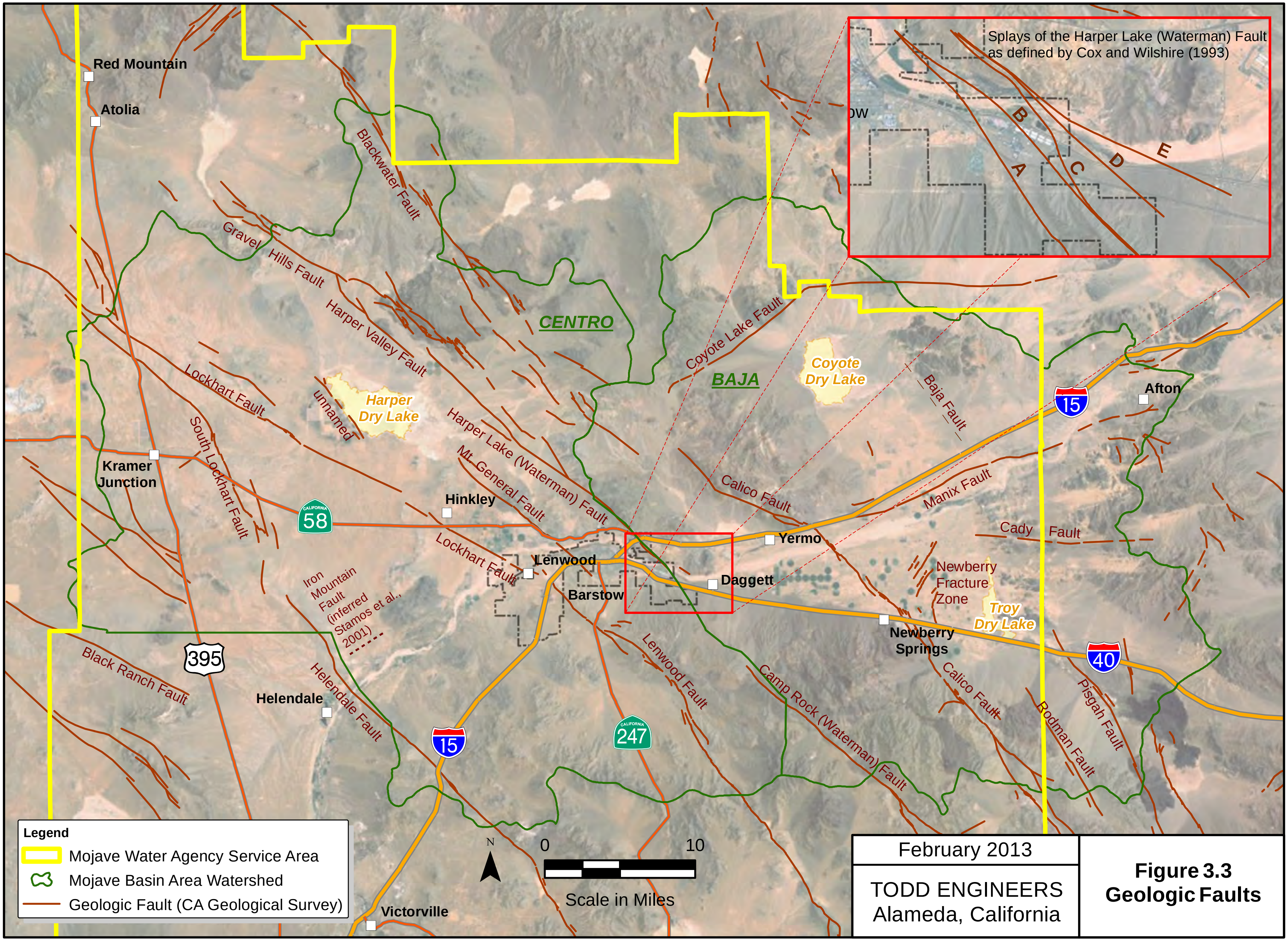
Other faults in the Centro Subarea include the Iron Mountain Fault, Lockhart Fault, South Lockhart Fault, Lenwood Fault, Mt. General Fault, Harper Valley Fault, Harper Lake Fault, and Camp Rock-Harper Lake (Waterman) Fault. Within the Baja Subarea, other faults include the Calico Fault, Manix Fault, Cady Fault, Baja Fault, and Newberry Fracture Zone.

The effect of faulting on groundwater flow and quality in the Study Area has been identified and evaluated in previous studies through groundwater level mapping (DWR, 1967; Lines, 1996; Stamos et al., 2003, Stamos et al., 2009), regional groundwater flow modeling (Hardt, 1971; Stamos et al., 2001); and geochemical analysis (Stamos, et al., 2003). Key findings on the effects of faulting on groundwater flow and chemistry from these studies are incorporated in the conceptual hydrogeologic models (Sections 4 and 5).

3.4 Ancestral Mojave River and Paleolakes

The middle to late Pleistocene was a key period of depositional history that influenced significantly the hydrogeology of the Centro and Baja subareas. During this period, the Mojave River outlet at Afton Canyon had not yet been eroded and the Mojave River drained into a series of large lakes, whose location and size varied with time. These large paleolakes included the ancestral Harper Lake in the Centro Subarea and ancestral Manix Lake in the Baja Subarea (**Figure 3.4**). The paleolakes represented a relatively low-energy depositional environment that resulted in thick, fine-grained deposits of silts and clays.

The evolution of these paleolake bed deposits, including the changing paleoenvironments and paleohydrology, has been extensively studied for more than 90 years by numerous investigators. Many of these references were compiled and/or cited in a special Geological Society of America (GSA) publication dedicated to this topic (GSA, 2003), in particular Cox, Hillhouse and Owen (2003). Numerous



February 2013	**Figure 3.3** **Geologic Faults**
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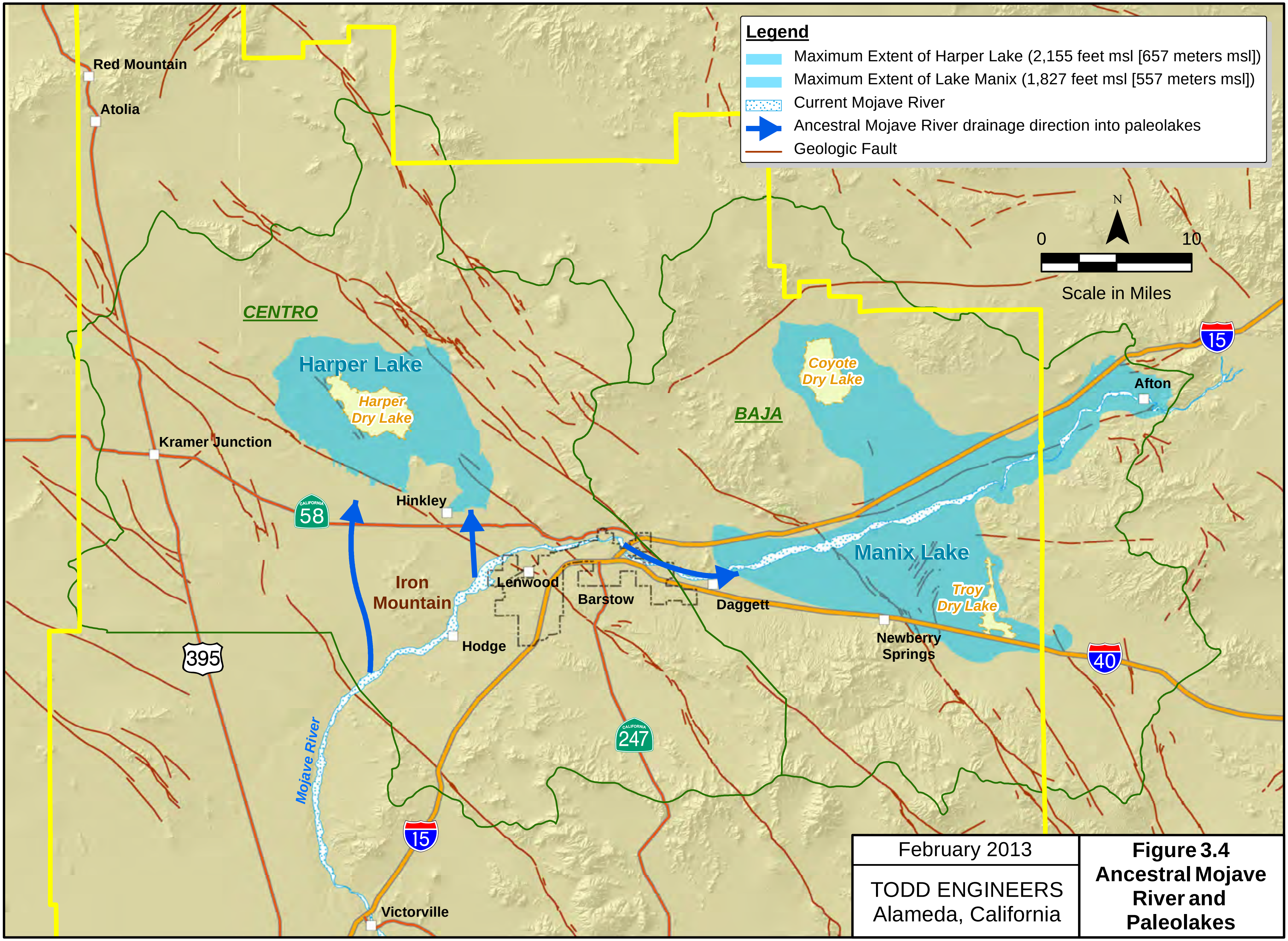

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Figure 3.4
Ancestral Mojave River and Paleolakes

additional investigators (e.g., Reheis and Redwine, 2008 and Garcia, 2010) have contributed to the understanding of the sequence of filling, abandonment, and highstand of the paleolakes.

Stratigraphic studies and age-dating of sediments have indicated that about 3.3 million years ago (Ma), uplift along San Gorgonio Mountain and the San Andreas Fault created the ancestral Mojave River's northward drainage pattern. As uplift along the San Bernardino Mountains progressed, the ancestral river channel began to infill a low basin in the vicinity of Victorville and also possibly drained eastward to the Lucerne Valley. The drainage was blocked to the north by a topographic high associated with a basement arch.

As deposition raised the basin floor, the river began to over-top the topographic high and flow northward beyond Victorville. The formation of this northward channel is estimated to have occurred between about 475,000 to 525,000 years ago (475 – 525 ka). The ancestral Mojave River flowed first to Harper Lake, turning a playa into a pluvial lake (i.e., a Pleistocene lake formed during periods of heavy rainfall) fed from the south by the river. Soon afterward, the Mojave River drainage extended eastward past Barstow and terminated in a low-lying area referred to as Manix Lake (**Figure 3.4**). Researchers have postulated that old alluvial fan sediments near Barstow may have initially prevented the river from reaching the Manix Lake area; however, deposition at Harper Lake eventually raised the river sufficiently high to overcome this barrier. Age-dating suggests that the river may have arrived at Manix Lake as early as 500 ka.

Even though the river is thought to have reached Manix Lake relatively soon after breaching the high north of Victorville, Harper Lake was not permanently abandoned. During the next several hundred thousand years, the river fed both Harper and Manix lakes. Tectonic activity along faults is postulated to have resulted in the termination of the river switching between the two lakes over time. Episodic downcutting (erosion) and aggrading (deposition) also controlled the interaction of the river with the two paleolakes.

Figure 3.4 shows the general direction of flow taken by the ancestral Mojave River across the Basin. Initially, the river flowed into Harper Lake along two routes: 1) west of Iron Mountain and 2) east of Iron Mountain and northward through the Hinkley Valley. As the primary upstream channel was incised, the pathway west of Iron Mountain was abandoned, leaving a broad fluvio-deltaic plain in that area and allowing more flood water to flow north and eventually east towards Manix Lake. The areas corresponding to the highest water level in Harper Lake (2,155 feet msl) and Manix Lake (1,827 feet msl) as estimated by Enzel et al. (2003) and Reheis and Redwine (2008) are shown in **Figure 3.4**. The maximum extent of Harper Lake covered approximately 100 mi^2, while the maximum extent of Manix Lake covered about 270 mi^2.

As the modern canyon of the Mojave River was eroded past Barstow to Daggett (estimated to have begun around 60 -70 ka), sediment load in the river increased and was ultimately deposited in Lake Manix. These depositional events resulted in a large alluvial plain covering the central portion of the paleolake and isolating Coyote Lake in the north from Troy Lake in the south. The shrinking of Lake Manix decreased the lake's storage, increased surface outflow, and contributed to the overtopping of the lake's barrier to the east. Ultimately this erosion created the river's outflow point at Afton Canyon.

Within the areas once occupied by Lake Manix, the groundwater system is separated into shallow unconfined and deeper confined aquifers by the Manix (Clay) Beds. The Manix Beds are Pleistocene lacustrine (lake) deposits comprised of light blue to grey well-bedded clays, silts, and fine sands. The Manix Beds extend from the eastern edge of the Baja Subarea to within three to four miles of the Calico Fault and have a thickness of more than 120 feet beneath Camp Cady. Due to the presence of the Manix Beds, recharge to the deeper aquifer system east of the Calico Fault is limited to the 3- to 4-mile stretch of river west of Harvard Hill.

3.5 Aquifer Systems

Unconsolidated basin fill deposits in the Mojave River Basin have been delineated into two aquifer systems by the USGS: the Regional Aquifer and Floodplain Aquifer (Stamos et al., 2001). The width of the Floodplain Aquifer varies considerably across the Study Area, from less than one mile in many areas within the Centro Subarea up to several miles in the Hinkley Valley and in the central portion of the Baja Subarea.

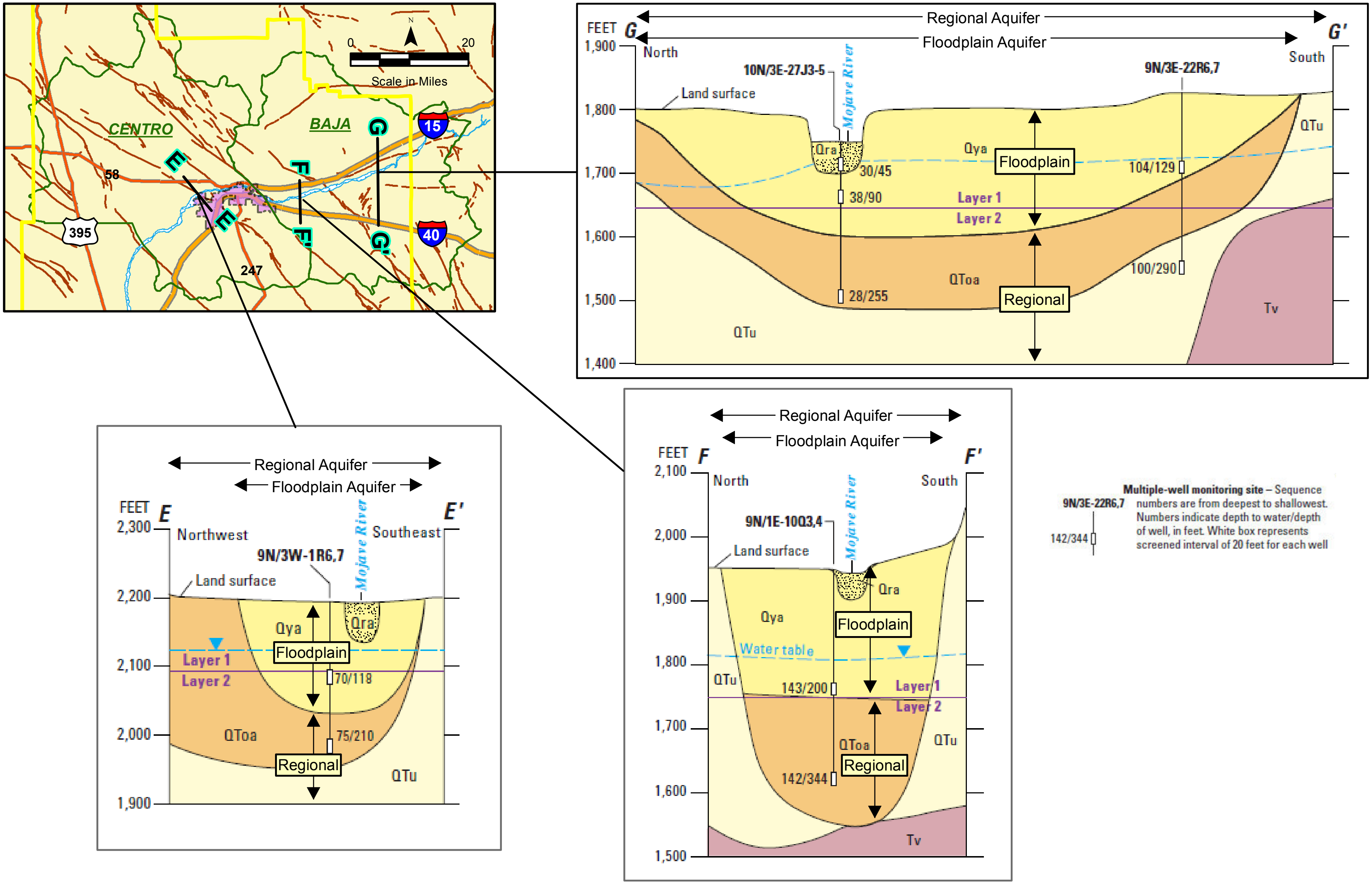
Figure 3.5 presents three cross sections across the Study Area developed by USGS (Stamos, et al., 2001) that illustrate the relationship between the Regional Aquifer and Floodplain Aquifer. As shown on the cross sections, alluvial deposits of late Pliocene to Holocene age (QTu and QToa) form the Regional Aquifer, which uncomformably underlies and surrounds Pleistocene to Holocene fluvial/alluvial deposits of the Floodplain Aquifer throughout the Mojave River Basin (Stamos et al., 2001). Directly beneath the river, permeable unconsolidated sand and gravel deposits of more recent Mojave River alluvium (Qra) and Younger Mojave River Alluvium (Qya) compose the Floodplain Aquifer.

3.6 Water Purveyors

Groundwater is pumped from both the Floodplain Aquifer and the Regional Aquifer for municipal, industrial, and agricultural supply. While most of the pumping is from private wells, there are three water purveyors in the Study Area.

Golden State Water Company Barstow (GSWC) represents the sole water purveyor in the Centro Subarea. GSWC supplies water to the City of Barstow and surrounding unincorporated areas from a network of 23 production wells located along the Mojave River (GSWC, 2011b). Based on 2010 water deliveries, GSWC customers are primarily residential users (55 percent) followed by commercial users (26 percent), institutional/government entities (12 percent), and industrial and other users (7 percent). GSWC groundwater production in WY 2009-10 totaled 6,257 AFY.

In the Baja Subarea, there are two small water purveyors: Daggett Community Services District (Daggett CSD) and Yermo Water District (Yermo WD). Collectively, Daggett CSD and Yermo WD provide water to about 300 primarily residential users in the western portion of the Baja Subarea. In WY 2009-10, combined groundwater production by the Yermo CSD and Yermo WD totaled 414 AFY.



Source: cross sections from Stamos, et al., 2001

February 2013	**Figure 3.5 Aquifer Systems**
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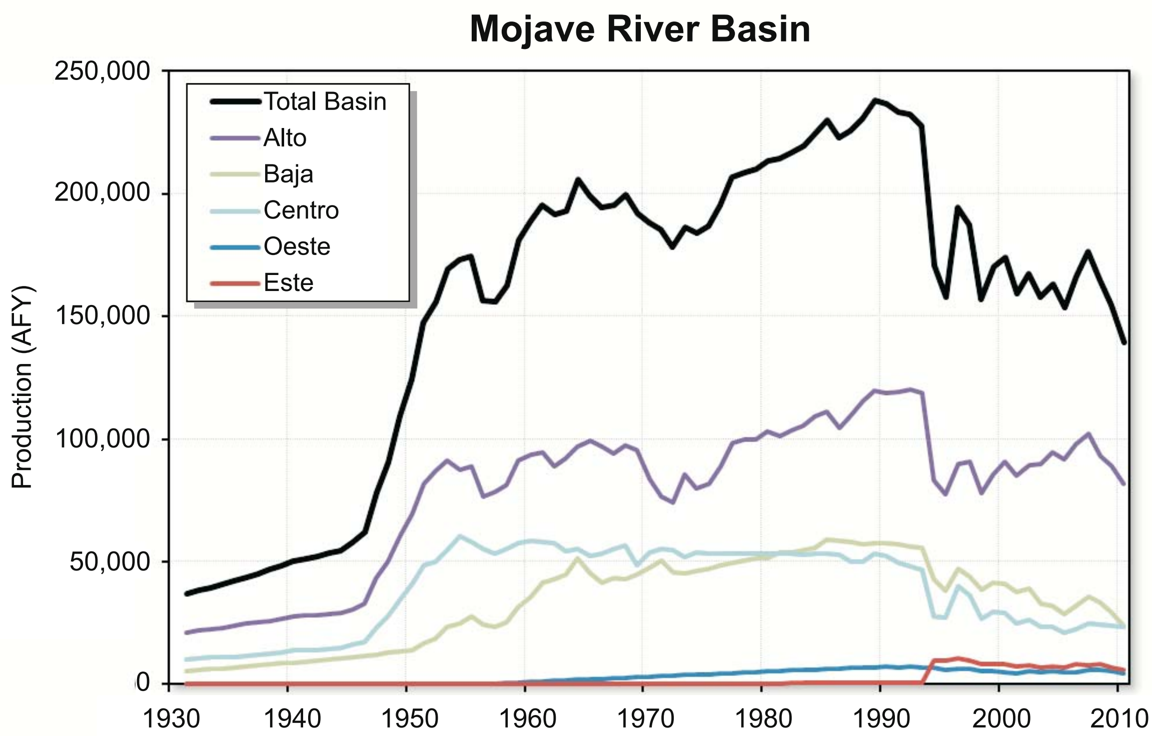
3.7 Basin and Study Area Groundwater Production

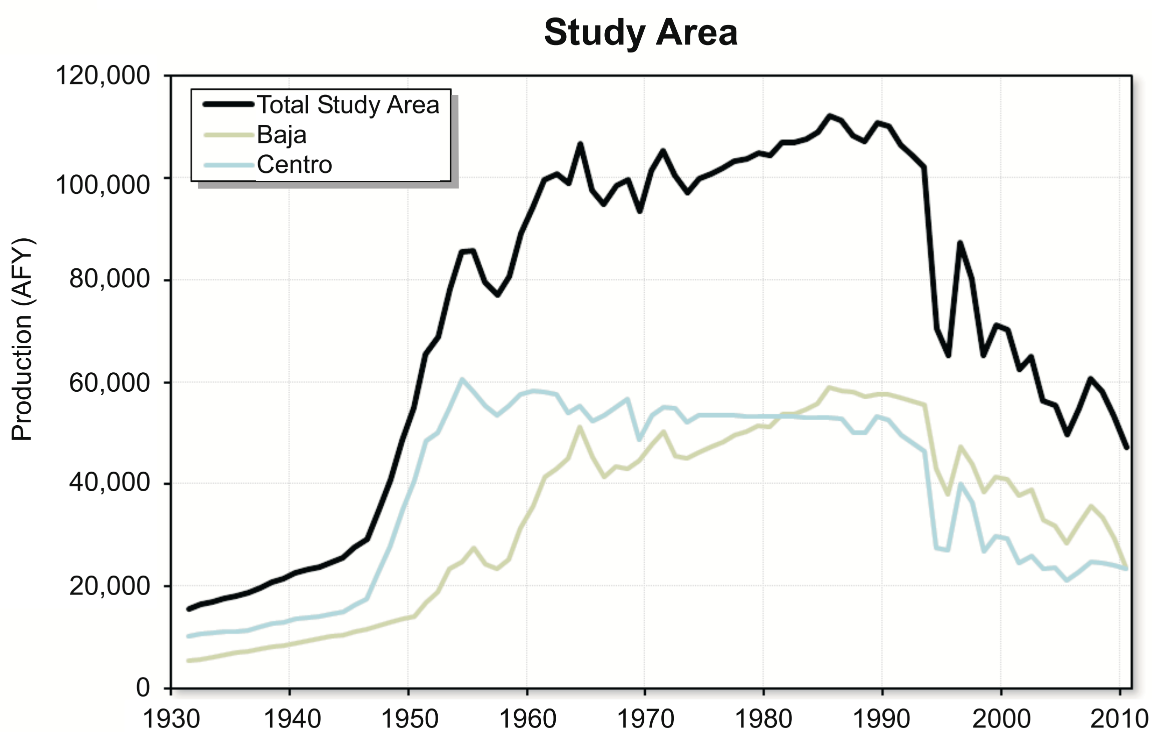
Figure 3.6 shows the estimated pumping for the Mojave River Basin and for individual subareas, including the Centro and Baja subareas, from Calendar Year (CY) 1930 through WY 2009-10. This chart was developed from pumping estimates from the USGS groundwater model (Stamos et al., 2001) and the MBA Watermaster (MBA Watermaster, 2011). Annual pumping volumes in the USGS model are calculated by calendar year from 1930 to 1999, while Watermaster pumping volumes are reported from WY 1993-94 to WY 2009-10. The chart combines the USGS model production values from 1930 to 1993 with production estimates (net re-circulated water associated with recreational lakes) from WY 1993-94 to WY 2009-10 as reported by the Watermaster.

The figure shows that pumping in the Alto and Centro subareas increased dramatically throughout the Basin from the mid-1940s through the mid-1950s. These increases coincided with the expansion of agriculture in the region. Although production also increased in Baja during this time period, the more significant increase in production occurred from the mid-1950s through the mid-1960s. While pumping in Centro remained relatively flat, gradual increases in pumping continued in Alto and Baja through the early 1990s. Total basin production peaked in 1989 at about 240,000 AFY. At this time, combined pumping in Centro and Baja represented about 110,000 AFY, or roughly 46 percent of the total basin production. Since the Judgment, pumping has declined significantly. Total basin production in WY 2009-10 (140,000 AF) represents about 60 percent of the historical peak production. Production in the Centro and Baja subareas in WY 2009-10 (23,400 and 23,767 AFY, respectively) represents about 40 percent of their respective historical peak production (**Figure 3.6**).

Figure 3.7 shows the spatial distribution of production in the Basin for four periods – 1950, 1970, 1990, and 2009. The figure shows that production in the Basin since 1950 has generally been concentrated along the river in the Floodplain Aquifer. However, production has historically also occurred in areas away from the river in the Regional Aquifer. Within the Centro Subarea, production in the Hinkley Valley and Harper Lake Area increased through the early 1990s but has since declined in these areas and elsewhere as a result of land use changes and mandated production decreases required by the Judgment (referred to as rampdown). Within the Baja Subarea, production increased systematically from 1950 through 1990, with most of the increase occurring south of the Mojave River. Since the Judgment, production has declined across the subarea with only limited production now occurring north of the river.

Groundwater production in the Floodplain Aquifer (and to a lesser extent in the Regional Aquifer) has induced increased recharge to the groundwater system from the Mojave River where streamflow occurs. Increased recharge along the river in upstream reaches causes depletion in streamflow, thereby reducing the amount of streamflow available for recharge to downstream reaches. The relative impact of upstream production on downstream flows over time has been cursorily evaluated in previous studies (Stamos, et al., 2001) and is discussed in further detail in the section on surface water hydrology (Section 3.10).





Alto production includes the Transition Zone.

Data Sources: - CY 1930 to 1993 (Stamos et al., 2001)
- WY 1993-94 to WY 2009-10 (Mojave Basin Area Watermaster, 1995 through 2011)

February 2013	**Figure 3.6**
TODD ENGINEERS Alameda, California	**Historical Basin and Study Area Groundwater Production (1930 - 2010)**

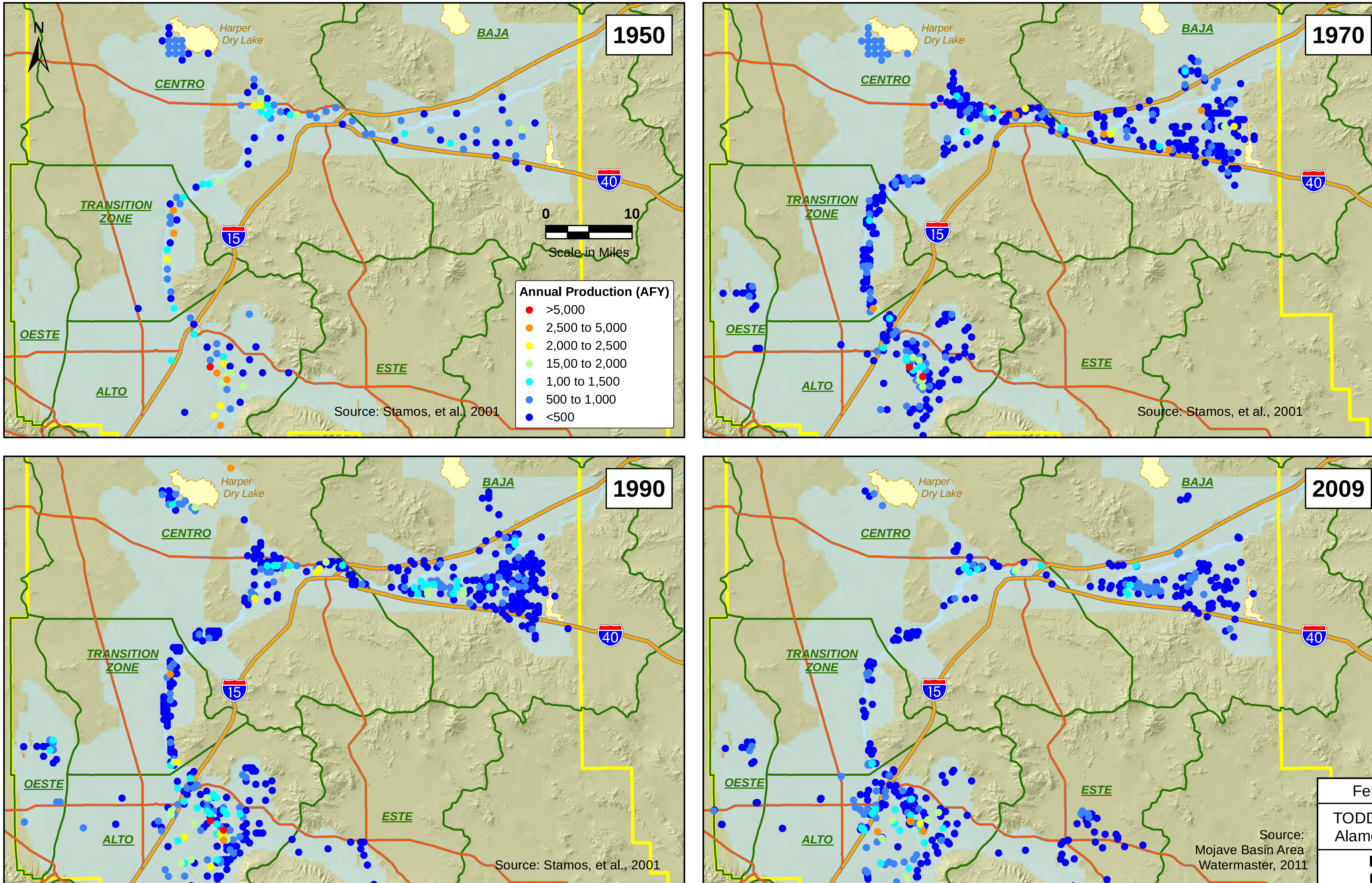


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Figure 3.7
Historical
Production

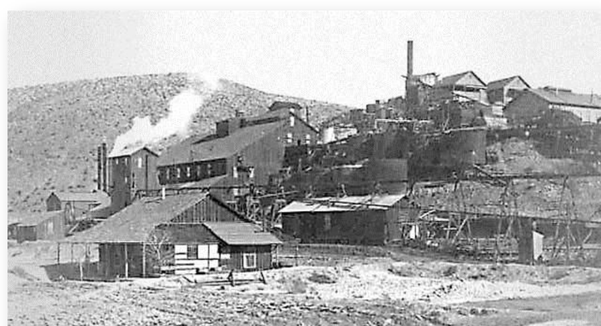
3.8 Land Use and Water Use

The High Desert environment within the Study Area consists of a mix of urban, agricultural, and undeveloped land. Most of the undeveloped land is owned by the federal government, including the U.S. Bureau of Land Management (BLM) and Department of Defense (DoD). Private (non-government) land is comprised of a mix of urban (residential, commercial, and industrial development), agricultural, rural residential, and undeveloped land. The City of Barstow represents the largest population center in the Study Area. Descriptions of historical and current land uses and associated water use in the Study Area are provided below. Locations of current land uses are shown on **Figure 3.8**.

3.8.1 Historic Mining Operations

Since the late 1800s, precious metals and industrial minerals have attracted miners to the local mountains surrounding the Mojave River. Despite the inconveniences of costly freight charges, crude mineral recovery methods, and scarcity of water, the prospect of discovering gold- and silver-rich ore gave birth to large-scale mining operations by the early 1880s.

The history of local mining is documented in a number of publications dating from the late 1800s and early 1900s. Key historical information on local mining was provided to Todd Engineers by George Kenline, Mining Geologist, formerly with the Mining and Environment Section of the San Bernardino County Land Use Services Department (Kenline, personal communication, 2010). In addition to his compilation of important mining documents, Mr. Kenline is highly knowledgeable on historical mining operations; he provided key documents and insights in support of this study. Many of these documents also provide historical information on the Mojave River. As Mr. Kenline notes, "mine development could not have occurred without water."



Associated ore processing mills were the primary water users. Mills were constructed in the local mountains and along the Mojave River where water was available for diversion and use. One such mill in Barstow, the Santa Fe Reduction Works, is pictured at right (circa 1898 – 1910). Mule trains and railroads were used to transport raw ore to the mills. Trees along the Mojave River were cut down and used for wood to fuel steam engines. After the cottonwoods and mesquite were removed near the mills, residents complained of cold winters because only thin strands of greasewood were left for heating fuel (Kenline, 2010). Coal was later shipped into the area to serve the mills and residents. Within the Centro and Baja subareas, at least fifteen processing mills were constructed in the vicinity of Barstow and Daggett between about 1881 and 1910. Summary information of these mills and the general locations are shown on **Figure 3.9**.

While detailed water use for each mill is largely unavailable, it has been estimated that approximately 2,000 gallons of water per ton of ore were used in the amalgamation process, and additional water was

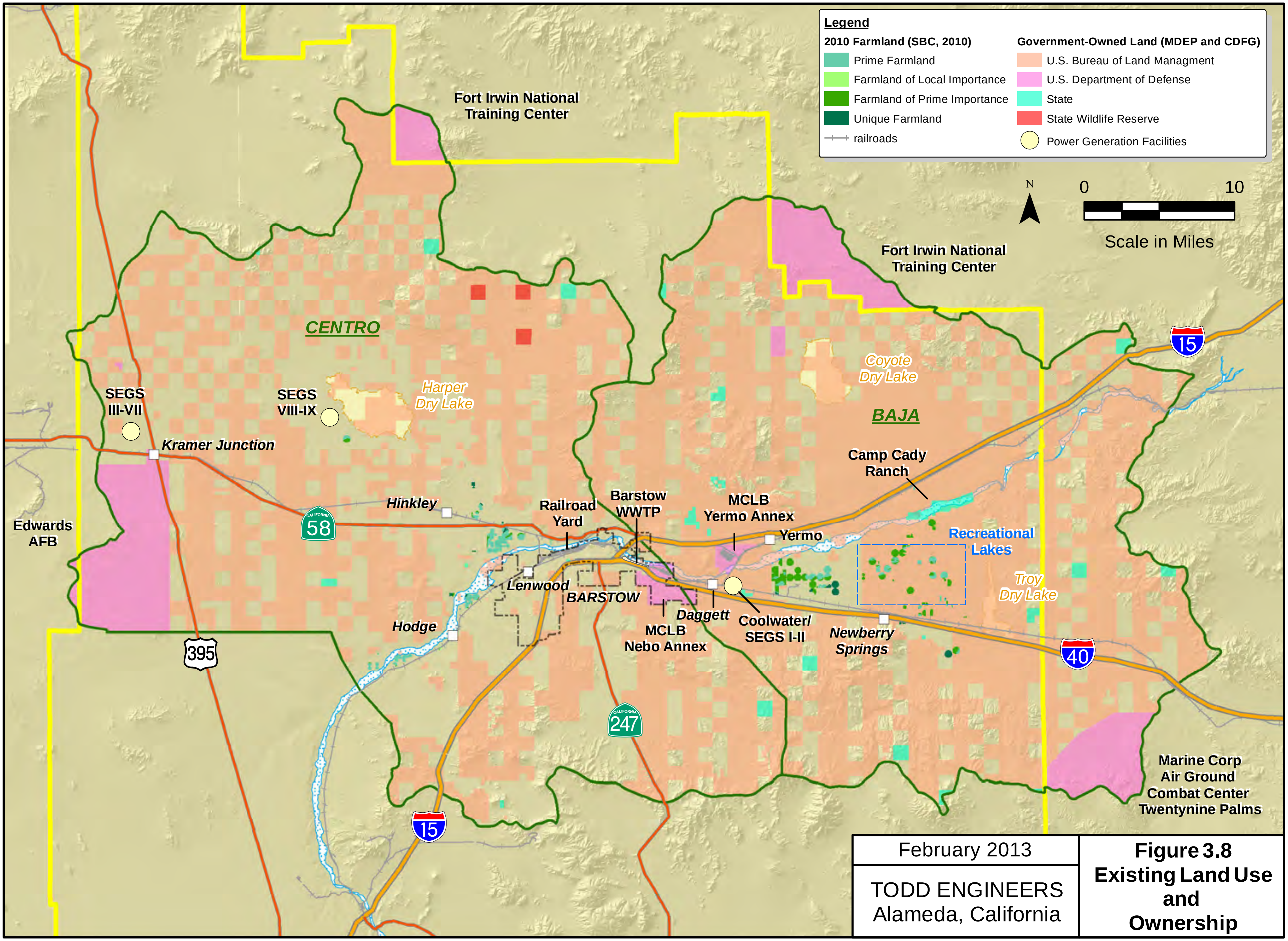


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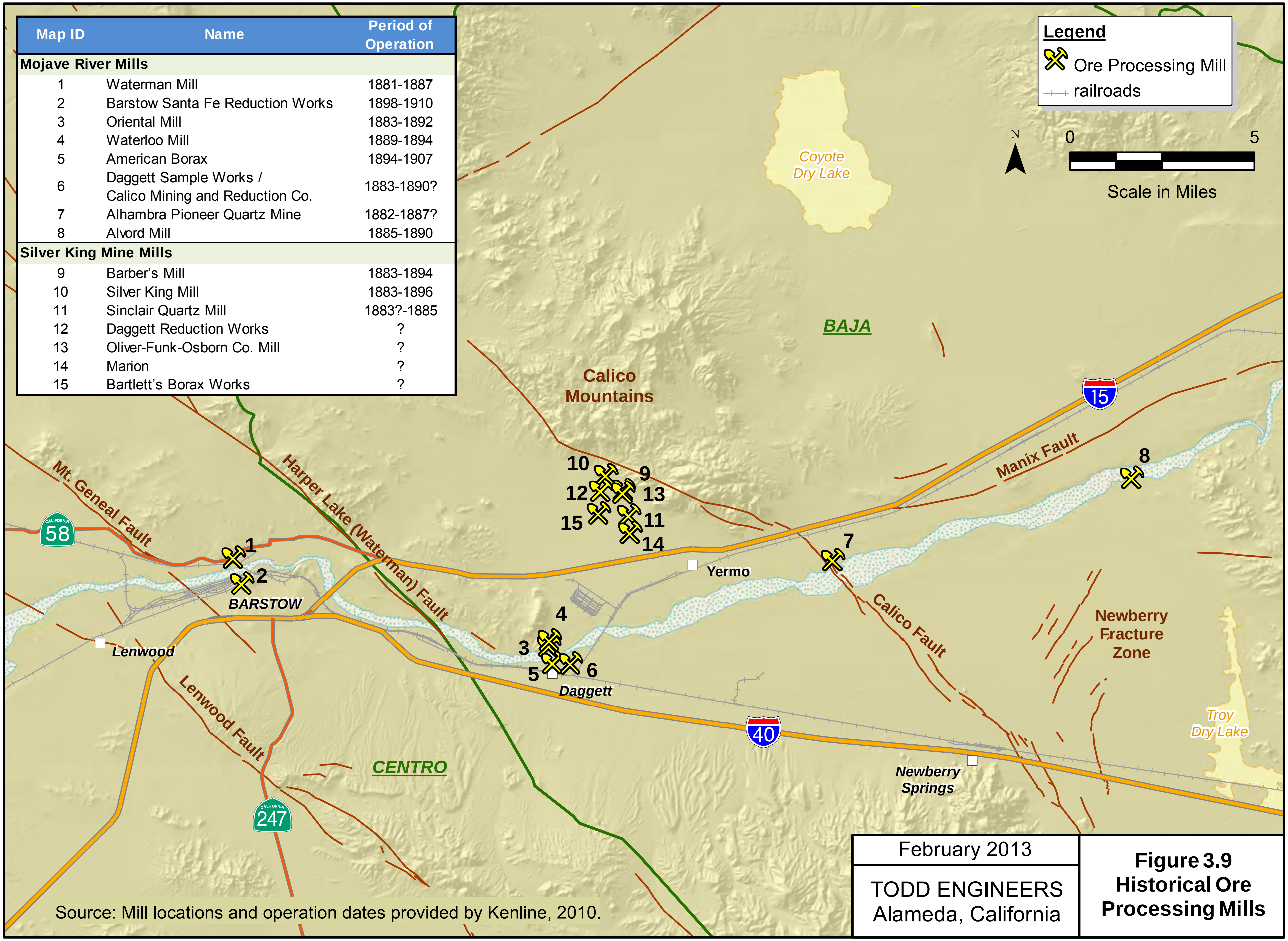
Figure 3.8
Existing Land Use and Ownership

Map ID	Name	Period of Operation
Mojave River Mills		
1	Waterman Mill	1881-1887
2	Barstow Santa Fe Reduction Works	1898-1910
3	Oriental Mill	1883-1892
4	Waterloo Mill	1889-1894
5	American Borax	1894-1907
6	Daggett Sample Works / Calico Mining and Reduction Co.	1883-1890?
7	Alhambra Pioneer Quartz Mine	1882-1887?
8	Alvord Mill	1885-1890
Silver King Mine Mills		
9	Barber's Mill	1883-1894
10	Silver King Mill	1883-1896
11	Sinclair Quartz Mill	1883?-1885
12	Daggett Reduction Works	?
13	Oliver-Funk-Osborn Co. Mill	?
14	Marion	?
15	Bartlett's Borax Works	?



Source: Mill locations and operation dates provided by Kenline, 2010.

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Figure 3.9
Historical Ore Processing Mills

used to power the mills and support the local workforce (Kenline, 2010). The Waterman Mine was reported to have produced 40,000 tons of ore before it closed in 1887 after silver prices declined. This tonnage indicates a water use of about 250 AF for amalgamation during its seven-year operation. The Barstow Santa-Fe Reduction Works (photograph above) was a large operation with a capacity to handle 200 tons of ore per day, with an estimated amalgamation water use of 1.2 AF/day; it processed gold ore transported by rail from the Bagdad Chase Mine located south of Ludwick (the largest producer of gold in San Bernardino County at the time). Gold ore was also transported by rail from the Randsburg Mine in Kern County for processing.

While some of the mills operated through the early 1900s, many began to close by the late 1880s and early 1890s as ore prices declined and gold and silver-rich ore bodies were depleted (Kenline, 2010; Trent, 2006). More recently, the local mining industry has been supported primarily by non-metallic mining (e.g., borax), which represents an important component of the region's economy.

An exception to the declining trend of the late 1890s/early 1900s was the gold, silver, and tungsten mines in the Randsberg, Red Mountain, and Atolia area, where mining continued at least through the 1950s with some mining activities extending into the 2000s. This area is located north of the Centro Subarea as shown on **Figure 1.1**. Additional information on historical mine operations and associated water use in the Randsburg, Red Mountain, and Atolia area is provided in **Appendix G** of this report.

3.8.2 Agriculture

Of the developed land in the Study Area, agriculture has historically been the primary land use in both subareas. Early irrigation supply was developed from the Mojave River. Dating back to at least the 1870s, irrigation ditches were constructed to convey water from the river to agricultural areas (CA Dept. of Engineering, 1917). Some of the ditches were originally constructed for mining purposes and later used for irrigation (Kenline, 2010). One large irrigation project was the Daggett Ditch, engineered by Southern California Improvement Company to divert Mojave River flows for irrigation. Sheet piling was driven across the river channel into underlying clay to dam water at the ditch. The Daggett Ditch ran four miles to the Daggett Ranch and an additional six miles to Minneola. Another regional ditch was constructed in 1910 by the Yermo Municipal Water Company. Apparently, remnants of these ditches remain in the area today.

Although there is some information regarding annual diversions along these early ditches, historical documents warn that reported amounts were typically exaggerated in order to establish surface water rights (CA Dept. of Engineering, 1917). The variable flows in the river and the drought of 1894 – 1904 prompted the need for an additional supply and by the 1920s, wells were installed in or near the river channel to pump water directly into the ditches (CA Dept. of Engineering, 1917; Lines, 1996). Over time, groundwater became the primary source of agricultural supply.

Agriculture continues to be the main land use in the Baja Subarea today. Alfalfa is the major crop grown in the area, representing roughly 70 percent of the agricultural water production in the Study Area. Grain, orchards, pasture, and livestock represent the remaining agricultural uses. Approximately 7,500 acres of agricultural land exists in the Study Area, of which about 2,500 acres are located in Centro and about 5,000 acres are located in Baja (California Department of Conservation, 2010). As shown in **Figure**

3.8 agricultural land in the Centro Subarea is generally concentrated along the Mojave River and extends northward towards Hinkley. In the Baja Subarea, agriculture is distributed across the valley between the Mojave River and Highway 40.

Since WY 1993-94, groundwater production for agriculture in Centro has averaged about 13,000 AFY, or slightly over 50 percent of average annual production (25,500 AFY). However, over that period agricultural production in Centro has gradually declined from between 12,000 and 25,000 AFY in the mid-1990s to between 11,000 and 12,000 AFY in recent years. Groundwater production for agriculture in Baja since WY 1993-94 has averaged about 27,000 AFY, or more than 80 percent of the total subarea production (32,500 AFY). Agricultural production in Baja has declined from between 30,000 and 38,000 AFY in the mid-1990s to between 22,000 and 27,000 AFY in recent years (MBA Watermaster, 1995-2011).

3.8.3 Urban Land Use

Major urban land uses in the Study Area include urban centers (City of Barstow and smaller unincorporated rural communities), military bases, industrial facilities, and recreational lakes. A summary of these land uses and associated water use and wastewater management practices is presented below. Locations of urban land uses are shown on **Figure 3.8**.

3.8.3.1 City of Barstow and Unincorporated Rural Communities

The City of Barstow (population 22,600) is the largest urban center in the Study Area. Additional smaller unincorporated communities in the Centro Subarea include Hodge (population 400), Lenwood (population 3,500), Hinkley (population 2,000), and Kramer Junction (population 2,800). The rural communities of Daggett (population 200) and Newberry Springs (population 4,000) represent the only non-military population centers in the Baja Subarea. As discussed previously, there are three water purveyors in the Study Area: GSWC in Centro, and Daggett CSD and Yermo WD in Baja. Non-municipal water demands in the Centro and Baja subareas are satisfied by local groundwater production. Currently, total water demand by residential, domestic, and Minimal Producers in the Study Area is approximately 11,500 AFY.

Historically, Barstow has operated three wastewater treatment plants (WWTPs), each located about one mile southeast of the central business district along the southern bank of the Mojave River. The WWTPs were constructed in 1938, 1953 and 1968. While the first WWTP initially provided primary treatment of domestic sewage, eventually industrial sewage was treated by the first after 1945. Both domestic and industrial wastewater was also treated at the second WWTP. Effluent from both WWTPs were discharged to evaporation/percolation ponds as well as irrigation fields until 19 68 (DPRA, 2010).

In 1968, Barstow replaced the earlier WWTPs with a new facility. The 1968 WWTP was initially constructed as a primary WWTP but was upgraded to an activated sludge plant (secondary treatment) in 1973 with several major system upgrades, including headworks equipment, grit system, and new primary sludge pumps. The WWTP was modified in 2009 to include two aeration basins to create anoxic and oxic zones for facilitation of nitrification/denitrification processes. Currently, the WWTP has a design capacity of 4.5 million gallons per day (MGD) and a peak flow rate of 7.5 MGD. Average daily flows are approximately 2.7 MGD. Effluent from the WWTP is discharged into eight ponds and two irrigated agricultural fields (DPRA, 2010).

3.8.3.2 Military Bases

The U.S. Marine Corp Logistics Base Barstow (MCLB) – consisting of the Nebo Annex, Yermo Annex, and Rifle Range – was established in 1942. The Nebo Main Base (1,571 acres) is located 3.5 miles east of the city of Barstow in the eastern Centro Subarea and contains base housing, administrative buildings, and covered storage for warehousing activities. The Yermo Annex (1,680 acres), located 7 miles east of Barstow in the Baja Subarea, is used for the storage of supplies and the maintenance, repair, overhaul, and reassembly of vehicles and weapons. Collectively the two annexes serve as one of two major supply and maintenance centers in the United States. Additionally, adjacent to the southern boundary of the Nebo Main Base is the Rifle Range (2,438 acres), a secure area used for practicing marksmanship skills (ATSDR, 2011).

The Nebo Annex has a population of approximately 1,500 military personnel and family members. Prior to 1977, the Nebo Main Base obtained potable water from six onsite production wells for drinking and operations. In 1997, the wells were shut down due to concerns over elevated TDS concentrations (ATSDR, 2011). Since then, water for the base has been obtained from the City of Barstow through GSWC. Production wells have since been used only for irrigation of an onsite golf course (DPRA, 2010).

Historically, the MCLB Nebo Annex operated a WWTP. From 1942 to 1976, secondary-treated effluent from the WWTP was discharged into onsite evaporation/percolation ponds. In 1976, a new WWTP comprised of pre-aeration, grit removal, and primary sedimentation, and oxidation in lined ponds, was placed online. In 2002, 0.2 to 0.4 mgd of wastewater was processed at the WWTP. More recently, the WWTP processed minimal amounts of wastewater. Prior to 1998, partially treated effluent was used to irrigate an onsite golf course, but this practice was discontinued (DPRA, Inc., 2010).

Other military bases surrounding the Study Area include Fort Irwin National Training Center to the north/northeast, Edwards Air Force Base to the west, and the U.S. Marine Corp Air Ground Combat Center – Twentynine Palms to the southeast (**Figure 3.8**).

3.8.3.3 Power Generation Facilities

An oil and natural gas power plant and several solar energy generating systems (SEGS) represent most of the industrial land uses in the Study Area (**Figure 3.8**). The Coolwater Generating Station (658 MW), an oil and natural gas power plant, is located in Daggett (Baja). The station consists of four dual-fuel power generating units. Built in the early 1960s, Unit 1 (65 MW) and Unit 2(81 MW) are conventional steam-driven units, while Units 3 (256 MW) and 4 (256 MW) are combined cycle units built in 1978 (GenOn, 2010).

There are nine solar power plants in the Centro and Baja subareas that collectively comprise the Solar Energy Generating Systems (SEGS), the first commercial and largest solar energy generating facility in the world. SEGS I–II (44 MW) are located in Daggett (Baja), while SEGS III–VII (150 MW) and SEGS VIII–IX (160 MW) are located at Kramer Junction and Harper Lake (Centro), respectively. The facilities were commissioned between 1984 and 1999 (NextEra Energy Resources, 2010). An additional SEGS facility, the 250 MW Abengoa Mojave Solar Project, is under construction following approval of the power purchase agreement with Pacific Gas and Electric by the California Public Utilities Commission in November 2011. The facility is located adjacent to SEGS VIII-IX near Harper Lake in the Centro Subarea and is scheduled for completion in Spring 2014 (**Figure 3.8**).

The water demand associated with the oil and gas and solar power generating facilities in the Study Area is primarily for heat exchange (steam generation/cooling) and solar panel cleaning. Since WY 1993-94, average annual groundwater production for power generation in the Centro and Baja subareas has been approximately 1,800 AFY and 2,700 AFY, respectively, representing about 7 percent of the total production in both subareas. The facility at Kramer Junction is supplied SWP water via a pipeline connection to the Antelope Valley-East Kern Water Agency (AVEK) system. MWA, AVEK and DWR have an agreement in place whereby MWA's SWP water is delivered from the California Aqueduct through AVEK's system directly to the Kramer Junction facility.

High TDS wastewater at both the Coolwater Generating Station and SEGS facilities are discharged to lined evaporation ponds regulated by the California Regional Water Quality Control Board, Lahontan Region (RWQCB).

3.8.3.4 Recreational Lakes

The eastern portion of the Baja Subarea contains approximately 400 acres of artificial recreational and professional water-ski lakes, many of which were constructed in the 1950s and early 1960s (see Recreational Lakes area on **Figure 3.8**). The lakes are clay-lined using the materials excavated when creating the lakes and filled with locally pumped groundwater. While most of the water pumped into the lakes returns to the groundwater system, a portion of the water is lost to the atmosphere through evaporation. Since WY 1993-94, the average annual groundwater pumped to offset the evaporative losses at the recreational lakes has been approximately 2,700 AFY, accounting for 8 percent of the total annual production in the Baja Subarea.

3.8.3.5 Transportation

As a result of the mining boom in Calico and Daggett in the late 1800s, railroads were constructed in the Barstow area to transport goods and people. Southern Pacific built a railroad from Mojave, California through Barstow to Needles in 1883. In 1884, ownership of the line from Needles to Mojave was transferred to the Santa Fe Railroad. Currently, Barstow is the hub of all west coast rail traffic for the Burlington Northern Santa Fe (BNSF) and the Union Pacific railroads and includes a large classification yard operated by BNSF (see Railroad Yard on **Figure 3.8**). Before the advent of the interstate highway system, Barstow was also an important stop on both Routes 66 and 91. The two routes merged in downtown Barstow and continued west to Los Angeles. Today, Barstow is a major transportation center for the Riverside-San Bernardino metropolitan area, located along several major highways including Interstate 15 and Interstate 40 (**Figure 3.8**).

3.8.4 Riparian Vegetation

Perennial flows and shallow groundwater conditions along the Mojave River in the Centro and Baja Subareas have historically supported riparian vegetation, including native cottonwood and willow trees, screwbean mesquite, saltgrass, and saltbush, vital to the survival of many desert wildlife species (Lines and Bilhorn, 1996; Lines, 1999). However, declining groundwater levels associated with historical overpumping has contributed to significant loss of native riparian habitat and to replacement of diverse native communities with invasive tamarisk (salt cedar) in many areas.

Exhibit H of the Judgment defines protected riparian areas to be maintained in the floodplain and establishes a Biological Resources Mitigation Trust Fund. While no protected riparian areas within the Centro Subarea are included in Exhibit H, some riparian vegetation is found along two reaches of the Mojave River: 1) a narrow five-mile reach east of Iron Mountain (south of Hodge) and 2) a two-mile reach downstream of the Barstow WWTP in the eastern end of the subarea. Included within Exhibit H in the Baja Subarea is Camp Cady Wildlife Area (Camp Cady), a 1,870-acre protected wildlife area located along the Mojave River 20 miles east of Barstow (**Figure 3.8**). Perennial flows and shallow groundwater conditions at Camp Cady have historically supported over 4 miles of thriving riparian vegetation. However, declining groundwater levels accompanied by recent wildfires and flooding have resulted in significant habitat loss over time and have stressed remaining riparian vegetation.

Prior to major groundwater level declines, average annual evapotranspiration (ET) of riparian vegetation in the Centro and Baja subarea was estimated to be on the order of 10,000 AFY (Hardt, 1971). In 1995, average annual ET was estimated to be about 3,000 AFY and 2,000 AFY in the Centro and Baja subareas, respectively (Lines and Bilhorn, 1996). The Lines and Bilhorn study relied on mapping aided by false-color infrared and low-level oblique photographs, vegetation and areal-density classification, and application of representative water-use rates based on selected studies in the southwestern United States. More recently, in cooperation with MWA, the U.S. Bureau of Reclamation (USBR) and Utah State University (USU) (2011) estimated riparian ET for 2007 and 2010 conditions in the Centro and Baja subareas. The USBR/USU study relied on mapping aided by airborne Light Detection And Ranging (LIDAR), multispectral and thermal infrared data, vegetation and surface classification using multispectral imagery, and application of an two-source ET model that considers independent energy fluxes for soil and canopy components. For the Centro Subarea, riparian ET was estimated to be about 4,500 AFY in 2007 and 3,600 AFY in 2010. For the Baja Subarea, riparian ET was estimated to be about 2,000 AFY in 2007 and 2,500 AFY in 2010 (USBR and USU, 2011). Of the total ET volumes in 2007 and 2010, invasive salt cedar account for approximately 40 to 45 percent in Centro and 35 to 45 percent in Baja. Rates do not include estimated ET by desert scrub species, which are shallow-rooted and rely on precipitation.

The extent of riparian areas along the Mojave River evaluated by Lines and Bilhorn (in 1995) and USBR/USU (in 2007 and 2010) are relatively similar. However, because of the different methodologies applied, results from the two studies cannot be easily compared to identify changes in riparian ET demand since 1995. Historical aerial photographs reviewed as part of a recent hydrogeologic investigation of Camp Cady Wildlife Area (Todd Engineers, 2013) indicate that the density and distribution of riparian habitat at Camp Cady has declined significantly since 1995. Such declines are attributable to local groundwater level declines (particularly in the western portion of Camp Cady), removal of vegetation from the main channel by winter floods in WY 2004-05, and two wildfires at Camp Cady in August 2005 that burned 670 acres along the northern bank of the river. Currently, the CDFG is evaluating the feasibility of restoring lost riparian habitat along the main channel through an engineered solution involving re-planting and irrigation with local groundwater (Todd Engineers, 2013). A complete copy of the Camp Cady hydrogeologic investigation report is presented in **Appendix D**. Additional mapping and assessment of riparian water demand using a methodology similar to that used by Lines and Bilhorn is needed to confirm and quantify changes in riparian ET demand since 1995.

In addition to the riparian habitat along the Mojave River, approximately 480-acres of engineered wetland/marsh in the southwestern corner of Harper Dry Lake provides habitat for resident wildlife and migratory waterfowl, shorebirds and wading birds. Prior to significant agricultural expansion in the region beginning in the mid-1900s, shallow groundwater conditions beneath Harper Dry Lake supported an extensive natural marsh in Harper Dry Lake. However, as local agriculture activities expanded, groundwater levels declined and the marsh gradually disappeared. By the late 1990s, only a small portion of the original marsh remained in the southwestern corner of Harper Dry Lake, fed by irrigation runoff from local alfalfa farming. In 1999, the closure of the Lockhart Ranch (the last alfalfa farm adjacent to Harper Dry Lake) resulted in the complete disappearance of the marsh and migratory bird populations.

In 2003, the owners of SEGS VIII-IX and BLM came to an informal agreement to mitigate the proposed expansion of the nearby solar field by pumping and conveying local groundwater to restore some of the lost wetland and marsh habitat at the southwestern corner of Harper Dry Lake. In partnership with the non-profit organization Friends of Harper Lake, BLM currently has the authority to manage and convey up to 75 AFY of groundwater to the site’s wetland and ponds as part of the mitigation. A parking lot and wildlife viewing area allow visitors to observe the wetland/marsh habitat and local wildlife and migratory and overwintering birds at Harper Dry Lake, which is now listed as an official California Watchable Wildlife site (CWW, 2012). Groundwater discharges to Harper Dry Lake are reduced in the summer season to mimic natural conditions, control cattail growth, and provide playa habitat for nesting snowy plovers. Future management plans involve continued expansion of the marshland and replacement of invasive vegetation with native plant colonies (BLM, 2004 and 2007).

3.8.5 Dune Sands and Historical Migration

In addition to the loss of riparian vegetation, declining water levels have also contributed to the de-stabilization of sand dunes and to wind-blown migration of sand across portions of the Study Area. Migrating sand has buried equipment, encroached on homes, blocked entrances to property, and destroyed cropland and pasture.

Conditions contributing to sand migration in the region have been researched and documented in numerous publications. These include studies of sediment transport from the Manix Basin to areas east of Afton Canyon (Evans, 1962; Sharp, 1966; Lancaster and Tchakerian, 2003) and more local investigations in the Barstow area (MWA, et al., 1973) and in the Minneola Road/Harvard Road area (J&M Land Restoration, 1991; Laity, 2003). The most comprehensive study was conducted by Dr. Julie Laity of California State University, Northridge (Laity, 2003). Information and concepts presented in these investigations were compared to groundwater data analyzed for this study including a recent groundwater investigation at Camp Cady (Todd Engineers, 2013). A summary of this information is provided below.

The location and morphology of aeolian (wind-derived) deposits were originally influenced by the course of the Mojave River, shallow groundwater conditions, and prevailing winds. Over geologic time, the Mojave River eroded and reworked regional alluvial sediments and bedrock units, resulting in large quantities of fluvial sand deposits. During floods, sand was mobilized and re-deposited, primarily in lower reaches of the channel or near dry lakes where flows decreased. These processes left large quantities of sand exposed in the channel. During dry periods, sand was blown from the channel by strong prevailing westerly winds.

Because prevailing winds are typically aligned along the axes of local valleys, sand migrations generally follows the river channel. But where the course of the river turned away from the wind direction, sand was re-deposited outside of the channel. In areas of relatively shallow groundwater, riparian vegetation served to anchor the wind-blown sand. Brush and clumps of vegetation continued to stabilize the sand as deposits thickened, and small shrub-anchored sand dunes were formed (referred to as coppice dunes). Some of the anchoring vegetation, such as mesquite, could thrive with a deeper water table and allowed the dunes to remain stable with some decline in water levels. According to Laity (2003), mesquite can thrive in areas where the depth to water is shallower than about 30 feet. However, as water levels fall below critical depths, anchoring vegetation dies and dunes become de-stabilized.

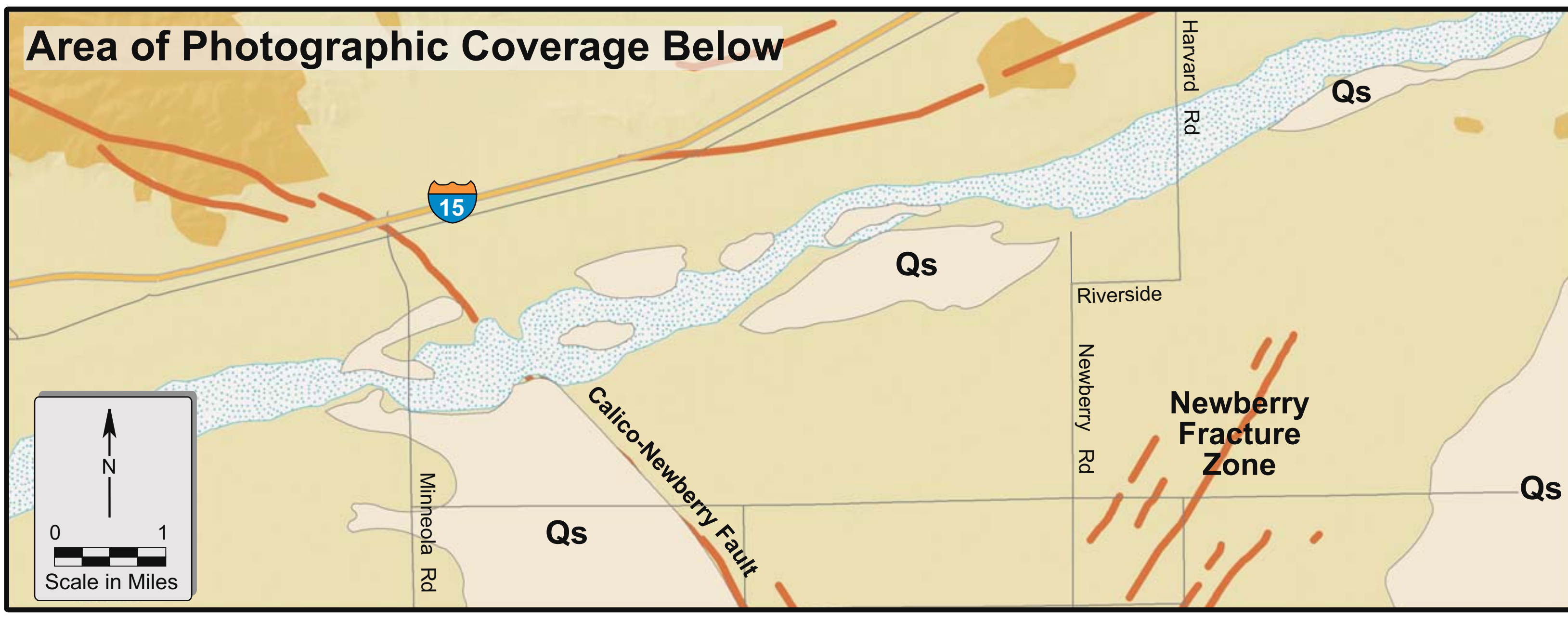
These coppice dune areas, mapped as Holocene aeolian deposits, are shown on the geologic map on **Figure 3.2** (labeled Qs on the map). In Centro, two areas of aeolian deposits have been delineated; one deposit occurs along the east side of the Harper Dry Lake playa and a second has been deposited along the south side of the Mojave River west of Barstow. In Baja, aeolian deposits are more numerous and cover larger areas. The three largest pods occur south of Coyote Dry Lake, west of Troy Dry Lake, and between the river and Highway I-40 in Central Baja (see Qs labels on **Figure 3.2**). Each of these discrete sand pods occurs in an area of historical shallow groundwater where a sufficient amount of anchoring vegetation such as mesquite exists.

For the aeolian deposits along the east side of the Harper Dry Lake playa, water levels have remained relatively shallow and dune deposits appear to be anchored currently with vegetation (as indicated by a review of recent aerial photographs). Sand migration problems in the Barstow area – as documented in 1973 – involved sand blowing from areas in and along the river channel rather than from coppice dune fields that had been de-stabilized (MWA, et al., 1973).

The de-stabilization of dunefields has occurred primarily in the Baja Subarea. In particular, dunes south of the river (from Minneola Road extending several miles east of Harvard Road) have been associated with severe and problematic sand migration. Here, private property has been impacted including the loss of homes (photograph below) and agricultural land. This area is shown in more detail by the local-scale geologic map on **Figure 3.10a** (a simplified enlargement of the area from the MWA and CSUF 2010 geologic map on **Figure 3.2**).

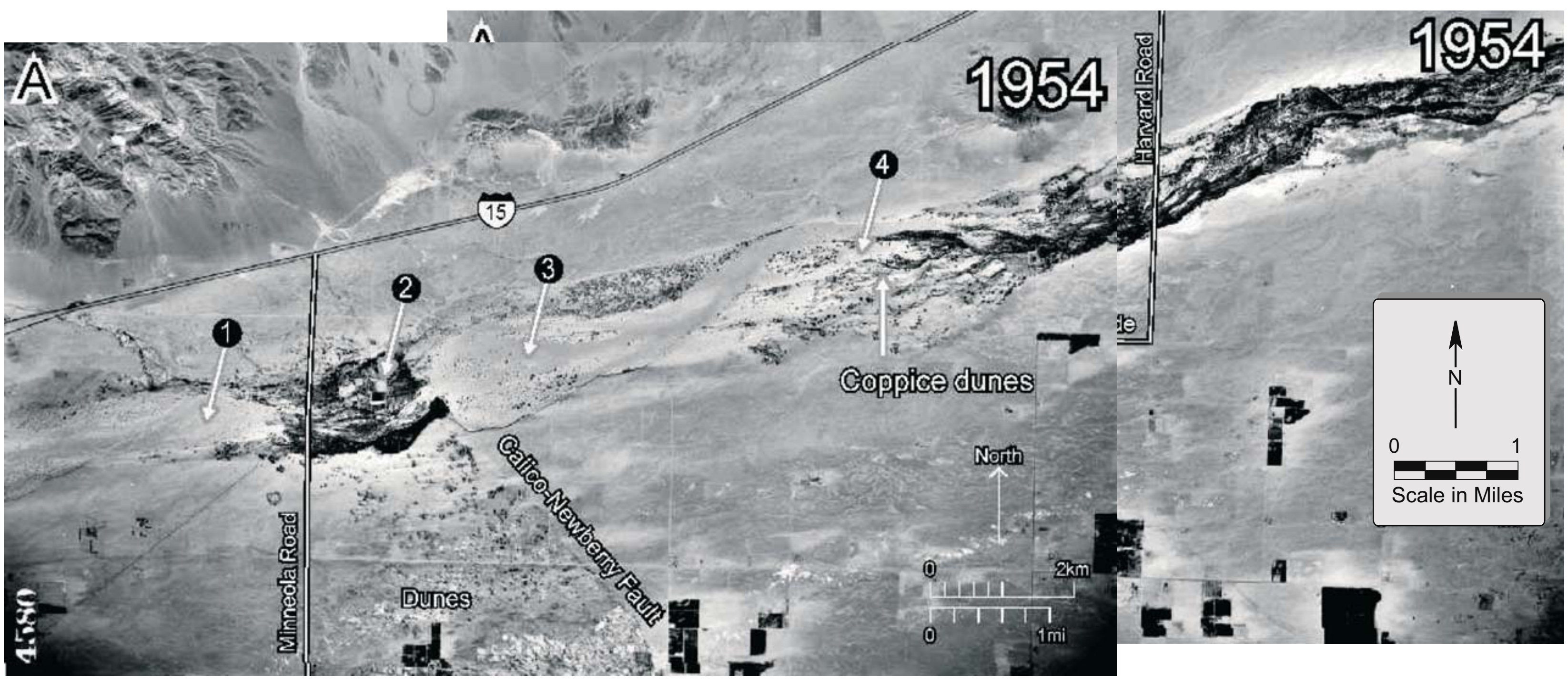
As shown on **Figure 3.10a**, pods of aeolian deposits occur within and adjacent to the Mojave River channel with several larger pods south of the river. Two of these pods represent de-stabilized coppice dunefields as interpreted by Laity (2003). The largest of the two deposits occurs generally east of Mineola Road and is bounded on the east by the Calico-Newberry fault. The second de-stabilized coppice dunefield has been mapped just west of Newberry Road and northwest of Riverside Road (**Figure 3.10a**). A smaller lenticular pod also occurs along the south side of the river east of Harvard Road (in the Camp Cady Wildlife Area). Aeolian deposits on the northwest side of Troy Lake are also included in the southwest corner of **Figure 3.10a**.

The two dunefields are labeled on a 1954 aerial photograph, reproduced from Laity (2003) and presented as **Figure 3.10b**. (The photograph generally covers the same area of the geologic map). The western dunefield is labeled “Dunes” below marker “2” and the eastern dunefield is labeled “Coppice dunes” at marker “4”. Water levels west of the Calico-Newberry fault zone have been close to the surface historically, supporting vegetation and even creating springs (baseflow) in the Mojave River until about the 1960s (Stamos, et al., 2001). Water levels were also shallow historically in the area of the dunefield at marker “4” where the grade of the river steepens. The riparian areas with anchoring vegetation west of the Calico-Newberry fault and at marker “4” can be readily seen on the 1954

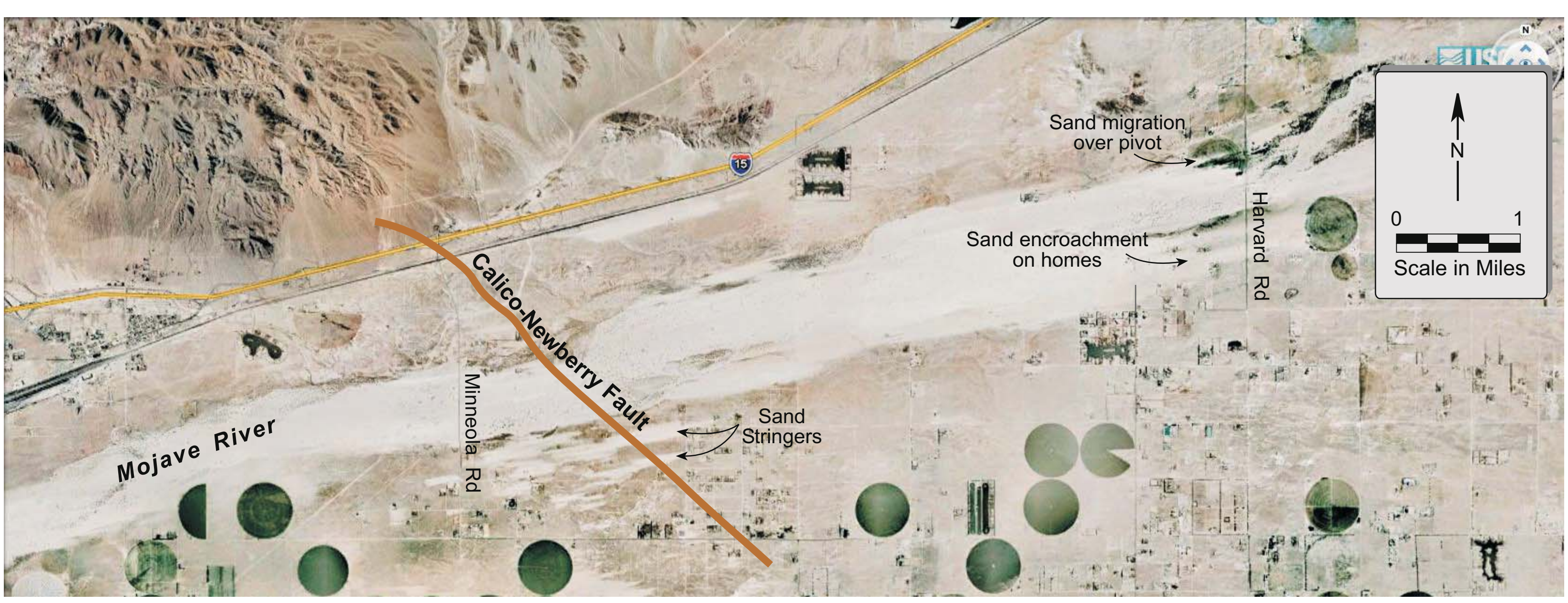


Qs - Holocene Aeolian Deposits

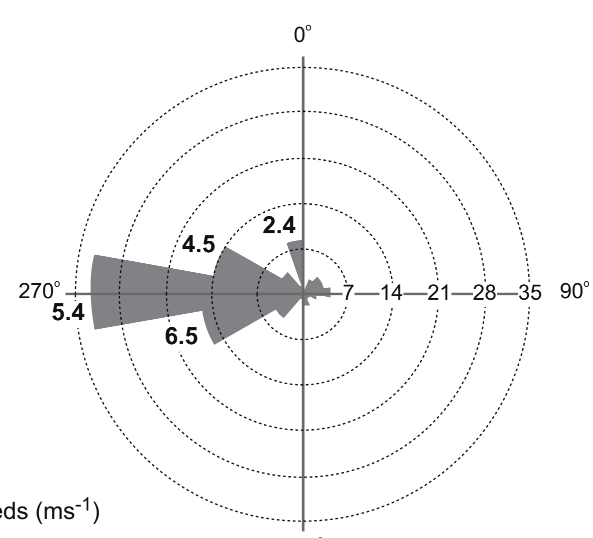
3.10a Geologic Map - Aeolian Deposits (Qs) (MWA and CSUF, 2010)



3.10b Aerial Photo 1954 (from Laity, 2003)



3.10c Aerial Photo 2010 (from Google Earth/USGS)



Values shown are average wind speeds (ms^{-1})

3.10d Wind Rose Diagram, Barstow-Daggett Airport 1992-1996 (From Laity, 2003)

February 2013	**Figure 3.10 Sand Migration in Central Baja Subarea**
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photograph (**Figure 3.10b)**. Since that time, water levels in both areas have declined below critical plant-supporting levels causing most of the anchoring vegetation to die (Laity, 2003). Water level declines described in Laity (2003) are consistent with the detailed water level analysis documented in Section 5 of this report.

Other factors have also resulted in the removal of anchoring vegetation. Vegetation has been scoured by the river during flood events, burned by wildfires, and, in some areas, cleared for development and agricultural purposes. With lower water levels, seedlings could not re-colonize and dunes were no longer stable (Laity, 2003). As a result of these combined factors, large quantities of exposed sand have been mobilized, as shown by the 2010 aerial photograph of the same area on **Figure 3.10c**.

The dramatic change in channel morphology and sand migration patterns are readily seen on **Figure 3.10c**. The dunes located west of the Calico-Newberry fault have migrated east, expanding the river channel, and developing sand stringers that are migrating across the fault (see label "Sand Stringers" on **Figure 3.10c**). The sand pod of former coppice dunes at marker "4" on the 1954 photograph has migrated east-northeast by 2010 and has rendered private property and homes unusable. Sand in the northern channel has migrated northeast and has begun to cover an agricultural field (pivot) just west of Harvard Road (**Figure 3.10c**).

These sand migration patterns are consistent with prevailing wind directions as shown by the Rose Diagram of wind direction and speed measured at the Barstow-Daggett airport (**Figure 3.10d**). The diagram illustrates the strong westerly winds and also indicates that the wind direction during the highest average wind speeds (6.5 meters per second) have a northeasterly component.

In the future, the channel sand and cannibalized dune sands are expected to continue to migrate downwind in an east-northeast direction. The pod south of the river would be expected to continue to migrate across Harvard Road, inundating additional properties on the way and eventually reaching the pivots east of Harvard Road (**Figure 3.10c**). Migration of sand in the channel is also expected to increase with time. Blowing sand storms are also likely to increase, especially during months of the strongest winds (March through June) (Laity, 2003).

Aeolian deposits near Coyote and Troy Dry Lakes are judged less susceptible for migration. Water levels have remained relatively shallow beneath Coyote Dry Lake. Even though water levels have declined beneath Troy Dry Lake, the area is characterized as a local "sand sink" where further westward migration of sand would be buffered by the adjacent Cady Mountains.

3.9 Climate

For this study, monthly precipitation records from climate stations in the Mojave River region were compiled; summary information for each station is presented in **Table 3.1**. As described in the following sections, these data have been evaluated to better understand the contribution of runoff from precipitation in the Mojave River headwaters, local mountains, and valley floor.

Table 3.1
Mojave River Basin Area Precipitation Gages

Name	Station No.[a]	Elevation (feet msl)	Lat	Long	Gage Record		Record Gaps
					Start	End	
Lake Arrowhead	44671	5,205	34.233	-117.183	1948	Current	
Squirrel Inn 1	48476	5,243	34.233	-117.250	1909	1963	1929-41; 1950-54
Squirrel Inn 2	48479	5,682	34.233	-117.233	1920	1971	1920-29
Hesperia	43935	3,202	34.417	-117.300	1910	1977	1911-59
Apple Valley	40244	2,935	34.517	-117.217	1959	1987	
Victorville Pumping Plant	49325	2,858	34.533	-117.300	1917	Current	1918-38
Adelanto	40024	2,851	34.583	-117.417	1959	1977	
Daggett FAA Airport	42257	1,917	34.867	-116.783	1948	Current	
Barstow	40519	2,162	34.900	-117.017	1903	1980	1921-39
Barstow Fire Station	40521	2,220	34.900	-117.017	1980	Current	
Randsburg	47253	3,570	35.367	-117.650	1937	Current	

[a]Western Regional Climate Center (WRCC) COOP Station Number
feet msl = feet above mean sea level

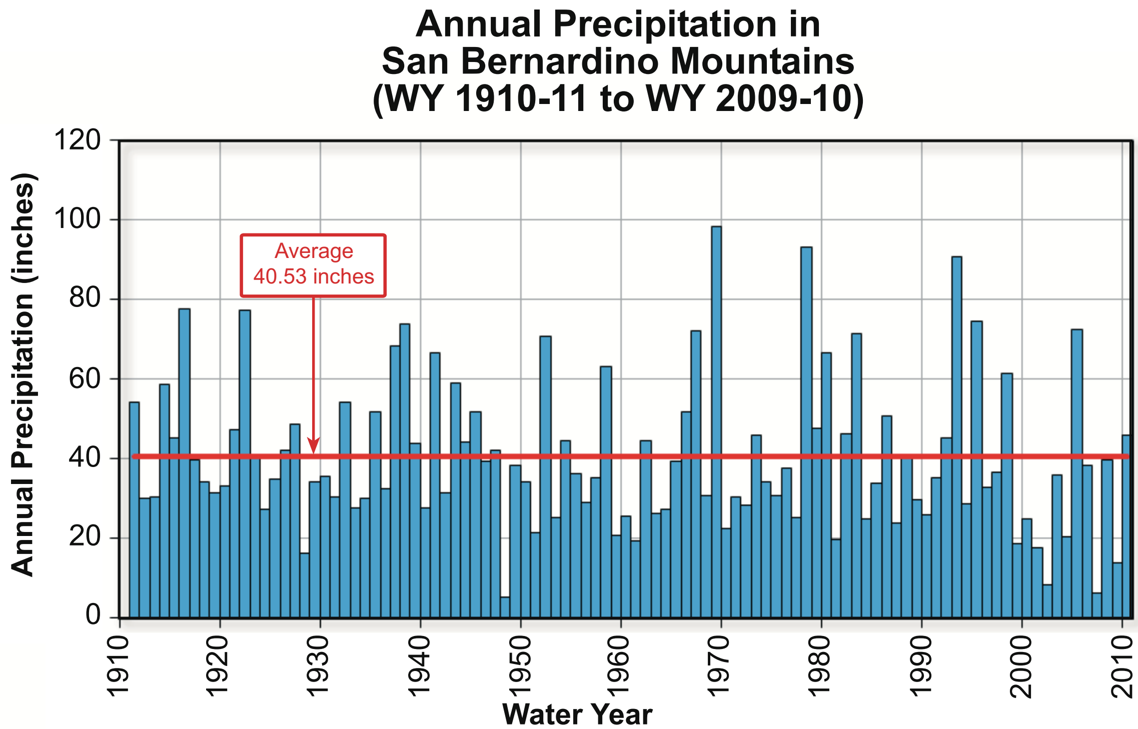
3.9.1 San Bernardino Mountains – Headwaters of the Mojave River

The Mojave River is formed by the confluence of two smaller streams, West Fork of the Mojave River and Deep Creek, at a location referred to as The Forks (general area shown on **Figure 1.1**). The headwaters of these streams are located in the San Bernardino Mountains in the vicinity of Lake Arrowhead, where elevations reach above 8,000 feet msl.

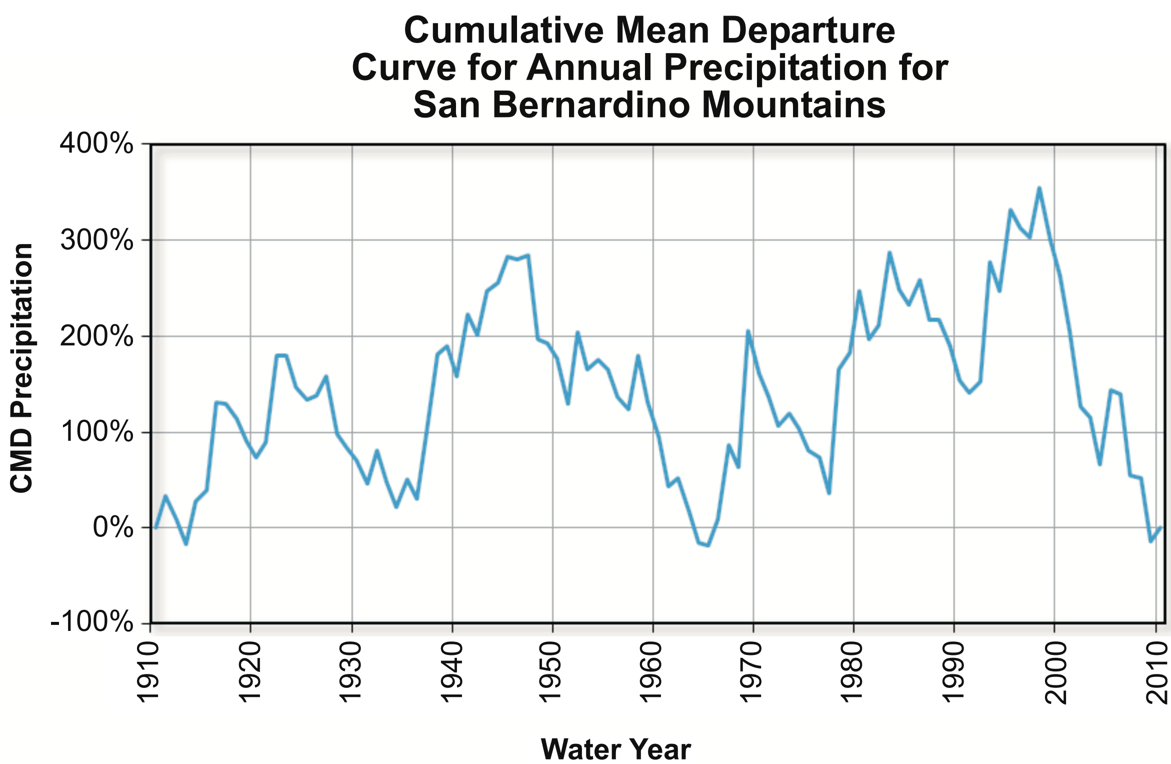
Historical records for three mountain precipitation stations, Lake Arrowhead (Station 44671) and Squirrel Inn 1 and 2 (Stations 48476 and 48479), provide a continuous precipitation record dating back to WY 1910-11 for the headwaters of the Mojave River. **Figure 3.11** shows the annual water year precipitation record for the San Bernardino Mountains from WY 1910-11 to WY 2009-10. For months with overlapping rainfall data, the highest monthly precipitation value is shown to reduce the effect of short-term data gaps.

As shown on the graph, average annual precipitation for the combined 100-year record is 40.53 inches. The highest total annual rainfall on record is 98.24 inches (WY 1968-69). Other notable wet years include WYs 1977-78 (93.03 inches), 1979-80 (66.72 inches) 1982-83 (71.41 inches), 1992-93 (90.88 inches), 1994-95 (74.51 inches), and 2004-05 (72.32 inches). Recent dry years include WYs 2001-02 (8.40 inches) and 2006-07 (6.18 inches).

In order to illustrate the varying climatic records over time, a cumulative mean departure (CMD) curve of the annual rainfall record in the San Bernardino Mountains was developed (lower graph on **Figure 3.11**). The CMD curve represents the cumulative annual departures relative to the average annual precipitation of 40.53 inches. As a result, positive (increasing) slopes represent relatively wet years,



Data Source: Squirrel Inn 1 and 2 and Lake Arrowhead rain gages.



February 2013	**Figure 3.11 Annual Precipitation and Cumulative Mean Departure Curve San Bernardino Mountains (WYs 1911-2010)**
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while negative (decreasing) slopes represent relatively dry years. The CMD curve is useful for identifying an appropriate study period with average climatic conditions as well as for understanding the relationships between rainfall, stream discharge, and groundwater system response.

As shown by the CMD curve on **Figure 3.11**, most of the slopes are increasing from 1910 to 1946, indicating overall above-average rainfall conditions (with the exception of the drought cycle in the late 1920s/early 1930s). The early wet period was followed by an extended dry period from 1946 through 1964. More recently, moderately dry time periods spanning eight to nine years (e.g., WYs 1969-70 to 1976-77, WYs 1983-84 to 1991-92, and WYs 1995-96 to 2002-03) have been separated by some of the wettest years on record (e.g., WYs 1977-88, 1982-83, 1992-33, 1994-95, 2004-05). For the Judgment, the 60-year period from WY 1930-31 to WY 1989-90 was selected to represent long-term water supply conditions in the Basin. Over this period, average annual rainfall was 41.09 inches.

3.9.2 Desert Floor Precipitation

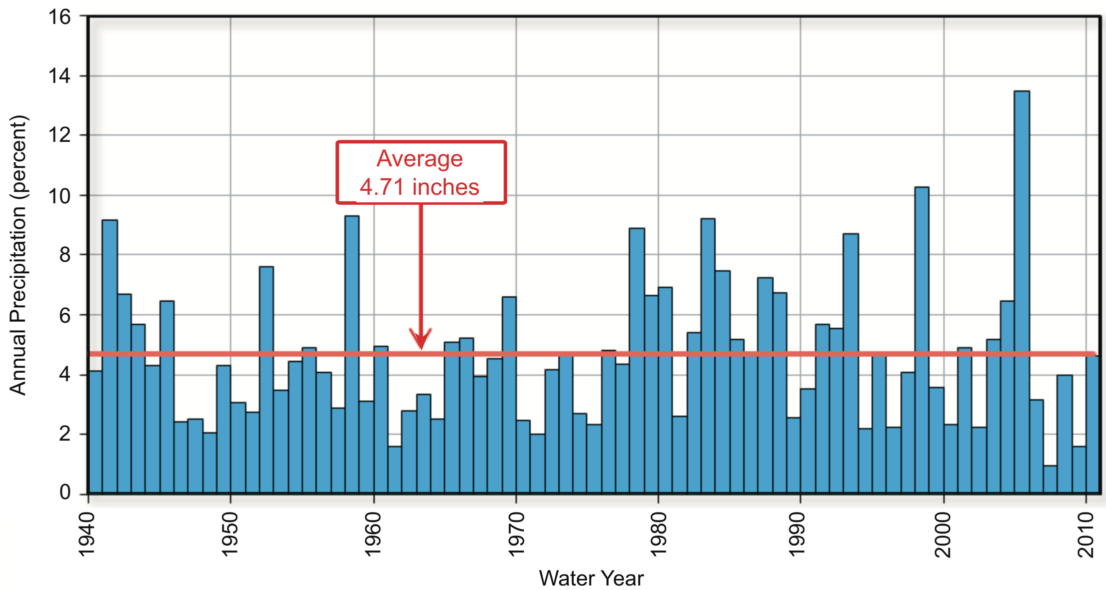
Previous water supply papers and investigations have thoroughly evaluated the precipitation patterns in the San Bernardino Mountains, as storm runoff from this area is the predominant factor controlling streamflow in the Mojave River. More recently, investigators have been interested in rainfall patterns on the desert valley floor and local mountains to better understand the contribution and timing of storm runoff from surrounding local mountains on Mojave River flows. **Figure 3.12 (top graph)** shows the combined record from three rainfall gages on the valley floor (Barstow, Barstow Fire Station, and Daggett in **Table 3.1**) from WY 1939-40 to WY 2009-2010. For months with overlapping data, the highest monthly precipitation value is shown to reduce the effect of short-term data gaps. The upper precipitation graph on **Figure 3.12** shows that the average annual rainfall over this 71-year period was 4.71 inches.

In order to compare precipitation patterns on the desert floor to patterns in the headwaters region, the respective CMD curve for precipitation in the San Bernardino Mountains is compared to the CMD curve for precipitation on the desert floor on the lower graph of **Figure 3.12**. A comparison of the mountain and desert floor CMD curves reveals a considerable divergence in precipitation patterns since the mid-1960s. Major differences in rainfall patterns are evident during three periods:

- In the latter half of the 1960s, precipitation in the San Bernardino Mountains was above normal, while precipitation on the valley floor was close to average
- In the 1980s, precipitation in the mountains was near average, while precipitation on the valley floor was above average,
- In the mid 1990s, precipitation in the mountains was above average, while rainfall on the valley floor was below average.

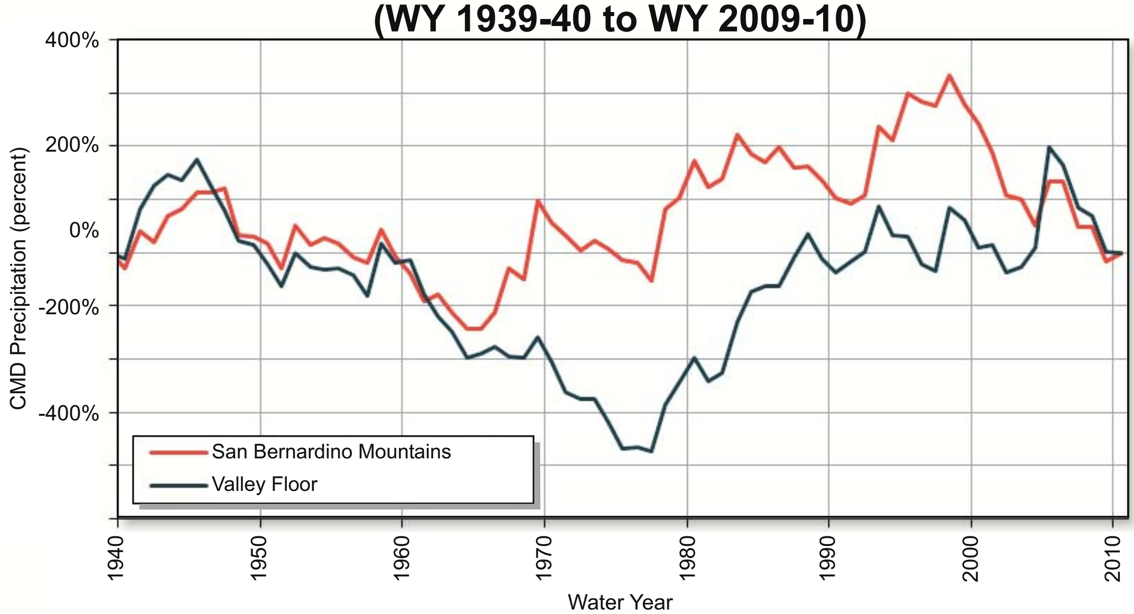
The divergence of the CMD curves can be summarized as higher variability in annual precipitation in the San Bernardino Mountains relative to more consistent precipitation observed on the valley floor.

Annual Precipitation on Desert Floor in Study Area
(WY 1939-40 to WY 2009-10)



Data Source: Barstow, Barstow Fire Station, and Daggett rain gages.

Cumulative Mean Departure Curve
Annual Precipitation - Study Area
Desert Floor vs. San Bernardino Mountains
(WY 1939-40 to WY 2009-10)



February 2013	Figure 3.12 Annual Precipitation and Cumulative Mean Departure Curve Desert Floor in Study Area (WY 1940 to WY 2010)
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3.9.3 Precipitation in Local Desert Mountains

Currently, no rain gages are located in the local desert mountains within the Study Area. As a consequence, the precise orographic effect of the local mountains on precipitation patterns is uncertain. Previous studies have relied on published isohyetal maps to quantify the contribution of local runoff to groundwater recharge along the basin margins and to discharge in the Mojave River (DWR, 1967; Wagner and Bonsignore, 2012).

A review of four published isohyetal maps (**Figure 3.13**) indicates that estimated average annual precipitation likely reaches up to 10 inches/year in the upper portions of the Study Area watershed. Variations in rainfall estimates between the maps are primarily attributable to the contouring methods applied and to a lesser extent to the different periods represented by each map. Contours in the DWR, Rantz, and James maps were contoured manually from gage data, while the Oregon State University (OSU) map is based on the Parameter-elevation Regressions on Independent Slopes Model (PRISM) mapping system. PRISM uses point measurements of precipitation, temperature, and other climatic factors to account for rain shadows, coastal effects, and temperature inversions. PRISM maps are recognized as the highest-quality spatial datasets currently available and are used by the U.S. Department of Agriculture (USDA). Additionally, the PRISM map is based on more recent rainfall data (1971 to 2000), while the other maps are based on rainfall from 1931 to 1960 (DWR); 1900 to 1960 (Rantz), and 1960 to 1991 (James). For these reasons, the PRISM map is judged the most reliable source for average annual rainfall in the local mountains of the Study Area.

3.10 Surface Water Hydrology: The Mojave River

The defining surface feature in the Basin is the Mojave River, an ephemeral stream fed primarily by storm runoff from the northern slopes of the San Bernardino Mountains. Other sources of stream flow in the river include localized groundwater discharge to surface water (baseflow), direct discharges of treated effluent, and ungaged local storm runoff from ephemeral desert washes. Streamflow losses from the river represent the primary source of groundwater recharge in the Basin; these have varied in response to both physical and human factors over time.

Because the Centro and Baja subareas are located in the downstream portion of the Basin and are subject to physical conditions and activities that occur upstream of the Study Area, the complete Mojave River hydrologic system was evaluated for this study. Previous studies have characterized the hydrology of the Mojave River to understand the dynamic relationship between surface water flows and groundwater recharge and discharge (CA State Mining Bureau, 1890; DWR, 1967; Hardt, 1969 and 1971; Durbin and Hardt, 1974; Buono and Lang, 1980; Lines, 1996; Stamos, et al., 2001). This study builds upon existing knowledge as well as additional independent examination of stream gage records through WY 2009-10.

The Mojave River is formed by the confluence of two tributary streams at The Forks (**Figure 1.1**). From The Forks, the Mojave River flows north through Victorville, then north-northeast to Barstow, and finally east towards Afton Canyon, where it exits the Basin approximately 100 miles from its origin. The Mojave River terminates at Silver Dry Lake near Baker, approximately 20 miles downstream of Afton Canyon.

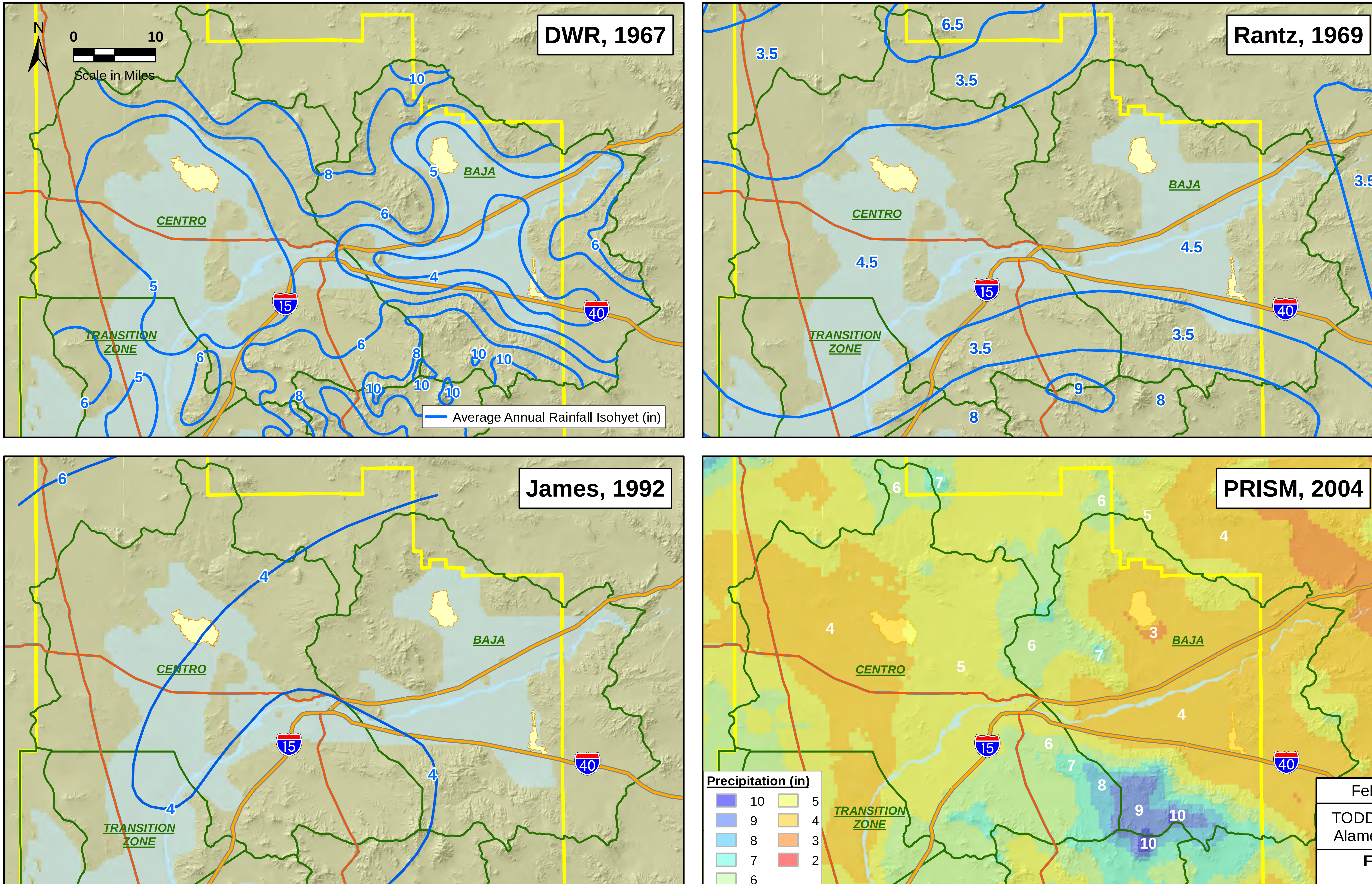

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Figure 3.13
Rainfall
Isohyetal Maps

Although the river is characterized as ephemeral, many reaches had been documented as having perennial flow historically. In areas of a relatively deep water table and permeable alluvium, surface flow can be reduced or consumed locally by groundwater recharge. Conversely, in areas where bedrock or low permeability sediments restrict shallow groundwater storage, groundwater rises and can discharge into the surface channel as baseflow. These conditions result in the "disappearance" and "reappearance" of surface flow along various reaches, leading historical investigators to call it a "hide-and-seek river." The following text from an 1890 report of the California State Mining Bureau identifies areas of recharge/discharge in the Mojave River as observed in the late 1880s:

> Within its entire length …the river in the dry season rises to the surface, and afterwards sinks eight times.
>
> - Its first disappearance is at the forks, twelve miles above Victor, and its flow is subterranean for a distance of twelve miles.
> - It rises at Victor and sinks again in the sand for five miles;
> - appears again near Oro Grande, runs on the surface for five miles, and sinks between that place and Cottonwood Station, on the line of the California Southern Railroad;
> - rises at Cottonwood, is visible for one mile, then sinks for a distance of fifteen;
> - rises at Barstow, and is seen at this point for half a mile, then disappears for six miles,
> - coming to the surface at Fish Ponds, (it) runs a mile in view, and goes out of sight again for twelve miles.
> - Coming to the surface again at Hawley's Station, this ***hide-and-seek river*** runs for about half a mile, then sinks and is not afterwards seen until Camp Cady is reached;
> - here it is visible for a mile, where it sinks again for eighteen miles to rise once more at Cave Canon.
>
> From this point the flow is visible for ten miles, till the river sinks for the last time near Soda Lake, excepting in the season of floods; then it rises twenty miles below the lake, and after uniting with the Amargosa disembogues into Death Valley near Saratoga Springs (reformatted from California State Mining Bureau, 1890).

These general areas of recharge and discharge are consistent with those documented by Lines (1996) and Stamos, et al. (2001) into the 1930s. But, as groundwater pumping increased and water levels declined across the region, many of the perennial reaches became dry and flowed only in response to stormflow. By the mid-1900s, only a few reaches continued to have perennial flow (Stamos, et al., 2001). Detailed stream gage data for various reaches of the river date back to the early 1900s and allow detailed assessments of the surface water hydrology of the river.

The USGS has historically operated eight stream gaging stations on the Mojave River and its two main tributaries above the Mojave River (Forks) Dam. A summary of the USGS stream gage stations is provided in **Table 3.2** (locations of active gages are shown on **Figure 1.1**).

Table 3.2
Mojave River Stream Gage Summary

Station Name	USGS Station No.	Lat	Long	Period of Record		Major Record Gaps	Status
				Start	End		
Deep Creek near Hesperia, CA	10260500	34.343	-117.226	1904	current	1922-29	Active
West Fork Mojave River near Hesperia, CA[a]	10261000	34.341	-117.241	1930	1971		Inactive
West Fork Mojave River above Forks Reservoir near Hesperia, CA[a]	10260950	34.339	-117.258	1974	current		Active
Mojave River at Lower Narrows near Victorville, CA	10261500	34.573	-117.321	1900	current	1901-02; 1905-30	Active
Mojave River at Wild Crossing near Helendale, CA	10261900	34.783	-117.277	1966	1970		Inactive
Mojave River near Hodge, CA	10262000	34.836	-117.192	1930	1993	1932-1970	Inactive
Mojave River at Barstow, CA	10262500	34.907	-117.023	1930	current		Active
Mojave River at Afton, CA	10263000	35.037	-116.384	1929	current	1932-52; 1978-80	Active

[a]Combined flows at West Fork Mojave River and Deep Creek represent flows into Mojave River

As shown in **Table 3.2**, five stream gages have collectively provided a near-continuous record of Mojave River discharge since 1930. The West Fork and Deep Creek gages together represent the total inflows to the Basin, while the Lower Narrows, Barstow, and Afton gages provide a record of downstream discharges.

However, no gages currently exist at the upstream boundaries of either the Centro or Baja subarea. As shown in **Figure 1.1**, stream discharge at the Helendale Fault (the upstream boundary of the Centro Subarea) is ungaged; the Lower Narrows gage, located approximately 15 miles upstream of the Helendale Fault, is the closest stream gaging station. Between the Helendale Fault and Lower Narrows gage (i.e., Transition Zone), treated effluent has been discharged directly into the Mojave River by the Victor Valley Wastewater Resources Agency (VVWRA) since 1985. Average annual effluent discharges have increased over time from less than 5,000 AFY in the late 1980s up to about 15,000 AFY in WY 2009-10 (MBA Watermaster, 2011). Combined flows of natural runoff at the Lower Narrows gage and wastewater discharges must be considered in estimating surface water inflow into the Study Area. A hydrologic assessment of the Transition Zone has recently been conducted (MBA Watermaster, 2012) to quantify the relationship between natural streamflow, effluent discharges, and groundwater recharge since the early 1990s. The methodology and results of this evaluation are discussed in the water balance section of the Centro conceptual hydrogeologic model (Section 4); a copy of the Transition Zone water budget is provided in **Appendix H**.

Similar to the Centro Subarea boundary, streamflow at the Baja Subarea upstream boundary (the Waterman Fault) is ungaged. The Barstow gage is located 5 miles upstream of the Waterman Fault and provides an indication of the stormflows that reach the Baja Subarea. However, streamflow estimates are complicated by additional wastewater discharges between the gage and the boundary. A hydrologic analysis of the reach between the Barstow gage and Waterman Fault was recently conducted (MWA, 2011a) to quantify the relationship between natural streamflow, effluent discharges at the Barstow WWTP, and groundwater recharge in this reach since the early 1990s. Methodology and results of this evaluation are discussed in the water balance sections of the conceptual hydrogeologic models.

The Afton gage is located approximately 10 miles downstream of the adjudicated boundary of the Baja Subarea and provides a reasonable estimate of all outflows from the Baja Subarea.

Annual discharges for the five active gages from WY 1930-31 to WY 2009-10 are tabulated in **Table 3.3**.

Table 3.3
Annual Streamflow for Mojave River Gages (WY 1930-31 to WY 2009-10)

Water Year	Deep Creek near Hesperia (10260500)	West Fork Mojave River near Hesperia (10261000 & 10260950)	Combined Discharge at The Forks	Mojave River at Lower Narrows (10261500)	Mojave River at Barstow (10262500)	Mojave River at Afton (10263000)
1930-1931	12,347	3,088	15,436	22,463	0	1,267
1931-1932	67,212	34,561	101,773	84,180	37,477	7,909
1932-1933	14,474	7,952	22,426	23,915	0	930
1933-1934	11,684	4,430	16,115	23,820	0	930
1934-1935	39,974	17,624	57,599	33,806	1,184	930
1935-1936	18,836	5,266	24,102	20,422	0	930
1936-1937	111,489	57,633	169,122	150,246	103,879	53,472
1937-1938	142,167	76,596	218,764	188,037	138,094	65,968
1938-1939	29,981	10,521	40,501	29,675	550	930
1939-1940	24,103	7,052	31,155	27,469	0	930
1940-1941	103,099	58,024	161,124	143,332	96,003	45,535
1941-1942	17,990	8,021	26,011	25,789	100	930
1942-1943	92,523	57,375	149,899	127,293	90,974	45,735
1943-1944	48,186	38,574	86,760	77,641	36,254	16,151
1944-1945	46,331	24,414	70,744	54,641	22,087	7,383
1945-1946	39,806	14,665	54,470	43,228	12,577	2,961
1946-1947	27,234	23,042	50,276	37,206	2,876	930
1947-1948	10,512	3,119	13,631	26,333	0	930
1948-1949	15,483	7,505	22,988	22,854	0	930
1949-1950	8,764	3,651	12,415	21,628	0	930
1950-1951	2,218	0	2,218	20,824	0	930
1951-1952	59,122	43,818	102,940	66,773	12,548	2,050
1952-1953	6,696	2,123	8,819	21,810	0	990
1953-1954	37,318	17,065	54,382	31,232	0	953
1954-1955	13,080	4,801	17,881	22,528	0	913
1955-1956	14,119	2,115	16,234	21,751	0	903
1956-1957	18,779	3,296	22,075	20,557	0	752
1957-1958	102,994	45,893	148,887	98,041	20,067	2,784
1958-1959	13,649	4,699	18,348	20,341	4	596
1959-1960	8,695	74	8,769	19,282	0	683
1960-1961	4,237	248	4,484	18,904	0	669
1961-1962	50,932	16,302	67,234	26,756	734	563
1962-1963	5,559	85	5,644	17,034	0	752
1963-1964	10,174	732	10,906	17,099	1	539
1964-1965	15,116	6,329	21,445	16,797	6	566

Table 3.3 (continued)
Annual Streamflow for Mojave River Gages (WY 1930-31 to WY 2009-10)

Water Year	Deep Creek near Hesperia (10260500)	West Fork Mojave River near Hesperia (10261000 & 10260950)	Combined Discharge at The Forks	Mojave River at Lower Narrows (10261500)	Mojave River at Barstow (10262500)	Mojave River at Afton (10263000)
1965-1966	82,586	33,672	116,258	51,010	6,352	4,782
1966-1967	80,910	47,166	128,076	74,212	7,693	1,466
1967-1968	17,059	7,548	24,608	18,796	0	357
1968-1969	217,768	123,730	341,498	291,090	146,600	72,730
1969-1970	14,043	3,059	17,102	23,117	0	543
1970-1971	14,846	5,582	20,428	20,431	0	360
1971-1972	21,724	1,602	23,326	22,790	44	597
1972-1973	40,680	23,668	64,348	34,719	151	310
1973-1974	18,329	8,839	27,168	17,745	0	436
1974-1975	12,156	4,683	16,839	16,617	0	158
1975-1976	17,482	6,204	23,686	20,184	1	296
1976-1977	9,858	1,850	11,708	28,209	2	898
1977-1978	230,308	132,319	362,628	209,111	50,458	46,743
1978-1979	81,763	30,452	112,214	72,337	5,560	1,289
1979-1980	193,965	113,195	307,160	229,567	137,654	71,361
1980-1981	11,577	4,510	16,087	23,151	0	1,382
1981-1982	41,322	16,439	57,762	35,349	1	1,052
1982-1983	147,275	114,891	262,166	189,168	92,989	13,308
1983-1984	21,970	7,363	29,333	27,025	42	1,816
1984-1985	16,238	8,324	24,562	21,063	0	682
1985-1986	33,076	12,874	45,950	16,962	0	550
1986-1987	10,122	680	10,803	14,465	0	562
1987-1988	12,393	4,968	17,361	16,143	8	915
1988-1989	7,645	3,273	10,918	11,480	0	432
1989-1990	6,415	1,370	7,785	8,915	0	546
1990-1991	31,534	6,698	38,232	10,963	0	742
1991-1992	47,142	28,405	75,547	24,560	29	628
1992-1993	297,322	131,213	428,534	285,389	122,779	66,589
1993-1994	21,615	14,620	36,235	10,913	0	483
1994-1995	139,349	59,604	198,953	113,279	11,111	434
1995-1996	27,013	7,840	34,853	11,031	0	632
1996-1997	21,052	10,660	31,712	8,211	0	646
1997-1998	124,701	45,260	169,962	83,506	10,512	1,287
1998-1999	7,837	1,472	9,309	9,409	0	565
1999-2000	14,455	4,843	19,298	6,990	0	283

Table 3.3 (continued)
Annual Streamflow for Mojave River Gages (WY 1930-31 to WY 2009-10)

Water Year	Deep Creek near Hesperia (10260500)	West Fork Mojave River near Hesperia (10261000 & 10260950)	Combined Discharge at The Forks	Mojave River at Lower Narrows (10261500)	Mojave River at Barstow (10262500)	Mojave River at Afton (10263000)
2000-2001	12,757	4,660	17,417	5,618	0	350
2001-2002	2,451	0	2,451	4,550	0	239
2002-2003	31,001	3,197	34,197	6,242	0	249
2003-2004	14,338	22,585	36,922	5,384	0	394
2004-2005	234,758	120,466	355,224	192,590	126,168	44,638
2005-2006	77,885	29,061	106,946	27,252	182	186
2006-2007	5,424	442	5,866	4,943	0	150
2007-2008	36,429	13,952	50,381	9,154	10	166
2008-2009	27,818	3,097	30,915	4,361	0	112
2009-2010	76,873	26,043	102,916	19,174	374	190
Ave 31-10	**48,227**	**23,288**	**71,515**	**49,511**	**16,177**	**7,672**
Ave 31-90	**43,440**	**22,149**	**65,589**	**51,956**	**17,050**	**8,247**

Notes:

(1) Gaging station 10261000 was operated from October 1929 to September 1971. Gaging station 10260950 has been operated since October 1975. Inflow for 1972–74 for West Fork was based on inflow at gaging station 102621100, Mojave River below Mojave River Forks Reservoir.

(2) Discharge for missing years at Afton 1932-52 and 1978-80 were estimated by Watermaster (2011)

3.10.1 Stream Discharge

Annual discharges for each of the five gages can be used to identify and assess historical trends in stream discharge and groundwater recharge. **Figures 3.14 and 3.15** show the annual stream discharges in the Mojave River measured at the active stream gages from WY 1930-31 to WY 2009-10. Discharges in Deep Creek and West Fork Mojave River are combined to show the total inflow at The Forks (top chart on **Figure 3.14**).

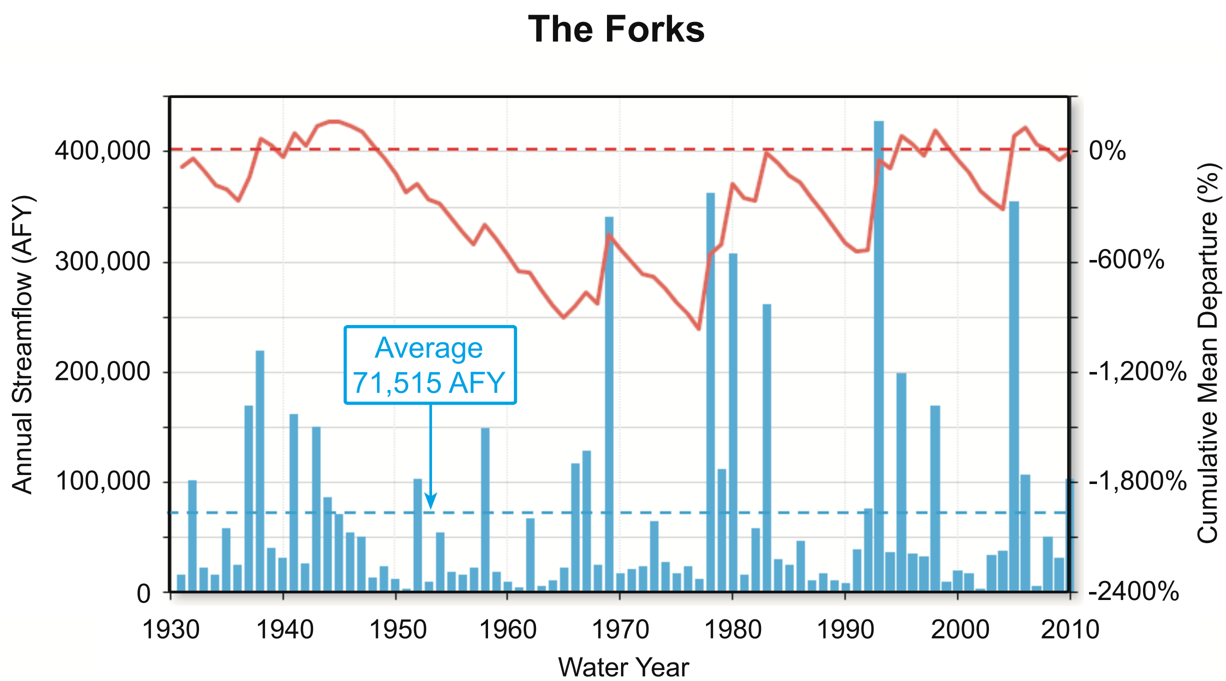
Depicted on each chart for each gage are the annual volumes (blue columns) and the CMD curve for stream discharge (solid red line). The CMD curve represents the cumulative difference (departure) in annual discharge relative to mean annual stream discharge at the respective gage from WY 1930-31 to WY 2009-10 and is a useful method for identifying trends within the period of record. Positively-sloped sections of the CMD curve represent periods of above-average stream discharge, while negatively-sloped sections of the curve represent periods of below-average stream discharge. The dashed straight red line represents zero departure from the long-term average (or mean) discharge, a condition that would result if annual discharge for every year was equal to the mean discharge. The area above the dashed red line represents above-average discharge, while the area below the dashed red line represents below-average or deficit discharge. At any given time, if the CMD curve is located above the line representing zero departure from long-term average discharge, this indicates that average annual discharge from WY 1930-31 to the given year has been above the long-term average from WY 1930-31 to WY 2009-2010. Conversely, if the CMD curve is located below the line representing zero departure from long-term average discharge, this indicates that average annual discharge from WY 1930-31 to the given year has been below the long-term average from WY 1930-31 to WY 2009-2010. Because the CMD curve is a measure of cumulative conditions relative to the long-term average, the CMD curve always begins and ends at zero departure from long-term average. Examination of the CMD curves for each stream gage and the relative comparison of the CMD curves between stream gages allows for the evaluation of increasing and decreasing trends in discharge by stream reach over time.

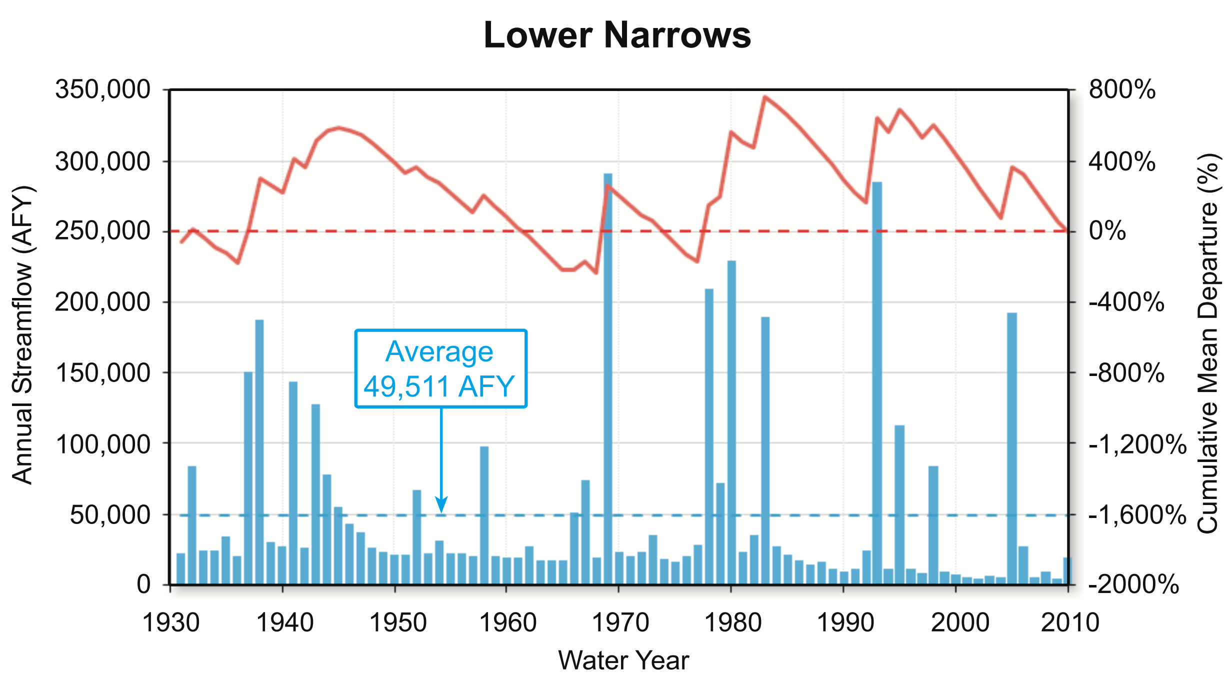
To facilitate the discussion of discharge trends over time, average annual discharges at each gage are presented in **Table 3.4** for selected time periods. These time periods include:

- the base period used in the Judgment (WY 1931-90),
- portions of the base period separated into three climatic conditions (WYs 1931-45, 1946-68, and 1968-90),
- recent (post-1990) time periods separated into the post-base period (WY 1991-2010), post Judgment period (WY 1996-2010) and a recent wet period (WY 1993-2005).

For each gage and time period, average annual discharge volumes in AFY are provided in the top 1/3 of the table and compared to the gage's average annual discharge over the base period in percent, shown in the middle 1/3 of the table). Finally, average annual discharges of the three downstream gages are compared to the average annual discharge at The Forks for each time period in percent, shown in the lower 1/3 of the table.

Using the data summaries provided in **Table 3.4** and the streamflow data presented on **Figures 3.14 and 3.15**, a discussion of historical discharges for each gage is provided below.





February 2013	**Figure 3.14 Annual Streamflow for The Forks and Lower Narrows Stream Gages**
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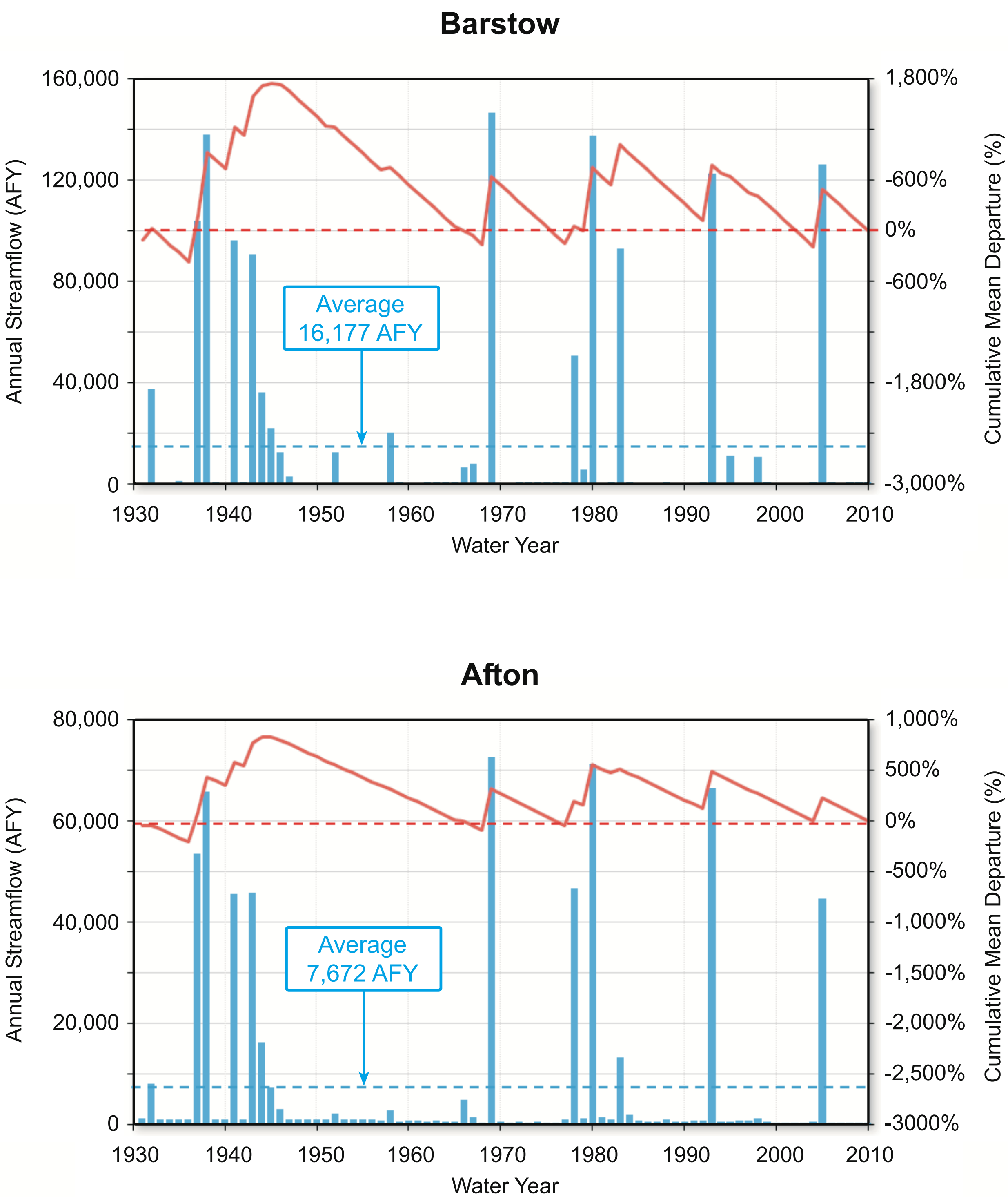

February 2013	**Figure 3.15 Annual Streamflow for Barstow and Afton Stream Gages**
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Table 3.4
Average Annual Mojave River Discharge and Net Recharge for Selected Periods

Time Period (Water Year to Water Year)	Stream Discharge				Net Recharge (Leakage less Baseflow)			
	The Forks	Lower Narrows	Barstow	Afton	The Forks To Lower Narrows	Lower Narrows To Barstow	Barstow to Afton	Total (The Forks to Afton)
	Average (AFY)				**Average (AFY)**			
base period (1931-90)	65,589	51,956	17,050	8,247	13,633	34,907	8,802	57,342
early base period (1931-45)	79,435	68,849	35,107	16,662	10,587	33,742	18,445	62,773
middle base period (1946-68)	40,565	31,956	2,733	1,214	8,608	29,223	1,519	39,350
late base period (1969-90)	79,802	59,497	18,848	9,449	20,304	40,649	9,399	70,353
post base period (1991-10)	89,293	42,176	13,558	5,948	47,117	28,618	7,610	83,345
post Judgment (1996-10)	67,225	26,561	9,150	3,339	40,664	17,411	5,811	63,885
recent wet period (1993-05)	105,774	57,163	20,813	8,984	48,612	36,349	11,829	96,790
	% of Average Discharge for Base Period				**% of Average Net Recharge for Base Period**			
base period (1931-90)	100%	100%	100%	100%	100%	100%	100%	100%
early base period (1931-45)	121%	133%	206%	202%	78%	97%	210%	109%
middle base period (1946-68)	62%	62%	16%	15%	63%	84%	17%	69%
late base period (1969-90)	122%	115%	111%	115%	149%	116%	107%	123%
post base period (1991-10)	136%	81%	80%	72%	346%	82%	86%	145%
post Judgment (1996-10)	102%	51%	54%	40%	298%	50%	66%	111%
recent wet period (1993-05)	161%	110%	122%	109%	357%	104%	134%	169%
	% of Discharge at The Forks							
base period (1931-90)	100%	79%	26%	13%				
early base period (1931-45)	100%	87%	44%	21%				
middle base period (1946-68)	100%	79%	7%	3%				
late base period (1969-90)	100%	75%	24%	12%				
post base period (1991-10)	100%	47%	15%	7%				
post Judgment (1996-10)	100%	40%	14%	5%				
recent wet period (1993-05)	100%	54%	20%	8%				

The Forks (combined Deep Creek and West Fork gages)

The upper chart on **Figure 3.14** shows the annual discharge in the Mojave River measured at The Forks. Discharge at The Forks is perennial and the magnitude of discharge is related directly to storm patterns in the San Bernardino Mountains. Average annual discharge at The Forks is 71,515 AFY over the 80-year period from WY 1930-31 to WY 2009-10 and 65,589 AFY over the 60-year base period (WY 1930-31 to WY 1989-90) (**Table 3.4**). The CMD curve for annual discharge at The Forks indicates that the wet climatic conditions observed from 1936 to 1945 provided only small above-average stream discharges (**Figure 3.14**). This was followed by an extended dry period that lasted over 20 years until the record flood of 1969. By the end of the dry period, small gains in discharge from 1936 to 1945 were replaced by a large deficit in stream discharge. Since 1969, five large flood years (1978, 1980, 1983, 1993, and 2005) have generally separated periods of small discharge volumes. Discharge generated from these large flood years over the past 30 years has helped to reverse the significant historical deficit discharges at The Forks gage (illustrated by the CMD curve returning to 0% deviation from the long-term average).

Lower Narrows Gage

The lower chart on **Figure 3.15** shows the annual discharge in the Mojave River measured at the Lower Narrows gage. As illustrated by the blue columns, discharge at Lower Narrows is perennial because of shallow subsurface bedrock forcing groundwater to discharge to surface water as baseflow above the gage. Average annual discharge at Lower Narrows is 49,511 AFY over the 80-year period from WY 1931 to 2010 and 51,956 AFY over the 60-year base period from WY 1931 to 1990 (**Table 3.4**). The CMD curve for annual discharge at Lower Narrows, while generally similar to the CMD curve for the Forks, shows some distinct differences (**Figure 3.14**). During the wet period from 1936 to 1945, significant above-average stream discharges developed at the Lower Narrows. By the end of the 20-year dry period from 1946 to 1968, cumulative gains in discharge were effectively reversed. Since 1969, the large flood years have been separated by periods of very little discharge. Over the period of record, the frequency and duration of deficit discharge (when the CMD curve is below the dashed zero line) has been low and short, due to the large multi-year above-average discharges through the mid-1940s (+325,000 AF) and large single-year discharges in more recent times.

Barstow Gage

The upper chart on **Figure 3.15** shows the annual discharge in the Mojave River measured at the Barstow gage. As illustrated by the blue columns, discharge at Barstow occurs only during wet years when significant storm runoff is generated. Average annual discharge at Barstow is 16,177 AFY over the 80-year period from WY 1931 to 2010 and 17,050 AFY over the 60-year base period from WY 1931 to 1990 (**Table 3.4**). The CMD curve for annual discharge at Barstow shows that the wet climatic conditions from 1936 to 1945 resulted in substantial above-average stream discharge at Barstow (**Figure 3.15**). However, by the end of the 20-year dry period from 1946 to 1968, the cumulative gains from 1936 to 1945 were effectively reversed. Since 1969, five flood years (1978, 1980, 1983, 1993, and 2005) have separated periods of little to no discharge. Similar to the CMD curve for the Lower Narrows, the frequency and duration of deficit discharge (when the CMD curve is below the zero line) over the period of record has been low and short, due to the large above-average discharges through the mid-1940s (+280,000 AF) and large single-year discharges in more recent times.

Afton Gage

The lower chart on **Figure 3.15** shows the annual discharge in the Mojave River measured at the Afton gage. While much smaller in magnitude than the baseflows occurring at the Lower Narrows, the blue columns illustrate that annual discharge at Afton is perennial with groundwater discharge to surface water above the gage. Stormflows in the Mojave River only reach Afton during very wet years. Average annual discharge at Afton is 7,672 AFY over the 80-year period from WY 1931 to 2010 and 8,247 AFY over the 60-year base period from WY 1931 to 1990 (**Table 3.4**). The CMD curve for discharge at Afton resembles the CMD curve at Barstow but is more muted. Over the period of record, the frequency and duration of deficit discharge (when the CMD curve is below the zero line) has been low and short, due to the large multi-year above-average discharges through the mid-1940s (+70,000 AF) and large single-year discharges in more recent times.

Historical Trends in Discharge (during the Base Period)

The base period can be separated into three periods based on general climatic conditions as follows:

- early wet base period (WY 1931-45),
- intermediate dry period (or middle base period, WY 1946-68)
- post-drought period (or late base period, WY 1969-90).

Average annual discharges for at The Forks and three downstream gages for the three time periods are provided in **Table 3.4** and discussed below.

During the early wet period, average annual discharges at The Forks and Lower Narrows were slightly above their respective base-period averages (121 percent and 133 percent, respectively). Over the same period, cumulative average annual discharges at the Barstow and Afton gages were more than twice their respective base-period averages (206 percent and 202 percent, respectively).

During the intermediate dry period, average annual discharges at The Forks and Lower Narrows were below their respective base-period averages (both 62 percent). Over the same period, average annual discharges at the Barstow and Afton gages were significantly below their respective base-period averages (16 percent and 15 percent, respectively), as expected given the dry conditions.

During the late post-drought portion of the base period, average annual discharge at The Forks and all three downstream gages were slightly above their respective base-period averages (ranging from 111 to 122 percent). With respect to The Forks and Lower Narrows, average annual discharges over this post-drought period were similar to discharges observed during the early wet period prior to the drought. However, average annual discharges at the Barstow and Afton gages over the post-drought period were much lower compared to their respective discharges during the early wet period prior to the drought.

As a percentage of discharge at The Forks, the discharge at each of three downstream gages has declined since the 20-year drought from 1946 to 1968 relative to its respective base-period average and early wet portion of the base period. Larger declines generally occur in the downstream direction. This is shown in **Table 3.4** and summarized by the following:

1) While average annual discharge at Lower Narrows averaged 79 percent of discharge at The Forks over the base period, average annual discharge at Lower Narrows gradually declined over this period (87 percent of discharge at The Forks during the early dry period, 79 percent during the drought, and 75 percent during the post-drought portion of the base period)
2) While average annual discharge at Barstow averaged 26 percent of discharge at The Forks over the base period, average annual discharge at Barstow has declined over this period (44 percent of discharge at The Forks during the early dry period, 7 percent during the drought, and 24 percent during the post-drought portion of the base period)
3) While average annual discharge at Afton averaged 13 percent of discharge at The Forks over the base period, average annual discharge at Afton has declined over this period (similar to Barstow) with 21 percent of discharge at The Forks during the early dry period, 3 percent during the drought, and 12 percent during the post-drought portion of the base period.

Current Trends in Discharge (since the Base Period)

Discharges for three "post-base period" time periods are also shown in **Table 3.4**. These include a "post-base period" (WY 1991 to WY 2010), "post Judgment" period (WY 1996 to WY 2010); and recent wet period book-ended by the WY 1992-93 and WY 2004-05 floods.

The table shows that following the base period, average annual discharge at The Forks has been above its base-period average (136 percent). In contrast, average annual discharges at the three downstream gages have been below their respective base-period averages (81 percent at Lower Narrows, 80 percent at Barstow, and 72 percent at Afton).

Similarly, since the Judgment (WY 1996 to WY 2010), average annual discharge at The Forks has been similar its base-period average (102 percent). However, discharges at the three downstream gages have been below their base-period averages (51 percent at Lower Narrows, 54 percent at Barstow, and 40 percent at Afton).

Finally, over a recent wet period that includes the 1992-93 and 2004-05 floods (WY 1992-93 to 2004-05), average annual discharge at The Forks was 161 percent of its base-period average. During this same period, average annual discharges at the three downstream gages were each slightly above their base-period averages (110 percent at Lower Narrows, 122 percent at Barstow, and 109 percent at Afton).

As a percentage of discharge at The Forks, the discharge at each of three downstream gages has declined in recent times relative to its respective base-period average and late portion of the base period. Declines have generally been more pronounced in the downstream direction. This is documented in **Table 3.4** and summarized by the following:

1) Average annual discharge at Lower Narrows has been below its 79 percent base-period average (47 percent of discharge at The Forks since 1990, 40 percent of discharge at The Forks since 1996, and 54 percent of discharge at The Forks during a recent wet period)
2) Average annual discharge at Barstow has been below its 26 percent base-period average (15 percent of discharge at The Forks since 1990, 14 percent of discharge at The Forks since 1996, and 20 percent of discharge at The Forks during a recent wet period)

3) Average annual discharge at Afton has been below its 13 percent base-period average (7 percent of discharge at The Forks since 1990, 5 percent of discharge at The Forks since 1996, and 8 percent of discharge at The Forks during a recent wet period)

3.10.2 Net Stream Recharge

Streamflow is the primary source of groundwater recharge in the Study Area. To evaluate trends in stream recharge over time, the differences in annual stream discharge between adjacent gaged stream locations—representing net recharge—were computed for the following three gaged reaches:

- Upper Reach (The Forks to Lower Narrows gage)
- Middle Reach (Lower Narrows gage to Barstow gage)
- Lower Reach (Barstow gage to Afton gage)

The computed annual net recharge values are shown in **Figure 3.16** as blue columns. Also included in each of the charts are the CMD departure curves for net recharge. It is noted that net recharge represents the net effect of two processes: 1) streamflow losses to groundwater and 2) groundwater discharge to surface water as baseflow.

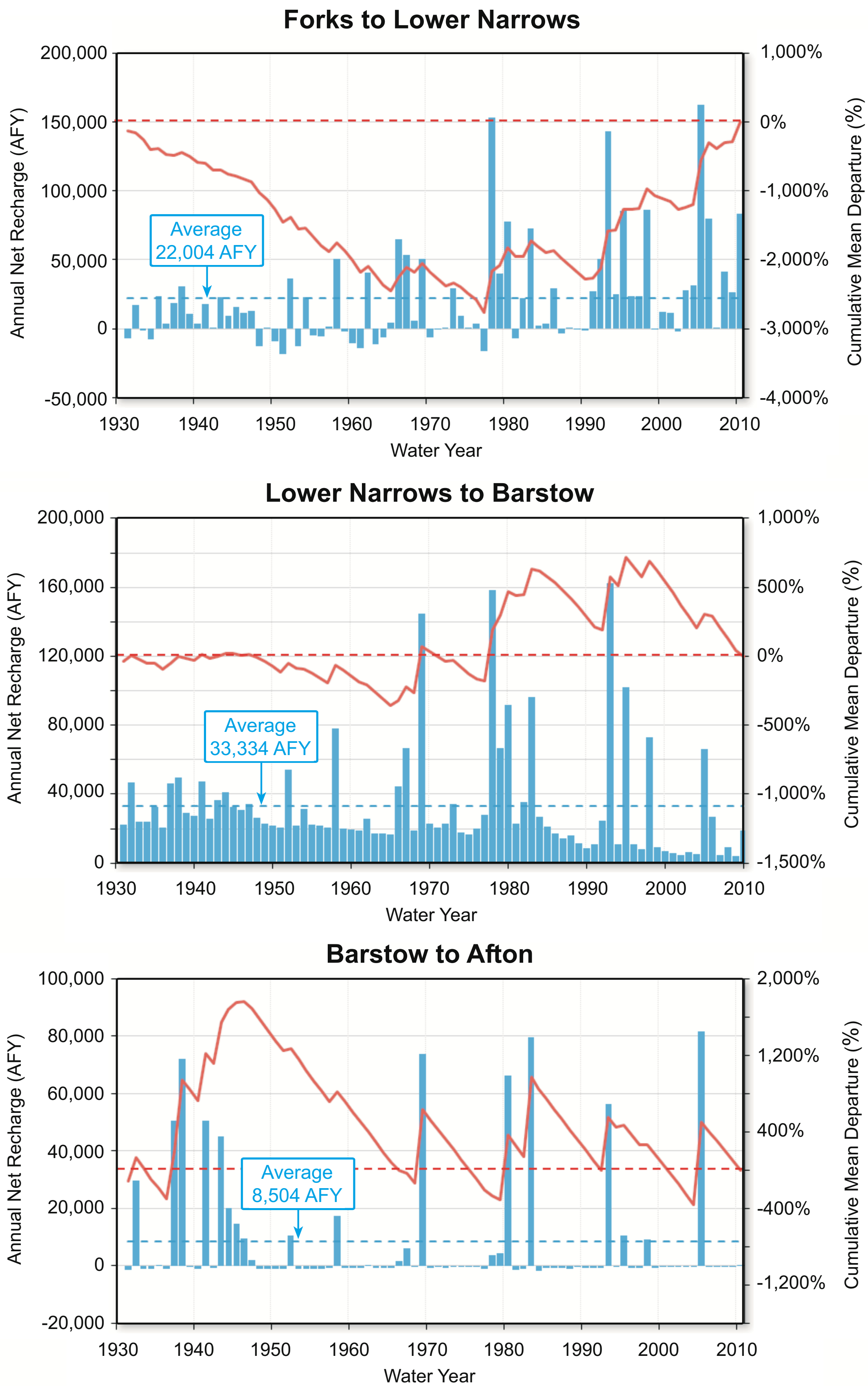
To facilitate discussion of net recharge, average annual net recharge volumes over the three reaches are shown for the selected periods in **Table 3.4** and compared in a similar fashion as stream discharge in the previous section.

In addition, **Figure 3.17** shows plots for the three reaches in which annual net recharge volumes (normalized to the upstream gage) are plotted against annual discharge at the respective upstream gage for each reach.

Upper Reach (The Forks to Lower Narrows gage)

The upper chart on **Figure 3.16** shows the annual net recharge for the upper reach of the Mojave River between The Forks and Lower Narrows gage. Average annual net recharge for this reach is 22,004 AFY over the 80-year period from WY 1931 to WY 2010 and 13,633 AFY over the 60-year base period (WY 1931 to WY 1990). The CMD curve for this reach indicates that, despite the wet climatic conditions observed from 1936 to 1945, net stream recharge in the upper reach was below the base-period average (evidenced by the negative-sloping CMD line). This negative trend extended through the 20-year drought, during which baseflow at the Lower Narrows was larger than streamflow losses in the upper reach for several years (blue bars with negative values). Interestingly, net recharge in the upper reach was relatively low for the 1969 flood year. It was not until the 1978 flood that significant net recharge occurred in the upper reach. This relationship can be explained partly due to higher mean daily discharges associated with the winter storms of 1969 versus 1978. Since 1978, large flood years have generated most of the groundwater recharge with other non-flood years also contributing significantly. Net recharge generated over the past 30 years has reversed the historical large deficit for this reach.

The upper chart on **Figure 3.17** shows annual net recharge in the upper reach as a percentage of discharge at the Forks from WY 1931 to WY 2010 (years with small negative net recharge values are not shown). For each year, annual discharge at The Forks is plotted against net recharge normalized to the annual discharge at The Forks for that year. The figure shows that smaller annual discharges at The Forks



Note: Stream losses (leakage) minus baseflow

February 2013	Figure 3.16
TODD ENGINEERS Alameda, California	**Annual Net Recharge by Reach (AFY)**

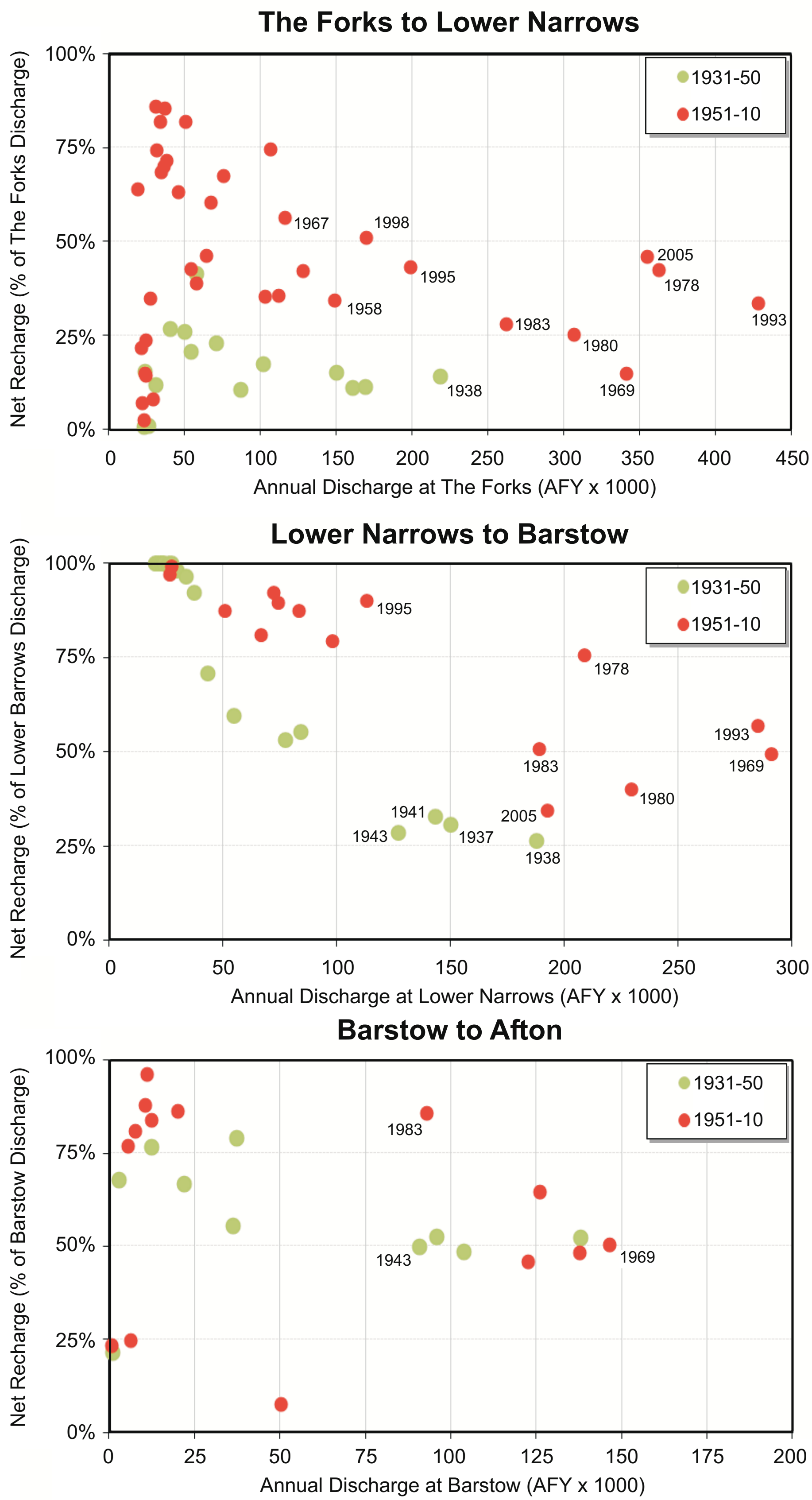


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Figure 3.17
Annual Net Recharge by Reach (% Upstream Gage)

generally correspond to a higher percentage of net recharge, while larger annual discharges at The Forks generally correspond to a lower percentage of net recharge to groundwater. Separation of the dataset into a pre-development period (WY 1931-1950) and post-development period (WY 1951-2010) indicates that net recharge in the upper reach (as a percentage of discharge at The Forks) has been higher during the post-development period (evidenced by the red dots plotting higher than the green dots in the chart).

Middle Reach (Lower Narrows gage to Barstow gage)

The middle chart on **Figure 3.16** shows the annual net recharge for the middle reach between the Lower Narrows and Barstow gages. Average annual net recharge for this reach is 33,334 AFY over the 80-year period from WY 1931 to WY 2010 and 34,907 AFY over the 60-year base period (WY 1931 to WY 1990). The CMD curve for this reach indicates that, despite the wet climatic conditions observed from 1936 to 1945, net recharge between Lower Narrows and Barstow was similar to the base-period average. Over the 20-year drought from 1946 to 1968, net recharge was slightly below average. Unlike the upper reach, the 1969 flood represented one of the single highest groundwater recharge years for the Lower Narrows to Barstow reach. Since the record flood of 1969, five large flood years (1978, 1980, 1983, 1993, 1995, 1998, and 2005) have provided most of the groundwater recharge in the middle reach. Net recharge during large flood years have served to offset the gradual decline in baseflow observed at Lower Narrows over time (MBA Watermaster, 2011).

The middle chart on **Figure 3.17** shows the annual net recharge from Lower Narrows to Barstow as a percentage of discharge at Lower Narrows from WY 1931 to WY 2010. For each year, annual discharge at Lower Narrows is plotted against net recharge normalized to the annual discharge at Lower Narrows for that year. The figure shows that smaller annual discharges at Lower Narrows generally correspond to a higher percentage of net recharge, while larger annual discharges at Lower Narrows generally correspond to a lower percentage of net recharge. Separation of the dataset into a pre-development period (WY 1931-1950) and post-development period (WY 1951-2010) indicates that net recharge in the middle reach has been higher during the post-development period.

Lower Reach (Barstow gage to Afton gage)

The lower chart on **Figure 3.16** shows the annual net recharge for the lower reach between the Barstow and Afton gages. Average annual net recharge for this reach is 8,504 AFY over the 80-year period from WY 1931 to WY 2010 and 8,802 AFY over the 60-year base period (WY 1931 to WY 1990). The CMD curve for this reach indicates that the wet climatic conditions observed from 1936 to 1945 produced net recharge in the lower reach well above the base-period average. Over the 20-year drought from 1946 to 1968, annual net stream gains to groundwater were minimal (or negative for years when no stormflows were recorded at Barstow). The 1969 flood represented one of the single highest groundwater recharge events for the Barstow to Afton reach. However, net stream gains to groundwater were relatively insignificant for the 1978 flood year. Since 1978, four large flood years (1980, 1983, 1993, and 2005) have provided most of the groundwater recharge in the lower reach.

The lower chart on **Figure 3.17** shows the annual net recharge from Barstow to Afton as a percentage of discharge at Barstow from WY 1931 to WY 2010 (years with small negative net recharge values are not shown). For each year, annual discharge at Barstow is plotted against net stream gains normalized to the annual discharge at Barstow for that year. While more variable than the charts representing the upper and middle reaches on the figure, the chart shows that smaller annual discharges at Barstow generally correspond to a higher percentage of net recharge in the lower reach, while larger annual discharges at Barstow generally correspond to a lower percentage of net recharge. Separation of the dataset into a pre-development period (WY 1931-1950) and post-development period (WY 1951-2010) indicates that conditions pertinent to recharge in the lower reach have been similar over the period of record, and that any variability in net recharge in the lower reach over time is primarily controlled by the volume of discharge that reaches the Barstow gage.

Historical Trends in Net Recharge (during the Base Period)

The base period can be separated into three time periods based on general climatic conditions. The three periods include an early wet period (WY 1931-45), intermediate dry period (WY 1946-68), and late post-drought period (WY 1969-90). Average annual net recharge for the upper, middle, and lower reaches for the three periods are shown in **Table 3.4** and discussed below.

During the early wet period, average annual net recharge volumes in the upper and middle reaches were near or below their respective base-period averages (78 percent and 97 percent, respectively). Over the same period, average annual net recharge volume in the lower reach was well above its respective base-period average (210 percent).

During the intermediate dry period, net recharge volumes in the upper and middle reaches were below their respective base-period averages (63 percent and 84 percent, respectively). Over the same period, average annual net recharge in the lower reach was well below its respective base-period average (17 percent).

During the late post-drought portion of the base period, average annual net recharge in the upper reach was above its respective base-period average (149 percent) and the net recharge observed during the early wet period prior to the drought (149 percent compared to 78 percent). Average annual net recharge in the middle reach was above its respective base-period average (116 percent) and the net recharge observed during the early wet period prior to the drought (116 percent compared to 97 percent). Finally, average annual net recharge in the lower reach over the post-drought period was slightly higher than its respective base-period average (107 percent) but well below the net recharge observed during the early wet period prior to the drought (107 percent compared to 210 percent).

Current Trends in Net Recharge (since the Base Period)

Net recharge for three "post-base period" time periods are also shown in **Table 3.4**. These include the post-base period (WY 1991 to WY 2010, post Judgment period (WY 1996 to WY 2010); and recent wet time period book-ended by the WY 1992-93 and WY 2004-05 floods.

The table shows that since the base period (from WY 1991 to WY 2010) average annual net recharge in the upper reach has been well above its base-period average (346 percent). In contrast, average annual net recharge values for the middle and lower reaches have been slightly below their respective base-period averages (82 percent and 86 percent, respectively).

Similarly, since the Judgment (WY 1996 to WY 2010), average annual net recharge in the upper reach has been well above its base-period average (298 percent). In contrast, average annual net recharge values for the middle and lower reaches have been well below their respective base-period averages (50 percent and 66 percent, respectively).

Finally, over a recent wet period that included the 1992-93 and 2004-05 floods (WY 1992-93 to 2004-05), average annual net recharge for the upper reach was 357 percent of its base-period average. During this same period, average annual net recharge values in the middle and lower reaches were each slightly above their base-period averages (104 percent and 134 percent, respectively).

3.10.3 Summary of Mojave River Discharge and Net Stream Recharge

Previous studies have concluded that the principal factors controlling the frequency and magnitude of downstream flows in the Mojave River are the frequency, magnitude, and duration of runoff in the San Bernardino Mountains and the absorption capacity of the river channel. These factors are complex and inter-related; the absorption capacity of the channel is a function of the intrinsic characteristics of the unsaturated zone sediments (e.g., effective porosity and hydraulic conductivity) and, at any given time, the depth to the water table, local and regional hydraulic gradients in the shallow aquifer system, and amount of water held in the unsaturated zone (i.e., from antecedent floods). Additionally, upstream clearance of vegetation within the banks of the river for flood protection (which occurred in the Alto Transition Zone until the mid-1980s) can also affect the downstream conveyance of winter stormflows (SBCFCD, 2011). Consequently, it is difficult to apportion the historical variability in downstream flows to climatic factors versus human-related activities.

For the purpose of this study, and based on the examination of stream gage records through WY 2010, the following conclusions can be made regarding Mojave River discharge and net stream recharge to groundwater in the Basin:

- Average annual discharge at the downstream gages (as a percentage of discharge at The Forks) has generally declined over the period of record with larger declines occurring in the downstream direction.
- Since 1990, discharge at The Forks has been above its base-period average, while discharges at the three downstream gages have been below their respective base-period averages, with larger declines occurring in the downstream direction.
- Since 1990, the average annual net stream recharge for the upper reach (The Forks to Lower Narrows) has increased more than three-fold compared to its base-period average. As a consequence, the net stream recharge in the middle reach (Lower Narrows to Barstow) and lower reach (Barstow to Afton) have decreased relative to their respective base-period averages.
- The proportion of the discharge at The Forks that (net) recharges the groundwater system within the upper reach has increased since the 1950s. Similarly, the proportion of the discharge at Lower Narrows that recharges the groundwater system within the middle reach has increased since the 1950s.

- In contrast to the upper and middle reaches, the proportion of discharge at Barstow that recharges the groundwater system within the lower reach has not changed measurably since the 1930s. The variability in net recharge in the lower reach is thus primarily dependent on the amount of discharge reaching the Barstow gage.

3.10.4 Potential Effect of Upstream Dams on Downstream Mojave River Flows and Groundwater Recharge

In addition to the variability in climate and factors related to the absorption capacity of the channel, stakeholders in the Centro and Baja subareas have questioned whether the construction and operation of Cedar Springs Dam and Mojave River Dam, two dams located in the headwaters of the Mojave River, have affected downstream flows and recharge. To address this question, a focused evaluation of the potential impacts of the upstream dams was conducted for this study, the results of which are documented in **Appendix B**.

The evaluation: 1) describes the history of surface water flow conditions in the Mojave River headwaters both prior to and following the construction of the Cedar Springs Dam and Mojave River Dam; 2) documents the data, methods of analysis, and key findings from previous studies that directly or indirectly address the potential impact of the dams on downstream flows and groundwater recharge; and 3) presents refined conclusions on the downstream impact of the dams supported by streamflow data collected through WY 2010.

Results of the evaluation indicate that the construction and operation of Cedar Springs Dam and Mojave River Dam have likely resulted in little to no impact on the volume of flows reaching downstream areas of the basin. The detention effect of the dams on downstream flows is relatively small compared to the effect of groundwater level declines beneath the river channel since the late 1940s/early 1950s, which has generally increased the absorption potential of the Mojave River.

3.10.5 Ungaged Local Storm Runoff

Previous studies have identified ungaged local storm runoff as a component of the natural water supply within the Study Area. Five investigations (DWR, 1967; Hardt, 1971; Lines, 1996; Stamos, et al., 2001; and Wagner and Bonsignore, 2012) present independent and varying estimates of ungaged local runoff that contributes to Mojave River flows and/or directly to groundwater recharge. Because each study uses varying study area boundaries, methods of analysis, and data sources, a focused evaluation of ungaged local runoff was conducted for this study, the results of which are documented in **Appendix C**. The evaluation describes the analytical methods and limitations of previous works and presents revised estimates of ungaged local runoff based on a consistent methodology using the most current and reliable information.

Results of the focused evaluation indicate that the use of a runoff coefficient of 0.5 percent of rainfall on upland (non-basin) areas is reasonable. Applying the 0.5 percent runoff coefficient to the weighted-average rainfall for various sub-drainages within the Study Area indicates the following:

- The estimated ungaged local runoff within the Centro Subarea is 1,230 AFY. Of this amount about 540 AFY generally occurs within the Mojave River drainage basin including all of the area southeast of Hinkley Gap; the remaining 690 AFY is generated from rainfall on non-basin areas (northeast of the Hinkley Gap) that drains towards Harper Dry Lake.

- The estimated total ungaged local runoff within the Baja Subarea is 980 AFY. Of this amount about 770 AFY occurs within the Mojave River drainage basin (including areas that drain to Kane Wash and Troy Dry Lake) upstream of the Afton gage; the remaining 220 AFY is generated from rainfall in mountain areas that drains towards Coyote Dry Lake.
- Given the moderate elevation of the local mountains and their close proximity to the desert floor, the variability of local runoff from year to year is much more likely to be closely correlated to the amount and pattern of rainfall on the desert floor versus those in the San Bernardino Mountains.

Similar to previous studies, local runoff is assumed to directly recharge the groundwater system (i.e., is not subject to further evaporation) either beneath ungaged ephemeral washes, the Mojave River channel, or along the margins of the basin.

4. CENTRO SUBAREA-BASIN CONCEPTUAL MODEL

The Centro Subarea is situated downstream of the Alto/Transition Zone Subarea and upstream of the Baja Subarea. Groundwater occurs in a complex geologic setting, and groundwater storage, levels, and flow have been influenced over time by local and upstream pumping. Groundwater quality, too, has been influenced by the local geology and human activities.

This section describes the conceptual model of the Centro Subarea, including geology, groundwater occurrence and flow, groundwater level trends and storage, a water budget, and groundwater quality.

4.1 Centro Faults and Hydraulic Barriers

The Mojave River basin lies within the Eastern California Shear Zone, a region of concentrated seismic activity that stretches north-northeast from the San Andreas Fault across the Mojave Desert and into the Owens Valley. Major geologic structures in the Centro Subarea (shown on **Figure 3.3**) include the Helendale, Iron Mountain, Lockhart, Mt. General, and Harper Lake-Camp Rock (Waterman) faults. Previous studies have identified these faults as partial barriers to groundwater flow using primarily groundwater level data as well as water quality and isotopic analyses (DWR, 1967, Hardt, 1971, Stamos, 2001, Stamos and Predmore, 1995, Lines, 1996; Stamos et al., 2003; Mendez and Christensen, 1997; Stamos et al., 2009). Faults were represented in two USGS groundwater models with varying hydraulic properties to simulate potential impedance to groundwater flow (Hardt, 1971 and Stamos et al., 2001). The current understanding of the major faults with respect to their location and effect on groundwater flow is described below and summarized in **Table 4.1**. Also included on the table are the parameters used to represent the faults in the two USGS models.

4.1.1 Helendale Fault

The Helendale Fault is the boundary between the Alto (Transition Zone) and Centro subareas. The fault extends from the east side of Kramer Hills, across the Mojave River, and southeastward into Lucerne Valley (**Figure 3.3**). Numerous studies, beginning with DWR Bulletin No. 84 (1967), have evaluated the effect of the fault on groundwater levels and groundwater quality. Most recently, a field investigation by USGS (Stamos et al., 2003) confirmed previous findings that the fault impedes flow in the older less permeable alluvial deposits of the Regional Aquifer, but does not restrict flow within the overlying younger and recent Mojave River deposits of the Floodplain Aquifer. The Helendale Fault acts as a barrier and causes water to move upward towards the land surface, which in part accounts for the presence of phreatophytes upstream of the fault. Historically, there has been an upward vertical hydraulic gradient upstream of the Helendale Fault between the shallower Floodplain Aquifer and deeper Regional Aquifer. However, because of local and regional production, the vertical gradient has reversed since the early 1990s and is now downward. Downstream of the fault, the current and historical movement of water has been from the Floodplain Aquifer downward to the Regional Aquifer.

Table 4.1
Hydraulic Parameters Used to Simulate Geologic Faults in the Centro Subarea

Subarea	Fault	Hydraulic Effect		Fault represented in USGS Groundwater Models				
				Hardt, 1971[a]	Stamos, 2001 (Conductance for Model Layers)[b]			
		Floodplain Aquifer	Regional Aquifer	Transmissivity (gpd/ft)	Layer 1 Floodplain[c] (1/day)	Layer 1 Regional (1/day)	Layer 2 Floodplain (1/day)	Layer 2 Regional (1/day)
Centro	Helendale Fault	No	Yes	NM	1×10^{30}	2×10^{-10}	2×10^{-8}	2×10^{-8}
Centro	Lockhart Fault (Hinkley Valley)	No	Yes	27,000	1×10^{30}	(N) 1×10^{-4} (S) 1×10^{-8}	1×10^{-8}	1×10^{-8}
Centro	Lockhart Fault (Harper Lake)	NP	Yes	2,500	NP	1×10^{30}	NP	1×10^{-6}
Centro	Iron Mountain Fault	Yes	Yes	NM	1×10^{-14}	1×10^{-14}	1×10^{-14}	1×10^{-14}
Centro	Mount General Fault	Yes	Yes	NM	1×10^{-8}	1×10^{-8}	1×10^{-8}	1×10^{-8}
Centro/Baja	Waterman Fault	Yes	Yes	3,500	(C) 5×10^{-3} (E) 5×10^{-7}	(C) 5×10^{-3} (E) 5×10^{-7}	(C) 5×10^{-3} (E) 5×10^{-7}	(C) 5×10^{-3} (E) 5×10^{-7}

[a] Single transmissivity value used to represent fault in single-layer model
[b] Conductance (1/day) represents hydraulic conductivity of hydraulic flow barrier (in feet/day) divided by barrier width (feet)
[c] Large conductance value indicates no barrier to groundwater flow
NP = Not present in Model Layer
NM = Not modeled (Helendale Fault not modeled by Hardt because fault does not impact river deposits where most of the groundwater movement occurs)
gpd/ft = gallons per day per foot
(N) and (S) refer to the portion of the fault north and south of the Mojave River
(C) and (E) refer to the individual faults identified in the Harper Lake-Camp Rock Fault Zone by Cox and Wilshire (1993)

As noted in Table 4.1, Hardt (1971) did not simulate the effect of the Helendale Fault in the electrical analog model of the Basin, because groundwater level data indicated that most of the groundwater movement in the vicinity of the Helendale Fault occurs in the Floodplain Aquifer, which is unaffected by the fault. Similarly, Stamos et al. (2001) assigned a high conductance of 1×10^{30} day^{-1} to the Helendale Fault in Layer 1 of the floodplain to ensure that the fault did not represent a barrier to groundwater flow in the Floodplain Aquifer. However, a relatively low conductance was assigned to the Helendale Fault for Layer 1 of the model outside the floodplain (2×10^{-10} day^{-1}) and for Layer 2 of the model (2×10^{-8} day^{-1}).

4.1.2 Iron Mountain Fault

Steep hydraulic gradients (over 200 feet in less than 2 miles) between the Helendale Fault and Iron Mountain on the southwest side of the Mojave River have suggested the presence of a groundwater flow barrier (**Figure 3.3**). While no other evidence exists confirming the presence of a geologic fault at this location, Stamos et al. (2001) named this inferred geologic structure the Iron Mountain Fault and assigned low conductance value of 1×10^{-14} day^{-1}, effectively impeding subsurface flow across its inferred location.

4.1.3 Lockhart Fault

The Lockhart Fault trends northwest-southeast and extends from north of Kramer to south of Harper Lake, through exposed bedrock between Lynx Cat Mountain and Iron Mountain, across Hinkley Valley and Lenwood, and into the hills south of Barstow (**Figure 3.3**). The Lockhart Fault partially impedes groundwater flow in the south Harper Valley area and in the older alluvium in the Hinkley area.

Hardt (1971) modeled the effect of the Lockhart Fault in the Harper Valley area with a relatively low transmissivity of 2,500 gpd/ft. Stamos et al. (2001) assigned a high conductance of 1×10^{30} day^{-1} to the Lockhart Fault in Layer 1 in the Harper Valley area, ensuring that the fault did not represent a barrier to groundwater flow (**Table 4.1**). However, a relatively low conductance was assigned for Layer 2 of the model in the Harper Valley area (1×10^{-6} day^{-1}) and for Layer 2 of the model (2×10^{-8} day^{-1}).

Hardt (1971) modeled the effect of the Lockhart Fault in the Hinkley Valley area using a relatively high transmissivity of 27,000 gpd/ft in Hinkley Valley (**Table 4.1**). Stamos et al. (2001) assigned a relatively low conductance to the Lockhart Fault in Layer 1 of the model north of the river in the Hinkley Valley area (1×10^{-4} day^{-1}) and south of the river southeast of Lenwood (1×10^{-8} day^{-1}. The conductance assigned to the Lockhart Fault north and south of the river was 1×10^{-8} day^{-1}. A high conductance was assigned to the Lockhart Fault in Layer 1 within the floodplain (1×10^{30} day^{-1}) to ensure that the fault did not represent a barrier to groundwater flow in the shallow Floodplain Aquifer. A relatively low conductance was assigned to the Lockhart Fault for Layer 2 of the model within the floodplain (1×10^{-8} day^{-1}).

4.1.4 Mount General Fault

The Mt. General Fault is parallel to and between the Lockhart and Waterman faults and extends across the Hinkley Valley through the western portion of Barstow (**Figure 3.3**). Water level data indicate that this fault is a partial barrier to groundwater flow in both the regional and floodplain aquifers (Stamos, et al., 2001). Stamos et al. (2001) assigned the same relatively low conductance of 1 x 10^{-8} day^{-1} to the Mt. General Fault for both model layers (**Table 4.1**).

4.1.5 Harper Lake-Camp Rock (Waterman) Fault

The Harper Lake-Camp Rock (Waterman) Fault occurs about five miles east of Barstow and extends from the Waterman Hills in the north to the Newberry Mountains in the south (**Figure 3.3**). The general trace of the Harper Lake (Waterman) Fault represents the central portion of the boundary between the Centro and Baja subareas. The fault was first mapped by Dibblee (1970) and later refined by Cox and Wilshire (1993) to include five separate northwest-to-southeast trending faults identified from west to east as Faults A through E. The faults cross through the Barstow WWTP and MCLB- Nebo Annex area (see **Figure 3.3**). Faults C and E have been identified as partial barriers to groundwater flow in both the Floodplain and Regional aquifers (Stamos and Predmore, 1995; Mendez and Christensen, 1997; Stamos et al., 2001). Most of the groundwater flow across the fault is likely through the river deposits overlying the fault (Hardt, 1971).

Hardt (1971) modeled the effect of the Waterman Fault using a relatively low transmissivity value of 3,500 gpd/ft in the single-layer electrical analog model. Stamos et al. (2001) assigned a conductance value of 5 x 10^{-3} and 5 x 10^{-7} day^{-1} to Fault C and E, respectively.

4.1.6 Other Faults

In addition to the major faults described above, an unnamed fault that borders the southwestern edge of Harper Dry Lake impedes groundwater flow from northeast to southwest. Other faults in the Centro Subarea, including the Lenwood, South Lockhart, Gravel Hills, Blackwater, and Harper Valley faults, generally occur in consolidated bedrock areas and thus do not significantly impact groundwater flow in the Basin.

4.2 Centro Basin Geometry

As discussed in Section 3.2, consolidated pre-Tertiary igneous and metamorphic rocks (pTb) and Tertiary sedimentary and volcanic rocks (Ts and Tv) compose the basement complex underlying the basin fill deposits of the Study Area. These rocks (along with Quaternary basalt [Qv]) are considered non-water bearing (DWR, 1967). The crystalline complex and Tertiary rocks cropping out in the local mountains and hills also underlie the valley floor, but are overlain by Quaternary deposits that generally comprise the water-bearing aquifers in the Basin (DWR, 1967). For this study, the degree of weathering and cementation/consolidation of older Quaternary alluvial deposits (Qoa) described in well driller's logs was closely examined to develop a surface representing the base of unconsolidated sediments. This surface serves as the basis for estimating the available extractable groundwater in storage in various portions of the Study Area and is similar in concept to the surface developed by DWR in its Bulletin No. 84 (1967) representing the base of freshwater.

As a result of faulting, the elevation of the base of unconsolidated sediments is highly variable across the Study Area. Depths to the base of unconsolidated sediments (in feet below ground surface or feet-bgs) in the Study Area were mapped for this study using lithologic logs in well completion reports and borehole geophysical logs.

Figure 4.1 shows the available well data in the Centro Subarea used in geologic mapping and hydrogeologic cross section development. The upper left map (labeled A) shows the 4,455 wells of record in the Centro Subarea symbolized by total well depth, which ranges from less than 100 feet-bgs to 820 feet-bgs. Of these wells, 1,978 wells have lithologic information, and 1,872 wells have well construction information. Additionally, well yield and drawdown information contained in well driller's logs and available pump test records were available for 134 wells distributed across the subarea. Hydraulic information was used to estimate an aquifer transmissivity for these wells as shown in the upper right map (labeled B) on **Figure 4.1**.

Lithologic descriptions for 554 wells indicate that the base of unconsolidated sediments was penetrated and low water-yielding, semi-consolidated to consolidated basin fill sediments or basement complex rocks were encountered. As shown on **Figure 4.1** (map C), these wells are concentrated along the Mojave River, in Hinkley Valley, and around Harper Lake. These wells provide reliable control points for mapping the depth to the base of unconsolidated sediments. This depth is less certain in south Harper Valley and west of Iron Mountain due to the lack of well data in those areas (**Figure 4.1,** map C).

In addition to lithologic and aquifer hydraulic data, water level and water quality information were used to interpret hydrogeologic boundaries and geologic contacts. In areas where available well data were limited, bedrock elevations were estimated based on observed trends in the slope of the base of unconsolidated sediments in the vicinity and elsewhere in the Study Area. Additionally, in areas where multiple wells contain conflicting lithologic descriptions, wells with the more detailed lithologic descriptions (e.g., USGS wells) were given more weight over driller's logs with more general lithologic descriptions. In addition, driller's logs were examined in local clusters to identify "outlier" lithologic descriptions.

Figure 4.1 (map D) presents contours representing the depth to base of unconsolidated sediments in the Centro Subarea. Because these deposits are present on the surface of the basin, the contours also represent the total thickness of the unconsolidated sediments. These contours were interpolated using GIS Spatial Analyst and the inverse-distance weighted method to develop a final surface representing the thickness of unconsolidated sediments, as shown on **Figure 4.2**. The following observations can be made regarding the analysis and the resultant map:

- The thickness of unconsolidated sediments along the Mojave River varies considerably, ranging from less than 100 feet south/southeast of Iron Mountain to greater than 700 feet south of the Lockhart Fault and greater than 600 feet east of Barstow.
- In the Hinkley Valley, the sequence of unconsolidated sediments gradually thins to the north from about 400 feet thick near the river to less than 200 feet thick at the Hinkley Gap.
- In the Harper Lake area, the base of unconsolidated sediments is generally between 500 and 600 feet-bgs. This depth represents the contact between sediments of the upper alluvial aquifer and Quaternary basalt deposits that form Black Mountain and underlie Harper Lake. A previous

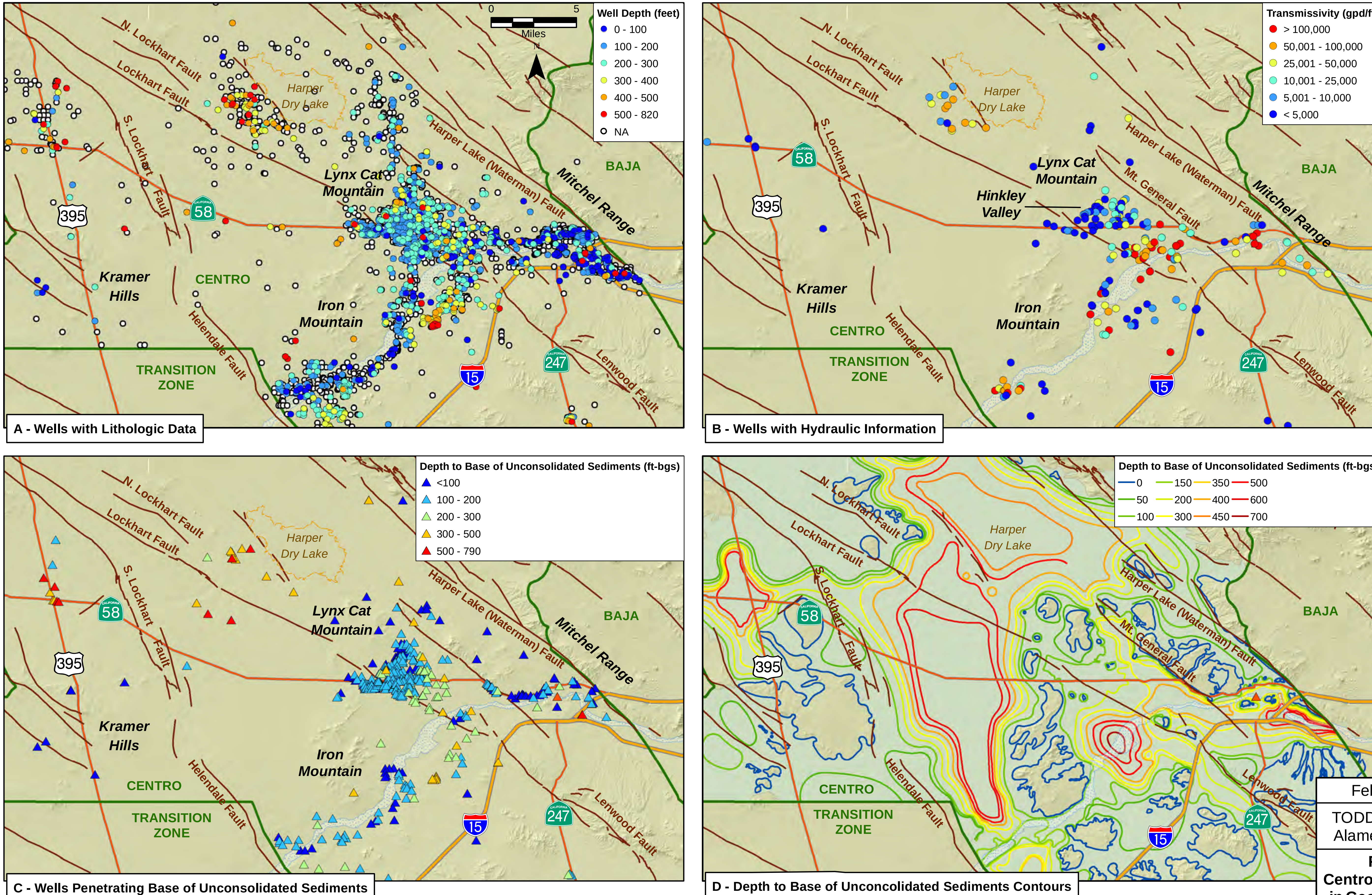

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Figure 4.1
Centro Well Data Used in Geologic Mapping

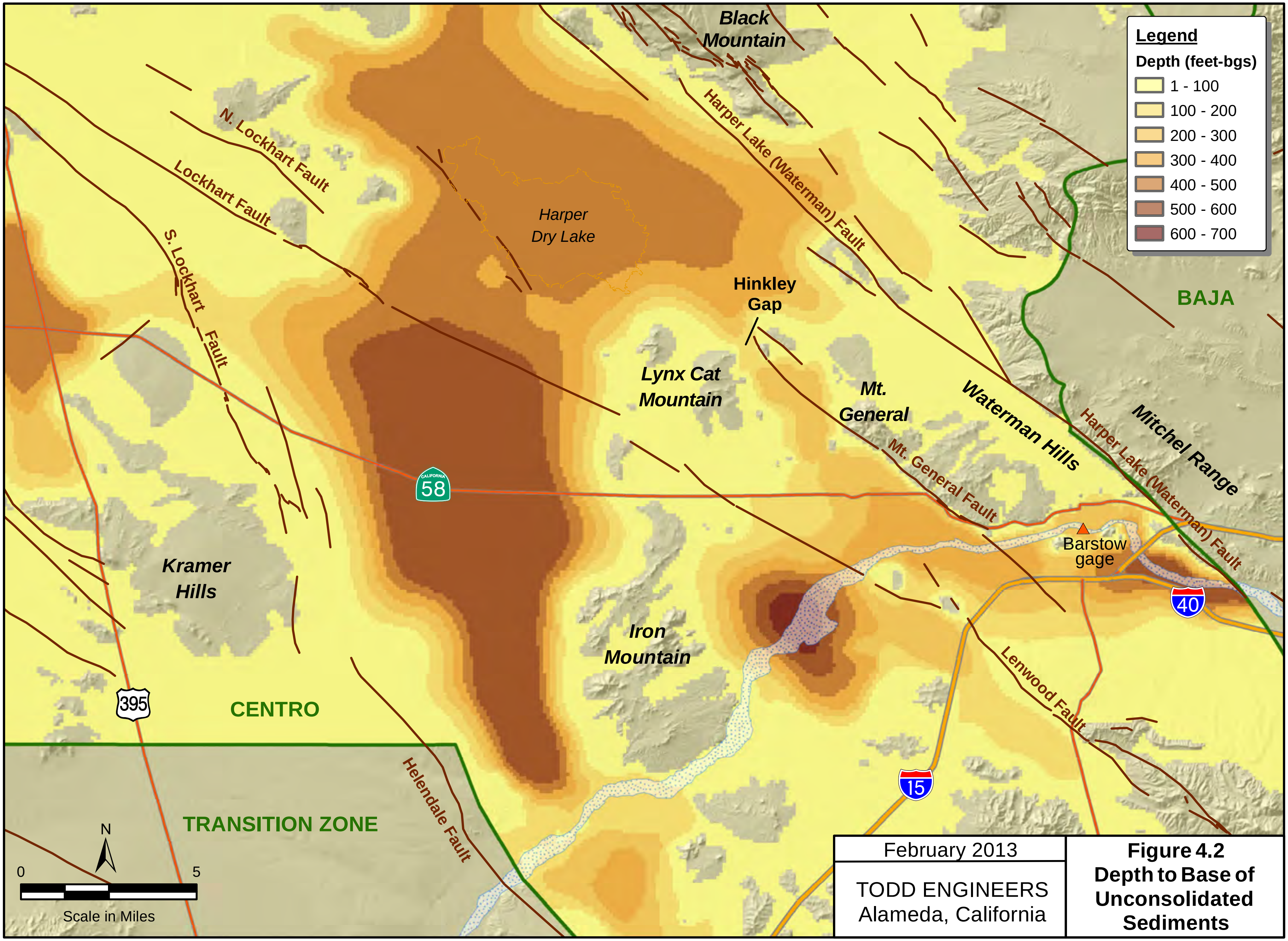

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Figure 4.2
Depth to Base of Unconsolidated Sediments

study by The Mark Group (1989) mapped a lower aquifer unit beneath the Quaternary basalt deposits; however, no hydraulic information has been presented to date that confirms the hydraulic properties of these alluvial sediments. For the purposes of this study, the top of the basalt deposit at the Harper Lake area is assumed to represent the base of unconsolidated deposits in the area.

- In the south Harper Valley area (south of Lockhart Fault and west of Iron Mountain), the depth to the base of unconsolidated sediments is estimated at about 600 feet-bgs. As shown in **Figure 4.1** (maps A, B, and C), the number of deep wells in the vicinity is limited. Further, reliable estimates of aquifer properties in the area are not available. For the purpose of this study, the depth to the base of unconsolidated sediments was based on an extrapolation of regional data and limited to 600 feet-bgs; however, the actual depth is less certain than other portions of the Centro Subarea basin.

4.2.1 Centro Hydrogeologic Cross Sections

Five hydrogeologic cross sections (Cross Sections A-A' through E-E') across the Centro Subarea were prepared for this study. Cross section locations are shown on **Figure 3.2** and were oriented to maximize the amount of hydrogeologic data on each section. Cross sections are presented on **Figures 4.3 through 4.6**. Each cross section was developed using geologic maps, well construction, lithologic, and single-well aquifer pumping test information, and historical groundwater level and quality data. For each well, lithologic information has been normalized to reflect the relative percentage of coarse-grained and fine-grained sediments or degree of weathering for consolidated rock. The depth to the base of unconsolidated sediments is also shown and generally correlates to the lithology of depicted wells; apparent inconsistencies between the interpreted depth to base of unconsolidated sediments and lithology of depicted wells on the sections reflect the consideration of all available lithologic, aquifer hydraulic, and groundwater quality information in a given local area. Consolidated deposits are labeled as bedrock on the cross sections. Note the vertical exaggeration, which allows clear depiction of lithology in wells.

Groundwater levels from 1959 and 2010 are depicted on each section to illustrate the change in water levels over the past 50 years. While it is recognized that groundwater levels in the vicinity of the Mojave River fluctuate considerably in response to intermittent stormflows, comparison of 1959 and 2010 groundwater levels represent long-term water level changes in the Floodplain Aquifer. As shown in **Table 3.4**, in the decade prior to 1959, the only significant annual flows recorded at the Barstow gage were in 1957-58 (20,100 AFY) and 1951-52 (12,500 AFY). In the decade prior to 2010, significant annual flows were recorded at the Barstow gage only in 2004-05 (126,000 AFY) and 1997-98 (10,500 AFY). These data indicate that 1959 and 2010 provide representative water level data that are not being locally influenced by a then-current large recharge event.

Ground surface elevations on the cross sections are estimated from the MWA Digital Elevation Model (DEM). The horizontal limits of the Floodplain and Regional aquifers shown on the cross sections are taken from Stamos et al. (2001), while the vertical extents are interpreted from available lithologic, pumping test, and water level data. Key features on each cross section are described below.

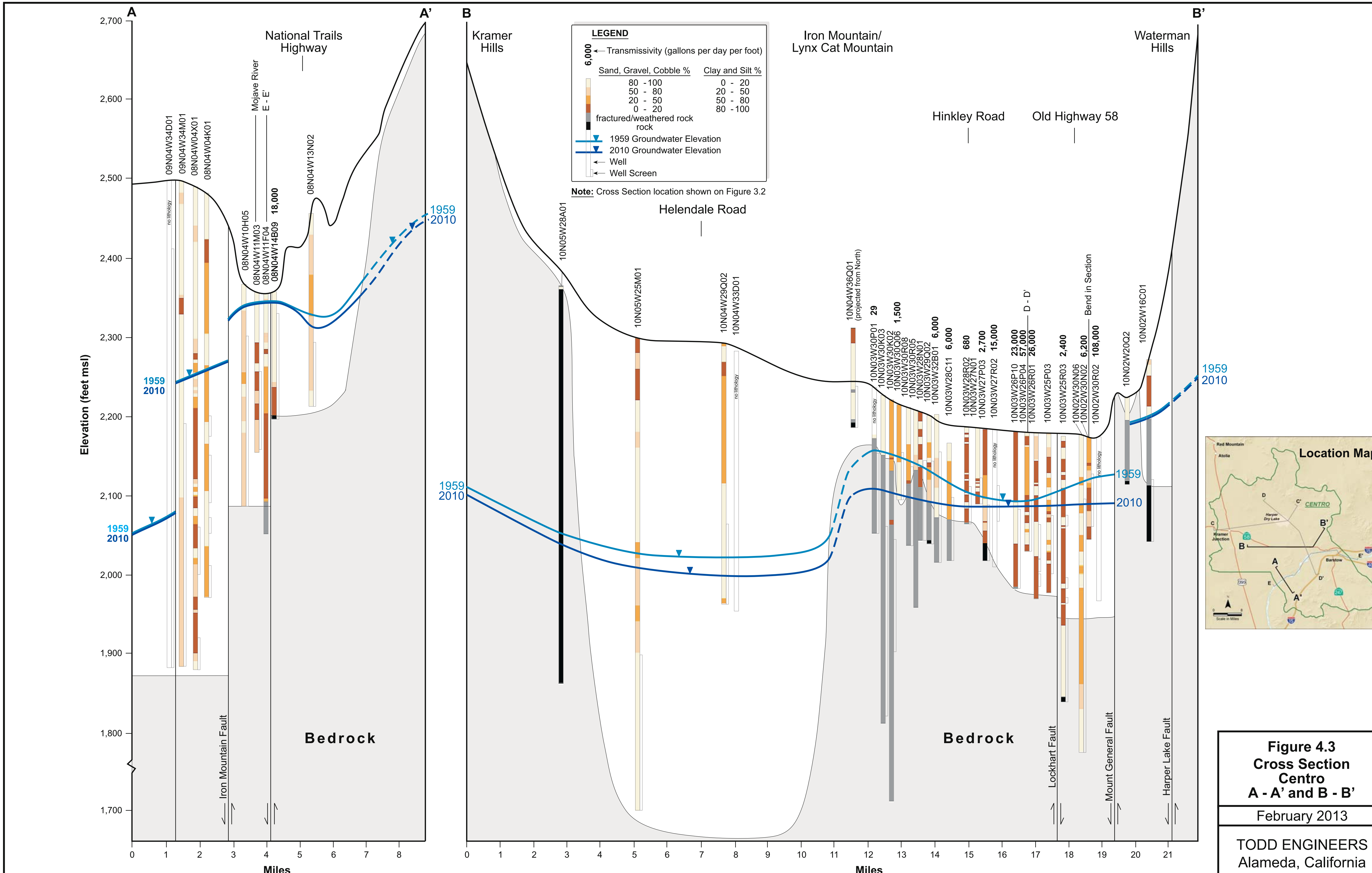

Figure 4.3
Cross Section Centro A - A' and B - B'

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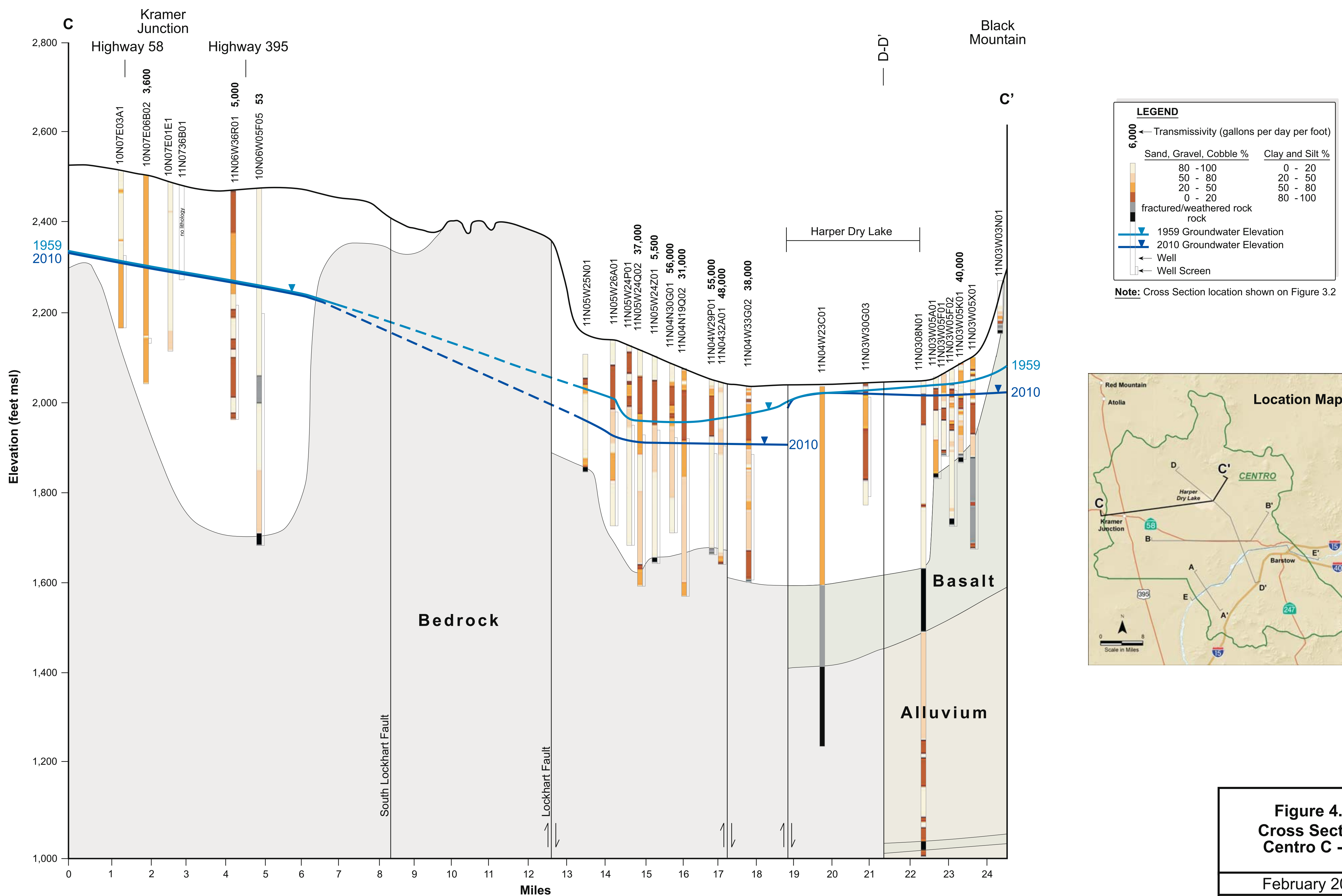

Figure 4.4
Cross Section
Centro C - C'

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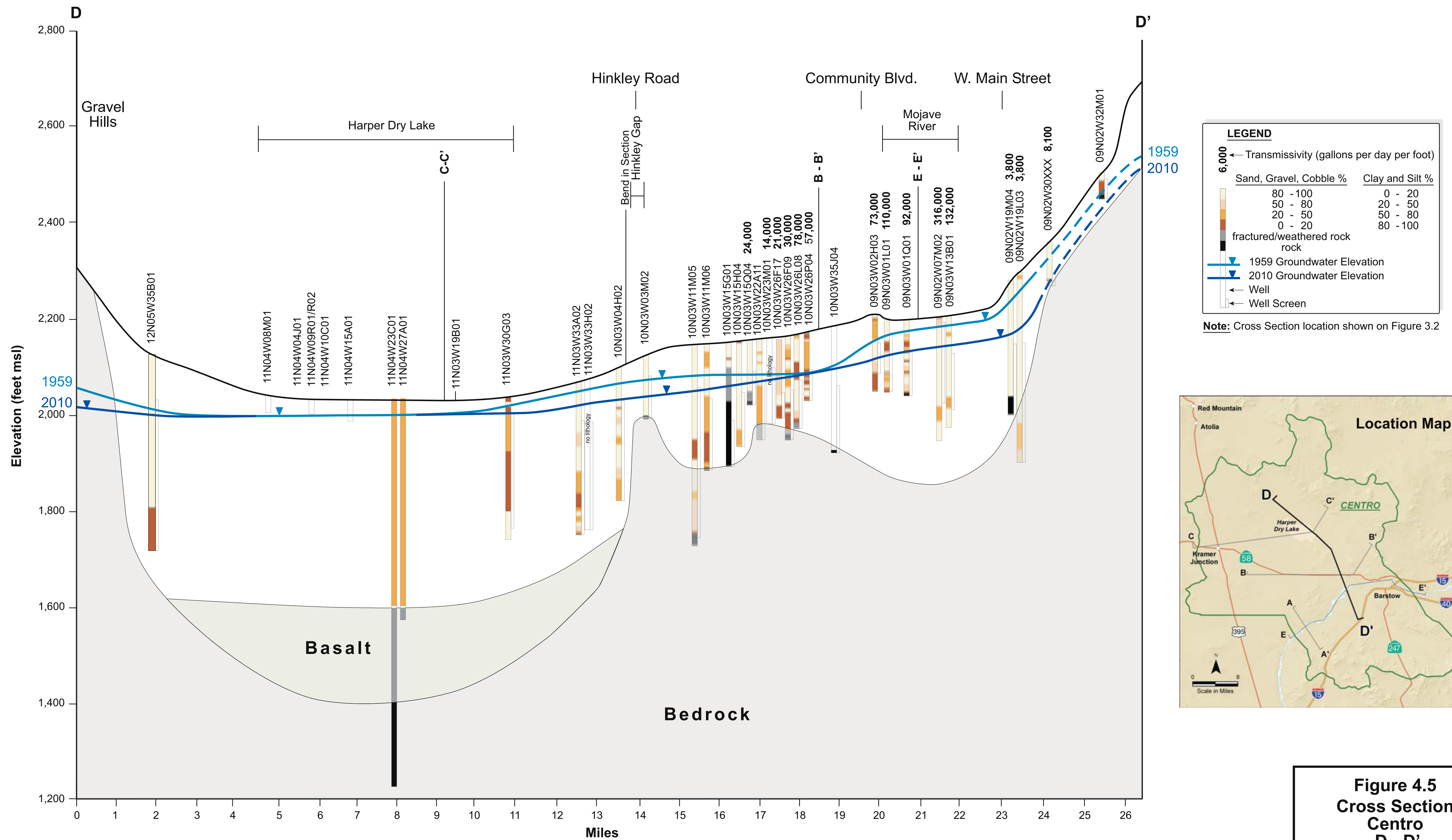

Figure 4.5
Cross Section
Centro
D - D'

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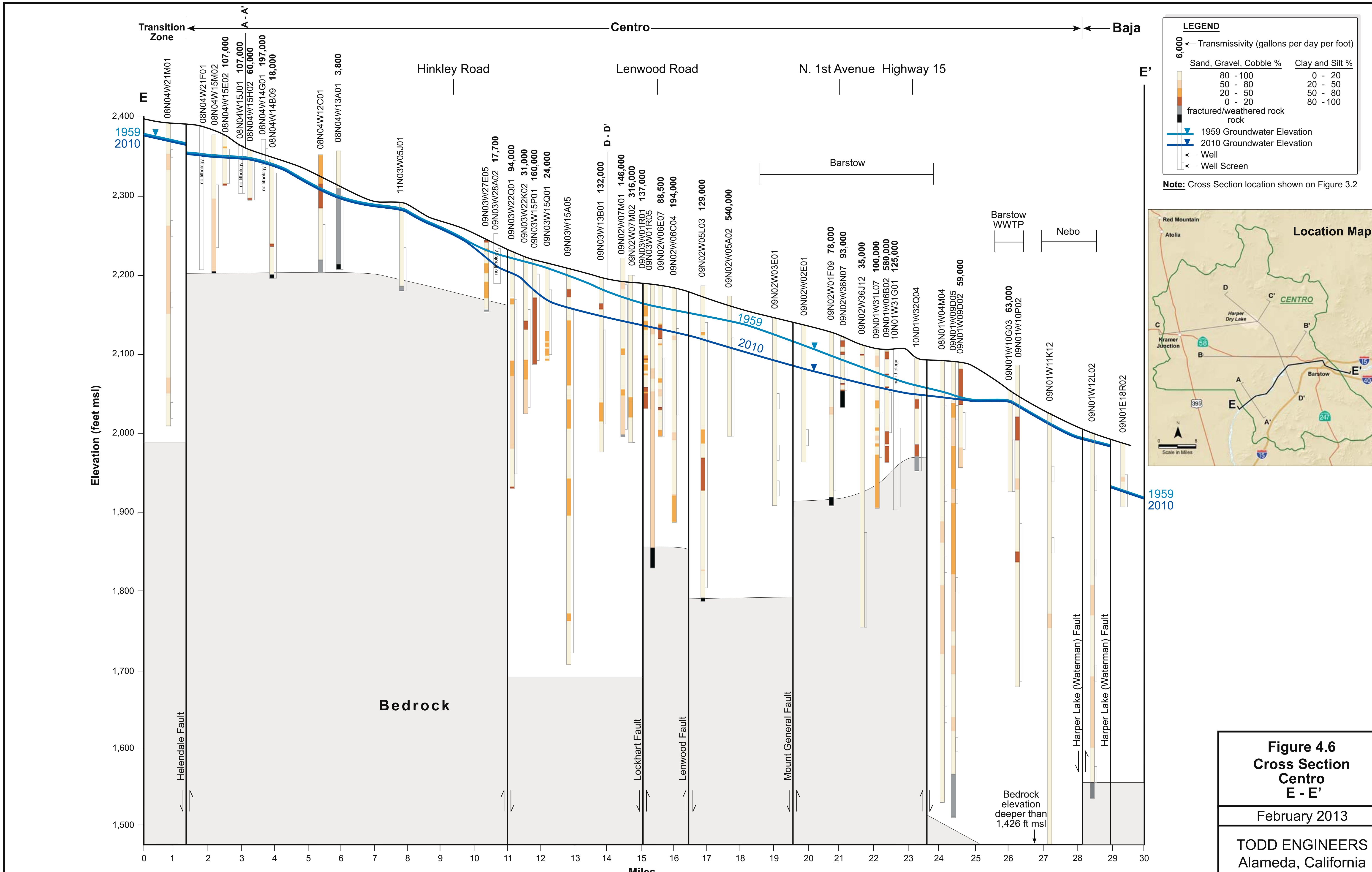

Figure 4.6
Cross Section
Centro
E - E'

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Centro Cross Section A-A'

Cross section A-A' (**Figure 4.3**) is a 9-mile cross section oriented perpendicular to the Mojave River at the southern end of the Centro Subarea (downstream of the Helendale Fault). The section begins in the southern portion of Harper Valley in the northwest, crosses the Iron Mountain Fault and Mojave River and terminates in older alluvial fan deposits just west of Interstate Highway 15 (see **Figure 3.2**). As shown on **Figure 4.3**, the base of unconsolidated sediments varies from about 200 feet-bgs in the southeast portion of the Basin to more than 600 feet-bgs in the northwest. The Floodplain Aquifer is generally constrained laterally within the 2-mile zone of the modern river channel and vertically down to about 200 feet-bgs. Groundwater levels indicate a steep hydraulic gradient (more than 200 feet in 2 miles) across the Iron Mountain Fault (including nearby fault splays). The hydraulic gradient indicates that subsurface flow in the river channel is largely impeded to the northwest. Historical groundwater level changes in this area have been relatively minor, with only small differences (less than 10 feet) observed to the southeast due to localized pumping. Historical groundwater level response along the river to pumping and stormflow recharge events in this area has been relatively small. This is due in part to limited historical pumping and the hydraulic effect of the Helendale Fault, which impedes groundwater flow in the regional aquifer, resulting in generally shallow groundwater conditions both upstream and downstream of the fault.

Centro Cross Section B-B'

Cross Section B-B' (**Figure 4.3**) is a 24-mile cross section that begins at the Kramer Hills in the west, crosses the southern portion of Harper Valley and the alluvial-filled gap between Lynx Cat Mountain and Iron Mountain (south of the Hinkley Gap), extends across Hinkley Valley and terminates in the Waterman Hills (**Figure 3.2**). As shown on **Figure 4.3**, the base of unconsolidated sediments varies significantly across the section, from more than 600 feet-bgs in south Harper Valley to less than 100 feet-bgs in the gap between the Lynx Cat Mountain and Iron Mountain, and between 200 and 250 feet-bgs across Harper Valley. While the hydraulic properties of the Regional Aquifer within south Harper Valley have not been well characterized, estimated aquifer transmissivities in Hinkley Valley range from less than 5,000 gpd/ft to greater than 20,000 gpd/ft, with higher transmissivities in areas where saturated sediments are thicker. The lithology and well construction details in the Hinkley Valley show that local aquifer production zones are confined beneath a thick regional (clay) aquitard.

Previous studies have evaluated the hydraulic connection of Hinkley Valley and south Harper Valley through the gap between Lynx Cat Mountain and Iron Mountain (Ebbs, 2007). While the hydraulic gradient indicates flow from Hinkley Valley towards south Harper Valley, groundwater flow is probably largely limited by the presence of a shallow bedrock ridge in the subsurface. Groundwater levels have declined in the south Harper Valley area by about 20 feet over the past 50 years (1959 to 2010) as a result of historical pumping in the Harper Lake area. Over the same period, groundwater levels have declined from about 10 to 30 feet in Hinkley Valley; however, as shown on the cross section, groundwater levels in 1959 in the Hinkley Valley had already declined to some degree in response to local pumping.

Centro Cross Section C-C'

Cross section C-C' (**Figure 4.4**) is a 25-mile cross section that begins at Kramer Junction in the west, crosses through Harper Dry Lake, turns northeast and terminates at the base of Black Mountain (**Figure 3.2**). As shown on **Figure 4.4**, the base of unconsolidated sediments is greater than 700 feet-bgs in the Kramer Junction area; however, aquifer transmissivities indicate that the permeability of unconsolidated sediments is relatively low (aquifer transmissivities generally less than 5,000 gpd/ft). In the Harper Dry Lake area, the base of unconsolidated sediments ranges from about 500 to 600 feet-bgs. This depth represents the contact between older alluvial sediments comprising the upper alluvial aquifer and Quaternary basalt deposits that form Black Mountain and underlie Harper Dry Lake. Aquifer production zones at Harper Dry Lake are locally confined beneath a regional clay aquitard. As previously mentioned, The Mark Group (1989) mapped a lower alluvial aquifer beneath the Quaternary basalt deposits, which has been incorporated into the cross section interpretation. Considering the older age of alluvial sediments beneath the basalt unit, the consolidated nature of sediments encountered at depth in wells located west of Harper Dry Lake, and the likely negative impact of basalt flows on underlying permeability, the top of the basalt deposit (where it occurs) is assumed to represent the base of unconsolidated sediments in the Harper Dry Lake are for this study. Aquifer transmissivities are relatively high west of Harper Dry Lake, ranging from 30,000 to 60,000 gpd/ft.

The hydraulic gradient indicates some groundwater flow from Kramer Junction towards Harper Dry Lake; however, groundwater flows are limited by the lower-permeability older sediments separating these two areas. Historically, pumping in the Harper Lake area has resulted in local groundwater level declines exceeding 100 feet in some areas. Groundwater levels have partially recovered as a result of decreased pumping since the Judgment, with overall net groundwater level declines of between 20 and 50 feet over the past 50 years.

Centro Cross Section D-D'

Cross Section D-D' (**Figure 4.5**) is a 26-mile cross section that begins in the Gravel Hills northwest of Harper Dry Lake, crosses through Harper Dry Lake and the Hinkley Gap, continues along the central axis of Hinkley Valley across the Mojave River, and terminates in the hills southwest of Barstow near Interstate Highway 15 (**Figure 3.2**). As shown on **Figure 4.5**, the ground surface elevation decreases along the flowpath taken by the ancestral Mojave River (from right to left) across Hinkley Valley, through the Hinkley Gap, and into Harper Dry Lake. The base of unconsolidated sediments is highly variable across the section, ranging from about 200 feet-bgs at the Hinkley Gap to about 500 feet at Harper Dry Lake. Groundwater levels generally mimic the topography confirming that streamflow losses from the Mojave River represent the principal source of recharge along the section. Historical pumping in Hinkley Valley has resulted in local groundwater level declines of about 10 to 30 feet in over the past 50 years. In the vicinity of the Hinkley Gap, groundwater levels have declined by about 30 to 40 feet over the past 50 years, and the saturated thickness is currently less than 100 feet. Historical subsurface flows through the Hinkley Gap are discussed further in the water budget section (Section 4.7).

Centro Cross Section E-E'

Cross section E-E' (**Figure 4.6**) is a 30-mile cross section oriented along the Mojave River that extends across the entire Centro Subarea from the Helendale Fault to the Waterman Fault (**Figure 3.2**). As shown on **Figure 4.6**, the slope of the river is relatively constant across the Centro Subarea, but the base of unconsolidated sediments varies dramatically as a result of local geologic faulting.

The base of unconsolidated sediments is relatively shallow in the upstream portion of the Centro Subarea (ranging from 100 to 200 feet). Northeast of Iron Mountain, the alluvial basin thickens dramatically to more than 500 feet and then varies between 200 and 500 feet through the Barstow area. East of Barstow, the alluvial basin thickens again to more than 600 feet, with most of the section represented by older alluvial sediments comprising the Regional Aquifer (**Figure 4.6**).

Historically, groundwater levels have been relatively stable in the upstream portion of the Centro Subarea. This is due to a combination of factors, including the shallow bedrock that constrains groundwater flow to the Floodplain Aquifer upstream of the Helendale Fault, the relatively thin alluvium east of Iron Mountain (100 to 200 feet), and the relatively small amount of local pumping along the river in this area. In the central portion of the section where local municipal groundwater pumping is concentrated, groundwater levels have fluctuated by up to 50 feet in response to annual pumping and recharge from intermittent stormflows. East of Barstow, groundwater levels have historically been stabilized by effluent return flows from the Barstow WWTP and limited local pumping (**Figure 4.6**).

4.3 Centro Basin Fill Deposits and Aquifer Parameters

Collectively, the thickness and geometry of the basin fill deposits discussed above define the three-dimensional groundwater basin containing Centro Subarea groundwater. Groundwater flow and storage in this basin are controlled by parameters of the basin fill aquifers such as transmissivity and storativity. Existing data, independent estimates, and modeled values of these parameters are discussed below.

4.3.1 Aquifer Transmissivity

Transmissivity (T) represents the ease with which groundwater flows through an aquifer and can be measured from a constant-discharge pumping test or estimated empirically from specific capacity data (measured in a well in gallons per minute per foot of drawdown, gpm/ft of dd). The T value is directly proportional to specific capacity and can be estimated by multiplying the specific capacity by a coefficient of 1,500 for an unconfined aquifer (Driscoll, 1986). Because this empirical method is impacted by well efficiency (which is commonly less than 100 percent), the T value is considered a conservative estimate of the actual transmissivity of the aquifer. Corrections based on well efficiencies could not be made because available historical pumping test data did not allow for reliable time-drawdown analysis (which can be used to estimate efficiency). In addition, the application of the 1,500 coefficient also underestimates the T value for a confined aquifer (by 25 percent). Nonetheless, the application of one coefficient provides a consistent method useful for identifying spatial trends. Therefore, the empirical estimation of T was derived from available specific capacity data without modification. Available hydraulic data sources for this evaluation included pump test results supplied through MWA Watermaster records and hydraulic information contained in DWR driller's logs. These T values were used to supplement other aquifer parameter data in the subarea.

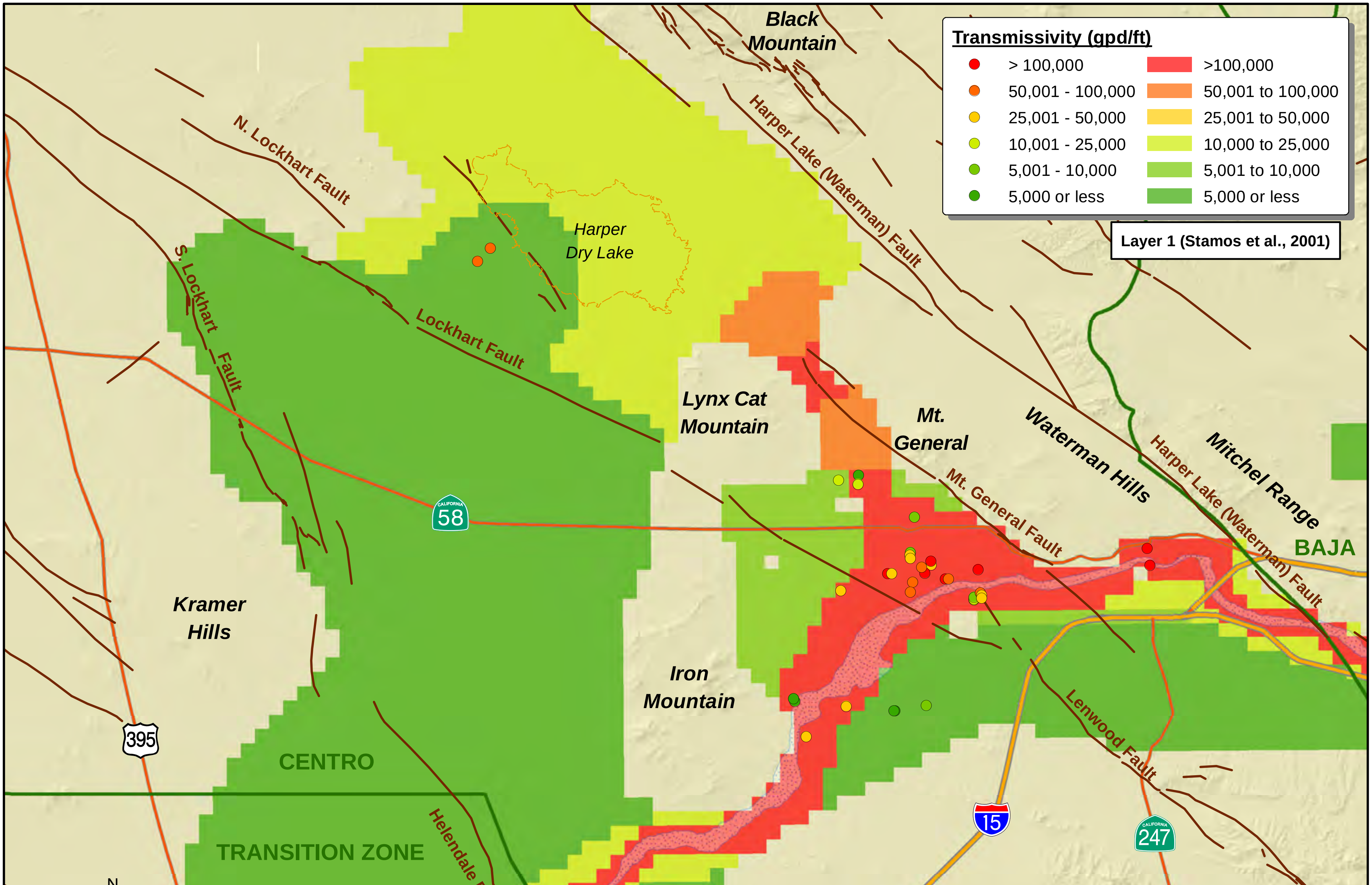
The spatial distribution of T values for wells in the Centro Subarea are shown on **Figure 4.1 (map B).** For comparison, T values for Layer 1 (**Figure 4.7a**) and Layer 2 (**Figure 4.7b**) of the USGS groundwater flow model are also provided (Stamos, et al., 2001). Transmissivity (and hydraulic conductivity) estimates for all wells with hydraulic information in the Centro Subarea are provided in **Appendix E**.

As shown in **Figures 4.1 (map B), 4.7a and 4.7b**, the T values generally indicate higher T values of younger fluvial wash sediments of the Floodplain Aquifer along the Mojave River and lower T values of the older alluvial fan sediments of the Regional Aquifer. Estimated aquifer T values generally range from 50,000 to greater than 100,000 gpd/ft within the Floodplain Aquifer. Relatively high T values are also evident in wells located in Hinkley Valley, depicting a flowpath of the ancestral Mojave River to Harper Lake. Moderately high T values are also evident in wells located west of Harper Dry Lake. As shown on **Figure 4.1 (map B)**, there are almost no wells with hydraulic data in the southern Harper Valley area west of Iron Mountain. Despite the relatively large thickness of alluvial sediments in this area, a relatively low transmissivity was assigned in the USGS model for this area because of the older, undisturbed alluvial fan deposits of the Regional Aquifer.

4.3.2 Aquifer Storativity

The storativity (S) of an aquifer is the volume of water released from or taken into storage per unit surface area of aquifer per unit change in water level. For an unconfined aquifer, the S value is referred to as specific yield. The distribution of aquifer S values in the Floodplain and Regional aquifers in the Study Area has been estimated in several studies using various methods, including comparison of groundwater level changes to calculated streamflow losses following flood events (Lines, 1996), estimations from geologic samples, and the calibrated results of electrical analog and numerical groundwater flow models developed by Hardt (1971) and Stamos et al. (2001), respectively. Based on specific yield estimates from collected formation samples substantiated by the calibration of the electrical analog groundwater model of the Basin, Hardt (1971) concluded that the average specific yield for the Floodplain and Regional aquifers in the Study Area is 20 and 12 percent, respectively. Based on water-level changes measured at specific wells, Lines (1996) estimated a range of specific yields from 14 to 39 percent, decreasing from upper stem to lower stem of the river. Recently, MWA (2011a) performed laboratory tests on river channel samples in the Barstow-Waterman Fault area and estimated a specific yield of 9 percent for the floodplain sediments.

Figure 4.8 shows the S values within the Centro Subarea from the 2001 USGS model (Stamos et al., 2001), the most reliable source of S values on a regional scale in the Study Area. As shown on the figure, S values in the Centro Subarea range from 12 to 22 percent, with higher values assigned to the coarse-grained deposits along the Mojave River system and lower values assigned to deposits comprising the Regional Aquifer. These values were used in combination with a map of saturated thickness of unconsolidated sediments to estimate available groundwater in storage.



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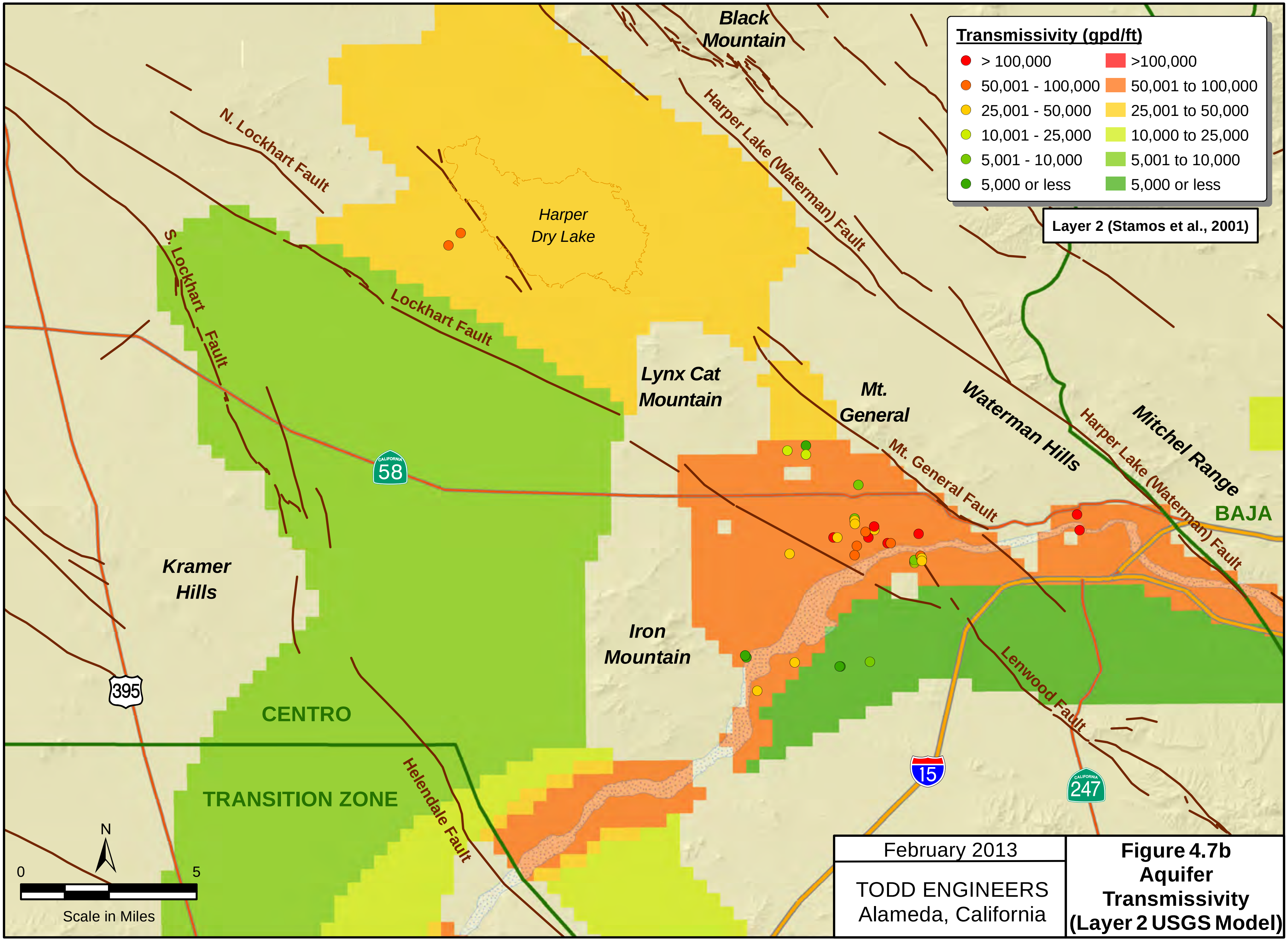

Transmissivity (gpd/ft)
> 100,000
50,001 - 100,000
25,001 - 50,000
10,001 - 25,000
5,001 - 10,000
5,000 or less
>100,000
50,001 to 100,000
25,001 to 50,000
10,000 to 25,000
5,001 to 10,000
5,000 or less
Layer 2 (Stamos et al., 2001)
Black Mountain
Harper Dry Lake
N. Lockhart Fault
S. Lockhart Fault
Lockhart Fault
Harper Lake (Waterman) Fault
Lynx Cat Mountain
Mt. General
Mt. General Fault
Waterman Hills
Mitchel Range
BAJA
Kramer Hills
Iron Mountain
Lenwood Fault
Helendale Fault
CENTRO
TRANSITION ZONE
58
395
15
247
N
0
5
Scale in Miles
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Figure 4.7b
Aquifer Transmissivity
(Layer 2 USGS Model)

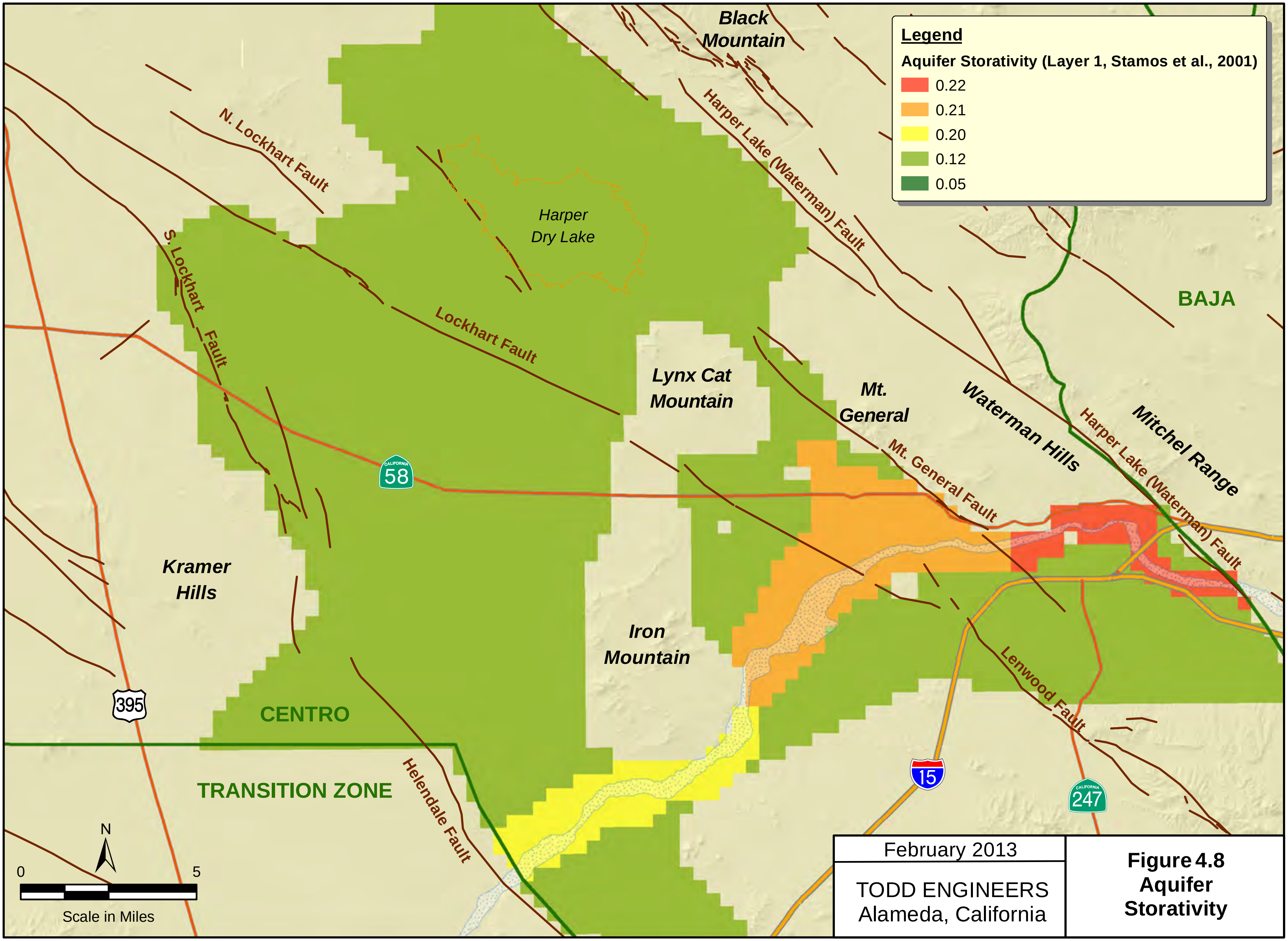

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Figure 4.8
Aquifer Storativity

4.4 Centro Groundwater Occurrence and Flow

The MWA groundwater level database was used to assess groundwater occurrence and flow within the Study Area over time. Groundwater level measurements were calibrated to the project DEM to produce a groundwater level contour map and depth to water map representing current 2010 conditions (**Figure 4.9 and 4.10**), and historical 1959 conditions (**Figures 4.11 and 4.12**) for the Centro Subarea. Groundwater level contour maps illustrate the vertical height of the water table in relation to mean sea level (representing 0 feet elevation) and are useful for analyzing groundwater flow directions across the subarea over time. Depth to water maps illustrate the depth of the water table in relation to the ground surface and are useful in identifying the thickness and available potential storage capacity of the unsaturated zone in various portions of the subarea. Contour intervals on the water level maps are 10 feet for most areas but are variable locally to allow analysis of sparse data and areas of anomalies. The 1959 and 2010 groundwater levels are also depicted on Centro Subarea Cross Sections A-A' through E-E' (**Figures 4.3 through 4.6**). Previous investigators who mapped groundwater levels in the Study Area include Stamos and Predmore (1995), Mendez and Christensen (1997), and Stamos et al. (2009).

Figure 4.9 shows the 2010 groundwater levels in the Centro Subarea. The figure shows that groundwater levels range from more than 2,300 feet msl near the Helendale Fault to about 2,000 feet msl near the Harper Lake (Waterman) Fault and about 1,900 feet msl in the Harper Dry Lake Area. As indicated by the contours in the figure, groundwater flow is controlled by shallow and exposed bedrock that forms Iron Mountain and Lynx Cat Mountain in the central portion of the subarea. Along the Mojave River channel, the hydraulic gradient is relatively constant, due to the intrinsic high permeability of channel wash sediments and the lack of geologic fault barriers in the Floodplain Aquifer. A steep hydraulic gradient is observed across the Iron Mountain Fault, indicating the barrier effect of the fault on groundwater flow from the Mojave River to the south Harper Lake area. Other hydraulic gradient contrasts occur across the Lockhart Fault in the south Harper Valley area and the unnamed fault bordering the western shoreline of Harper Lake, indicating partial impedance of subsurface flow across these features. As shown in the southern portion of **Figure 4.9**, groundwater follows the Mojave River channel from the Helendale Fault along the southeastern side of Iron Mountain before bifurcating in the vicinity of the Lenwood Fault. From there, most of the groundwater continues along the channel through Barstow eventually exiting the Subarea across the Harper Lake (Waterman) Fault, while some portion of groundwater flows from the Lenwood area north/northeast across Hinkley Valley, through Hinkley Gap, beneath Harper Dry Lake, and across the unnamed fault west of the dry lake towards the pumping depression to the west.

Figure 4.10 shows the depth to water in 2010 across the Centro Subarea. A color gradient and contours are used to represent areas with varying water table depths. Areas with a relatively shallow water table (e.g., 20 feet-bgs or less) are highlighted in red, while areas with a deep water table (e.g., 300 to 400 feet-bgs) are highlighted in blue. As shown in the figure, the depth to water beneath the Mojave River is relatively shallow (less than 20 feet-bgs), particularly in the upper and lower reaches. As a result of groundwater production and lack of significant stormflows in the Mojave River since WY 2004-2005, there is a slightly deeper water table in the middle portion of the subarea (40 to 80 feet-bgs). The water table is approximately 80 feet to 100 feet-bgs in the Hinkley Valley. The deepest water table in the

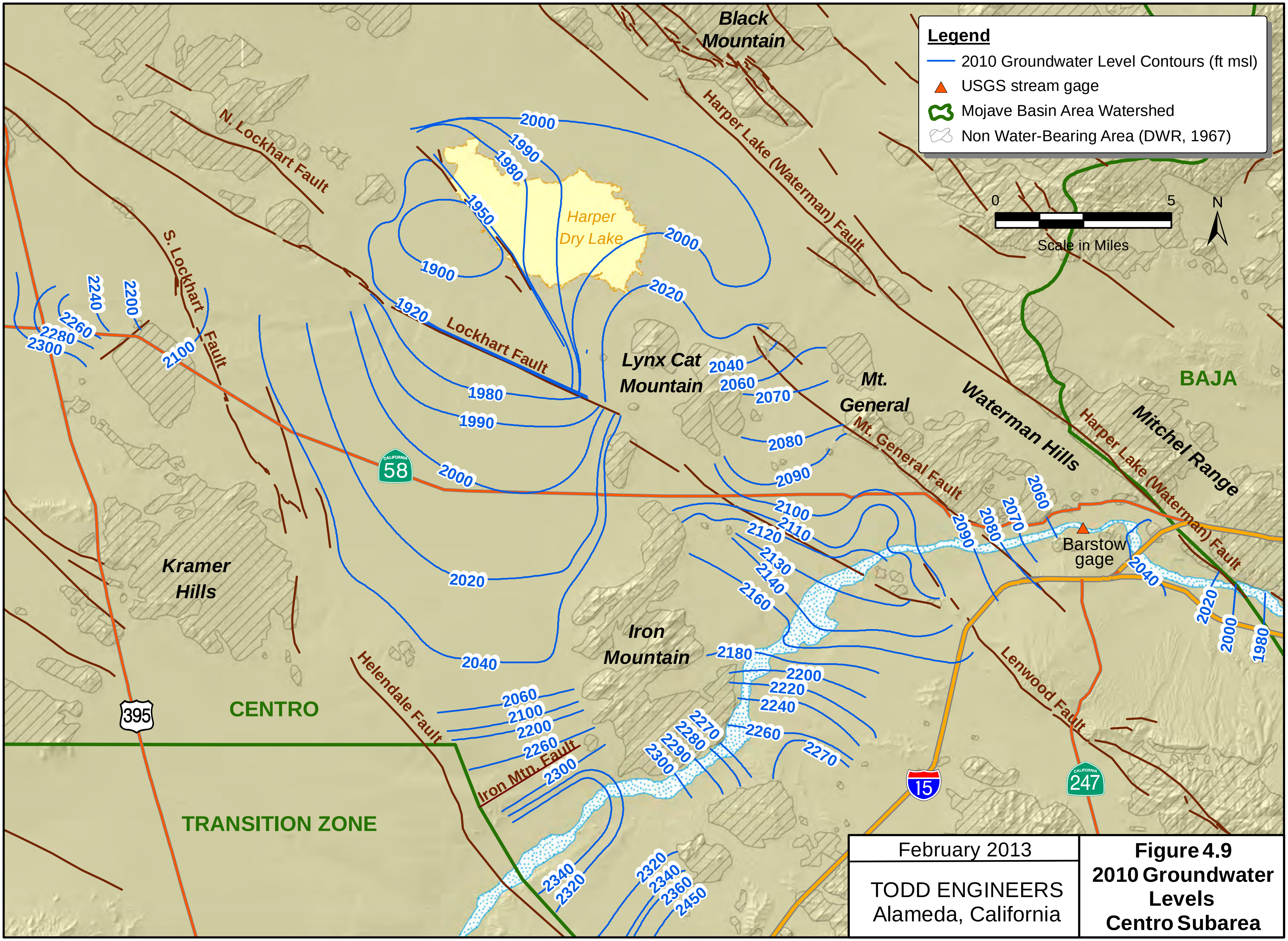

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Figure 4.9
2010 Groundwater Levels
Centro Subarea

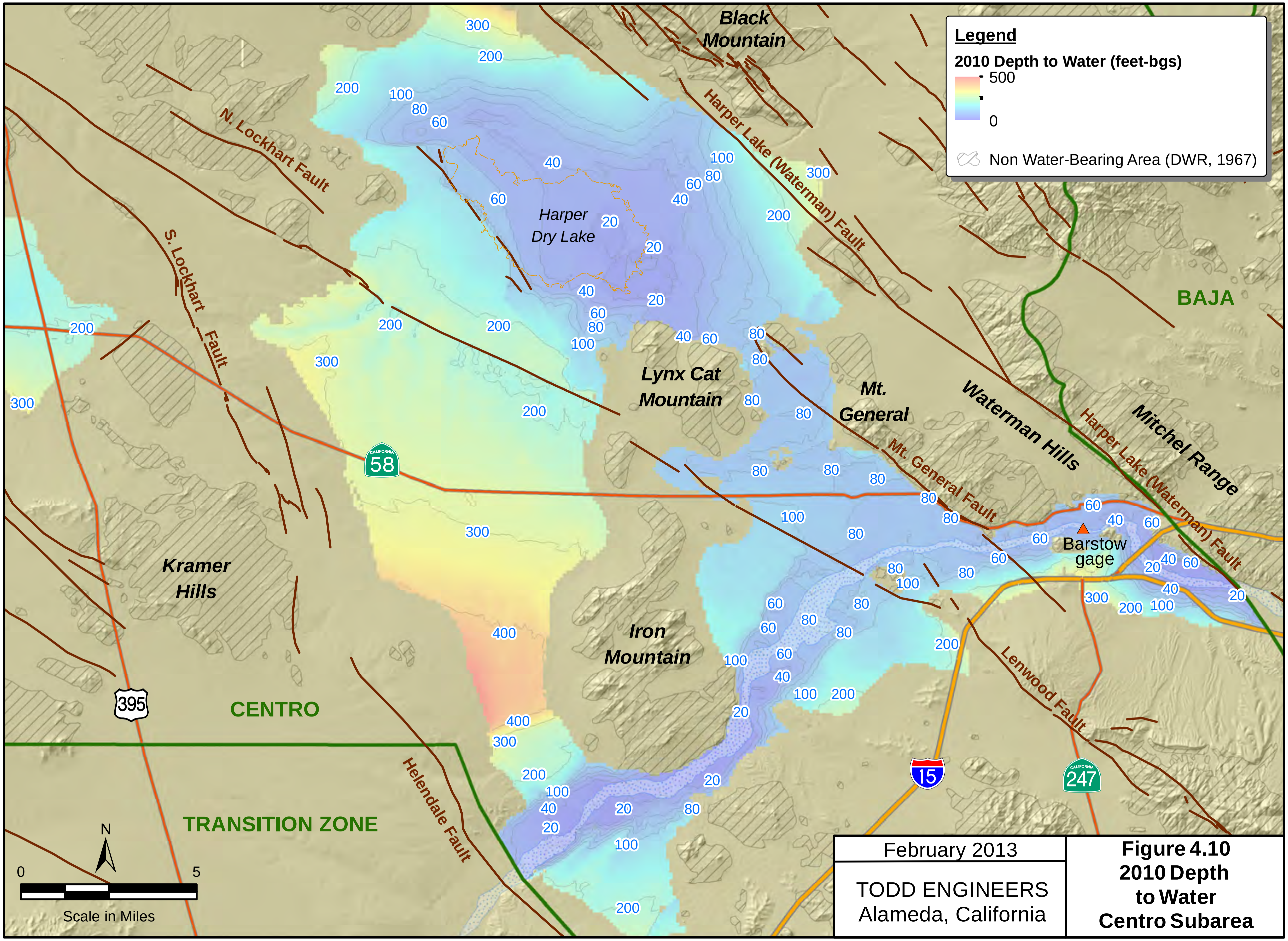

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Figure 4.10
2010 Depth to Water
Centro Subarea

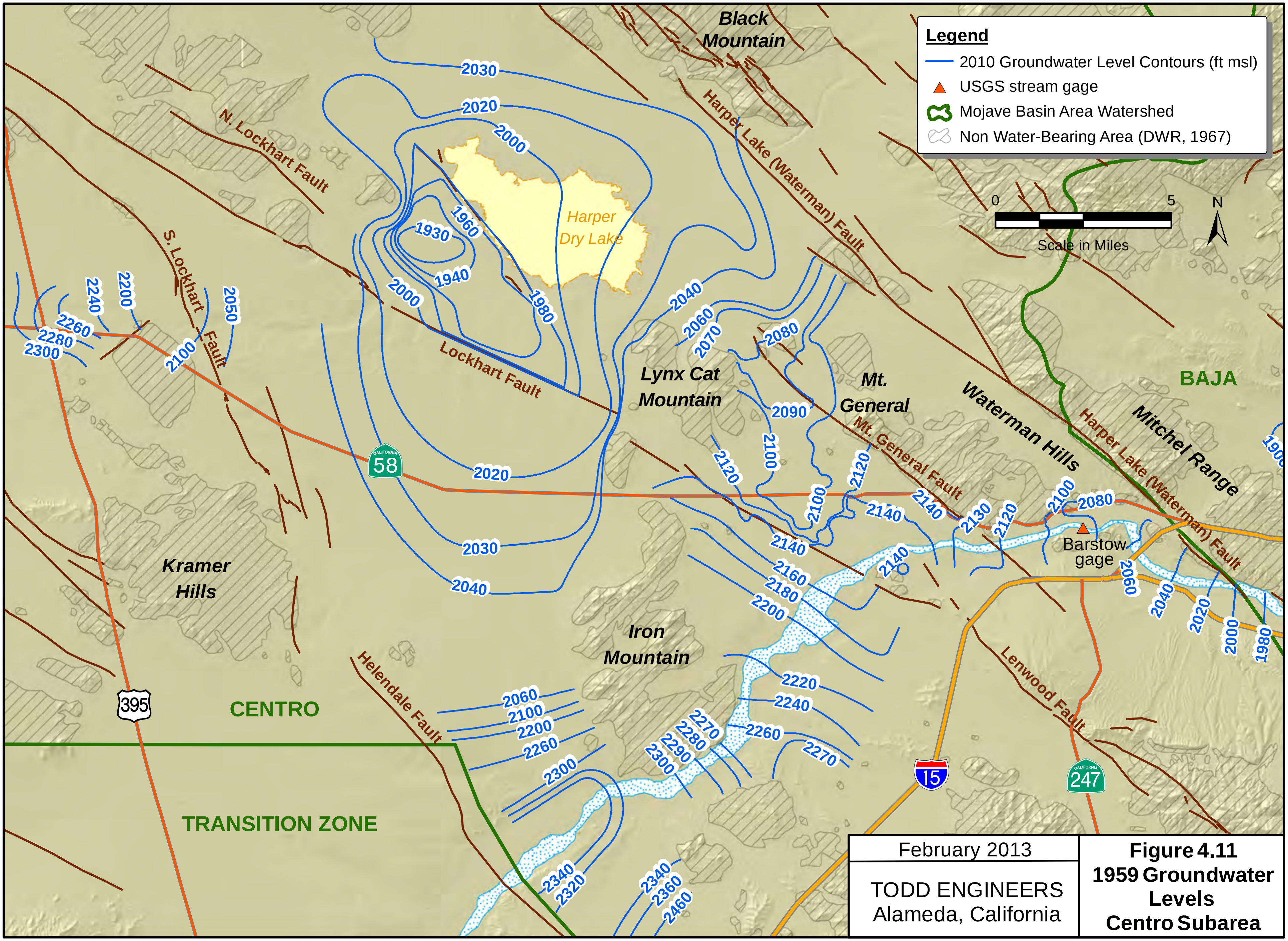

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Figure 4.11
1959 Groundwater Levels
Centro Subarea

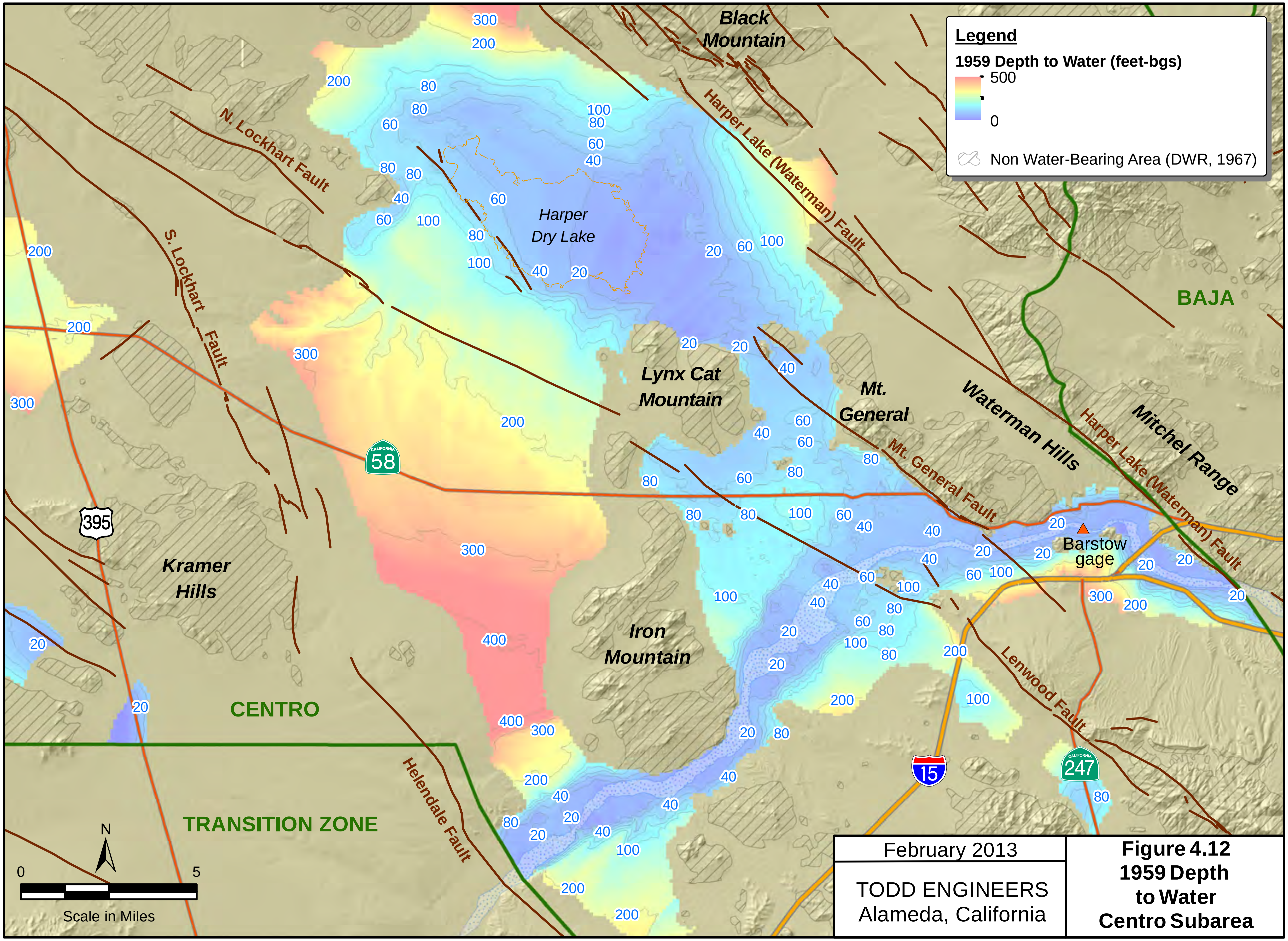

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Figure 4.12
1959 Depth to Water
Centro Subarea

Centro Subarea occurs in the south Harper Valley (ranging from 200 to 400 feet-bgs). Depth to water beneath Harper Dry Lake ranges from 20 to 40 feet-bgs but increases to about to 150 feet-bgs in the vicinity of the pumping depression to the west.

4.5 Centro Groundwater Level Trends

Figures 4.11 and 4.12 show the 1959 groundwater levels and 1959 depth to water in the Centro Subarea, respectively. Collectively, **Figures 4.9 through 4.12** indicate that groundwater conditions in 1959 were relatively similar to current (2010) conditions. Groundwater flow patterns have not changed significantly from 1959 to 2010 (**Figures 4.9 and 4.11**) The depth to water in the Mojave River channel from northeast of Iron Mountain through Barstow is about 30 to 40 feet lower in 2010 (**Figure 4.10**) compared to 1959 (**Figure 4.12**); however, groundwater levels in the vicinity following the winter storms of WY 2004-2005 were generally similar to 1959 groundwater levels. To further examine changes in groundwater levels over time, a 1959 to 2010 groundwater level change map is shown on **Figure 4.13**. The map was developed in ArcGIS by creating, and then subtracting, the surface representing the 2010 water elevation from the surface representing the 1959 groundwater elevation. The resulting groundwater level change surface was digitally smoothed in ArcGIS to minimize residual artifacts created during surface interpolation. Notwithstanding the variability in groundwater levels in the river channel, the figure shows that groundwater levels have declined over the past 50 years across the subarea, ranging from 10 to 30 feet along the Mojave River channel, 10 to 20 feet in the south Harper Valley, 10 to 30 feet in Hinkley Valley, 10 to 30 feet at Harper lake, and 30 to greater than 50 feet west of Harper Lake.

In order to evaluate water level trends and fluctuations during this period, water level hydrographs were prepared for wells with sufficient water level records over time. **Figures 4.15 through 4.18** present water level hydrographs of selected wells across the Centro Subarea grouped into four local areas referred to herein as south Centro, central Centro, east Centro, and the Harper Lake area. The areal coverage of each map is shown on **Figure 4.14**. On each figure, long-term hydrographs are shown from 1930 to 2010, while hydrographs with more recent data are shown from 1990 to 2010 and are highlighted in yellow. For areas with limited information, groundwater levels from multiple wells are combined on one hydrograph. Similarly, groundwater levels in nested wells (with variable screen depths) are combined to illustrate the vertical gradient and responses to recharge at these locations.

Also included on the basemaps to facilitate discussion of groundwater level trends are the following:

- 2010 groundwater elevation contours
- Average annual verified groundwater production of water supply wells of Stipulated Parties from WY 1993-94 through WY 2008-09 (open red circles sized according to pumping volume)
- Areas along the Mojave River that have responded measurably to recent storm recharge events across the Study Area in 1993, 1995, 1998, and 2005 floods (light blue shading on pertinent basemaps)

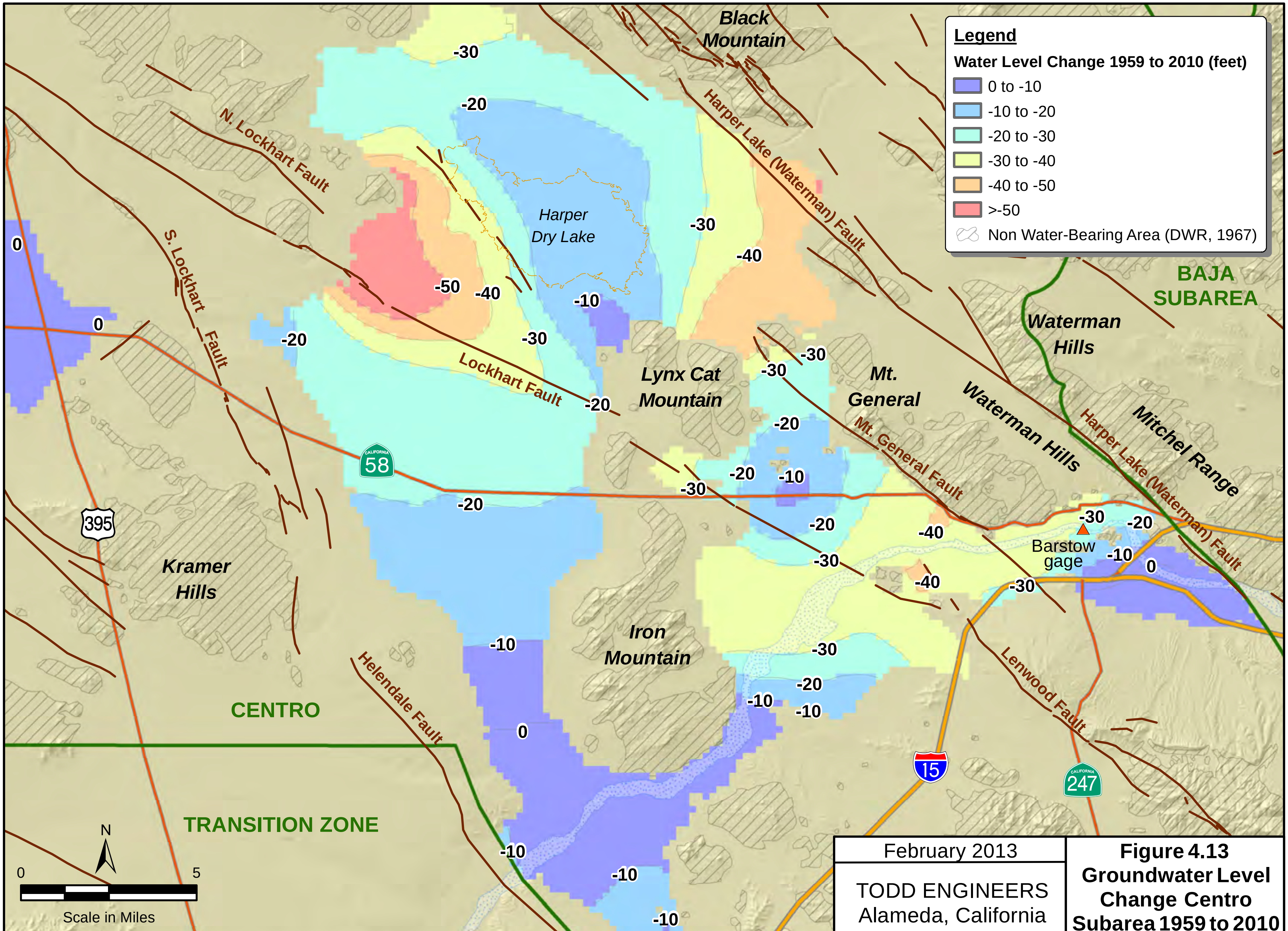

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Figure 4.13 Groundwater Level Change Centro Subarea 1959 to 2010

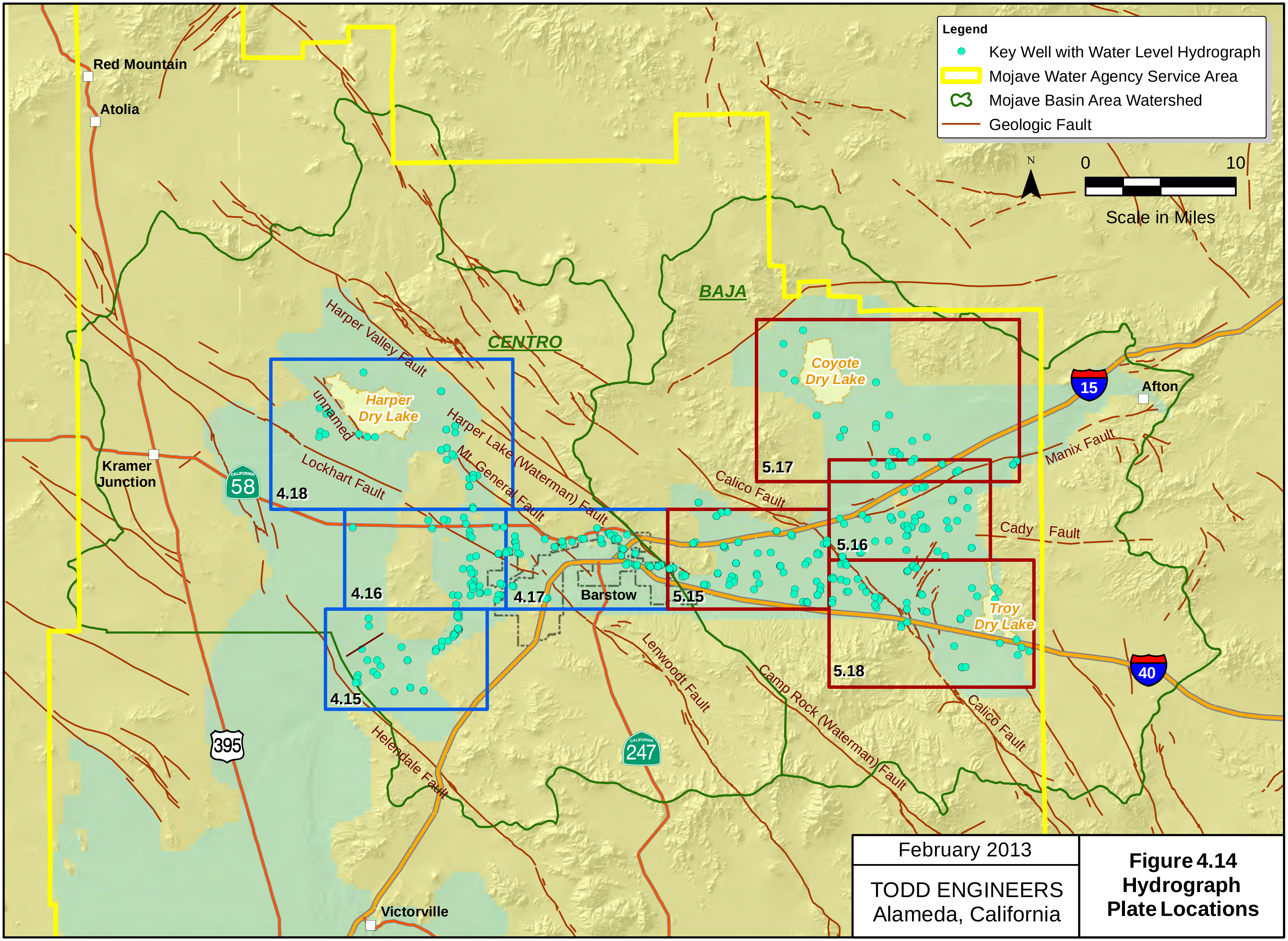

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Figure 4.14
Hydrograph Plate Locations

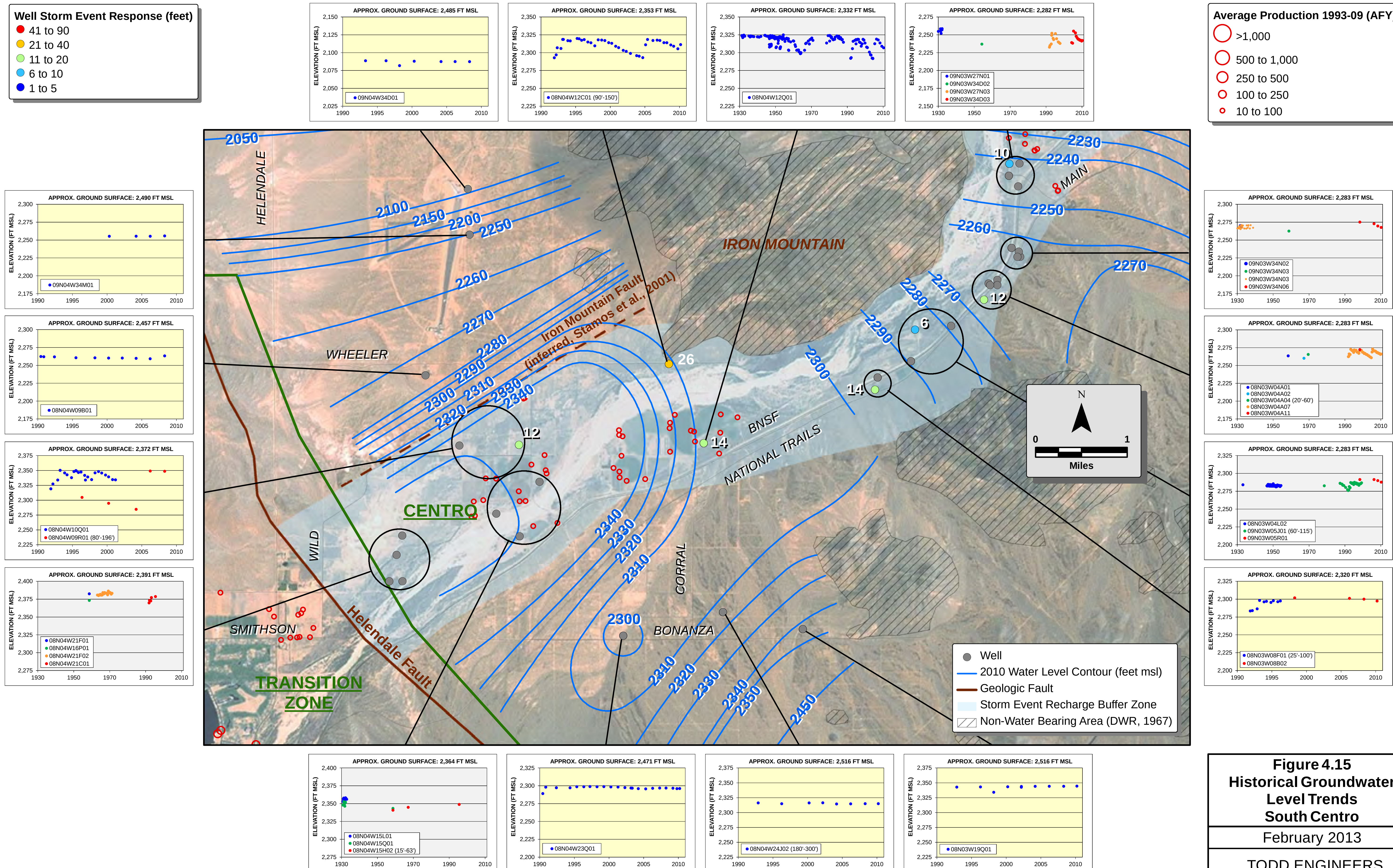

Figure 4.15
Historical Groundwater Level Trends
South Centro

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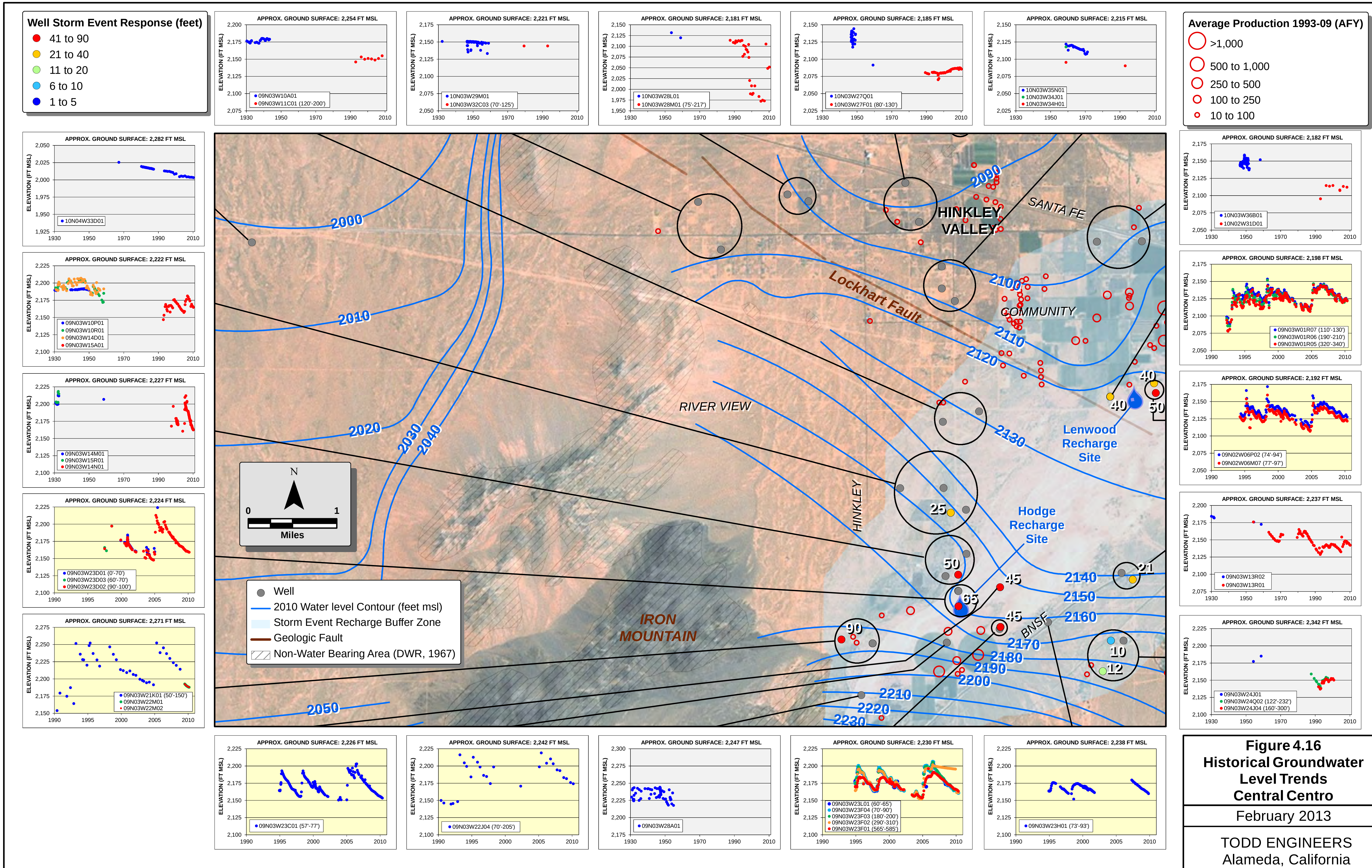

Figure 4.16
Historical Groundwater Level Trends
Central Centro

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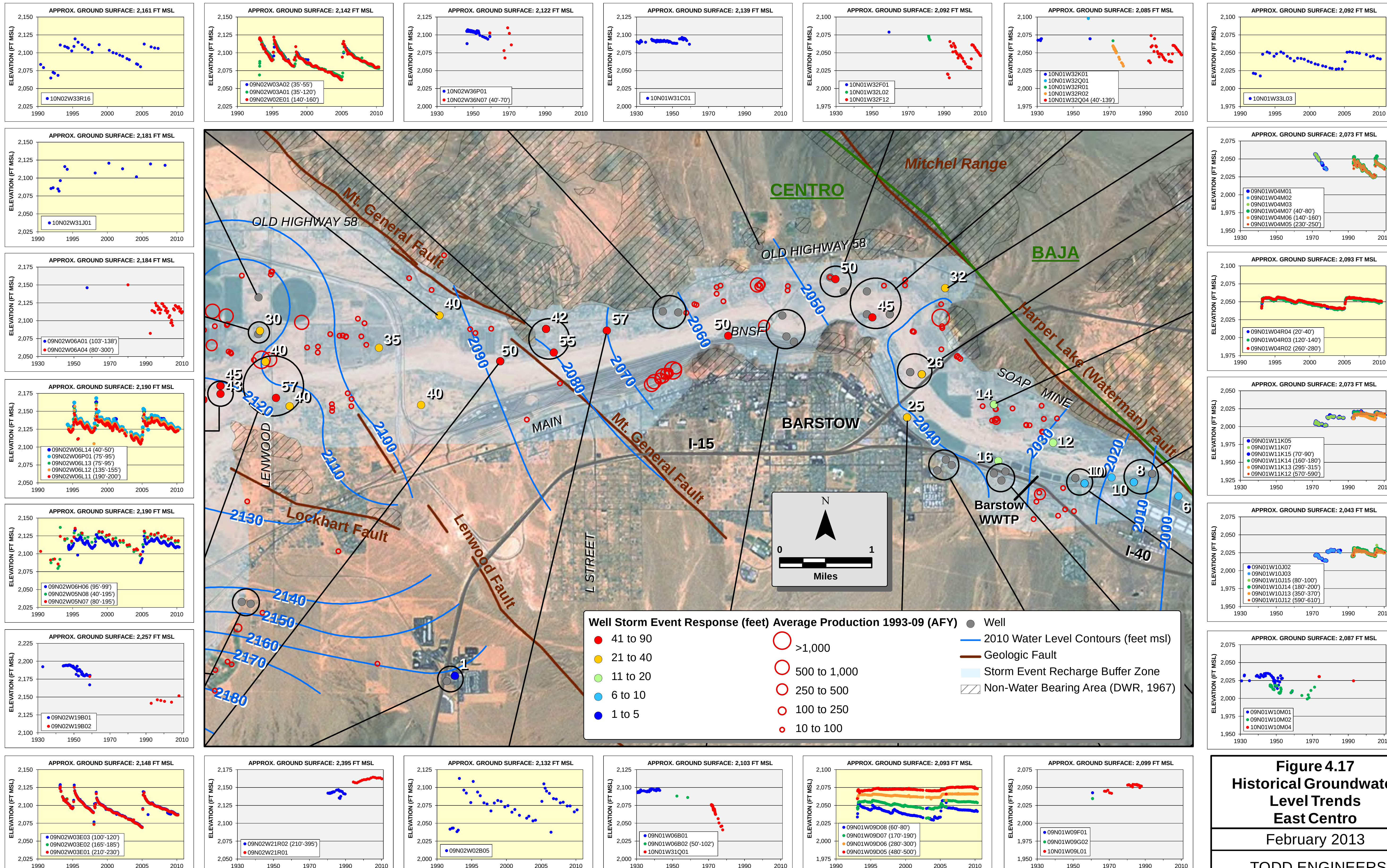

Figure 4.17
Historical Groundwater Level Trends
East Centro

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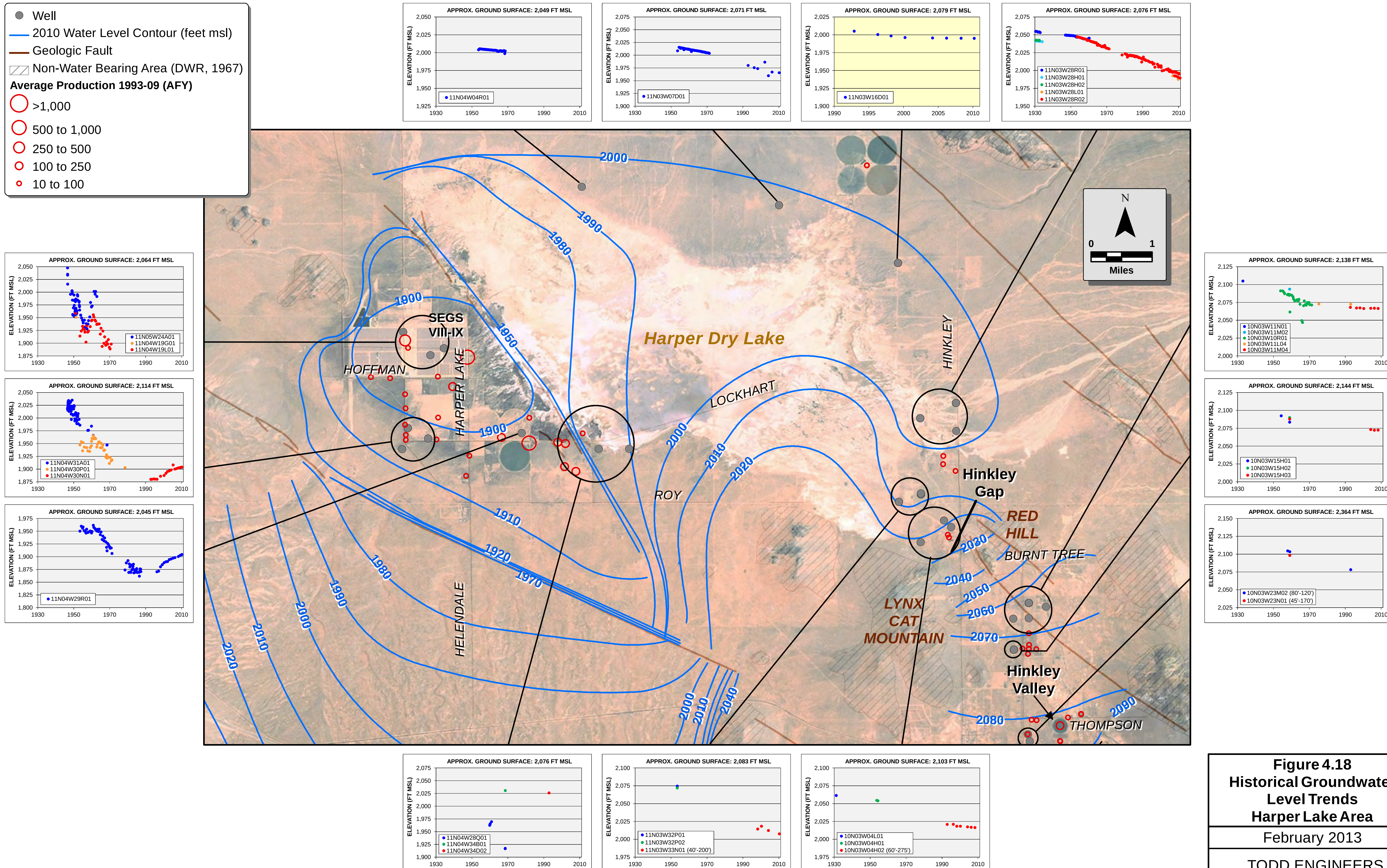

Figure 4.18
Historical Groundwater Level Trends
Harper Lake Area

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- Wells within the storm event recharge area with reliable storm event responses (circles colored based on the maximum groundwater level response to 1993, 1995, 1998, and 2005 storm events on pertinent basemaps)

The evaluation of specific hydrographs is revealing about local factors affecting wells (e.g., local production and proximity to the river). In reviewing the following maps and graphs, it is important to recognize the larger, regional context; a discussion is provided at the end of this section.

Figure 4.15 shows 16 water level hydrographs in the southern portion of the Centro Subarea downgradient of the Helendale Fault in the vicinity of Iron Mountain. Hydrographs on this figure generally indicate that local groundwater levels have been relatively stable over time. This is due in part to 1) the barrier effect of the Helendale Fault, which impedes groundwater flow in the regional aquifer, resulting in shallow groundwater conditions in the vicinity of the fault and 2) limited groundwater production downstream of the fault due to the relatively thin alluvium in the area (as shown on Centro cross sections A-A’ and E-E’). Verified annual production for this south Centro area has averaged less than 1,000 AFY since WY 1994. Water levels in the wells along the river have recorded the largest fluctuations as local water levels rise in response to storm recharge events. Maximum groundwater level fluctuations in seven wells along the river range from 10 to 15 feet, with the exception of one well (08N04W12C01 – second hydrograph from the left on the top of the figure) in which water levels have fluctuated a maximum of 26 feet.

Figure 4.16 shows 20 water level hydrographs in the central portion of the Centro Subarea, which extends from south Harper Valley in the west and across Iron Mountain into the southern portion of Hinkley Valley in the east. The one hydrograph in south Harper Valley (10N04W33D01; upper hydrograph in the left column) shows a gradual decline of about 25 feet over the past 50 years (about 0.5 feet per year). These declines are a result of historical groundwater pumping to the north in the Harper Lake area.

Wells located along the margins of and outside of the storm recharge zone in the Hinkley Valley (hydrographs in the upper right corner of the figure) show average declines of about 50 feet since 1950 (about 0.8 feet per year). For wells located southwest of the river channel along the margins of the storm recharge zone (two lower hydrographs in the right column), groundwater levels have declined by about 30 to 40 feet since 1930.

Wells within the storm recharge zone (shaded area along the Mojave River) fluctuate in response to stormflows in the river, but the response varies considerably along this reach. Water levels rise from as little as 10 feet southwest of the channel up to about 40 to 60 feet within the channel. Storm event response in one well adjacent to and west of Iron Mountain (09N03E21K01; lower hydrograph in left column) is estimated at 90 feet. The large storm event responses within the channel are primarily a result of 1) the high permeability of local shallow sediments in the main channel, 2) the relatively narrow width of the Floodplain Aquifer in this vicinity, and 3) the concentrated local groundwater production along the river between storm events. Verified annual production south of the Lockhart Fault since WY 1993-94 has averaged about 2,000 AFY; north of the Lockhart Fault, verified annual production over the same period has averaged close to 5,000 AFY.

Also shown on **Figure 4.16** are the locations of the MWA Hodge and Lenwood recharge sites, which have both been used to recharge SWP water since 1999. Through WY 2009-10, a total of 13,639 and 10,670 AF has been recharged at the Hodge and Lenwood recharge sites, respectively. While somewhat muted by the response to storm events, hydrographs of wells adjacent to the Hodge and Lenwood recharge sites confirm the positive benefits of enhanced historical recharge. For example, an extended period of recharge at the Hodge and Lenwood sites occurred during the spring and summer of 2006, during which no stormflows were recorded in this portion of the river. The water level hydrograph of 09N03W23D02 (second hydrograph from bottom in left column) and 09N03W23C01 (left hydrograph in bottom row) both show a positive groundwater level response of about 25 feet over this period. Similarly, water level hydrographs of wells adjacent to the Lenwood recharge site (09N02W06P02, 09N02W06M07 and 09N03W01R05-07; hydrographs in right column with yellow highlighting) each show a positive groundwater level response of about 10 feet during the 2006 recharge period. The maximum response is slightly lower for wells near the Lenwood recharge site, because total recharge at the Lenwood site was only about 900 AF compared to about 3,800 AF at the Hodge site in the first half of 2006.

Figure 4.17 shows 23 water level hydrographs in the eastern portion of the Centro Subarea from the Lenwood area, across downtown Barstow and the Barstow WWTP to the Harper Lake (Waterman) Fault. The few long-term hydrographs in the figure reveal that groundwater levels along this reach of the Mojave River were historically shallow and stable prior to groundwater development in the 1940s and 1950s. However, as local production increased, groundwater levels began to decline in the central portion of the reach as early as the 1960s; groundwater levels in the vicinity of the Barstow WWTP have been stabilized by historical effluent discharges. More recently, groundwater level declines caused by local production have generally recovered within the main channel following significant storm recharge events.

With the exception of a few wells, almost all of the wells represented in the figure are screened within the Floodplain Aquifer and respond significantly to storm event recharge. Maximum groundwater level response is generally higher (ranging from 40 to 60 feet) from the Lockhart Fault to about 1.5 miles upstream of the Barstow WWTP, because 1) the alluvial aquifer is relatively narrow in this location, 2) channel sediments are highly permeable, and 3) concentrated local production (including municipal production by the GSWC for the City of Barstow) significantly lowers groundwater levels and increases the recharge capacity of the Floodplain Aquifer beneath the channel prior to storm events. Verified annual production since WY 1993-94 between the Lockhart Fault and Mt. General Fault has averaged about 5,000 AFY; downgradient of the Mt. General Fault, verified annual production over the same period has averaged about 8,400 AFY. Groundwater levels have historically been stable in the vicinity and downgradient of the Barstow WWTP due to consistent effluent discharges in this portion of the reach. As a result, storm recharge responses are smaller (ranging from 5 to 15 feet) in this area.

Figure 4.18 shows 12 water level hydrographs in the northwestern portion of the Centro Subarea from the Harper Lake Area in the west across the Hinkley Gap into the northern Hinkley Valley in the southeast. The figure shows a systematic decline in groundwater levels across this region, although the magnitude of the decline varies across the area. Groundwater level declines have been greatest west of Harper Dry Lake. Three hydrographs in this area (left column) show that groundwater levels declined between 80 and 100 feet from 1950 through 1990 (2 to 2.5 feet per year). These declines are associated with historical agricultural pumping, which averaged about 9,000 AFY over the base period and exceeded 13,000 AFY from the late-1950s through the mid-1980s. Since the Judgment, agricultural land west of Harper Dry Lake has been gradually converted to industrial land uses (e.g., SEGS VIII-IX), and local production has declined. Verified production since WY 1993-94 has averaged about 2,500 AFY; verified production was about 1,700 AFY in WY 2008-09. In turn, groundwater levels have recovered by some 25 to 30 feet west of Harper Dry Lake over the past 20 years.

Southeast of Harper Dry Lake and downgradient of the Hinkley Gap, groundwater levels have declined between 50 and 75 feet from 1950 to 2010 (0.8 to 1.25 feet per year). Since local production has historically been minimal in this area, declines southeast of Harper Dry Lake can be attributed primarily to historical groundwater production in the Hinkley Valley (which has reduced the saturated thickness of alluvial sediments across the Hinkley Gap and, in turn, reduced subsurface inflow to Harper Lake). Despite the presence of fine-grained sediments underlying Harper Dry Lake and the unnamed fault west of Harper Dry Lake serving as a partial hydraulic barrier, production west of Harper Dry Lake may also contribute partially to groundwater level declines east of Harper Dry Lake, given the westerly direction of groundwater flow beneath Harper Dry Lake towards the historical pumping depression to the west and the conceptual understanding that groundwater evaporation at Harper Dry Lake may have ceased as early as the 1960s (Stamos et al., 2001). As indicated in the three hydrographs on the right column of **Figure 4.18**, groundwater levels in the northern portion of Hinkley Valley have also declined by some 30 to 40 feet since pre-development conditions.

The declining water level trend in 11N03W07D01 (second from left in top row of hydrographs) suggests that historical pumping north of Harper Dry Lake has resulted in localized groundwater level declines.

Effects of Regional Scale Pumping on Groundwater Level Trends

Groundwater level trends in Centro are affected directly by local Centro Subarea pumping and indirectly by upstream regional pumping. Upstream regional pumping affects downstream groundwater levels primarily by reducing downstream flows and recharge beneath the Mojave River. Results of the evaluation of stream gage records (Section 3.10) indicate that Mojave River flows—and consequently recharge from river leakage—has declined in the lower portions of the Basin since the 1950s, reflecting combined climatic and anthropogenic factors (e.g., upstream pumping).

The USGS assessed the influence of historical groundwater production in the upper portions of the Basin (i.e., Transition Zone, Alto, Este, Oeste subareas) on the frequency and magnitude of intermittent Mojave River flows and groundwater level declines in the Centro and Baja subareas (Stamos et al., 2001). For this assessment, USGS simulated historical conditions with no pumping in the upper region of the basin (Alto, Transition Zone, Este, and Oeste subarea) using the Mojave River Basin groundwater flow model. Under the “no upper Basin pumping” scenario, simulated groundwater levels in the Alto and Transition Zone subareas were near the altitude of the streambed throughout the upper region; this caused potential recharge from the Mojave River to be rejected in the upper region, thereby allowing more streamflow to reach and recharge the lower region. For the Centro model subarea, simulation results showed that groundwater recharge from the Mojave River increased by 13,110 AFY and groundwater discharge also increased by 6,530 AFY (e.g., to increased ET and discharge to the river). The net effect of the "no upper Basin pumping" scenario was a reversal of the Centro groundwater storage decline amounting to 6,580 AFY. Applying this annual effect to the entire simulation period 1931 – 1990 indicates that the upstream effect amounts to 394,800 AF over the simulation period; this represents most of the groundwater lost from storage in the Centro model subarea.

4.6 Centro Groundwater Storage

For an analysis of groundwater in storage, 2010 groundwater elevations (**Figure 4.9**) and elevations representing the base of unconsolidated sediments (**Figure 4.2**) were imported into the project GIS database. The thickness of saturated unconsolidated sediments was determined electronically by computing the difference in elevation between raster surfaces generated from each dataset (**Figure 4.19**). The raster representing the thickness of saturated unconsolidated sediments was then multiplied with the raster surface representing the estimated aquifer storativity of Layer 1 of the USGS model to estimate groundwater in storage. Model subareas consistent with those used in the USGS groundwater flow model (**Figure 4.20**) were used to estimate groundwater in storage and historical changes in groundwater storage across the Study Area. For the Centro Subarea, the area representing the Harper model subarea in the USGS model report was further subdivided in this Study, herein referred to as the North Harper Lake and South Harper Lake model subareas.

Using this methodology, groundwater storage was estimated for the four model subareas within Centro (Centro, South Harper Valley, South Harper Lake, and North Harper Lake) on **Figure 4.20**; these estimates are summarized in the table below.

Table 4.2
2010 Groundwater in Storage - Centro Subarea

Subarea/ Model Subarea	Area[a] (acres)	Average Saturated Thickness of Unconsolidated Sediments (feet)	Aquifer Storativity[b]	Estimated Groundwater in Storage[c] (AF)
	(a)	(b)	(c)	(a x b x c)
Centro Subarea				
Centro	54,448	201	0.12 - 0.22	1,923,000
South Harper Valley	45,059	254	0.12	1,371,000
South Harper Lake	15,502	296	0.12	551,000
North Harper Lake	40,972	322	0.12	1,584,000
Total	**155,980**			**5,429,000**

[a]Area of saturated alluvial sediments defined on Figure 4.19 within model subarea
[b]Model Layer 1 (Stamos et al., 2001)
[c]Volume of groundwater above base of unconsolidated sediments
Note: Average Saturated Thickness values are rounded to nearest integer in table

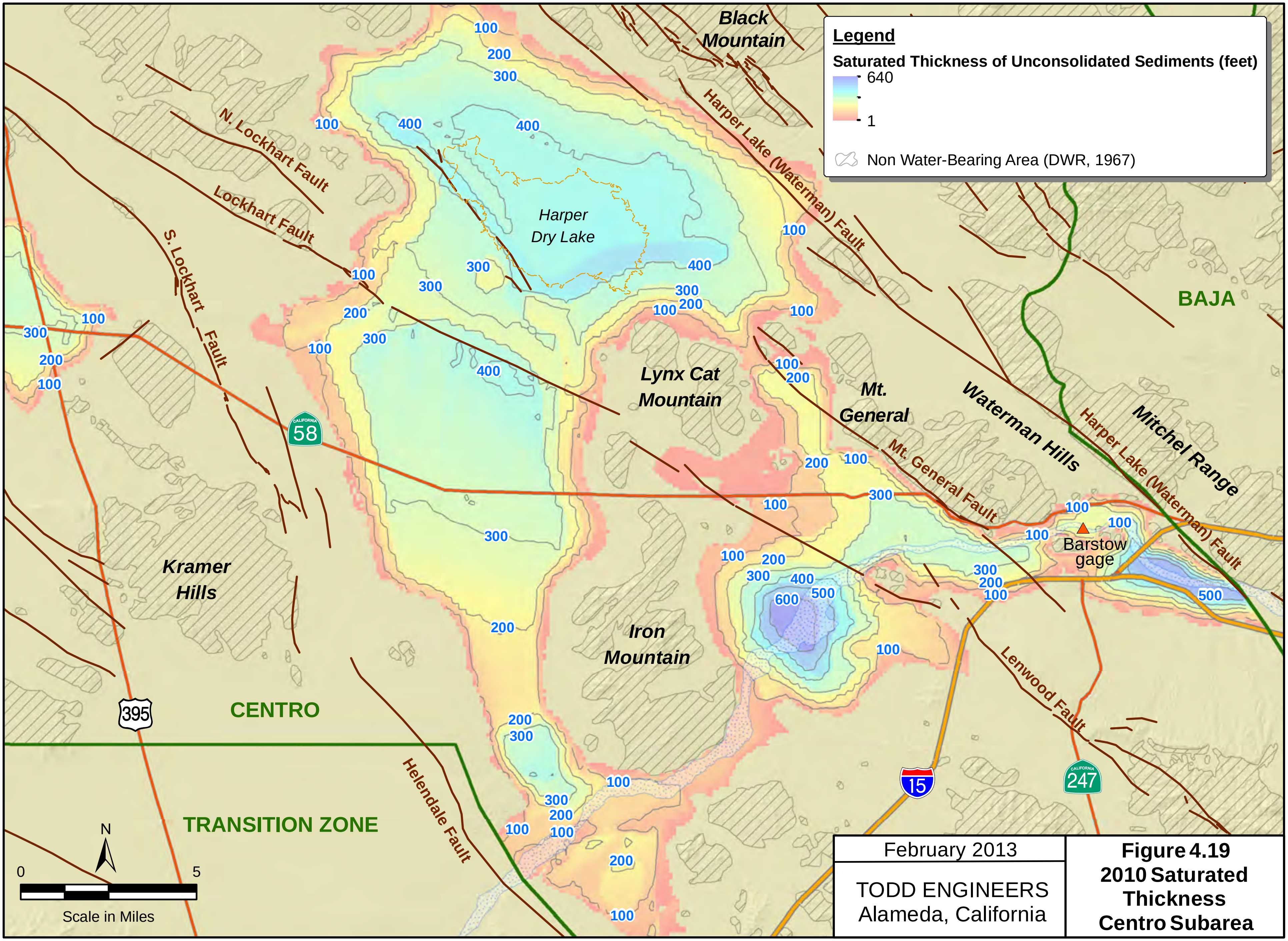
Legend
Saturated Thickness of Unconsolidated Sediments (feet)
640
1
Non Water-Bearing Area (DWR, 1967)
Black Mountain
Harper Dry Lake
Lynx Cat Mountain
Mt. General
Waterman Hills
Mitchel Range
Kramer Hills
Iron Mountain
Barstow gage
BAJA
CENTRO
TRANSITION ZONE
N. Lockhart Fault
Lockhart Fault
S. Lockhart Fault
Harper Lake (Waterman) Fault
Mt. General Fault
Lenwood Fault
Helendale Fault
58
395
15
247
Scale in Miles
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Figure 4.19
2010 Saturated Thickness
Centro Subarea

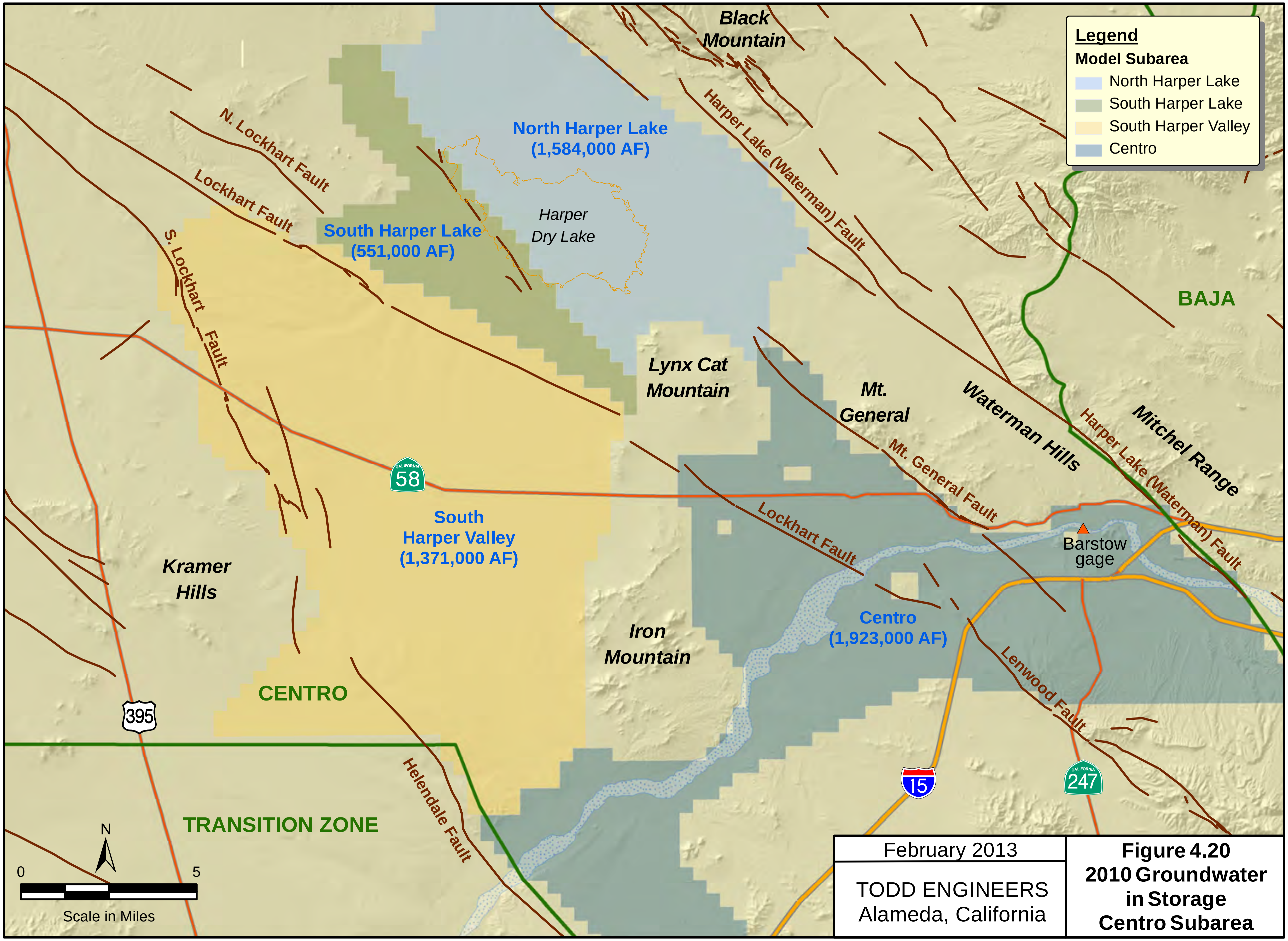

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Figure 4.20
2010 Groundwater in Storage
Centro Subarea

As shown in the table, the estimated groundwater in storage within the Centro Subarea is 5,429,000 AF. Of the total storage volume, 35.4 percent (1,923,000 AF) is stored in the Centro model subarea, 25.3 percent (1,371,000 AF) is stored in the South Harper Valley model subarea, 10.1 percent (551,000 AF) is stored in the South Harper Lake model subarea, and 29.2 percent (1,584,000 AF) is stored in the North Harper Lake model subarea.

These values represent the amount of stored groundwater that theoretically could be pumped with wells (albeit without consideration of long-term sustainability, economic or environmental factors). It is recognized that the application of the storativity value in Layer 1 to the entire sequence may overestimate the groundwater in storage in the deeper portions of the basin. Nonetheless, these totals provide a more rigorous estimate of the total amount of groundwater in storage than past evaluations and are reasonable for planning purposes.

The groundwater storage volumes estimated herein are similar to estimates that would result if the USGS model storativity values were applied to the depth to base of fresh water contours presented in Bulletin No. 84 (DWR, 1967). This is because both estimates are based on interpreted porosity/water quality contrasts in semi-consolidated to consolidated Quaternary older alluvium deposits identified in well driller's logs. The groundwater storage volumes in this report are much smaller than the estimates made previously by SSI (1990), which are based on model inversion of gravimetric data and estimates of total porosity (rather than effective porosity). While the SSI method provides an approximation of the depth to consolidated Tertiary and pre-Tertiary basement rocks, the method used to invert the raw gravity data was not performed at a resolution appropriate for identifying density and porosity contrast observed within Quaternary older alluvial deposits. Additionally, it is clear that the contouring method applied to inverted model data in the SSI study was not verified against basement rock outcrops and incorrectly overestimates the depth to consolidated rock along the basin margins, where bedrock and shallow semi-consolidated to consolidated, Quaternary older alluvial deposits occur in the shallow subsurface. As a consequence of these inaccuracies, the SSI report is judged to overestimate groundwater storage across the Study Area and, as such, its use is limited.

4.7 Centro Subarea Water Budgets

This section summarizes the groundwater inflows (sources) and outflows (sinks) within the Centro Subarea. Various sources of information, including the USGS Mojave River Basin groundwater flow model, MWA Watermaster annual reports, and other technical studies, were used to document the subarea water budget over an 80-year period from calendar year (CY) 1931 through WY 2009-2010.

In order to relate changes in the subarea water budget to evolving land use and groundwater management over time, separate water budgets were developed for time periods prior to and since the Judgment. For this study, a copy was obtained from MWA of the original USGS groundwater model converted into Groundwater Vistas format. Model input files were verified against information reported in Stamos et al. (2001) to ensure that input and output files were identical to those generated by the original USGS model. The USGS model provides the only reliable estimates of subarea inflows, outflows, and changes in groundwater storage on an annual basis prior to the Judgment.

Since the development of the USGS groundwater flow model, groundwater use has changed considerably in response to production rampdown mandated by the Judgment. Additionally, the understanding of surface water flows across the Helendale Fault and Waterman Fault has improved, and estimates of consumptive use and return flows covering the latter portion of the transient simulation period have been refined. To better understand the groundwater budget of the Centro Subarea since the Judgment, a water budget from WY 1993-94 through WY 2009-10 was developed incorporating improved annual estimates of groundwater production, consumptive use, and return flows from Watermaster and revised estimates of ungaged local mountain runoff.

Major inflows accounted for in the Centro Subarea water budget include:

- Recharge from Mojave River leakage
- Subsurface inflow from the Transition Zone
- Return flow from irrigation
- Return flow from WWTP effluent discharges
- Artificial recharge of SWP water

Major outflows accounted for in the Centro Subarea water budget include:

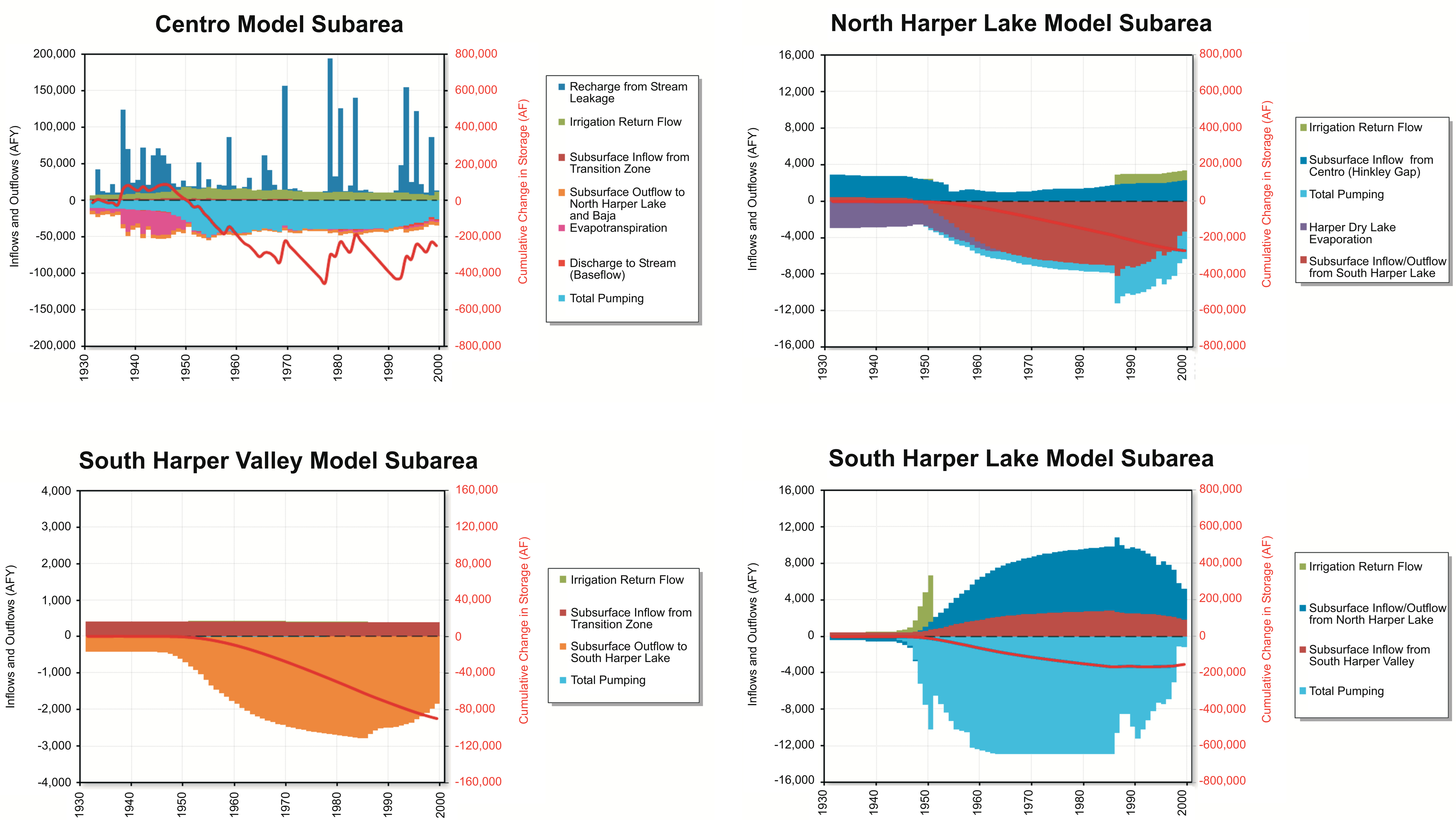
- Groundwater pumping
- Groundwater discharge to the Mojave River (baseflow)
- Subsurface outflow to the Baja Subarea at Harper Lake (Waterman) Fault
- Evapotranspiration (transpiration by phreatophytes and free water evaporation)
- Bare-soil evaporation (at Harper Dry Lake)

4.7.1 USGS Model Centro Subarea Water Budget (1931 to 1999)

While several studies have been conducted to estimate the various components of the groundwater budget for the Mojave River Basin, the documented input files and results of groundwater flow model simulations conducted by Stamos et al., (2001) provide the most reliable estimates of basin inflows and outflows prior to the Judgment. These data and simulations allow for the development of a transient water balance of the Centro Subarea for the model period from 1931 to 1999. Estimates of water budget components derived from the model are documented in this section.

Because groundwater occurrence and flow across the Centro Subarea varies considerably and is subject to numerous inter-related stresses, water budgets for four separate areas within Centro (model subareas) were developed from model outputs for this study. The water budgets for these four areas specifically help to define the hydraulic relationship between the north and south Harper Dry Lake areas and their relationships to the floodplain and regional aquifer systems along the Mojave River. The water budgets also account for groundwater storage changes west of Iron Mountain between the Iron Mountain Fault and Lockhart Fault. **Figure 4.20** shows the boundaries of the four model subareas, herein referred to as Centro, South Harper Valley, South Harper Lake, and North Harper Lake. The combined water budgets presented for the Centro and South Harper model subareas in this report correspond to the water budget reported for the Centro model subarea in the USGS model report (Stamos, et al., 2001), while the combined water budgets for the North and South Harper Lake model subareas in this report correspond to the budget reported for the Harper model subarea in the USGS model report.

Figure 4.21 shows the annual water budgets from the USGS model for the four model subareas from 1931 to 1999. Shown on each chart are the individual surface water and groundwater inflows and outflows and the cumulative change in groundwater storage (red lines). Average annual data from these budgets, along with surface water streamflow data, are summarized in **Tables 4.3a through 4.3d.** Averages are presented for two periods: the judgment-defined base period (1931 to 1990) and the full transient simulation (1931 to 1999). Complete documentation of each water budget, including annual inflows and outflows for each model subarea, is tabulated in **Appendix F**.



February 2013	**Figure 4.21**
TODD ENGINEERS Alameda, California	**Water Budget for Centro, South Harper Valley, North Harper Lake, and South Harper Lake Model Subareas (1931 to 1999)**

Table 4.3a
USGS Centro Model Subarea Water Budget (1931 to 1999)

	Ave (1931-90)	Ave (1931-99)
INFLOWS		
Surface Water Inflow	33,459	37,517
Mojave River (at Helendale Fault)	*31,349*	*35,358*
Ungaged Tributaries	*2,110*	*2,105*
Artificial Recharge - Lenwood and Hodge	*0*	*54*
Recharge from Stream Leakage	23,799	26,661
Subsurface Inflow from Transition Zone (at Helendale Fault)	1,162	1,134
Irrigation Return Flow	9,585	9,207
WWTP Effluent Return Flow	1,179	1,358
Barstow upper sewage ponds	*416*	*401*
Barstow lower sewage ponds	*671*	*819*
Barstow irrigated field	*55*	*96*
MCLB Nebo Golf Course	*36*	*41*
Total Groundwater Inflows	**35,725**	**38,360**
OUTFLOWS		
Surface Water Outflow - Mojave River (at Waterman Fault)	-10,476	-11,925
Groundwater Discharge to Stream (baseflow)	-207	-399
Subsurface Outflow	-3,186	-3,274
to Baja Model Subarea (at Waterman Fault)	*-1,462*	*-1,506*
to North Harper Lake Model Subarea(at Hinkley Gap)	*-1,724*	*-1,768*
Evapotranspiration	-6,508	-5,881
Total Pumping	-32,567	-32,402
Total Groundwater Outflows	**-42,468**	**-41,956**
Annual Change in Groundwater Storage	**-6,743**	**-3,596**

Table 4.3b
USGS South Harper Valley Model Subarea Water Budget (1931 to 1999)

	Ave (1931-90)	Ave (1931-99)
INFLOWS		
Subsurface Inflow - Transition Zone (at Helendale Fault)	404	401
Irrigation Return Flow	0	0
Total Groundwater Inflows	**404**	**402**
OUTFLOWS		
Subsurface Outflow - to South Harper Lake Model Subarea	-1,627	-1,706
Total Pumping	-1	-1
Total Groundwater Outflows	**-1,628**	**-1,707**
Annual Change in Groundwater Storage	**-1,224**	**-1,305**

Table 4.3c
USGS South Harper Lake Model Subarea Water Budget (1931 to 1999)

	Ave (1931-90)	Ave (1931-99)
INFLOWS		
Subsurface Inflow	5,316	5,627
from North Harper Lake Model Subarea	3,689	3,921
from South Harper Valley Model Subarea (at Lockhart Fault)	1,627	1,706
Irrigation Return Flow	239	208
Total Groundwater Inflows	**5,556**	**5,835**
OUTFLOWS		
Total Pumping	-8,320	-8,056
Agricultural Irrigation	[a]	[a]
Industrial	[a]	[a]
Total Groundwater Outflows	**-8,320**	**-8,056**
Annual Change in Groundwater Storage	**-2,764**	**-2,221**

Table 4.3d
USGS North Harper Lake Model Subarea Water Budget (1931 to 1999)

	Ave (1931-90)	Ave (1931-99)
INFLOWS		
Subsurface Inflow (from Centro through Hinkley Gap)	1,724	1,768
Irrigation Return Flow	91	216
Total Groundwater Inflows	**3,681**	**3,898**
OUTFLOWS		
Subsurface Outflow to South Harper Lake Model Subarea	-3,689	-3,921
Total Pumping	-670	-978
Agricultural Irrigation	[a]	[a]
Industrial	[a]	[a]
Harper Dry Lake Evaporation	-1,150	-1,000
Total Groundwater Outflows	**-5,509**	**-5,899**
Annual Change in Groundwater Storage	**-3,695**	**-3,915**

[a] Average annual pumping by sector could not be estimated from model outputs, because the lack of irrigation return flows for several years could be represented by 1) perching of irrigation return flow in the Harper Dry Lake area assumed in the USGS model and/or 2) industrial pumping, for which return flow is assumed to be zero.

Observations from the charts on **Figure 4.21** and **Tables 4.3a through 4.3d** are summarized below.

<u>Change in Groundwater Storage</u> - In each of the four model subareas within Centro, groundwater storage losses occurred over the base period (1931 to 1990) and transient simulation period (1931 to 1999) (**Tables 4.3a through 4.3d**). Average annual storage changes during the 1931-90 base period from the Centro, South Harper Valley, South Harper Lake, and North Harper Lake model subareas were -6,743 AFY, -1,224 AFY , -2,764 AFY, and -3,695 AFY respectively, for a combined average annual groundwater storage change of -14,426 AFY. Average annual storage changes over the transient simulation period from the Centro, South Harper Valley, South Harper Lake, and North Harper Lake model subareas were -3,596 AFY, -1,305 AFY, -2,221 AFY, and -3,915 AFY, respectively, for a combined average annual storage loss of -11,037 AFY. While storage losses in the South Harper Valley, North Harper Lake, and South Harper Lake model subareas were relatively similar for both time periods, storage losses in the Centro model subarea were smaller for the transient simulation period relative to the base period because of large storm recharge events that occurred in 1993, 1995, and 1998.

As shown on **Figure 4.21**, groundwater storage losses resulted from significant increases in historical groundwater production beginning in the late 1940s in the Centro and South Harper Lake model subareas primarily. Total groundwater production within the entire Centro Subarea averaged 41,558 AFY and 41,436 AFY during the base period and transient simulation period, respectively. Of the total production, about 78 percent occurred in the Centro model subarea, 20 percent occurred in the South Harper Lake model subarea, and 2 percent occurred in the North Harper Lake model subarea.

<u>Return Flows</u> – In the USGS model, irrigation return flows were estimated to be 50 percent of total agricultural pumping in all model subareas from 1931 to 1950. From 1951 through 1999, irrigation return flows were estimated at 35 percent in the Centro model subarea and portions of the North and South Harper Lake model subareas (outside of the perched water table condition interpreted in the vicinity of Harper Dry Lake, where return flows to the Regional Aquifer system were assumed to be zero). These return flow percentages were based on a method developed by the MBA Watermaster used to calculate total agricultural production from 1986 through 1994 and USDA-defined crop consumptive use rates estimated for each model subarea. No return flows were assigned for municipal production; rather specific WWTP effluent return flows were estimated for the Barstow WWTP sewage ponds and irrigated fields and MCLB Nebo Golf Course. Average annual WWTP effluent return flows within the Centro model subarea were 1,179 AFY for the base period and 1,358 AFY for the transient simulation period. Return flows associated with septic tank discharges within the Centro Subarea were not simulated in the model.

<u>Recharge from Stream Leakage</u> - While highly variable on an annual basis, recharge from Mojave River leakage averaged 23,799 AFY and 26,661 AFY during the base period and transient simulation period, respectively (**Table 4.3a**). These volumes account for 93 percent of the total natural recharge in the Centro model subarea (with the other 7 percent represented by subsurface inflow from the Transition Zone). Contained in recharge from stream leakage are local ungaged tributary flows from five mapped ephemeral washes based on work by Lines (1996). Average annual recharge volumes from local ungaged tributary flows were 2,110 AFY and 2,105 AFY for the base period and transient simulation period, respectively. A focused evaluation of the ungaged tributary flows conducted for this study indicates that the annual local ungaged tributary flows by Lines are significantly overestimated (see **Appendix C** for detailed explanation). Additionally, a small volume of stream leakage (54 AFY) is derived from enhanced recharge at the MWA Lenwood and Hodge sites in 1999.

<u>Subsurface Inflows and Outflows</u> – Subsurface inflow from the Transition Zone into the Centro Subarea averaged 1,566 AFY and 1,535 AFY during the base period and transient simulation period (**Tables 4.3a and 4.3c**). This value is similar to the DWR (1967) estimate of 2,000 AFY, which was based on a Darcy calculation. Of the total subsurface inflow, 74 percent flows into the Centro model subarea (1,162 AFY during the base period and 1,134 AFY during the transient simulation period), while the remaining 26 percent flows into the South Harper model subarea (404 AFY during the base period and 401 AFY during the transient simulation period).

Subsurface flow from the Centro model subarea across the Hinkley Gap represents the primary subsurface inflow to the North Harper Lake model subarea. Average annual subsurface flow through Hinkley Gap was 1,724 AFY and 1,768 AFY during the base period and transient simulation period, respectively. Model estimates of subsurface flow through Hinkley Gap are similar to other estimates based on Darcy calculations supported by geologic log interpretation (DWR, 1967; Ebbs, 2007; CSUF, 2010) and electrical resistivity surveys (AS&T, 2007), which range from 1,000 to 1,468 AFY. (Note: The Mark Group (1989) estimated that subsurface flow through the Hinkley Gap was about 2,700 AFY using a Darcy calculation. However, this estimate was based on a cross-sectional width of 8 miles, which is not possible given that the distance between Red Hill and Lynx Cat Mountain from peak to peak is only 3 miles). Notably, subsurface flow through the Hinkley Gap decreased slightly when production in the Harper model subarea (southwest of Harper Dry Lake) increased significantly from 1950 to 1990. The decrease in subsurface flow across Hinkley Gap is attributable to simultaneous groundwater level declines occurring in the Hinkley Valley resulting in a decrease in saturated thickness at the gap.

Subsurface flow from the South Harper Valley model subarea across Lockhart Fault (**Table 4.3b**) represents the primary subsurface inflow into the South Harper Lake model subarea. Average annual subsurface flow from the South Harper Valley model subarea across Lockhart Fault was 1,627 AFY and 1,706 AFY during the base period and transient simulation period, respectively. Subsurface inflows from the South Harper Valley model subarea to South Harper Lake model subarea across the Lockhart Fault increased from less than 1,000 AFY prior to the 1950s to a maximum of about 2,800 AFY in the mid-1980s. Subsurface flows decreased in the latter portion of the simulation period to less than 2,000 AFY in response to decreased pumping and some groundwater level recovery in the southwest Harper Lake area.

Annual model water budgets for the North Harper Lake and South Harper Lake model subareas (**Appendix F**) suggest that between 1931 and 1947 groundwater flowed from South Harper Lake across the unnamed fault on the western side of Harper Dry Lake and evaporated beneath Harper Dry Lake. However, as a result of increased groundwater production west of Harper Dry Lake, groundwater that once discharged beneath Harper Dry Lake began flowing across the unnamed fault west of Harper Dry Lake towards the pumping depression in the South Harper Lake model subarea starting in the late 1940s. The rate of subsurface flow from North Harper Lake into South Harper Lake increased (up to more than 8,000 AFY) in 1986, corresponding to the peak of local agricultural production. Model water budgets suggest that groundwater discharge to Harper Dry Lake may have ceased sometime in the mid-1960s. The rate at which groundwater flowed from North Harper Lake to South Harper Lake gradually decreased from 1986 through 1999 in response to significant curtailment of local groundwater production over that period. The subsurface flow dynamics simulated in the USGS model are generally supported by groundwater elevation contour and depth to water maps and well hydrographs prepared for this study; however, additional hydrogeologic investigation is needed to confirm the hydraulic connection between the North Harper Lake and South Harper Lake model subareas.

Subsurface outflow from the Centro model subarea to the Baja Subarea across the Harper Lake (Waterman) Fault averaged 1,462 AFY and 1,506 AFY during the base period and transient simulation period, respectively (**Table 4.3a**). Historically, annual subsurface outflows to the Baja Subarea correlated directly to the annual volume of river discharge and recharge from river leakage in the Centro Subarea; however, in the latter portion of the transient model simulation period, subsurface outflows were less variable as a result of consistent annual effluent discharges at the Barstow WWTP.

<u>Evapotranspiration (ET)</u> – ET losses occurred in the Centro Model Subarea only and averaged 6,508 AFY and 5,881 AFY during the base period and transient simulation period, respectively (**Table 4.3a**). ET was much higher in the 1930s and 1940s (averaging over 18,000 AFY) but declined significantly beginning in 1950. ET averaged only about 1,110 AFY in the later portion of the transient simulation period.

<u>Groundwater Discharge to Harper Dry Lake</u> – Estimated evaporation of groundwater beneath Harper Dry Lake averaged 1,150 AFY and 1,000 AFY during the base period and transient model period, respectively (**Table 4.3c**). Dry lake evaporation was initially estimated at 2,800 AFY in the early years of the model but gradually declined beginning in the mid-1940s when local groundwater levels declined. Simulation results indicate that evaporation of groundwater beneath Harper Dry Lake ceased in the 1960s.

<u>Surface Water Flow</u> – Because of the important role of surface water as the primary source of recharge to the subarea, surface water inflows and outflows are presented with the groundwater budgets (see gray shading on **Table 4.3a**). For the Mojave River, inflows occur at the Helendale Fault and outflows occur at the Harper Lake (Waterman) Fault. As shown on **Table 4.3a**, Mojave River inflow averaged 31,349 AFY and 35,358 AFY during the base period and transient simulation period, respectively. Mojave River outflow across the Harper Lake (Waterman) Fault averaged 10,476 AFY and 11,925 AFY during the base period and transient simulation period, respectively. These data indicate that, on average, about 25 percent of Mojave River inflows leave the subarea with about 75 percent reduction, primarily to groundwater recharge. However, these amounts are highly variable as indicated by the recharge (from stream leakage) portion of the Centro Model Subarea chart on the top of **Figure 4.21**. It is noted that while streamflows at the Lower Narrows, Barstow, and Afton gages were used for model calibration, only the combined flows at the Deep Creek and West Fork of the Mojave River gages above The Forks Dam were used as model inputs.

Figure 4.22 shows the cumulative change in groundwater storage for the four model subareas combined. The figure shows that groundwater storage in the Centro Subarea declined more than 760,000 AF from 1931 to 1999, with most of the storage losses occurring between 1950 and the late

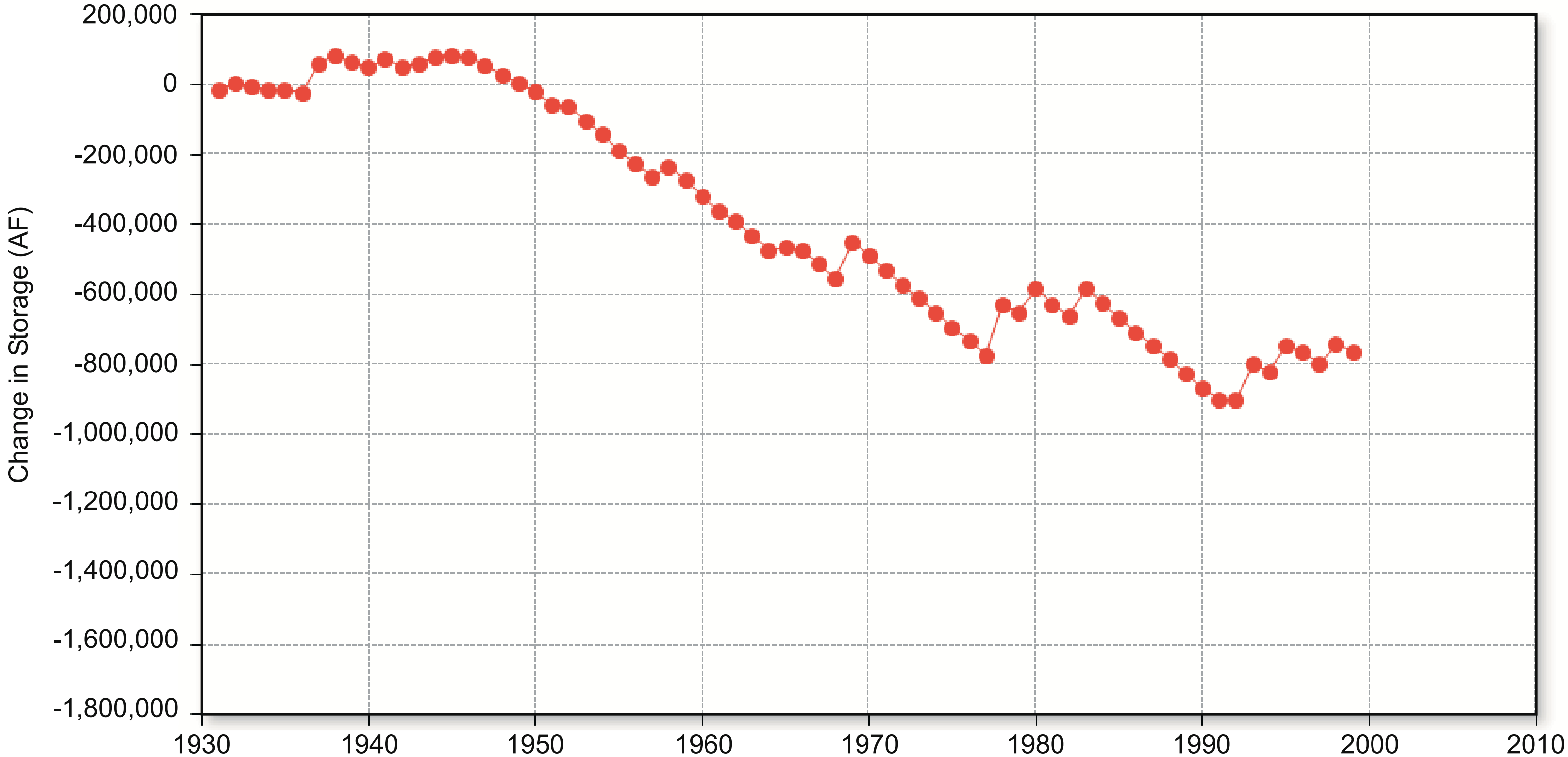


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Figure 4.22
Groundwater Storage Change for Centro Subarea (1931 to 1999)

1970s. From the late 1970s to the end of the transient simulation period, groundwater inflows and outflows for the entire Centro Subarea were generally in balance.

4.7.2 Centro Subarea Water Budget (WY 1993-94 to WY 2009-10)

A water budget for the Centro Subarea from WY 1993-94 to WY 2009-10 was developed to better understand subarea hydrogeologic conditions since the Judgment and to incorporate more recent and reliable estimates of surface water flows across the Helendale and Harper Lake (Waterman) faults and consumptive use and return flows. Annual inflows and outflows for the same model subareas as defined in the USGS model (Centro, South Harper Valley, South Harper Lake, and North Harper Lake) are tabulated in **Tables 4.4a through 4.4d** and shown on **Figures 4.23**. The four model subarea water budgets were also combined to produce a single water budget for the entire Centro Subarea, which is tabulated in **Table 4.5** and shown on **Figure 4.24**. Additionally, the water budgets developed for the North and South Harper Dry Lake model subareas are compared to recent findings by the California Energy Commission (CEC), who as part of their environmental review for the proposed Abengoa Mojave Solar Project (MSP), conducted model simulations to estimate the operational yield of the Harper Lake Basin (CEC, 2011).

Sources of information and assumptions used to estimate individual water budget components are summarized below:

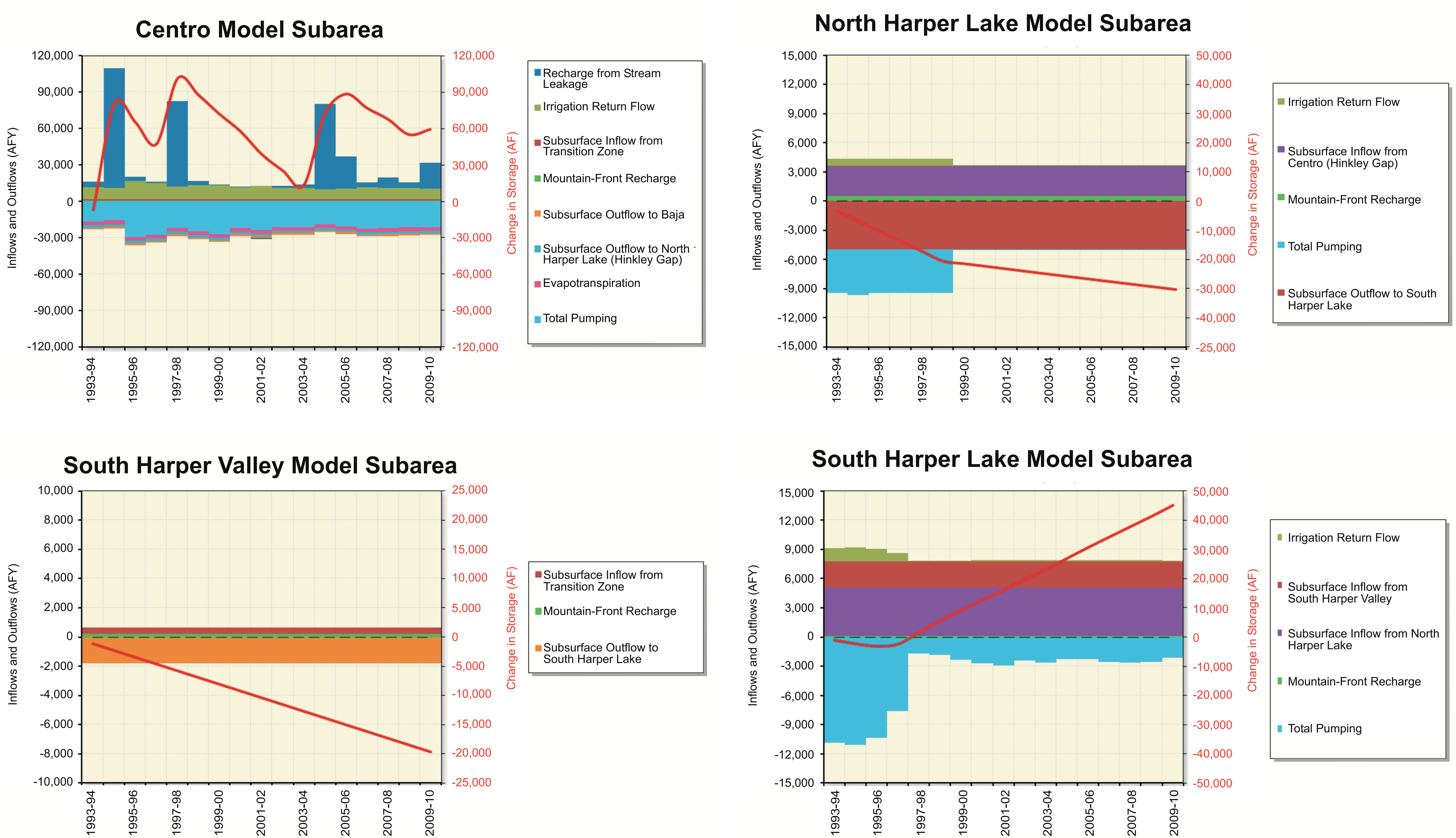
- Annual surface water inflows at the Helendale Fault were estimated from discharge data at the USGS Lower Narrows gage and a detailed water budget of the Transition Zone developed by the MBA Watermaster (2012). The Transition zone water budget is presented in **Appendix H**.

- Annual surface water outflows at the Harper Lake (Waterman) Fault were estimated from discharge data at the USGS Barstow stream gage and estimation of annual streamflow losses (groundwater storage gains) between the Barstow gage and Waterman Fault following storm recharge events (MWA, 2011a).

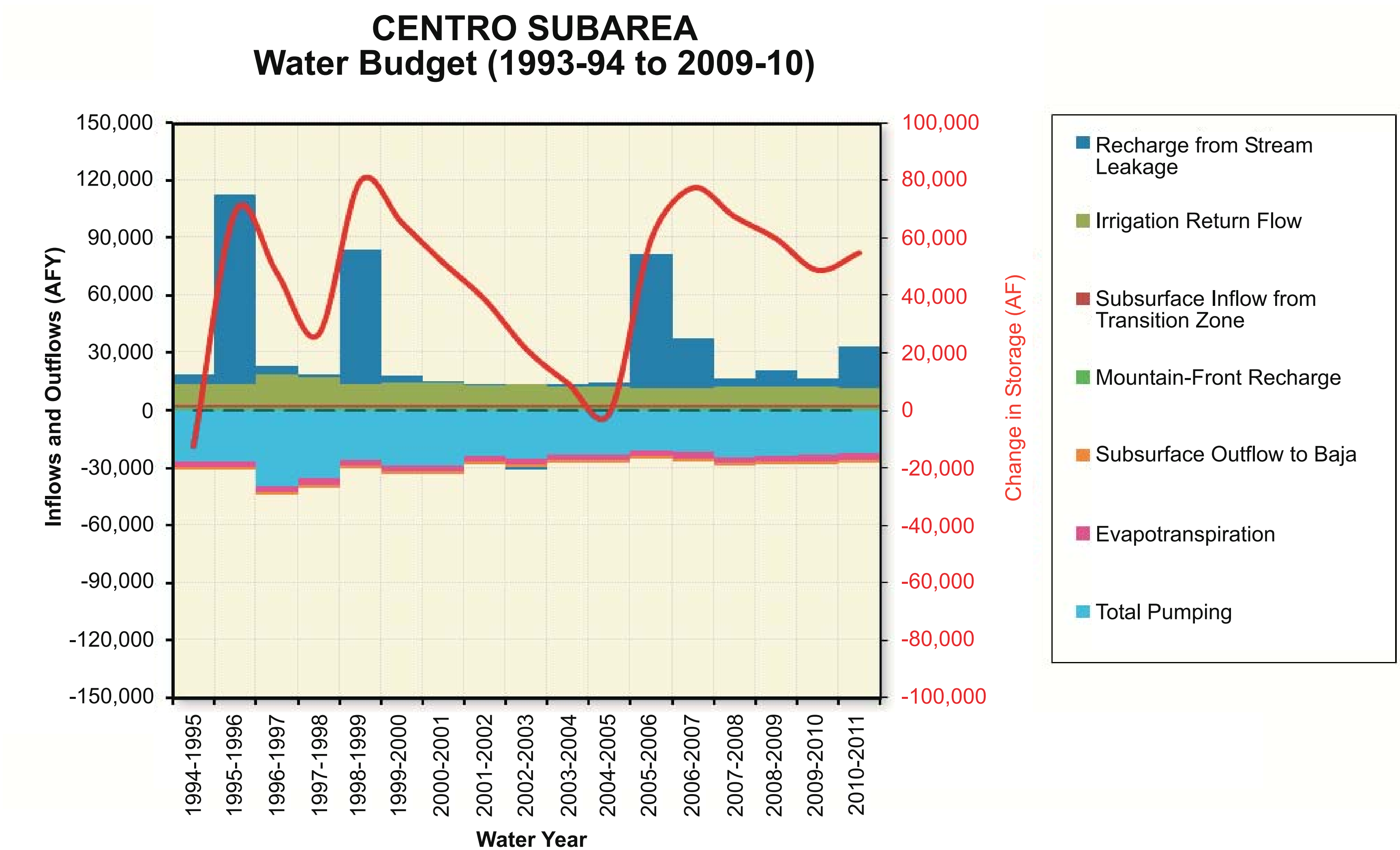
- Annual volumes of SWP water recharged through the Hodge and Lenwood recharge facilities were provided directly by MWA.

- Subsurface inflows at Helendale Fault and outflows at Harper Lake (Waterman) Fault represent the average annual rates over the base period (1931 to 1990) estimated from the USGS model. While annual subsurface flows vary in the USGS model, previous studies of groundwater level changes across the Helendale Fault and Waterman Fault have indicated no significant change in groundwater levels and hydraulic gradient since the 1960s, when reliable water level data were available (CSUF, 2006).

- Subsurface flows through the Hinkley Gap (from Centro to Harper) are controlled by groundwater levels and hydraulic gradients. Local groundwater levels in this area have been relatively stable since WY 1993-94 and are reflective of hydrogeologic conditions observed in the latter years of the USGS transient simulation period. For the water budget, the average



February 2013	**Figure 4.23**
TODD ENGINEERS Alameda, California	**Water Budgets for Centro, South Harper Valley, North Harper Lake, and South Harper Lake Model Subareas (WY 1993-94 to WY 2009-10)**



February 2013	**Figure 4.24**
TODD ENGINEERS Alameda, California	**Water Budget for Centro Subarea (WY 1993-94 to WY 2009-10)**

- annual simulated subsurface flow at the Hinkley Gap from 1994 to 1999 (2,100 AFY) was applied directly for each year of the water budget (from WY 1993-94 through WY 2009-10).

- Subsurface flows across the Lockhart Fault (from South Harper Valley to South Harper Dry Lake) are also controlled by groundwater levels and hydraulic gradients. Historically, groundwater level declines in the South Harper Lake model subarea increased subsurface flows across the Lockhart Fault. However, since the Judgment, groundwater levels have stabilized and recovered partially in the southwest Harper Lake pumping depression. As a consequence, subsurface flows across the Lockhart Fault have also stabilized. For the water budget, a constant subsurface flow rate of 1,800 AFY was applied for each year from WY 1993-94 through WY 2009-10, just below the annual flow rate estimated in the last year of the USGS model.

- Similar to the Lockhart Fault, subsurface flows across the unnamed fault west of Harper Dry Lake (from North Harper Dry Lake to South Harper Dry Lake) are controlled by groundwater levels and hydraulic gradients. Historically, groundwater level declines in the South Harper Lake model subarea increased subsurface flows across the unnamed fault. However, since groundwater production west of Harper Dry Lake has been curtailed, groundwater levels have stabilized and recovered partially in the southwest Harper Lake pumping depression. As a consequence, subsurface flows across the unnamed fault have also stabilized. For the water budget, a constant subsurface flow rate of 3,300 AFY was applied for each year from WY 1993-94 through WY 2009-10, slightly below the annual flow rate estimated in the last year of the USGS model.

- Mountain front-recharge estimates were derived from results of a focused analysis on local mountain runoff documented in **Appendix C**. Mountain-front recharge estimates represent 0.49 percent of average annual rainfall on contributing water shed areas outside the Mojave River Basin model boundary. Recharge estimates were apportioned to the four model subareas.

- Groundwater production, agricultural and urban consumptive use and return flow estimates were obtained directly from the MBA Watermaster. For WYs 1993-94 to 2000-01 (with the exception of WY 1996-97), a weighted-average consumptive use factor of 59 percent (return-flow factor of 41 percent) was applied to total production to estimate return flows for the overall Centro Subarea. Separate agricultural and urban consumptive use and return flow volumes were available for WY 1996-97.

- Riparian evapotranspiration (ET) was estimated from values reported in the riparian studies conducted by the USGS (Lines and Bilhorn, 1996) and the USBR and USU (2011). As described in the land use section, average annual ET was estimated to be about 3,000 AFY in the Centro Subareas (Lines and Bilhorn, 1996). This value is used in the Judgment. More recently, riparian ET in 2007 and 2010 was estimated to be about 4,500 AFY and 3,600 AFY, respectively (USBR and USU, 2011). Volumes cited for the USBR and USU study do not include estimated ET by desert scrub species, which are shallow-rooted and rely on precipitation. For the water budget, a constant value of 3,000 AFY was assumed.

- Results of the USGS model showed that groundwater evaporation beneath Harper Dry Lake likely ceased in the 1960s due to local groundwater level declines. For the water budget, it was assumed that groundwater level recoveries beginning in the 1990s have been insufficient to re-establish groundwater evaporation beneath Harper Dry Lake.

Table 4.4a
Centro Model Subarea Water Budget (WY 1993-94 to WY 2009-10)

	Average[1]	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10
INFLOWS																		
Surface Water Inflow (at Helendale Fault)	27,242	5,009	108,212	3,794	1,545	80,074	3,509	691	607	-1,275	1,533	2,649	192,184	26,172	4,229	8,297	4,690	21,188
Mojave River at Lower Narrows (gage data)	30,739	10,923	113,270	11,032	8,217	83,501	9,403	6,995	5,616	4,549	6,246	5,384	192,554	27,250	4,940	9,151	4,362	19,177
Estimated losses from Lower Narrows gage to Helendale Fault	3,498	5,914	5,058	7,238	6,672	3,427	5,894	6,304	5,009	5,824	4,713	2,735	370	1,078	711	854	-328	-2,011
Net Recharge from Stream	18,972	5,009	98,970	3,794	1,545	70,547	3,509	691	607	-1,275	1,533	2,649	70,381	26,172	4,229	8,287	4,690	21,188
SWP Water Artificial Recharge (Hodge+ Lenwood)	1,430	0	0	0	0	0	1,039	3,842	2,406	0	1,752	2,321	4,127	6,391	1,917	107	27	380
Subsurface Inflow from TZ Subarea (at Helendale Fault)	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162
Mountain-Front Recharge (0.5% Runoff Non-Basin Area)	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530
Return Flows	10,235	9,634	9,404	14,874	13,181	10,281	11,452	11,687	9,759	10,891	9,214	9,238	8,326	8,846	9,631	9,429	9,209	8,944
Consumptive Use Agriculture					-7,101					-6,456	-5,827	-5,623	-5,015	-5,830	-6,874	-7,380	-7,529	-8,081
Consumptive Use Urban					-7,357					-6,079	-6,094	-6,291	-5,758	-5,840	-6,020	-5,368	-4,910	-4,266
Total Groundwater Inflows	**32,329**	**16,335**	**110,065**	**20,360**	**16,418**	**82,520**	**17,691**	**17,912**	**14,464**	**11,308**	**14,191**	**15,900**	**84,526**	**43,101**	**17,469**	**19,514**	**15,618**	**32,204**
OUTFLOWS																		
Surface Water Outflow - Mojave River at Waterman Fault	-8,270	0	-9,242	0	0	-9,527	0	0	0	0	0	0	-121,803	0	0	-10	0	0
Mojave River at Barstow (gage data)	-8,727	0	-11,111	0	0	-10,512	0	0	0	0	0	0	-126,168	-182	0	-10	0	-374
Estimated losses from Barstow gage to Waterman Fault	457	0	1,869	0	0	985	0	0	0	0	0	0	4,365	182	0	0	0	374
Subsurface Outflow	-3,562	-3,562	-3,562	-3,562	-3,562	-3,562	-3,562	-3,562	-3,562	-3,562	-3,562	-3,562	-3,562	-3,562	-3,562	-3,562	-3,562	-3,562
to Baja Model Subarea (Waterman Fault)	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462
to North Harper Lake Model Subarea (at Hinkley Gap)	-2,100	-2,100	-2,100	-2,100	-2,100	-2,100	-2,100	-2,100	-2,100	-2,100	-2,100	-2,100	-2,100	-2,100	-2,100	-2,100	-2,100	-2,100
Evapotranspiration	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000
Total Pumping (including Minimal Producers)	-22,287	-16,606	-15,880	-29,591	-27,639	-22,069	-24,874	-27,068	-22,190	-23,426	-21,135	-21,152	-19,099	-20,516	-22,525	-22,176	-21,648	-21,291
Total Pumping (less Minimal Producers)	-21,387	-15,706	-14,980	-28,691	-26,739	-21,169	-23,974	-26,168	-21,290	-22,526	-20,235	-20,252	-18,199	-19,616	-21,625	-21,276	-20,748	-20,391
Minimal Producers	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900
Total Groundwater Outflows	**-28,849**	**-23,168**	**-22,442**	**-36,153**	**-34,201**	**-28,631**	**-31,436**	**-33,630**	**-28,752**	**-29,988**	**-27,697**	**-27,714**	**-25,661**	**-27,078**	**-29,087**	**-28,738**	**-28,210**	**-27,853**
Annual Change in Storage (AF)	**3,480**	**-6,833**	**87,623**	**-15,793**	**-17,783**	**53,889**	**-13,745**	**-15,718**	**-14,288**	**-18,680**	**-13,506**	**-11,814**	**58,865**	**16,023**	**-11,618**	**-9,224**	**-12,592**	**4,351**
Cumulative Change in Storage (AF)		**-6,833**	**80,790**	**64,998**	**47,215**	**101,103**	**87,359**	**71,641**	**57,354**	**38,674**	**25,168**	**13,353**	**72,218**	**88,241**	**76,623**	**67,399**	**54,806**	**59,157**

Table 4.4b
South Harper Valley Model Subarea Water Budget (WY 1993-94 to WY 2009-10)

	Average[1]	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10
INFLOWS																		
Subsurface Inflow - (Helendale Fault)	404	404	404	404	404	404	404	404	404	404	404	404	404	404	404	404	404	404
Mountain-Front Recharge (0.49% Runoff Non-Basin Area)	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250
Total Groundwater Inflows	**654**	**654**	**654**	**654**	**654**	**654**	**654**	**654**	**654**	**654**	**654**	**654**	**654**	**654**	**654**	**654**	**654**	**654**
OUTFLOWS																		
Subsurface Outflow to South Harper (Lockhart Fault)	-1,800	-1800	-1800	-1800	-1800	-1800	-1800	-1800	-1800	-1800	-1800	-1800	-1800	-1800	-1800	-1800	-1800	-1800
Total Groundwater Outflows	**-1,800**	**-1,800**	**-1,800**	**-1,800**	**-1,800**	**-1,800**	**-1,800**	**-1,800**	**-1,800**	**-1,800**	**-1,800**	**-1,800**	**-1,800**	**-1,800**	**-1,800**	**-1,800**	**-1,800**	**-1,800**
Annual Change in Storage (AF)	**-1,146**	**-1,146**	**-1,146**	**-1,146**	**-1,146**	**-1,146**	**-1,146**	**-1,146**	**-1,146**	**-1,146**	**-1,146**	**-1,146**	**-1,146**	**-1,146**	**-1,146**	**-1,146**	**-1,146**	**-1,146**
Cumulative Change in Storage (AF)		**-1,146**	**-2,292**	**-3,438**	**-4,584**	**-5,730**	**-6,876**	**-8,022**	**-9,168**	**-10,314**	**-11,460**	**-12,606**	**-13,752**	**-14,898**	**-16,044**	**-17,190**	**-18,336**	**-19,482**

Table 4.4c
South Harper Lake Model Subarea Water Budget (WY 1993-94 to WY 2009-10)

	Average[1]	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10
INFLOWS																		
Subsurface Inflow	5,100	5,100	5,100	5,100	5,100	5,100	5,100	5,100	5,100	5,100	5,100	5,100	5,100	5,100	5,100	5,100	5,100	5,100
from North Harper Lake Model Subarea	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300
from South Harper Valley (at Lockhart Fault)	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800
Mountain-Front Recharge (0.49% Runoff)	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85
Return Flows	252	929	956	879	590	15	23	58	95	107	77	95	84	81	108	107	81	1
Consumptive Use Agriculture		-5,265	-5,415	-4,980	-3,344	-87	-131	-329	-536	-604	-434	-536	-473	-456	-613	-608	-458	-6
Consumptive Use Urban		-1,058	-1,028	-1,066	-1,143	-1,036	-1,054	-1,189	-1,190	-1,221	-1,106	-1,109	-942	-960	-980	-1,032	-1,190	-1,434
Total Groundwater Inflows	**5,437**	**6,114**	**6,141**	**6,064**	**5,775**	**5,200**	**5,208**	**5,243**	**5,280**	**5,292**	**5,262**	**5,280**	**5,269**	**5,266**	**5,293**	**5,292**	**5,266**	**5,186**
OUTFLOWS																		
Harper Dry Lake Evaporation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Pumping	-2,782	-7,252	-7,398	-6,925	-5,077	-1,138	-1,208	-1,576	-1,820	-1,931	-1,616	-1,740	-1,499	-1,497	-1,701	-1,747	-1,729	-1,441
Agriculture	-1,680	-6,194	-6,370	-5,859	-3,934	-102	-154	-387	-630	-710	-510	-631	-557	-537	-721	-715	-539	-7
Urban (Industrial)	-1,102	-1,058	-1,028	-1,066	-1,143	-1,036	-1,054	-1,189	-1,190	-1,221	-1,106	-1,109	-942	-960	-980	-1,032	-1,190	-1,434
Total Groundwater Outflows	**-2,782**	**-7,252**	**-7,398**	**-6,925**	**-5,077**	**-1,138**	**-1,208**	**-1,576**	**-1,820**	**-1,931**	**-1,616**	**-1,740**	**-1,499**	**-1,497**	**-1,701**	**-1,747**	**-1,729**	**-1,441**
Annual Change in Storage (AF)	**2,655**	**-1,138**	**-1,258**	**-861**	**698**	**4,062**	**4,000**	**3,667**	**3,460**	**3,361**	**3,646**	**3,540**	**3,770**	**3,769**	**3,592**	**3,545**	**3,537**	**3,745**
Cumulative Change in Storage (AF)		**-1,138**	**-2,395**	**-3,257**	**-2,558**	**1,504**	**5,504**	**9,171**	**12,631**	**15,991**	**19,637**	**23,176**	**26,946**	**30,714**	**34,306**	**37,852**	**41,389**	**45,134**

Table 4.4d
North Harper Lake Model Subarea Water Budget (WY 1993-94 to WY 2009-10)

	Average[1]	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10
INFLOWS																		
Subsurface Inflow	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100
from Centro (at Hinkley Gap)	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100
Mountain-Front Recharge (0.49% Runoff)	340	340	340	340	340	340	340	340	340	340	340	340	340	340	340	340	340	340
Return Flows	163	451	470	451	451	451	451	1	6	7	7	7	2	2	2	2	2	2
Consumptive Use Agriculture		-2,555	-2,665	-2,555	-2,555	-2,555	-2,554	-4	-32	-41	-39	-41	-12	-14	-13	-13	-13	-13
Consumptive Use Urban		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Groundwater Inflows	**2,603**	**2,891**	**2,910**	**2,891**	**2,891**	**2,891**	**2,891**	**2,441**	**2,446**	**2,447**	**2,447**	**2,447**	**2,442**	**2,442**	**2,442**	**2,442**	**2,442**	**2,442**
OUTFLOWS																		
Harper Dry Lake Evaporation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subsurface Outflow to South Harper Lake	-3,300	-3,300	-3,300	-3,300	-3,300	-3,300	-3,300	-3,300	-3,300	-3,300	-3,300	-3,300	-3,300	-3,300	-3,300	-3,300	-3,300	-3,300
Total Pumping	-1,085	-3,006	-3,135	-3,006	-3,006	-3,006	-3,005	-5	-38	-48	-46	-48	-14	-16	-15	-15	-15	-15
Agriculture	-1,085	-3,006	-3,135	-3,006	-3,006	-3,006	-3,005	-5	-38	-48	-46	-48	-14	-16	-15	-15	-15	-15
Urban (Industrial)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Groundwater Outflows	**-4,385**	**-6,306**	**-6,435**	**-6,306**	**-6,306**	**-6,306**	**-6,305**	**-3,305**	**-3,338**	**-3,348**	**-3,346**	**-3,348**	**-3,314**	**-3,316**	**-3,315**	**-3,315**	**-3,315**	**-3,315**
Annual Change in Storage (AF)	**-1,782**	**-3,415**	**-3,525**	**-3,415**	**-3,415**	**-3,415**	**-3,414**	**-864**	**-892**	**-901**	**-899**	**-901**	**-872**	**-874**	**-873**	**-873**	**-873**	**-873**
Cumulative Change in Storage (AF)		**-3,415**	**-6,940**	**-10,355**	**-13,770**	**-17,185**	**-20,599**	**-21,464**	**-22,356**	**-23,257**	**-24,156**	**-25,057**	**-25,929**	**-26,802**	**-27,675**	**-28,548**	**-29,420**	**-30,293**

Table 4.5
Centro Subarea Water Budget (WY 1993-94 to WY 2009-10)

	Average[1]	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10
INFLOWS																		
Surface Water Inflow (at Helendale Fault)	27,242	5,009	108,212	3,794	1,545	80,074	3,509	691	607	-1,275	1,533	2,649	192,184	26,172	4,229	8,297	4,690	21,188
Mojave River at Lower Narrows (gage data)	30,739	10,923	113,270	11,032	8,217	83,501	9,403	6,995	5,616	4,549	6,246	5,384	192,554	27,250	4,940	9,151	4,362	19,177
Estimated losses from Lower Narrows gage to Helendale Fault	3,498	5,914	5,058	7,238	6,672	3,427	5,894	6,304	5,009	5,824	4,713	2,735	370	1,078	711	854	-328	-2,011
Net Recharge from Stream	18,972	5,009	98,970	3,794	1,545	70,547	3,509	691	607	-1,275	1,533	2,649	70,381	26,172	4,229	8,287	4,690	21,188
SWP Water Enhanced Recharge (Hodge+ Lenwood)	1,430	0	0	0	0	0	1,039	3,842	2,406	0	1,752	2,321	4,127	6,391	1,917	107	27	380
Subsurface Inflow from TZ Subarea (at Helendale Fault)	1,566	1,566	1,566	1,566	1,566	1,566	1,566	1,566	1,566	1,566	1,566	1,566	1,566	1,566	1,566	1,566	1,566	1,566
Mountain-Front Recharge (0.49% Runoff Non-Basin Area)	1,205	1,205	1,205	1,205	1,205	1,205	1,205	1,205	1,205	1,205	1,205	1,205	1,205	1,205	1,205	1,205	1,205	1,205
Return Flows	10,650	11,014	10,829	16,204	14,222	10,747	11,926	11,746	9,860	11,005	9,297	9,340	8,412	8,929	9,741	9,538	9,292	8,947
Consumptive Use Agriculture					-13,000					-7,100	-6,300	-6,200	-5,500	-6,300	-7,500	-8,000	-8,000	-8,100
Consumptive Use Urban					-8,500					-7,300	-7,200	-7,400	-6,700	-6,800	-7,000	-6,400	-6,100	-5,700
Total Groundwater Inflows	**33,823**	**18,794**	**112,570**	**22,769**	**18,538**	**84,065**	**19,244**	**19,050**	**15,644**	**12,501**	**15,353**	**17,081**	**85,691**	**44,263**	**18,658**	**20,703**	**16,780**	**33,286**
OUTFLOWS																		
Surface Water Outflow - Mojave River at Waterman Fault	-8,270	0	-9,242	0	0	-9,527	0	0	0	0	0	0	-121,803	0	0	-10	0	0
Mojave River at Barstow (gage data)	-8,727	0	-11,111	0	0	-10,512	0	0	0	0	0	0	-126,168	-182	0	-10	0	-374
Estimated losses from Barstow gage to Waterman Fault	457	0	1,869	0	0	985	0	0	0	0	0	0	4,365	182	0	0	0	374
Subsurface Outflow to Baja (Waterman Fault)	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462	-1,462
Evapotranspiration	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000	-3,000
Harper Dry Lake Evaporation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Pumping (including Minimal Producers)	-26,154	-26,864	-26,413	-39,522	-35,722	-26,213	-29,087	-28,649	-24,048	-25,405	-22,797	-22,940	-20,612	-22,029	-24,241	-23,938	-23,392	-22,747
Total Pumping (less Minimal Producers)	-25,254	-25,964	-25,513	-38,622	-34,822	-25,313	-28,187	-27,749	-23,148	-24,505	-21,897	-22,040	-19,712	-21,129	-23,341	-23,038	-22,492	-21,847
Minimal Producers	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900	-900
Total Groundwater Outflows	**-30,616**	**-31,326**	**-30,875**	**-43,984**	**-40,184**	**-30,675**	**-33,549**	**-33,111**	**-28,510**	**-29,867**	**-27,259**	**-27,402**	**-25,074**	**-26,491**	**-28,703**	**-28,400**	**-27,854**	**-27,209**
Annual Change in Storage (AF)	**3,207**	**-12,532**	**81,695**	**-21,215**	**-21,646**	**53,390**	**-14,305**	**-14,061**	**-12,866**	**-17,366**	**-11,906**	**-10,321**	**60,617**	**17,772**	**-10,045**	**-7,697**	**-11,074**	**6,077**
Cumulative Change in Storage (AF)		**-12,532**	**69,163**	**47,948**	**26,302**	**79,692**	**65,387**	**51,327**	**38,460**	**21,094**	**9,188**	**-1,133**	**59,484**	**77,255**	**67,210**	**59,513**	**48,438**	**54,515**

Conclusions from the water budgets presented in **Tables 4.4a through 4.4d, Table 4.5, and Figures 4.23 and 4.24** are summarized below.

Change in Groundwater Storage – Annual groundwater storage changes in each of the four model subareas varied considerably from WY 1993-94 through WY 2009-10.

Within the Centro model subarea, there was an average annual groundwater storage gain of 3,480 AFY, resulting in a cumulative gain of 59,157 AF (**Table 4.4a** and **Figure 4.23**, top left chart). Positive gains are primarily the result of large storm recharge events in WYs 1994-95, 1997-98, and 2004-05 and indicate that the Centro Subarea has been in operational balance since WY 1993-94.

Within the South Harper Valley model subarea, an estimated -1,146 AFY was lost from groundwater storage, resulting in a cumulative storage loss of -19,482 AF (**Table 4.4b** and **Figure 4.24**, second from top chart). Storage losses in the South Harper Valley model subarea are attributable to the historical increase in subsurface flow across the Lockhart Fault to the South Harper Lake model subarea.

Within the South Harper Lake model subarea, an estimated 2,655 AFY was gained in groundwater storage, resulting in a cumulative storage gain of 45,134 AF from WY 1993-94 through WY 2009-10 (**Table 4.4c** and **Figure 4.24**, second from bottom chart). Storage gains are attributable to significant declines in groundwater production since WY 1997-98 and an assumed constant rate of subsurface inflow from the North Harper Lake model subarea.

Within the North Harper Lake model subarea, an estimated -1,782 AFY was lost from storage, resulting in a cumulative storage loss of -30,293 AF from WY 1993-94 through WY 2009-10 (**Table 4.4d** and **Figure 4.24**, bottom chart). Storage losses are attributable to agricultural production exceeding 3,000 AFY from WY 1993-94 through WY 1998-99 and assumed constant rate of subsurface outflow to the South Harper Lake model subarea.

Overall, based on the combined water budgets of the four model subareas, groundwater storage increased by 54,515 AF in the Centro Subarea from WY 1993-94 through WY 2009-10 (**Table 4.5** and **Figure 4.25**).

Consumptive Use/Return Flows – Weighted-average consumptive use and return flows in the Centro Subarea averaged 59 and 41 percent of total production, respectively. Total agricultural and urban consumptive use in the Centro Subarea was 263,570 AF between WY 1993-94 to WY 2009-10 (**Table 4.5** and **Figure 4.25**). Of this volume, 204,884 AF (78 percent) occurred in the Centro model subarea, 43,011 AF (16 percent) occurred in the South Harper Lake model subarea, and 15,673 AF (6 percent) occurred in the North Harper Lake model subarea.

Recharge from Stream Leakage – Recharge from stream leakage averaged 18,972 AFY for a total of 322,523 AF (**Table 4.5**). Of the total volume of recharge, 239,897 AF (or 74 percent) occurred during WYs 1994-95, 1997-98, and 2004-05.

Enhanced Recharge – From WY 1993-94 through WY 2009-10, SWP water was recharged at the Hodge and Lenwood recharge sites during 11 of the 17 years. Over this period, combined artificial recharge averaged 1,430 AFY, totaling 24,309 AF.

<u>Subsurface Flow</u> – For the water budget, the average annual subsurface inflow from the Transition Zone across the Helendale Fault was estimated by applying the average annual flow rate over the base period from the USGS model (1,566 AFY). Of this volume, 1,162 AFY flowed into the Centro model subarea, and 404 AFY flowed into the South Harper Valley model subarea. Average subsurface flow through the Hinkley Gap and across the Lockhart Fault was 2,100 and 1,800 AFY, respectively. The average annual subsurface flow across the unnamed fault west of Harper Dry Lake (from North Harper Lake to South Harper Lake) was estimated by from the 1999 flow rate from the USGS model (3,300 AFY). The average annual subsurface outflow to the Baja Subarea across the Harper Lake (Waterman) Fault was estimated by applying the average annual flow rate over the base period from the USGS model (1,462 AFY).

<u>Evapotranspiration (ET)</u> – For the water budget, the annual ET (3,000 AFY) under 1995 land use conditions were applied as a constant value.

<u>Groundwater Discharge to Harper Dry Lake</u> – Results of the USGS model showed that groundwater evaporation beneath Harper Dry Lake halted in the 1960s due to significant groundwater level declines. For the water budget, it was assumed that groundwater level recoveries have been insufficient to restore evaporation beneath Harper Dry Lake.

<u>Surface Water Flow</u> – Surface water inflow across the Helendale Fault averaged 27,242 AFY, representing an average annual stream loss of 3,498 AFY in the Transition Zone (between the Lower Narrows gage and Helendale Fault). Surface water outflow across the Harper Lake (Waterman) Fault averaged 8,270 AFY as a result of 457 AFY of stream losses between the Barstow gage and Harper Lake (Waterman) Fault.

<u>Perennial Yield of the Combined North and South Harper Lake Model Subareas</u> – Potential future development has raised concerns over the perennial yield of the Harper Dry Lake Area. To satisfy the environmental requirements by the CEC for the proposed Abengoa Mojave Solar Project (MSP), refinements to the conceptual hydrogeologic model of the Harper Lake Area were conducted by Layne GeoSciences (LGS, 2009). For the LGS study, an independent groundwater model was also developed but was ultimately abandoned following unsuccessful attempts to calibrate the model. The CEC encouraged and approved the selection of the USGS groundwater flow model by Stamos, et al. (2001) to evaluate the potential groundwater impacts from the proposed Abengoa Mojave Solar Project. Datasets were updated, and simulations were rigorously reviewed. In addition to analyzing potential project-specific groundwater impacts, the CEC conducted additional simulations to estimate the "operation yield" for the Harper Lake Basin, defined as the maximum pumping rate resulting in no long-term cumulative loss in Harper Lake Basin groundwater storage. Simulation results indicate that the operational yield of the Harper Lake Basin is 6,235 AFY (CEC, 2011). The estimated operational yield is slightly higher than the combined average annual natural inflows to the South and North Harper Lake model subareas from WY 1993-94 to WY 2009-10 developed for this study (4,450 AFY). Without the results of model simulations conducted by the CEC, it is not clear to what degree differences are a result of different basin areas/boundary conditions and/or applied return flow percentages.

4.8 Centro Groundwater Quality

Numerous studies have characterized groundwater quality in the Study Area. Early work assessed the general suitability of groundwater as a water supply source (Stone, 1957; DWR, 1964a and 1967; Miller, 1969; DWR 1983) and characterized the impact of industrial and municipal wastewater discharges on groundwater quality in the Barstow area (CDPH and DWR, 1960; CDPH, 1966; Miller, 1969; CDPH, 1970; Brown and Caldwell Engineering, 1973; Hughes, 1975; Eccles, 1981; Geraghty & Miller, 1990). Despite local groundwater quality degradation in Barstow and variability elsewhere, these studies generally confirmed the suitability of groundwater for beneficial uses in the region. More recently, groundwater quality data, including intrinsic tracers, have been used to confirm sources of groundwater recharge and travel times along interpreted flowpaths in the Floodplain and Regional aquifers (Izbicki and Michel, 2004; Izbicki et al., 2004). Investigations have also been conducted to identify the source and occurrence of key groundwater contaminants, including hexavalent chromium (Cr-VI) and arsenic, in the Mojave Desert region (Ball and Izbicki, 2004; Welch et al., 2004).

For this study, groundwater quality data collected through 2010 were evaluated using geochemical plotting techniques, including Trilinear and Stiff diagrams. These plotting methods are useful for identifying sources of recharge and illustrating geochemical changes along recognized subsurface flowpaths as a result of the interactions between groundwater, subsurface sediments, and geologic structures. Additionally, maximum groundwater concentrations measured over the past 10 to 20 years were plotted for selected inorganic constituents (including TDS, arsenic, boron, chromium, fluoride, nitrate, and perchlorate) to identify areas that are potentially degraded by common naturally-occurring and anthropogenic contaminants. Additionally, a map is provided of active regulated environmental facilities, and historical groundwater contamination issues are summarized related to the Barstow Slug, Barstow WWTP, Burlington Northern Santa Fe Barstow Railway Yard, MCLB Barstow, and PG&E Hinkley.

4.8.1 Source Water (Trilinear) Diagrams and Stiff Plots

Trilinear Diagrams

Complete analyses of major cations and anions were available for approximately 250 wells in the Centro Subarea. For each well, inorganic water quality data from the most recent sampling event was plotted on a Trilinear Diagram. This technique plots the major anions and cations in percent milliequivalents per liter (% meq/L) to characterize groundwater and differentiate samples of varying water quality. **Figure 4.25** presents trilinear diagrams for wells in the Centro Subarea grouped into seven regions. Five regions include wells located along the Mojave River from upstream of the Helendale Fault to the Waterman Fault. The other two regions include wells located on the western and southeastern side of Harper Dry Lake. For reference, the signature of Mojave River water based on surface water quality samples collected at The Forks and Lower Narrows gage is shown on each Trilinear Diagram (open red circle).

As shown on **Figure 4.25**, groundwater from most wells located along the Mojave River plot in the central portion of the diamond on the Trilinear Diagram, exhibiting a neutral-calcium type cation and neutral-bicarbonate type anion signature similar to that of Mojave River water. As shown on all five of the Trilinear Diagrams from wells along the river, cation composition varies along a tight mixing line

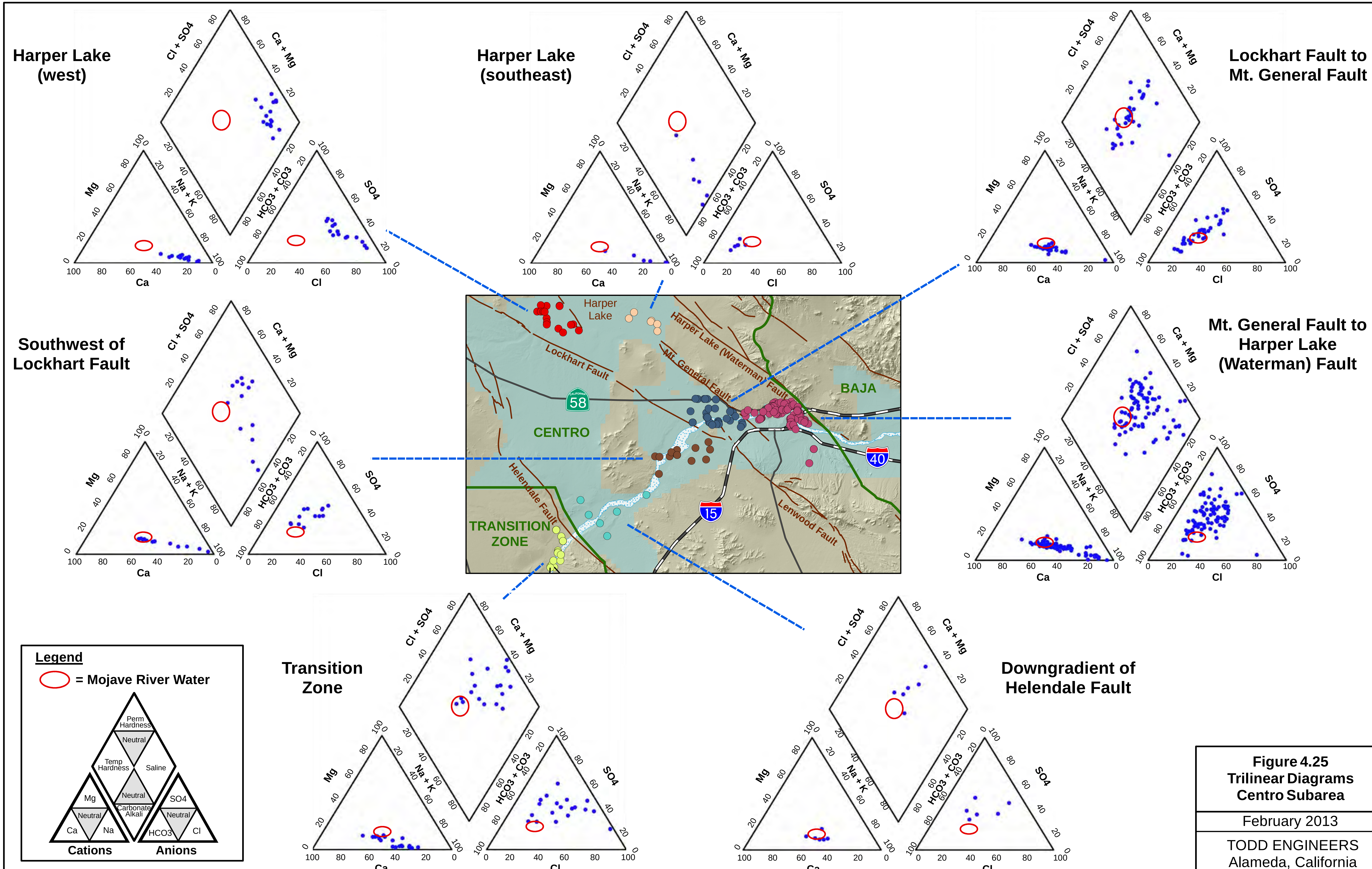


Figure 4.25
Trilinear Diagrams
Centro Subarea

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between Mojave River water and pure sodium-type water (which plots towards the lower right of the cation triangle). In contrast, the relative composition of major anions is more variable.

The Trilinear Diagrams illustrate the effect of three major processes that occur along groundwater flow paths from the Mojave River. These are:

1) Cation exchange between calcium in groundwater and sodium on subsurface (primarily clay) sediments

2) Reduction in bicarbonate content (relative to chloride and sulfate) of Mojave River recharge water, and

3) Recharge of local mountain runoff, which has a relative sodium content greater than Mojave River water and a relative bicarbonate content similar to Mojave River water.

These processes explain much of the variability in groundwater quality observed along the Mojave River. For example, in the Trilinear Diagram for wells located southwest of the Lockhart Fault, groundwater in wells located near the main channel (Floodplain Aquifer) is recharged by Mojave River water and plot near the center of the diamond (with some bicarbonate losses), while groundwater located southeast of the Mojave River (Regional Aquifer) are also recharged partly by local mountain runoff (with higher sodium-bicarbonate content) and plot in the lower right portion of the diamond.

Downgradient of the Helendale Fault, a higher relative chloride and sulfate content and low bicarbonate content is observed in several wells. This distinct signature likely reflects the upward flow of older groundwater from the Regional Aquifer to the Floodplain Aquifer due to the increasing barrier effect of the fault with depth. Similarly, groundwater in several wells in the Barstow area (Mt. General Fault to Waterman Fault) has a higher relative chloride and sulfate content and low bicarbonate content. Some of these wells tap older groundwater of the Regional Aquifer north and south of the Mojave River, while groundwater in Floodplain Aquifer wells are influenced by the barrier effect of the Harper Lake (Waterman) Fault and effluent discharges from the Barstow WWTP.

Groundwater in the Harper Lake area varies considerably from groundwater along the Mojave River. In southeast Harper Lake, groundwater is a sodium-bicarbonate type, indicative of mixing between groundwater that flows through the Hinkley Gap and recharge from local mountain runoff. In contrast, groundwater in west Harper Lake is a sodium-chloride type. This signature is common for groundwater within evaporative lake deposits and is attributable to leaching of sodium and chloride from evaporative lake deposits as well as additional cation exchange in groundwater that flows from southeast Harper Lake and south Harper Valley across the Lockhart Fault.

Stiff Diagrams

The same water quality data used in the Trilinear Diagrams were plotted as Stiff Diagrams to examine visually the geochemical signatures of groundwater. Stiff Diagrams for wells with reliable well construction information and more recent water quality data are shown on **Figure 4.26**. It is noted that the most recent water quality samples for wells in the Harper Dry Lake area ranged from 1950s through 2009. However, the relative similarity in Stiff Diagram shapes of neighboring wells indicate that hydrogeologic conditions along recognized groundwater flow paths towards Harper Dry Lake have not significantly altered subsurface geochemical processes over the past 60 years. Stiff Diagrams characterize water quality by plotting major anion and cation concentrations in meq/L along three parallel horizontal axes for each water sample. Connecting the points for each ion creates a polygon, the distinctive shape of which allows for visual comparison of groundwater quality data across the subarea. For example, a Stiff Diagram that has a "T" or "anvil" shape generally denotes brackish or briny groundwater; if the shape is a "backward check mark", ion exchange is indicated; and a "blocky" or "arrowhead" shape pointing to the right indicates groundwater with very low TDS. Groundwater samples with similar inorganic water quality will plot as similar shapes. The concentration of total dissolved solids (TDS) for each well is indicated by the color and the relative size of the Stiff Diagram. A blue-colored Stiff Diagram represents a relatively low TDS concentration, whereas a red-colored Stiff Diagram represents a high TDS concentration. Values shown on each Stiff Diagram represent the depth of top and bottom of the well screen or the total well depth for wells lacking well screen information.

Along the Mojave River, the pattern of Stiff Diagrams varies considerably. Generally, wells recharged by streamflow losses have TDS concentrations less than 500 milligrams per liter (mg/L) and exhibit higher relative bicarbonate content and neutral to high relative calcium content. TDS concentrations and the relative chloride content generally increase in deeper wells along the main channel and wells located away from the main channel. Exceptions to these Stiff Diagram patterns include wells located along the river downgradient of the Helendale Fault and in eastern Barstow.

Stiff Diagrams of wells in the southeast Harper Lake area indicate that local mountain runoff likely contributes to the groundwater signature and relatively low TDS concentrations in this area. In contrast, Stiff Diagrams in the west Harper Lake area reflect the leaching of sodium- and chloride-rich evaporative sediments at Harper Dry Lake. With the exception of the Helendale Fault area, no clear vertical trends in TDS concentrations are observed in the areas and at depths monitored (down to about 600 feet-bgs) within the Centro Subarea.

4.8.2 Total Dissolved Solids (TDS)

Figure 4.27 allows a more detailed examination of the variability in TDS concentrations throughout the subarea. As shown on the figure, well symbols are color-coded for the maximum TDS concentration measured in monitoring wells from 1990 to 2010. Generalized areas of elevated TDS are shaded in light red to highlight areas of interest. In general, TDS concentrations in the central portion of the subarea range from 250 to 1,000 mg/L; the secondary (aesthetic) MCL for TDS is 500 mg/L, while the upper and short-term secondary MCLs are 1,000 and 1,500 mg/L, respectively. TDS concentrations above 1,000 mg/L occur in the vicinity of the Helendale Fault, where higher TDS groundwater in the Regional Aquifer

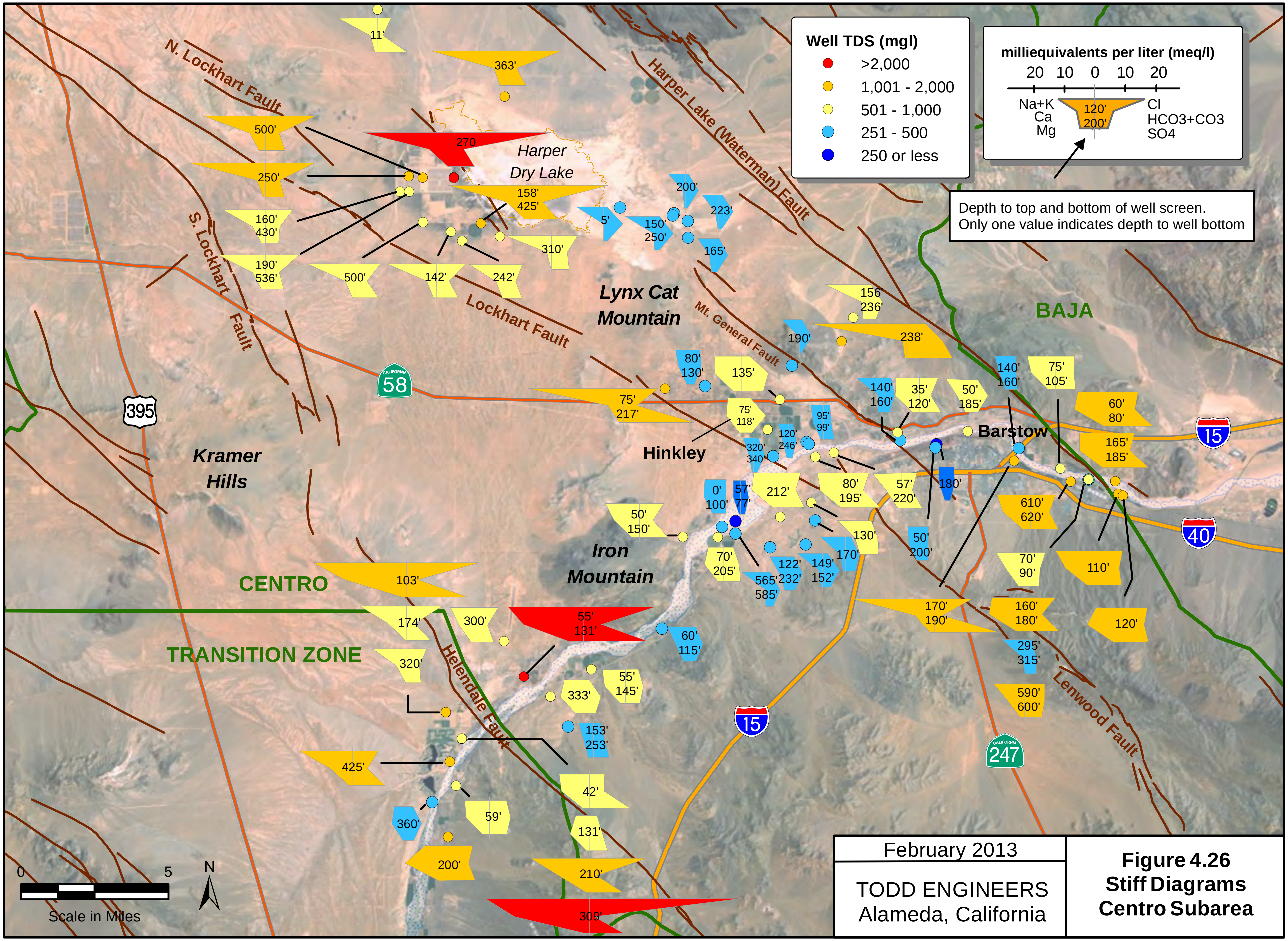

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Figure 4.26
Stiff Diagrams
Centro Subarea

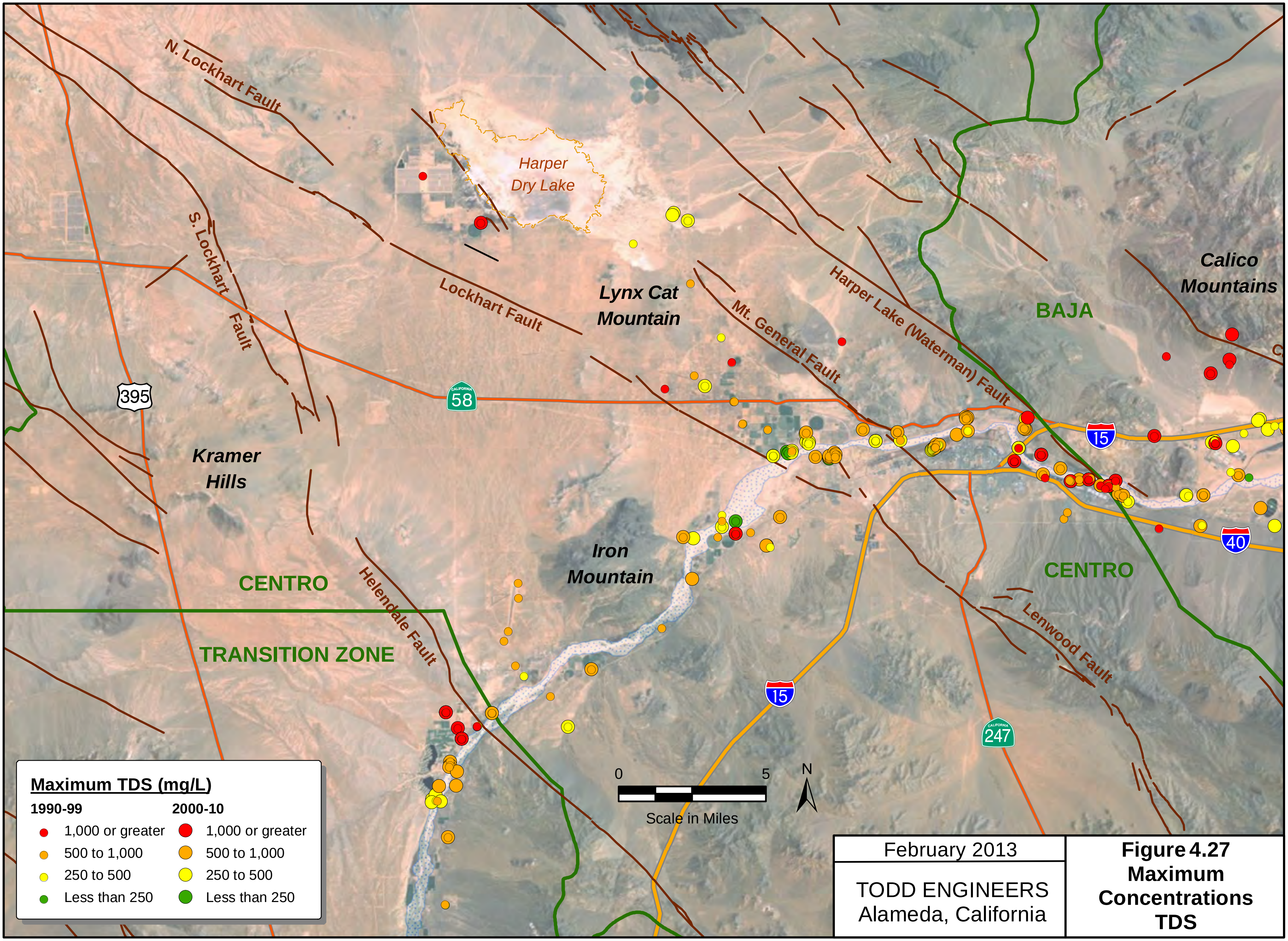

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Figure 4.27
Maximum Concentrations TDS

is directed upward by the fault into the Floodplain Aquifer. Elevated TDS also occurs west of Harper Dry Lake, where sodium and chloride are leached from evaporative lake deposits. Finally, elevated TDS concentrations occur in eastern Barstow upstream of the Harper Lake (Waterman) Fault primarily as a result of effluent discharges from the Barstow WWTP. The upward movement of groundwater from the Regional Aquifer into the Floodplain Aquifer west of the Harper Lake (Waterman) Fault also has been interpreted to contribute to the elevated TDS.

4.8.3 Arsenic

Arsenic is a naturally-occurring semi-metal. Arsenic compounds are used in wood preservatives, paints, dyes, metals, drugs, soaps and semi-conductors. Arsenic occurs naturally in sulfide-rich sediments and in zones having high iron oxide concentrations. It has also been found at high concentrations in shallow aquifers within closed hydrologic basins where evaporation rates exceed precipitation (Welch, et al., 2000). The most common natural cause of elevated arsenic concentrations in groundwater is arsenic released from iron oxides (as arsenic-III or arsenic-V complex anions), which can occur in the presence of organic carbon or alkaline groundwater conditions. The federal and state primary MCL for arsenic is 0.01 mg/L.

Figure 4.28 shows the maximum arsenic concentrations measured in Centro Subarea monitoring wells from 1990 to 2010. As shown on the map, maximum arsenic concentrations exceed the MCL in several areas, including areas previously identified as having elevated TDS concentrations (i.e., upstream of the Helendale Fault, west Harper Dry Lake, and eastern Barstow). In addition, elevated arsenic concentrations occur in some wells located southeast of Harper Lake, between the Lockhart Fault and Mt. General Fault, and in the main channel northwest of Barstow. With the exception of the Barstow area where elevated arsenic concentrations may be associated with effluent discharges, elevated arsenic concentrations across the Centro Subarea likely reflect natural sources.

4.8.4 Boron

Boron is a naturally-occurring element generally occurring as oxide compounds (i.e., borates).Boron is used in numerous industrial and domestic products, with its most prevalent use in household detergents, added as a bleaching agent. As such, boron concentrations in groundwater are controlled by geological weathering processes generally from marine-deposited clays and by wastewater treatment and discharge practices. Boron is an essential element for plant growth but above certain concentrations can be toxic to aquatic and terrestrial organisms. Boron tolerance for plants ranges from as low as 0.5 mg/L (e.g., peach and onion) up to 4 to 6 mg/L (e.g., alfalfa) (Maas, 1987). While there is no MCL for boron, the California Department of Public Health (CDPH) has established a drinking water notification level for boron of 1 mg/L.

Figure 4.29 shows the maximum boron groundwater concentrations measured in monitoring wells from 1990 to 2010. As shown on the map, maximum boron concentrations in areas monitored are generally less than 1 mg/L with only isolated occurrences where boron concentrations exceed 1 mg/L. Boron exceeds 3 mg/L in the vicinity of the Barstow WWTP.

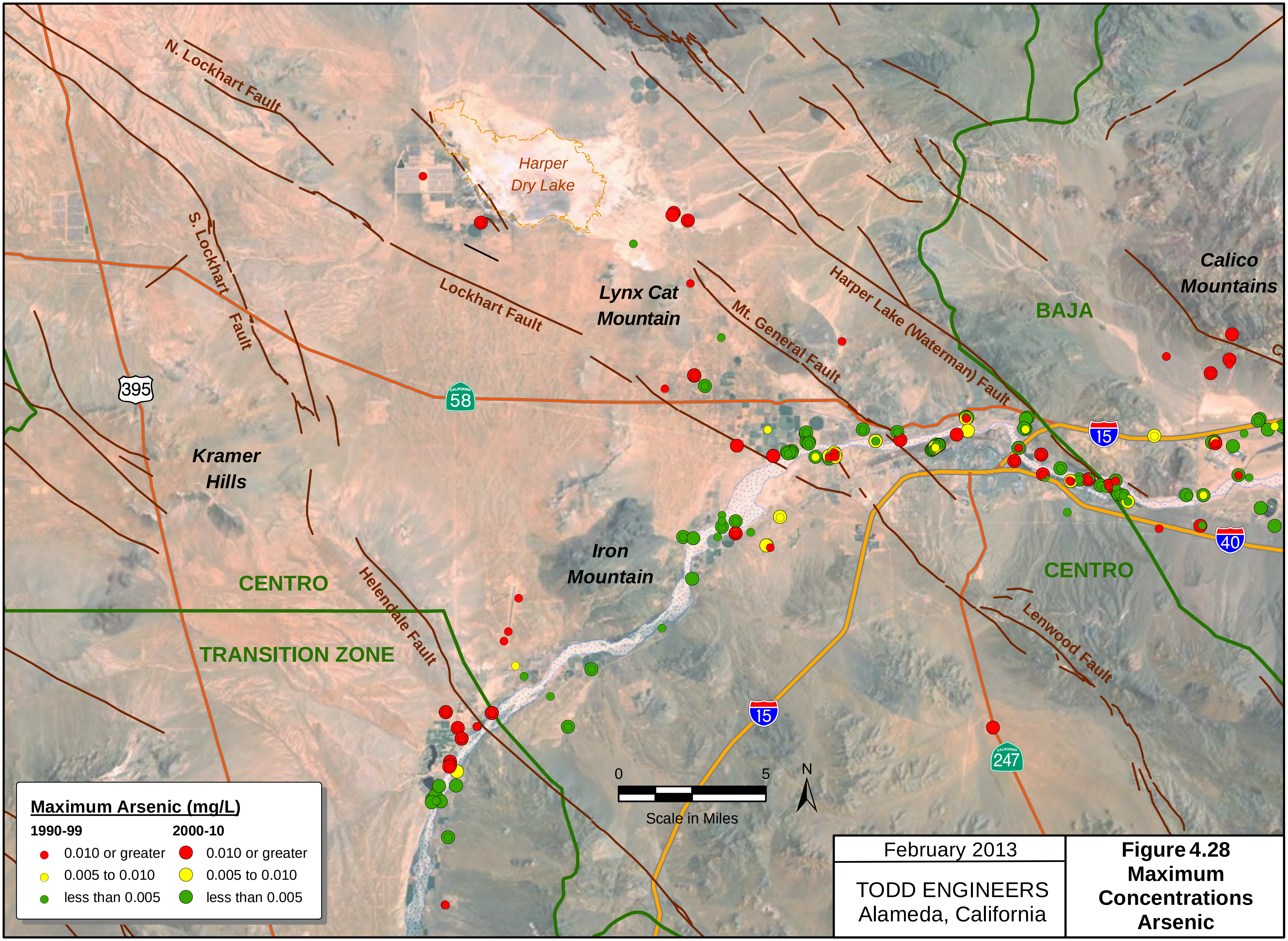

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Figure 4.28
Maximum Concentrations Arsenic

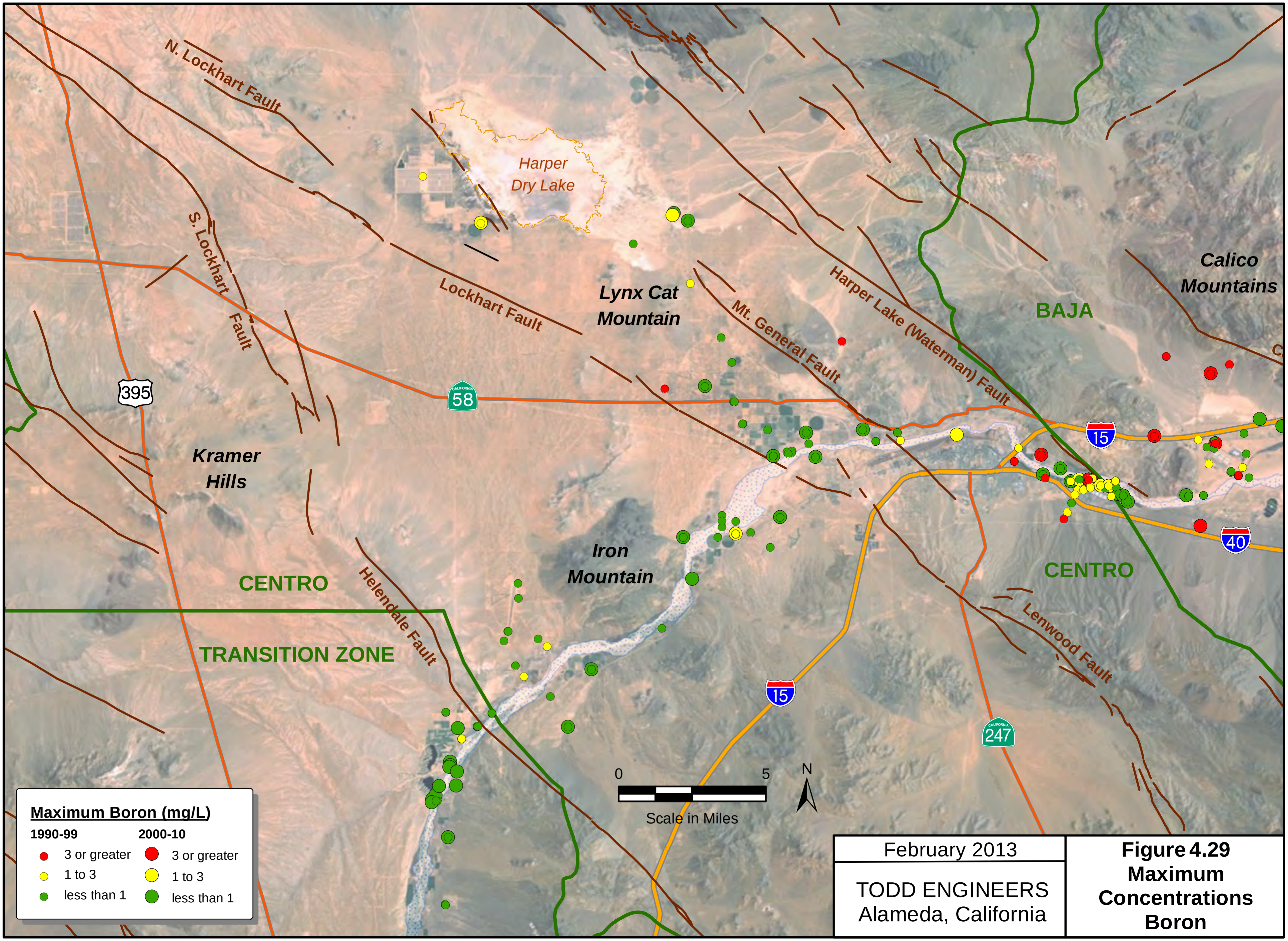

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Figure 4.29
Maximum Concentrations Boron

4.8.5 Hexavalent Chromium (Cr-VI)

Chromium is a naturally-occurring metal that is used in metal alloys, protective coatings, magnetic tapes, and pigments for paints, cement, paper, rubber, and floor coverings. Under most environmental conditions, chromium occurs as chromium-III oxide (Cr-III), an essential trace compound in the human diet that is relatively non-toxic. However, with oxidizing conditions, an alkaline pH range, presence of manganese oxide (MnO_2) and chromium-containing minerals, chromium may also occur in its hexavalent form as chromium-6 (Cr-VI). Cr-VI is a suspected human carcinogen that is highly soluble in groundwater.

The CDPH currently regulates Cr-Vl under the Primary MCL for total chromium of 50 micrograms per liter (ug/L). On July 27, 2011, the California Office of Environmental Health Hazard Assessment (OEHHA) recommended a Public Health Goal (PHG) of 0.02 ug/L. A PHG is not a drinking water regulatory standard, but rather represents a level of contaminant that does not pose a significant health risk (CDPH, 2012). The CDPH uses PHGs to develop drinking water standards or MCLs for specific contaminants and is in the process of developing a MCL for Cr-Vl (CDPH, 2012).

Figure 4.30 shows the maximum Cr-VI concentrations measured in monitoring wells in the Centro Subarea from 1990 to 2010. As shown on the map, Cr-VI concentrations in monitored areas generally range from less than 1 ug/L up to 4 ug/L. Such concentrations appear to be representative of background Cr-VI groundwater concentrations in the Study Area. Elevated concentrations above 4 ug/L have been observed in eastern Barstow. In addition to local, sporadic detections of Cr-VI in scattered monitoring wells, a plume of elevated Cr-VI concentrations in groundwater has been delineated in the Hinkley Valley associated with a PG&E natural gas compressor station. The current extent of the Cr-VI groundwater plume is also shown on the map (red and pink highlighted areas between the Lockhart and Mt. General faults represent groundwater Cr-VI concentrations exceeding 50 and 3.1 µg/L, respectively).

4.8.6 Fluoride

Fluoride is a naturally occurring halogen element originating from the weathering of rocks and soils. In groundwater, it occurs as an anion. Fluoride can also originate from runoff and infiltration of chemical fertilizers in agricultural areas, septic and sewage treatment system discharges in communities with fluoridated water supplies, and liquid waste from industrial sources. The federal and state MCL for fluoride is 2 mg/L.

Figure 4.31 shows the fluoride concentrations measured in monitoring wells in the Centro Subarea. As shown on the map, fluoride concentrations in areas monitored are generally below the MCL, with the exception of some wells in the eastern Barstow and southeast Harper Lake areas.

4.8.7 Nitrate-Nitrite as Nitrogen (N)

Nitrate and nitrite are naturally-occurring anions and are most commonly produced for use in agricultural fertilizers because of their high solubility and biodegradability. Nitrate and nitrite are also present in raw and treated wastewater. These sources can pose risks to urban and rural drinking water supplies. The federal and state MCL is 10 mg/L for nitrate-nitrite measured as N (nitrogen).

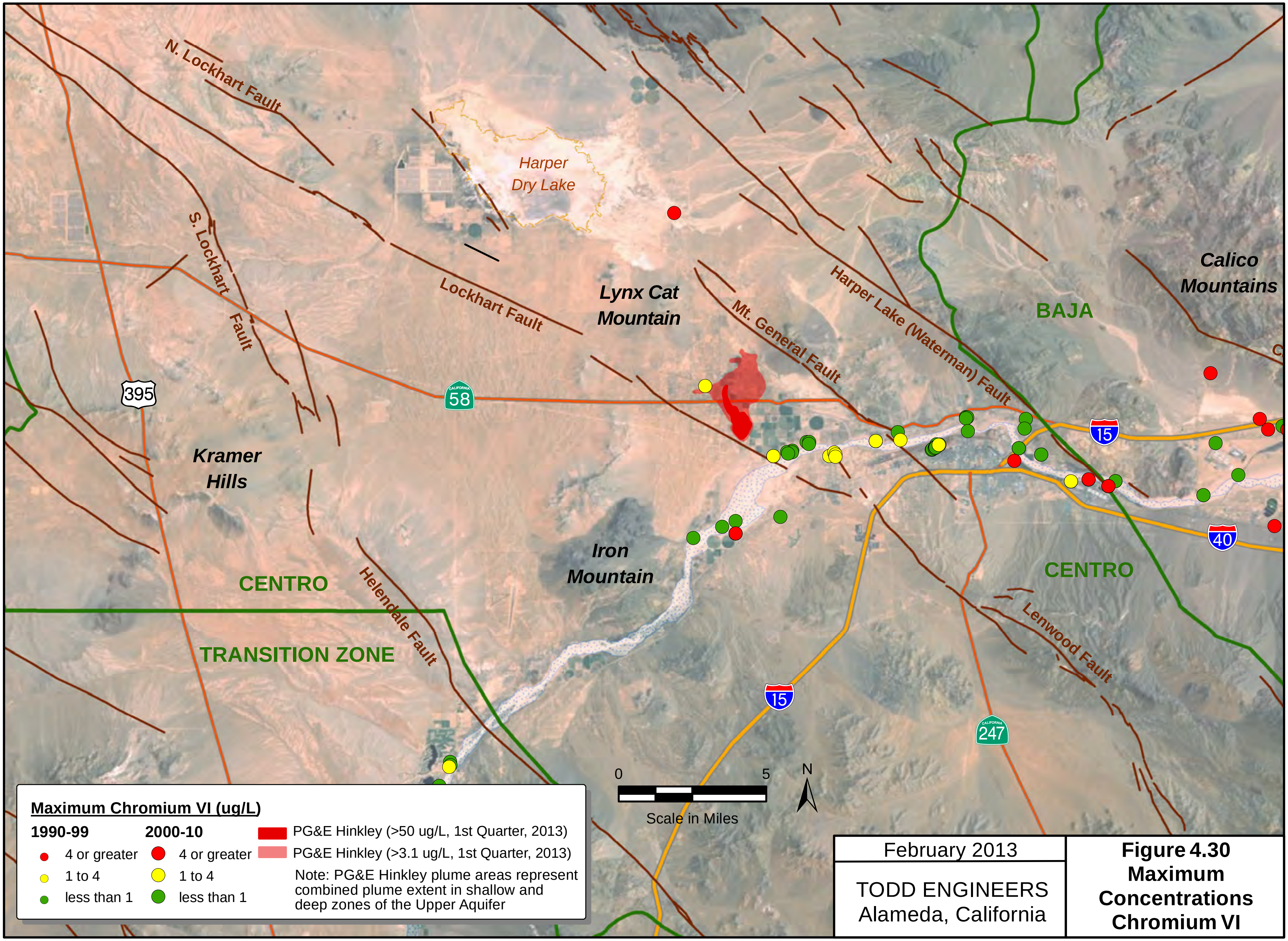

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Figure 4.30
Maximum Concentrations Chromium VI

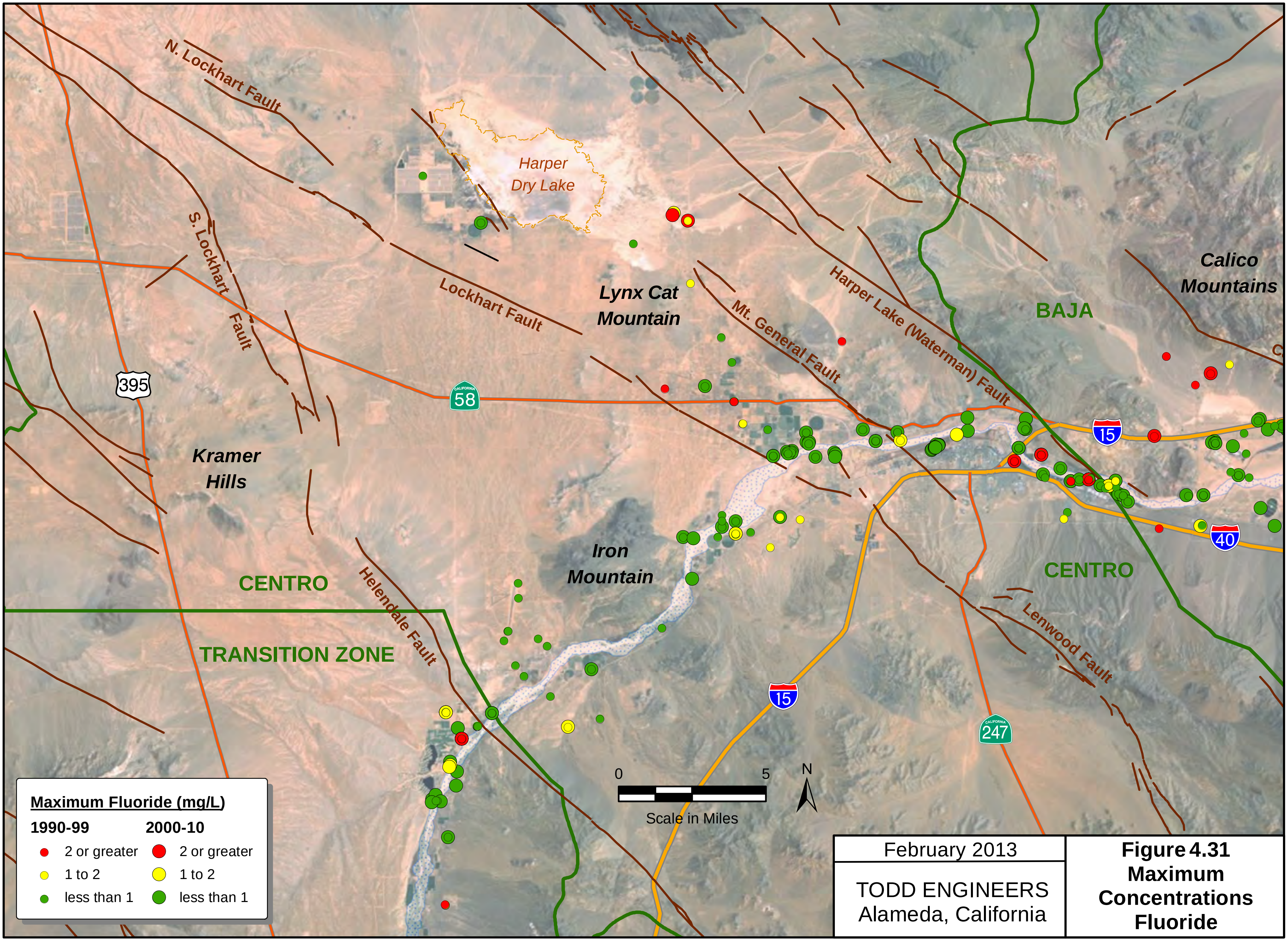

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Figure 4.31
Maximum Concentrations Fluoride

Figure 4.32 shows the maximum nitrate-nitrite as N concentration measured in monitoring wells from 1990 to 2010. As shown on the map, nitrate-nitrite concentrations are generally below the MCL in most areas, with the exception of eastern Barstow in the vicinity of the Barstow WWTP. Effluent discharges from the Barstow WWTP are regulated by the RWQCB, and a recent study has demonstrated the effectiveness of denitrification processes in reducing nitrate concentrations downstream of the WWTP (DPRA, 2010).

4.8.8 Perchlorate

Perchlorate is both a naturally occurring and human-made chemical that is used as a solid rocket fuel oxidizer. It is also used in fireworks, flares and explosives. The natural form is commonly found in desert environments. Perchlorate can also be present in degraded bleach and in some fertilizers. Perchlorate is a regulated drinking water contaminant in California, with an MCL of 6 µg/L.

Figure 4.33 shows the maximum perchlorate concentrations measured in monitoring wells from 1990 to 2010. As shown on the figure, perchlorate concentrations are generally below the MCL in the few areas that have been monitored to date. The one exception is in the Barstow area, where perchlorate concentrations above the MCL were detected in multiple municipal and domestic production wells in December 2010. Through an ongoing site assessment with groundwater and soil sampling, the RWQCB has determined that improper disposal of firework-producing chemicals at one residence north of the Mojave River is the source of contamination. Alternative remediation actions will be considered once the extent of contamination is fully characterized.

4.8.9 Regulated Environmental Contamination Sites

Figure 4.34 shows the active regulated environmental facilities in the Centro Subarea. (Sites in the Baja Subarea are discussed in the next section). As shown on the figure, active cleanup program sites include PG&E in Hinkley and the BNSF railroad and a perchlorate spill in Barstow, among others. Military cleanup sites include MCLB Nebo Annex and Edwards Air Force Base. Land disposal sites include wastewater discharges at SEGS III-VII and Shaharold Mine near Kramer Junction, SEGS VIII-X at Harper Lake, PG&E in Hinkley, and Lenwood-Hinkley and Barstow landfills. Additionally, there are a handful of active leaking underground storage tank (LUST) sites in the greater Barstow area.

4.8.10 Historical Contamination Issues

The Centro Subarea has a history of localized groundwater contamination related to waste and wastewater discharges and spill and leaks at industrial and military facilities. A summary of the nature and status of key groundwater contamination issues is presented below.

The Barstow Slug and Current Barstow WWTP Operations

Beginning in 1950s, studies were conducted to address assertions that industrial, commercial, and domestic waste and wastewater discharges had degraded groundwater quality in the Barstow area. Early studies found that groundwater quality in the main river channel had been locally degraded by local discharges with respect to petroleum hydrocarbons, phenols, dissolved organic carbon (DOC)

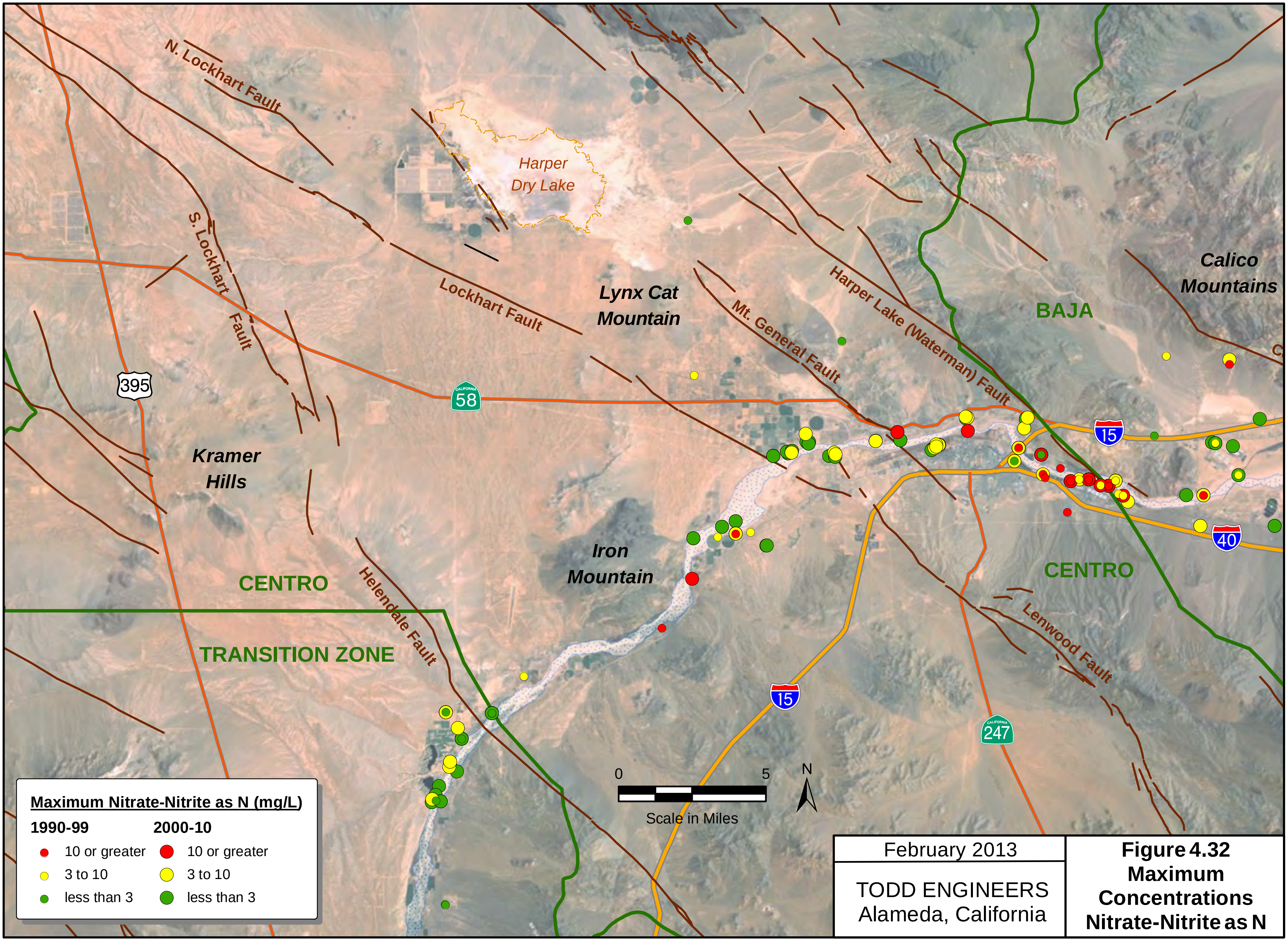

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Figure 4.32
Maximum Concentrations Nitrate-Nitrite as N

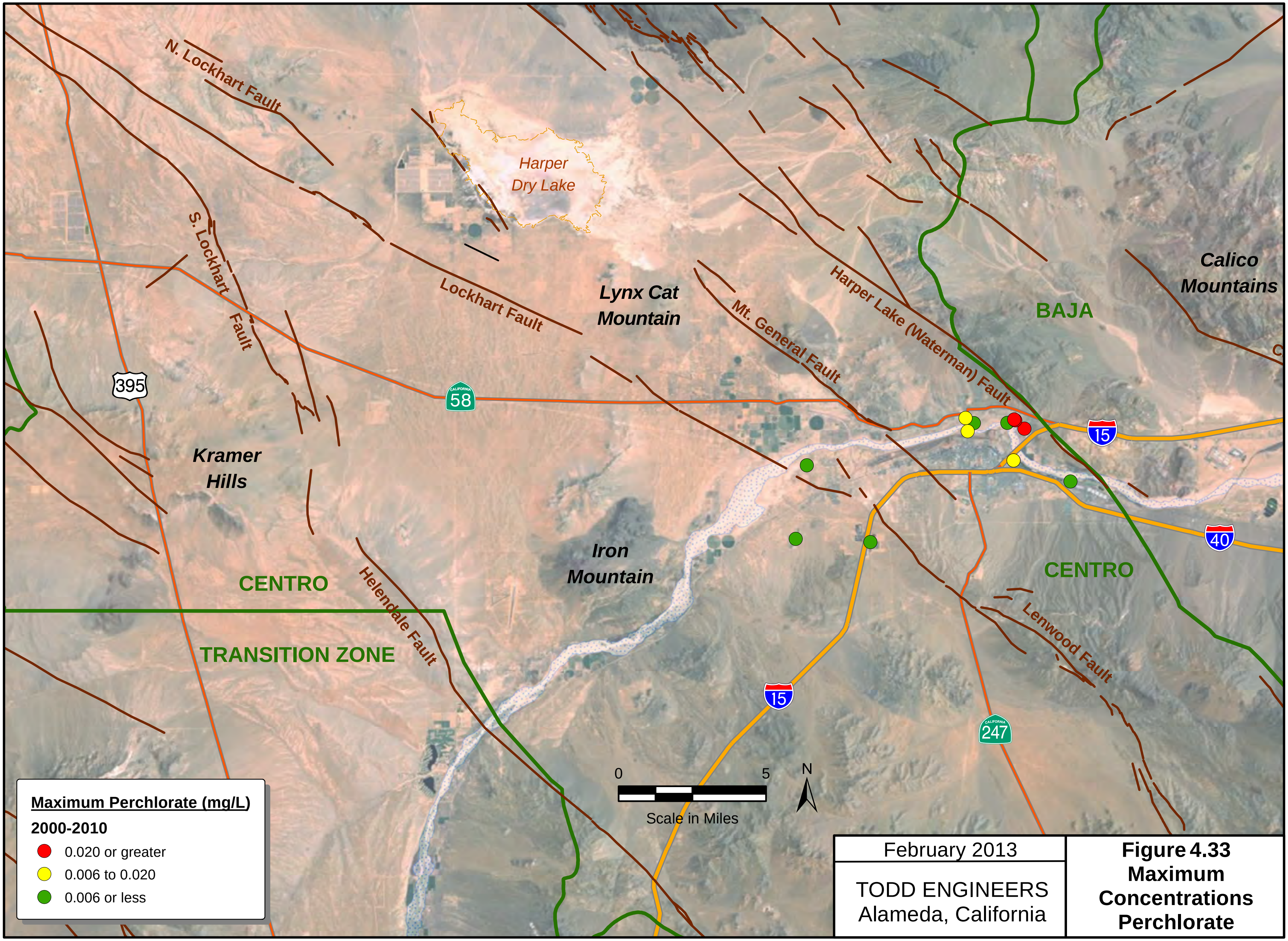

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Figure 4.33
Maximum Concentrations Perchlorate

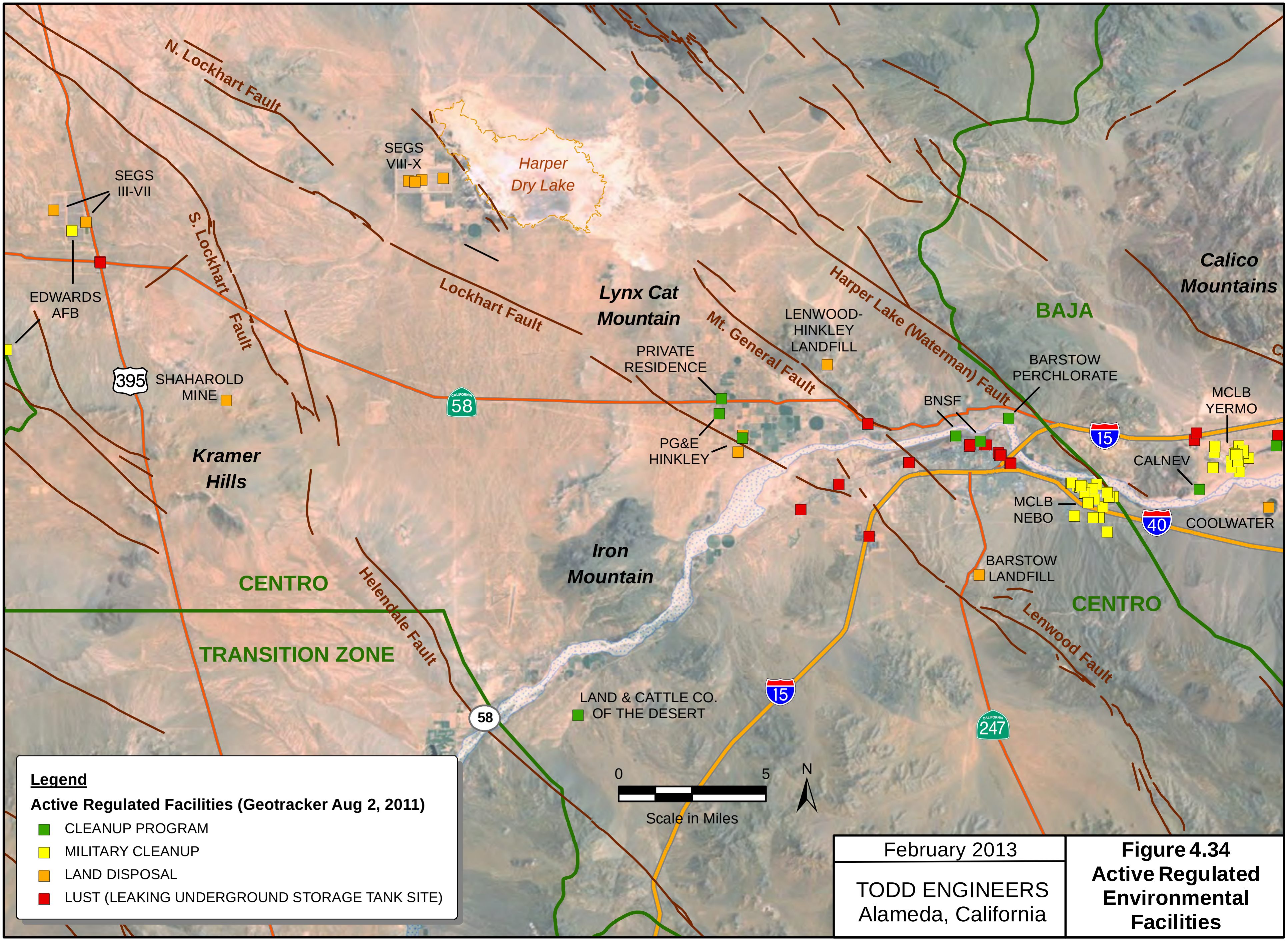

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Figure 4.34
Active Regulated Environmental Facilities

methylene blue active substances (MBAS), and TDS (CDPH and DWR, 1960; CDPH, 1966 and 1970). The contaminant plume, collectively referred to as the "Barstow Slug," forced the closure of several local domestic wells. A remediation project was originally planned to address elevated TDS concentrations in the 1970s, but the project was not implemented. Additional studies in the 1980s found that most organic contaminants had been attenuated and/or diluted to background levels by large storm recharge events. Nonetheless, elevated TDS concentrations persisted and were correlated with ongoing discharges from the Barstow and MCLB Nebo WWTPs (Eccles, 1981; James M. Montgomery Consulting Engineers, 1984). A later study by Geraghty & Miller (1990) confirmed that concentrations of organic constituents of concern, including DOC, MBAS, and trichloroethene (TCE) were below MCLs and did not appear to present a continuing threat to groundwater quality. Of the inorganic constituents evaluated, nitrate was found to have exceeded its respective MCL in some wells in the Barstow area. While most of the nitrate was assumed to be related to WWTP discharges, elevated nitrate upstream of the WWTP was attributed to local agriculture.

In 1994 and 1997, Densmore, et al. examined groundwater quality conditions at the Nebo and Yermo annexes and determined that effluent discharges from the City of Barstow's WWTP were the primary source of the groundwater degradation. However, TDS concentrations upstream of the Harper lake (Waterman) Fault were also found to be greater than 2,000 mg/L in the Regional Aquifer, with the hydraulic head sufficiently high to discharge poor-quality water to the Floodplain Aquifer.

Since 1990, the City of Barstow has worked closely with the RWQCB to identify and eliminate sources of elevated TDS that enter the WWTP. Through an aggressive source control program, the City has reduced the concentration of TDS in its effluent from greater than 1,000 mg/L to less than 800 mg/L.

Burlington Northern Santa Fe (BNSF) Barstow Railway Yard

The Burlington Northern Santa Fe Railway Company (BNSF) operates railway maintenance facilities in the City of Barstow. Investigations at its facilities have indicated groundwater plumes within the Floodplain Aquifer of chlorinated hydrocarbons and diesel-related constituents. As required by the RWQCB, BNSF is actively recovering free-phase petroleum hydrocarbons, with installation and operation of two permeable reactive barriers and an air sparing/soil vapor extraction remediation facility in the area of the chlorinated hydrocarbon plume to the east.

In 1989, a pipeline at the BNSF Barstow Yard ruptured, releasing diesel fuel into the unsaturated zone. A subsequent investigation indicated diesel fuel floating on the groundwater table surface beneath and downgradient of the release site. BNSF has installed a soil vapor extraction/bioventing system to restore the beneficial uses of the groundwater. However, rising groundwater levels caused by above-average recharge has rendered the system inoperative because the air injection/extraction wells are now screened below the water table surface. BNSF has proactively monitored the groundwater during the last several years, and there is no evidence of plume migration.

MCLB – Barstow

Over the past 50 years, maintenance activities at the MCLB Barstow generated large quantities of waste, including waste oils, fuels, solvents, paint residues, grease, hydraulic fluids, battery acids, various gases, and low-level radiation sources. Other hazardous substances used or generated on the base included pesticides, herbicides, polychlorinated biphenyls (PCBs), calcium hypochlorite, and sodium. Past waste disposal practices reflected the accepted procedures at the time and included disposal in landfills, burn trenches, and other miscellaneous sites on the base (Jacobs Engineering Group, 1995).

Historical groundwater pollution identified in the early 1980s at the Nebo Annex has resulted in the construction of two groundwater remediation facilities, or Operable Units (OUs). The groundwater OUs at the Nebo Annex address two plumes of volatile organic compounds (VOCs). The North Nebo plume contains tetrachloroethene (PCE) and is approximately 1,500 feet by 4,000 feet in areal extent and limited to the upper 20 feet of the aquifer. The remedial strategy for the North Nebo plume is an air sparging/soil vapor extraction system and natural attenuation of the remaining contaminant mass in the groundwater. The anticipated cleanup timeframe to achieve the drinking water standard of 5 µg/L for PCE is estimated at 15 years. The South Nebo plume of VOCs contains mostly TCE. The plume is approximately 1,000 feet by 800 feet in areal extent and is migrating easterly at a rate of approximately 20 feet per year. The plume has migrated off the MCLB base boundary and has impacted one private drinking water well. A pump and treat system has been used for plume containment. The anticipated cleanup timeframe using a pump and treat remedial strategy is estimated at 105 years (ATSDR, 2011).

PG&E Hinkley

As mentioned previously, extensive investigations by Pacific Gas and Electric (PG&E) Generating Station have identified a plume of groundwater degraded by Cr-VI, which leaked from onsite wastewater ponds. The current dimensions of the plume are approximately two miles in length and one-quarter mile in width. PG&E no longer uses Cr-VI in its facility operations and has implemented an aggressive corrective action program to monitor and remediate locally degraded groundwater. Current activities are focused on characterizing the horizontal and vertical extent of the plume, which has migrated below the laterally extensive confining blue clay aquitard in some areas into older cemented and weathered alluvial sediments.

5. BAJA SUBAREA-BASIN CONCEPTUAL MODEL

The Baja Subarea is situated downstream of the Centro Subarea. Like Centro, groundwater occurs in a complex geologic setting. Baja groundwater storage, levels, and flow have been influenced significantly over time by local and upstream pumping. Groundwater quality has been influenced by the local geology and human activities.

This section describes the conceptual model of the Baja Subarea, including faults, basin geometry, hydrogeologic units and aquifer parameters, groundwater occurrence and flow, groundwater level trends, groundwater storage, a water budget, and groundwater quality.

5.1 Baja Faults and Hydraulic Barriers

Major geologic structures in the Baja Subarea are shown on **Figure 3.3** and include the Camp Rock-Harper Lake (Waterman) Fault, which represents the boundary between the Centro and Baja subareas, the Calico Fault (and associated Newberry Fracture Zone), Manix Fault, and Baja Fault. Previous researchers have identified these structures as partial barriers to groundwater flow using primarily groundwater level data (DWR, 1967, Hardt, 1971, Stamos et al., 2001, Stamos and Predmore, 1995, Lines, 1996; Stamos et al., 2003; Stamos et al., 2009). Other faults in the Baja Subarea include the Coyote Lake, Cady, Rodman, and Pisgah faults. These faults generally occur in consolidated bedrock areas and do not significantly impact groundwater flow in the Basin. The following sections describe the historic and current understanding of each of the major faults with respect to its location and influence on groundwater flow.

5.1.1 Camp Rock-Harper Lake (Waterman) Fault

The Camp Rock-Harper Lake (Waterman) Fault occurs about 5 miles east of Barstow and extends from the Waterman Hills in the northwest to the Newberry Mountains in the southeast. The general trace of the Harper Lake (Waterman) Fault represents the central portion of the boundary between the Centro and Baja subareas. The fault was first mapped by Dibblee (1970) and later refined by Cox and Wilshire (1993) to include five separate northwest-to-southeast trending fault splays identified from west to east as Faults A through E. The fault splays cross through the Barstow WWTP and MCLB- Nebo Annex area (see map inset on **Figure 3.3**). Faults C and E have been identified as partial barriers to groundwater flow in both the lower Floodplain and Regional aquifers (Stamos and Predmore, 1995; Mendez and Christensen, 1997; Stamos et al., 2001). Most of the groundwater flow across the fault is likely through the river deposits overlying the fault (Hardt, 1971).

Hardt (1971) modeled the effect of the Harper Lake (Waterman) Fault using a relatively low transmissivity value of 3,500 gpd/ft in the single-layer electrical analog model. Stamos et al. (2001) assigned a conductance value of 5×10^{-3} and 5×10^{-7} day^{-1} to Faults C and E, respectively. These values are summarized in **Table 5.1**.

Table 5.1
Hydraulic Parameters Used to Simulate Geologic Faults in the Baja Subarea

Subarea	Fault	Hydraulic Effect		Fault represented in USGS Groundwater Models				
				Hardt, 1971[a]	Stamos, 2001 (Conductance for Model Layers)[b]			
		Floodplain Aquifer	Regional Aquifer	Transmissivity (gpd/ft)	Layer 1 Floodplain (1/day)	Layer 1 Regional (1/day)	Layer 2 Floodplain (1/day)	Layer 2 Regional (1/day)
Centro/Baja	Harper Lake (Waterman) Fault	Yes	Yes	3,500	(C) 5×10^{-3} (E) 5×10^{-7}	(C) 5×10^{-3} (E) 5×10^{-7}	(C) 5×10^{-3} (E) 5×10^{-7}	(C) 5×10^{-3} (E) 5×10^{-7}
Baja	Calico Fault	Yes	Yes	2,500	2×10^{-5}	2×10^{-9}	2×10^{-9}	2×10^{-9}
Baja	Baja Fault	Yes	Yes	NM	1×10^{-8}	1×10^{-8}	NP	NP

[a]Single transmissivity value used to represent fault in single-layer model
[b]units for conductance (1/day) represents hydraulic conductivity of hydraulic flow barrier (in feet/day) divided by barrier width (feet)
NP = Not present in Model Layer
NM = Not modeled
gpd/ft = gallons per day per foot

5.1.2 Calico Fault

The Calico Fault trends southeastward from the Calico Mountains, across the Baja Subarea and through the northeast flank of the Newberry Mountains and Rodman Mountains. Water levels on the southwest side of the fault have historically been higher than those on the northeast side, and the offset has increased over time from about 30 feet in the 1950s to about 50 feet currently. Hardt (1971) modeled the effect of the Calico Fault using a low transmissivity value of 2,500 gpd/ft in the single-layer electrical analog model. Stamos et al. (2001) assigned a conductance value of 2×10^{-5} in the Layer 1 within the floodplain and a lower conductance of 2×10^{-9} elsewhere (**Table 5.1**).

The Newberry Fracture Zone is a cluster of splays associated with the Calico Fault. While groundwater levels are not impeded significantly within the Newberry Fracture Zone, these faults have affected the depth of consolidated bedrock locally.

5.1.3 Manix Fault

The Manix Fault begins at the foot the Calico Mountains and extends eastward through Harvard Hill and Manix Wash and crosses the Mojave River near Afton. While the fault trace is well defined, previous studies have not found that the Manix Fault significantly impacts groundwater flow in the Basin.

5.1.4 Baja Fault

Stamos et al. (2001) was the first to infer the presence of a northwest-southeast trending fault north of the Mojave River in the far eastern portion of the Baja Subarea east of Camp Cady (referred to as the Baja Fault). The fault is not well defined and is inferred from groundwater levels in only one production well. Stamos et al. (2001) assigned a conductance value of 1×10^{-8} to the Baja Fault in the USGS groundwater model (**Table 5.1**).

5.2 Baja Basin Geometry

Figure 5.1 presents available well data in the Baja Subarea used in geologic mapping and hydrogeologic cross section development. The upper left map (labeled A) shows the 3,803 wells on record in the Baja Subarea symbolized by total well depths, which range from less than 100 feet-bgs to 800 feet-bgs. Of these wells, 1,826 wells have lithologic information, and 1,674 wells have well construction information. Additionally, well yield and drawdown information contained in well driller's logs and available pumping test records were available for 202 wells distributed across the subarea. Hydraulic information was used to estimate the distribution of aquifer transmissivity as shown in the upper right map (labeled B) on **Figure 5.1**.

Of the available wells on record, lithologic information in 157 wells indicate that semi-consolidated to consolidated basin fill sediments or basement complex rocks were encountered. As shown in the lower left map (labeled C) on **Figure 5.1**, these wells are concentrated along the outer margins of the basin. These wells provide reliable control points for mapping the depth to the base of unconsolidated sediments.

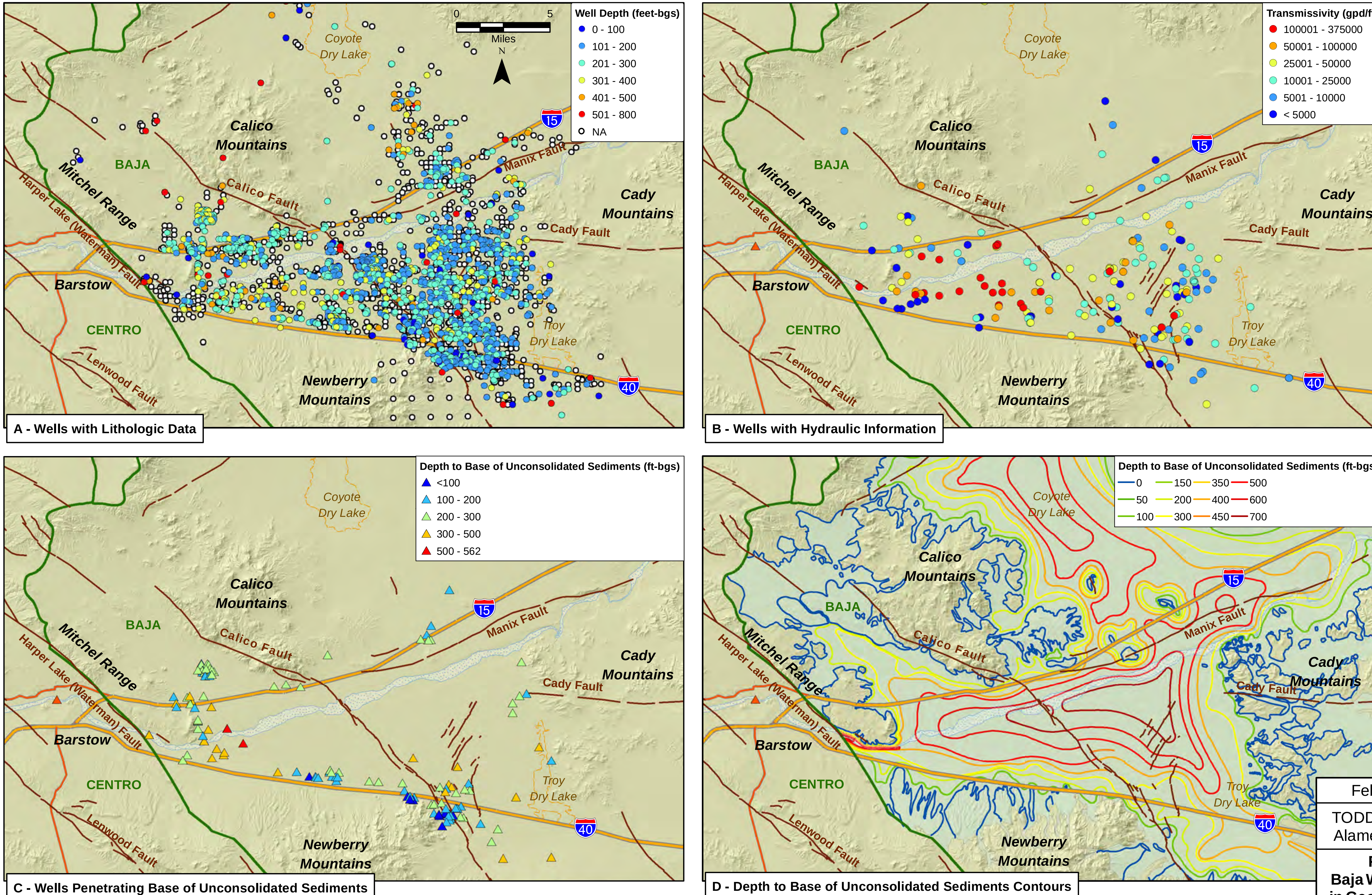

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Figure 5.1
Baja Well Data Used in Geologic Mapping

In addition to lithologic and aquifer hydraulic data, water level and water quality information were used to interpret hydrogeologic boundaries and geologic contacts. In areas where available well data were limited, bedrock elevations were estimated based on observed trends in the slope of the base of unconsolidated sediments in the vicinity and elsewhere in the Study Area. When wells in close proximity contained conflicting lithologic descriptions, wells with the more detailed lithologic descriptions were given more weight over the more general descriptions on driller's logs. Also, driller's logs from clusters of wells were compared together to identify and remove from consideration "outlier" lithologic descriptions. Collectively, these data were used to develop the depth to the base of unconsolidated sediments (primary aquifers) in the Baja Subarea.

The lower right map (labeled D) on **Figure 5.1** shows contours representing the depth to base of unconsolidated sediments. These contours were interpolated using GIS Spatial Analyst and the inverse-distance weighted method to develop a final surface representing the depth to base of unconsolidated sediments, as shown on **Figure 5.2**. Observations on the unconsolidated sediment map are summarized below.

- The base of unconsolidated sediments varies considerably, ranging from less than 100 feet-bgs along the margins of the basin down to 700 feet in the central interior portion of the basin bounded generally by the Calico Fault, Mojave River, and Newberry Fracture Zone.
- Shallow consolidated units interrupt and isolate the three deepest portions of the basin (south-central portion, Coyote Dry Lake, and a smaller, deep area to the east) (**Figure 5.2**). In the vicinity of Coyote Lake, the depth to the base of unconsolidated sediments is about 600 feet. Unconsolidated sediments extend to a similar depth in the eastern portion of the basin north of the Cady Mountains.
- The base of unconsolidated sediments appears to be offset along the Calico Fault in the southern portion of the basin, with the eastern side slightly higher in elevation than the western side.

5.2.1 Baja Hydrogeologic Cross Sections

Six hydrogeologic cross sections (Cross Sections A-A' through F-F') were prepared across the Baja Subarea. Cross section locations, shown on **Figure 3.2,** were located to incorporate the maximum amount of hydrogeologic data in the subarea. Cross sections are presented on **Figures 5.3 through 5.6**. Each cross section was developed using geologic maps, well construction, lithologic, and single-well aquifer pumping test information, and historical groundwater level and quality data. Note the vertical exaggeration. Key features in each cross section are described below.

Baja Cross Section A-A'

Cross section A-A' (**Figure 5.3**) is a 17-mile cross section oriented northwest to southeast across the lower portion of the Baja Subarea along the axis between Coyote Lake and Troy Lake. The section begins north of the Mojave River (left on the figure) and extends southeast through Harvard Hill and the Manix Fault. The section continues across the Mojave River and Newberry Fracture Zone and terminates in

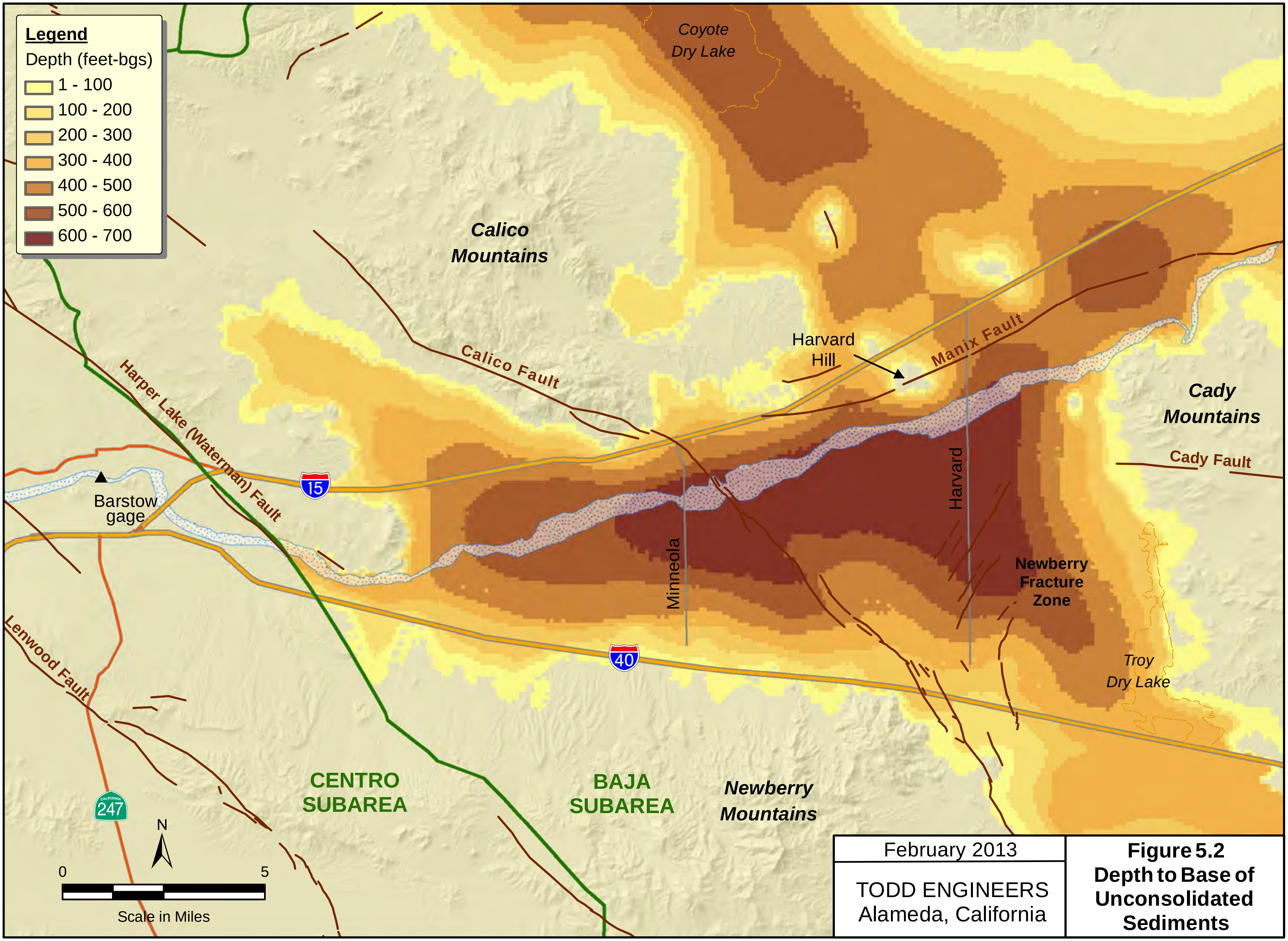

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Figure 5.2
Depth to Base of Unconsolidated Sediments

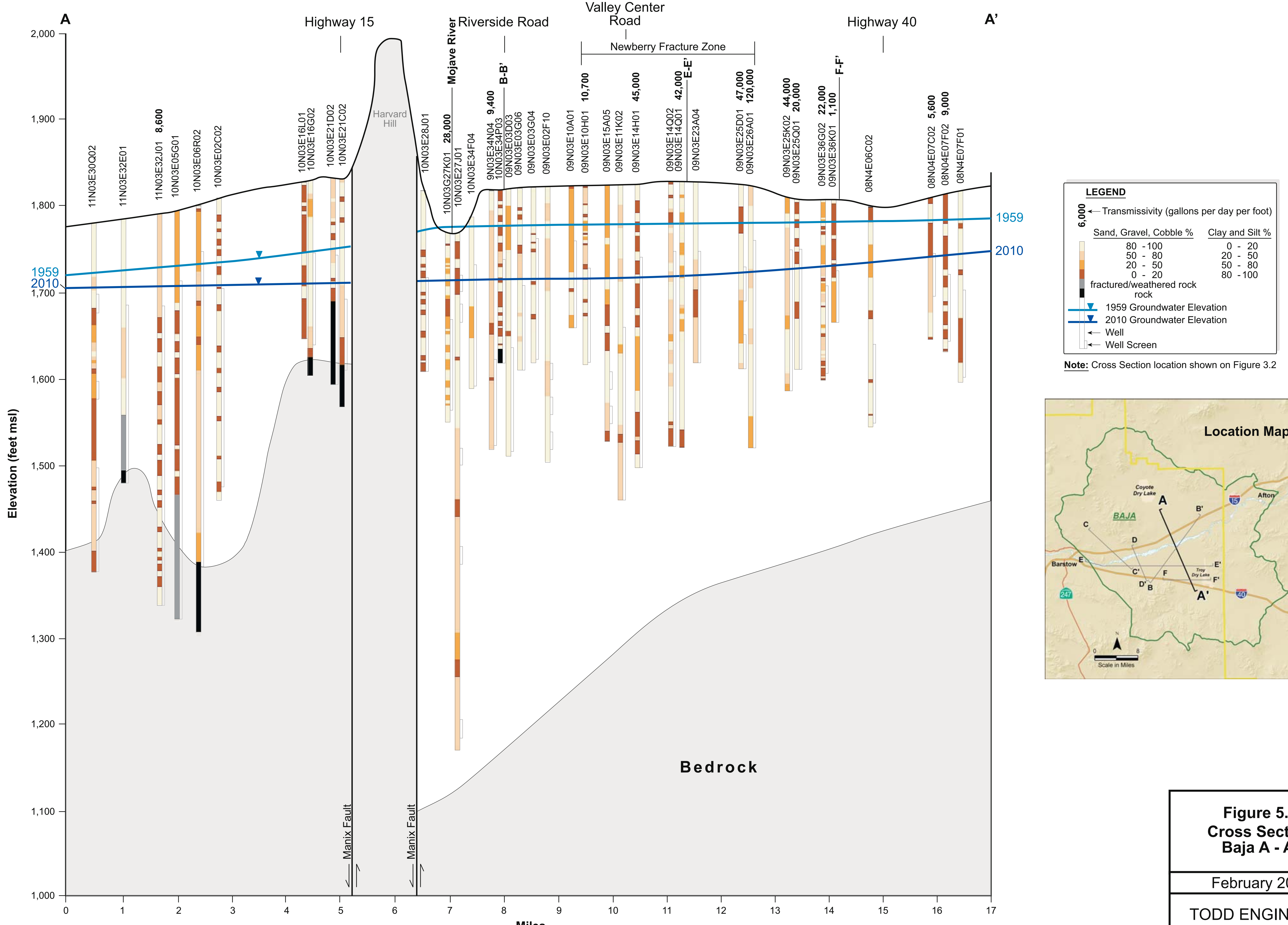

Figure 5.3
Cross Section
Baja A - A'

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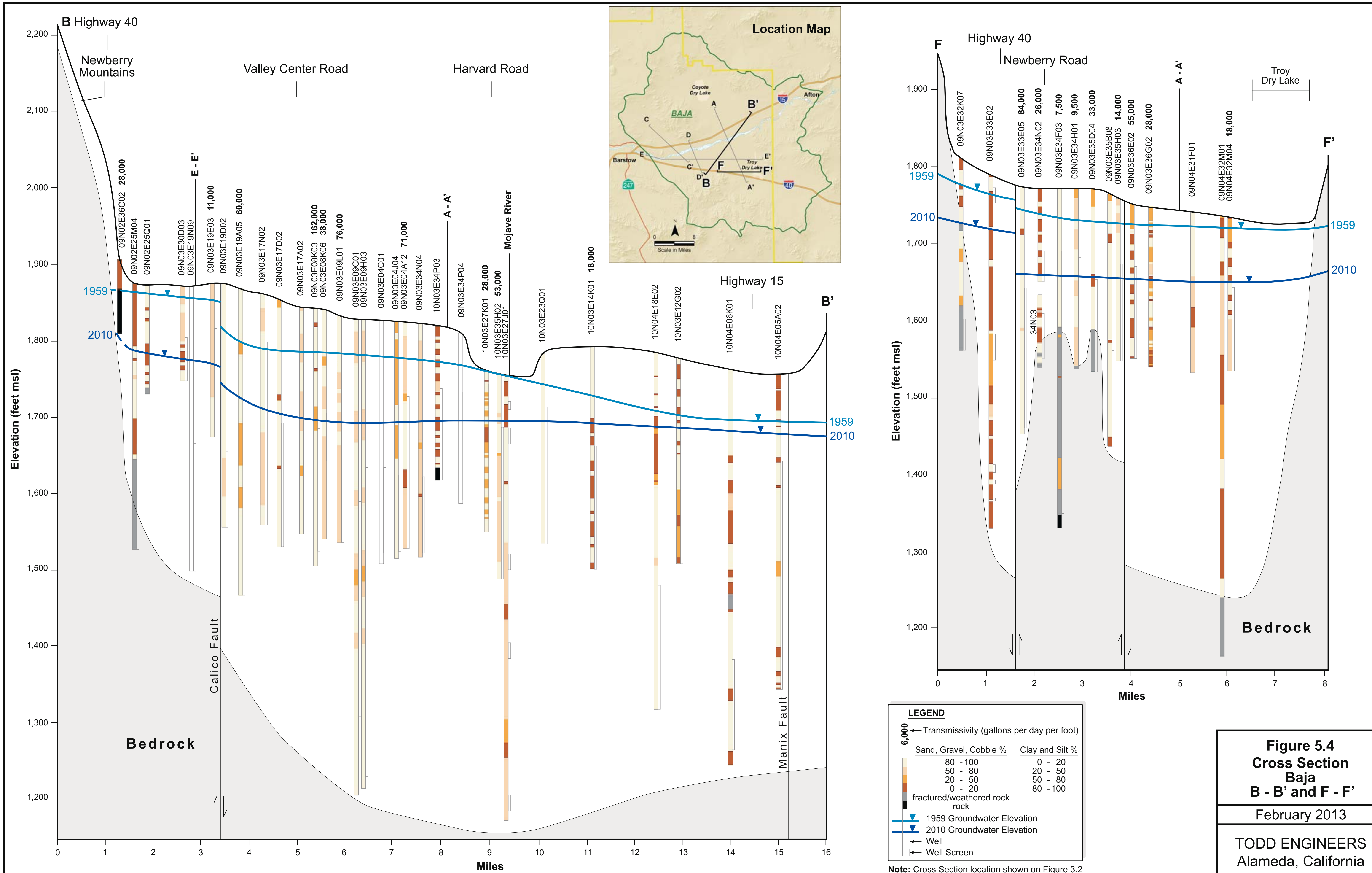

Figure 5.4
Cross Section
Baja
B - B' and F - F'

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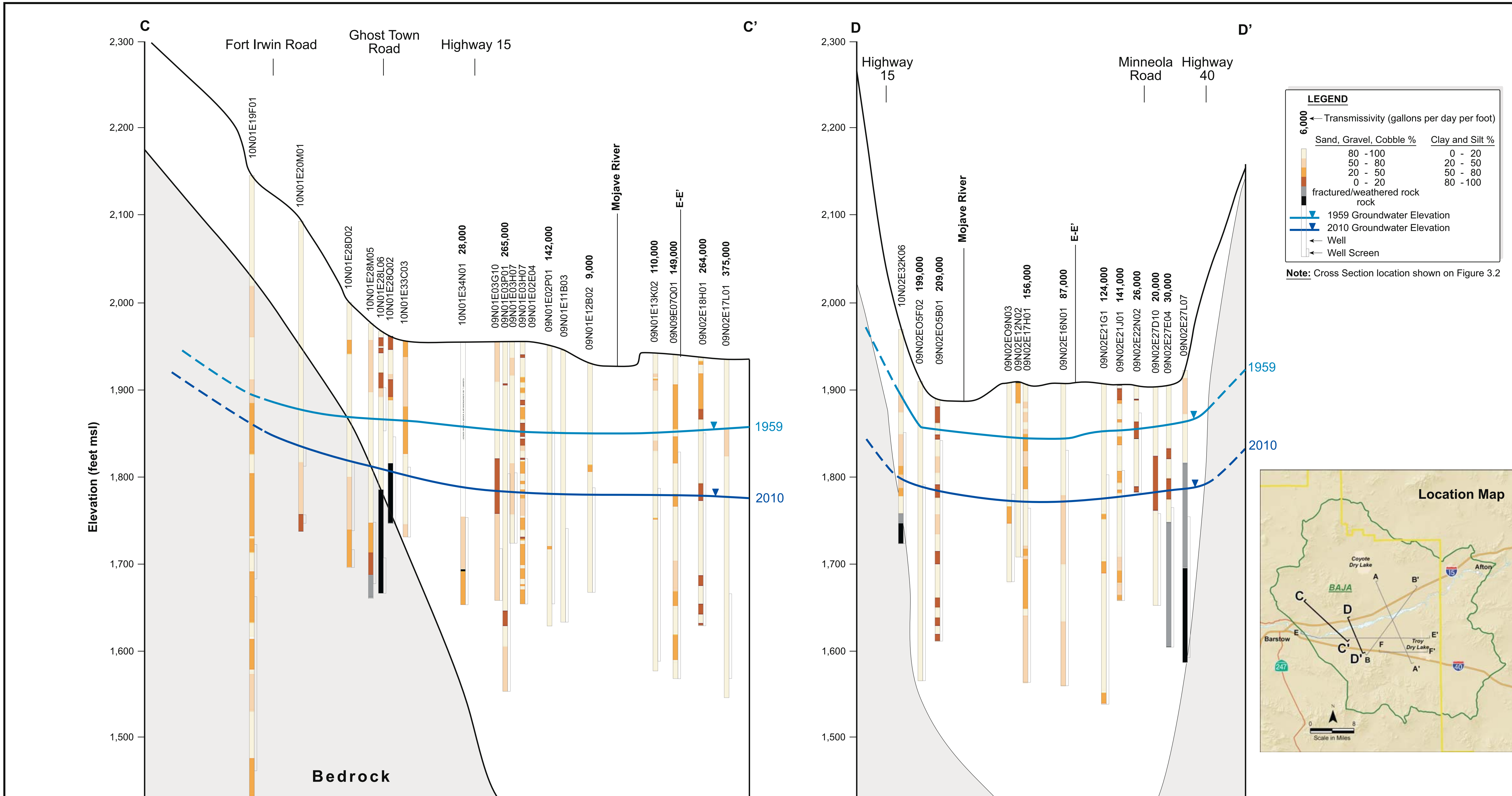

Figure 5.5
Cross Section
Baja
C - C' and D - D'

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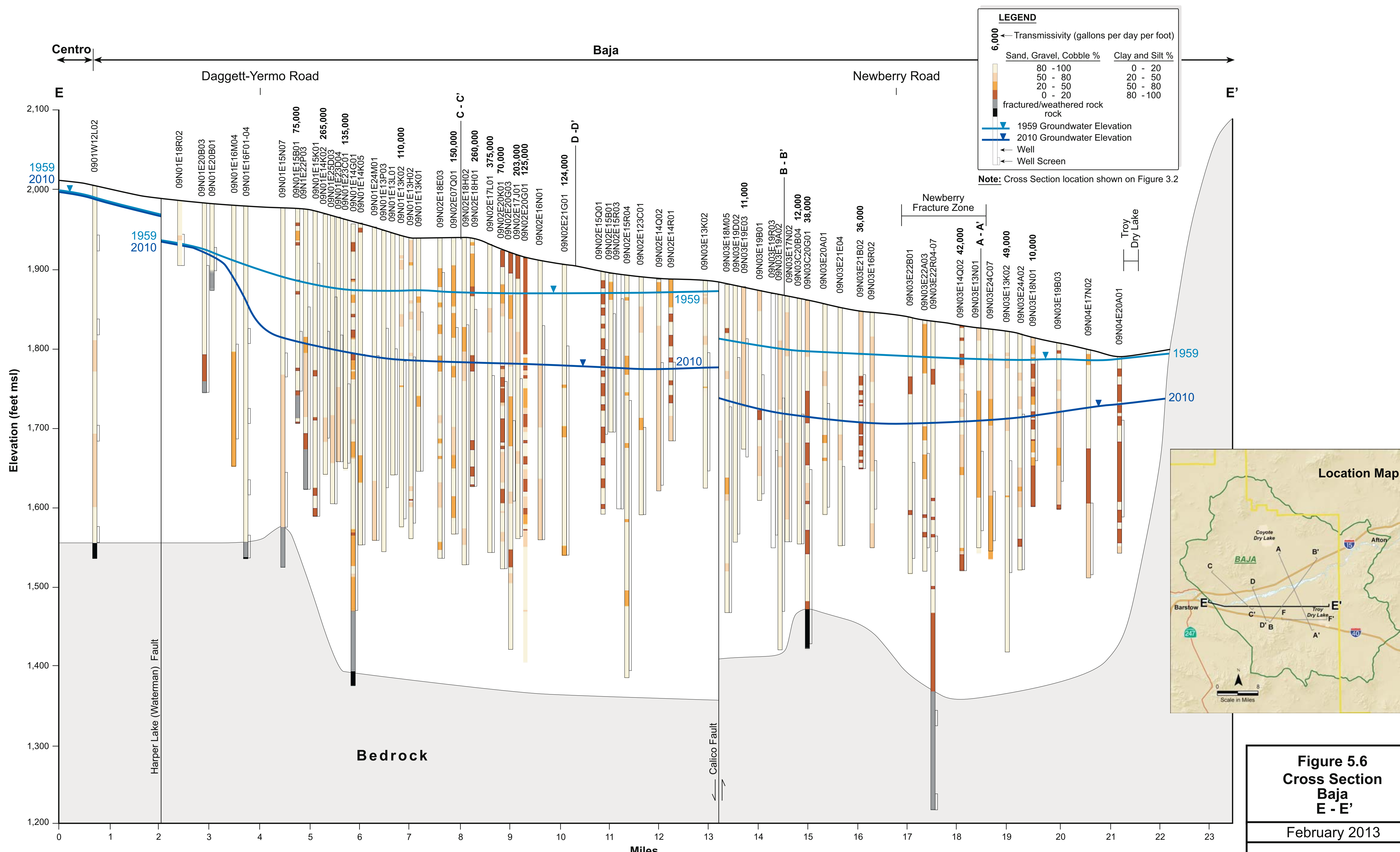

Figure 5.6
Cross Section
Baja
E - E'

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undifferentiated Quaternary alluvial fan deposits south of Interstate Highway 40 and east of Troy Dry Lake.

As shown on the section, Harvard Hill represents exposed (Tertiary sedimentary) basement rock. The base of unconsolidated sediments varies from less than 200 to 400 feet-bgs north of Harvard Hill; south of Harvard Hill and the southern splay of the Manix Fault, the base of unconsolidated sediments is deeper (about 700 feet-bgs), but gradually rises to about 350 feet-bgs in the south. Alluvial deposits are comprised of recent river wash deposits in the main channel of the Mojave River surrounded by younger inter-bedded clays, silts, and fine sands, which comprise the Manix Beds. The groundwater system is separated into a shallow unconfined aquifer and deeper confined aquifers by the Manix Clay Beds (represented by the darker colors on the well profiles, generally in the upper 200 feet).

Aquifer transmissivities estimated from well hydraulic test data are labeled on the cross sections above the well names. As shown on **Figure 5.3**, transmissivities south of the Mojave River generally range from about 20,000 gpd/ft to 50,000 gpd/ft; south of the Newberry Fracture Zone, a higher percentage of fine-grained sediments corresponds with lower aquifer transmissivities (less than 20,000 gpd/ft). North of Harvard Hill, well aquifer transmissivities are even lower (less than 10,000 gpd/ft) because of the high percentage of fine-grained sediments.

Groundwater levels are relatively flat across the section, which is oriented perpendicular to groundwater flow. Historical groundwater level changes in this area have been significant, with declines ranging from 40 to 70 feet over the past 50 years (compare the water levels from 1959 to 2010 as shown on **Figure 5.3**). Larger declines are observed beneath and south (right) of the river.

Baja Cross Section B-B’

Cross Section B-B’ (**Figure 5.4**) is a 16-mile southwest-to-northeast cross section located in the central to lower portion of the Baja Subarea. The section begins in the Newberry Mountains in the southwest, cuts northeast across Newberry Springs and the Calico Fault, crosses the Mojave River, and terminates in the alluvial fan below the Alvord Mountains in the northeast. As shown in the figure, the base of unconsolidated sediments ranges from less than 100 feet-bgs to about 400 feet-bgs west (left) of the Calico Fault. East of the Calico Fault, the base of unconsolidated sediments extends to 700 feet-bgs. South of the Mojave River (left on the cross section), aquifer transmissivities generally range from 60,000 gpd/ft to more than 100,000 gpd/ft, corresponding with generally coarse-grained sediments identified in well driller’s logs. North of the river (right on the cross section), aquifer transmissivities are generally lower, reflecting the higher percentage of fine-grained sediments.

The section is oriented transverse to the direction of groundwater flow. As shown on the cross section, groundwater levels are offset by 40 to 50 feet across the Calico Fault. Historical groundwater level changes have been significant in the region, ranging from 40 to 80 feet over the past 50 years. Larger declines are observed beneath and south (left on the section) of the river.

Baja Cross Sections C-C’

Cross section C-C’ (**Figure 5.5**) is an 11-mile northwest-to-southeast cross section in the upper portion of the Baja Subarea. The section begins in the alluvial fan between the Mitchel Range and Calico

Mountains, crosses the Mojave River, and terminates 3-miles south of the Mojave River. As shown on the figure, the base of unconsolidated sediments increases from about 100 feet-bgs in the northwest to about 500 feet-bgs beneath and south of the river.

Well aquifer transmissivities north and south of the river generally exceed 100,000 gpd/ft, and in some cases 300,000 gpd/ft in this area. Historical groundwater level changes have been significant in the upper portion of the basin, ranging from 70 to 80 feet over the past 50 years.

Baja Cross Section D-D’

Cross Section D-D’ (**Figure 5.5**) is a 7-mile northwest-southeast cross section in the upper-central portion of the Baja Subarea. The section begins in the Calico Mountains east of Yermo, crosses the Mojave River and terminates in the older alluvial fans overlying basement rocks that form the Newberry Mountains. As shown on the figure, the base of unconsolidated sediments ranges from less than 100 feet-bgs along the basin margins to about 500 feet-bgs in the interior portion of the basin.

Similar to Cross Section C-C’ about 5 miles to the west, aquifer transmissivities north and south of the river exceed 100,000 gpd/ft, and in some cases 200,000 gpd/ft in the portion of the basin traversed by D-D’. Historical groundwater level changes have been significant in the upper/central portions of the basin, ranging from 80 to 90 feet over the past 50 years.

Baja Cross Section E-E’

Cross section E-E’ (**Figure 5.6**) is a 23-mile cross section that extends from the Harper Lake (Waterman) Fault in the west across the axis of the valley south of the Mojave River and terminates at Troy Dry Lake in the east.

As shown in the figure, the base of unconsolidated sediments is relatively shallow in the western portion of the Baja Subarea (ranging between 300 and 400 feet). However, the alluvial basin thickens to more than 600 feet in the valley. The base of unconsolidated sediments is slightly shallower between the Calico Fault and Newberry Fracture Zone. Aquifer transmissivities between 100,000 and 300,000 gpd/ft are common in the upper portion of the basin west of the Calico Fault, where sediments are predominantly coarse-grained. The percentage of fine-grained sediments gradually increases to the east, corresponding with the low-energy depositional environment of ancestral Lake Manix. Well aquifer transmissivities between the Calico Fault and Troy Dry Lake generally range from 10,000 to 50,000 gpd/ft.

The cross section illustrates the barrier effect of the Harper Lake (Waterman) and Calico faults and the magnitude of groundwater level declines across the central axis of the Baja Subarea, which range from 50 to 80 feet over the past 50 years.

Baja Cross Section F-F’

Cross section F-F’ (**Figure 5.4**) is an 8-mile cross section in the eastern portion of the Baja Subarea that begins at the northeastern foot of the Newberry Mountains and extends directly east across the Calico Fault and Newberry Fracture Zone to the southern tip of Troy Dry Lake. The section shows the effect of the Calico Fault and associated splays within the Newberry fracture zone on the base of unconsolidated sediments and groundwater levels in this area. Sediments are comprised equally of interbedded fine-and coarse-grained deposits. Aquifer transmissivities generally range from 10,000 to 30,000 gpd/ft with some higher transmissivities associated with deeper wells. As observed across the Baja Subarea, groundwater level declines are significant and range from about 60 to 80 feet in this area.

5.3 Baja Basin Fill Deposits and Aquifer Parameters

5.3.1 Aquifer Transmissivity

Figure 5.7a and 5.7b shows the spatial distribution of T values for wells in the Baja Subarea as estimated by Todd Engineers from well hydraulic data. For comparison, T values for Layer 1 (**Figure 5.7a**) and Layer 2 (**Figure 5.7b**) of the USGS groundwater flow model are also shown (Stamos, et al, 2001). T (and hydraulic conductivity) estimates for all wells with hydraulic information in the Baja Subarea are provided in **Appendix E**.

As shown in the figures, the T values estimated from available specific capacity data generally confirm the higher permeability of younger fluvial wash sediments composing the Floodplain Aquifer (**Figure 5.7a**) and the lower permeability of the older alluvial fan sediments composing the Regional Aquifer (**Figure 5.7b**) as defined in the groundwater flow model. Estimated T values generally range from 50,000 to greater than 300,000 gpd/ft within the Floodplain Aquifer. High T values are observed in the western portion of the basin within the Baja Subarea, corresponding to the higher energy of the ancestral Mojave River as it exited the Centro Subarea. With the exception of the main Mojave River channel, T values generally decline from west to east and towards Coyote and Troy dry lakes.

5.3.2 Aquifer Storativity

Figure 5.8 shows the S values within the Baja Subarea from the 2001 USGS model (Stamos et al., 2001), the most reliable source of S values on a regional scale in the Study Area. As shown on the figure, S values in the Baja Subarea range from 5 to 22 percent, with higher values assigned to the coarse-grained deposits associated with the Mojave River system and lower values assigned to deposits comprising the Regional Aquifer. These values were used in combination with a map of saturated thickness of unconsolidated sediments to estimate available groundwater in storage.

5.4 Baja Groundwater Occurrence and Flow

Groundwater level data and the project digital elevation model were used to produce a groundwater level contour map and depth to water map representing current (2010) conditions (**Figure 5.9 and 5.10**), and historical (1959) conditions (**Figures 5.11 and 5.12**) for the Baja Subarea. The 1959 and 2010 groundwater levels are also depicted on Baja Subarea Cross Sections A-A' through F-F' (**Figures 5.3 through 5.6**). Previous investigators who mapped groundwater levels in the Study Area include Stamos and Predmore (1995), Mendez and Christensen (1997), and Stamos et al. (2009).

Figure 5.9 shows the 2010 groundwater levels in the Baja Subarea. The figure shows that groundwater elevations range from 2,000 feet above mean sea level (feet msl) at the Centro/Baja subarea boundary to less than 1,600 feet msl one mile east of Camp Cady. In the central portion of the Baja Subarea

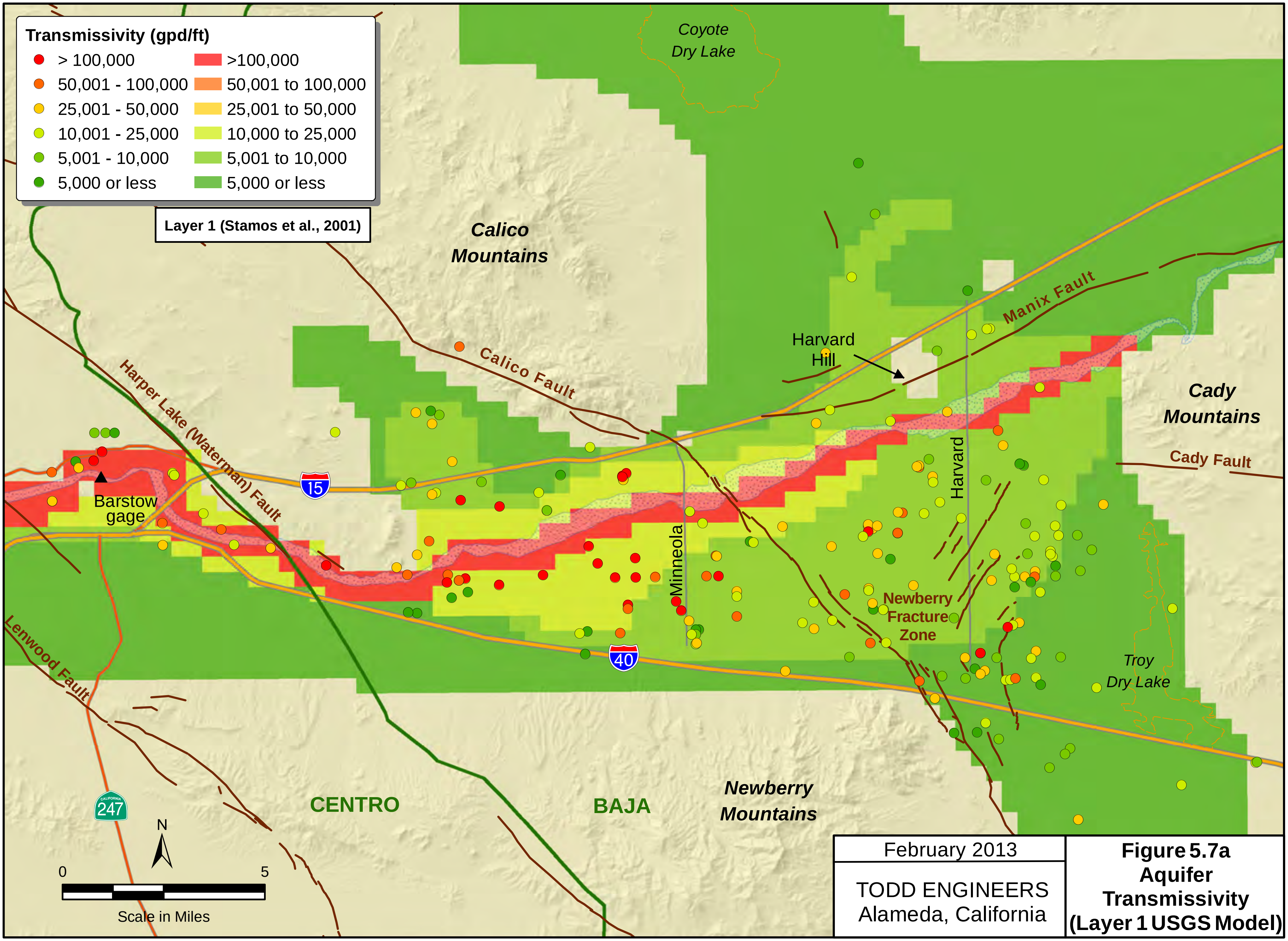

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Figure 5.7a
Aquifer Transmissivity
(Layer 1 USGS Model)

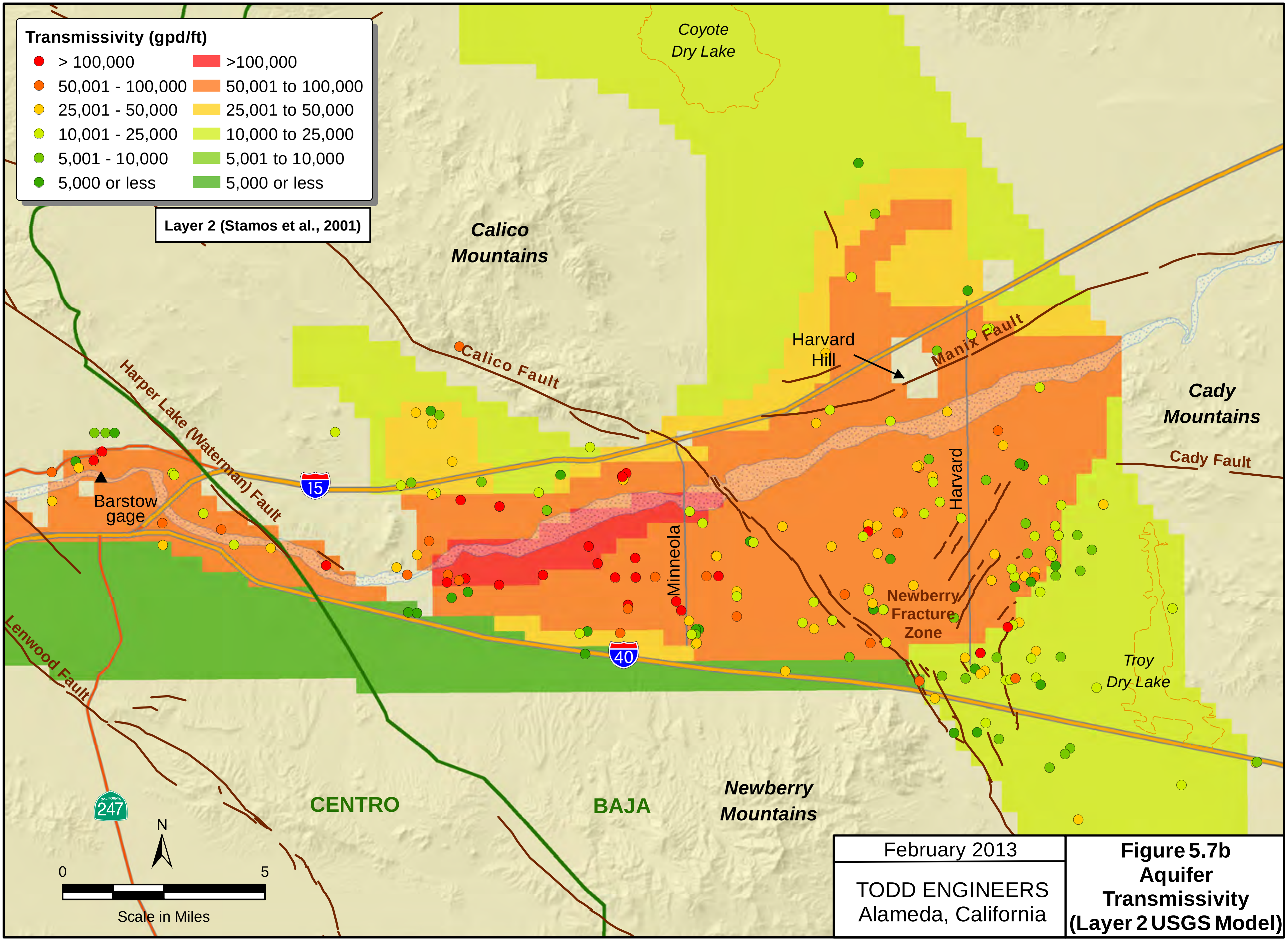

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Figure 5.7b
Aquifer Transmissivity (Layer 2 USGS Model)

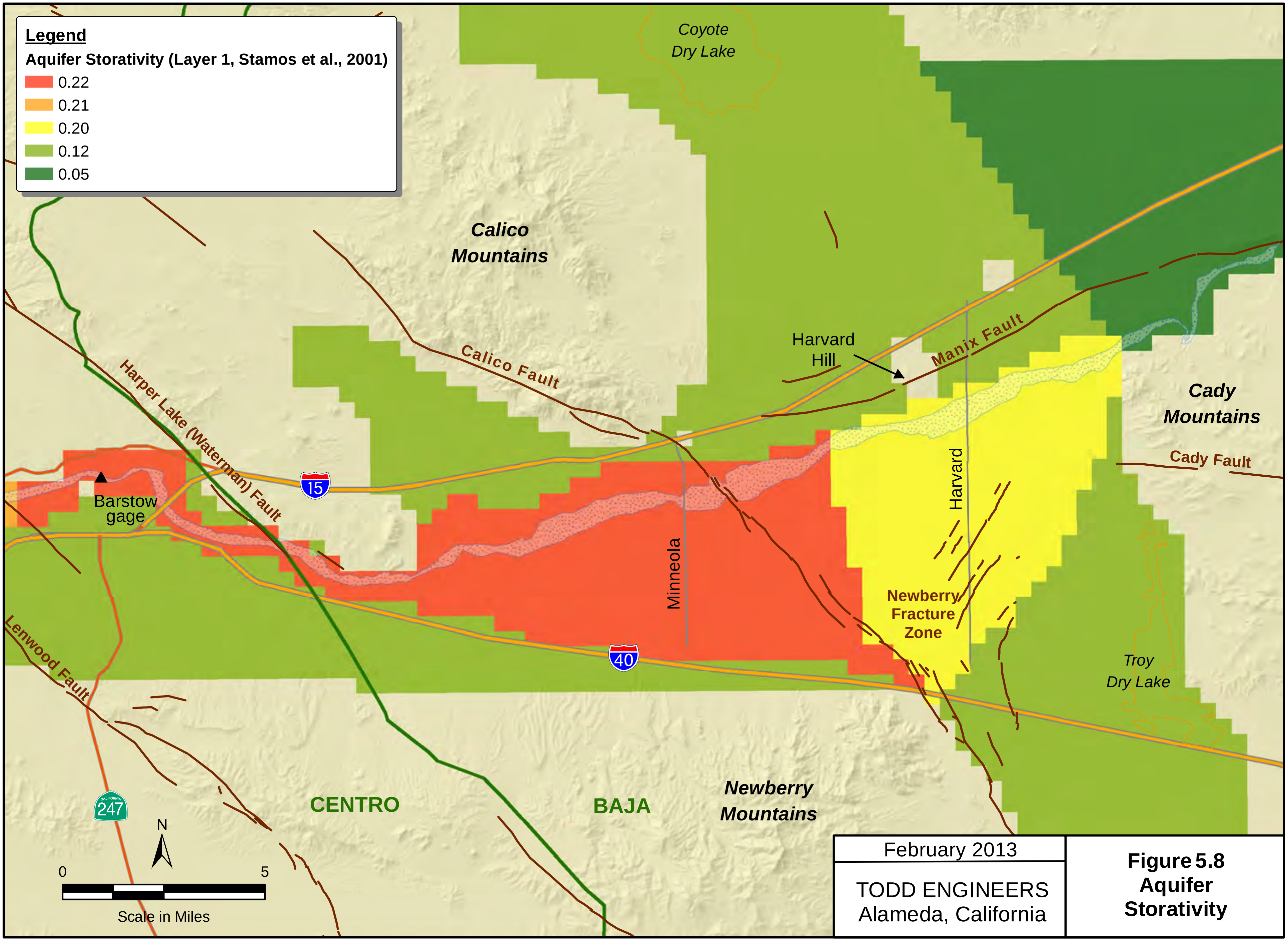

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Figure 5.8
Aquifer Storativity

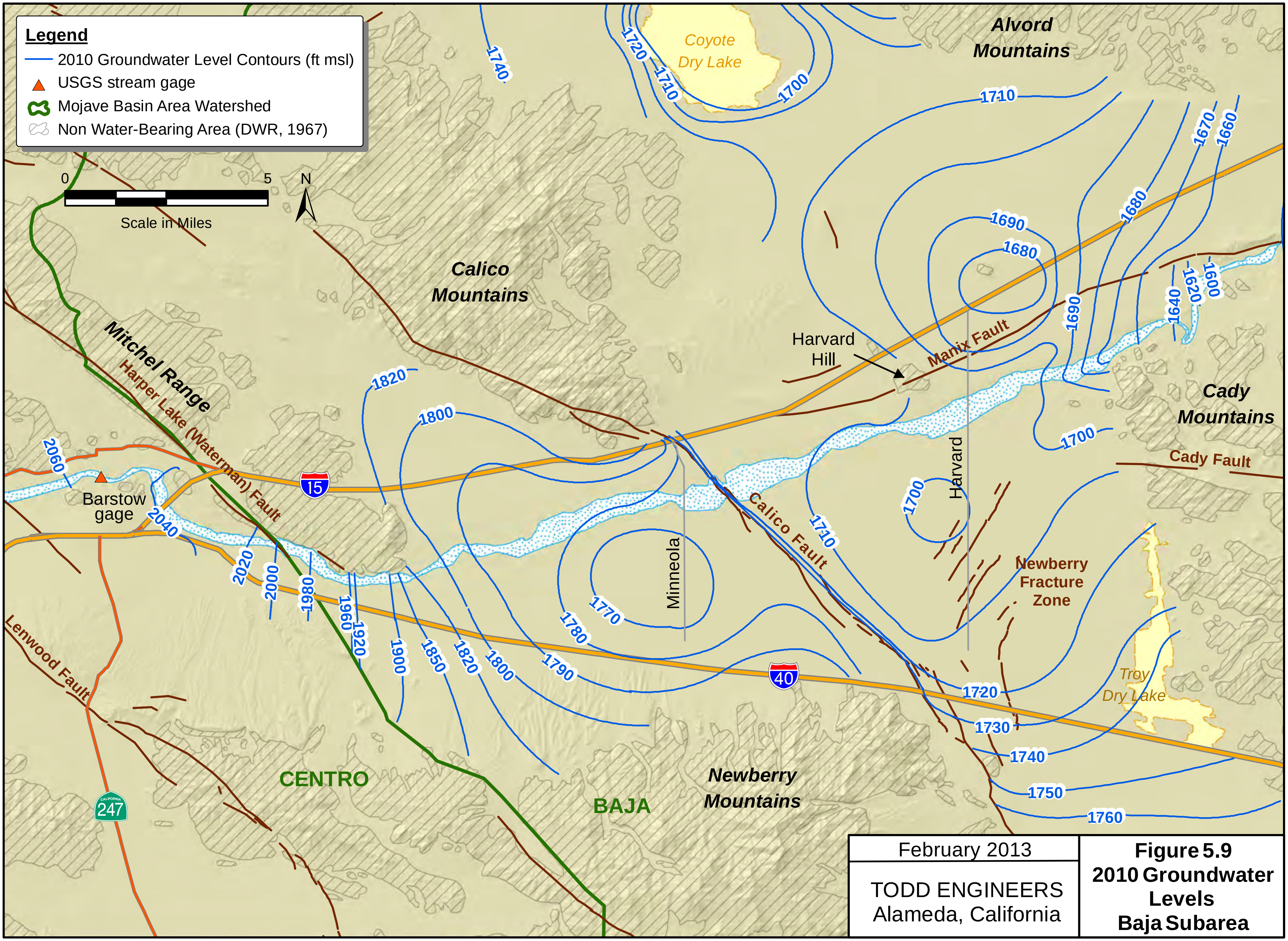

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Figure 5.9
2010 Groundwater Levels
Baja Subarea

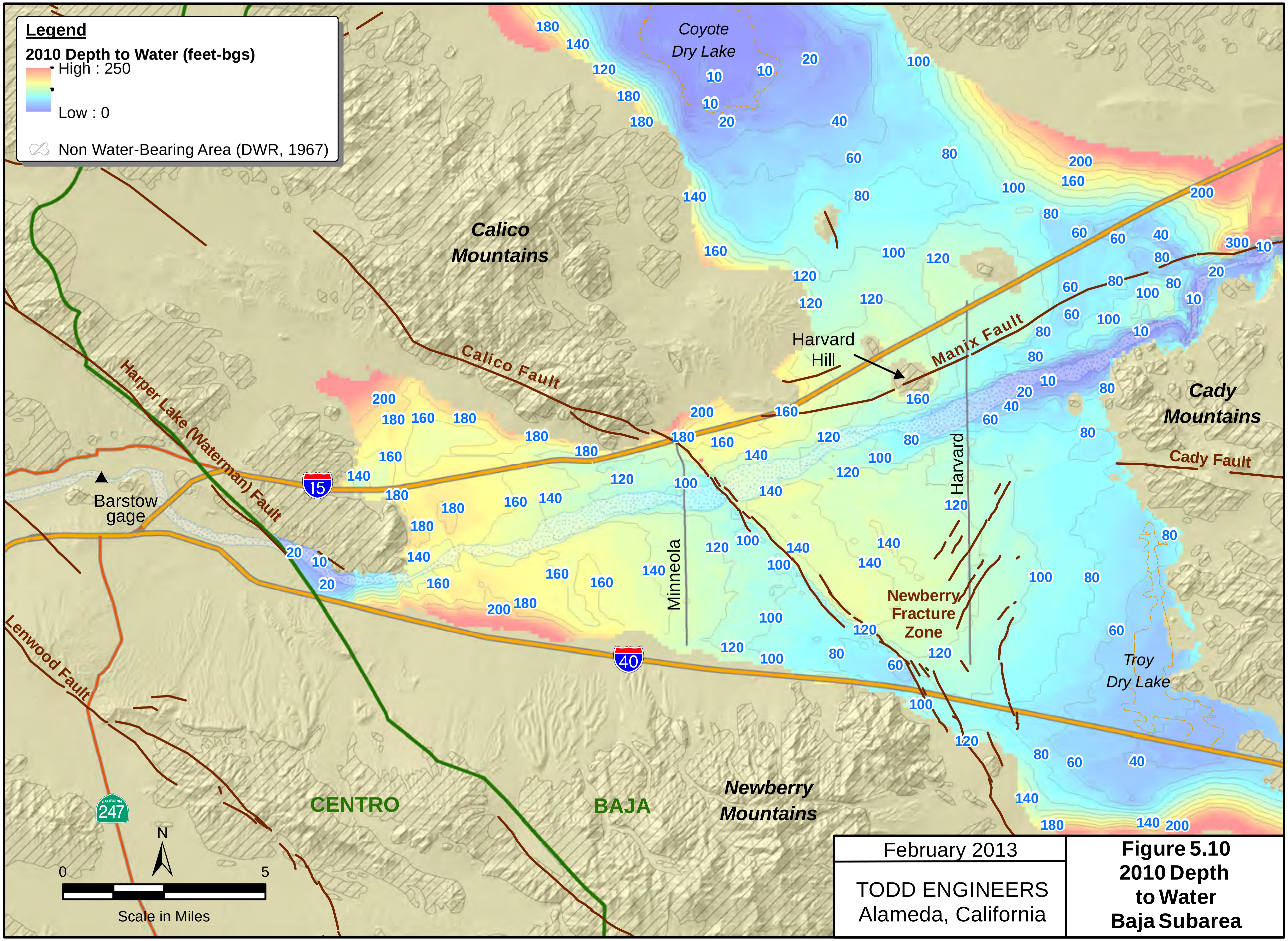

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Figure 5.10
2010 Depth to Water
Baja Subarea

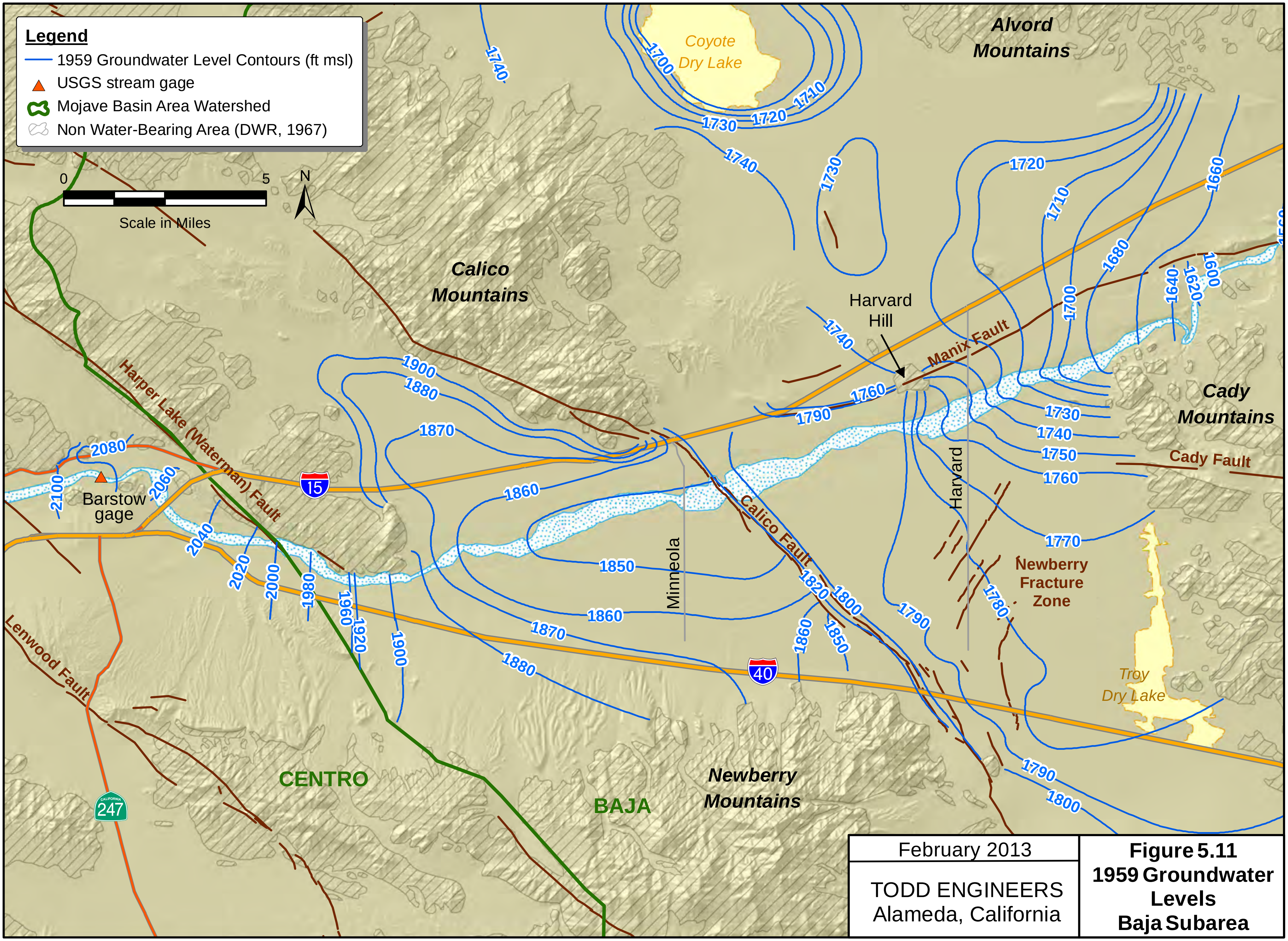

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Figure 5.11
1959 Groundwater Levels
Baja Subarea

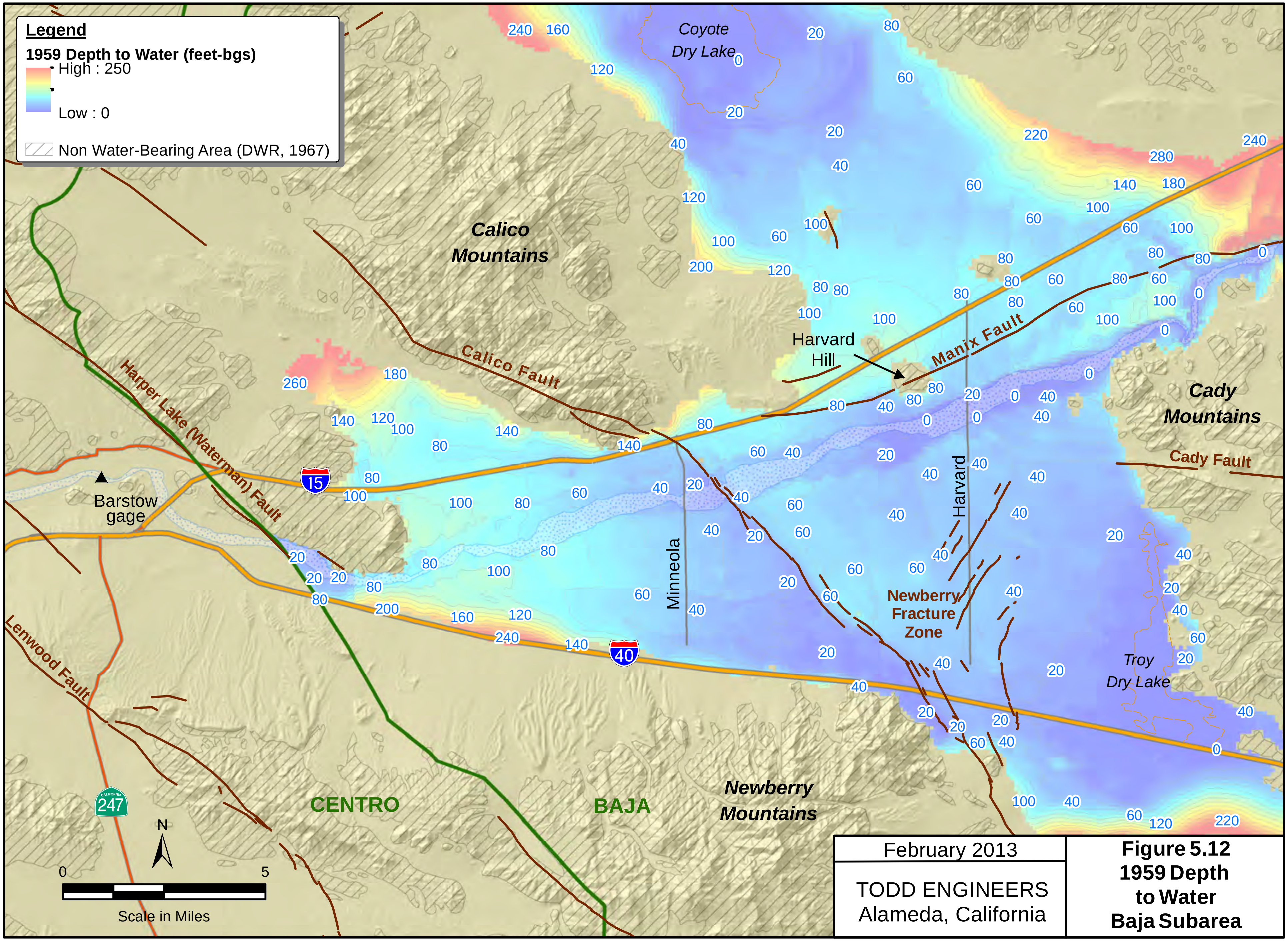

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Figure 5.12
1959 Depth to Water
Baja Subarea

between Interstates 15 and 40, groundwater levels upgradient (west) of the Calico Fault are at or above 1,770 feet msl, while the groundwater levels over the roughly 5-mile by 5-mile area east (downgradient) of the Calico Fault ranges from 1,700 to 1,710 feet msl. Groundwater level depressions associated with concentrated pumping are visible at several locations, including the area between Interstates 15 and 40 at Minneola Road, at Harvard Road near the Newberry Fracture Zone, and in the vicinity of Interstate 15 at Harvard Road. Groundwater level contours also show that Coyote Lake represents an area of groundwater discharge (via evaporation).

Figure 5.10 shows a 2010 depth to water map across the Baja Subarea. As shown in the figure, depth to water generally ranges from 100 to 160 feet-bgs in the central portion of the Basin. Within the main channel, depth to water is less than 10 to 20 feet-bgs at the Centro/Baja boundary and a few miles east of Harvard Hill in the vicinity of Camp Cady. Elsewhere, groundwater occurs near the ground surface beneath Coyote Dry Lake (less than 10 feet-bgs) and at relatively shallow depths beneath Troy Dry Lake (40 to 50 feet-bgs).

5.5 Baja Groundwater Level Trends

This section presents hydrographs for specific wells in the Baja Subarea. Evaluation of specific hydrographs is revealing about local factors affecting wells (e.g., local production and proximity to the river). In reviewing the following maps and graphs, it is important to recognize the larger, regional context; a discussion is provided at the end of this section.

Figures 5.11 and 5.12 show groundwater levels and depths to water during 1959 in the Baja Subarea, respectively. **Figure 5.13** shows a groundwater level change map from 1959 to 2010. Together, the figures reveal that groundwater levels in the central portion of the basin from 5 miles west of Minneola Road to Harvard Hill have declined by as much as 80 feet. Along the western boundary of Camp Cady, groundwater levels have declined by about 60 feet over the past 50 years. Comparison of 1959 and 2010 groundwater level contour maps indicate show that the hydraulic gradient east of the Calico Fault has decreased dramatically resulting in a reduction in regional groundwater flow towards the Camp Cady area. In the Coyote Lake and Afton areas, groundwater levels have been relatively stable over time.

Figures 5.15 through 5.18 present water level hydrographs of selected wells across the Baja Subarea grouped into four general locations – west Baja, east Baja, the Coyote Lake area, and the Newberry Springs/Troy Lake area. The areal coverage of each map is shown on **Figure 5.14**. Longer-term hydrographs are shown from 1930 to 2010, while hydrographs with more recent data are shown from 1990 to 2010 and are highlighted in yellow. For areas with limited information, data from multiple wells are combined on some charts. Similarly, groundwater levels in nested wells (with variable screen interval depths) are combined on one chart to illustrate the vertical gradient at these locations. For reference, 2010 groundwater elevation contours are also included on each basemap. In addition, areas along the Mojave River that have responded measurably to large storm recharge events are shaded in blue.

Figure 5.15 shows 23 water level hydrographs in the western portion of the Baja Subarea from the Harper Lake (Waterman) Fault to the Calico Fault. Beginning in the lower left on the figure, groundwater

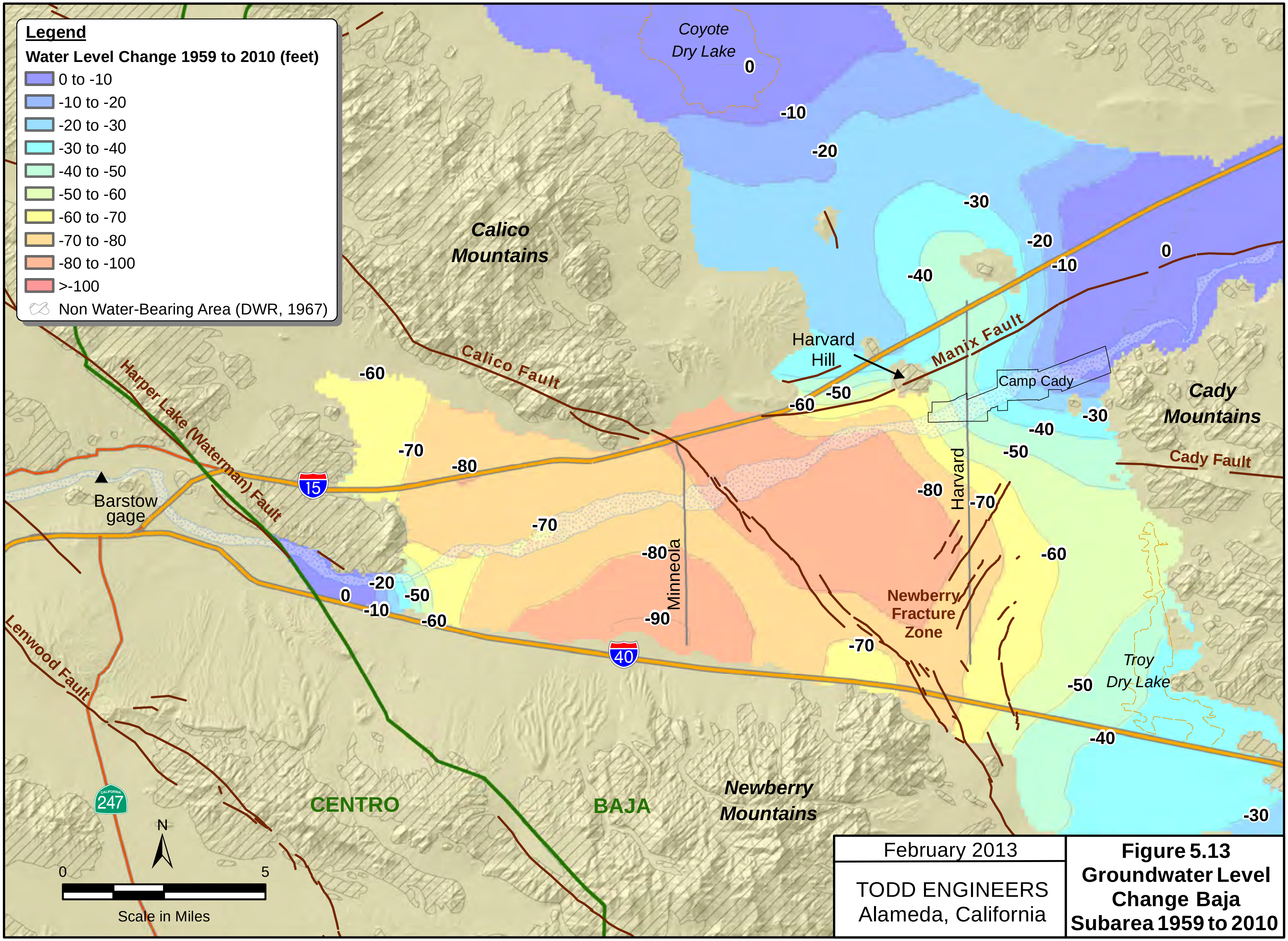

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Figure 5.13
Groundwater Level Change Baja Subarea 1959 to 2010

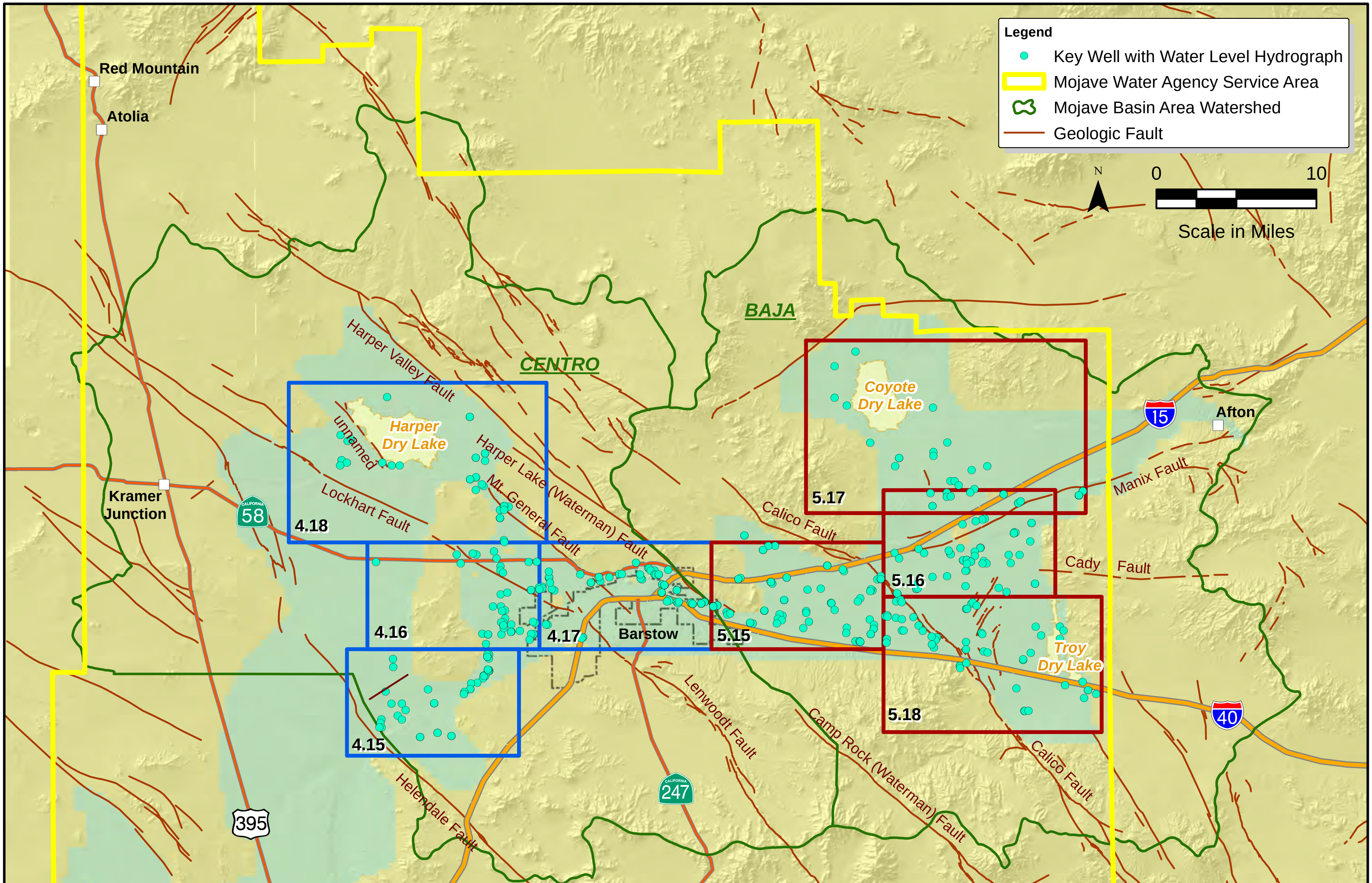

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Figure 5.14
Hydrograph Plate Locations

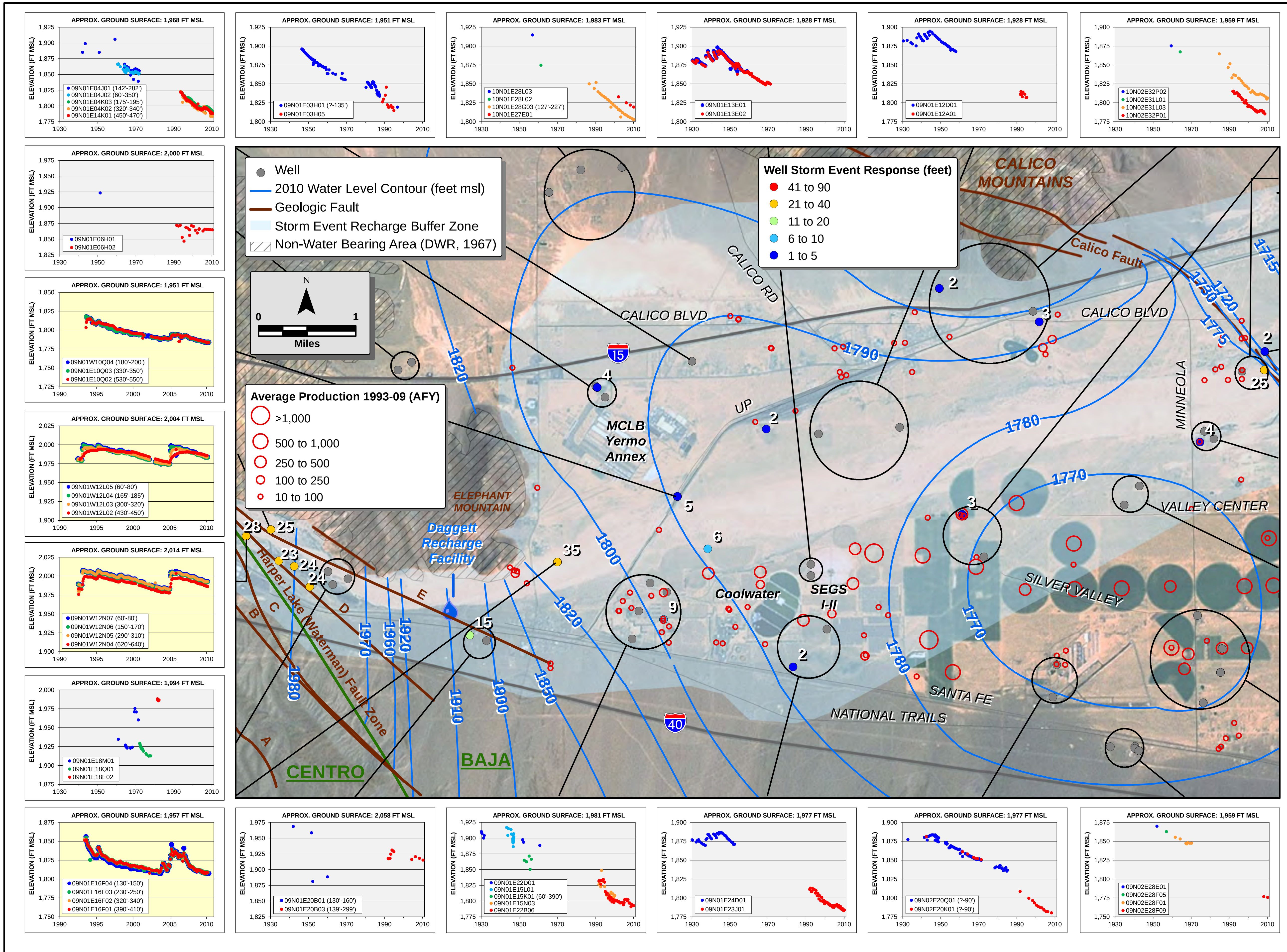

Figure 5.15
Historical Groundwater Level Trends West Baja

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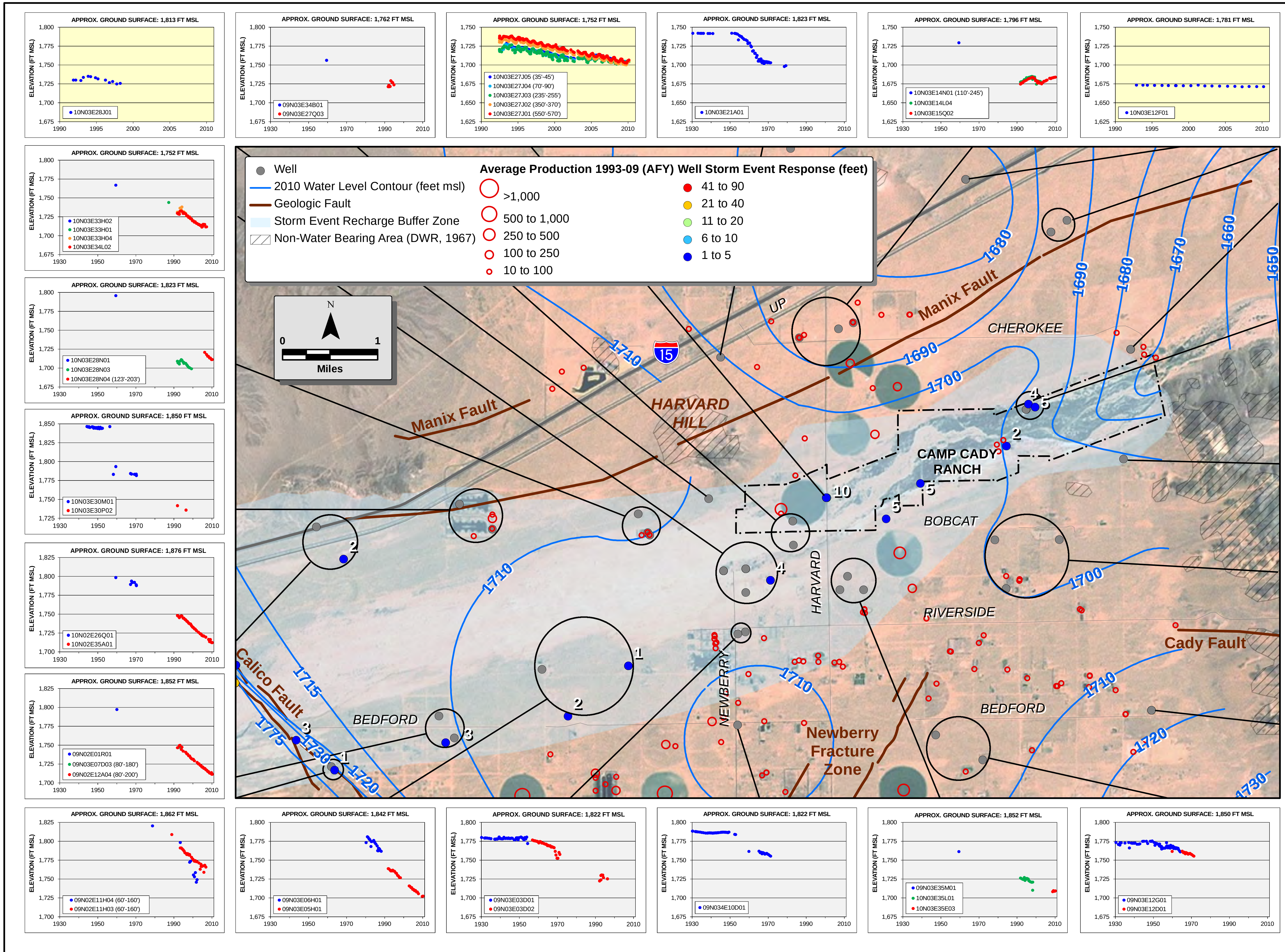

Figure 5.16
Historical Groundwater Level Trends
East Baja

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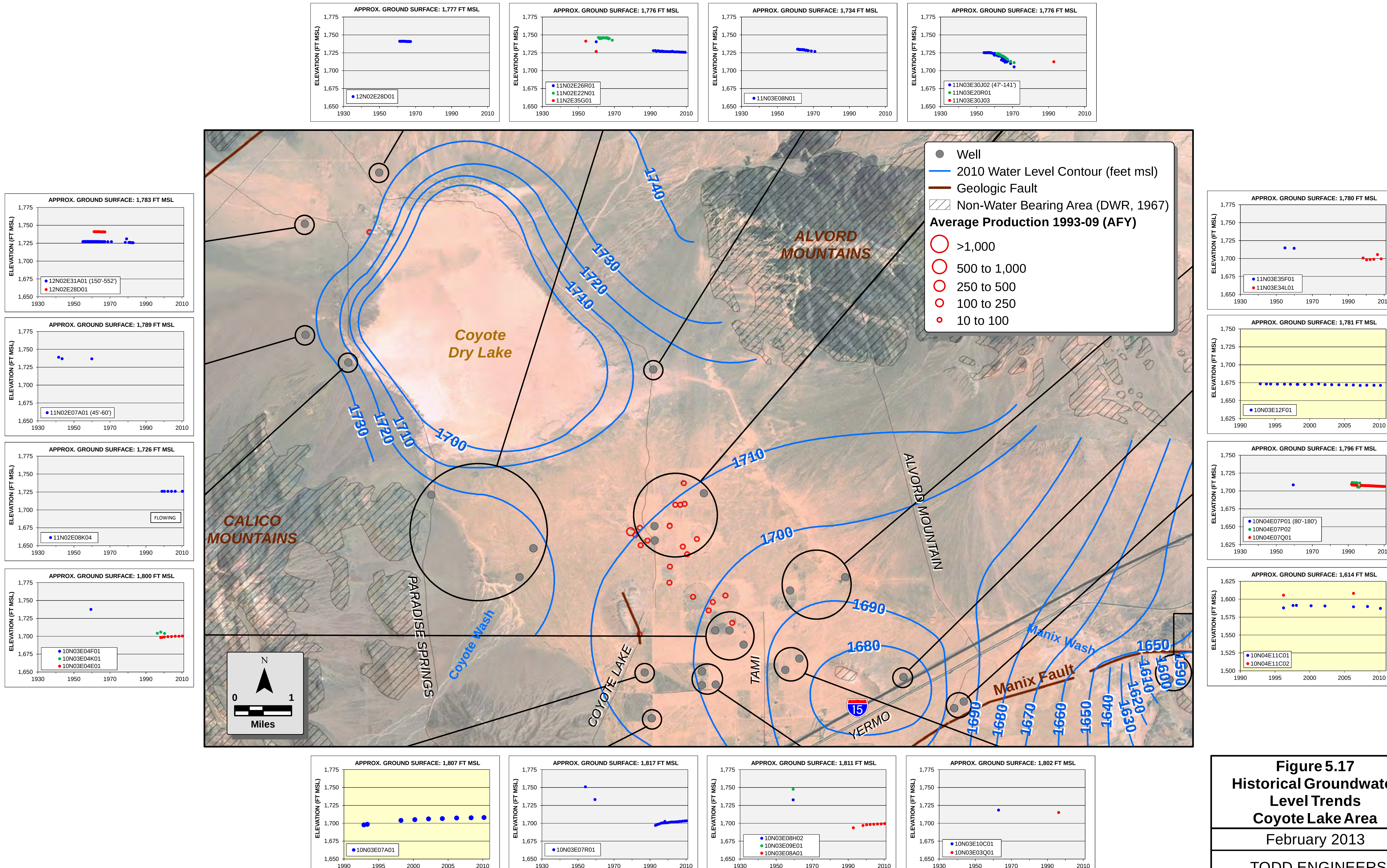

Figure 5.17
Historical Groundwater Level Trends
Coyote Lake Area

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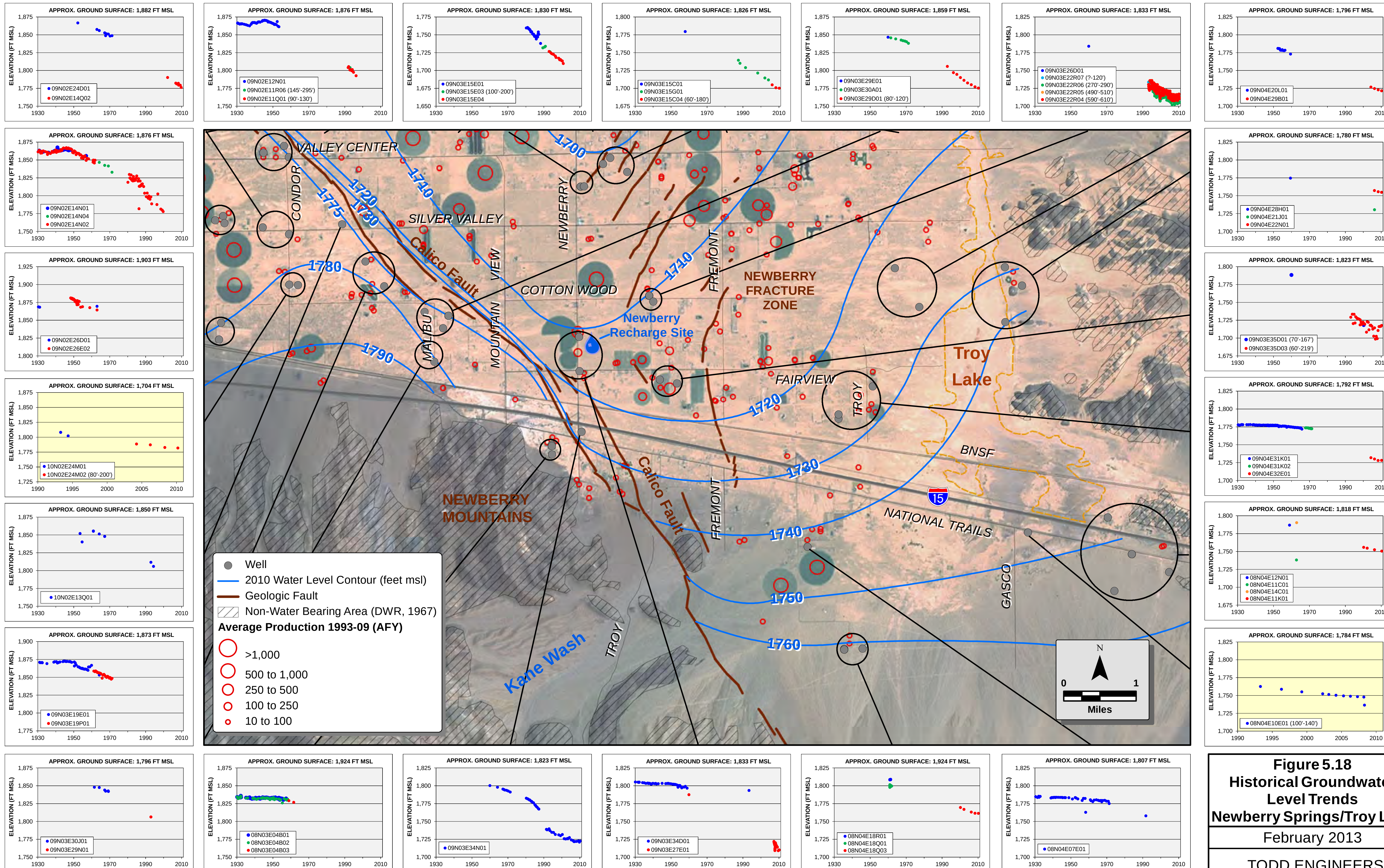

Figure 5.18
Historical Groundwater Level Trends
Newberry Springs/Troy Lake

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levels near the Harper Lake (Waterman) Fault are shown to decline gradually in response to local downgradient production; however, these wells recover quickly in wet years that produce significant downstream Mojave River flows. Maximum groundwater level responses during recent storm events range from 23 to 28 feet in the five wells located in the channel within the Waterman Fault Zone. These large storm event responses are the result of 1) the high permeability of shallow sediments in the main channel, 2) the narrow width of the Floodplain Aquifer at this location, and 3) the hydraulic barrier effect of the individual splays of the Harper Lake (Waterman) Fault.

Groundwater levels east of the Harper Lake (Waterman) Fault declined between 60 and 80 feet from 1950 through 1990 (1.5 to 2.0 feet per year). These declines are associated with historical increases in local and regional pumping. With regard to local pumping, total estimated groundwater production in the Baja Subarea upstream of the Calico Fault consistently increased prior to the Judgment from less than 7,000 AFY in 1950 to 19,000 AFY in 1970 and 31,000 AFY in 1990. Since the Judgment, production has gradually declined as a response to prescribed rampdown across the Baja Subarea. Verified production upstream of the Calico Fault since WY 1993-94 has averaged about 19,000 AFY; verified production was about 17,000 AFY in WY 2008-09. Since the Judgment, groundwater level declines have continued at a rate similar to those observed prior to the Judgment; the rate of decline in some wells appears to have decreased marginally most likely in response to localized decreases in groundwater production (see third hydrograph from the left on the bottom row and second hydrograph from right in upper row in **Figure 5.15**).

Maximum groundwater level response of wells along the river to storm recharge events is generally less than 10 feet between the MCLB Yermo Annex and the Calico Fault. This relatively small response is due primarily to an increase in the width of the Floodplain Aquifer east of the Waterman Fault rather than a decrease in permeability.

As shown on the far right of the figure, there are two well clusters near the Calico Fault. One cluster (09N02E03K05-09) is located upgradient of the fault within the main channel, while the downgradient well cluster (09N02E03G06-09) is located about 300 feet north of the main channel. These two hydrographs are located on the right side of **Figure 5.15** and highlighted in yellow. As shown on the hydrographs, maximum groundwater level response is much higher in the well cluster upgradient of the fault (25 feet) compared to the downgradient well cluster. A closer examination of local hydrogeologic conditions illustrates the complexity of storm event recharge around geologic faults. In the downgradient well cluster location, surface water must percolate through 125 feet of heterogeneous sediments before reaching the water table (in addition to the 300 feet of lateral distance water must travel to reach the downgradient well cluster). Along its flowpath, water spreads horizontally on less permeable deposits in the vadose zone and diffuses vertically. While similar heterogeneous sediments were encountered in both well clusters, the vadose zone in the upgradient well cluster is only about 60 feet thick. Additionally, the Calico Fault acts as a horizontal barrier to groundwater flow, backing up local stormflows that would otherwise flow across the fault unimpeded. For these reasons, a lower maximum groundwater level response is expected for the downgradient well cluster, even if local vadose zone sediments have similar hydraulic properties.

Also shown on **Figure 5.15** downstream of the Harper Lake (Waterman) Fault is the location of the Daggett recharge site, which has recharged SWP water since 2003. Through WY 2009-10, a total of 11,299 AF have been recharged at the Daggett recharge site. While somewhat muted by the response to storm events, hydrographs of wells adjacent to the Daggett recharge site confirm the positive benefits of SWP water recharge. For example, an extended period of recharge at the Daggett site occurred during the spring and summer of 2006, during which no stormflows were recorded in this portion of the river. A total of about 2,200 AFY was recharged from March through July 2006 at the Daggett recharge facility. The water level hydrograph of nested USGS monitoring well 09N01E16F01-04 (left corner hydrograph) and 09N01E10Q02-04 (third hydrograph from the top in the left column) both show positive groundwater level responses during this period. While not shown on the figure, groundwater levels in well 09N02E07Q03, located about 5 miles downstream of the Daggett recharge site along the southern banks of the river, also appears to respond to recharge activities at the Daggett facility.

Figure 5.16 shows 23 water level hydrographs in the eastern portion of the Baja Subarea centered along the Mojave River east of the Calico Fault. The figure shows that groundwater levels have declined an average of about 1.5 feet per year in areas upgradient and south of Camp Cady since the 1950s. These declines correspond to increases in local and regional production.

Focusing on local production, total estimated groundwater production in the Baja Subarea east of the Calico Fault (including areas not shown on the figure) dramatically increased from less than 7,000 AFY in 1950 to about 27,000 AFY in 1970. Production east of the Calico Fault generally stabilized through the 1980s and 1990s, averaging about 26,000 AFY through 1990. Since the Judgment, production has gradually declined as a response to prescribed rampdown across the Baja Subarea. Verified production upstream of the Calico Fault since WY 1993-94 has averaged about 15,000 AFY; verified production was about 14,000 AFY in WY 2008-09. Since the Judgment, groundwater level declines have continued at a rate similar to those observed prior to the Judgment.

Water levels to the northeast and southeast of Camp Cady are more stable than south of the river as illustrated by the four hydrographs highlighted in yellow on the right side of the figure. Although water level trends in 10N04E20D01 are similar to surrounding wells, actual water levels have historically been much lower (about 100 feet lower than groundwater level contours as drawn). Examination of the database record indicates that these levels likely represent pumping (or only partially recovered) water levels. Two hydrographs provide information on the vertical hydraulic gradients beneath the Camp Cady area. The hydrograph for a USGS monitoring well cluster on Harvard Road (10N03E27J01-05 – highlighted in yellow at the top of the figure) shows that an upward vertical hydraulic gradient in 1992 has gradually shifted to a flat to slightly downward gradient with current depth to groundwater at approximately 50 feet-bgs. Water level measurements at a monitoring well cluster installed by MWA and CDFG in 2006 (10N04E19N02-N04 – highlighted in yellow on the right side of the figure) indicate relatively stable groundwater levels with a slightly upward vertical gradient. Hydraulic pressure in the deep aquifer zone causes groundwater levels to rise just below the ground surface in 10N04E19N02. Groundwater levels rise up to about 1 to 10 feet in response to storm recharge events along the river downstream of the Calico Fault.

Figure 5.17 shows 16 water level hydrographs in the Coyote Lake area. The figure shows that groundwater levels just north of Interstate Highway 15 historically declined between 20 and 50 feet between 1950 and 1990 as a result of local (and regional) production. Since the Judgment, declines in production have allowed groundwater levels to stabilize and partially recover in some areas. Groundwater levels north of and beneath Coyote Dry Lake have been stable over time. Groundwater levels in a well at Coyote Dry Lake (11N02E03K01) have been observed to be artesian (or slightly above the surface of Coyote Dry Lake). Minor water level declines from 1960 through 1980 are observed along the southern edge of the lake (near Coyote Wash and southwest of Alvord Mountains).

Figure 5.18 shows 23 water level hydrographs in the Newberry Springs/Troy Lake area. Similar to other areas near concentrated pumping across the Baja Subarea, the figure shows that groundwater levels in this area have systematically declined at an average rate of between 1.5 and 2 feet per year. Since the Judgment, groundwater levels have continued to decline at a rate similar to those observed prior to the Judgment.

Also shown on **Figure 5.18** is the location of the Newberry Springs recharge site (on Newberry Rd. between Cottonwood and Fairview), which has recharged SWP water since 2006. Through WY 2009-10, a total of 1,816 AF have been recharged at the Newberry Springs recharge site. Some positive response to managed recharge at the Newberry Springs site is shown on the hydrograph for 09N03E27E01 (fourth hydrograph from left on bottom row of **Figure 5.18**).

<u>Effects of Regional Scale Pumping on Groundwater Level Trends</u>

Groundwater level trends in Baja are affected directly by local Baja Subarea pumping and indirectly by upstream regional pumping. Upstream regional pumping affects downstream groundwater levels primarily by reducing downstream flows and recharge beneath the Mojave River. Results of the evaluation of stream gage records (Section 3.10) indicate that Mojave River flows—and consequently recharge from river leakage—has declined in the lower portions of the Basin since the 1950s, reflecting combined climatic and anthropogenic factors (e.g., upstream pumping).

The USGS assessed the influence of historical groundwater production in the upper portions of the Basin (i.e., Transition Zone, Alto, Este, Oeste subareas) on the frequency and magnitude of intermittent Mojave River flows and groundwater level declines in the Centro and Baja subareas (Stamos et al., 2001). For this assessment, USGS simulated historical conditions with no pumping in the upper region of the basin (Alto, Transition Zone, Este, and Oeste subarea) using the Mojave River Basin groundwater flow model. Under the “no upper Basin pumping” scenario, simulated groundwater levels in the Alto and Transition Zone subareas were near the altitude of the streambed throughout the upper region; this caused potential recharge from the Mojave River to be rejected in the upper region, thereby allowing more streamflow to reach and recharge the lower region. For the Baja subarea, the USGS simulation of a “no upper Basin pumping” scenario showed that groundwater recharge from the Mojave River in the Baja Subarea increased on average 3,860 AFY over the Base Period (1931 to 1990), but groundwater discharge also increased by 630 AFY. The net effect of the “no upper Basin pumping” scenario was a net decrease in Baja groundwater storage decline amounting to 3,230 AFY. Applying this annual effect to the simulation period from 1931 to 1990 amounts to 193,800 AF of groundwater storage loss in the Baja Subarea due to upper Basin pumping (i.e., in Transition Zone, Alto, Este, Oeste subareas), a significant portion of groundwater lost from storage (21 percent) during the simulation period (Stamos et al., 2001). The USGS did not simulate the effect of upstream pumping in Centro on stream discharge and recharge in Baja.

5.6 Baja Groundwater Storage

In order to estimate groundwater in storage for the Baja Subarea, 2010 groundwater levels (**Figure 5.9**) and elevations representing the base of unconsolidated sediments (**Figure 5.2**) were imported into the project GIS database. The thickness of saturated basin fill sediments was determined electronically by computing the differences in elevation between raster surfaces generated from each dataset (**Figure 5.19**). The storativity (specific yield) from Layer 1 of the USGS model was applied to the saturated thickness to compute the amount of groundwater in storage. Applying the specific yield of Layer 1 may overestimate the groundwater in storage in the deeper portions of the basin; however, this simplified approach provides reasonable estimates for planning purposes. Groundwater storage estimates for various model subareas in the Baja Subarea are shown on **Figure 5.20** and summarized below.

Table 5.2
2010 Groundwater in Storage – Baja Subarea

Subarea/ Model Subarea	Area (acres)	Average Saturated Thickness of Unconsolidated Sediments (feet)	Aquifer Storativity[a]	Estimated Groundwater in Storage[b] (AF)
	(a)	(b)	(c)	(a x b x c)
Baja Subarea				
Baja	130,395	329	0.05 - 0.22	6,816,000
Coyote	42,430	376	0.12	1,916,000
Afton	6,084	162	0.05	49,000
Total	**178,908**			**8,781,000**

[a]Model Layer 1 (Stamos et al., 2001)
[b]Volume of groundwater above base of unconsolidated sediments
Note: Average Saturated Thickness values are rounded to nearest integer in table

The table shows that the estimated total groundwater storage in the Baja Subarea is 8,781,000 AF. Of the total storage volume, about 77.6 percent (6,816,000 AF) is stored in the main portion of the Baja Subarea including areas north and south of the Mojave River. About 21.8 percent occurs in the Coyote model subarea, with less than one percent in the Afton model subarea. These values represent the amount of stored groundwater that potentially could be pumped with wells. Even though some areas likely have lower specific yields, especially with depth, these totals provide a more rigorous estimate of the total amount of groundwater in storage than past evaluations.

Groundwater storage estimates reported in this study are similar to estimates that could be made by applying the USGS model storativity values to the depth to base of fresh water contours presented in Bulletin No. 84 (DWR, 1967). This is because both estimates would be based on observed and estimated

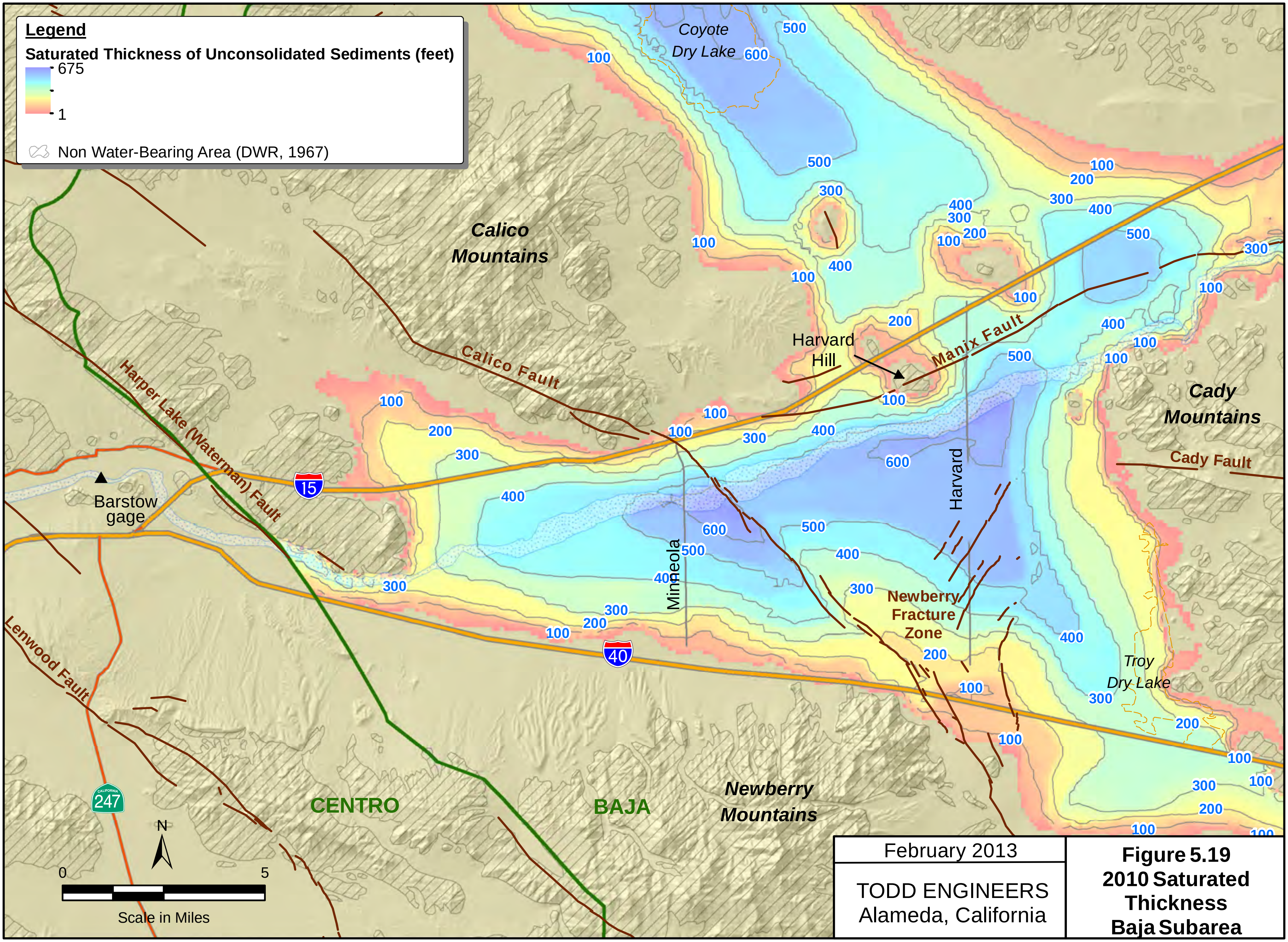

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Figure 5.19
2010 Saturated Thickness
Baja Subarea

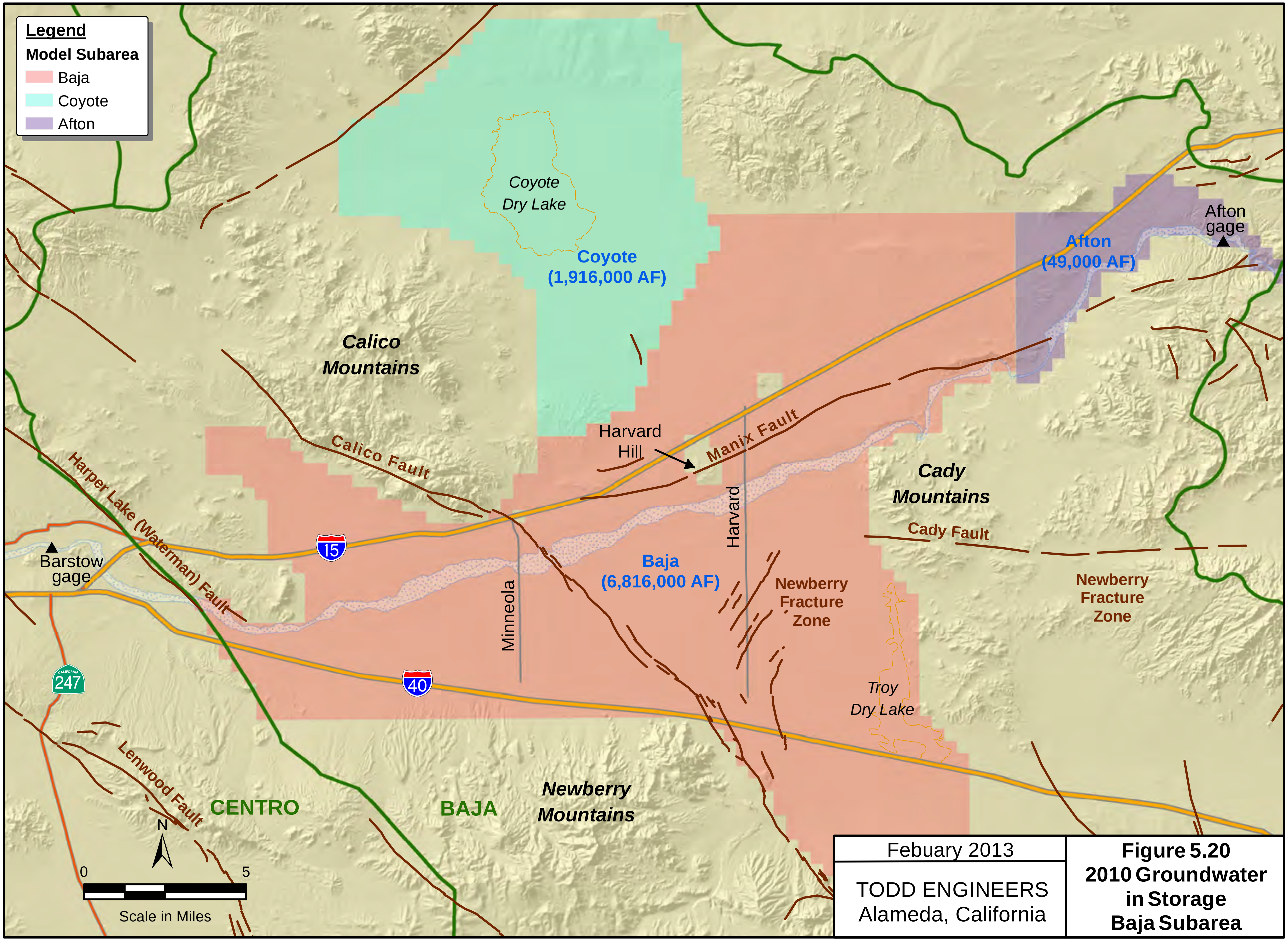

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Figure 5.20
2010 Groundwater in Storage
Baja Subarea

porosity contrasts in semi-consolidated to consolidated Quaternary older alluvium deposits identified in well driller's logs. The groundwater storage estimates in this report are smaller than estimates made previously by SSI (1990), which are based on model inversion of raw gravimetric data and assumptions of aquifer porosity. While the SSI method provides an approximation of the depth to consolidated Tertiary and pre-Tertiary basement rocks, the method used to invert the raw gravity data was not performed at a resolution appropriate for identifying the density and porosity contrasts observed within Quaternary older alluvial deposits. Additionally, the contouring method applied to inverted model data in the SSI study overestimates the depth to consolidated rock along the basin margins. Accordingly, the SSI report overestimates groundwater storage across the Study Area.

5.7 Baja Subarea Water Budgets

This section summarizes the groundwater inflows (sources) and outflows (sinks) within the Baja Subarea over time. Various sources of information, including the USGS Mojave River Basin groundwater flow model, MWA Watermaster annual reports, and other technical works, were used to document the subarea water budget covering an 80-year period from CY 1931 through WY 2009-2010.

Major inflows accounted for in the Baja Subarea water budget include:

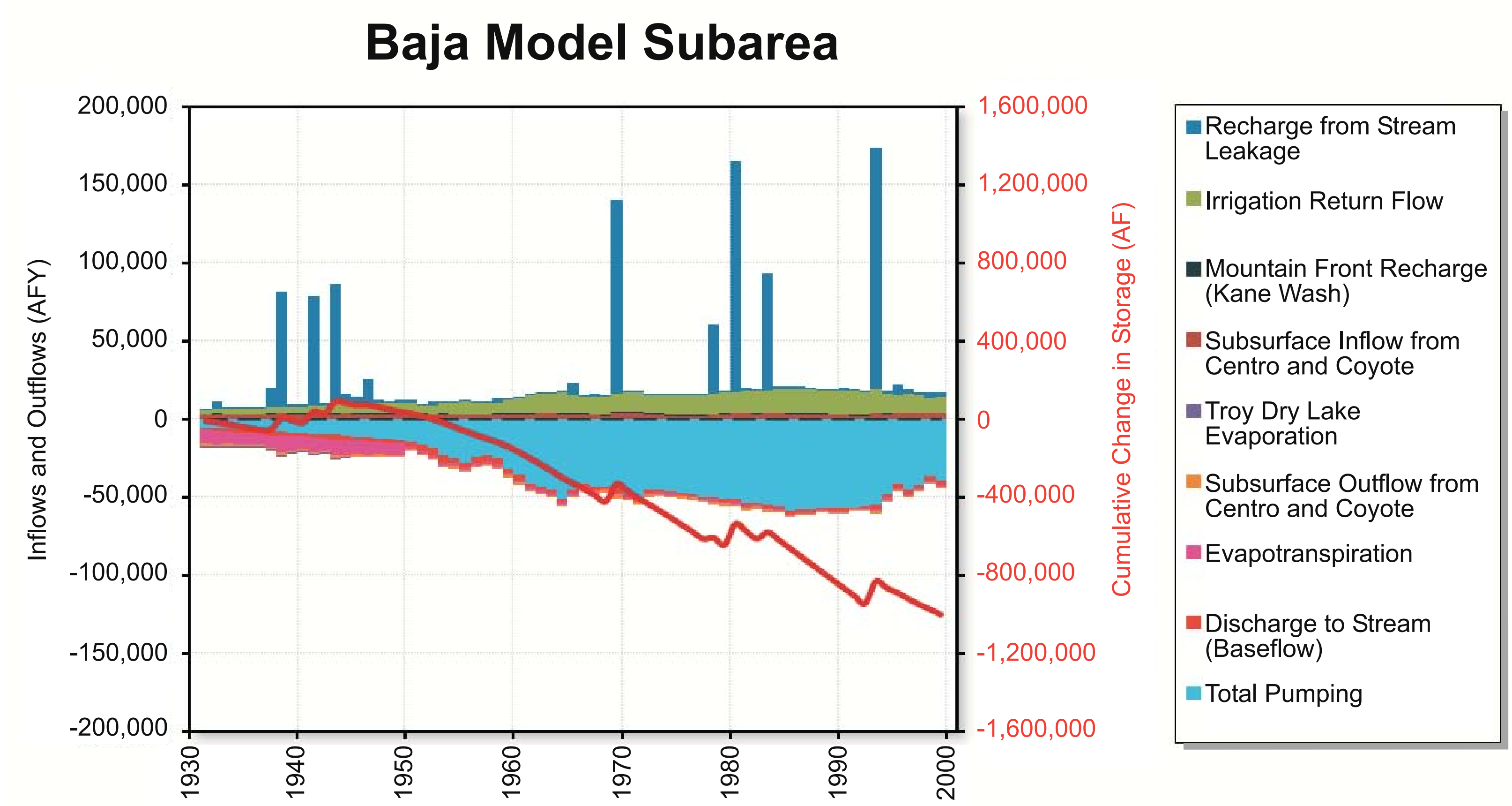
- Recharge from Mojave River leakage from Harper Dry Lake (Waterman) Fault to Afton gage
- Subsurface inflow from Centro Subarea
- Return flow from irrigation
- Return flow from WWTP effluent discharges
- Artificial recharge of SWP water

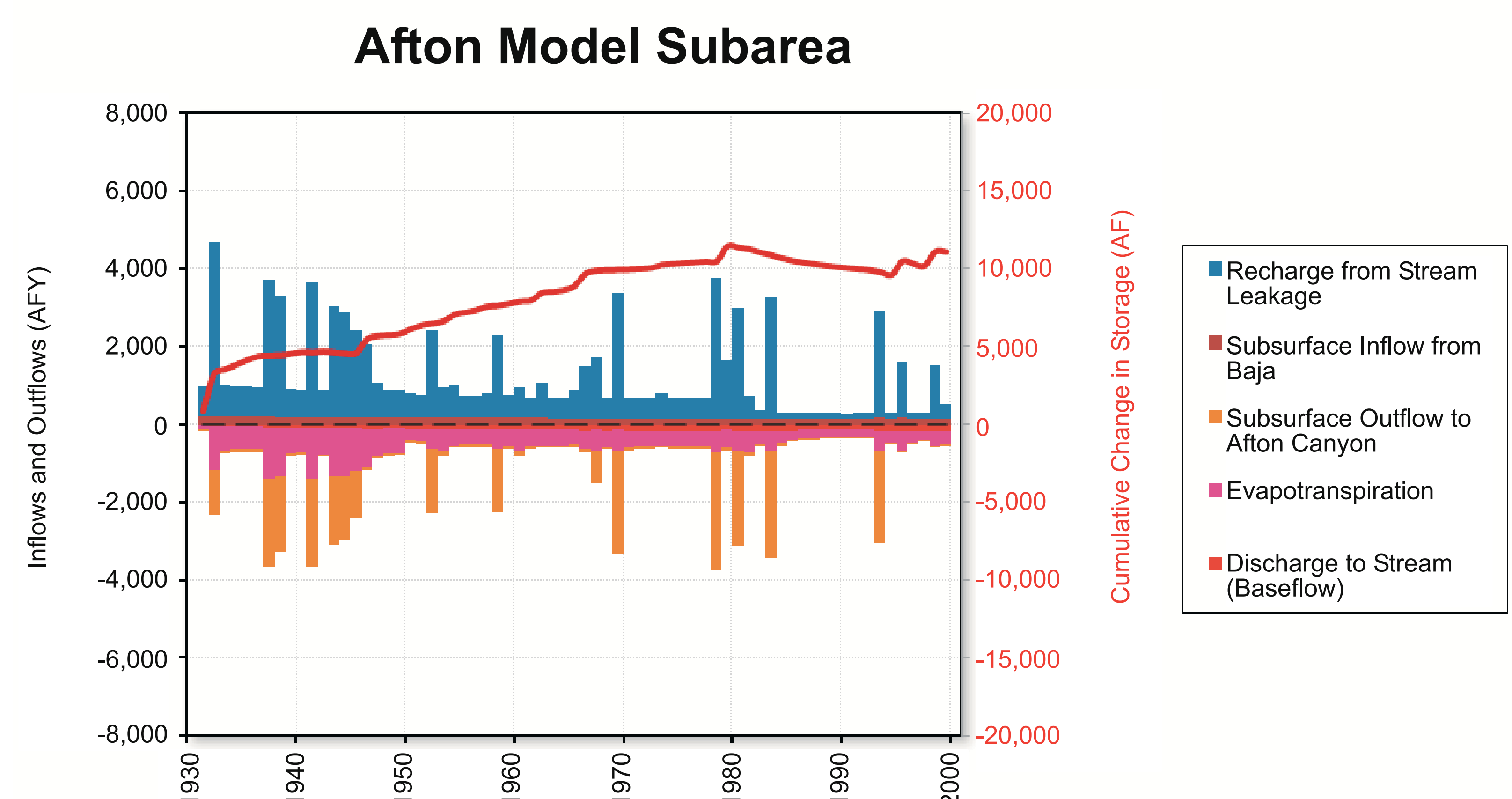
Major outflows accounted for in the Baja Subarea water budget include:

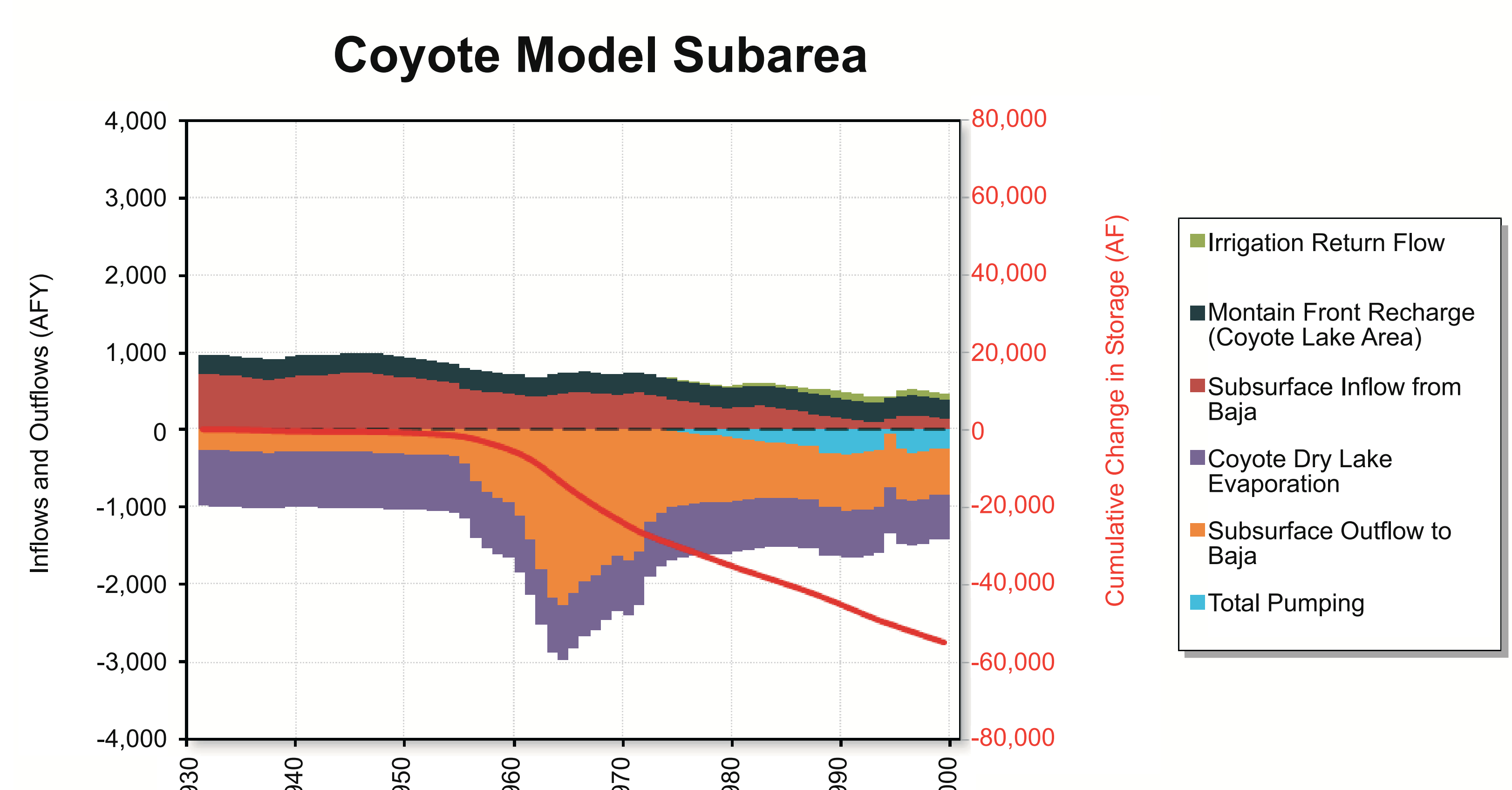
- Groundwater pumping
- Groundwater discharge to the Mojave River (baseflow)
- Subsurface outflow (at MWA boundary)
- Evapotranspiration (transpiration by phreatophytes and free water evaporation)
- Bare-soil evaporation (at Coyote and Troy dry lakes)

5.7.1 USGS Model Baja Subarea Water Budget (1931 to 1999)

Figure 5.20 shows the boundaries of the Baja, Coyote, and Afton model subareas, identical to the model subareas used in the Stamos report for water budget calculations. **Figure 5.21** summarizes the annual water budgets from the USGS model for these three model subareas from 1931 to 1999. Shown on each chart are the individual surface water and groundwater inflows and outflows and the cumulative change in groundwater storage (red lines). The average annual surface water and groundwater inflows and outflows for the base period (1931 to 1990) and the full transient simulation (1931 to 1999) for the three model subareas are summarized in **Tables 5.3a through 5.3c**. Complete documentation of each water budget is provided in **Appendix F.** Figure 5.22 depicts the cumulative change in storage in the







February 2013 TODD ENGINEERS Alameda, California	**Figure 5.21** **Water Budgets for Baja, Coyote, and Afton Model Subareas**

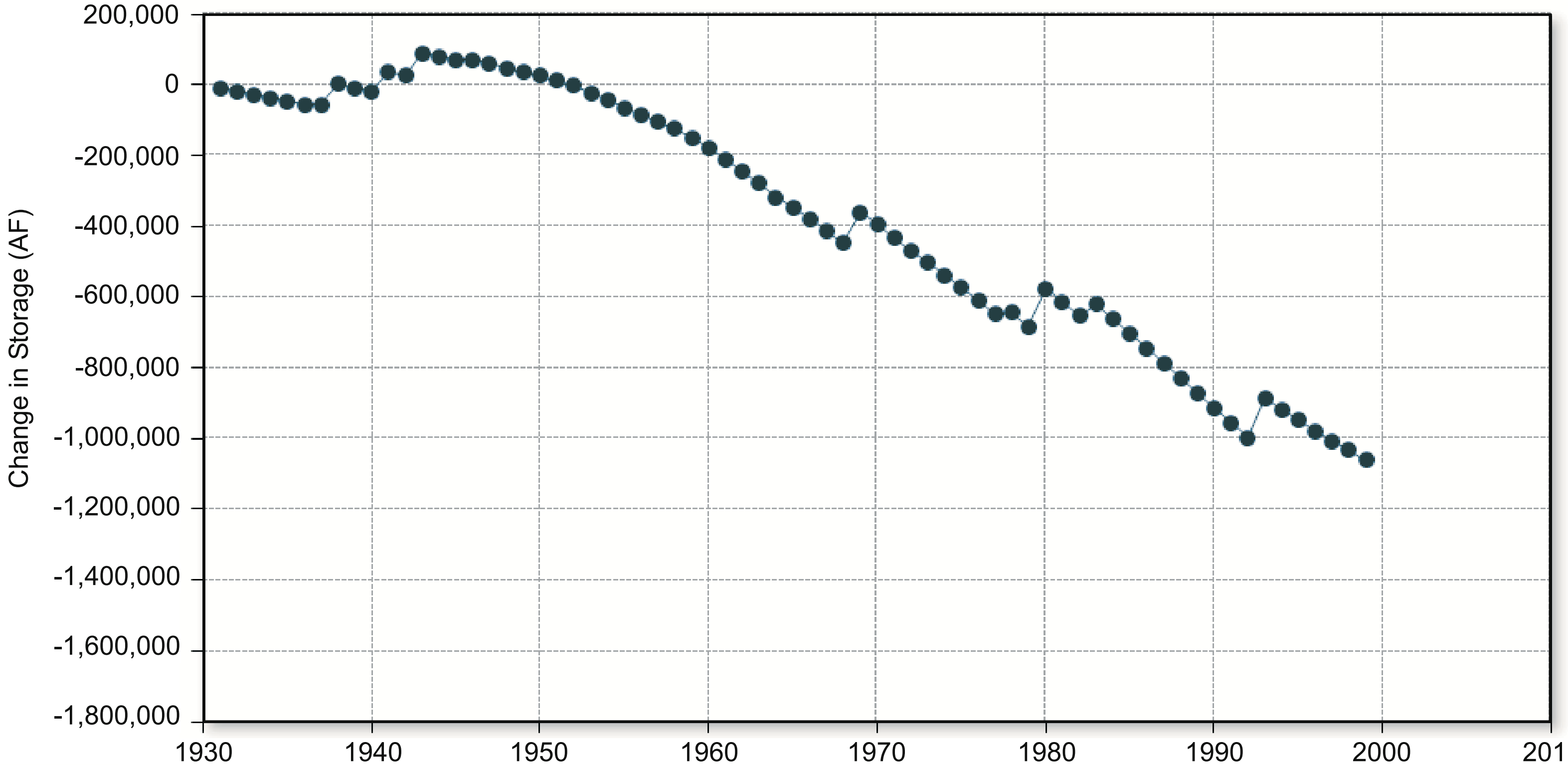


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Figure 5.22
Groundwater Storage Change for Baja Subarea (1931 to 1999)

Table 5.3a
USGS Baja Model Subarea Water Budget

	Ave (1931-90)	Ave (1931-99)
INFLOWS		
Surface Water Inflow	14,070	15,485
Mojave River (at Waterman Fault)	*10,476*	*11,925*
Surface Water Inflow - Ungaged Tributaries	*3,593*	*3,559*
Recharge from Stream Leakage	12,015	13,023
Subsurface Inflow	2,921	2,947
from Centro (at Waterman Fault)	*1,462*	*1,506*
from Coyote (net flows)	*289*	*319*
Mountain-Front Recharge (Kane Wash)	647	647
Irrigation Return Flow	9,020	9,371
WWTP Effluent Return Flow	375	398
Nebo Sewage Ponds	*329*	*346*
Yermo Sewage Ponds	*47*	*52*
Total Groundwater Inflows	**24,603**	**26,386**
OUTFLOWS		
Surface Water Outflow - Mojave River (to Afton)	-3,806	-4,168
Groundwater Discharge to Stream (baseflow)	-2,204	-2,182
Subsurface Outflow to Afton	-170	-169
Evapotranspiration	-3,653	-3,324
Troy Dry Lake Evaporation	-1	-1
Total Pumping	-32,245	-34,156
Agricultural Irrigation	*-30,866*	*-32,360*
Municipal, Industrial, Domestic	*-375*	*-398*
Recreational Lakes (evaporation)	*-1,003*	*-1,398*
Total Groundwater Outflows	**-39,443**	**-40,954**
Annual Change in Groundwater Storage	**-14,465**	**-14,568**

Table 5.3b
USGS Coyote Model Subarea Water Budget

	Ave (1931-90)	Ave (1931-99)
INFLOWS		
Subsurface Inflow from Baja Model Subarea	504	457
Mountain-Front Recharge (Coyote Lake Area)	259	259
Irrigation Return Flow	12	20
Total Groundwater Inflows	**775**	**736**
OUTFLOWS		
Subsurface Outflow to Baja Model Subarea	-793	-776
Total Pumping	-43	-70
Coyote Dry Lake Evaporation	-701	-687
Total Groundwater Outflows	**-1,537**	**-1,533**
Annual Change in Groundwater Storage	**-762**	**-797**

Table 5.3c
USGS Afton Model Subarea Water Budget

	Ave (1931-90)	Ave (1931-99)
INFLOWS		
Surface Water Inflow - Mojave River from Baja	3,806	4,168
Recharge from Stream Leakage	1,162	1,107
Subsurface Inflow from Baja Model Subarea	170	169
Total Groundwater Inflows	**1,333**	**1,276**
OUTFLOWS		
Surface Water Outflow - Mojave River to Afton Canyon	-3,760	-4,159
Groundwater Discharge to Stream (baseflow)	-122	-126
Evapotranspiration	-539	-511
Subsurface Outflow to Afton Canyon	-504	-478
Total Groundwater Outflows	**-1,165**	**-1,115**
Annual Change in Storage (AF)	**167**	**161**

adjudicated portion of the Baja Subarea (excluding the Afton model subarea). Key components of the water budgets, illustrated on the charts on **Figures 5.21 and 5.22** and summarized in **Tables 5.3a through 5.3c**, are discussed below.

<u>Change in Groundwater Storage</u> - Groundwater storage in the adjudicated portion of the Baja Subarea (excluding the Afton model subarea) declined by over 1,060,000 AF from 1931 to 1999, with relatively consistent annual storage losses estimated since 1950 (**Figure 5.22**). Average annual storage losses during the base period (1931 to 1990) from the Baja and Coyote model subareas were -14,465 AFY and -762 AFY, respectively (**Tables 5.3a and 5.3b**). Average annual storage losses over the entire transient simulation period (1931 to 1999) from the Baja and Coyote model subareas were -14,568 AFY and -797 AFY, respectively. Small average annual storage gains were estimated in the Afton model subarea over the base period (167 AFY) and transient simulation period (161 AFY).

Groundwater storage losses were a result of two factors: 1) significant increases in historical groundwater production beginning in the late 1940s in the Baja model subarea followed by increased groundwater production in the Coyote model subarea beginning in the mid-1970s; and 2) diminished recharge from Mojave River leakage since the pre-development period as a result of regional production in upstream subareas. Total groundwater production across the Baja Subarea averaged 32,288 AFY and 34,226 AFY during the during the base period and transient simulation period, respectively. Based on simulations with the USGS model, upper basin pumping (not including Centro) was estimated to account for 193,800 AF of groundwater storage loss over the base period (1931 to 1990), equivalent to approximately 21 percent of the 913,620 AF of groundwater lost from storage in the Baja Subarea over the same period. The USGS did not simulate the effect of upstream pumping in Centro on stream discharge and recharge in Baja. Additional discussion of the effects of regional-scale pumping on groundwater levels in the Baja Subarea is presented in Section 5.5.

<u>Return Flows</u> – In the USGS model, irrigation return flows were estimated to be 50 percent of total agricultural pumping in all model subareas from 1931 to 1950. From 1951 through 1999, irrigation return flows were estimated at 29 percent in the Baja and Coyote model subareas based on a method developed by the MBA Watermaster used to calculate total agricultural production from 1986 through 1994 and USDA-defined crop consumptive use rates estimated for each model subarea. No return flows were assigned for municipal production; rather specific WWTP effluent return flows were estimated for the MCLB Nebo and Yermo sewage ponds (although physically located in the Centro Subarea, the Nebo sewage ponds were included in the Baja model subarea water budgets in the USGS model). Average annual WWTP effluent return flows within the Baja model subarea were 375 AFY for the base period and 398 AFY for the transient simulation period. Return flows associated with septic tank discharges within the Baja Subarea were not simulated in the model.

<u>Recharge from Stream Leakage</u> - While highly variable from year to year, recharge from Mojave River leakage in the Baja model subarea averaged 12,015 AFY and 13,023 AFY during the base period and transient simulation period, respectively (**Table 5.3a**). These volumes account for about 77 percent of the Baja model subarea natural recharge. Contained in these volumes are local ungaged tributary flows from five mapped ephemeral washes in the Baja Subarea, based on estimates by Lines (1999). Recharge from stream leakage in the Afton model subarea averaged 1,162 and 1,107 AFY during the base period and transient simulation period, respectively (**Table 5.3c**). Average annual local ungaged tributary flows were 3,593 AFY and 3,559 AFY for the base period and transient simulation period, respectively. In addition, the USGS model tabulates separately mountain-front recharge for the Coyote Lake (259 AFY) and Kane Wash areas (647 AFY). A focused evaluation of the ungaged tributary flows conducted for this study indicates that the annual local ungaged tributary flows by Lines, while similar in magnitude to the findings from the focused evaluation conducted for this study, are overestimated for the tributaries identified (see **Appendix C** for detailed explanation). The results of the focused analysis indicate that estimated total ungaged local runoff within the Baja Subarea is 960 AFY. Of this amount about 755 AFY is generated within the Mojave River drainage basin upstream of the Afton gage with 630 AFY occurring above the Caves area.

Subsurface Flows – Subsurface inflows from the Centro Subarea across Harper Lake (Waterman) Fault averaged 1,462 AFY and 1,506 AFY during the base period and transient simulation period, respectively. Groundwater discharges to surface water in the eastern portion of the Baja Subarea. Accordingly, surface water outflows in the Mojave River represent total natural outflows from the Baja Subarea through Afton Canyon.

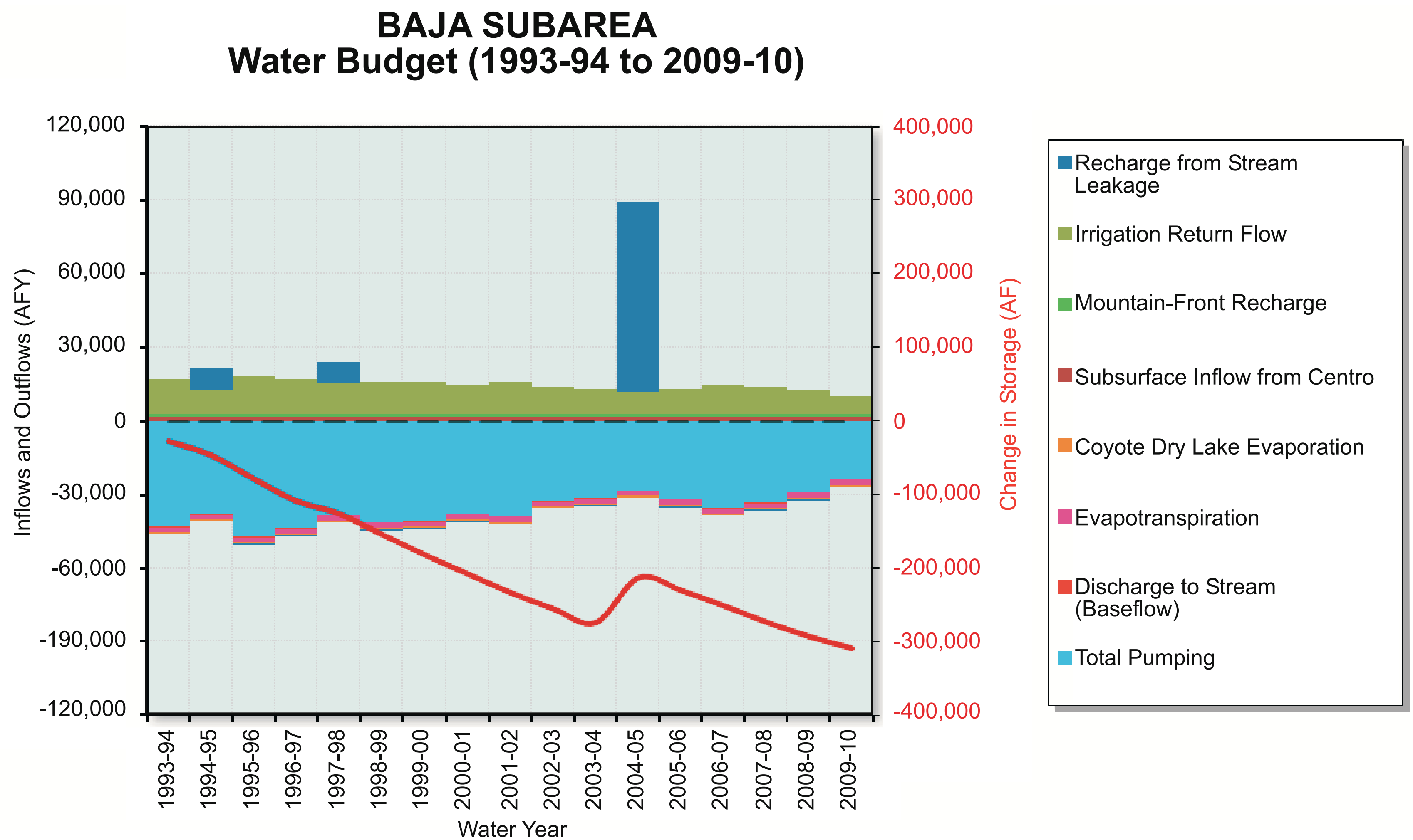
Evapotranspiration (ET) – Model simulated ET averaged 3,653 AFY and 3,324 AFY during the base period and transient simulation period, respectively. ET was much higher from 1931 to about 1950 due to shallower simulated groundwater conditions. From 1951 to 1999, ET averaged only about 1,350 AFY.

Groundwater Discharge to Coyote and Troy Dry Lakes – Simulated evaporation at Coyote Dry Lake averaged 701 AFY and 687 AFY during the base period and transient model period, respectively. Evaporation declined slightly over time due to small local groundwater level declines. Over the last five years of the model period, simulated evaporation of groundwater beneath Coyote Dry Lake averaged about 600 AFY. No groundwater evaporation occurs beneath Troy Dry Lake, because depth to groundwater has historically ranged between 20 and 50 feet-bgs.

Surface Water Flow – Simulated surface water inflow across the Waterman Fault was 14,070 AFY and 15,485 AFY during the base period and transient simulation period, respectively. Simulated surface water outflow as measured at the MWA boundary separating the Baja and Afton subareas was 3,806 AFY and 4,168 AFY during the base period and transient simulation period, respectively.

5.7.2 Baja Subarea Water Budget (WY 1993-94 to WY 2009-10)

A water budget for the Baja Subarea from WY 1993-94 to WY 2009-10 was developed to better understand subarea hydrogeologic conditions since the Judgment and to incorporate more recent and reliable estimates of surface water flows across the Harper Lake (Waterman) Fault and consumptive use and return flows. Annual inflows and outflows are tabulated in **Table 5.4** and also depicted on **Figure 5.23**. For the water budget, annual surface water inflows at the Harper Lake (Waterman) Fault were estimated from Barstow gage data and estimation of groundwater storage gains between the Barstow gage and Harper Lake (Waterman) Fault following storm recharge events (MWA, 2011a). Groundwater production and consumptive use estimates were obtained directly from annual Watermaster reports. Refined estimates of ungaged local mountain runoff/recharge were derived from a focused analysis documented in **Appendix C**.



February 2013	**Figure 5.23**
TODD ENGINEERS Alameda, California	**Water Budget for Baja Subarea (WY 1993-94 to WY 2009-10)**

Table 5.4
Baja Subarea Water Budget (WY 1993-94 to WY 2009-10)

	Average[1]	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10
INFLOWS																		
Surface Water Inflows (at Waterman Fault)	8,270	0	9,242	0	0	9,527	0	0	0	0	0	0	121,803	0	0	10	0	0
Mojave River at Barstow (gage data)	8,727	0	11,111	0	0	10,512	0	0	0	0	0	0	126,168	182	0	10	0	374
Estimated losses from Barstow gage to Waterman Fault	-457	0	-1,869	0	0	-985	0	0	0	0	0	0	-4,365	-182	0	0	0	-374
Net Recharge from Stream[a]	5,538	0	9,218	-280	-241	8,592	-234	-8	-110	0	0	-113	77,369	-14	0	-26	-7	0
SWP Water Enhanced Recharge (Daggett + Newberry Spgs)	771	0	0	0	0	0	0	0	0	0	296	2,807	2,608	3,895	3,133	64	1	311
Subsurface Inflow from Centro Subarea (at Waterman Fault)	1,462	1,462	1,462	1,462	1,462	1,462	1,462	1,462	1,462	1,462	1,462	1,462	1,462	1,462	1,462	1,462	1,462	1,462
Mountain-Front Recharge (0.5% Runoff Non-Basin Area)	980	980	980	980	980	980	980	980	980	980	980	980	980	980	980	980	980	980
Return Flows (Total Pumping Net Re-Circulated less CU)	12,120	14,979	10,004	15,844	14,951	13,056	13,817	13,742	12,437	13,645	11,021	10,584	9,499	10,781	12,172	11,496	9,937	8,067
Consumptive Use Agriculture			-22100	-24700	-20800	-18100	-18700	-17600	-15200	-15200	-14300	-14100	-12600	-14500	-17200	-16200	-13900	-10400
Consumptive Use Urban			-5800	-6500	-7900	-7100	-8600	-9500	-9900	-9900	-7400	-6900	-6200	-6600	-6200	-5600	-5200	-5300
Total Groundwater Inflows	**20,871**	**17,421**	**21,664**	**18,006**	**17,152**	**24,090**	**16,025**	**16,176**	**14,769**	**16,087**	**13,759**	**15,720**	**91,918**	**17,104**	**17,747**	**13,976**	**12,373**	**10,820**
OUTFLOWS																		
Surface Water Outflow - Mojave River at Afton	-2,999	-483	-391	-633	-646	-1,287	-578	-283	-350	-239	-249	-394	-44,638	-186	-150	-166	-112	-190
Groundwater Discharge to Stream at Afton (baseflow)	-267	-483	-367	-353	-405	-352	-344	-275	-240	-239	-249	-281	-204	-172	-150	-130	-105	-190
Evapotranspiration	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000	-2,000
Coyote Dry Lake Evaporation	-600	-600	-600	-600	-600	-600	-600	-600	-600	-600	-600	-600	-600	-600	-600	-600	-600	-600
Troy Dry Lake Evaporation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Pumping (Net Re-Circulated Water)	-36,121	-42,798	-37,904	-47,044	-43,651	-38,256	-41,117	-40,842	-37,537	-38,745	-32,721	-31,584	-28,299	-31,881	-35,572	-33,296	-29,037	-23,767
Total Pumping net re-circulated (not including aquaculture and rec lakes)	-31402	-39,443	-33,241	-42,269	-38,826	-33,549	-36,335	-35,512	-32,825	-33,842	-27,903	-26,701	-23,395	-27,044	-30,891	-28,544	-24,557	-18,953
Minimal Producers	-2000	-2000	-2000	-2000	-2000	-2000	-2000	-2000	-2000	-2000	-2000	-2000	-2000	-2000	-2000	-2000	-2000	-2000
Aquaculture and Recreational Lakes (evaporation)	-2705	-1355	-2663	-2775	-2825	-2707	-2782	-3330	-2712	-2903	-2818	-2883	-2904	-2837	-2681	-2752	-2480	-2586
Total Groundwater Outflows	**-38,988**	**-45,881**	**-40,871**	**-49,997**	**-46,656**	**-41,208**	**-44,061**	**-43,717**	**-40,377**	**-41,584**	**-35,570**	**-34,465**	**-31,103**	**-34,653**	**-38,322**	**-36,026**	**-31,742**	**-26,557**
Annual Change in Storage (AF)	**-18,116**	-28,460	-19,207	-31,991	-29,504	-17,118	-28,036	-27,541	-25,608	-25,497	-21,811	-18,745	60,815	-17,549	-20,575	-22,050	-19,369	-15,737
Cumulative Change in Storage (AF)		-28,460	-47,666	-79,657	-109,161	-126,279	-154,315	-181,855	-207,463	-232,960	-254,771	-273,516	-212,701	-230,249	-250,824	-272,874	-292,242	-307,979

[a]negative net recharge from stream represents additional discharge to stream in addition to calculated baseflow at Afton

Sources of information used to estimate individual water budget components are summarized below:

- Annual surface water inflows at the Harper Lake (Waterman) Fault were estimated from discharge data at the USGS Barstow stream gage and estimation of annual streamflow losses (groundwater storage gains) between the Barstow gage and Harper Lake (Waterman) Fault following storm recharge events (MWA, 2011a).

- Annual volumes of SWP water recharged through the Daggett and Newberry Springs recharge facilities were provided directly by MWA.

- Subsurface inflow at the Harper Lake (Waterman) Fault represents the average annual rates over the base period (1931 to 1990) estimated from the USGS model. While annual subsurface flows vary in the USGS model, previous studies of groundwater level changes across the Waterman Fault have indicated no significant change in groundwater levels and hydraulic gradient since the 1960s, when reliable water level data were first available (CSUF, 2006).

- Mountain front-recharge estimates were derived from results of a focused analysis on local mountain runoff documented in **Appendix C**. Mountain-front recharge estimates represent 0.49 percent of average annual rainfall on contributing watershed areas outside the Mojave River Basin model boundary. Recharge estimates were apportioned to the three model subareas.

- Groundwater production, consumptive use, and return flow estimates were obtained directly from the MBA Watermaster. For WYs 1993-94, a weighted-average consumptive use factor of 65 percent (return-flow factor of 35 percent) was applied to total production (net re-circulated water for recreational lakes) to estimate return flows.

- Riparian ET was estimated from values reported in the riparian studies conducted by the USGS (Lines and Bilhorn, 1996) and the USBR and USU (2011). As described in the land use section, average annual ET based on 1995 conditions was estimated to be about 2,000 AFY in the Baja subarea (Lines and Bilhorn, 1996). More recently, riparian ET in 2007 and 2010 was estimated to be about 2,000 AFY and 2,500 AFY in the Baja Subarea, respectively (USBR and USU, 2011). Aerial photographs indicate significant riparian loss at Camp Cady since 1995; however, CDFG is also considering alternative strategies to restore lost riparian habitat along the main channel through an engineered solution involving re-planting and irrigation with local groundwater. For the water budget, a constant value of 2,000 AFY was assigned for riparian ET.

- Groundwater discharge to Coyote and Troy Dry Lake – Groundwater discharge to Coyote Dry Lake is controlled by local groundwater levels. Local groundwater levels in this area have been relatively stable since WY 1993-94 and are reflective of hydrogeologic conditions observed in the latter years of the USGS transient simulation period. For the water budget, the average annual simulated groundwater evaporation rate beneath Coyote Dry lake from 1994 to 1999 (600 AFY) was applied directly for each year of the water budget (from WY 1993-94 through WY 2009-10).

Figure 5.23 and **Table 5.4** reveal the following:

Change in Groundwater Storage – Over the 17-year period from WY 1993-94 to WY 2009-10, the estimated rate of groundwater storage decline in the adjudicated portion of the Baja Subarea was slightly higher than historical declines, averaging -18,116 AFY (compared to -15,365 AFY from 1931 to 1999) for a cumulative storage loss of -307,979 AF. The increased rate of storage loss was a result of two factors: 1) average annual production in the Baja Subarea (36, 121 AFY) exceeding the natural water supply over this period despite recent decreases in production below 30,000 AFY in response to rampdown; and 2) below-average recharge from Mojave River leakage as a result, in part, of the continued effect of upstream regional production reducing Mojave River flows entering the Baja Subarea.

Consumptive Use/Return Flows – Weighted-average consumptive use and return flows averaged 66 and 34 percent of total production (net-recirculated water for recreational lakes), respectively. Total agricultural and urban consumptive use in the Baja Subarea averaged 24,001 AFY between WY 1993-94 to WY 2009-10.

Recharge from Stream Leakage – Recharge from stream leakage over this period averaged 5,538 AFY for a total of 94,149 AF. Of the total volume of recharge, 77,369 AF (or 82 percent) occurred during WY 2004-05.

Subsurface Inflow – For the water budget, the average annual subsurface inflow from the Centro Subarea across the Harper Lake (Waterman) Fault (estimated over the base period from the USGS model at 1,462 AFY) was applied as a constant rate. While variations in subsurface flow have likely occurred historically, groundwater levels upstream of the Harper Lake (Waterman) Fault have been relatively stable due to effluent discharges from the Barstow WWTP. Investigations of groundwater levels and hydraulic gradients across the Harper Lake (Waterman) Fault by MWA indicate no significant change in groundwater levels and the hydraulic gradient across the Harper Lake (Waterman) Fault since reliable water level data were collected in the 1960s (CSUF, 2006).

Evapotranspiration (ET) – For the water budget, a constant annual ET rate under 1995 land use conditions (2,000 AFY) was applied.

Groundwater Discharge to Coyote Dry Lake – The average annual simulated groundwater evaporation rate beneath Coyote Dry Lake was 600 AFY.

Surface Water Flow – Surface water inflow across the Harper Lake (Waterman) Fault averaged 8,270 AFY, as a result of 457 AFY of stream losses between the Barstow gage and Harper Lake (Waterman) Fault. Surface water outflow as represented by Afton gage flows averaged 2,999 AFY.

5.8 Baja Groundwater Quality

5.8.1 Source Water (Trilinear) Diagrams and Stiff Plots

Trilinear Diagrams

Complete analyses of major cations and anions were available for approximately 150 wells in the Baja Subarea. **Figure 5.24** shows trilinear diagrams for wells in the Baja Subarea grouped into eight general regions. Seven regions include wells located between the Harper Lake (Waterman) Fault and Calico Fault. The eighth region includes wells east of the Calico Fault in the lower portions of the subarea (circled in yellow). For reference, the signature of Mojave River water is shown on each diagram (open red circle). General groundwater quality trends based on the Trilinear Diagrams are described below.

As shown on **Figure 5.24**, groundwater in the majority of wells upstream of the Calico Fault plot in the central portion of the diamond on the Trilinear Diagram, exhibiting a neutral-to-calcium type cation and neutral-to-bicarbonate type anion signature, resembling that of Mojave River water. Major cation composition of groundwater varies along a mixing line between Mojave River water and pure sodium type water. Increases in sodium generally coincide with increases in sulfate. These trends reflect the combination of three processes:

- Cation exchange (from calcium to sodium) along groundwater flowpaths away from the river
- Contribution of older elevated TDS/sulfate groundwater in wells screened in cemented/consolidated sediments (e.g., deep wells in the main channel, wells located north of Yermo, and wells screened in older alluvial fan sediments south of the southern margins of the Basin downstream of the Harper Lake [Waterman] Fault)
- Recharge from local mountain runoff, which has a high relative sodium content and similar relative bicarbonate content as the Mojave River water. Wells located downstream of the Harper Lake (Waterman) Fault and along the Calico Fault exhibit a high relative bicarbonate content.

East of the Calico Fault in the lower portion of the Baja Subarea, groundwater quality varies significantly along the river. Wells located along the Mojave River just downstream of the Calico Fault exhibit a signature similar to that of Mojave River water. However, further east at Camp Cady Wildlife Area, wells have a higher relative sodium content. Groundwater at shallow depths is comprised of local stream losses and older groundwater flowing from the south/southwest towards Camp Cady. Wells screened below laterally extensive clay deposits associated with the Manix Clay Beds are not directly recharged by local stream losses and plot in the lower right portion of the diamond (due to higher sodium content).

Relative sodium and chloride content increases with increasing distance from the river to the south (Newberry Fracture Zone, Kane Wash, and Troy Dry Lake) and north (towards Coyote Dry Lake). This trend is attributable to additional cation exchange along groundwater flowpaths across the lower Baja Subarea and leaching of sodium and chloride from evaporative lake deposits (associated with ancestral Lake Manix and the current Coyote and Troy dry lakes). The signature for one well located at the Ironwood Christian Academy (gold dot on the map) confirms that groundwater pumped beneath the

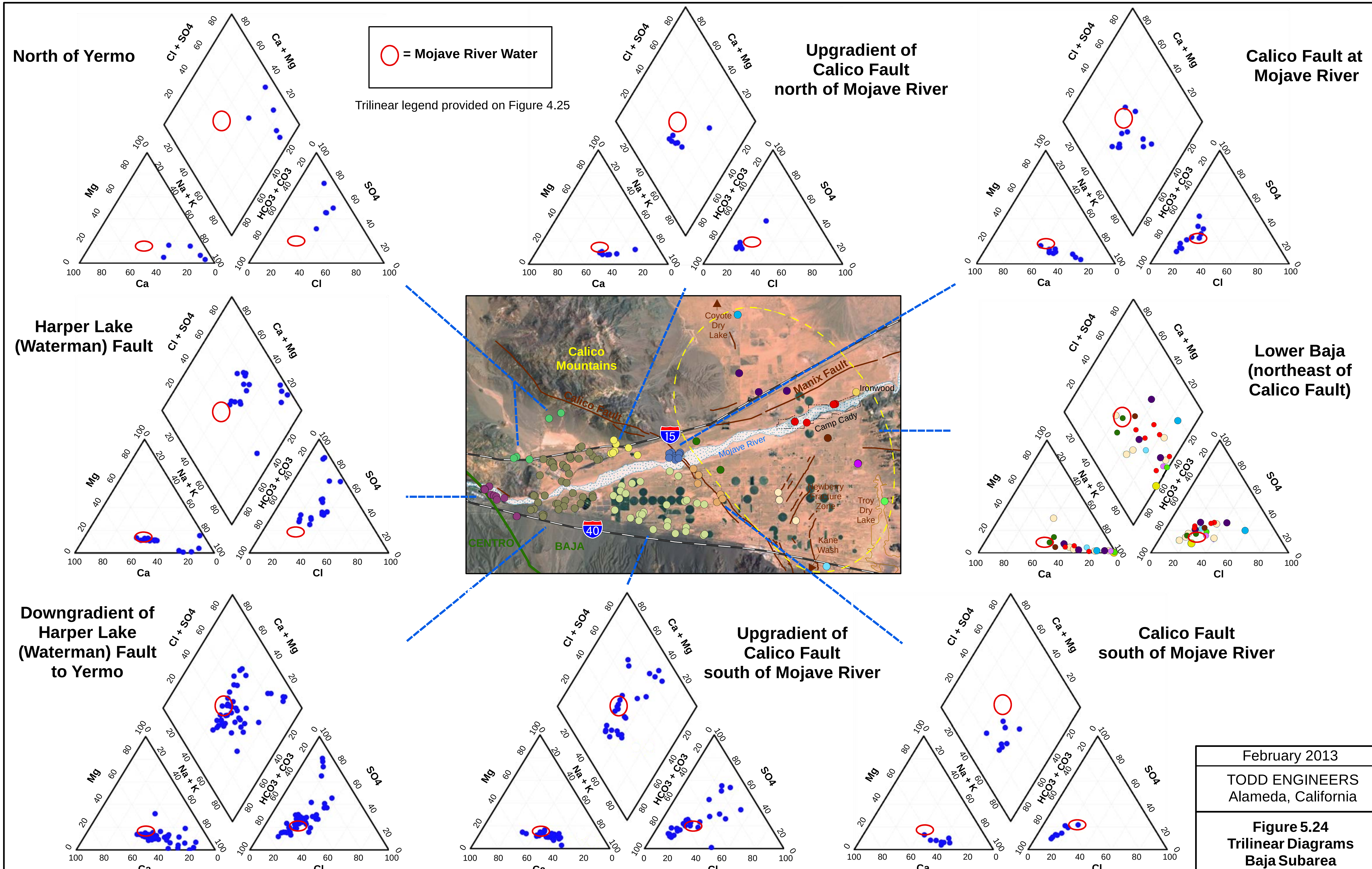


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Figure 5.24
Trilinear Diagrams
Baja Subarea

Ironwood property is locally confined, relatively old, and not recharged locally by the Mojave River system.

Stiff Diagrams

Figure 5.25 shows the Stiff Diagrams of selected wells across the Baja Subarea. As shown on the figure, TDS concentrations in the western subarea between the Harper Lake (Waterman) Fault and Yermo are elevated, ranging from 500 to 2,000 mg/L. Chemical signatures reflect the combined effect of effluent discharges from the Barstow WWTP and the upward flow of groundwater from the Regional Aquifer into the Floodplain Aquifer near the Harper Lake (Waterman) Fault. Upstream of the Calico Fault, Stiff Diagrams of wells north of Yermo and south of the major agricultural fields confirm the lateral extent of unconsolidated sediments comprising the Basin. Across the central axis of the Basin, TDS concentrations are relatively consistent, ranging between 250 to 500 mg/L. TDS concentrations increase in the lower portions of the subarea towards Troy Dry Lake in the south and Coyote Dry Lake in the north. Interestingly, groundwater in the Troy Dry Lake area (and Ironwood Christian Academy) is a sodium-bicarbonate type, which is different from the sodium-chloride type groundwater that occurs south of Coyote Dry Lake (and at Harper Dry Lake in the Centro Subarea).

5.8.2 Total Dissolved Solids (TDS)

Figure 5.26 shows the maximum TDS concentration measured in Baja Subarea monitoring wells from 1990 to 2010. As shown on the map, TDS concentrations across the subarea generally range from 250 to 1,000 mg/L. TDS concentrations above 1,000 mg/L occur downstream of the Harper Lake (Waterman) Fault, where higher TDS water in the Regional Aquifer is directed upward by the fault into the Floodplain Aquifer and where effluent discharges from the Barstow WWTP influence groundwater quality. Elevated TDS concentrations are also observed north of the MCLB Yermo Annex and southwest of the Calico Mountains. Several wells in this area are screened in the Regional Aquifer or consolidated bedrock. In addition, TDS concentrations are elevated due to leaching of sodium and chloride from evaporative deposits associated with a local playa lake bounded by Highway 15 and Ghost Town and Calico roads. While recent monitoring data are limited, elevated TDS concentrations are known to occur near Coyote and Troy dry lakes.

5.8.3 Arsenic

Figure 5.27 shows the maximum arsenic concentrations measured in Baja Subarea monitoring wells from 1990 to 2010. As shown on the map, maximum arsenic concentrations exceed the federal and state primary MCL for arsenic (0.01 mg/L) in several areas, including areas previously identified as having elevated TDS concentrations (i.e., in the vicinity of the Harper Lake (Waterman) Fault, southwest of the Calico Mountains). In addition, elevated arsenic concentrations occur in wells located in the lower Baja Subarea east of the Calico Fault. With the exception of the Barstow area where elevated arsenic concentrations are likely associated with effluent discharges, elevated arsenic concentrations across the Baja Subarea are likely natural occurrences.

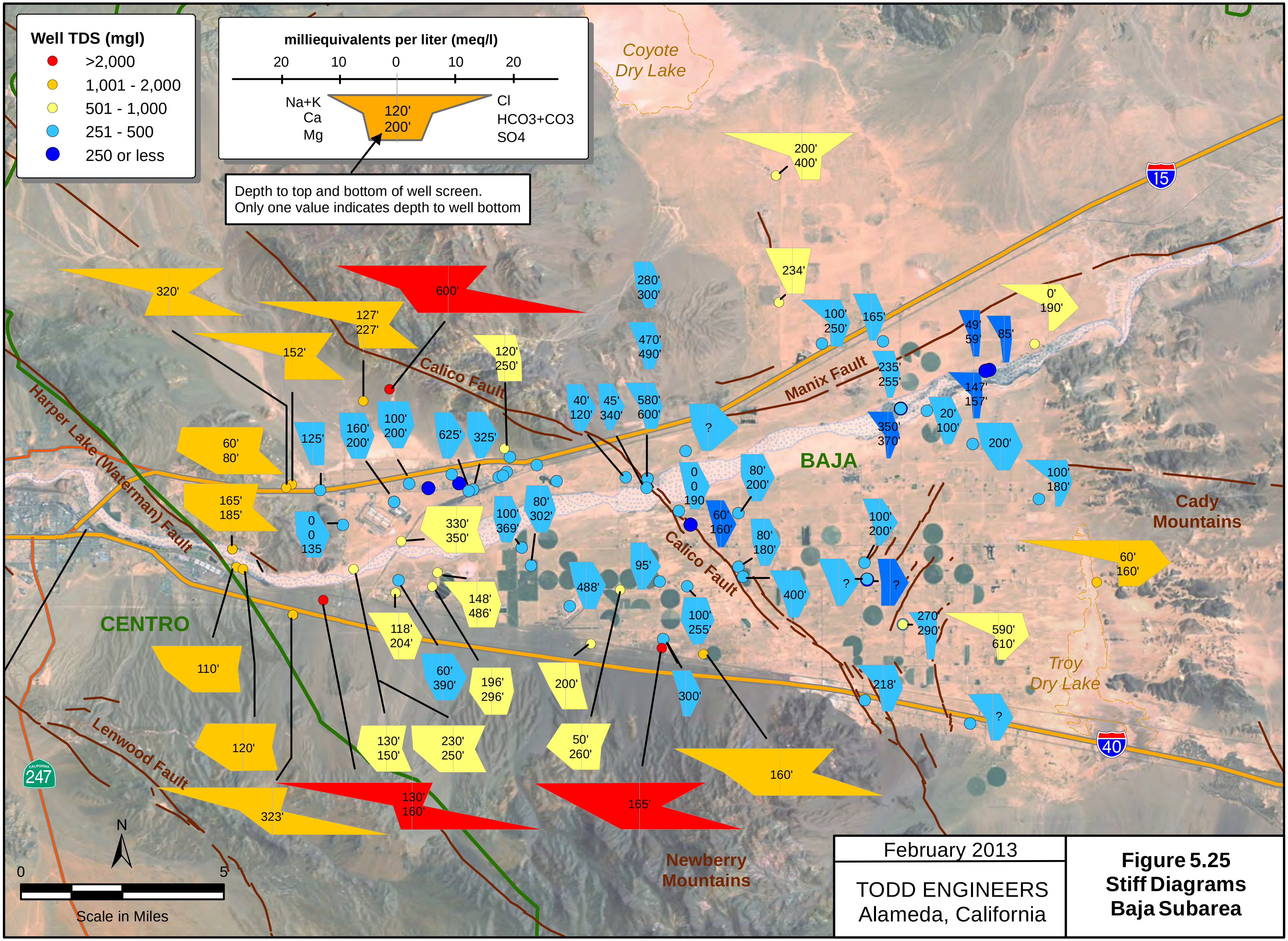

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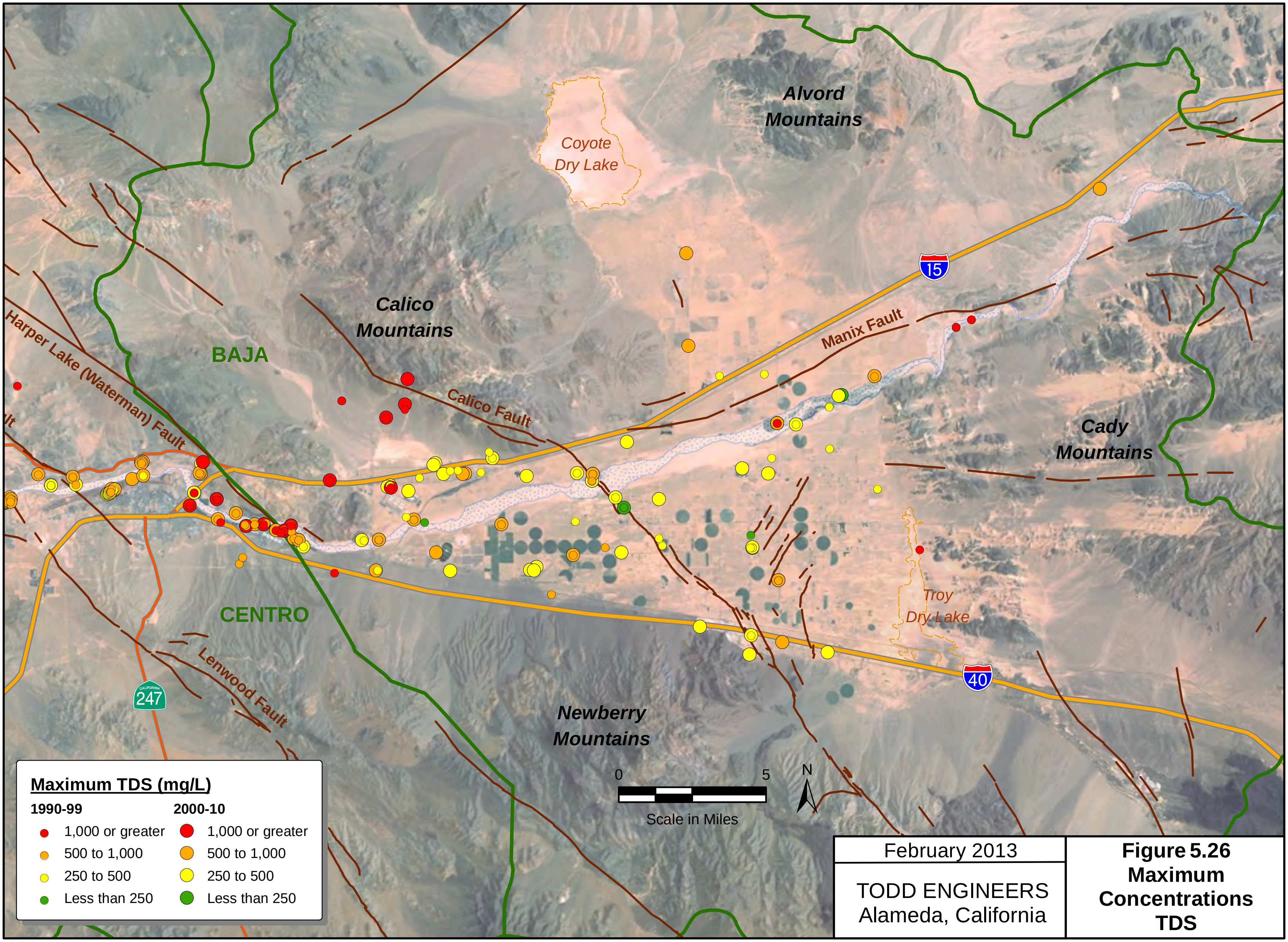
Figure 5.25
Stiff Diagrams
Baja Subarea



February 2013	Figure 5.26 Maximum Concentrations TDS
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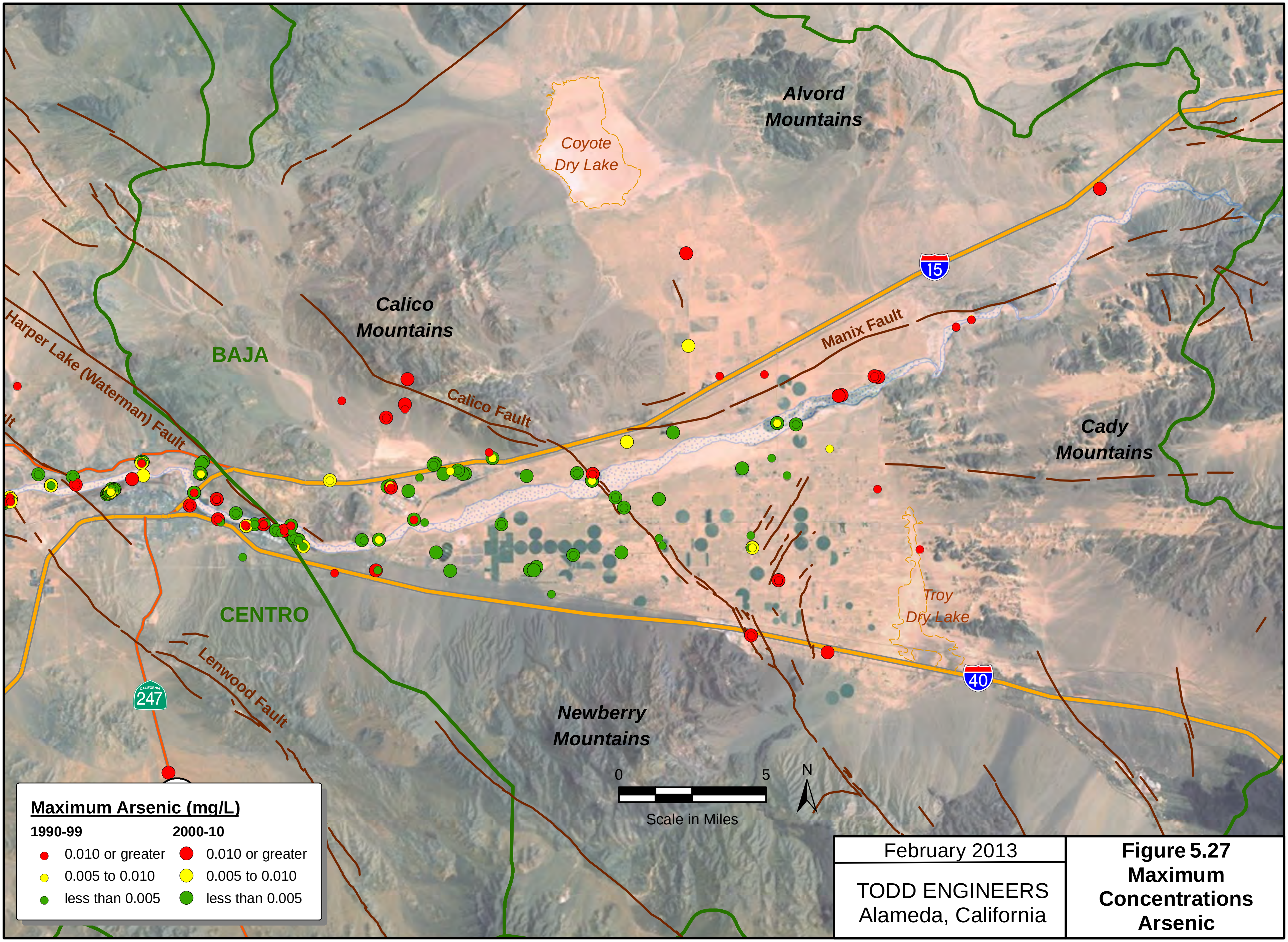

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Figure 5.27
Maximum Concentrations Arsenic

5.8.4 Boron

Figure 5.28 shows the maximum boron groundwater concentrations measured in monitoring wells in the Baja Subarea from 1990 to 2010. As shown on the map, maximum boron concentrations in areas monitored are generally less than the drinking water notification level for boron (1 mg/L) with only isolated occurrences where boron concentrations exceed 1 mg/L. Boron exceeds 3 mg/L downstream of the Barstow WWTP and in the area north of Yermo/southwest of the Calico Mountains. With the exception of the Barstow area where elevated boron concentrations are probably associated with effluent discharges, boron concentrations across the Baja Subarea are likely to reflect natural sources.

5.8.5 Hexavalent Chromium (Cr-VI)

Figure 5.29 shows the maximum Cr-VI concentrations measured in monitoring wells in the Baja Subarea from 1990 to 2010. The CDPH currently regulates Cr-Vl under the Primary MCL for total chromium of 50 micrograms per liter (ug/L). On July 27, 2011, the California Office of Environmental Health Hazard Assessment (OEHHA) recommended a Public Health Goal (PHG) of 0.02 ug/L. A PHG is not a drinking water regulatory standard, but rather represents a level of contaminant that does not pose a significant health risk (CDPH, 2012). The CDPH uses PHGs to develop drinking water standards or MCLs for specific contaminants and is in the process of developing a MCL for Cr-Vl (CDPH, 2012). As shown on the map, Cr-VI concentrations in monitored areas range from less than 1 ug/L to greater than 4 µg/L. Elevated concentrations above 4 ug/L have been observed in eastern Barstow and may be associated with effluent discharges. Elevated Cr-VI concentrations northeast of Yermo, near the Calico Fault, and in the eastern subarea likely reflect background concentrations in the region.

5.8.6 Fluoride

Figure 5.30 shows the fluoride concentration measured in monitoring wells in the Baja Subarea. As shown on the map, areas of elevated fluoride concentrations above the MCL (2 mg/L) coincide with areas of elevated arsenic, including downstream of the Barstow WWTP, north of Yermo and in the far eastern portions of the subarea. With the exception of the Barstow area where elevated fluoride concentrations are likely associated with effluent discharges, elevated fluoride concentrations elsewhere are probably natural in origin.

5.8.7 Nitrate/Nitrate as N

Figure 5.31 shows the maximum nitrate-nitrite as N concentration measured in monitoring wells in the Baja Subarea from 1990 to 2010. As shown on the map, nitrate-nitrite concentrations are below the MCL in most areas, with the exception of the area near the Barstow WWTP. Effluent discharges from the Barstow WWTP are regulated by the RWQCB, and a recent study has demonstrated the effectiveness of denitrification processes in reducing downstream nitrate concentrations (DPRA, 2010).

5.8.8 Perchlorate

Figure 5.32 shows the maximum perchlorate concentrations measured in monitoring wells in the eastern Centro Subarea and Baja Subarea from 1990 to 2010. As shown on the figure, results of recent

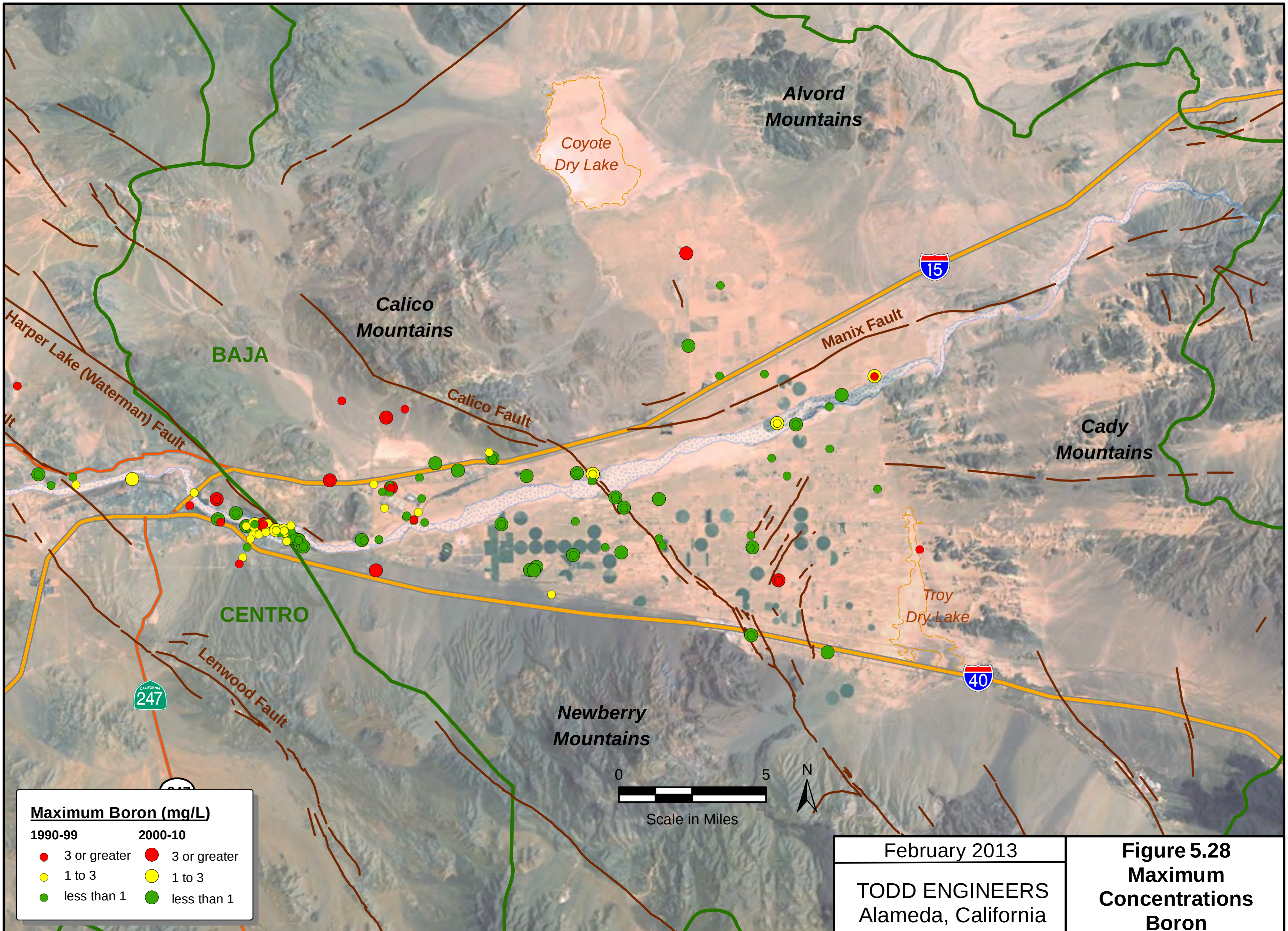

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Figure 5.28
Maximum Concentrations Boron

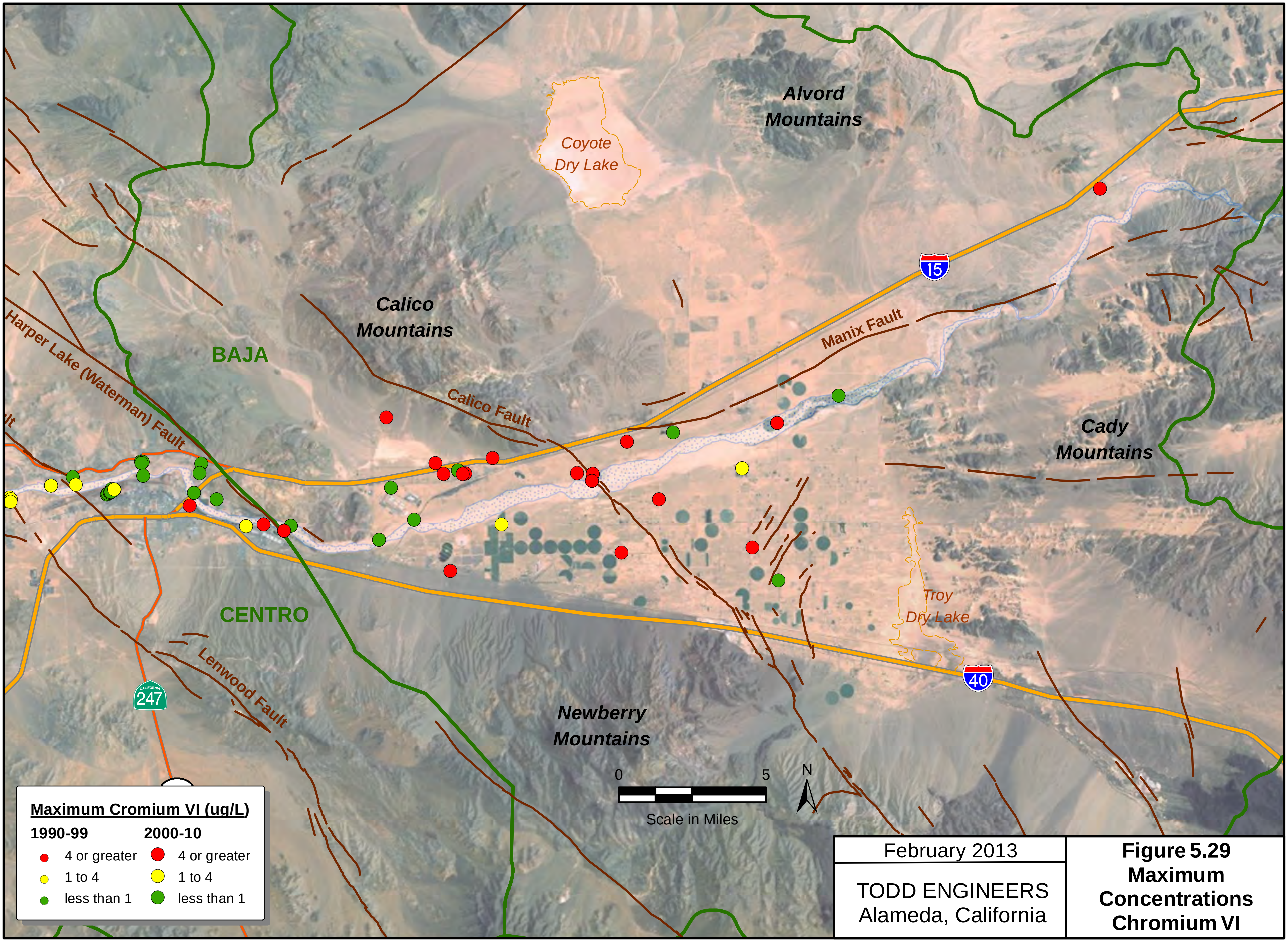

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Figure 5.29
Maximum Concentrations Chromium VI

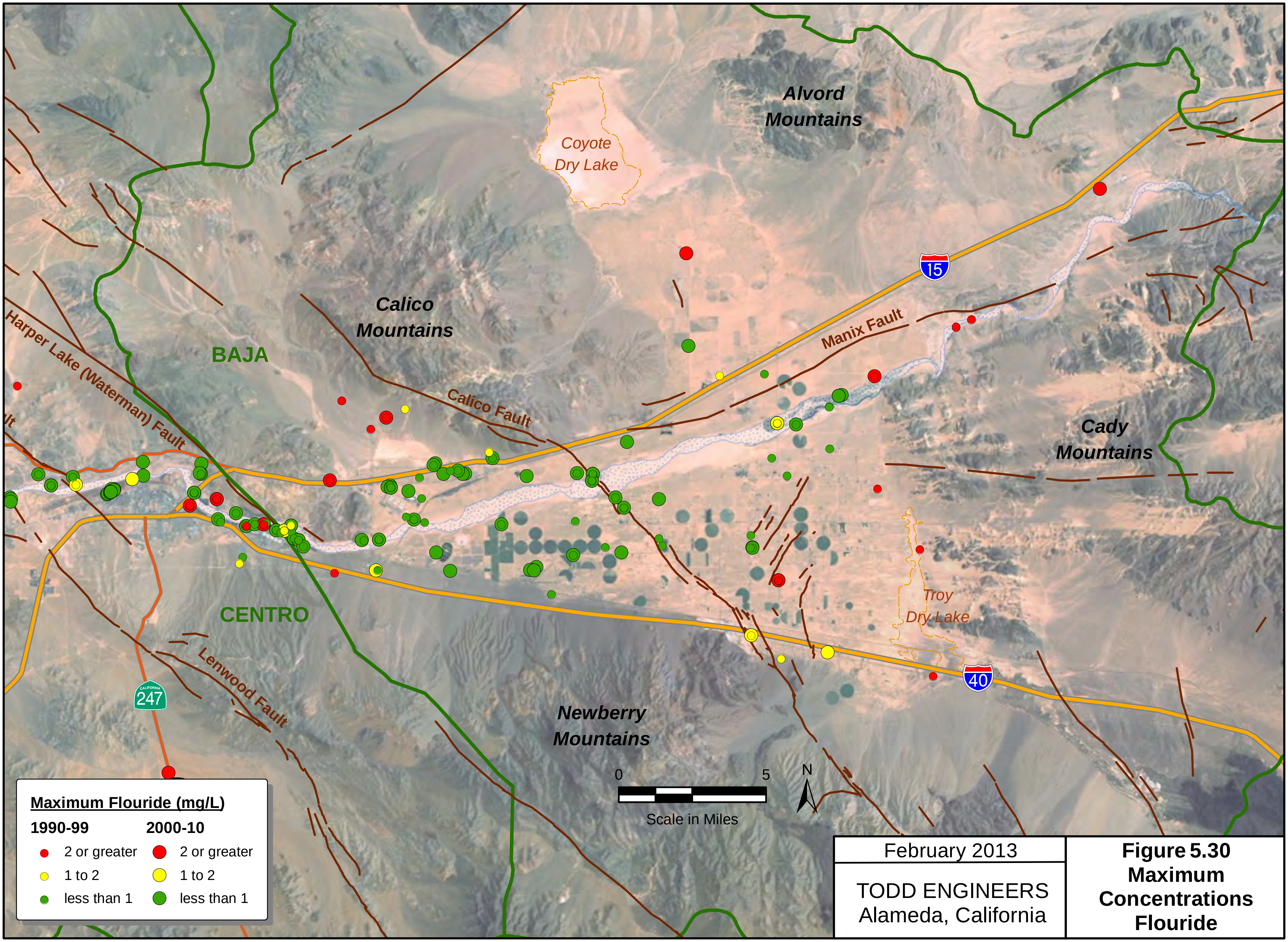

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Figure 5.30
Maximum Concentrations Flouride

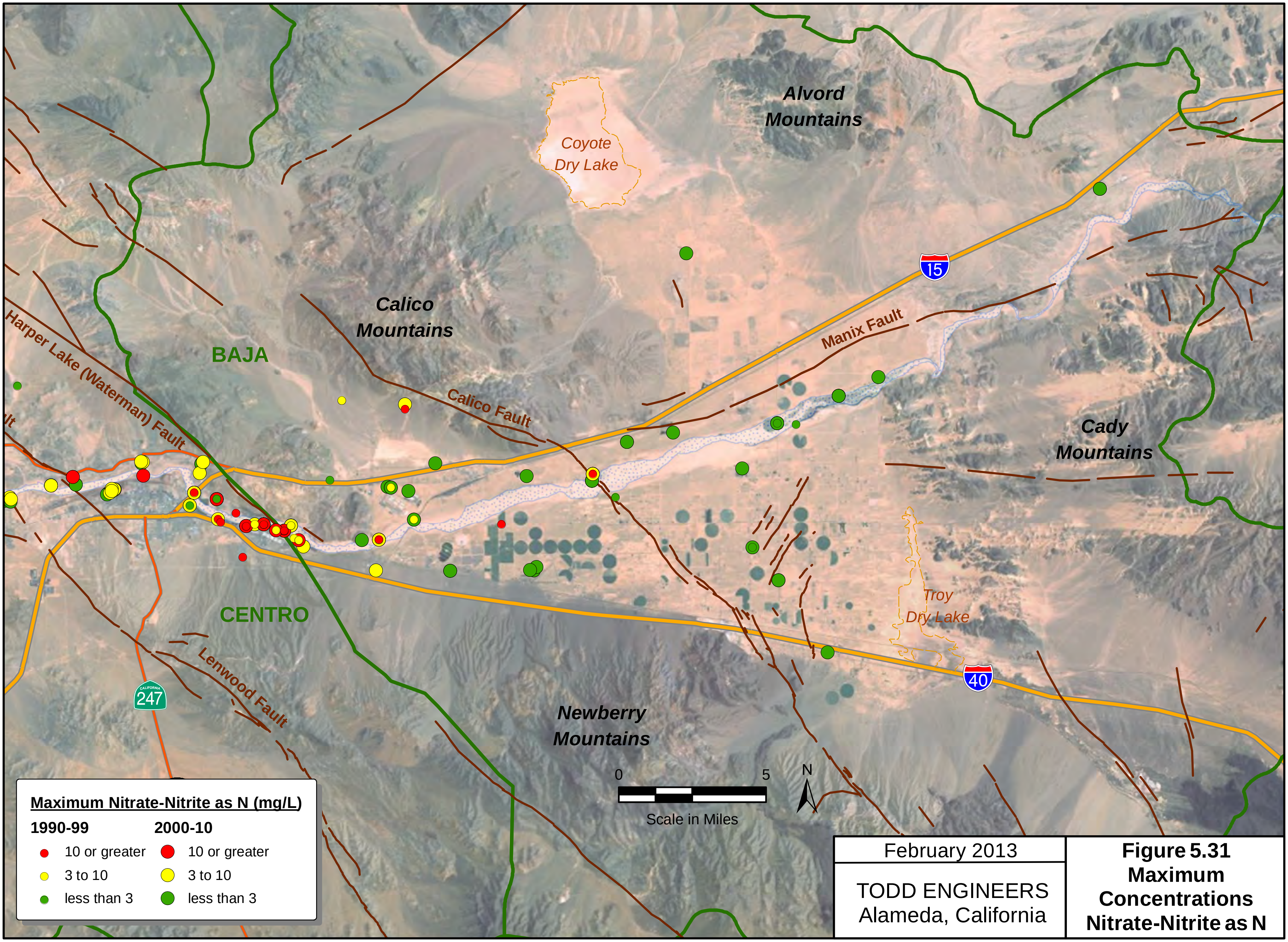

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Figure 5.31
Maximum Concentrations Nitrate-Nitrite as N

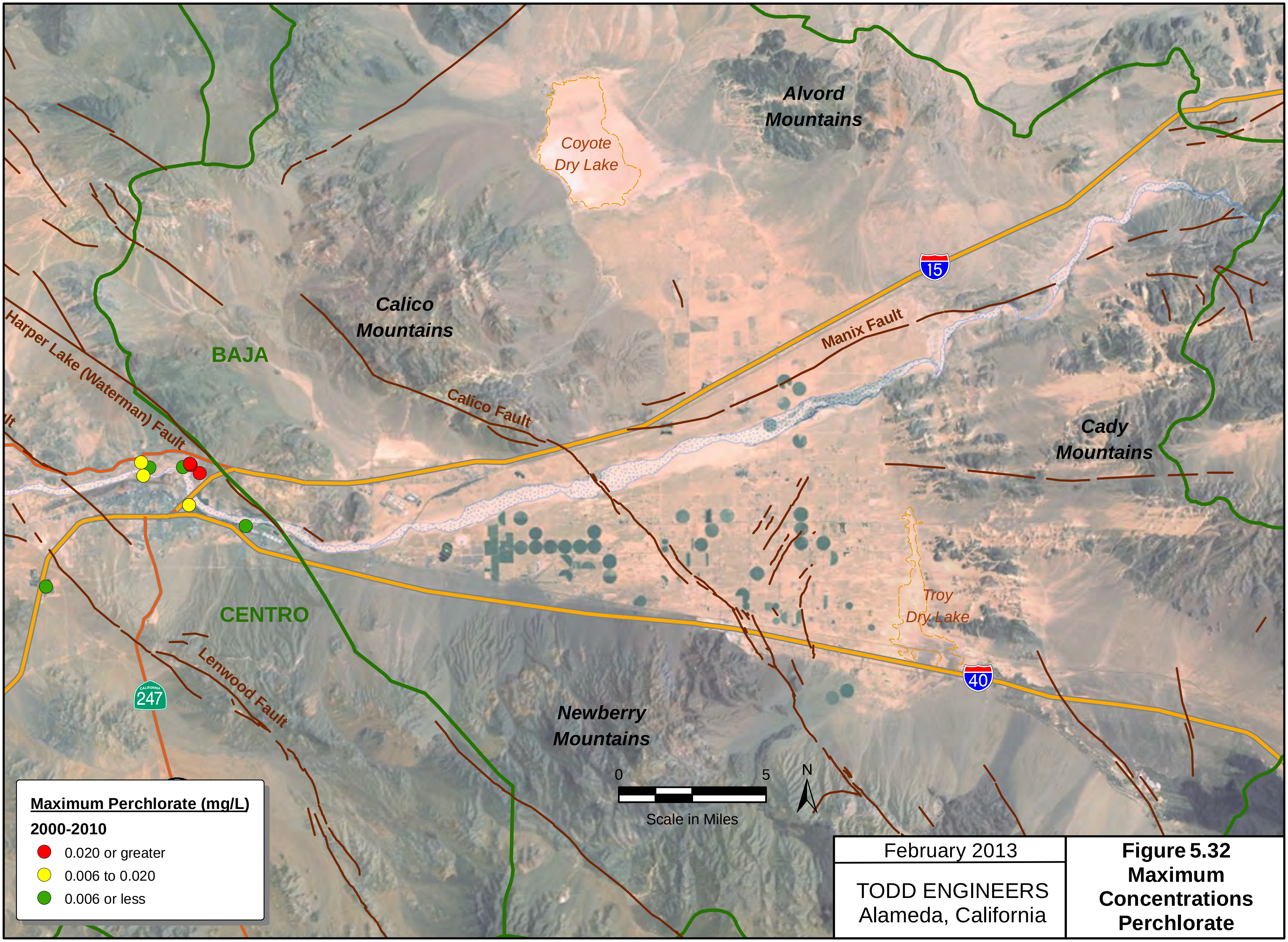

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Figure 5.32
Maximum Concentrations Perchlorate

sampling for perchlorate related to the perchlorate plume identified in Barstow indicate that the impact of groundwater is limited to the Centro Subarea at this time.

Regulated Environmental Contamination Sites

Figure 5.33 shows the active regulated environmental facilities in the Baja Subarea. As shown on the figure, cleanup programs include MCLB Yermo Annex, CALNEV Barstow Terminal, Yermo railyard, and the Barstow-Daggett Airport. Land disposal sites include wastewater discharges at SEGS I-II, Coolwater Generating Station, and a clay processing plant, landfill, and compressor station in Newberry Springs. Additionally, there are five leaking underground storage tank (LUST) sites in the Yermo area.

A summary of the nature and status of key groundwater contamination issues is presented below.

MCLB Yermo Annex

Two groundwater Operable Units (OUs) at the MCLB Yermo Annex address a plume of volatile organic compounds (VOCs.) The suspected sources of the groundwater pollution are the old sanitary landfill, the old industrial waste treatment plant, and former discharges to a French-drain system. The plume of VOCs is traveling in an easterly direction at a rate of approximately 60 to 70 feet per year; it has migrated beyond the base boundary and impacted two private drinking water wells. The MCLB installed a groundwater pump and treatment system to contain the plume and remove dissolved phase contaminants. Additionally, two air sparge-soil vapor extraction systems have been operated. Currently, the groundwater plume is shrinking and does not pose a threat to off-site receptors (ATSDR, 2011).

CALNEV Barstow Terminal

In 1992, the CALNEV Pipe Line Company discovered three significant releases of petroleum hydrocarbons to subsurface soils at the facility. A subsequent soil and groundwater investigation indicated groundwater contamination with respect to benzene, toluene, ethylbenzene, and xylenes (BTEX) and methyl tert-butyl ether (MTBE). CALNEV has installed and is currently operating a vapor extraction system to remove the volatile components of the release from the unsaturated zone. Groundwater concentrations of petroleum hydrocarbons have been declining over time, and the groundwater plume is being contained onsite (CH2M Hill, 2002).

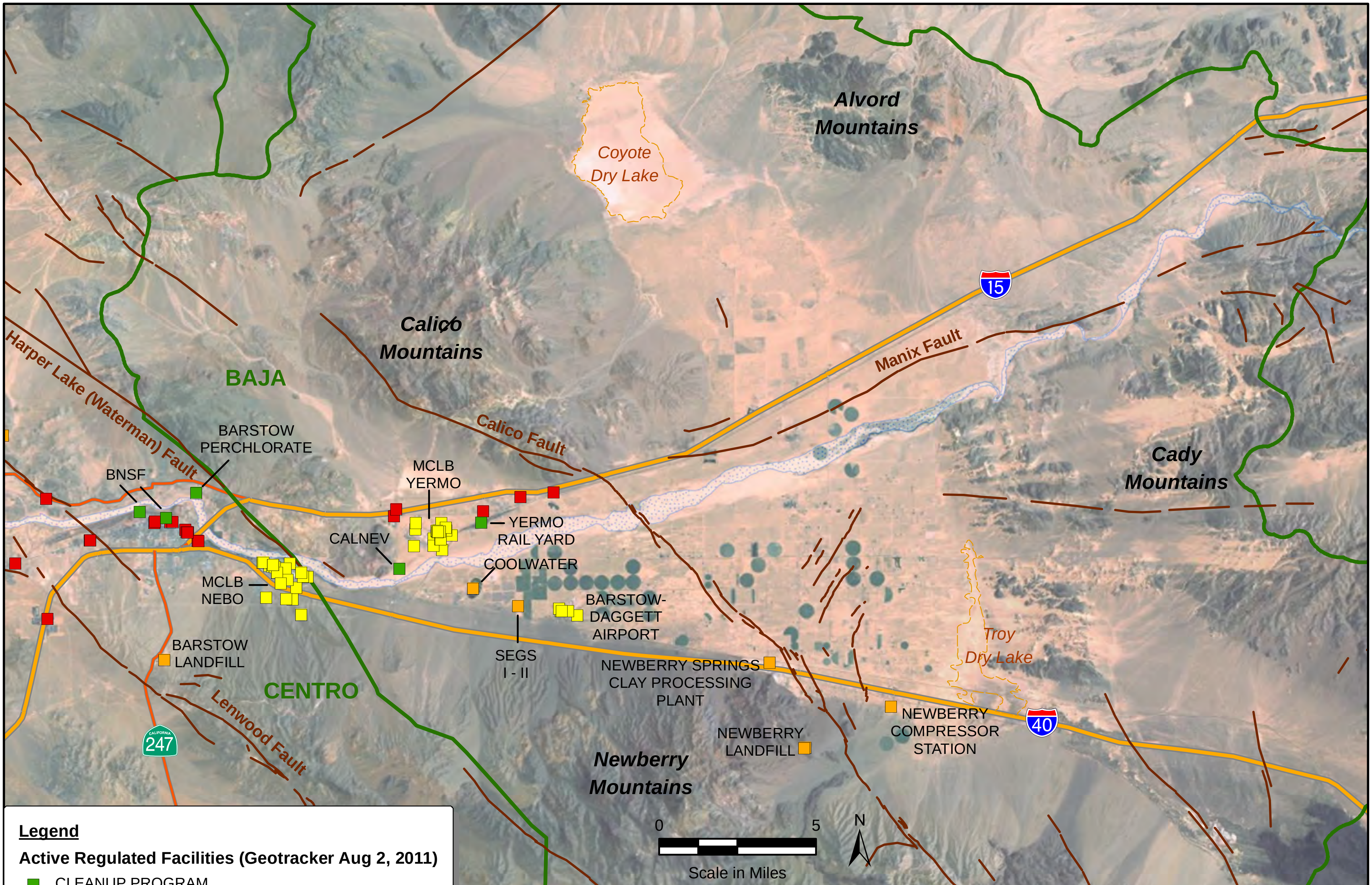

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Figure 5.33
Active Regulated Environmental Facilities

6. ASSESSMENT OF WATER SUPPLY AND DEMAND

6.1 Overview

This section describes historic and current water usage and the methodology used to project future demands within MWA's service area, specifically the Baja and Centro Subareas. Water usage is divided into sectors such as residential, industrial, institutional, landscape, agricultural, and other purposes. To undertake this evaluation, existing land use data and new housing construction information were compiled from each of the retail water purveyors and projections prepared in the Mojave Water Agency 2004 Integrated Regional Water Management Plan (IRWMP) (SWS, 2004). The IRWMP is the master plan for MWA water management activities through the year 2020. This information was then compared to historical trends for new water service connections and customer water usage information. In addition, weather and water conservation effects on historical water usage were factored into the evaluation.

For MWA's 2010 UWMP, a demand forecast model was developed that combines population growth projections with water use data to forecast total water demand in future years. Water uses were broken out into specific categories and assumptions made about each to accurately project future use. The same model and methodology are used in this section to estimate the water demand projections.

This section also describes the water supply available to MWA in general and specifically to the Baja and Centro Subareas for the 25-year period 2010-2035.

6.2 Population

Population data for 2000 through 2010 were estimated by subarea by MWA. Using draft Southern California Association of Governments (SCAG) 2012 Regional Transportation Plan (RTP) growth forecast (baseline of 2008), it is predicted that the MWA service area will grow at a rate of approximately 2.5 percent per year from 2010 through 2035. **Table 6.1** uses the assumption that each of the subareas grow at the nearest city-wide rate, with the Alto Subarea having the highest annual change in rate at 2.7 percent over the 2010-2035 period.

The Baja and Centro subareas are projected to grow at annual rates of 2.5 and 2.0 percent, respectively, over the 2010-2035 period. MWA's 2010 UWMP provides more details on the projected population methodology.

Table 6.1
Current and Projected Population Estimates – MWA Service Area

Subarea	2005	2010	2015	2020	2025	2030	2035	Annual % Change 2010-2035
Alto	302,389	341,421	387,124	432,826	479,786	526,746	573,705	2.7%
Baja	5,414	5,570	6,280	6,990	7,661	8,332	9,004	2.5%
Centro	34,716	36,145	39,840	43,535	47,010	50,485	53,960	2.0%
Este	6,680	7,695	8,528	9,361	10,169	10,977	11,785	2.1%
Oeste	9,206	9,582	10,310	11,038	11,738	12,437	13,136	1.5%
Morongo	36,434	36,944	38,931	40,918	42,211	43,504	44,798	0.9%
Total MWA Region	**394,839**	**437,357**	**491,013**	**544,668**	**598,575**	**652,481**	**706,388**	**2.5%**

Source is MWA 2010 UWMP, Table 2-1. 2010 data are current based upon 2009 estimate, and are not a projected number.

6.3 Historic Water Demand

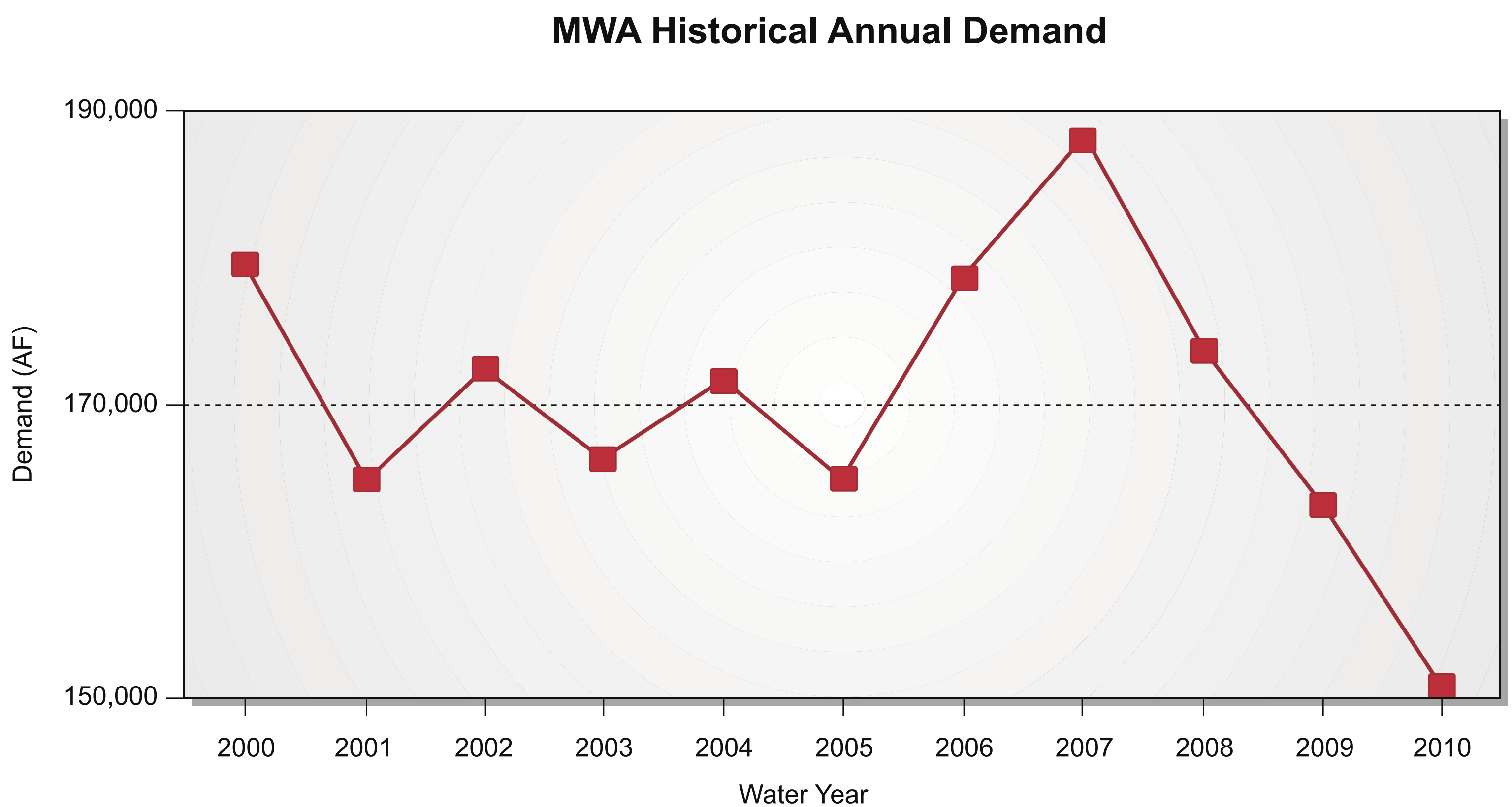
Predicting future water supply requires accurate historic water demand patterns and water usage records. **Figure 6.1** illustrates the change in water demand since 2000. Note that the figure includes minimal water producers and two power plants that are supplied directly with State Water Project (SWP) water.

Table 6.2 presents the total water demand by subarea, including direct SWP supplies and groundwater pumping amounts, which are the historical groundwater pumping quantities for the MWA from 2000 through 2010.

6.4 Projected Water Demand

6.4.1 Water Use Data Collection

Current water use data were collected and broken out by water use sector into as much detail as possible, to allow for detailed analysis and for making different assumptions about each type of water use for future years. These assumptions became the basis for projections developed in MWA's population and water demand forecast computer model. Data were compiled from various sources, depending upon availability.



February 2013	**Figure 6.1**
TODD ENGINEERS Alameda, California	**MWA Historical Annual Demand**

Table 6.2
Total Water Demand by Subarea (AFY)

Subarea	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Alto	90,801	84,968	88,968	93,108	97,776	97,491	103,413	106,838	95,552	91,531	87,001
Baja	41,020	37,661	38,931	32,871	31,769	28,484	32,118	35,735	33,514	28,777	23,151
Centro	30,695	26,127	26,946	24,534	24,399	22,522	24,273	26,211	25,805	24,787	24,320
Este	8,008	7,510	7,688	6,860	7,537	6,981	8,411	8,050	8,299	7,101	5,863
Oeste	5,016	4,462	5,248	4,962	5,430	4,882	5,152	5,690	5,766	5,207	4,503
Mojave Basin Area Total[(a)]	**175,540**	**160,728**	**167,781**	**162,335**	**166,911**	**160,360**	**173,367**	**182,524**	**168,936**	**157,403**	**144,838**
Morongo[(b)]	5,440	5,524	5,831	5,348	5,861	5,879	6,300	6,403	5,797	5,990	5,794
Total MWA	**180,980**	**166,252**	**173,612**	**167,683**	**172,772**	**166,239**	**179,667**	**188,927**	**174,733**	**163,393**	**150,632**

Source is MWA's 2010 UWMP, Table 2-2. For the Baja and Centro Subareas, the totals do not match MWA's 2010 UWMP because the Minimal Producers for those subareas have been refined per MWA's 2011 Minimal Producer Study (2011c), as discussed in Section 6.4.4. Also, for the Centro Subarea, revisions have been made to the Golden State Water Company (GSWC) - Barstow 2005 through 2010 water usages (per the GSWC-Barstow 2010 UWMP) as discussed in Section 6.7.1.

(a) DWR Public Water System Statistics data for municipal water production, MBA Watermaster Annual Reports, Appendix L in water years (ending September 30) for non-municipal production (industrial, agricultural, lakes, and golf courses), plus Minimal Producers (estimated at 6,200 AFY) and two power plants that are supplied directly with SWP water have been added to totals.

(b) MWA's Demand Forecast Model from historical data.

MBA Watermaster water-year data were used for Minimal Producers (individuals producing 10 AF or less of water within the boundaries of the Judgment) and all parties to the Judgment except water retailers. For retailers, the DWR annual Public Water System Statistics (PWSS) (2009b) data were used, if available, because they break out metered water deliveries by customer class and number of connections by customer class. Where DWR data were not available, water production and connection data were gathered from a combination of sources that provided a complete dataset, including annual reports to the CDPH, surveys sent out to retail water purveyors by the Alliance for Water Awareness and Conservation (AWAC), and data provided directly to MWA by retailers.

The combined data sources were considered accurate; for the Mojave Basin Area, combined yearly water use totals by subarea were generally within two percent of the MBA Watermaster verified annual production numbers. In addition to water use data, the number of residential service connections was collected for each retailer to estimate service area population and per capita water use.

6.4.2 Water Use Projection Methodology

Water uses were broken into 11 categories, and assumptions were made about each to determine projections. Demand projections were based largely on population growth. Past and current population data were available by subarea and by retail water purveyor.

The water uses identified below include those supplied by retail water purveyors as well as other parties to the Judgment, Minimal Producers, and customers that MWA provides directly with SWP water. Retail water uses include Single-Family and Multi-Family Residential, Commercial Industrial and Institutional (CII), Unaccounted, Landscape Irrigation, and the “Other” category. Non-retail uses include Industrial, Recreational Lakes, Minimal Producers, Golf Courses, and Agriculture. Each category is explained and the assumptions used in the projection model are described below:

1. <u>Single Family Residential (SFR)</u>: Single Family detached dwellings. SFR projections were made based upon gallons per capita per day (GPCD) and population (GPCD was converted to acre-feet per year (AFY), multiplied by yearly SFR population to calculate demand in AFY). The GPCD in years 2000-2010 was calculated in the model by converting total SFR demand to Gallons per Day and dividing by SFR population. MWA’s 2010 UWMP evaluated three possibilities for the potential future SFR GPCD range based upon varying levels of conservation:

    a. No conservation beyond the year 2010: GPCD remains flat at the 2010 level (152 GPCD in the Mojave Basin and 113 GPCD in the Morongo Area). This represents the high end of the range.

    b. Extreme conservation on a regional basis: GPCD in the Mojave Basin decreases by 2020 to the current Morongo Area level of 113 GPCD, and GPCD in the Morongo Area decreases 5 percent (to 107 GPCD). This represents the low end of the range.

    c. Moderate conservation. Halfway between the high end of the range and the low end of the range as defined above (133 GPCD by 2020 for Mojave Basin and 110 GPCD by 2020 for Morongo Area).

While a significant reduction in per-capita use has occurred in the Mojave Basin over the past decade, GPCD is still substantially higher than in the Morongo Area. Voluntary conservation programs, State-Mandated GPCD reductions, tiered rate structures at the retail level, and the continuously increasing cost of water will all influence future water demands. Recognizing these factors and the fact that a substantial potential still exists for reductions in SFR per-capita use, moderate conservation is anticipated to be the most likely future scenario, and was used in the MWA 2010 UWMP and is used in the SFR component of demand forecast shown in this report.

2. Multiple Family Residential (MFR): The MFR category is comprised of apartments, condominiums, townhouses, duplexes, and mobile home parks. Use is projected to increase in proportion to overall population growth, with a 2010 baseline.

3. Industrial Users: This category contains industrial use by entities that are parties to the Judgment. Industrial users connected to municipal water systems are not included in this category, but are grouped in with the Commercial/Industrial/ Institutional (CII) category. Because of the wide variety of industrial producers, they were grouped into categories and assumptions made for each category for expected future water use. Specific major projects that are currently in development stages were included in the projections:

   - Power Plants: Power plant water use has declined from 7,800 AF in 2000 to 6,100 AF in 2010. Existing power plants are not anticipated to increase water use. The LUZ Solar Plant in Kramer Junction (Centro Subarea) is also provided directly with SWP water at an average of 1,300 AFY, and is expected to use the same amount of SWP water in the future. Future regional power plant water use is projected to remain flat starting in 2015.

   - Cement Plants: Operate either in on/off mode, but cannot increase production due to plant limitations, environmental and air permit issues. If demand exceeds production capacity, cement is imported. Future cement plant water use is assumed to equal the yearly average from 2000-2010.

   - Ready-Mix Cement and Aggregate/Batch Plants: Production is primarily a factor of new construction rather than total population in the area. Population growth is projected to be relatively linear, so demand is projected to equal the yearly average from 2000-2010.

   - Compressor Stations (gas lines): The compressor stations are owned by Pacific Gas & Electric (PG&E) and Southern California Gas (SCG) for major gas lines that run to the Los Angeles area. The water is used for cooling. Use has increased about 30 percent from 2000-2010, and is projected to remain at the 2010 level in future years.

   - Railroads: Railroad use has declined significantly since 2000 and is projected to remain at the 2010 level in future years.

   - Mining: Mining water use has remained relatively flat and is projected to continue at the average of 2000-2010 use for future years.

   - Other: Other use was identified as primarily temporary transfers of production rights for specific road construction projects. This temporary use of water is not expected to continue in future years; therefore future water use in this category is projected to be zero.

4. Commercial/Institutional/Industrial (CII): Called Commercial/Institutional in the DWR UWMP 2007 reporting instructions (DWR, 2007a), and defined as "Retail establishments, office buildings, laundries, schools, prisons, hospitals, dormitories, nursing homes, hotels" (not intended to include Industrial/Manufacturing). However, nearly all water retailers included metered industrial use in with this category, primarily because they do not separate commercial and industrial customers in their billing systems. Industry included in this category is considered "baseline use" because it accounts primarily for smaller industries and shops associated with the local population, and is expected to grow with population.

   A linear regression method, based upon current population and CII demands, was used to determine the relationship between population growth and CII usage and to project forward using linear regression. Future CII demand is correlated to population using the following formula:

   $$\text{CII demand} = -49.85 + 0.0295x \quad \text{where } x \text{ is the current population}$$

   Because the growth is unpredictable, the model does not assume any conservation in this category.

5. Recreational Lakes: California Department of Fish and Game - Camp Cady and several lakes in the Baja Subarea, including Crystal Lakes Property Owners Association, Lake Waikiki, Lake Wainani Owners Association, O. F. D. L., Inc., and Sundown Lakes, Inc.

6. Unaccounted: Calculated as the difference between total water production and metered deliveries reported by retail water purveyors. From 2000-08, Unaccounted water averaged 8 percent of total municipal production. For retailers that had only total production data available, 8 percent of production was allocated into the unaccounted category. Unaccounted water decreased substantially starting in 2008, and according to representatives from the retail water purveyors, this is due to a variety of efforts recently undertaken by many of the retailers to reduce their unaccounted water losses. The makeup of this category is not entirely known; however, it is likely that this difference is composed of water pumped to waste from production wells, lost to leaks, and from meter inaccuracies. With a 2010 baseline, unaccounted use is projected to increase in proportion with increases in municipal production.

7. Minimal Producers: Producers of 10 AF or less within the boundaries of the Judgment; primarily homeowners with their own wells. Minimal Producer use is projected to increase in proportion with increases in overall population.

8. Golf Courses: It is anticipated that substantial population growth will generate demand for new Golf Courses. Golf Course water use is projected to increase proportionally with increases in population.

9. Other: Defined in the DWR UWMP 2007 reporting instructions (DWR, 2007a) as "fire suppression, street cleaning, line flushing, construction meters, temporary meters." These uses are assumed to grow with population. Construction water is likely to have varied significantly over the 2000-2010 period due to changing rates of growth, so "Other" use is projected to increase in proportion with increases in population based upon the average per-capita use for the period of 2000-2010.

10. Landscape Irrigation: Defined in the DWR UWMP 2007 reporting instructions (DWR, 2007a) as "parks, play fields, cemeteries, median strips, and golf courses." This use category increased at a faster pace than population during the period of 2000-2008, most likely because medians and street landscaping were developed primarily in the construction boom during that period. With 2010 as a baseline, Landscape Irrigation use is projected to increase in proportion with increases in population.

11. Agriculture: Projected to remain flat at the 2010 level.

Table 6.3 summarizes the MWA's projected water demands by subarea through 2035, based primarily on the MWA 2010 UWMP (Table 2.3 in UWMP). For the Baja and Centro Subareas, the totals do not match MWA's 2010 UWMP because of the revised documentation obtained for Minimal Producers discussed in Section 6.4.4. Also, for the Centro Subarea, revisions have been made to the GSWC-Barstow 2005 through 2010 water year usages as discussed in Section 6.7.1.

Table 6.3
Projected Water Demands by Subarea for MWA (AFY)

Subarea	2005	2010	2015	2020	2025	2030	2035
Alto	97,491	87,001	93,994	99,440	108,851	118,262	127,674
Baja	28,484	23,151	23,847	24,204	24,521	24,822	25,108
Centro	22,522	24,320	25,414	26,205	27,009	27,813	28,617
Este	6,981	5,863	6,607	6,771	6,970	7,170	7,369
Oeste	4,882	4,503	4,767	4,930	5,089	5,247	5,404
Morongo	5,879	5,794	7,102	7,372	7,590	7,809	8,028
Total	**166,239**	**150,632**	**161,731**	**168,922**	**180,030**	**191,123**	**202,200**

Source is MWA's 2010 UWMP, Table 2-3. For the Baja and Centro Subareas, the totals do not match MWA's 2010 UWMP. See Sections 6.4.4 and 6.7.1.

Tables 6.4 and **6.5** summarize the Baja and Centro Subareas projected water demands through 2035, respectively. Both tables are based primarily on the MWA 2010 UWMP. Deliveries are assumed to increase at the same rate as the population rate from 2010-2035, as presented in **Table 6.1**. The totals do not match MWA's 2010 UWMP because of the revisions made to the Minimal Producers discussed in Section 6.4.4. No landscape irrigation is assumed, and totals assume moderate conservation.

Table 6.4
Baja Subarea Current and Projected Water Deliveries (By Customer Type) (AFY)

Water Use Sector	2005	2010	2015	2020	2025	2030	2035
All Retail Water Use[(a)]	2,200	1,774	1,922	2,062	2,174	2,271	2,352
Non-Retail Water Use[(b)]	24,084	19,679	20,011	20,011	20,011	20,011	20,011
Minimal Producers	2,200	1,698	1,914	2,131	2,336	2,540	2,745
Total	**28,484**	**23,151**	**23,847**	**24,204**	**24,521**	**24,822**	**25,108**

(a) Includes Single Family Residential, Multi-Family Residential, Commercial Industrial and Institutional (CII), Unaccounted, Landscape Irrigation, and the "Other" category.
(b) Includes Industrial, Recreational Lakes, Golf Courses, and Agriculture, but excludes Minimum Producers.

Table 6.5
Centro Subarea Current and Projected Water Deliveries (By Customer Type) (AFY)

Water Use Sector	2005	2010	2015	2020	2025	2030	2035
All Retail Water Use[(a)]	8,658	7,295	8,084	8,834	9,539	10,244	10,949
Non-Retail Water Use[(b)]	12,264	16,109	16,320	16,268	16,279	16,290	16,301
Minimal Producers	1,600	916	1,010	1,103	1,191	1,279	1,367
Total	**22,522**	**24,320**	**25,414**	**26,205**	**27,009**	**27,813**	**28,617**

(a) Includes Single Family Residential, Multi-Family Residential, Commercial Industrial and Institutional (CII), Unaccounted, Landscape Irrigation, and the "Other" category.
(b) Includes Industrial, Recreational Lakes, Golf Courses, and Agriculture, but excludes Minimum Producers.

6.4.3 Return Flow

Return flow is calculated as a percent of the water production for each water use category, per the methodology outlined in the MWA's Watermaster Consumptive Water Use Study and Update of Production Safe Yield Calculations for the Mojave Basin Area (Webb, 2000). Return flow factors for each category per the study are explained below. The Watermaster is currently developing revised return flow factors to reflect changes in water use over the past decade. The revised numbers are anticipated to be available in 2012, and will replace the factors listed below, if different in future planning documents.

1. <u>All municipal uses (SFR, MFR, CII, Unaccounted, Landscape Irrigation, and Other)</u>: 50 percent of production. Embedded within this calculation is return flow from effluent generated by municipal wastewater treatment facilities within MWA (directly recycled or recharged to groundwater). Only imported wastewater (described in Section 6.10.2) is accounted for as a

separate supply in Table 6.9, and all other wastewater/recycled water is a component of the "Return Flow" category of supply.

2. Industrial Producers: No return flow.

3. Recreational Lakes: total production minus calculated consumptive use. Consumptive use equals the annual surface evaporation rate (6.7 feet in the Centro and Baja subareas) multiplied by lake surface area. Return flow equals 16 percent of production in Centro and Baja, based on 1996-97 water year production numbers, with return flow calculated as (total production) minus (consumptive use) divided by total production (%). This percent return flow factor was applied to all years.

4. Minimal Producers: 50 percent of production.

5. Golf Courses: total production minus calculated consumptive use. Consumptive use equals the net irrigation acreage times the consumptive use factor identified in the Webb study. Return flow equals 57 percent of production in Centro. There are no golf courses in the Baja Subarea.

6. Agriculture: total production minus calculated consumptive use. Consumptive use equals the net irrigated acreage times the appropriate consumptive use factor identified in the Webb study. Return flow is calculated as a percent of agricultural production for each subarea: Baja, 37.2 percent; Centro, 39.2 percent.

6.4.4 Minimal Producers

MWA completed a recent update to the minimal producer production estimates based a detailed GIS-based accounting of land uses among MPs (MWA, 2011c). The analysis estimated the water production of each individual Minimal Producer and found that many Minimal Producers use substantially less than one (1) AFY (which was assumed in the 2000 Webb study) if they have relatively small amounts of irrigated vegetation on their property. The MWA study concluded that Minimal Producer production in Baja and Centro is 1,698 and 916 AFY, respectively. These revised production assumptions are less than those previously used of 2,200 and 1,600 AFY for the Baja and Centro Subareas, respectively. Thereby, reducing overall production approximately 1,200 AFY in the MWA demand forecast model for the years 2009 through 2010.

6.5 Water Hauling

California Health and Safety Code (H&SC) Section 111120 requires operators of water haulers (WH) operating in California to obtain a Water Hauler License issued by the Department of Public Health's (CDPH) Food and Drug Branch (FDB). The Water Hauler License is required to haul water in bulk for drinking, culinary or other purposes involving a likelihood of the water being ingested by humans. "In bulk" means containers having capacities of 250 gallons or greater.

Water hauling vehicles are defined as self-propelled or towed vehicles having an attached water tank, with or without pumps, hoses and accessory equipment for filling or distribution of water. The tank must exceed 250 gallons capacity and comply with all applicable state and federal laws and regulations.

Use of convertible trucks, dump trucks or flat-bed trucks with detachable tanks is allowed if the tanks are securely attached. No detached tank or vehicle without a tank will be inspected or licensed.

FDB will perform an inspection of the WH vehicle(s) prior to issuance of the license. FDB will also conduct periodic inspections once the license has been issued. Inspections are conducted to ensure that the facility is in compliance with the applicable state and federal laws and regulations. The annual license fee was $453 in 2011.

According to the CDPH, there were five licensed potable water haulers within MWA's service area in 2011. In the Baja or Centro Subareas, there is only one licensed potable water hauler, which is the Bureau of Land Management in the City of Barstow. According to Bureau of Land Management staff, the water hauling license is associated with water used at a campground (Ironwood Christian Camp) for minimum personal use. The remaining four licensed water haulers are all within the Morongo Subarea.

6.6 Baja Subarea Water Demand

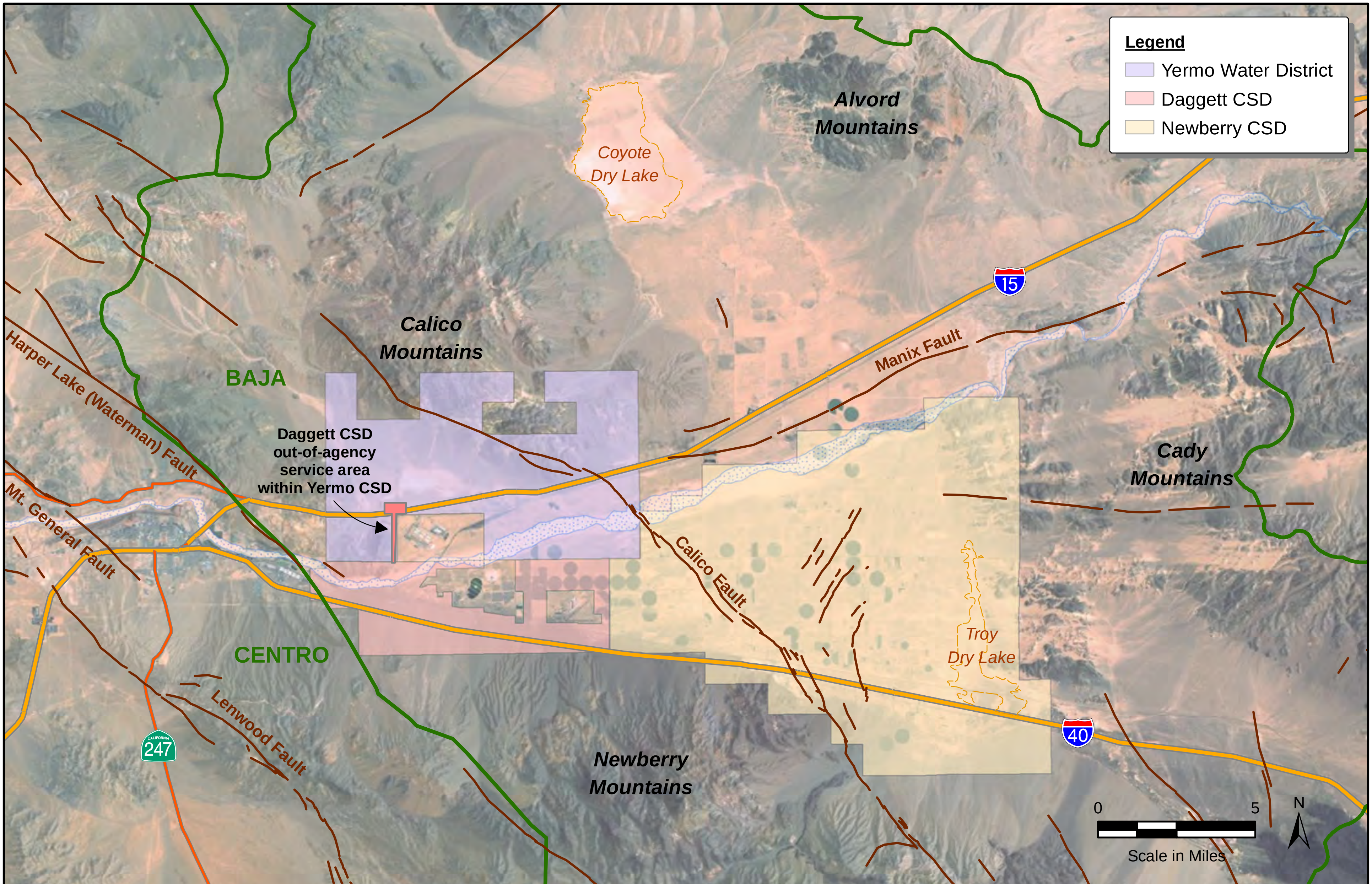
6.6.1 Water Purveyors

In the Baja Subarea, there are two water companies, the Yermo Water District/Yermo CSD and Daggett Community Services District (CSD), both of which provide domestic water to areas within the Yermo CSD, as shown on **Figure 6.2**. In the areas not within a municipal water provider service area, including Harvard, water service is provided on-site through wells.

The Yermo CSD Board of Directors controls the Yermo Water District, which provides water to two separate and small portions of the Yermo community, with approximately 300 metered customers. Facilities include an eight-inch water pipeline for commercial use and fire flow requirements, which was questioned by Local Agency Formation Commission of the County of San Bernardino (LAFCO) for capacity issues in 2009 when the ownership was still with the Yermo Water Company. The eight-inch water pipeline is still in use. The Yermo Water District has limited resources for fire protection services and relies on other fire protection agencies to fulfill this service. The need for fire services is anticipated to remain constant. Needs of the transient traffic along Interstate 15 and the railroads traveling through the area are expected to increase.

In 2010, the Yermo CSD purchased the Yermo Water Company, which was a private water company regulated by the California Public Utilities Commission (PUC) and held the water rights to the area (Ceinar, 2010). Yermo CSD has water production rights to 453 AF annually as determined by the adjudication. The FPA for Yermo CSD was at 62.5 percent of BAP for 2010-11, which permitted Yermo CSD with 283 AF of FPA.

As shown in **Figure 6.2,** Daggett CSD provides domestic water to a 1.25 square mile area within the Yermo CSD (LAFCO, 2009). Since 1984, Daggett CSD has provided water service within the western portion of Yermo CSD territory due to the need for service to the Silver Valley High School and Silver Valley Unified School District offices. In addition, Daggett CSD currently serves water to 13 residential parcels and 10 commercial parcels within the area. Any request submitted for the expansion of the service area would require that Daggett CSD provide a study showing the capacity for service through



Note: Newberry CSD does not supply domestic water to residents; it supplies its own facilities and provides water for fire protection purposes (water trucks). See Section 6.6.1 for more discussion.

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Figure 6.2
Baja Subarea Retail and Other Water Providers

lines and storage facilities and a payment schedule that would acknowledge buy-in-costs for the facilities.

Daggett CSD has water production rights (also known as Base Annual Production (BAP)) to supply 304 AF annually as determined in the adjudication. Daggett is within the Baja Subarea, and Free Production Allowance (FPA) was at 62.5 percent of the Base Annual Production for 2010-2011, which permitted Daggett CSD 190 AF of FPA.

The Newberry Springs community has no existing public water system, and water is provided largely by private wells. Newberry CSD does not supply domestic water to residents; it supplies its own facilities and provides water for fire protection purposes (water trucks). Newberry CSD's Strategic Plan indicates that water service is a long-range goal contingent on funding, which would include purchase of additional water rights (LAFCO Resolution No. 3064, 2009). Newberry CSD has water production rights to 23 AF annually as determined by the Judgment.

Table 6.6 presents the historical groundwater pumping quantities by purveyor for the Baja Subarea from 2000 through 2010.

Table 6.6
Historic Water Purveyor Demand for Baja Subarea (AFY)

Purveyor [(a)]	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Daggett CSD	278	271	259	262	255	248	258	293	270	272	252
Yermo Water District	453	453	363	122	137	137	137	137	137	126	162
Domestic – Watermaster [(b)]	1,323	1,323	1,323	1,323	1,323	1,323	1,323	1,323	1,323	1,323	1,323
Minimal Producers[(c)]	2,200	2,200	2,200	2,200	2,200	2,200	2,200	2,200	2,200	1,698	1,698
Total	**4,254**	**4,247**	**4,145**	**3,907**	**3,915**	**3,908**	**3,918**	**3,953**	**3,930**	**3,419**	**3,435**

(a) From DWR Public Water System Statistics data for municipal water production, MBA Watermaster Annual Reports, Appendix L in water years for non-municipal production (industrial, agricultural, lakes, golf courses).
(b) "Domestic- Watermaster" –Watermaster estimate of the portion of municipal water production for domestic uses.
(c) Source is MWA's Minimal Producer Study, completed February 2011 (MWA, 2011c).

6.6.2 Projected Water Demand

The water purveyors discussed in the previous section are all relatively small with little to no growth expected, so MWA combined them and used the model to project their future demand. Therefore, their projected water demand is included in **Table 6.4**, discussed previously.

6.7 Centro Subarea Water Demand

6.7.1 Water Purveyors

In the Centro Subarea, there is one water purveyor: the Golden State Water Company (GSWC) Barstow, with no other small water purveyors. GSWC is an investor-owned public utility company that owns 38 water systems throughout California regulated by the California PUC. The following information was obtained from the 2010 UWMP Barstow (GSWC, 2011a).

Located in San Bernardino County, the GSWC Barstow System serves the City of Barstow and the surrounding unincorporated areas. The service area is primarily characterized by residential land use, with some commercial and industrial land use. GSWC elected to utilize the preliminary 2012 Regional Transportation Plan (RTP) population projections for the Barstow System as provided by MWA in order to align future growth and projected water use for both agencies.

Table 6.7 presents the historical groundwater pumping quantities by purveyor for the Centro Subarea from 2000 through 2010 (GSWC, 2011a). Because the GSWC 2010 UWMP was finalized after MWA's 2010 UWMP was completed, the MWA demand forecast model did not have the latest water usage data for the GSWC. Therefore, revisions were made to Golden State Water Company-Barstow (GSWC-Barstow) 2005 through 2010 water year usages (per the GSWC 2010 UWMP) in the MWA demand forecast model that effect the water demands projections for the Subarea. Previously, the demand forecast model assumed the estimates for the retailer to be approximately 50-200 AFY higher than the actual water usage per the GSWC 2010 UWMP for years 2005 through 2010. The modifications made to the GSWC demands decrease/reduce the water usage from 2005 through 2010 in the MWA demand forecast model.

Table 6.7
Historic Water Purveyor Demand for Centro Subarea (AFY)

Purveyor	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
GSWC-Barstow	9,348	8,239	8,353	8,188	7,672	7,109	7,385	7,779	7,131	6,517	6,257

6.7.2 Projected Water Demand

Table 6.8 summarizes the GSWC - Barstow projected water demands through 2035 (GSWC, 2011a). The totals assume SBX7-7 compliance.

Table 6.8
GSWC – Barstow Current and Projected Water Deliveries (By Customer Type) (AFY)

Water Use Sector[a]	2005[b]	2010[b]	2015	2020	2025	2030	2035
Single Family Residential	3,324	2,711	4,060	4,496	4,945	5,394	5,843
Multi-Family	788	731	861	954	1,049	1,144	1,239
Commercial	1,671	1,656	2,025	2,242	2,466	2,692	2,915
Industrial	40	24	49	53	57	64	68
Institutional/ Government	962	771	1,245	1,380	1,515	1,658	1,793
Landscape	313	340	421	463	511	559	602
Agriculture	0.07	0.00	0.22	0.22	0.22	0.22	0.22
Other[c]	11	24	36	40	44	48	52
Projected Water Sales	**7,109**	**6,257**	**8,697**	**9,628**	**10,587**	**11,559**	**12,512**
Unaccounted For/ System Losses	1,549	1,038	1,198	1,326	1,458	1,592	1,723
Total Baseline Water Demand	**8,658**	**7,295**	**9,895**	**10,954**	**12,045**	**13,151**	**14,235**
Water Savings	0	0	0	1,216	1,333	1,465	1,576
Total Water Demand with Savings	**8,658**	**7,295**	**9,895**	**9,738**	**10,712**	**11,686**	**12,659**

(a) Source is GSWC Final 2010 UWMP, Tables 3-11 and 3-14. Totals assume SBX7-7 compliance.
(b) Based on calendar year.
(c) Other accounts for any service connections not included in any other category, including idle or inactive connections.

6.8 Water Supply Overview

This section describes the water resources available to the MWA Baja and Centro Subareas for the 25-year period from 2010 to 2035. MWA's current and planned supplies are summarized in **Table 6.9.** The local supplies are discussed in detail in **Section 6.10** of this report. The source is MWA's 2010 UWMP; see Sections 6.4.4 and 6.7.1 for differences.

Table 6.9
MWA Summary of Current and Planned Water Supplies (AFY)

Water Supply Source	2010	2015	2020	2025	2030	2035
Existing Supplies						
Wholesale (Imported)						
SWP [(a)]	49,680	51,480	53,880	53,880	54,778	54,778
Local Supplies[(b)]						
Net Natural Supply	59,973	59,973	59,973	59,973	59,973	59,973
Agricultural Depletion from Storage[(c)]	3,492	3,946	4,125	4,283	4,434	4,577
Return Flow[(d)]	61,593	67,051	70,565	76,008	81,441	86,866
Wastewater Import[(e)]	5,304	5,397	5,491	5,789	6,087	6,385
Total Existing Supplies	**180,042**	**187,847**	**194,034**	**199,933**	**206,713**	**212,579**
Projected Demands[(f)]	***150,632***	***161,731***	***168,922***	***180,030***	***191,123***	***202,200***

(a) Assumes 60% of Table A amount as the long-term supply until 2029 and then assume 61% in 2029 and after, based on the California Department of Water Resources 2009 contractor Delivery Reliability Report for MWA.
(b) Source: MWA's demand forecast model.
(c) Refer to Section 6.10.4 for an explanation of this supply.
(d) Refer to Section 6.10.3 for an explanation of this supply.
(e) Refer to Section 6.10.2 for an explanation of this supply.
(f) See Table 6.3 in this chapter, assuming "moderate" conservation.

Tables 6.10 and 6.11 summarize the water resources available to the Baja and Centro Subareas, respectively, between 2010 and 2035. The SWP supply is discussed in Section 6.9, while local supplies are discussed in detail in Section 6.10 of this report.

Table 6.10
Baja Subarea Current and Planned Water Supplies (AFY)

Water Supply Source	2010	2015	2020	2025	2030	2035
Existing Supplies						
Wholesale (Imported)						
SWP (a)	0	0	0	0	0	0
Local Supplies(b)						
Net Natural Supply	11,428	11,428	11,428	11,428	11,428	11,428
Agricultural Depletion from Storage(c)	3,492	3,946	4,125	4,283	4,434	4,577
Return Flow(d)	8,231	8,473	8,651	8,810	8,960	9,103
Wastewater Import(e)	0	0	0	0	0	0
Total Existing Supplies	**23,151**	**23,847**	**24,204**	**24,521**	**24,822**	**25,108**
Projected Demands(f)	***23,151***	***23,847***	***24,204***	***24,521***	***24,822***	***25,108***

(a) Assumes worst-case scenario where only SWP is used to meet difference in demand. See Section 6-9.
(b) Source: MWA's demand forecast model.
(c) Refer to Section 6.10.4 for an explanation of this supply.
(d) Refer to Section 6.10.3 for an explanation of this supply.
(e) Refer to Section 6.10.2 for an explanation of this supply.
(f) See Table 6.3 in this chapter, assuming "moderate" conservation.

Table 6.11
Centro Subarea Current and Planned Water Supplies (AFY)

Water Supply Source	2010	2015	2020	2025	2030	2035
Existing Supplies						
Wholesale (Imported)						
SWP (a)	1,190	1,190	1,190	1,190	1,190	1,190
Local Supplies(b)						
Net Natural Supply	18,500	18,500	18,500	18,500	18,500	18,500
Agricultural Depletion from Storage(c)	0	0	0	0	0	0
Return Flow(d)	9,072	9,637	10,034	10,437	10,841	11,244
Wastewater Import(e)	0	0	0	0	0	0
Total Existing Supplies	**28,762**	**29,327**	**29,724**	**30,127**	**30,531**	**30,934**
Projected Demands(f)	***24,320***	***25,414***	***26,205***	***27,009***	***27,813***	***28,617***

(a) Luz Solar Power Plant – Kramer has contract with MWA for 1,190 AFY of SWP. Also see Section 6-9.
(b) Source: MWA's demand forecast model.
(c) Refer to Section 6.10.4 for an explanation of this supply.
(d) Refer to Section 6.10.3 for an explanation of this supply.
(e) Refer to Section 6.10.2 for an explanation of this supply.
(f) See Table 6.3 in this chapter, assuming "moderate" conservation.

As documented in the 2010 UWMP, MWA has four sources of water supply – natural surface water flows, wastewater imports from outside the MWA service area, SWP imports, and return flow from pumped groundwater not consumptively used. A fifth source, “Agricultural Depletion from Storage,” is also shown as a supply and is described in Section 6.10.4. In MWA’s demand forecast projection model, natural and SWP supply are expressed as an annual average, although both sources of supply vary significantly from year to year. Almost all of the water use within MWA is supplied by pumped groundwater. Native surface supply, return flow, and SWP imports recharge the groundwater basins. MWA has an average natural supply of 59,973 AFY as shown in **Table 6.9**. For the Baja and Centro Subareas, the natural supply is 11,428 and 18,500 AFY, respectively.

The projected demands shown in **Table 6.9** represent total demands within MWA, including pumped groundwater and direct SWP use, assuming moderate conservation beyond 2010 as explained previously in Section 6.4. Per MWA’s 2010 UWMP, available supplies are sufficient to meet projected demands beyond the year 2035. It should be noted that return flow as a supply is shown to increase over time because it is a function of water demand.

Appendix I provides documentation for supply/demand forecasts through 2035 based upon no conservation and extreme conservation.

6.9 Wholesale (Imported) Water Supplies

Imported water supplies are available to MWA from the State Water Project (SWP). MWA is one of 29 water agencies (contractors) that have a SWP water supply contract with DWR. Each water supply contract contains a Table A, which lists the maximum amount of water an agency may request each year throughout the life of the contract. Table A is used in determining each contractor’s proportionate share, or allocation, of the total SWP water supply DWR determines to be available each year.

According to the water supply contract between the DWR and MWA (revised October 12, 2009), MWA’s maximum annual entitlement from the SWP (Table A amount) is 82,800 AFY from 2010 to 2014; 85,800 AFY from 2015 to 2019; and 89,800 AFY from 2020 to 2035 (**Table 6.12**, from MWA 2010 UWMP, Table 3-3). Previously MWA’s Table A amount was 50,800 AFY, but was augmented with two purchases of additional Table A supply. In 1997, MWA purchased 25,000 AF from Berrenda Mesa Water District, bringing MWA’s Table A amount to 75,800 AF. In 2009, MWA purchased an additional 14,000 AF of Table A from Dudley Ridge Water District, which will be transferred incrementally to MWA. The first transfer of 7,000 AF occurred in 2010, with 3,000 AF to be transferred in 2015 and 4,000 AF in 2020. These transfers are reflected in **Table 6.12**.

Table 6.12
Current and Planned Wholesale Water Supplies (AFY)

Water Supply Sources	2010	2015	2020	2025	2030	2035
California State Water Project	82,800	85,800	89,800	89,800	89,800	89,800

Source is MWA's 2010 UWMP, Table 3-3.

While Table A identifies the maximum annual amount of water a SWP contractor may request, the amount of SWP water actually available and allocated to SWP contractors each year is dependent on a number of factors and can vary significantly from year to year. The primary factors affecting SWP supply availability include hydrology, the amount of water in SWP storage at the beginning of the year, regulatory and operational constraints, and the total amount of water requested by SWP contractors.

In an effort to assess the impacts of these varying conditions on SWP supply reliability, DWR issued its "State Water Project Delivery Reliability Report, 2009 update" (DWR, 2009c) in August 2010. The 2009 SWP Report shows a continuing erosion of the ability of the SWP to deliver water. For current conditions, the dominant factor for these reductions is the restrictive operational requirements contained in the federal biological opinions regarding Sacramento-San Joaquin Delta species. Deliveries estimated for the 2009 SWP Report are reduced by the operational restrictions of the biological opinions issued by the U.S. Fish and Wildlife Service in December 2008 and the National Marine Fisheries Service in June 2009 governing the SWP and Central Valley Project operations.

For future conditions, the 2009 SWP Report includes the potential effects of climate change to estimate future deliveries. The changes in runoff patterns and amounts are included along with a potential rise in sea level. Sea level rise has the potential to require more water to be released to repel salinity from entering the Delta in order to meet the water quality objectives established for the Delta.

The updated analyses in the 2009 SWP Report indicate that the SWP—using existing facilities operated under current regulatory and operational constraints and future anticipated conditions, and with all contractors requesting delivery of their full Table A amounts in most years—could deliver 60 percent of Table A amounts on a long-term average basis.

DWR also prepared Delivery Reliability Reports (DRRs) for long-term average SWP supplies to individual SWP contractors based upon the unique conditions that impact each contractor. The DRR for MWA indicated average reliability would be 60 percent in 2009 and will increase to 61 percent in 2029. **Table 6.13** (based on MWA's 2010 UWMP, Table 3-4) provides the projected SWP water available to MWA over the next 25 years, based on the MWA's maximum Table A amounts from 2010 to 2035 and the supply reliability analyses provided in the 2009 SWP Report and associated DRR.

Table 6.13
Current and Planned Wholesale Water Supplies Available (Long-Term Average)

Wholesaler (Supply Source)	2010	2015	2020	2025	2030[(a)]	2035[(b)]
California State Water Project (SWP)						
% of Table A Amount Available	60%	60%	60%	60%	61%	61%
Anticipated Deliveries (AFY)	49,680	51,480	53,880	53,880	54,778	54,778

Source is MWA's 2010 UWMP, Table 3-4.
(a) Assumes 61% of Table A amount from 2029 and after.
(b) The DWR SWP Delivery Reliability Report 2009 projects SWP supplies to 2029. This 2010 UWMP covers the period from 2010 to 2035. Therefore, available supplies from 2030 to 2035 are assumed the same as 2029.

In **Table 6.9**, 60 percent of the Table A amount is assumed as the long-term supply until 2029 and then 61 percent is assumed in 2029 and after, based on the DWR 2009 DRR (2009c) for MWA. In **Tables 6.10 and 6.11**, worst-case scenarios are assumed for the SWP supply; only the difference needed to meet the demand is used.

6.10 Local Water Supplies

MWA's local supply of water includes natural surface water flows, return flow from pumped groundwater not consumptively used, and wastewater imports from outside the MWA service area. All three sources are discussed in the following subsections. A fourth source, "Agricultural Depletion from Storage," is also shown as a supply and is described in Section 6.10.4.

6.10.1 Net Natural Supply

MWA has an average net natural supply of 59,973 AFY, which includes surface water and groundwater flows in the five subareas of the Mojave Basin Area and in the Morongo Basin/Johnson Valley Area ("Morongo"), as shown in **Table 6.9**. The estimates for the Mojave Basin Area are derived by the MBA Watermaster.

Within the constraints of the Judgment, the MBA Watermaster Engineer recently revised the net natural supply for the Baja Subarea upwards from 5,500 AFY to 11,428 AFY (Wagner and Bonsignore, 2012). Revisions to water budget components included the following:

1. Average surface water inflow to the Baja Subarea across the Waterman Fault was increased from 14,000 AFY to 16,406 AFY. This revision is based on an evaluation of stream leakage between the Barstow stream gage and Waterman Fault for large storm events from 1993 to 2011 to account for the effect of current land use conditions (e.g., recent trends in Barstow WWTP discharges). The average stream leakage rate for recent large storms was then applied to historical discharge volumes measured at the Barstow gage over the base period (1931 to 2010).
2. Surface water outflow from the Baja Subarea across the Afton gage was reduced from 8,200 AFY to 5,611 AFY. This revision accounts for the observed, consistent decline in surface water flow

across the Afton gage since 1931. The new number represents the average discharge rate over the base period, excluding the period of incomplete data from 1932 to 1952.

3. Net subsurface inflow into Baja was increased from 1,200 AFY to 1,581 AFY, which represents the base period subsurface inflow into the Baja model subarea from the Centro (1,462 AFY) and Coyote model subareas (289 AFY) less subsurface outflow to the Afton model subarea (170 AFY).
4. Additional ungaged inflows of 952 AFY from Kane Wash, Boom Creek, and other desert washes were included.

The projected net natural water supply for the Baja Subarea is higher than the estimate derived from the USGS model water budget for the base period documented in Section 5.7.1 (7,654 AFY; calculated as the sum of average annual natural inflows [recharge from stream leakage, subsurface inflow across the Waterman Fault, and mountain-front recharge from Kane Wash and the Coyote Lake Area] less the sum of average annual natural outflows [groundwater discharge to stream, subsurface outflow to the Afton model subarea, evapotranspiration from phreatophytes, and Coyote and Troy dry lake evaporation] for the Baja and Coyote model subareas). Similarly, the projected net natural water supply is higher than the estimate derived from the water budget developed from WY 1993-94 to WY 2009-10 documented in Section 5.7.2 (5,113 AFY; calculated as the sum of average annual natural inflows [net recharge from stream, subsurface inflow across the Waterman Fault, and mountain-front recharge] less the sum of average annual natural outflows [groundwater discharge to stream at Afton, evapotranspiration by phreatophytes, and Coyote Dry Lake evaporation]).

The revised average annual surface water flow across the Waterman Fault (16,406 AFY) is reflected in the revised net natural supply for Baja (11,428 AFY); however, the net natural water supply for the Centro Subarea (18,500 AFY) remains based on the original average annual surface water flow across the Waterman Fault of 14,000 AFY.

The MBA Watermaster utilizes the projected net natural water supply estimates, consistent with the requirements of the Judgment, to calculate annual yield for each of the five subareas and to define the quantities of water that each stipulating party can produce without incurring replenishment obligations under the Judgment. This determination and other information will ultimately result in the final calculation of Replacement Water and Makeup obligations of the stipulating parties. This procedure has a direct effect on the calculation of the largest demand for imported water supply and has been adjudicated by the Court. It is necessary to maintain the Mojave Basin Area long-term average supply regardless of actual variability in surface water flows.

6.10.2 Wastewater Import

Treated wastewater effluent is imported to MWA from three wastewater entities serving communities in the San Bernardino Mountains outside MWA's service area. Treated wastewater effluent from the Crestline Sanitation District and Lake Arrowhead Community Services District is imported to the Alto Subarea, and effluent from the Big Bear Area Regional Wastewater Agency is imported to the Este Subarea. Wastewater imports from outside MWA are recharged into the Mojave River Groundwater Basin and represent a relatively small portion of MWA's overall water supply portfolio. Currently, no wastewater effluent is imported to the Baja or Centro Subareas.

6.10.3 Return Flow

A portion of pumped groundwater returns to the aquifer and becomes part of the available water supply; this is defined as the return flow. For example, nearly all indoor water use returns to the basin either by percolation from septic tanks or treated wastewater effluent produced by municipal wastewater facilities. The portion of the groundwater pumped that does not return to the aquifer is consumptive use.

Return flow shown in **Table 6.9** is calculated as a percent of the previous years' water production for each water use category, per the methodology outlined in the Webb Study (Webb, 2000). Return flow factors per the Webb Study were explained previously in Section 6.4.3 and, on a regional basis, average approximately 40 percent of the groundwater production. The return flows shown in **Table 6.9** represent aggregate flows from all sources. Return flows from municipal demands are calculated as 50 percent of total municipal groundwater production, with a portion of those flows resulting from septic tanks and a portion from recycled wastewater.

6.10.4 Agricultural Depletion from Storage

Agriculture accounts for the largest water demand in the Baja Subarea. **Table 6.9** identifies Agricultural Depletion from Storage as a local supply. Baja agricultural producers have repeatedly reported to MBA Watermaster (and the court) that they will not be able to purchase supplemental water. Consequently, Baja producers rely on storage depletion as a supply. Therefore, in order to avoid showing demand from Baja agriculture on imported water supplies, the MWA projection model treats consumptive use of agriculture as a supply derived from storage depletion.

6.11 Groundwater

As discussed in Section 1, the MWA service area overlies all or a portion of 36 groundwater basins and subbasins as defined by DWR Bulletin 118-03. Collectively, these basins and subbasins are grouped into two larger hydrogeologically distinct areas. Basins along the Mojave River and adjacent areas are referred to as the Mojave River Groundwater Basin. Remaining basins in the southeastern MWA service area are referred to as the Morongo Basin/Johnson Valley Area or "Morongo Area". The Mojave River Groundwater Basin is the larger and more developed of the two areas. These basins overlie two broad hydrologic regions also defined in DWR Bulletin 118-03. Most of the Mojave River Groundwater Basin lies within the South Lahontan hydrologic region. The Morongo Area and the Este Subarea of the Mojave River Groundwater Basin lie in the Colorado River hydrologic region.

6.11.1 Mojave River Groundwater Basin

The Baja and Centro Subareas are both within the Mojave Basin Area groundwater basin, which has been further divided into subareas for groundwater management and/or adjudication purposes. Subareas within the Mojave River Groundwater Basin include Oeste, Alto, Este, Centro and Baja as defined in the Mojave Basin Judgment and shown on **Figure 1.1**.

6.11.1.1 Available Groundwater Supplies

Recent and projected groundwater pumping within each subarea of the Mojave Basin Area is summarized in **Tables 6.2** and **6.14**, respectively. Values in **Table 6.14** are from MWA's 2010 UWMP, Table 3-6. In the Mojave Basin Area, BAP rights were assigned by the Judgment to each producer using 10 AFY or more, based on historical production. BAP is defined as the producer's highest annual use verified for the five-year base period from 1986-90. Parties to the Judgment are assigned a variable FPA by the MBA Watermaster, which is a percentage of BAP set for each subarea for each year. The allocated FPA represents each producer's share of the water supply available for that subarea. This FPA is reduced or "ramped-down" over time until total FPA comes into balance with available supplies.

Production Safe Yield (PSY) is also determined for each subarea for each year. The PSY in each subarea is assumed to equal the average net natural water supply plus the expected return flow from the previous year's water production. Exhibit H of the Judgment requires that, in the event the FPA exceeds the estimated PSY by five percent or more of BAP, Watermaster recommends a reduction in FPA equal to, but not more than, a full five percent of the aggregate subarea BAP. Any water user that pumps more than their FPA in any year is required to buy "Replacement Water" equal to the amount of production in excess of the FPA. Replacement Obligations can be satisfied either by paying the MBA Watermaster to purchase imported water from MWA or by temporarily transferring unused FPA within that subarea from another party to the Judgment.

Table 6.14
Mojave Basin Area Projected Groundwater Production (AFY)

Mojave Basin Area[(a)]	2010	2015	2020	2025	2030	2035
Subareas						
Alto	84,226	93,994	99,440	108,851	118,262	127,674
Baja	23,151	23,847	24,204	24,521	24,822	25,108
Centro	23,130	24,224	25,015	25,819	26,623	27,427
Este	5,863	6,607	6,771	6,970	7,170	7,369
Oeste	4,503	4,767	4,930	5,089	5,247	5,404
Total	**140,873**	**153,439**	**160,360**	**171,250**	**182,124**	**192,982**

Source is MWA's 2010 UWMP, Table 3-6.
(a) Acre-foot numbers represent groundwater production only and do not include demands met directly with SWP sources.

Table 6.15 shows the current FPA for water year 2010-2011 for the Baja and Centro Subareas and the estimated PSY (from Annual MBA Watermaster Reports). Also shown in **Table 6.15** is the verified production for water year 2009-10 for comparison. FPA as shown in **Table 6.15** is greater than PSY by more than 5 percent for the Centro Subarea. Water levels remain stable in most areas currently because verified production is less than the available supply. Based on these recommendations, FPA for all uses in Centro remain at 80 percent of BAP. All production in the Baja Subarea has been ramped-down to 62.5 percent of BAP, principally due to the extent of the overdraft and the predominance of agricultural production in Baja, which precludes the opportunity to have industrial and municipal producers achieve balance through a disproportionate share of the ramp-down. Given the constraints imposed by the Judgment and direction from the Court regarding ramp-down, it is the MBA Watermaster's recommendation to the Court that the FPA be set as follows for the Baja and Centro Subareas for water year 2011-2012:

- Baja Subarea – 62.5 percent of BAP
- Centro Subarea – 80 percent of BAP

Table 6.15
Baja and Centro Subarea Production Safe Yield and Current Free Production Allowance (AFY)

Mojave Basin Subarea	Base Annual Production	2010-2011 FPA	Production Safe Yield	Percent Difference[(a)]	2009-2010 Verified Production
Baja	66,157	43,863	20,679	35.00%	21,539
Centro	56,269	45,349	33,375	21.30%	21,847

(a) This value represents the percent of BAP that PSY departs from FPA.

6.11.1.2 Power Plants

MWA directly supplies imported SWP water to two power plants. One power plant is in the Centro Subarea (LUZ Solar Plant) and is entirely dependent upon SWP water delivered by exchange through the Antelope Valley-East Kern Water Agency (AVEK) system. MWA has an existing transfer agreement to transfer up to 2,250 AFY via AVEK to the LUZ Solar Power Plant located near Kramer Junction. LUZ currently has water stored in the Alto Subarea to offset potential SWP delivery reductions when allocations are low. The other power plant is in the Alto Subarea.

6.11.2 Groundwater Banking Programs

Groundwater banking programs involve storing available SWP surface water supplies during wet years in groundwater basins in, for example, the San Joaquin Valley. Water is stored either directly by surface spreading or injection, or indirectly by supplying surface water to farmers for use in lieu of their intended groundwater pumping. During water shortages, the stored water could be extracted and conveyed through the California Aqueduct to MWA as the banking partner, or used by the farmers in exchange for their surface water allocations, which would be delivered to MWA as the banking partner through the California Aqueduct. Several conjunctive use and groundwater banking opportunities are available to MWA.

MWA has its own conjunctive use program to take advantage of the fact that the available MWA SWP supply on average is still greater than the demand in the service area. MWA is able to store this water for future use when SWP supplies are not available. This activity also allows MWA to take advantage of wet year supplies because of the abundant groundwater storage available in the Basins. This concept is used in the planned water supply projects such as the Regional Recharge and Recovery (R-Cubed) Project.

Table 6.16 (from MWA's 2010 UWMP, Table 3-13) shows the storage available in MWA's existing banked accounts by subarea as of December 31, 2010. The MWA-Owned Stored Water is SWP water that MWA has purchased over the past years and stored in various groundwater basins for use in the event of limited SWP supply or groundwater shortage. MWA will continue to make such purchases when available to ensure the supply of water to their retailers. Some individual retailers in the MWA service area have their own individual banked storage accounts; the Retailer-Owned Stored Water is owned by one of MWA's retailer agencies and consists of SWP purchased by MWA and then bought by the retailer.

Table 6.16
Status of MWA Groundwater Storage Accounts (AF)

Subarea	MWA-Owned Stored Water[a]	Retailer-Owned Stored Water[b]	Total Stored Water
Alto	58,592	28,851	87,443
Baja	18,128	0	18,128
Centro	17,377	0	17,377
Este	1,357	0	1,357
Oeste	0	0	0
Morongo	0	17,146	17,146
Total	**95,454**	**45,997**	**141,451**

Source is MWA's 2010 UWMP, Table 3-13.
(a) MWA's banked groundwater storage accounts as of December 31, 2010.
(b) Retailer-owned water is owned by one of MWA's retailer agencies and consists of excess SWP purchased by MWA and then bought by the retailer.

7. CONCLUSIONS

The Centro and Baja subareas are the two largest subareas in the Mojave River Basin Management Area and account for 50 percent of the Mojave River Basin. Both subareas have a unique set of hydrologic and hydrogeologic conditions and land use and water use profiles. Given their respective locations along the Mojave River, both subareas are affected by upstream water use, insofar as it affects downstream flows in the river.

The current understanding of hydrogeologic conditions in the Centro and Baja subareas has evolved from decades of scientific study. The primary objective of this study is to integrate the historical body of knowledge gathered from previous studies with results of additional evaluations using current datasets and information to produce one comprehensive document to be a foundation for future management decisions in the Centro and Baja subareas. A synopsis of the respective conceptual hydrogeologic model and assessment of water demand for the Centro and Baja subareas, including study findings critical to future groundwater management, is presented below.

7.1 Key Findings

7.1.1 Historical Land Use and Water Use

Beginning with early exploration mining in the late 1800s followed by the expansion of agriculture accompanied by urban growth in the 1900s, water demand in the Study Area and overall Basin increased dramatically. Within the Centro Subarea, production in the Centro model subarea and Harper Lake Area increased through the early 1990s. However, it has since declined in these areas as a result of land use changes (e.g., from agricultural to municipal/industrial land uses) and mandated production decreases (rampdown) required by the Judgment. Within the Baja Subarea, production increased systematically from 1950 through 1990, with most of the increase occurring south of the Mojave River. Since the Judgment, production has declined across the subarea with only minor production now occurring north of the river. Currently, agricultural pumping accounts for roughly 50 percent and 80 percent of the total pumping in Centro and Baja, respectively.

7.1.2 Precipitation

The Mojave River is fed primarily by storm runoff on the northern slopes of the San Bernardino Mountains. Long-term average annual precipitation in the San Bernardino Mountains is 40.53 inches. In contrast, average annual rainfall on the valley floor in the Study Area is only 4.71 inches. Rainfall in the local mountains also generates storm runoff that contributes to Mojave River flows and groundwater recharge along the margins of the Mojave River Basin within the Study Area. Seasonal and annual precipitation patterns in the San Bernardino Mountains vary considerably compared to the valley floor.

While the precise orographic effect of the local mountains on precipitation patterns is uncertain (due to the lack of existing rain gages), available rainfall isohyet maps indicate that annual rainfall in the upper watershed areas within the Study Area ranges from 6 to 10 inches.

7.1.3 Stream Hydrology and Local Mountain Runoff

Streamflow losses from the Mojave River represent the primary source of recharge in the Basin. The principal factors controlling the volume of downstream flows in the Mojave River are the frequency, magnitude, and duration of runoff in the San Bernardino Mountains and the absorption capacity of the river channel. These factors are complex and inter-related; the absorption capacity of the channel is a function of the intrinsic characteristics of the unsaturated zone sediments and, at any given time, the depth to the water table, local and regional hydraulic gradients in the shallow aquifer system, and amount of water held in the unsaturated zone.

Mojave River flows—and consequently recharge from river leakage—has declined in the lower portions of the Basin since the 1950s. Average annual discharge at the Lower Narrows, Barstow, and Afton gages (as a percentage of discharge at The Forks) has generally declined over the period of record (1931 to 2010) with larger declines occurring in the downstream direction.

Since 1990, discharge at The Forks has been above its base-period average, while discharges at the three downstream gages have been below their respective base-period averages, with increasing declines downstream. The average annual net stream recharge for the upper reach (The Forks to Lower Narrows) has increased more than three-fold compared to its base-period average. Because the upper reach is absorbing available stream flows, the net stream recharge in the middle reach (Lower Narrows to Barstow) and lower reach (Barstow to Afton) have decreased relative to their respective base-period averages.

The proportion of the discharge at The Forks that becomes net recharge to the groundwater system within the upper reach has increased since the 1950s. Similarly, the proportion of the discharge at Lower Narrows that recharges the groundwater system within the middle reach has increased. In contrast to the upper and middle reaches, the proportion of discharge at Barstow that recharges the groundwater system within the lower reach has not changed measurably since the 1930s. The variability in net recharge in the lower reach is primarily dependent on the amount of discharge reaching Barstow.

Results of a focused evaluation of Mojave River flows and two dams located in the headwaters of the Mojave River in the San Bernardino Mountains – Cedar Springs Dam and Mojave River Dam – indicate that the volume of flows reaching downstream areas of the Basin are minimally affected by the dams. The detention effect of the dams on downstream flows is relatively small compared to the effect of groundwater level declines beneath the river channel since the late 1940s/early 1950s, which has generally increased the absorption potential of the Mojave River.

Results of a focused evaluation on local mountain runoff indicate that the use of a runoff coefficient of 0.5 percent of rainfall on upland (non-basin) areas is reasonable. Applying a 0.5 percent runoff coefficient to the weighted-average rainfall within the Study Area indicates that the estimated ungaged local runoff within the Centro Subarea is 1,230 AFY. The estimated total ungaged local runoff within the Baja Subarea is 980 AFY.

7.1.4 Geology, Aquifer Systems and Hydraulic Properties

The local geology is characterized by sedimentary alluvial basins underlain by consolidated Tertiary and pre-Tertiary rocks that crop out in the local mountain ranges and hills. Of the unconsolidated basin fill sediments, generally coarse-grained Quaternary alluvium deposited by the ancestral and modern Mojave River comprises the Floodplain Aquifer, one of two major aquifer systems in the Study Area. The Floodplain Aquifer is underlain and enveloped by older alluvial fan deposits that form the Regional Aquifer.

Numerous, primarily northwest-southeast trending geologic faults cross the Study Area. Several faults represent partial barriers to groundwater flow (particularly in older alluvial deposits) and affect local groundwater quality (e.g., elevated TDS groundwater in the Regional Aquifer is forced upward into the Floodplain Aquifer by the Helendale Fault). As a result of tectonic activity and faulting, the elevation of the base of unconsolidated sediments is highly variable across the Study Area.

In Centro, the base of unconsolidated sediments along the Mojave River ranges from less than 100 feet south/southeast of Iron Mountain to greater than 700 feet south of the Lockhart Fault and greater than 600 feet in eastern Barstow. In the Hinkley Valley, the sequence of unconsolidated sediments gradually thins to the north from about 400 feet thick near the river to less than 200 feet thick at the Hinkley Gap. In the Harper Lake area, the base of unconsolidated sediments is between 500 and 600 feet-bgs. In the southern portion of Harper Valley, the depth to the base of unconsolidated sediments is estimated at about 600 feet-bgs. However, the number of deep wells in the vicinity is limited, and the actual depth is less certain than other portions of the Centro Subarea.

In Baja, the base of unconsolidated sediments ranges from less than 100 feet-bgs along the margins of the basin down to 700 feet in the central interior portion of the basin bounded generally by the Calico Fault, Mojave River, and Newberry Fracture Zone. Shallow consolidated units interrupt and isolate the three deepest portions of the basin (south-central portion, Coyote Dry Lake, and a smaller, deep area to the east). In the vicinity of Coyote Lake, the depth to the base of unconsolidated sediments is about 600 feet. Unconsolidated sediments extend to a similar depth in the eastern portion of the basin north of the Cady Mountains. The base of unconsolidated sediments appears to be offset along the Calico Fault in the southern portion of the basin, with the eastern side slightly higher in elevation than the western side.

In Centro, estimated aquifer transmissivity (T) values generally range from 50,000 to greater than 100,000 gpd/ft within the Floodplain Aquifer. Relatively high T values are evident in Hinkley Valley, depicting the flowpath of the ancestral Mojave River to Harper Lake. Moderately high T values are also evident west of Harper Lake. Storativity (S) values range from 12 to 22 percent, with higher values assigned to the coarse-grained deposits along the Mojave River system and lower values assigned to deposits comprising the Regional Aquifer.

In Baja, estimated T values generally range from 50,000 to greater than 300,000 gpd/ft within the Floodplain Aquifer. High T values are observed in the western portion of the basin within the Baja Subarea, corresponding to the higher energy of the ancestral Mojave River as it exited the Centro

Subarea. With the exception of the main Mojave River channel, T values generally decline from west to east and towards Coyote and Troy dry lakes.

7.1.5 Groundwater Occurrence and Flow

In Centro, groundwater follows the Mojave River channel from the Helendale Fault along the southeastern side of Iron Mountain before bifurcating in the vicinity of the Lenwood Fault. From there, most of the groundwater continues along the channel through Barstow eventually exiting the Subarea across the Harper Lake (Waterman) Fault, while some portion of groundwater flows from the Lenwood area north/northeast across Hinkley Valley, through Hinkley Gap, and beneath Harper Dry Lake, towards the pumping depression west of Harper Lake.

Groundwater level trends are affected directly by local pumping within the subarea and indirectly by upstream regional pumping. In the Centro model subarea, the effect of upstream regional pumping as simulated using the USGS model represents most of the groundwater lost from storage in the Centro model subarea since 1931. In Baja, the effect of upper Basin pumping as simulated using the USGS model amounts approximately 22 percent of groundwater lost from storage during the simulation period. The effect of upstream pumping in Centro on the Baja subarea was not accounted for in the simulation.

Groundwater level declines have resulted in the loss of riparian vegetation in the Study Area and contributed to the de-stabilization of sand dunes and to wind-blown migration of sand across portions of the Study Area. Groundwater level declines continue to threaten remaining riparian vegetation at Camp Cady Wildlife Area in eastern Baja.

7.1.6 Groundwater in Storage

The estimated groundwater in storage within the Centro Subarea is 5,429,000 AF. This volume has been apportioned among various subsections within the Centro Subarea in the USGS model (referred to as *model subarea*). Of the total storage volume, slightly more than 35.4 percent (1,923,000 AF) is stored in the Centro model subarea, 25.3 percent (1,371,000 AF) is stored in the South Harper Valley model subarea, 10.1 percent (551,000 AF) is stored in the South Harper Lake model subarea, and 29.2 percent (1,584,000 AF) is stored in the North Harper Lake model subarea.

The estimated total groundwater storage in the Baja Subarea is 8,781,000 AF. Similar to Centro, the amount of groundwater in storage can be apportioned to various *model subareas* within the Baja Subarea. Of the total storage volume, about 78 percent (6,816,000 AF) is stored in the Baja model subarea, 22 percent (1,916,000 AF) is stored in the Coyote model subarea, and less than one percent (49,000 AF) is stored in the Afton model subarea.

Groundwater storage values represent the amount of stored groundwater that theoretically could be pumped with wells (albeit without consideration of long-term sustainability, economic or environmental factors).

7.1.7 Centro Subarea Water Budget

1931 to 1999 (USGS model): Groundwater storage in the Centro Subarea declined more than 760,000 AF from 1931 to 1999, with most of the storage losses occurring between 1950 and the late 1970s. The USGS water budgets indicate that groundwater level and storage trends are affected directly by local pumping within the subarea and indirectly by upstream regional pumping. Based on simulations with the USGS model, upper basin pumping was the major factor in historical groundwater storage declines in the Centro model subarea. From the late 1970s to the end of the transient simulation period, groundwater inflows and outflows for the entire Centro Subarea were generally in balance. In each of the four model subareas within Centro, groundwater storage losses occurred over the base period (1931 to 1990) and transient simulation period (1931 to 1999). Average annual storage changes over the transient simulation period from the Centro, South Harper Valley, South Harper Lake, and North Harper Lake model subareas were -3,596 AFY, -1,305 AFY, -2,221 AFY, and -3,915 AFY, respectively, for a combined average annual storage loss of -11,037 AFY.

WY 1993-94 to WY 2009-10: Since the implementation of the Judgment, the Centro Subarea has been in operational balance as a result of large storm recharge events and production rampdown. Groundwater storage increased by 54,515 AF in the Centro Subarea from WY 1993-94 through WY 2009-10. Within the Centro model subarea, there was an average annual groundwater storage gain of 3,480 AFY, resulting in a cumulative gain of 59,157 AF. Positive gains are primarily the result of large storm recharge events in WYs 1994-95, 1997-98, and 2004-05.

Within the South Harper Valley model subarea, an estimated -1,146 AFY was lost from groundwater storage, resulting in a cumulative storage loss of -19,482 AF. Storage losses in the South Harper Valley model subarea are attributable to the historical increase in subsurface flow across the Lockhart Fault to the South Harper Lake model subarea, which is assumed to have continued through WY 2010.

Within the South Harper Lake model subarea, an estimated 2,655 AFY was gained in groundwater storage, resulting in a cumulative storage gain of 45,134 AF from WY 1993-94 through WY 2009-10. Storage gains are attributable to significant declines in groundwater production since WY 1997-98 and subsurface inflow from the North Harper Lake model subarea.

Within the North Harper Lake model subarea, an estimated -1,782 AFY was lost from storage, resulting in a cumulative storage loss of -30,293 AF from WY 1993-94 through WY 2009-10. Storage losses are attributable to agricultural production exceeding 3,000 AFY from WY 1993-94 through WY 1998-99 and subsurface outflow to the South Harper Lake model subarea.

Estimated annual storage losses in the South Harper Valley and North Harper Lake model subareas are not expected to continue as groundwater levels continue to recover in the South Harper Lake model subarea in response to the transition from agriculture to industrial land use (solar farms) in the area.

7.1.8 Baja Subarea Water Budget

1931 to 1999 (USGS model): Groundwater storage in the adjudicated portion of the Baja Subarea declined by over 1,060,000 AF from 1931 to 1999, with relatively consistent storage losses observed from 1950 through 1999. Evaluation of the groundwater level data and water budgets indicate that groundwater level trends are affected directly by local pumping within the subarea and indirectly by upstream regional pumping. Based on simulations with the USGS model, upper basin pumping (not including Centro) was estimated to account for about 21 percent of groundwater lost from storage in the Baja Subarea over the base period (1931 to 1990). The USGS did not simulate the effect of upstream pumping in Centro on stream discharge and recharge in Baja. Average annual storage changes during the base period from the Baja and Coyote model subareas were -14,465 AFY and -762 AFY, respectively. Average annual storage changes over the entire transient simulation period from the Baja and Coyote model subareas were -14,568 AFY and -797 AFY, respectively.

WY 1993-94 to WY 2009-10: Over this 17-year period, the estimated rate of groundwater storage decline in the adjudicated portion of the Baja Subarea was slightly higher than historical declines, averaging -18,116 AFY for a cumulative storage loss of -307,979 AF. The increased rate of storage loss was a result of two factors: 1) average annual production in the Baja Subarea (36, 121 AFY) exceeding the natural water supply over this period (7,980 AFY; excluding enhanced recharge and return flows) despite recent decreases in production below 30,000 AFY in response to rampdown; and 2) below-average recharge from Mojave River leakage as a result, in part, of the continued effects of upstream regional production reducing Mojave River flows entering the Baja Subarea.

7.1.9 Groundwater Quality

Groundwater quality varies across the Study Area but is generally suitable for beneficial uses in the region. Groundwater from most wells located along the Mojave River has a signature similar to that of Mojave River water. Three processes that occur along groundwater flow paths from the Mojave River explain most of the variability in groundwater quality away from the river. These are:

1. Cation exchange between calcium in groundwater and sodium on subsurface (primarily clay) sediments
2. Reduction in bicarbonate content (relative to chloride and sulfate) of Mojave River recharge water, and
3. Recharge of local mountain runoff, which has a relative sodium content greater than Mojave River water and a relative bicarbonate content similar to Mojave River water.

In Centro, groundwater quality is also affected by the barrier effect of the Helendale Fault in the south, leaching of sodium and chloride from evaporative lake deposits as well as additional cation exchange in groundwater that flows towards southwest Harper Dry Lake, and the barrier effect of the Waterman Fault and effluent discharges from the Barstow WWTP in eastern Centro. In Baja, groundwater quality is influenced by leaching of sodium and chloride from evaporative lake deposits as well as additional cation exchange in groundwater that flows towards Coyote and Troy dry lakes.

Concentrations of TDS and other common constituents of concern that occur in the Study Area are generally below federal and state MCLs. Within the Study Area, potentially degraded groundwater occurs in 1) the Mojave River area in eastern Barstow/western Baja, 2) the Harper Lake Area, 3) the north Yermo area, and 4) eastern Baja Subarea near Troy Dry Lake. This report identifies and describes active environmental contamination sites; all known sites are undergoing active review and/or remediation.

7.1.10 Water Demand and Supply

Water demand is documented for the Centro and Baja Subareas, based primarily on the recent MWA 2010 UWMP but also including recent revisions. Water supplies also are documented. Overall, in the Centro Subarea, comparison of water demand and supply indicates that supplies are greater than existing and future demands. In the Baja Subarea, comparison of water demand and supply indicates a balance of supply and demand; however, this is based in part on depletion of groundwater storage and return flows from groundwater pumping (that is being ramped down).

7.2 Knowledge Gaps

The following knowledge gaps have been identified in this study:

- Distribution and pattern of rainfall in local mountains surrounding Baja and Centro subareas
- Basin depth and hydraulic properties of deep sediments in south Harper Valley, central Baja, and lower alluvial aquifer (below Quaternary basalt) at Harper Dry Lake
- Amount of reduction in Mojave River discharge and recharge in the Baja Subarea as a result of pumping in the Centro Subarea.
- Effect of historical upstream flood protection measures (e.g., historical clearance of vegetation within the banks of the river) on downstream stormflow and recharge.
- Lag-time of irrigation return flows to groundwater, particularly where regionally extensive clay aquitards are present (e.g., Harper Lake Area and eastern Baja)

8. REFERENCES

Numerous documents reviewed for this study contain important information related to the hydrogeologic and water supply and demand conditions of the Centro and Baja subareas. While some of these documents were not cited directly in the report, they have been included in this reference list to document Todd Engineers' comprehensive consideration of references and to aid the reader in locating key references in the future.

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Appendix A

Subject-Specific Document Timelines for the Centro and Baja Subareas

- Mojave River Hydrology and Upstream Dams
- Ungaged Local Mountain Runoff
- Harper Lake Area
- Riparian Vegetation and Water Demand

Appendix B

Evaluation of Potential Impacts of Cedar Springs Dam (Silverwood Lake) and Mojave River Dam on Downstream Mojave River Flows and Groundwater Recharge

Appendix C

Evaluation of Ungaged Local Mountain Runoff in Centro and Baja Subareas

Appendix D

Final Report
Hydrogeologic Investigation
of Camp Cady Wildlife Area
Newberry Springs, CA

Todd Engineers

January 2013

Appendix E

Summary of Well Hydraulic Information

Appendix F

USGS Groundwater Model
Water Budget Tables for Model Subareas
(1931 to 1999)

Appendix G

Summary of Hydrogeologic Conditions and Historical Mining Northwest of Centro Subarea in the Randsburg, Red Mountain, and Atolia Area

Appendix H

Mojave Basin Area Watermaster
Mojave River Hydrology Analysis
Alto Transition Zone Water Budget
Water Years 1993-94 to 2009-10

Appendix I

Demand Projections for High and Low Conservation Assumptions