Kennedy/Jenks Consultants

303 Second Street, Suite 300 South
San Francisco, California 94107
415-243-2150
FAX: 415-896-0999

Groundwater Study for the Mesquite Lake Subbasin

March 2010

Prepared for

Twentynine Palms Water District
72401 Hatch Road
Twentynine Palms, CA 92277-2935

K/J Project No. 0964003*00

Table of Contents

List of Tables... *iv*

List of Figures... *iv*

List of Appendices... *v*

List of Acronyms... *vi*

Executive Summary... *I*

Section 1: Introduction 1-1

1.1 Purpose 1-1
1.2 Scope of Work 1-1
1.3 Previous Studies 1-2

Section 2: Twentynine Palms Area 2-1

2.1 Study Area 2-1
2.2 Twentynine Palms Water District 2-1
2.3 Water Production and Usage 2-2
2.4 Physical Setting 2-2
2.4.1 Topography 2-2
2.4.2 Vegetation 2-3
2.4.3 Soil 2-4
2.5 Climate 2-5
2.6 Hydrology 2-6
2.6.1 Streamflow 2-6
2.6.2 Playa Lakes 2-6
2.6.3 Springs 2-6
2.7 Geology 2-7
2.7.1 Geologic Setting 2-7
2.7.2 Structural Geology 2-8
2.7.3 Units 2-9
2.7.4 Regional Correlations 2-10

Section 3: Groundwater 3-1

3.1 Aquifers 3-1
3.1.1 Tertiary Alluvium 3-1
3.1.2 Quaternary Alluvium 3-2
3.2 Regional Groundwater Movement 3-2
3.2.1 Regional Groundwater Elevation Maps 3-2
3.2.2 Regional Groundwater Flow 3-3
3.2.3 Groundwater Flow Within the Study Area 3-4

Table of Contents (cont'd)

3.3 Groundwater Basins ... 3-5
3.3.1 Indian Cove Subbasin ... 3-6
3.3.2 Fortynine Palms Subbasin ... 3-7
3.3.3 Eastern Subbasin ... 3-8
3.3.4 Mesquite Lake Subbasin ... 3-10
3.3.5 Dale Basin ... 3-12
3.4 Basin Groundwater Storage Estimates ... 3-12
3.5 Water Quality ... 3-13
3.5.1 Water Quality Issues ... 3-13
3.5.2 Regional Water Quality ... 3-14
3.5.3 Water Quality Trends ... 3-15

Section 4: Hydrologic Budget ... 4-1
4.1 Approach ... 4-1
4.2 Precipitation ... 4-1
4.2.1 Maxey-Eakin Method ... 4-2
4.2.2 Maxey-Eakin Results ... 4-3
4.3 Evapotranspiration ... 4-3
4.4 Well Discharge ... 4-4
4.5 Groundwater Inflow and Outflow ... 4-4
4.6 Changes in Groundwater Storage ... 4-5

Section 5: Groundwater Model ... 5-1
5.1 Purpose ... 5-1
5.2 General Approach ... 5-1
5.3 Numerical Model Setup Overview ... 5-2
5.4 Calibration Summary ... 5-4
5.5 Model-Based Evaluation of Groundwater Flow ... 5-5
5.6 Model-Based Hydrologic Budget ... 5-7
5.7 Model-Based Insights to the Conceptual Model ... 5-8
5.8 Application of Model Results ... 5-10

Section 6: Evaluation of Long-Term Groundwater Pumping Scenarios ... 6-1
6.1 Background ... 6-1
6.2 Approach ... 6-1
6.3 Pumping Scenarios ... 6-2
6.4 Evaluation of Pumping Using Hydraulic Budget Method ... 6-3
6.4.1 Scenario 1 Using Hydraulic Budget Method ... 6-4
6.4.2 Scenario 2 Using Hydraulic Budget Method ... 6-5
6.4.3 Scenario 3 Using Hydraulic Budget Method ... 6-6
6.4.4 Scenario 4 Using Hydraulic Budget Method ... 6-7
6.5 Evaluation of Pumping using MODFLOW Model ... 6-7
6.5.1 Scenario 1 Using MODFLOW Model ... 6-8

Table of Contents (cont'd)

6.5.2 Scenario 2 Using MODFLOW Model 6-9
6.5.3 Scenario 3 Using MODFLOW Model 6-10
6.5.4 Scenario 4 Using MODFLOW Model 6-12
6.5.5 Scenario 5 Using MODFLOW Model 6-13
6.5.6 Scenario 6 Using MODFLOW Model 6-14
6.6 Sensitivity Analysis 6-15
6.6.1 Scenario 7 – Hydraulic Conductivity Sensitivity Analysis 6-15
6.6.2 Scenario 8 –Specific Yield Sensitivity Analysis 6-16
6.7 Evaluation of Pumping Scenarios by Basin 6-18

Section 7: Conclusions 7-1

7.1 Objective 7-1
7.2 Groundwater Pumping Evaluation 7-1
7.2.1 Baseline Scenarios 7-2
7.2.2 Mesquite Lake Pumping Scenarios 7-2
7.2.3 Alternative Pumping Scenarios 7-3
7.2.4 Scenario Results by Subbasin 7-3
7.3 Summaries 7-4

References .... *i*

Table of Contents (cont'd)

List of Tables

3-1 Water Quality Summary for TPWD Production Wells
4-1 Maxey-Eakin Parameters
4-2 Subbasin Water Budgets for Recharge Method 1
4-3 Subbasin Water Budgets for Recharge Method 2
5-1 Hydrologic and Numerical Model Budget Comparison
5-2 Numerical Model Budget Summary

List of Figures

1-1 Site Location Map
2-1 Regional Map
2-2 Groundwater Basins
2-3 Map of Landforms
2-4 Study Area Geologic Map
2-5 Cross Section Map
2-6 Geologic Cross Section A-A’
2-7 Geologic Cross Section B-B’
2-8 Geologic Cross Section C-C’
2-9 Geologic Cross Section D-D’
2-10 Geologic Cross Section E-E’
2-11 Geologic Cross Section F-F’
3-1 Groundwater Elevation Contours: 1947
3-2 Groundwater Elevation Contours: 1982
3-3 Groundwater Elevation Contours: 2008
4-1 Map of Annual Rainfall
4-2 Annual Pumping from TPWD Wells by Basin
5-1 Model Domain Map for Mesquite Lake Groundwater Model
5-2 2008 Groundwater Elevations for Model Layer 1, Transient Simulation, Mesquite Lake Groundwater Model
5-3 Wells in Mesquite Lake Groundwater Model
5-4 Observed versus Computed Target Values for Transient Calibration

Table of Contents (cont'd)

6-1 Hydrographs for Wells in the Indian Cove Basin
6-2 Hydrographs for Wells in the Fortynine Palms Basin
6-3 Hydrographs for Wells in the Eastern Basin
6-4 Hydrographs for Wells in the Mesquite Basin
6-5 Change in Water Levels from 2008 to 2033 for Scenario 1
6-6 Change in Water Levels from 2008 to 2033 for Scenario 2
6-7 Change in Water Levels from 2008 to 2033 for Scenario 3
6-8 Change in Water Levels from 2008 to 2033 for Scenario 4
6-9 Change in Water Levels from 2008 to 2033 for Scenario 5
6-10 Change in Water Levels from 2008 to 2033 for Scenario 6
6-11 Change in Water Levels in 2033 from Scenario 6 to Sensitivity Scenario 7A
6-12 Change in Water Levels in 2033 from Scenario 6 to Sensitivity Scenario 7B
6-13 Change in Water Levels in 2033 from Scenario 6 to Sensitivity Scenario 8A
6-14 Change in Water Levels in 2033 from Scenario 6 to Sensitivity Scenario 8B
6-15 Difference in 2033 Water Levels Between Scenarios 1 and 3
6-16 Difference in 2033 Water Levels Between Scenarios 2 and 4
6-17 Difference in 2033 Water Levels Between Scenarios 1 and 5
6-18 Difference in 2033 Water Levels Between Scenarios 2 and 6

List of Appendices

A Geology and Hydrogeology
B Climatological Analysis
C Regional Groundwater Basin Data
D Hydrologic Budget Calculations
E Groundwater Model Development
F Groundwater Model Calibration Data
G Hydraulic Budget Evaluation of Pumping Results
H MODFLOW Model Evaluation of Pumping Results
I MODFLOW Model Sensitivity Analysis Results

List of Acronyms

Abbreviation	Definition
A	area
af	acre-feet
afy	acre-feet per year
asl	above mean sea level
b	aquifer thickness
DEM	Digital Elevation Model
DPH	California Department of Public Health
DRI	Desert Research Institute
DWR	California Department of Water Resources
ESI	Environmental Simulations Incorporated
ESRI	Environmental Systems Research Institute, Inc.
ET	evapotranspiration
ET_0	reference evapotranspiration
GHB	general head boundary
GIS	geographical information system
gpd	gallons per day
gpm	gallons per minute
GWMP	Groundwater Management Plan
GWV5	Groundwater Vistas 5
h	groundwater head
HFB	horizontal flow barrier
JBWD	Joshua Basin Water District
JTNM	Joshua Tree National Monument
K	hydraulic conductivity
K_h	horizontal hydraulic conductivity
K_{sat}	saturated hydraulic conductivity
K_z	vertical hydraulic conductivity
L	length
MCAGCC	Marine Corps Air Ground Combat Center
MCL	maximum contaminant level
µg/L	Micrograms per liter
mg/L	Milligrams per liter
MGD	Million Gallons per Day
MWA	Mojave Water Agency
n	porosity
NCDC	National Climate Data Center
NED	National Elevation Dataset
PCG2	Preconditioned Conjugate-Gradient 2
q	water flux density
Q_{in}	groundwater inflow
Q_{out}	groundwater outflow

Abbreviation	Definition
Q_s	surface water discharge
Q_w	well discharge
R	recharge
REV	representative elementary volume
S	storage
SBCO	San Bernardino County
SCS	Soil Conservation Service
S_s	specific storage
STATSGO	State Soil Geographic Database
S_y	specific yield
T	transmissivity
TDS	total dissolved solids
TPWD	Twentynine Palms Water District
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USMC	U.S. Marine Corps
USN	U.S. Navy
UWMP	Urban Water Management Plan
WRCC	Western Regional Climate Center

Executive Summary

This executive summary provides an overview of the findings, conclusions, and recommendations of this comprehensive groundwater study of the Mesquite Lake Subbasin in the Twentynine Palms area.

Objectives

The Twentynine Palms Water District (TPWD) is considering increasing groundwater pumping in the Mesquite Lake Subbasin from 0.95 million gallons per day (MGD) in 2008 to 3.0 MGD by 2015 while simultaneously decreasing pumping in the Indian Cove, Fortynine Palms, and Eastern Subbasins by a similar amount. This change in groundwater pumping is being proposed to stabilize declining groundwater levels in the Indian Cove, Fortynine Palms, and Eastern Subbasins by reducing groundwater pumping. An underlying assumption for this change is that the Mesquite Lake Subbasin will experience smaller groundwater level declines due to its larger size. However, groundwater from the Mesquite Lake Subbasin will require additional water treatment, thus requiring a large capital expense.

The overall objective of this groundwater study is to provide TPWD with the requested evaluation of the overall impacts and benefits resulting from shifting of groundwater pumping between subbasins for the purpose of supporting decision-makers on determining the relative merits of implementing this project. The analysis for this groundwater study consists of two primary components:

- Groundwater characterization – The groundwater characterization provides the understanding of the regional groundwater system necessary to evaluate the impacts of shifting groundwater pumping between the different groundwater subbasins.
- Evaluation of changes in pumping – Changes in the distribution of groundwater pumping will have different impacts and benefits in the different groundwater basins. This evaluation will provide a quantitative assessment of these impacts and benefits based on the groundwater characterization.

A summary of each of these phases of the groundwater study is provided below.

Groundwater Characterization

The groundwater characterization provides the framework necessary to understanding the regional groundwater system provides the basis of understanding for how pumping changes will impact the different groundwater subbasins. The groundwater characterization provides an analysis of the quantity of groundwater in the basin, the hydraulic movement of groundwater through the aquifer, and sources and volumes of natural recharge. It also includes an analysis of the regional geology for defining the geometry of the groundwater subbasins and the distribution the groundwater aquifers, and for evaluating the aquifer properties.

This work is based on a review and analysis of data from TPWD and previous studies in the region. The results of these efforts served as a foundation for the construction, calibration, and application of a numerical groundwater model of the basin that was developed to evaluate the impacts resulting from changing the distribution of groundwater pumping between the subbasins. The scope of work for this portion of the groundwater study includes:

- Reviewing, compiling, and summarizing available data and information on the study area hydrogeology, and combining this knowledge to create a hydrogeologic assessment of the study area, from which the conceptual model of the study area hydrology could be created.

- Defining the groundwater basin using standard geologic methods including the development of regional scale cross sections to define the basin geometry, extent of the groundwater aquifers, and characterizing key hydrogeological features.

- Developing a detailed yearly hydrologic budget for the study area subbasins based on standard hydrologic methods.

- Developing and calibrating a numerical groundwater model for the basin using MODFLOW.

The hydrogeologic characteristics pertinent to the objectives of this study are determined for each groundwater subbasin. These hydrogeologic characteristics are summarized here by groundwater subbasin as follows.

Indian Cove Subbasin

The Indian Cove Subbasin is the southwestern-most of the TPWD subbasins. This subbasin is divided by the east-west trending Pinto Fault into southern and northern sections.

- TPWD has operated eight wells in this subbasin since 1957. Groundwater production peaked at 2,076 acre-feet in 1985. In 2008, TPWD groundwater production was 691 acre-feet from four wells.

- Water quality in the Indian Cove Subbasin is generally quite good, with total dissolved solids (TDS) ranging from 100 to 260 mg/L with an average of 149 mg/L. Fluoride concentrations range from 0.2 to 4.0 mg/L with an average of 1.4 mg/L, based on TPWD production well and DWR (1984) data.

- Groundwater levels have declined by about 80 to 100 feet over the past 50 years in the areas north of the Pinto Fault. South of the Pinto Fault, groundwater levels have been relatively stable.

- Groundwater within the Indian Cove Subbasin generally flows from south to north in the southern section of the subbasin, and from west to east in the northern section.

- Most groundwater recharge to the Indian Cove Subbasin is derived from subsurface flow from the Joshua Tree Subbasin to the west. The remaining groundwater recharge is derived from infiltration of runoff from precipitation from the highlands to the south.

- Groundwater pumping is the primary groundwater outflow from the subbasin. Other outflows include groundwater flow to the Fortynine Palms and Mesquite Lake Subbasins.

Fortynine Palms Subbasin

The Fortynine Palms Subbasin is located between the Indian Cove and Eastern Subbasins. It is bordered on the south by the Little San Bernardino Mountains and on the north by the Oasis Fault[1].

- TPWD has operated six wells in this subbasin with records back to 1953. Groundwater production peaked at 1,620 acre-feet in 2002. In 2008, TPWD groundwater production was 1,024 acre-feet from two wells.

- Water quality in the Fortynine Palms Subbasin is generally quite good, with TDS ranging from 100 to 220 mg/L with an average of 153 mg/L Fluoride concentrations range from 0.3 to 3.6 mg/L with an average of 1.4 mg/L, based on TPWD production well and DWR (1984) data.

- Groundwater levels have declined by about 70 to 100 feet over the past 50 years.

- Groundwater within the Fortynine Palms Subbasin generally flows from west to east.

- The majority of groundwater recharge is derived from subsurface flow primarily from the Indian Cove Subbasin, but with some also coming in from the Eastern Subbasin and the Mesquite Lake Subbasin. The remaining groundwater recharge is derived from infiltration of runoff from precipitation from the highlands to the south.

- Groundwater pumping is the primary groundwater outflow from the subbasin. Other outflows include groundwater flow to the Mesquite Lake Subbasin.

Eastern Subbasin

The Eastern Subbasin is the southeastern-most subbasin in the study area. It is bordered on the south by the Little San Bernardino Mountains and on the north by the Oasis Fault. The subbasin is divided into northern and southern sections by the Pinto Fault. The southern section contains no TPWD wells.

- TPWD has operated three wells in this subbasin with records back to 1953. Groundwater production peaked at 829 acre-feet in 2002. In 2008, TPWD groundwater production was 737 acre-feet from two wells. One of the production wells in this subbasin does not produce potable water.

- Water quality in this subbasin is not as good as in the two subbasins to the west, with TDS ranging from 145 to 305 mg/L with an average of 191 mg/L Fluoride concentrations

[1] This fault is known in most references as the Pinto Mountain Fault, but is referred to in this report as the Oasis Fault to easily differentiate it from the Pinto Fault just to the south. This follows the naming convention given in Riley and Worts (1952, 1953).

range from 0.4 to 7.2 mg/L with an average of 3.4 mg/L, based on TPWD production well and DWR (1984) data.

- Groundwater levels have declined by about 70 to 100 feet over the past 50 years.

- Groundwater in the southern part of the subbasin flows from south to north. Groundwater in the north part of the subbasin flows generally from southeast to northwest.

- The majority of groundwater recharge is derived from the infiltration of runoff from precipitation from the Little San Bernardino Mountains to the south. Historically, groundwater flowed from the Fortynine Palms Subbasin into this subbasin; however, declining water levels in the Fortynine Palms Subbasin have reversed this flow.

- Groundwater pumping is the primary groundwater outflow from the subbasin. The other primary outflows include groundwater flow to the Fortynine Palms and Mesquite Lake Subbasins. Another potential outflow is evapotranspiration of shallow groundwater at the Oasis of Mara.

Mesquite Lake Subbasin

The Mesquite Lake Subbasin occupies the northern part of TPWD. It is bounded on the north by the Transverse Arch, on the east by the Mesquite Fault, on the south by the Oasis Fault, and on the west by Copper Mountain.

- This subbasin contains only one TPWD well, which began production in 2003. Groundwater production to date peaked in 2008 at 950 acre-feet.

- Water quality in the Mesquite Lake Subbasin is poorer than that in the other three subbasins. TDS varies from 160 mg/L in the south of the subbasin to 3,180 mg/L in the area of Mesquite Dry Lake. Fluoride varies from 2.0 mg/L on the northern border of the Fortynine Palms Subbasin to 22.0 mg/L in the southeastern corner of the subbasin (DWR, 1984). In TPWD-TP-1, TDS ranging from 320 to 350 mg/L with an average of 335 mg/L. Fluoride concentrations range from 5.9 to 6.3 mg/L with an average of 6.1 mg/L.

- Groundwater levels have been relatively stable over the past 50 years with variations ranging from an increase of 10 to declines of up to 10 feet.

- Groundwater in the Mesquite Lake Subbasin flows from the periphery of the subbasin towards the area of the Mesquite Dry Lake. In the northwest, groundwater is funneled around the south ends of the Surprise Spring and Elkins Faults before running east to northeast toward Mesquite Spring. South of the bedrock ridge (which extends from the Copper Mountain block eastward into the southern part of the Mesquite Subbasin), groundwater flows generally east before crossing the Bagley Fault into the main part of the Mesquite Lake Subbasin. From here, groundwater flows north toward Mesquite Spring.

- The majority of groundwater recharge is derived from subsurface flow primarily from the adjacent subbasins. The majority of this recharge is derived from the Surprise Spring and Deadman Lake Subbasins to the north, and the Copper Mountain Subbasin to the west. Groundwater recharge from the Indian Cove, Fortynine Palms, and Eastern Subbasins is considered minor. There is considered to be little to no groundwater recharge derived from the infiltration of precipitation or runoff in this subbasin.

- Groundwater outflow occurs chiefly as evapotranspiration of shallow groundwater at the Mesquite Dry Lake area. Most of the rest of the groundwater outflow is to the Dale Basin to the east, with minor outflows to the Deadman Lake and Fortynine Palms Subbasins. Increasing groundwater pumping since 2003 is becoming a more important outflow from the subbasin.

Groundwater Pumping Evaluation

The objective of this evaluation is to provide an analysis of the potential impacts and benefits of the proposed shift in future pumping conditions. This shift consists of increasing groundwater pumping to the Mesquite Lake Subbasin up to 3.0 MGD with a concomitant decrease in pumping in the Indian Cove, Fortynine Palms and Eastern Subbasins.

Reduced groundwater pumping is intended to help stabilize groundwater level declines in the Indian Cove, Fortynine Palms and Eastern Subbasins. Historically, most of TPWD's groundwater pumping was derived from the Indian Cove and Fortynine Palms Subbasins primarily due to the better water quality. Elevated levels of naturally occurring inorganic constituents, primarily fluoride, occurring in the Eastern and Mesquite Lake Subbasins require additional water treatment. Therefore, groundwater pumping from these subbasins was limited. However, the Indian Cove and Fortynine Palms Subbasins have experienced long-term groundwater level declines over the past 50 years.

The potential future groundwater conditions in the groundwater subbasins are evaluated by two methods, a hydrologic budget analysis and a numerical MODFLOW groundwater model. The MODFLOW model provides a more comprehensive analysis that incorporates more of the detailed hydrogeologic information of the groundwater subbasins whereas the hydrologic budget is a more simplified approach that is limited to a regional-scale analysis. The hydrologic budget approach is useful because it is a more straightforward approach that can be use to corroborate the model results.

The MODFLOW model was developed for the Mesquite Lake, Indian Cove, Fortynine Palms and Eastern Subbasins. The model aquifer properties and boundary conditions are consistent with the groundwater characterization and were calibrated to more than 566 measured groundwater elevations from 60 wells in the basin. The calibration demonstrates that the model is capable of simulating previously observed groundwater trends over time across the entire model domain and provides the basis for using the model in a predictive manner. Based on this ability to simulate historical conditions, the model can serve as a useful tool to evaluate potential future trends in groundwater conditions.

The hydrologic budget method consists of a tabulation of the total groundwater inflows and outflows from the basin and enables estimates of the change in groundwater storage. Using the historical data, a correlation factor was developed that relates the change in groundwater storage to groundwater pumping for each subbasin. For the future pumping scenarios, this correlation factor was applied to the proposed groundwater pumping in each subbasin on an annual basis to project changes in storage.

For the analysis, a series of potential future pumping scenarios was developed for evaluating the response of groundwater levels to various potential future groundwater pumping scenarios. These scenarios were developed to answer the following questions:

- Baseline Scenarios address the question “What are the impacts of continuing the current pumping distribution into the future?”
- Mesquite Lake Pumping Scenarios address the question “What are the impacts and benefits of shifting pumping to the Mesquite Lake Subbasin?”
- Alternative Pumping Scenarios make an initial attempt to address the question “Can the proposed pumping plan be optimized?”

A summary of the results by scenario is provided below.

Baseline Scenarios

The purpose of the Baseline Scenario is to provide a reference condition representing future conditions if current practices were conducted without change. This answers the question “What are the impacts of continuing the current pumping distribution into the future?”

For this analysis, current groundwater pumping rates were projected into the future using the same distribution of pumping to the four groundwater subbasins as was observed in 2008. Two scenarios were evaluated. The first assumes that 2008 groundwater pumping conditions are constant into the future, and the second assumes a growth rate of approximately 1 percent per year. The scenarios are evaluated over the 25-year period of analysis that repeats the natural hydrology from the calibrated model.

The results of the baseline scenario indicate that historical patterns of groundwater level declines would continue into the future. The scenarios indicate that some of the TPWD wells in the Indian Cove and Fortynine Palms Subbasins may not be able to sustain these pumping rates and that new wells would need to be constructed in these subbasins to sustain these pumping rates. Groundwater pumping in the Mesquite Lake Subbasin is based on 2008 pumping rates, which are higher than the long-term historical average. Therefore, the Baseline Scenarios indicate some increased drawdown in this subbasin compared to historical patterns.

Mesquite Lake Pumping Scenarios

The Mesquite Lake Pumping Scenarios are designed to answer the question “What are the impacts and benefits of shifting pumping to the Mesquite Lake Subbasin?” For the Mesquite Lake Pumping Scenarios, groundwater pumping in the Mesquite Lake Subbasin is increased from 0.95 million gallons per day (MGD) in 2008 to 3.0 MGD by 2015. Groundwater pumping is simultaneously decreased in the Indian Cove, Fortynine Palms, and Eastern Subbasins by a similar amount. Other than the changes in the distribution of groundwater pumping, the same assumptions were applied as used in the Baseline Scenarios. Two scenarios were run, one assuming 2008 pumping rates, and the other assuming a one percent annual growth in pumping rates.

The results of the Mesquite Lake Pumping Scenarios indicate that groundwater levels will stabilize in the Indian Cove, Fortynine Palms, and Eastern Subbasins. Relative to the Baseline Scenario, the groundwater levels in the Indian Cove, Fortynine Palms, and Eastern Subbasins are significantly higher. This demonstrates that there is a significant benefit to shifting groundwater pumping out of these subbasins.

In the Mesquite Lake Subbasin, the increased groundwater pumping would result in increased drawdown; however, this will be concentrated near the proposed pumping locations. Over most of the subbasin, groundwater level declines are less. Over 25 years, declines would range from 90 to 95 feet near the proposed wellfield to 6 to 25 feet of drawdown over most of the subbasin. The impacts of increased groundwater pumping are less than those observed in the Indian Cove, Fortynine Palms, and Eastern Subbasins because of the larger size and thickness of the Mesquite Lake Subbasin.

Alternative Pumping Scenarios

The purpose of the Alternative Pumping Scenarios is to evaluate whether groundwater levels in the Indian Cove, Fortynine Palms, and Eastern Subbasins can be actively managed by shifting the remaining groundwater production between them. This makes an initial attempt at answering the question “Can the proposed pumping plan be optimized?” The purpose of operational optimization is to achieve a balance between managing groundwater levels and operational costs such as those associated with water treatment. The Alternative Pumping Scenario provides an evaluation of varying the remaining groundwater pumping distribution in the Indian Cove, Fortynine Palms, and Eastern Subbasins, and provides a preliminary evaluation of potential operational optimization.

Other than the changes in the distribution of groundwater pumping, the same assumptions were applied as used in the Mesquite Lake Pumping Scenarios and Baseline Scenarios. Two scenarios were run, one assuming 2008 pumping rates, and the other assuming a one percent annual growth in pumping rates.

For the Alternative Pumping Scenarios, the remaining groundwater pumping in the Eastern Subbasin was redistributed to the Indian Cove and Fortynine Palms Subbasins. The Alternative Pumping Scenario evaluates shifting a higher proportion of the remaining groundwater pumping to the Indian Cove and Fortynine Palms Subbasins to take advantage of better natural water quality and to further improve groundwater level in the Eastern Subbasin. The results of the Alternative Pumping Scenarios indicate that groundwater levels in the Indian Cove and Fortynine Palms Subbasins can sustain this additional pumping with only minor variations, while eliminating pumping in the Eastern Subbasin reduces groundwater level declines in the Eastern Subbasin. Relative to the Baseline Scenario, the groundwater levels in Indian Cove, Fortynine Palms, and Eastern Subbasins are significantly higher.

These results demonstrate that there is the potential to move groundwater pumping around spatially to improve groundwater conditions. Likewise, the groundwater pumping could be rotated among the Indian Cove, Fortynine Palms, and Eastern Subbasins over time to better manage groundwater levels. The MODFLOW model provides a method to support this style of operations management, and could be deployed as a quantitative tool to optimize wellfield operations in the future.

Conclusions

The overall findings of this study are that shifting pumping to the Mesquite Lake Subbasin would mitigate the decline in groundwater levels in Indian Cove, Fortynine Palms, and Eastern Subbasins. Groundwater levels in these subbasins tend to stabilize over time and are projected to be approximately 20 to 100 feet higher relative to baseline conditions (i.e. continuation of current pumping practices).

Groundwater pumping in the Mesquite Lake Subbasin would produce localized drawdowns near the proposed wellfield; however, subbasin-wide groundwater level declines are expected to be much less because of the large size of the subbasin. Over a 25-year time period, groundwater level declines are projected to range from 90 to 95 feet near the proposed wellfield, representing less than 10 percent of the total saturated thickness of the aquifer at this location. Groundwater levels in the remainder of the subbasin are expected to range from declines of near 25 feet close to the wellfield to little to no change farther from the wellfield. Subbasin-wide groundwater level declines are expected to be much less than in the southern subbasins because of the large size and volume of alluvial sediments in the Mesquite Lake Subbasin.

Any groundwater study will have some level of uncertainty due to the inherent natural variability of hydrogeological conditions. Uncertainty must be addressed to help support decision making. A sensitivity analysis was conducted using the MODFLOW model to help evaluate the effects of uncertainty of aquifer properties relative to evaluating the impacts and benefits of shifting groundwater pumping between subbasins. The sensitivity analysis looked at hydraulic conductivity and specific yield of the aquifer. The results of the sensitivity analysis indicate that similar conclusions would be reached within the range of aquifer variability evaluated.

To further address potential uncertainty within the groundwater study, conservative assumptions were applied regarding the amount of annual groundwater recharge, because of the uncertainty of estimating recharge for the groundwater model. These conservative assumptions give a high degree of confidence in the conclusion that the proposed shift in pumping will result in the mitigation of groundwater level declines in the Indian Cove, Fortynine Palms, and Eastern Subbasins. A more detailed analysis of groundwater recharge would likely result in somewhat higher recharge, which may produce results with similar or slightly improved groundwater levels with respect to the results of this groundwater study.

Section 1: Introduction

This report presents the findings and conclusions of a comprehensive groundwater study of the Mesquite Lake Subbasin in the Twentynine Palms area. These efforts include an extensive review and summation of background material, groundwater characterization, and quantification of the various components of the hydrologic budget. The results of these efforts served as a foundation for the construction, calibration, and application of a numerical model of the basin.

1.1 Purpose

The Twentynine Palms Water District (TPWD) was formed in 1954. Until 2003, all water supplied to TPWD was extracted from the three subbasins in the southern part of the TPWD service area, the Indian Cove, Fortynine Palms, and Eastern Subbasins (Figure 1-1). Due to the arid environment of the area, there is limited groundwater recharge into these subbasins, and the increased pumping has resulted in groundwater level declines. Pumping has been concentrated in these southern subbasins because of the superior water quality compared to that in the Mesquite Lake Subbasin, where fluoride concentrations are of concern. In 2003, the first production well in the Mesquite Lake Subbasin (TPWD-TP-1) began providing water to TPWD, with that production now passing through the Twentynine Palms Fluoride Removal Water Treatment Plant. TPWD is considering increasing groundwater pumping in the Mesquite Lake Subbasin to 3.0 million gallons per day (MGD) by 2015, with a concomitant decrease in pumping in the Indian Cove, Fortynine Palms, and Eastern Subbasins.

The purpose of this study is to provide TPWD with an evaluation of the potential overall changes in groundwater conditions resulting from shifting of groundwater pumping from the Indian Cove, Fortynine Palms, and Eastern Subbasins to the Mesquite Lake Subbasin. To provide this evaluation, this groundwater study provides an analysis of the quantity of groundwater in the basin, the movement of groundwater through the aquifer, and sources and volumes of natural recharge. A numerical groundwater model was developed to investigate the effect of shifting groundwater production between the subbasins.

1.2 Scope of Work

The overall objective of this groundwater study is to provide TPWD with the requested evaluation of the overall impacts and benefits resulting from shifting of groundwater pumping between subbasins for the purpose of supporting decision-makers on determining the relative merits of implementing this project. The analysis for this groundwater study consists of two primary components:

- Groundwater characterization – The groundwater characterization provides the understanding of the regional groundwater system necessary to evaluate the impacts of shifting groundwater pumping between the different groundwater subbasins.

- Evaluation of changes in pumping – Changes in the distribution of groundwater pumping will have different impacts and benefits in the different groundwater basins. This evaluation will provide a quantitative assessment of these impacts and benefits based on the groundwater characterization.

To accomplish these objectives, the following forms the primary scope of work for the groundwater study:

- Summarize the current knowledge of the hydrogeology of the study area.
- Refine uncertain components of the hydrologic budget for the study area.
- Create and calibrate a numerical model that simulates the hydrologic conditions of the study area.
- Use the numerical model and other hydrologic methods as tools to predict the effect of shifting pumping in the future.

This report presents a comprehensive and detailed description of the Mesquite Lake Subbasin and other important groundwater subbasins in the area, through the development and use of the model as a tool. The tasks of this project include:

- Task 1 involves reviewing, compiling, and summarizing available data and information on the study area hydrology, and combining this knowledge to create a hydrogeologic assessment of the study area, from which the conceptual model of the study area hydrology could be created.
- Task 2 involves creating a detailed yearly hydrologic budget for the study area subbasins, for which some components had to be estimated based on hydrologic methods.
- Task 3 consists of planning, constructing, and calibrating a numerical groundwater model for the basin.
- Task 4 covers the development and analysis of the effect of various future build-out scenarios on water levels and boundary fluxes in the model domain, as well as sensitivity analyses on two different hydrologic parameters. Use the numerical model and other hydrologic methods are used as tools to predict the effect of shifting pumping in the future.
- Task 5 involves preparing this report to document the results of each of the previous tasks.

1.3 Previous Studies

The groundwater study is based in large part on review of previous groundwater studies in the area. Numerous previous studies exist for the study area, mostly performed by the U.S. Geological Survey (USGS). Recently, Nishikawa et al. (2003, 2004) performed a very extensive study on the hydrology of the Warren, Joshua Tree, and Copper Mountain Valley Basins in the southwestern part of the study area. This study includes a geochemical study of nitrate concentrations, and also a hydrogeological analysis of the area, including a numerical groundwater model. Importantly, the eastern boundary of this groundwater model abuts the western boundary of the Indian Cove Subbasin, providing information on the inputs into TPWD area from the west. Kennedy/Jenks/Todd (2007) conducted a comparable groundwater study of the Ames Valley, Johnson Valley and Means Valley Groundwater Basins for the Mojave Water Agency to the west of TWPD.

The California Department of Water Resources (DWR) produced a report in 1984 on the groundwater hydrology of the four subbasins in the TPWD area (the Indian Cove, Fortynine Palms, Eastern, and Mesquite Lake Subbasins), detailing groundwater production, changes in water levels, and especially the occurrence of fluoride in the area and its possible sources. This report was the first to look at TPWD area in isolation from the rest of the subbasins in the study area.

The most important early study on the area was performed by the USGS in cooperation with the U.S. Navy (USN), which then controlled the military base in the basin, now operated by the U.S. Marine Corps (USMC) and called the Marine Corps Air Ground Combat Center (MCAGCC). This study was published in two parts by Riley and Worts (1952, 1953). These researchers for the first time produced a comprehensive hydrogeological study of the area from the San Bernardino Mountains in the west to the Bullion Mountains in the east, and from the Oasis (or Pinto Mountain) Fault and Copper Mountain and related bedrock highs to the west in the south to Hidalgo (or Coffin) Mountain, the Mud Hills, Deadeye Mountain, and other bedrock highs in the north. This study covers the occurrence and extent of groundwater and surface water, as well as initial estimates of recharge and evapotranspiration (ET) in the various subbasins within the study area. It also gives a first look at the subsurface through documentation and testing of USN supply and test wells throughout the Surprise Spring, Deadman Lake, and Mesquite Lake Subbasins. This study also provides the first information on groundwater chemistry in the subbasins.

Section 2: Twentynine Palms Area

The Twentynine Palms area surrounds the city of Twentynine Palms, California, stretching to the north and west. The study area extends beyond the TPWD boundaries (Figure 2-1), including all of the groundwater basins bounded by the San Bernardino Mountains in the west, the Little San Bernardino Mountains in the south, the Bullion and Sheephole Mountains in the east, and a series of bedrock highs including Deadeye and Hidalgo Mountains and the Mud Hills in the north. The boundaries of the study area extend beyond those of TPWD, because the groundwater flow system contributing groundwater to the TPWD subbasins is much larger than the TPWD area. The study area contains a total of 13 individual groundwater basins (Figure 2-2).

2.1 Study Area

TPWD is located in the high desert of Southern California, approximately 72 miles due east of the City of San Bernardino and 35 miles northeast of the City of Palm Springs. TPWD service area encompasses approximately 86.6 square miles and includes the City of Twentynine Palms.

TPWD is located within the boundaries of two groundwater basin, identified as the Twentynine Palms and Joshua Tree Basins by DWR (2003). Faults and other barriers divide TPWD into four smaller subbasins; here termed the Indian Cove, Fortynine Palms, Eastern, and Mesquite Lake Subbasins (Figure 2-2). Groundwater in the study area is compartmentalized into a number of individual basins that are more or less separated from one another by hydrologic barriers, including bedrock ridges, faults, and folds. The degree of separation between these subbasins is dependent upon the character of the barriers separating them. Figure 2-2 also identifies the key geologic features that form the boundaries of these basins.

2.2 Twentynine Palms Water District

TPWD was formed in 1954 through the combination of three previously-existing, privately-owned water companies: Abell Water Company, Condor Mutual Water Company, and Pacific Water Company. TPWD purchased their wells, storage facilities, and piping to create its initial infrastructure. TPWD largely services single-family residences, with some multi-family residential units, commercial properties, and minor light industry. There is no community sewage system and wastewater is disposed of through individual septic tank and tile field disposal systems. From TPWD projections, population is anticipated to grow at a rate of about 2 percent annually, rising to 25,570 by 2030 (Kennedy/Jenks, 2005).

Residential development is currently the single largest land use within TPWD. Approximately 80 percent of the residential development is single-family homes. TPWD has an average density of 2.5 people per household (15,700 people with 6,320 residential connections). Commercial development composes less than 5 percent of the service area. There is no heavy industry in the area, and the largest employer is the MCAGCC. Population has grown very slowly and changes are most notable when the population at the USMC base fluctuates. Future projections of land use have the total development increasing with population, but the proportions of residential, commercial, and industrial development remaining the same as today (Kennedy/Jenks, 2005).

In 2008, the Groundwater Management Plan (GWMP) for TPWD was updated to reflect changes in the hydrology and groundwater extraction of the area, as well as to include the plans for the treatment plant in the Mesquite Lake Subbasin (Kennedy/Jenks, 2008). The Urban Water Management Plan (UWMP) was prepared in 2005, to help plan water resource management for the next few decades (Kennedy/Jenks, 2005). The Mojave Water Agency (MWA) produced a Regional Water Management Plan that includes a GWMP and UWMP in 2004 (MWA, 2004) for its area, which covers the basins west of the study area.

2.3 Water Production and Usage

TPWD water is derived solely from groundwater pumped from the supply wells located along the southern limit of the service area, plus one production well in the Mesquite Lake Subbasin (TPWD-TP-1). Currently, TPWD has ten active potable supply wells: five in the Indian Cove Subbasin, two in the Fortynine Palms Subbasin, two in the Eastern Subbasin, and one in the Mesquite Lake Subbasin. The remaining wells (three in the Indian Cove Subbasin, four in the Fortynine Palms Subbasin, one in the Eastern Subbasin, and one in the Mesquite Lake Subbasin) are inactive and/or used for groundwater monitoring. The locations of TPWD's production wells are shown on Figure 1-1. Available information indicates that more than 400 private wells have also been constructed within TPWD's service area (Kennedy/Jenks, 2008). Most of these wells are not currently operated.

Historical pumpage and water deliveries by TPWD have steadily increased since its formation in 1954. According to the UWMP (Kennedy/Jenks, 2005), the total water demand in the TPWD service area was 3,200 acre-feet (af) in 2004, with a projected demand of 3,450 af in 2010 and 3,760 af in 2015. Demand projections are given up to 2030, when the total pumpage is projected to be 4,680 af.

The existing TPWD production wells have produced up to 3,570 af (in 2002), a total that is projected to fall behind demand by 2012. The new treatment plant in the Mesquite Lake Subbasin is projected to provide 1.0 MGD in 2009, 1.3 MGD in 2010, 2.0 MGD in 2011, and finally 3.0 MGD in 2015. This will provide 3,360 acre-feet per year (afy) at full buildout. Using 2030 demand numbers, this leaves 1,320 afy to be pumped from wells in the Indian Cove, Fortynine Palms, and Eastern Subbasins.

2.4 Physical Setting

The features of the land surface (topography, vegetation, and soil) act as the interface and filter between atmospheric processes such as precipitation and the alluvial aquifers where groundwater is stored in the basins. Therefore, understanding the effect of land surface features on the hydrology of the study area is important.

2.4.1 Topography

The topography of the study area is dominated by mountain ranges of varying sizes separated by flat or gently sloping alluvial basins. The City of Twentynine Palms lies within a large alluvial basin bounded on all sides by mountain ranges of various sizes (Figure 2-3). The largest bounding mountain range is the San Bernardino Mountains to the west. This range is nearly continuous with the Little San Bernardino Mountains, which form the southern boundary of the basin, except for a small notch between the two that contains the towns of Yucca Valley and Morongo Valley and the highway connecting the basin to Interstate 10 to the south. A topographic drainage divide exists in this notch between the study basin and the small basins within the notch. Elevations in the San Bernardino Mountains reach 11,500 feet above mean sea level (asl) at San Gorgonio Mountain, and those in the Little San Bernardino Mountains reach 5,800 feet asl (Quail Mountain). The sides of these two mountain ranges abutting the basin are gentler than are their western and southern sides. The Little San Bernardino Mountains are more or less continuous with the Pinto Mountains to the east, which form the southern boundary of the easternmost part of the basin; their highest peak bounding the study area is Twentynine Palms Mountain, which reaches about 4,500 feet asl.

The north side of the basin is bounded by an array of northwest-southeast trending small mountain ranges that rarely exceed 4,000 feet asl, with the highest elevation being variously known as Coffin or Hidalgo Mountain (4,350 feet asl). The other important ranges along this boundary are Deadeye Mountain and the Mud Hills. Parallel to these ranges, but stretching the length of the basin and forming its northeast to eastern boundary are the Bullion Mountains, which reach over 3,800 feet asl along the study basin.

The only significant gap in the bounding ring of mountain ranges is that between the Bullion and Pinto Mountains, where rare extreme flood events leave the basin to collect in Dale Dry Lake to the southeast. This playa represents the ultimate terminus of both surface water (Riley and Worts, 1952) and groundwater (Riley and Worts, 1953) from the basin, which is thereby closed.

The basin floor itself has a gentle and fairly uniform slope to the southeast that is broken up by several bedrock outcrops. These include Copper Mountain (3,070 feet asl), Goat or Table Mountain (3,650 feet asl), the Bartlett Mountains (maximum elevation about 3,800 feet asl), Coyote or Bunker Mountain (2,750 feet asl), and the Zeitz Mountains (maximum elevation about 3,590 feet asl). Five subdued bedrock ridges run north-south through the eastern half of the basin, and these seem to be controlled by faulting (Riley and Worts, 1952). In addition to the bedrock outcrops, an interior divide called the Transverse Arch runs west to east from the Zeitz Mountains to the Bullion Mountains (Figure 2-3), representing a buried bedrock high (Londquist and Martin, 1991). Other than these interruptions, the basin floor falls slowly from about 3,600 feet asl along the San Bernardino Mountains on the west to about 1,800 feet asl along the Bullion Mountains to the east (Riley and Worts, 1952).

Low points within the basin floor are locations of internal drainage, and are occupied by playa lakes, which are almost always dry. Playa lakes within the basin include Emerson, Coyote, Deadman, and Mesquite Dry Lakes, as well as a small unnamed playa south of Mesquite Dry Lake and two small unnamed playas on the east side of Copper Mountain.

2.4.2 Vegetation

Due to the arid climate, vegetation is generally sparse throughout the study area. Two types of vegetation are present, and the difference between them is very important to the groundwater budget: xerophytic and phreatophytic vegetation. Xerophytic vegetation does not derive transpired water from the water table, instead collecting water from existing soil moisture. In contrast, phreatophytic vegetation directly taps the water table, and relies on shallow water tables to survive.

Only a few concentrations of phreatophytic vegetation exist in the study area, as described by Riley and Worts (1953). Of particular importance within the TPWD boundaries are the Oasis of Mara and Mesquite Dry Lake. The Oasis of Mara is a fairly small area of relatively dense vegetation, whereas Mesquite Dry Lake (and Mesquite Springs) is an extensive area of sparse vegetation.

Xerophytic vegetation exists throughout much of the study area, mostly concentrated in the small ephemeral streams that crisscross the land surface. The xerophytic vegetation is mostly shrubs. Rather than tapping groundwater for transpiration, xerophytic vegetation pulls water out of soil moisture, transpiring mostly during the wet season.

2.4.3 Soil

Soils form in place, and are therefore usually derived from the parent material on which they form (except in cases where significant windblown sediment is imported into the area). Three basic types of parent materials exist in the study area: bedrock, alluvium, and playa lakebeds. These three different parent materials can form very different soil types.

Thompson (1929) provided general descriptions of the soils in the Mojave Desert on the alluvial slopes and the playa lakes (from surveys in the area of Victorville and Apple Valley, northwest of the study area). All soils in this area were typified by having very little organic matter. Alluvial soils had little clay, generally being composed of weathered bits of rock. Some areas had caliche (layers of concentrated mineral salts), which can prevent downward movement of water, at depths from a few inches to a few feet. Alluvial soils make up most surfaces in the study area. Logs of wells in Riley and Worts (1953) indicate that soil thicknesses vary from 0 to 16 feet throughout the study area north of the Oasis Fault; presumably, similar figures would be found south of the fault.

Playa lake soils are typically very clayey and support little to no vegetation (Thompson, 1929; Nishikawa et al., 2004). These deposits vary from very hard and smooth to rough, depending greatly on the depth to groundwater; rough surfaces on the playas often indicate rising groundwater and active soil moisture evaporation. Playas with discharging groundwater are typified by accumulations of alkali and other mineral salts (Thompson, 1929), left behind by evaporating groundwater. These salts are particularly noteworthy in the area of Dale Dry Lake.

Soils overlying bedrock are typically thinner than other soils (USDA, 1994, as cited in Nishikawa et al., 2004), and made up mostly of pieces of the parent material on which they lie. These soils tend to be medium- to coarse-grained and include little silt and clay.

DWR (1984) included some information on soils for the TPWD area from a soil survey performed by the U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS) for the southwestern part of San Bernardino County (USDA, 1970). This survey indicated that soils in the Indian Cove Subbasin have above average infiltration and moderate permeability of 2.5 to 5.0 inches per hour, while the Fortynine Palms and Eastern Subbasin soils have below average infiltration and lower permeability of 0.2 to 0.8 inches per hour. As DWR (1984) notes, these are general classifications, and may not apply to localized parts of the basins. However, soils in the study area can likely be classified as having generally below average to average infiltration and low to moderate permeability, except on the playa lake surfaces, where infiltration is likely negligible and permeability is very low.

2.5 Climate

The study area varies from arid in its lower elevations to semiarid in the upper elevations (Troxell et al., 1954). San Bernardino Mountains to the west produce a rain shadow effect on the basin. This orographic effect causes most precipitation falling out from Pacific-derived air masses onto the mountains west of the topographic divide due to uplifting of the air masses (Riley and Worts, 1952). This distribution is true in general, meaning that the west sides of all mountain ranges bounding the basin are wetter than their eastern sides.

The climate of the Twentynine Palms area is typified by hot summers and mild winters. At the Twentynine Palms weather station, monthly average low temperatures range from 36°F in December and January to 72°F in July. Monthly average high temperatures vary from 63°F in December and January to 105°F in July. Temperatures also change spatially. Monthly average maximum temperatures decrease with increasing elevation; however, monthly average minimum temperatures did not show a significant relationship with elevation, indicating that the monthly average minimum temperature is not very different in the lower mountains and the basin floor.

Precipitation at the Twentynine Palms weather station averages 4.25 inches per year. The highest recorded rainfall was 12.32 inches in 1983 and the lowest was 0.74 inches in 1972. Precipitation was analyzed across the region with a period of records ranging from 3 to 75 years (Appendix B). Average annual precipitation ranges from less than 2.5 inches in the valleys to the east to over 6 inches per year in the San Bernardino Mountains to the west. Precipitation generally has a bimodal precipitation, with rainy seasons in the summer and winter (Friedman et al., 1992). Summer precipitation results from the import of monsoonal moisture from both the Gulf of California and the Gulf of Mexico (Troxell et al., 1954). Winter precipitation results from the movement of moisture east from the Pacific Ocean. Summer monsoon storms result from convective uplift of air over the basin floors, and tend to be typified by high-intensity, short duration rainfall events. Winter rainfall results from the orographic uplift of moist air fronts, and generally is lighter in intensity and longer in duration. Extensive statistical analyses performed on precipitation in the area, summarized here, are presented in detail in Appendix B.

ET is the process by which liquid water is transformed to water vapor; in evaporation, liquid water on or beneath the ground surface turns directly to vapor, while in transpiration this process is mediated by plants, which take in liquid water from the soil and release water vapor from their leaves. Because this area is so hot and arid, ET is very high. The reference evapotranspiration (ET_0, a semi-empirical quantity defined as the ET of a grass crop under standardized conditions, with water not limiting) at Joshua Tree was reported as 66.5 inches per year (Nishikawa et al., 2004), outstripping the annual precipitation rate by an order of magnitude.

2.6 Hydrology

In the arid to semiarid environment of the Twentynine Palms area, surface water is generally rare, localized, and short-lived. Exceptions exist, especially during extreme events. Surface water exists in the basin in three different forms: streamflow, playa lakes, and spring flow. The locations of surface water bodies are shown on Figure 2-3.

2.6.1 Streamflow

There are no perennial streams in the study area. Most stream channels in the Twentynine Palms area only flow ephemerally in response to the largest storms. Runoff is primarily generated in the mountains, but is quickly lost as recharge to the mountain front alluvial deposits, leading to very little surface flow leaving this area (Troxell et al., 1954). A substantial amount of runoff that actually passes the mountain front area and reaches the basins is then lost to evaporation (Kennedy/Jenks, 2001, 2008).

The San Bernardino and Little San Bernardino Mountains represent a large surface water divide, with channels on the north and east sides of the ranges tributary to the Great Basin, and channels on the south and west sides tributary to the Pacific Ocean (Troxell et al., 1954). The study area contains several surface water drainage basins that ultimately end in the various playa lakes, meaning that surface water is confined within the basins. In the event of an extraordinary stormflow, water may reach Dale Dry Lake (Thompson, 1929).

Nishikawa et al. (2004) present streamflow data from four USGS stream gages at Quail Wash, Pipes Creek, Long Creek, and Fortynine Palms Creek (Figure 2-3). Over the period of record, Quail Wash had measurable flow on an average of 0.9 days per year, totaling 1.1 afy. Fortynine Palms Creek had measurable flow on an average of 2.4 days per year, totaling 74.3 afy. These four gauges show streamflow to be highly intermittent, with the duration of surface flows limited to only 1 to 2 days in response to storms (Nishikawa et al., 2004). Long Creek, which had the highest average and maximum discharges, drains to the south side of the Little San Bernardino Mountains, and is therefore not strictly in the study area, although it heads in the northern foothills of the mountains, cutting across them.

2.6.2 Playa Lakes

Playa lakes form at the lowest elevations in a number of the surface drainage basins in the study area (Figure 2-3). These dry lakes represent, in some cases, the end of surface water drainages (as Emerson Dry Lake near the end of Pipes Wash). In other cases, they are topographic low points in their respective basins, where surface water ends up if runoff is high enough. The playa lakes in the study area are rarely sites of surface water collection, as runoff is too ephemeral to reach them.

2.6.3 Springs

Water discharging at springs has long been the most important hydrologic feature in the study area as the only easily available source of water. As early as 1921, the USGS mentioned the line of springs at Twentynine Palms known as the Oasis of Mara (Figure 2-3). Thompson (1929) noted that the springs here were about a mile long, and supported lush vegetation. Discharge at the time reached about a half mile out into the desert from the spring before being lost to infiltration and evapotranspiration. The Oasis of Mara, and other scarce surface water resources, became natural locations of development in this arid area, with towns concentrated around good water sources. Wells existed near the Oasis of Mara even at the time of the second Thompson report (1929). Riley and Worts (1953) noted that no water was at the surface at the Oasis of Mara in 1952 and 1953, indicating a great reduction in discharge from the spring here. This location has not been mentioned in more recent reports as a location of surface discharge, indicating that the spring has dried up.

Two other springs exist within the alluvial basins (Figure 2-3). Mesquite Spring once consisted of at least two pools, each 3 to 4 feet across and 2 feet deep, supporting a discharge of water that flowed about 200 feet into the desert (Thompson, 1929). No water level declines are noted in the area (Kennedy/Jenks, 2001, 2008), but discharge is not mentioned at this location in any report other than Thompson (1929), indicating that it likely has not had surface flow for some time. The other spring within the alluvial basin is Surprise Spring. At this location, Londquist (1991) mentions a pre-development discharge rate of 15 afy. A well drilled west of the spring had an artesian flow of 10 gpm in December 1951, drying the spring (Riley and Worts, 1952); flow had ceased by 1955 (Londquist, 1991). No other report mentions surface discharge at this spot, indicating that it is still dry.

Springs also exist in the mountain ranges bounding the study area. Many of these springs are supported by flow from fracture zones in the consolidated bedrock (Riley and Worts, 1952). Bader and Moyle (1958) reported on ten springs southwestern of the study area (around Morongo Valley), all of which issue within the mountains. Nishikawa et al. (2004) note that a few springs exist in the area of Joshua Tree, but that they are restricted to the higher elevation areas and many of them only flow during times of high annual precipitation. Because the discharge from mountain springs are not mentioned as providing runoff to the alluvial basins, it most likely disappears quickly after reaching the surface due to infiltration and/or evapotranspiration.

2.7 Geology

The geology of the basin is typical of many extensional basins throughout the western United States. Basin-bounding ranges are fronted by normal faults along which they have risen relative to the basin floor (Riley and Worts, 1952). Over time, the basin has filled with highly heterogeneous deposits. The sediments within the basin have been buried progressively deeper as more sediments have been laid down on top of them; those at the greatest depth are more compacted than are those near the ground surface. The basin geologic system is defined by the bedrock geology, the recent alluvial geology, and the structural features in the basin. The geologic descriptions given here are expanded in Appendix A.

2.7.1 Geologic Setting

The Twentynine Palms Basin is in the eastern Mojave Desert geomorphic province. The principal landforms are Cenozoic alluvial fans and alluvial plains bordered by mountains composed of Precambrian and Mesozoic igneous and metamorphic basement rock. Although the Cenozoic age of the basin-filling alluvial sediments in the Twentynine Palms Basin is known with reasonable certainty, the specific period during which particular sedimentary packages were laid down is less clear. Riley and Worts (1952, 1953) suggested that most of the alluvium was deposited during the Tertiary. This age assignment was based on indirect evidence, such as the apparent slight regional discordance of much of the sediments relative to the present-day land surface, and lithologic similarity to Miocene and Pliocene deposits in other parts of the Mojave Desert. On the other hand, Riley and Worts (1953) also noted that the lack of feldspar decomposition products (i.e., clay) in these deposits might indicate a Quaternary age. Later work suggested that a higher proportion of the sediments, especially in the southern parts of the basin, were more likely to be Quaternary-aged (Bedford and Miller 1997; Nishikawa et al. 2004).

2.7.2 Structural Geology

There are three sets of faults running through the basin (Riley and Worts, 1952): a set of normal faults running northwest, a second set of faults running almost due north, and a third set comprising three faults running east-west across the south end of the basin. Some of the faults are more important than others to the basin hydrogeology, as will be described later, and have therefore been more thoroughly studied. These faults are described herein. Large faults within the mountain complexes are not discussed in this report.

The first set of faults consists of five major faults that cross the basin in a generally north-northwest to northwest direction. The easternmost is the Mesquite Fault, which runs along the west side of the Bullion Mountains from the foothills of the Pinto Mountains in the south to the Mud Hills in the north (Riley and Worts, 1952). Deadman and Mesquite Dry Lakes are located directly on top of this fault. The next major fault to the west is the Surprise Spring Fault (also known as the Hidalgo Fault, Lewis, 1972), which runs from Hidalgo Mountain in the north to at least Surprise Spring , and probably further south (Riley and Worts, 1952). The Emerson Fault runs northwest from the northwest tip of Copper Mountain to the eastern boundary of Deadeye Mountain (Londquist and Martin, 1991). The Copper Mountain Fault runs north along the western edge of Copper Mountain, intersecting the Emerson Fault northeast of Goat Mountain. The Reche Fault (also known as the Homestead Valley Fault; Kennedy/Jenks/Todd, 2007) goes along the northeast side of Reche Butte, runs south across Pipes Wash, and perhaps reaches the northwest tip of the Zeitz Mountains, although it may pass all the way to the Oasis Fault (Riley and Worts, 1953). Londquist and Martin (1991) map this fault as reaching all the way from the Bartlett Mountains to the southern tip of Deadeye Mountain. Finally, the Pipes Fault (part of which correlates to the Johnson Valley Fault in Kennedy/Jenks/Todd, 2007) runs along the eastern edge of the San Bernardino Mountains to the Oasis Fault in the south (Riley and Worts, 1953).

A second set of faults runs generally north-south, with faults most important in the southern end of the basin and dying out toward the north. The easternmost of these faults is the Elkins Fault, which runs north from the Oasis Fault just east of Copper Mountain north to the eastern edge of Hidalgo Mountain (Riley and Worts, 1953). A second, unnamed fault goes north from Copper Mountain to Surprise Spring Fault. Finally, the Sand Hill Fault runs north from Coyote Mountain to run into the Emerson Fault (Riley and Worts, 1953).

The third set of fault runs east-west along the southern end of the basin. The Pinto Fault is not located positively, but is inferred to stretch across the entire basin (Riley and Worts, 1953). The Oasis Fault (also known as the Pinto Mountain Fault in many references), which was reported by Thompson (1929) as having a scarp 15 to 30 feet high next to the Oasis of Mara, is more or less parallel to the Pinto Fault, and about a mile north; these two faults bound a down-dropped block. Riley and Worts (1952) note that the Oasis Fault is not positively located at its west end, although later references (e.g. Nishikawa et al., 2004) show the fault extending at least to the western end of the study area. The Bagley Fault is about half a mile north of the Oasis Fault in the area of Twentynine Palms, and intersects with the Oasis Fault nearly 4 miles west of Adobe Road.

Several other faults do not fall into the three fault sets described above, but are visible on geologic maps and may be important to the hydrogeology. These faults are not named. One runs from the Pinto Fault in the area of Fortynine Palms Mountain northwest, terminating at the Elkins Fault (Riley and Worts, 1952). A second runs west-northwest from the foothills of the Bullion Mountains along the south end of the Mud Hills. The third is present along the southern edge of Ames Dry Lake, terminating on its east side at Hidalgo Mountain (Londquist and Martin, 1991). This fault was indicated partially by gravity surveys and partially by its effect on groundwater flow in the area. Two faults are present just west of Surprise Spring, extending at least as far south as Surprise Spring Road (Londquist and Martin, 1991); these faults show about 150 feet of displacement on their east sides. There is another fault a little east of Emerson Fault, which may be a northern extension of the Copper Mountain Fault.

In addition to the faulting in the area, folding has played a significant role in the geology and hydrology of the basin. The Transverse Arch represents an anticlinal fold or structural arch (Riley and Worts, 1952) that brings bedrock to within 500 feet of land surface (Londquist and Martin, 1991), with a cap of fine-grained sediments (Riley and Worts, 1953). Folding in the Mud Hills is also important to the basin structure (Riley and Worts, 1952).

2.7.3 Units

The geologic units present in the study area can be classified into four categories: pre-Tertiary and Tertiary to Quaternary bedrock units, Tertiary to Quaternary alluvial units, and Quaternary playa sediments. Further information on each of these units is available in Appendix A.

- Pre-Tertiary Bedrock: The bedrock of the mountain ranges is mostly made up of Precambrian igneous and metamorphic rocks and Jurassic-aged granite (Rogers, 1967). The Precambrian igneous and metamorphic rocks are a mixture of gabbro-diorite, gneiss, granite, and monzonitic porphyry (Riley and Worts, 1952), and are labeled pC or pCc on the geologic map (Figure 2-4). The Jurassic-aged granite (labeled grMz) intruded into the preexisting Precambrian rocks before solidifying.

- Tertiary to Quaternary Bedrock: Minor Tertiary basalts (dated as early Quaternary in Riley and Worts, 1952 and late Tertiary in Rogers, 1967) exist in the easternmost foothills of the San Bernardino Mountains, making up Black Lava Butte, Flat Top, and Black Hill (Tv on Figure 2-4). The basalt flows reach up to 200 feet thick, and also act as capstones, preventing the erosion of underlying sediments, leading to their 400 to 600-foot elevation over the surrounding basin floor (Riley and Worts, 1952).

- Tertiary to Quaternary Alluvium: Alluvium began filling the basin as early as the basin first was created through normal faulting along what are now mountain fronts, reaching thicknesses of possibly more than 4,500 feet in the middle of the Joshua Tree Subbasin, west of the TPWD basins (Nishikawa et al., 2004). Following the convention of Nishikawa et al. (2004), the sediments can be divided into a lower, Tertiary-aged layer, overlain by two Quaternary-aged layers. The thicknesses of the two Quaternary layers are about 400 feet each, while the Tertiary unit fills the rest of the basins. These layers are presented as Q on Figure 2-4. These layers are typified by fairly coarse deposits, containing mostly sand and gravel clasts with more minor proportions of silt and clay. The lower, Tertiary unit is slightly more compacted and cemented than are the Quaternary units. The alluvial units are discussed in more detail in Appendix A.

- Quaternary Playa Sediments: The numerous playa lakes in the area are visually obvious due to the presence of very fine sediments (silts and clays). Quaternary lake deposits (lumped into Q on Figure 2-4, but labeled separately as Ql on the map of Rogers, 1967) are present at Deadman, Mesquite, Coyote, Ames, and Emerson Dry Lakes, as well as several more unnamed lakes throughout the basin. These sediments generally rest directly on Quaternary sediments. Their thicknesses are mostly unknown, although at Mesquite Dry Lake they are at least 45 to 49 feet; the smaller playa lakes likely contain thinner deposits. As climate has dried out since the late Pleistocene, these dry lakes have become less and less important as locations of deposition; indeed, Riley and Worts (1952) speculate that any addition of sediment that has occurred in recent times has been nullified by the action of wind erosion.

2.7.4 Regional Correlations

Data from the TPWD well logs, the geologic map of Rogers (1967), two previous nearby hydrogeological studies, and two previous gravity surveys were interpreted and synthesized to construct six geological cross sections. For these cross sections, the alluvial deposits are subdivided into three layers consistent with the interpretation by Nishikawa et al. (2004). The upper two layers are each defined to be approximately 400 feet thick, except where offset by faults or interrupted by subsurface bedrock highs. The contact between the upper two layers is not restricted to a pre-determined elevation. Instead, the upper aquifer unit extends to approximately 400 feet below the ground surface and the middle aquifer unit extends to approximately 800 feet below ground surface. The lower aquifer unit is present below the middle aquifer unit, extending to the depth that bedrock is encountered. Where the bedrock is shallow, the lower and/or middle aquifer units are absent.

Depth to bedrock is constrained only at the two well locations where bedrock is encountered and at or near surface bedrock outcrops. At all other locations, depth to bedrock is inferred by the presence of faults and by the gravity maps of Moyle (1984) and Roberts et al. (2002). It should be pointed out that the depth to bedrock interpretations presented in Cross-sections A-A' through F-F' are consistently conservative, such that the thickness of basin sediments are not overestimated.

Six cross-sections were created to demonstrate the subsurface geology and how it varies throughout the TPWD area, as well as how the geology of this area correlates with that in adjacent basins. The cross-sections show the bedrock and alluvial units and the location of various faults in the area. The locations of these cross-sections are shown on Figure 2-5.

Cross-section A-A' (Figure 2-6) runs west-east primarily through the Indian Cove, Fortynine Palms, and Eastern Subbasins, where sediment thicknesses are generally greatest. The boundary with the Joshua Tree Subbasin to the west is clearly marked by the large offset along the Pinto Fault. The bedrock high in the middle of the cross-section is inferred from a gravity map (Roberts et al. 2002). The Oasis and Mesquite Faults are encountered on the eastern side of the cross-section, just to the north of where they merge, showing a small amount of offset and shallow bedrock depths. A small section of the Mesquite Lake Subbasin is encountered between these two faults.

Cross-section B-B' (Figure 2-7) runs southwest-northeast through the Fortynine Palms and Mesquite Lake Subbasins. The southernmost portion of the cross-section extends past the Pinto Fault and into the Little San Bernardino Mountains. The offsets along faults are largely inferred from mapped and interpreted relative fault motions. The dramatic increase in sediment thickness beneath TPWD-18 is an interpreted continuation of the bedrock trough and vast sediment thickness encountered at TPWD-TP1 (see also Cross-sections C-C', D-D', and F-F'). The existence of the bedrock trough is supported by the gravity map of Roberts et al. (2002).

Cross-section C-C' (Figure 2-8) runs northwest-southeast through the deepest part of the Mesquite Lake Subbasin, and into the Eastern Subbasin. The bedrock trough through TPWD-18 and TPWD-TP1 can be seen on the northwestern side of the cross-section. The southeastern side is dominated by faults and uplifted bedrock.

Cross-section D-D' (Figure 2-9) runs southwest-northeast through a section of the Indian Cove Subbasin, the Fortynine Palms Subbasin, and the Mesquite Lake Subbasin. Sediment thicknesses are generally shallow along D-D', except where the bedrock trough in the Mesquite Lake Subbasin is encountered around TPWD-TP1.

The graben between the Pinto and Oasis Faults is illustrated in Cross-section E-E' (Figure 2-10). The southwestern trace of the cross-section is the same as the western trace of A-A', but E-E' continues to the northeast beyond TPWD-10 and on across the shallower parts of the Mesquite Lake Subbasin. The aquifer units are relatively thin across much of the Mesquite Lake Subbasin because of the large bedrock high shown between the Oasis and Mesquite faults. The presence of this interpreted bedrock high is indicated by a bedrock outcrop that can be seen on the geologic map of Riley and Worts (1953), and inferred from aerial photography.

Cross-section F-F' (Figure 2-11) runs parallel to and southeast of Cross-section B-B'. These two cross-sections share the same general features. The southernmost portion of the F-F' extends past the Pinto Fault and into the Little San Bernardino Mountains. The offsets along faults are largely inferred from mapped and interpreted relative fault motions. The dramatic increase in sediment thickness west of the Mesquite Fault is defined by the bedrock trough beneath TPWD-TP1. This trough can be seen on the cross-sections presented herein, with the exception of A-A' (Figure 2-6).

Section 3: Groundwater

Since the beginning of increased development in the area, groundwater has been the most important source of water in this area. This section of the report discusses the inputs and outputs to groundwater, its compartmentalization, historic usage and declines, aquifer extents and parameters, and estimates of storage.

3.1 Aquifers

Groundwater in the study area is primarily present in Tertiary to Quaternary alluvium deposits (Riley and Worts, 1953). The ability of these materials to provide water to wells depends on their various properties. This section summarizes the materials and properties of the aquifers in the study area, while they are described in more detail in Appendix A.

Alluvium fills the study area basins from the bedrock surface to the land surface. The thickness of alluvium varies from zero near the mountain fronts to a possible thickness of more than 15,000 feet in the area of the Deadman Dry Lake (Roberts et al., 2002). Although previous sediment thickness figures do not exist for the TPWD area, this study estimated them to reach up to about 1,700 feet in the western part of the Indian Cove Subbasin (see Figure 2-6).

The alluvium is highly variable vertically and horizontally. Riley and Worts (1952) described the makeup of the sediments in the area of the Mud Hills (in the northeastern extremity of the study area) as being made up of interbedded fine to medium sand, medium to very coarse sand with lenses of pebble to large cobble-sized gravel, very fine, silty sand, and silty, sandy clay. Additionally, because the mountain fronts are the depositional area with the greatest energy in the basin system, these areas tend to have the coarsest alluvium (Kennedy/Jenks, 2001, 2008). The parts of the basin furthest from the mountain fronts, on the other hand, experience little depositional energy, and tend to host finer sediments.

Previous hydrogeological studies discussed above have defined Tertiary and Quaternary alluvial aquifer units of approximately constant thickness. Londquist and Martin (1991) used two layers, with the contact between the two generally placed at around 1,900 feet elevation, except where offset by faults. Nishikawa et al. (2004) defined three aquifer units. The lower unit was considered to occur below approximately 1,500 feet elevation. The contact between the middle and upper units occurs at approximately 2,000 feet elevation. Although different methods were used to differentiate the sediments, the convention of Nishikawa et al. (2004) is used for this groundwater study.

3.1.1 Tertiary Alluvium

The Tertiary alluvium directly overlies the bedrock. Riley and Worts (1953) described the analogous sediments in the Mud Hills area as being made up mostly of clayey sand, while Nishikawa et al. (2004) describe the unit in the Joshua Tree Subbasin as representing somewhat consolidated fanglomerates containing clasts of granite and gneiss. According to the cross-sections in Nishikawa et al. (2004), this unit reaches a saturated thickness of up to 3,000 feet. The maximum saturated thickness of this unit within the TPWD area is about 1,700 feet along the western edge of the Indian Cove Subbasin.

Sediments that have become deeply buried tend to be more consolidated, compacted, and cemented with depth. Therefore, the deepest sediments tend to be less transmissive of water than are the upper sediments. The hydraulic conductivity, K, is around 0.5 to 1 ft/d, while the transmissivity, T, is on the order of 750 ft^2/d. The specific yield, S_y, of this unit is 0.05, while the specific storage (S_s) is estimated to be 1×10^{-6} ft^{-1}. Because of the low transmissivity and specific storage of this unit, it is generally considered fairly unimportant as a source of water (Londquist and Martin, 1991).

3.1.2 Quaternary Alluvium

The lower Quaternary alluvium overlies the Tertiary alluvium. This unit is mostly (60 percent) made up of beds of coarse sand with little clay, with the rest composed of finer-grained beds made up of very fine silty sand to clay (Riley and Worts, 1953). The thickness of this unit varies from zero along the basin margins to a maximum of 400 feet in the western Indian Cove and eastern Mesquite Lake Subbasins and throughout much of the Joshua Tree Subbasin. K for this unit varies from 0.5 to 60 ft/d, and T varies from about 200 to 36,000 ft^2/d. S_y of these sediments varies from 0.12 to 0.14, while S_s is about 1×10^{-6} ft^{-1}.

The upper Quaternary alluvium is made up of unconsolidated sand and gravel. The thickness of this unit reaches about 400 feet in the Joshua Tree Subbasin, with a saturated thickness of 300 feet. Within the TPWD area, the sediment thickness is assumed to be about 400 feet. K for this unit varies from 5 to 60 ft/d, and T varies from 600 to 56,000 ft^2/d. S_y varies from 0.08 to 0.23.

3.2 Regional Groundwater Movement

This section provides a summary of the regional groundwater flow to provide context for evaluating how groundwater moves through the basins in the study area.

3.2.1 Regional Groundwater Elevation Maps

A series of groundwater elevation maps were developed for the entire region based on available groundwater elevation data. These regional groundwater maps demonstrate the regional groundwater flow and the interconnection between the various groundwater basins in the area. Groundwater maps are presented for 1947 (Figure 3-1), 1982 (Figure 3-2) and 2008 (Figure 3-3) to give a 60-year perspective on changes in groundwater levels in the region.

The primary source of groundwater in the study area is runoff from precipitation that falls in the adjacent highland areas. This is reflected on the groundwater elevations maps (Figures 3-1, 3-2, and 3-3) by the highest groundwater levels that occur near to the adjacent highlands. Recharge occurs primarily along the mountain fronts on the western and southern boundaries of the study area. Most of this recharge enters the Pipes Subbasin, with smaller amounts coming into the Pipes, Joshua Tree, Fortynine Palms, and Eastern Subbasins.

The interconnection between the various groundwater basins is primarily controlled by faults that extend across the basin. These faults act as barriers that limit the volume of groundwater that flows into the adjacent basin. These barriers are reflected on the groundwater elevations maps (Figures 3-1, 3-2, and 3-3) by distinct change in groundwater elevations, in some cases over 100 feet, across some of these faults. For some of these basins that are not adjacent to the highlands, this groundwater flow across the faults is the primary source of recharge.

Understanding this regional context is important for understanding how groundwater levels within an individual basin may respond to changes in groundwater pumping. A more detailed summary of regional groundwater flow and the interconnection between the groundwater basins is provided below.

3.2.2 Regional Groundwater Flow

Recharge that occurs in the Pioneertown Subbasin flows across the basin before entering the Pipes Subbasin to the east. This basin is very narrow and elongated in the north-south direction, and represents sediments between the San Bernardino Mountains and the Pipes Fault just to the east. Minor volumes of recharge also enter this basin from the mountains, but most of its supply comes from the Pioneertown Subbasin. The Pipes Fault, like many other faults in the study area, is an effective barrier to groundwater flow, due to a variety of reasons (Riley and Worts, 1952; Kennedy/Jenks/Todd, 2007). This barrier effect causes groundwater to flow mostly to the north in this basin, although groundwater likely slowly crosses the Pipes Fault along its entire length. Depending upon location along the fault, there is a drop in head of about 20 to 150 feet across the fault.

Water that leaves the Pipes Subbasin enters the Reche Subbasin to the east. This basin (and most of the others east of the Pipes Fault and north of the Oasis Fault) receives little to no recharge except from groundwater flow from adjacent basins. Water entering this basin flows northeast to east across the basin, generally following the surface expression of Pipes Wash. Groundwater flows east across the Reche Fault between Reche Butte and the Zeitz Mountains to the south, entering the Giant Rock Subbasin. At this point, the surface trace of Pipes Wash diverges from the groundwater flow, continuing north between Reche Butte and Spy Mountain, then turning east along the southern extent of Deadeye Mountain, flowing north along its eastern side, and terminating in Emerson Dry Lake. At the southern end of Deadeye Mountain, the wash spreads out into a fan configuration, indicating that some significant part of what surface flow reaches here may disperse in this area, either recharging or being lost to ET.

Within the Giant Rock Subbasin, groundwater flows away from its entry point to the east and the southeast. There is likely little to no groundwater that flows into the northern part of the basin around the east side of Goat Mountain. Because of the paucity of data in the southern part of the basin and the northern part of the Copper Mountain Subbasin, it is unclear whether any groundwater flows south across the western end of the Transverse Arch. The head in the Copper Mountain Subbasin is lower than that in the Giant Rock Subbasin, but the intervening topography is quite rugged, indicating the possible presence of bedrock highs that might restrict groundwater flow. It seems more likely that the majority of the groundwater in the Giant Rock Subbasin flows east across the Emerson and Sand Hill Faults into the Surprise Spring Subbasin.

After entering the Surprise Spring Subbasin, groundwater flows eastward toward the surface expression of Surprise Spring. Water levels indicate that water flows toward Surprise Spring from the northern part of the basin as well. There may be some water leaving the basin south across the Transverse Arch into the Mesquite Lake Subbasin (Riley and Worts, 1953), but

Londquist and Martin (1991) do not include this flux in their groundwater model. There is a water level difference of about 175 feet across the Arch, and Riley and Worts (1953) state that it is a “strong” barrier to flow. Since the 1950’s, groundwater levels at Surprise Spring have dropped substantially enhancing the effect of the natural depression that exists in the water table here.

According to the geologic map (Rogers, 1967), the fault is buried at Surprise Spring. However, groundwater may have actually flowed over the fault rather than through the fault plane; therefore, the ability of this fault to restrict flow is unknown. As groundwater head levels drop below the top of the fault plane, it is unknown the degree to which groundwater flux between these two basins will decrease. Londquist and Martin (1991) did not model the uppermost sediments as not faulted, and determined a conductance of 0.43 ft/d. If the fault plane does not reach to the surface, this calibrated conductance would be much too high. For this study, it was assumed that 90 percent of the groundwater discharging from the basin leaves the basin through the Surprise Spring Fault, with the remaining 10 percent crossing the Transverse Arch.

Within the Deadman Lake Subbasin, groundwater flows east across or around the north end of the Elkins Fault. There is likely little to no groundwater flow southward across the Transverse Arch between the Surprise Spring and Elkins Faults, as the differences in groundwater elevations across the Arch are minor (although data are sparse). Some of the groundwater flow moving east of the Elkins Fault is lost as ET at Deadman Dry Lake. It is assumed that the rest of the water flows south across the Transverse Arch into the Mesquite Lake Subbasin (Riley and Worts, 1953), but groundwater levels are only about 30 feet lower in the Mesquite Lake Subbasin. Groundwater may also flow east across the Bullion Fault, and then south along the front of the Bullion Mountains, where water levels are up to 200 or more feet lower than in the Mesquite Lake Subbasin.

What happens to groundwater once in the Copper Mountain Subbasin is unclear. The surface of Coyote Dry Lake is considered too impermeable to allow for ET, and groundwater levels are below the surface of the lake. Other than the Mesquite Lake Subbasin, all other neighboring basins have higher water levels, indicating that groundwater could flow east into the Mesquite Lake Subbasin. Lewis (1972) speculated that groundwater may flow around the southern end of Copper Mountain, north of the Oasis Fault, but he notes that there are no data to support this hypothesis. Groundwater may also flow around the northern end of Copper Mountain or may flow through fractures in the mountain block itself to the Mesquite Lake Subbasin. According to the water budget, about 100 afy of groundwater leaves this basin and it is assumed that it reaches the Mesquite Lake Subbasin.

3.2.3 Groundwater Flow Within the Study Area

The three basins south of the Oasis Fault (the Indian Cove, Fortynine Palms, and Eastern Subbasins) get recharge at the mountain front of the Little San Bernardino Mountains to the south. Groundwater recharged at the mountain front moves north and east across the basins, running up against and crossing (or, more likely, overtopping) the Oasis Fault to reach the Mesquite Lake Subbasin to the north. In the southwestern part of the Mesquite Lake Subbasin, bedrock is at or near the land surface, so groundwater may flow around the southern part of this ridge, crossing both the Chocolate Drop and Bagley Faults in the process.

The Mesquite Lake Subbasin also collects water from the basins along the southern edge of the study area. Recharge enters the Joshua Tree Subbasin from the Little San Bernardino Mountains to the south; because this basin is located along the higher and more windward side of this mountain range, it gets more recharge than do the basins to the east. Groundwater also flows into this basin from the Warren Valley Basin to the west (Nishikawa et al., 2004). Water flows northward across the Joshua Tree Subbasin away from the mountain front, with an additional eastward component. Groundwater levels are lower in the Copper Mountain and Indian Cove Subbasins, and groundwater likely outlets to both of these basins. Nishikawa et al. (2004) showed that no groundwater flows east into the Indian Cove Subbasin, but this may be because they set the conductance of the barrier between the two basins very low. There is a head difference across this barrier of about 34 feet prior to development, and more than 100 feet by 2008. For this study, it is assumed that 10 percent of the groundwater outflow goes into the Indian Cove Subbasin, with the remainder entering the Copper Mountain Subbasin.

In the Mesquite Lake Subbasin, groundwater flow converges toward the area of Mesquite Springs and Mesquite Dry Lake, which are at the topographic low point in the basin. Here, water is discharged as ET at the surface prior to development. All groundwater not lost as ET flows either over or through the Mesquite Fault into the Dale Basin to the east. Once in the Dale Basin, water continues to flow eastward toward the area of Dale Dry Lake, which is the topographic low point for the entire study area. There is no outlet from this basin, so all water in the system is lost here. The water is discharged from the lake area as ET. From aerial photography, it does not seem that there is significant vegetation in the area, so discharge occurs as evaporation from the lake sediments.

3.3 Groundwater Basins

The study area includes four groundwater subbasins. The Mesquite Lake Subbasin, the northernmost and largest of the four groundwater basins, is separated from the much smaller Indian Cove, Fortynine Palms, and Eastern Subbasins by the Oasis Fault, an east-west trending structure that is a major barrier to groundwater flow. The low permeability of the Oasis Fault has led to the formation of several springs and oases. The three smaller basins abut the Mesquite Lake Subbasin along the Oasis Fault, and are separated from each other in the east-west direction by inferred faults or flow barriers, across which significant changes in groundwater elevations occur. The three smaller subbasins are bounded on the south by the Little San Bernardino Mountains.

The subbasins are separated from one another by hydrologic barriers that include bedrock ridges, faults, and folds. The degree of separation depends a great deal on the permeability of the hydrologic barriers, as well as their continuity. This section defines the individual basins within the study area, as well as their bounding barriers and the degree to which they are effective (Figure 2-1).

The effectiveness of a fold, such as the Transverse Arch, depends on the degree of folding, and how deformed are the sediments within the fold. Also, an anticline (where the center of the fold is pushed upward, while the sides, or limbs, of the fold are pushed downward) would make a more effective barrier than would a syncline, where the center of the fold is pushed downward. Finally, a fold whose center is made up of bedrock would make a more effective barrier than would one cored by sediments.

Faults make effective barriers for several possible reasons (Riley and Worts, 1952). Sedimentary beds can be tilted near the fault, reducing horizontal conductivity. With movement along the fault, beds of differing permeability can be juxtaposed across the fault, reducing water movement. Clay within the fault zone can be smeared, and other sediments may be ground into a very fine deposit known as fault gouge within the plane of the fault. Finally, groundwater that circulates through the fault zone can deposit calcium carbonate in the fault plane, which acts as a cement. The effectiveness of a fault as a barrier to groundwater flow does not require a great deal of movement along the fault (Riley and Worts, 1952).

A more detailed discussion of the key characteristics of the four groundwater basins falling within the TPWD boundaries is provided below. The other basins are summarized as part of this study area to provide necessary regional context and insure consistency in evaluation with previous investigations. Additional data from the groundwater basins in the region are provided in Appendix C as a reference.

3.3.1 Indian Cove Subbasin

The Indian Cove Subbasin is located just east of the Joshua Tree Subbasin (Figure 1-1). It is bounded on the north by the Oasis Fault, which separates it from the Mesquite Lake Subbasin (Kennedy/Jenks, 2001, 2008). The eastern boundary is undetermined, separating this basin from the Fortynine Palms Subbasin. The southern boundary is the bedrock of the Little San Bernardino Mountains. The western boundary is an unnamed fault, across which is the Joshua Tree Subbasin (Nishikawa et al., 2004). The basin is floored by bedrock, which generally slopes northward with depth to bedrock ranging from 100 to 1,200 feet below ground surface (Kennedy/Jenks, 2001, 2008).

The Oasis Fault is known to be an effective barrier to groundwater flow along much of its length, as typified by the presence of the Oasis of Mara in the City of Twentynine Palms (Riley and Worts, 1953); DWR (1984) notes a probable water level difference of at least 100 feet across the Oasis Fault between this basin and the Mesquite Lake Subbasin. Several other faults exist within the basin, including a set of east-west striking subvertical faults and a steeply-dipping northwest-striking fault. These faults restrict groundwater flow perpendicular to them (Kennedy/Jenks, 2001, 2008), but the extent of this restriction is not known. The Pinto Fault may be an important barrier within the basin.

Recharge mainly occurs along the Little San Bernardino Mountains to the south as mountain front recharge. Rattlesnake Canyon empties into the southeast corner of the Indian Cove Subbasin, and may be the most significant source of runoff to the basin, and, therefore, the most mountain front recharge (at least based on the size and elevation of its watershed). As with other basins, it is unlikely that recharge from percolation of precipitation falling directly on the basin floor plays any kind of major role in the balance of groundwater (DWR, 1984). No previous recharge estimates have been made of the amount of water that enters the Indian Cove Subbasin from the Joshua Tree Subbasin to the west. Nishikawa et al. (2004) did note a water level drop of 90 feet across an unnamed, non-located fault. The water level in the Indian Cove Subbasin is more than 250 feet above the water level in the Fortynine Palms Subbasin to the east, indicating that there is some barrier between the two basins, although its character is not defined.

Groundwater outflow from the Indian Cove Subbasin is assumed to occur across the Oasis Fault into the Mesquite Lake Subbasin, or eastward into the Fortynine Palms Subbasin. No locations of historic groundwater discharge (i.e. springs) are recorded for this basin, nor are there any concentrations of vegetation. Pumping data are only known for wells operated by TPWD. In this basin, pumping began in 1957, and varied from about 30 afy initially to a peak of 2,075 afy in 1985. Recent discharge totals from this basin have been within a couple hundred afy of 1,000 afy. The production capacity for these eight wells is given as 2,385 afy (Kennedy/Jenks, 2005). The greatest discharge from a single well in the basin was about 620 afy, from TPWD-10 in 1976.

The groundwater levels vary more widely in the Indian Cove Subbasin than in others. Groundwater levels are reported for two sets of wells: one west of Indian Cove, just south of Copper Mountain (including TPWD-8, TPWD-10, and TPWD-11), and a second on the eastern side of Indian Cove (including TPWD-6, TPWD-7, TPWD-9, TPWD-12, and TPWD-15).

The groundwater elevations in the western group were around 2,280 feet asl in the 1960’s, when the first measurements were taken, and have fallen by more than 100 feet since then. Wells with at least 20 years of record indicate that water levels have dropped by between 1.5 and 2.5 feet per year from the 1960’s to the 2000’s. Groundwater elevation dropped most quickly from about 1970 to 1990 before decreasing more slowly to the present time.

The eastern group shows a distinct difference between wells in the northern and southern portions of the basin. TPWD-6 is representative of the northern grouping. Groundwater levels for TPWD-6 were about 2,260 feet asl in 1956, and in 2009 were about 2,180 feet asl. This represents a decline of 80 feet over 50 years. Over the 25 to 52 years of record for these wells, the groundwater levels have declined by between 1.4 and 1.7 feet per year. The water levels in the southern group wells range from about 2,210 to 2,440 feet asl, but within individual wells the groundwater elevation has not historically seen much decline. Water levels in these wells, over a 10-year period of record, actually increased between 0.1 and 0.5 feet per year in most wells, and dropped just over 1 foot per year in one.

The wells with at least a foot per year of groundwater level decline are all located between the Oasis and Pinto Faults. Wells south of the Pinto Fault do not experience as much decline in the groundwater level, indicating that the Pinto Fault is also (in addition to the Oasis Fault) an effective groundwater barrier, although it is not noted as such by Riley and Worts (1953).

3.3.2 Fortynine Palms Subbasin

The Fortynine Palms Subbasin is located directly east of the Indian Cove Subbasin (Figure 1-1). This basin is bounded on the north by the Oasis, Bagley, and Chocolate Drop Faults, which separate it from the Mesquite Fault (Kennedy/Jenks, 2001, 2008). The eastern boundary separating this basin from the Eastern Subbasin and western boundary separating this basin from the Indian Cove Subbasin are undetermined. The southern boundary is the bedrock outcropping of the Little San Bernardino Mountains. The known depth to bedrock in the basin is between 170 and 430 feet below ground surface (Kennedy/Jenks, 2001, 2008).

As in the Indian Cove Subbasin, the Oasis Fault forms an effective barrier to groundwater flow in this basin, with groundwater elevation dropping by possibly more than 100 feet across the fault (DWR, 1984). The effectiveness of the Bagley and Chocolate Drop Faults are unknown, although Riley and Worts (1953) note that there is a barrier located at the Bagley Fault, as indicated by groundwater elevation data. The Pinto Fault also traverses the southern part of this basin, although no wells exist south of it to indicate whether or not it is a barrier to flow. No other significant faults are known within this basin.

The major route for recharge into the basin is mountain front recharge from the Little San Bernardino Mountains. The major drainage entering the basin is Fortynine Palms Canyon, which may be a focal point for mountain front recharge. Of the three basins south of the Oasis Fault and east of Copper Mountain, this one has the smallest watershed and sediment volume (Kennedy/Jenks, 2001, 2008). As with other basins, it is unlikely that recharge from percolation of precipitation falling directly on the basin floor plays a major role in the balance of groundwater (DWR, 1984). There may be recharge or discharge occurring along the basin boundaries with the Indian Cove and Eastern Subbasins. The groundwater elevation is more than 250 feet higher in the Indian Cove Subbasin, indicating that there may be some flow into this basin from the Indian Cove Subbasin. The groundwater elevation is approximately the same in the Fortynine Palms and Eastern Subbasins, reducing the possibility that significant cross-barrier flow occurs between the basins.

Groundwater outflow from the basin is considered to flow across the Oasis Fault into the Mesquite Lake Subbasin to the north. Spring discharge and vegetation concentrations are not known within this basin. Pumping data are only known for six production wells operated by TPWD. In this basin, pumping began before 1953 (when the first records are available), and varied from about 260 afy in 1953 to a peak of 1,620 afy in 2002. Recent discharge totals from this basin have been within a couple hundred afy of 1,000 afy. The production capacity for these six wells is given as 2,466 afy (Kennedy/Jenks, 2005). The greatest discharge from a single well in the basin was about 920 afy, from TPWD-14 in 2007.

Water level records exist for 7 wells in the basin, including TPWD-3, TPWD-3B, TPWD-4, TPWD-5, TPWD-13, and TPWD-14. The earliest water levels reported for this basin (from 1939 to 1940), from TPWD-4 and TPWD-5, are 1,996 and 1,997 feet asl, respectively. From the 1940’s to about 1970, groundwater levels declined by about 1 foot per year before leveling off until about 1990, coinciding with a steep decline in pumping from this basin. Starting around 1990, pumping again increased in the basin, and water levels declined by about 70 feet by 2003, when pumping was again reduced and water levels again leveled off. Water levels in TPWD-13 and TPWD-14, in the southwestern part of the basin, have experienced a much steadier decline over their periods of record, with between 4.2 and 4.5 feet of decline per year since the first water level records in 1985. The other TPWD wells in the basin have had between 1.3 and 1.8 feet of groundwater decline per year. The most recent measured groundwater elevations in the TPWD wells, from June of 2009, ranged between 1,868 and 1,897 feet asl, indicating a decrease of at least 100 feet over the 70 years.

3.3.3 Eastern Subbasin

The Eastern Subbasin is located immediately to the east of the Indian Cove Subbasin (Figure 1-1). The northern boundary is the Oasis Fault, which separates it from the Mesquite Lake Subbasin (Kennedy/Jenks, 2001, 2008). The eastern boundary is undetermined, but may be a northward extension of the Pinto Mountains. The southern boundary is the bedrock of the

Little San Bernardino and Pinto Mountains. The western boundary is undetermined, and separates this basin from the Fortynine Palms Subbasin to the west. The depth to bedrock varies from 160 to 750 feet (Kennedy/Jenks, 2001, 2008). Groundwater supplies within the basin are limited, with most flow occurring in a shallow zone just above or just in the bedrock surface (Kennedy/Jenks, 2001, 2008).

As with the two basins to the west, the Oasis Fault is the most important groundwater flow barrier in the basin. In this basin, it is manifested by the Oasis of Mara (Riley and Worts, 1953), where significant quantities of groundwater have historically discharged to the surface (Thompson, 1921). Riley and Worts (1953) indicated that the southern boundary of the Mesquite Fault includes the Bagley and Chocolate Drop Faults, which are north of the Oasis Fault; the area between these faults and the Oasis Fault may therefore actually be part of the Eastern Subbasin, but the evidence for this is unclear, and will be examined below.

Recharge to this basin occurs from the Little San Bernardino and Pinto Mountains to the south, southwest, and southeast. Two major drainages enter this basin from the mountains to the south, presumably carrying runoff from the mountains onto the alluvium, where it percolates downward as mountain front recharge. This basin has the largest watershed and sediment volume of the three basins south of the Oasis Fault and west of Copper Mountain (Kennedy/Jenks, 2001, 2008). As with the other basins in the study area, rain falling directly onto the basin floor is not likely to be a significant source of recharge (DWR, 1984). Some minor recharge or discharge may occur into or out of the Fortynine Palms Subbasin, but because the two basins have similar groundwater elevations it is not likely to be a significant amount.

Prior to development, discharge from the basin probably occurred entirely as ET and groundwater discharge at the Oasis of Mara, as well as groundwater discharge elsewhere across the Oasis Fault. The groundwater elevation dropped by about 100 feet across the Oasis Fault (DWR, 1984), although there is a 200-foot difference between water levels in wells in the Eastern Subbasin and one well in the Mesquite Lake Subbasin about a mile north of the Chocolate Drop Fault (Riley and Worts, 1953). Although significant quantities of water have discharged or been lost to ET at the Oasis of Mara (Thompson, 1921 and 1929), the amount has never been quantified. Much of the surface discharge at the springs likely was recharged downstream into the Mesquite Lake Subbasin, representing a recharge source to that basin. There are no other known surface discharges or vegetation clusters within the basin.

Development began before 1953, but this is when the first pumping data are recorded for the basin. TPWD has operated 3 production wells within the basin, with total pumping ranging from about 200 afy in 1953 to a peak of 830 afy in 2002. Discharge amounts are not known from the many other wells located in the basin. Recent discharge totals from this basin have varied from 290 afy in 2003 to 740 afy in 2008. The production capacity for these three wells is given as 1,035 afy (Kennedy/Jenks, 2005). The greatest discharge from a single well in the basin was 580 afy from TPWD-16 in 2002. DWR (1984) noted a small amount of agriculture (jojoba beans) within the TPWD service area, although it's exact location, acreage, water use, or duration were not noted. There is currently no agriculture in this area (Kennedy/Jenks, 2005).

Groundwater elevations in the basin varied from 1,961 feet asl (the elevation of the ground surface at the Oasis of Mara) to 1,996 feet asl close to the western boundary of the basin. Thompson (1929) mentions two hand-dug wells about 0.25 miles west of the Oasis of Mara, with water levels at 17 and 28 feet below land surface. One well just north of the Oasis Fault had a water level of about 1,892 feet in 1946, about 100 feet lower than the water level in the Eastern Subbasin, but about 100 feet above the water level in the southeastern part of the Mesquite Lake Subbasin, indicating that this area could be part of some kind of boundary zone between the two basins. For wells with at least 20 years of record, water levels have mostly declined between 0.2 and 0.8 feet per year, although some wells near the Oasis of Mara have not seen declines as extreme. The most recent water levels reported varied from 1,903 to 1,946 feet asl. The water level in the well just north of the Oasis Fault showed a steady to slightly increasing water level for most of its period of record, with just one water level about 20 feet lower than the others at the end of its record.

3.3.4 Mesquite Lake Subbasin

The Mesquite Lake Subbasin is located south of the Deadman Lake Subbasin (Figure 1-1). The northern boundary is the Transverse Arch, which separates it from the Deadman Lake Subbasin (Riley and Worts, 1952). The eastern boundary is the Mesquite Fault, which separates it from the Bullion Mountains in the northern part of the basin and the Dale Basin in the southern part of the basin. The southern boundary is a combination of the Oasis, Chocolate Drop, and Bagley Faults, although Riley and Worts (1953) state that the southern boundary is not well-defined in the western part of the basin. The western boundary is Copper Mountain and several faults (such as the Elkins and Surprise Spring Faults), which separate this basin from the Copper Mountain Subbasin to the west. No significant barrier seems to exist between the Copper Mountain basin and the Mesquite Lake Subbasin at the southwestern corner (south of Copper Mountain), but presumably bedrock is close to the surface at this point, severely restricting flow, especially considering the depth to water in the Copper Mountain Subbasin.

Recharge to the Mesquite Lake Subbasin may occur at a variety of locations. However, groundwater recharge from high elevations within the basin itself (i.e. Copper Mountain) is considered negligible. Recharge to this basin is primarily from subsurface groundwater flow from adjacent basins including the Deadman Lake Subbasin (across the Transverse Arch), the Copper Mountain Subbasin (around the south end of Copper Mountain; Riley and Worts, 1953), and from the Indian Cove, Fortynine Palms, and Eastern Subbasins to the south (across the Oasis Fault). Some discharge at the Oasis of Mara in the Eastern Subbasin crosses the Oasis Fault on the surface, recharging downstream into the Mesquite Lake Subbasin. Additional recharge may occur within the basin, as runoff from the Little San Bernardino Mountains to the south may flow into this basin occasionally (Riley and Worts, 1953). Within the basin, groundwater flows toward Mesquite Dry Lake from all directions (Riley and Worts, 1953). Discharge from this basin occurs at the area of Mesquite Spring and Mesquite Dry Lake as ET (as shown by the dense vegetation on the western half of Mesquite Dry Lake) and groundwater flow over the Mesquite Fault into the Dale Basin (Riley and Worts, 1953).

The effectiveness of the Transverse Arch as a groundwater flow barrier is documented in the Surprise Spring and Deadman Lake Subbasin sections above. In summary, there is likely some recharge to the Mesquite Lake Subbasin across this barrier, especially at the southeast corner of the Surprise Spring Subbasin and the southwest corner of the Deadman Lake Subbasin, but the amount of this recharge has likely decreased through time as groundwater elevations in these basins have dropped due to development (Riley and Worts, 1953). The Mesquite Fault is considered “highly impervious” by Riley and Worts (1952), with groundwater levels varying by 200 feet over a distance of 100 horizontal feet from the west to the east side of the fault. As noted above, the Mesquite Fault is expressed on the surface by discharge at Mesquite Spring and a sharp delineation in the vegetation on the surface of the Mesquite Dry Lake.

The faults on the south side of the basin also form an effective barrier to groundwater flow. The Bagley Fault is a barrier, as indicated by differences in groundwater elevation on either side of the fault, although the degree to which it is a barrier is not noted (Riley and Worts, 1953). The Oasis Fault (also known as the Pinto Mountain Fault in several references) also seems to be a fairly effective barrier to groundwater flow along most of its length (Riley and Worts, 1953), with 100 feet of groundwater elevation difference across the fault in the eastern part of the basin, bordering the Eastern Subbasin, and more than 100 feet in the western part of the basin, bordering the Fortynine Palms and Indian Cove Subbasins (DWR, 1984). The Elkins Fault, which cuts through the middle of the basin, is likely a barrier to groundwater flow to some degree, although the lack of groundwater elevation data in the western part of the basin precludes definitive statements. Riley and Worts (1953) did note that some discharge does occur across the Elkins Fault.

Groundwater elevations in this basin have been recorded since at least 1940. Most water level measurements through the past 60 years are from the eastern part of the basin, near Mesquite Dry Lake, and the southern part of the basin, near the City of Twentynine Palms. Wells in the western half of the basin have only sparsely reported water levels, precluding definitive statements on the trends in water levels, so all descriptions here are limited to the eastern half of the basin. Water levels measured in the 1940's varied from 1,773 to 1,788 feet asl, and Riley and Worts (1952) noted that groundwater is confined by playa deposits along the western half of Mesquite Dry Lake. Since then, water levels have stayed pretty much the same, and in the eastern half of the basin varied from 1,752 to 1,793 feet asl. Most wells with long records have shown either steady water levels, or decreases by 4 to 5 feet; one well showed a decrease of 15 feet over a span of 40 years. Most wells with at least 10 years of record have shown between -0.1 and +0.1 feet per year of water level change, or water level declines of 0.1 to 0.4 feet per year. The greatest declines have occurred in the east-central and southeastern parts of the basin. The depth to groundwater varies from within 20 feet of the surface near Mesquite and Shortz Dry Lakes to more than 400 feet in the northwest corner of the basin (Kennedy/Jenks, 2001, 2008). Groundwater in the Mesquite Lake Subbasin moves generally eastward toward the Mesquite Fault.

Water has been pumped from this basin since at least the early 1950's, although the presence of water levels in the previous decade implies that some amount of water was discharged then as well. Two supply wells associated with the MCAGCC existed prior to the test well construction program of 1952-1953, although the total pumpage from them is not known. Riley and Worts (1953) estimate a total withdrawal of about 500 af in 1952, of which 450 af was from the MCAGCC supply wells. Since then, little reporting has been done on groundwater withdrawals in the basin. No new MCAGCC supply wells were placed in the basin in the well drilling campaign of 1952-1953. TPWD has one high-capacity supply well in the basin (discharge capacity of 3,395 afy; Kennedy/Jenks, 2005), which came on line in 2003, and has pumped between 610 and 950 afy since then. The static water level in this single well has dropped by about 5 feet over the 6-year period of record.

Two golf courses currently exist in the Mesquite Lake Subbasin. The Desert Winds Golf Course straddles the Mesquite Fault, and is administered by the USMC. This golf course has existed since approximately 1966, but the source of irrigation water is not known. Significant groundwater level declines have not been seen in the area of the golf course, suggesting water may be imported to here from other basins. The second course, Roadrunner Dunes Golf Course, lies just west of the Mesquite Fault in the southeastern part of the basin. It has been open since 1964, and presumably obtains irrigation water locally. Both of these golf courses may be significant to the water balance of the basin, as these areas tend to require significant amounts of irrigation, some of which percolates downward as recharge to the water table. The Roadrunner Dunes Golf Course also has two ponds that likely lose substantial water to evaporation, and possibly some to leakage to the water table as well.

3.3.5 Dale Basin

The Dale Basin is located immediately to the east of the Mesquite Lake Subbasin (Figure 1-1). Little work has been done on the hydrogeology of the Dale Basin, as it is not a host to significant population, nor does it contain many wells. Its western boundary is the Mesquite Fault, which separates it from the Mesquite Lake Subbasin. The northern boundary is the Bullion Mountains. The eastern boundary is the Sheep Hole Mountains. The southern boundary is the Pinto Mountains. The depth to bedrock in this basin is unknown.

The effectiveness of the Mesquite Fault as a flow barrier is discussed in the section on the Mesquite Lake Subbasin. Several other northwest-trending faults exist in the basin, but groundwater elevation data are much too sparse to even speculate on their effectiveness as barriers.

Recharge to the basin likely occurs all along its margins as mountain front recharge from the surrounding ranges. However, the lower elevation of these ranges and their greater distance from the source of winter moisture likely decreases the actual amount of runoff that reaches the basin floor. Recharge to this basin also occurs as groundwater flow over the Mesquite Fault (Riley and Worts, 1953). As with other basins in the region, precipitation directly onto the basin floor is not likely to be a significant source of recharge.

The Dale Basin has no surface outlet, and is ringed by bedrock, indicating that it is a completely closed basin, open only to recharge from the Mesquite Lake Subbasin. Therefore, all water entering this basin must discharge as ET at Dale Dry Lake (Riley and Worts, 1953). There is no record of groundwater discharge from wells in the basin, although a few scattered wells do exist, indicating at least minor withdrawals.

Groundwater levels within the basin vary from about 1,165 feet asl near Dale Dry Lake to about 1,550 feet asl near the Mesquite Fault. Water levels have increased by 0 to 0.7 feet per year in the 7 wells for which records exist, although most of the increases are due to single or few anomalously low water levels at the beginnings of the periods of record. Water levels within this basin have been basically stable since about 1960.

3.4 Basin Groundwater Storage Estimates

Many examples exist in the literature of estimates of storage in aquifers of the various basins in this study area. It must be noted here that the exact dimensions of the basins given in these references may not be exactly the same as the basin boundaries used in this report. DWR (1984) estimated the storage in the upper 100 feet of saturated sediments in the Indian Cove, Fortynine Palms, and Eastern Subbasins as 44,000, 38,000, and 50,000 af, respectively. They further noted that the storage in these basins was being depleted by 1,179, 190, and 145 afy, respectively, based on the average rate of water table elevation decline. Kennedy/Jenks (2001) gives an alternate quantification of storage as 83,000 af for the total of the Indian Cove Subbasin, with 65,000 af in the lower aquifer and 18,000 af in the upper aquifer.

Riley and Worts (1953) estimated the storage of groundwater in the Surprise Spring Subbasin to equal 520,000 af, and in the Deadman Lake Subbasin to equal 290,000 af, with these estimates only including the uppermost 100 feet of saturated sediments. They state that this number is about 400 times their estimate of annual recharge to the basins. Similarly, Lewis (1972) estimated the amount of groundwater in storage in many of the basins north of the Oasis Fault (values of *b* in parentheses). The Pipes Subbasin contained 120,000 af (*b* = 150 feet) as of 1969; the Reche Subbasin contained 240,000 af (*b* = 100 feet) as of 1969; the Giant Rock Subbasin contained 180,000 af (*b* = 100 feet) as of 1953; the Copper Mountain Subbasin contained 126,000 af (*b* = 100 feet) as of 1969; the Joshua Tree Subbasin contained 144,000 af (*b* = 150 feet) as of 1969; and the Surprise Spring Subbasin contained 322,000 af (*b* = 100 feet) as of 1967. Akers (1986) provided another estimate of storage of 750,000 af (*b* = 200 feet) in the Surprise Spring Subbasin as of 1982, a 60,000 af decline since pumping began in the basin.

3.5 Water Quality

TPWD conducts monthly groundwater quality monitoring for fluoride and arsenic, and monitors for other constituents according to the requirements set by the California Department of Public Health (DPH) Drinking Water Monitoring Schedule for all production wells (Kennedy/Jenks, 2008). No water quality monitoring is currently being performed on monitoring wells. Water quality data are also available from other studies. Sample results for TPWD wells are available as far back as 1951 for the Eastern and Fortynine Palms Subbasins and 1958 for the Indian Cove Subbasin. A summary of the water quality data for TDS and fluoride for the TPWD production wells is presented in Table 3-1.

3.5.1 Water Quality Issues

District groundwater is typically of good quality (Kennedy/Jenks, 2008). There is no known contamination in the District; however, groundwater monitoring is conducted to monitor for regulated constituents. For TPWD, the primary constituents of interest include fluoride, arsenic, nitrates and total dissolved solids (TDS).

Fluoride is a constituent of concern for TPWD. On 21 January 1993, TPWD was granted a variance from the California Primary Drinking Water Standard for fluoride, which states "the District shall not serve water containing fluoride levels in excess of 3.0 milligrams per liter (mg/L) or 75% of the U.S. Environmental Protection Agency Primary Drinking Water Standard (currently at 4.0 mg/L), whichever is higher" (Kennedy/Jenks, 2008). The DPH Maximum Contaminant Level (MCL) for fluoride in drinking water is 2.0 mg/L. According to the 2006 Consumer Confidence Report on the TPWD website, the variance shall be in effect for a period of up to 30 years from the date of issuance.

One potential source of fluoride is dissolution of fluoride-bearing minerals (such as apatite) in the rock matrix. These minerals may make up as much as 1 percent of the mineral content of the alluvial sediments. An alternative source of fluoride is derived from geothermal waters heated deep below the alluvial basins that discharge into the groundwater basin. These geothermal fluids may rise along several of the faults in the TPWD area. This geothermal input does not have to be a significant amount of water to impact the fluoride concentrations in the groundwater, if the geothermal water is highly enriched in fluoride. Further study would be required to definitively determine the source of fluoride to the study area waters.

The historic and current use of septic systems for wastewater disposal has an effect on groundwater quality (Kennedy/Jenks, 2008). Septic systems discharge their effluent into constructed permeable leach fields and/or to the shallow soil, where they are treated by biological organisms in the soil and/or degraded by other natural processes over time. Septic effluent is primarily characterized by elevated concentrations of nitrates. Other constituents from septic systems include ammonia, chloride, phosphorus, sodium, potassium, boron, volatile organic compounds, and bacteria. Releases from septic systems that are poorly designed (tanks are installed in areas with inadequate soils or shallow depth to ground water); poorly constructed or sealed; are improperly used, located, or maintained; or are abandoned may degrade groundwater and lead to elevated nitrates and other constituents (Kennedy/Jenks, 2008).

3.5.2 Regional Water Quality

In general, groundwater reaches chemical equilibrium with the minerals contained within the alluvial sediments over time. The concentration of different constituents in the groundwater is governed by the chemical properties of the groundwater and the minerals within the alluvial sediments. Therefore, groundwater that has spent more time (i.e. has a higher residence time) in the aquifer tends to have higher concentrations of chemical constituents than does water with a low residence time. Other inputs of chemical constituents can result from mixing of waters from different sources such as surface water or deep geothermal fluids. A third factor may be evaporation of groundwater, which leaves behind minerals, resulting in groundwater with elevated salts.

DWR (1984) published a study on the quality of groundwater in the TPWD subbasins. In general, water quality is considered high with low total dissolved solids (TDS) concentrations and alkalinity (i.e. groundwater is "soft"). The TDS content of groundwater in the area ranges from about 100 to 1,200 mg/l. The lowest TDS concentrations occur south of the Oasis Fault, with a wide range of values occurring east of the Mesquite Fault (Haley & Aldrich, 2000).

In the Indian Cove and Fortynine Palms Subbasins, the groundwater is fairly low in minerals with TDS concentrations between 100 and 250 mg/L. The dominant cations are calcium and sodium and the dominant anion is bicarbonate. Fluoride in the Indian Cove Subbasin has varied from 0.2 to 4.0 mg/L, while it has been between 0.3 and 3.6 mg/L in the Fortynine Palms Subbasin (Table 3-1). Nitrates (NO_3) range from 8 to 24 mg/L, and arsenic concentrations range from 2 to 31 micrograms per liter (µg/L). Elevated arsenic and nitrates are found in the western portion of the Indian Cove Subbasin (TPWD-8, TPWD-10, and TPWD-11). In other areas of the Indian Cove Subbasin and throughout the Fortynine Palms Subbasin (TPWD-6, TPWD-7, TPWD-9, and TPWD-12), concentrations of nitrates and arsenic are typically much lower. South of the Pinto Fault, fluoride concentrations are lower; however, TDS concentrations are higher (TPWD-15).

In the Eastern Subbasin, generally higher TDS and fluoride concentrations are found (Table 3-1) than in the Indian Cove and Fortynine Palms Subbasins. TDS concentrations are between 145 and 305 mg/L and fluoride concentrations range from 0.4 and 7.2 mg/L (Table 3-1). However, nitrates and arsenic are lower in the Eastern Subbasin compared to the Indian Cove and Fortynine Palms Subbasins. Nitrates (an NO_3) range from below detection limits to 10 mg/L, and arsenic concentrations range from 2 to 3 µg/L. The dominant cation is sodium and the dominant anion is bicarbonate. Concentrations in TPWD-16 are lower than those in the older TPWD-1 and TPWD-2 wells.

Groundwater in the Mesquite Lake Subbasin generally has higher TDS and fluoride concentrations (Table 3-1). In TPWD-TP-1, fluoride concentrations have ranged from 5.9 to 6.3 mg/L, and TDS has ranged from 320 to 350 mg/L. Arsenic concentrations range from 4.6 to 4.8 µg/L, and nitrates have not been detected in samples taken from TPWD-TP-1. The dominant cation is sodium and the dominant anion is bicarbonate. Over the entire basin, the range is much wider, representing the heterogeneity of the large Mesquite Lake Subbasin. DWR (1984) noted that the TDS concentrations are mostly between 300 and 1,300 mg/L, with the maximum concentration of 3,100 mg/L measured near Mesquite Dry Lake. Samples reported by DWR (1984) throughout the Mesquite Lake Subbasin for fluoride have varied between 3.0 and 22.0 mg/L. Concentrations in the area of the Mesquite Dry Lake are mostly around 11 mg/L.

3.5.3 Water Quality Trends

Overall, the trends in concentrations of inorganic constituents such as fluoride do not show any long-term trends. There is variability in the concentrations over time, but there are no long-term increasing or decreasing trends. This suggests that the concentrations of inorganic constituents in groundwater, such as fluoride, are primarily controlled by the local aquifer. There is no evidence that long-term groundwater pumping has resulted in significant changes in water quality. Based on the historical record, there have been no significant changes in water quality over time due to changes in groundwater pumping. Therefore, the proposed shift in groundwater pumping to the Mesquite Lake Subbasin from the Indian Cove, Fortynine Palms and Eastern Subbasins is not anticipated to cause any significant changes in the inorganic water quality.

Section 4: Hydrologic Budget

Understanding the hydrologic budget is a key element in evaluating the basin hydrogeology. The hydrologic budget represents a tabulation of each component of groundwater inflow and outflow into and out of the basin. Once defined, the hydrologic budget provides a basis for understanding how the basin has responded to historical pumping and provides a mechanism for estimating how the basin may respond to future changes in groundwater pumping.

This section details the estimates of the various components of the water budget from year to year, including the sources for the various numbers or how they are estimated for this study. A more detailed discussion of the methods is provided in Appendix D. A summary of the methodology is provided below.

4.1 Approach

Defining the hydrologic budget involves identifying and quantifying each component of groundwater inflow and outflow into and out of the basin. The net difference of the inflow and outflow represents the change in groundwater storage within the basin (Freeze and Cherry, 1979). The hydrologic budget components are estimated based on the hydrogeologic knowledge of the basins and by applying standard hydrologic methods. The hydrologic budget for the Twentynine Palms area can be defined by following equation:

$$\Delta S = R - ET - W + GW_{in} - GW_{out}$$

where ΔS is the change in groundwater storage, R is recharge from precipitation, ET is outflow due to evapotranspiration, W is well discharge, GW_{in} is groundwater inflow into the basin, and GW_{out} is groundwater outflow from the basin. Each component of the hydrologic budget above is generally reported in units of volume per time, typically afy.

4.2 Precipitation

Mountain front recharge is the primary source of recharge for the entire study area, as is typical in many settings within the semiarid Southwest (Wilson and Guan, 2004). Mountain front recharge is the percolation of water that runs off of surrounding highlands and infiltrates in the alluvial basin. In the study area, precipitation is greatest in the mountain ranges that surround the study area and typically quite low on the basin floor.

Recharge is greatest in the areas where a watershed from an area of high precipitation empties into the alluvial basin. As Figure 4-1 indicates, precipitation is greatest to the west of the study area, in the San Bernardino Mountains. The analysis used to develop Figure 4-1 is discussed in Appendix B. Other mountain ranges surrounding the study area see between 6 and 8 inches of rainfall per year, while the basin floors within the study area generally have between 3 and 5 inches of rainfall per year on average. The basin floor precipitation is likely too slight to lead to recharge in these parts of the study area. The distribution of precipitation around the study area indicates that recharge is most significant along the western edge, with lower amounts in basins bounding the Little San Bernardino Mountains, and even less on the other ranges bounding the study area, as well as the ranges and mountains internal to the study area.

The precipitation on the mountains, which mostly falls as rain, tends to become runoff rather than percolate into the hard, crystalline bedrock. It gathers into streams, flowing down off the mountain block. Once this runoff passes from the mountain block and flows onto the alluvial sediments of the mountain front, it begins to percolate into the soil. Except in extreme events, the runoff typically disappears quickly from the stream bed through either percolation into the streambed sediments or lost to evapotranspiration.

4.2.1 Maxey-Eakin Method

The Maxey-Eakin Method is a widely-used tool to estimate groundwater recharge for hydrologic studies in the semiarid to arid Southwest. This method was applied to 212 different basins in Nevada over 58 different studies performed by Office of the State Engineer of Nevada and the U.S. Geological Survey. Most of the studies in this series (e.g. Everett, 1964) modified the Maxey-Eakin method by using elevation as a proxy for rainfall, therefore allowing the use of topographic maps to calculate the areas of various elevation bands rather than rainfall bands, presumably because detailed topographic maps allowed for greater resolution than did the statewide precipitation map.

This method is attractive because of its simplicity, requiring only knowledge of how the average annual rainfall varies across a basin. First presented by Maxey and Eakin (1949, p. 40), and further explained by Eakin et al. (1951, p.79-81), the method calculates recharge as a percentage of rainfall, with this percentage varying by rainfall amount (Table 4-1). Areas of the basin that receive little rainfall (less than 8 inches) are assumed to contribute no recharge whatsoever to the basin, meaning that all rainfall falling on these areas is lost back to the atmosphere as evapotranspiration before it can reach the water table. Areas of the basin that receive over 20 inches of precipitation see an estimated 25 percent of that precipitation turned into recharge, with the rest being lost to evapotranspiration.

In the Maxey-Eakin analysis as implemented in its original form, the study basin was broken up into bands based on the estimated rainfall, which was based on a pre-existing rainfall map. The area of each band was then measured, and the total rainfall within each band was multiplied by the recharge percentage. The recharge of each band was then summed to create a total amount of recharge to the study basin. The recharge was taken as the bulk recharge to the basin as a whole, similar to the water budget approach being detailed here.

The Maxey-Eakin Method assumes that no recharge occurs where rainfall is less than 8 inches; therefore, most of the recharge in this study area must come from the mountains that surround that basin. To determine the mountain area that contributes to each basin, ArcGIS was used to create watershed areas for each basin from the DEM based on USGS topographic maps. The isohytel or rainfall map (Figure 4-1) was used to define rainfall bands, corresponding to the bands created by Maxey and Eakin. The recharge volume (in inches) was determined by multiplying the rainfall amount by the Maxey-Eakin recharge percentage of each rainfall band within the recharge watershed.

4.2.2 Maxey-Eakin Results

Precipitation recharge does not occur in most parts of the study area. In particular, the three basins south of the Mesquite Lake Subbasin receive very little precipitation recharge. Most (87 percent) of the mountain front recharge in the study area occurs in the Pioneertown Subbasin, because it taps high-elevation parts of the San Bernardino Mountains. Most of the rest of the recharge enters the Pipes (8 percent) and Joshua Tree (4 percent) Subbasins. The remaining recharge enters the Indian Cove, Fortynine Palms, and Deadman Lake Subbasins. On average, no recharge occurs in the Copper Mountain, Reche, Giant Rock, Surprise Spring, Mesquite, Eastern, and Dale Basins.

The recharge calculated for the Pioneertown Subbasin (633 afy) is quite close to the 500 afy estimated by Lewis (1972), but substantially less than the 2,000 afy estimate of average flow in Pipes Creek by Riley and Worts (1953), most of which would presumably recharge to the aquifer. Kennedy/Jenks/Todd (2007) estimated recharge based on a similar analysis. Total recharge to the Pioneertown and Pipes Subbasins was determined to be 686 afy, very close to the 690 afy estimated for these two subbasins in this study. MWA (2004) estimated a total recharge of about 700 afy to these two subbasins.

The first method for estimating annual recharge, described above, is applied for each year of the study, 1984 through 2008. This method results in zero recharge during very dry years, and quantifiable recharge across much of the study area, except areas such as the Dale Basin, during very wet years. The initial results of the recharge analysis indicate a much larger amount of recharge than has been estimated in previous reports, likely because the method seems to overestimate the recharge in extremely wet years.

The second annual recharge estimation method is estimated based only on a percentage of the steady state estimate. This method is closer to the estimates of Lewis (1972). From these results, it seems that the first method likely overestimates recharge, while the second method probably underestimates it. However, it is unclear which of the two is closest to reality. Therefore, the results of both methods are presented in the water budget analysis.

4.3 Evapotranspiration

ET of groundwater occurs where water is available at or near the land surface and consists of two processes. Evaporation can only occur where the water table or excess soil moisture is close enough to the land surface for vapor to diffuse from the unsaturated soil, or where there is standing water. Transpiration can occur when the water table is within the rooting depth of the vegetation, or when there is enough extra soil moisture for the plants to extract. Because of the aridity of this basin, and the generally very deep water tables, little ET occurs. ET of surface soil moisture can occur throughout the basin when the soil is moistened by precipitation, but this does not have a direct impact on groundwater.

ET only occurs in a couple of places in the TPWD area, the Mesquite Dry Lake, Mesquite Springs and the Oasis of Mara. Approximately 2 afy is lost at the Oasis of Mara, with 360 afy lost at the Mesquite Dry Lake. These are located in the topographically lowest parts of individual groundwater basins. Riley and Worts (1953) attempted to quantify ET at each of these locations.

Around Mesquite Dry Lake, water levels declined about 5 feet from 1952 to 2008, indicating that ET has likely decreased since the Riley and Worts (1953) estimate of 550 afy, but no more recent estimate is available. Mesquite, which tends to dominate the plant communities of the area, has a maximum rooting depth of 6 meters (Canadell et al., 1996), so a decrease of 6 meters would be assumed to eliminate ET in this basin; a linear decrease in ET was assumed with decreasing water levels. Extending this assumption, the estimated ET decreased from 385 afy in 1985 to 336 afy in 2008.

No estimate is available for ET at the Oasis of Mara, but Riley and Worts (1953) noted that there was no water present at the surface as of 1953. ET has likely decreased due to declining water levels. As a rough estimate, ET was assumed to be at most equal to that at Surprise Spring, 75 afy; because the vegetation at the Oasis of Mara has not died as has that at Surprise Spring, the value of ET was kept constant. However, the Maxey-Eakin Method estimates only about 2 afy of recharge to this basin under steady state, so the ET was set to be the lesser of either 75 afy or the annual recharge estimate.

4.4 Well Discharge

Since development began in the basin, well pumping has likely become the dominant outflow of groundwater in the study area. TPWD is the primary groundwater pumper in the study area. The TPWD service area includes portions of the Indian Cove, Fortynine Palms, Eastern, and Mesquite Lake Subbasins. For the Mesquite Lake Subbasin, The primary pumping in the study area is considered to be from TPWD wells from the four basins. Pumping has increased fairly steadily over time, and averages 1,286 afy in the Indian Cove Subbasin, 1,117 afy in the Fortynine Palms Subbasin, 366 afy in the Eastern Subbasin, and 774 afy in the Mesquite Lake Subbasin. TPWD has pumped here only since 2003. A summary of total pumpage per basin is shown on Figure 4-2. Pumping from the TPWD wells is listed in Appendix D.

As with previous studies (Nishikawa et al, 2004, Lewis, 1972), the pumping from domestic wells is considered relatively small on the basin scale, and is unquantifiable because the exact number of domestic wells in this basin is unknown. This is likely a valid assumption for the three basins south of the Oasis Fault, as these areas are mostly residential and few non-TPWD wells exist here. The Roadrunner Dunes Golf Course and the public park each pump approximately 290 afy (Mike Wright, Personal Communication, 10/29/2009).

4.5 Groundwater Inflow and Outflow

Groundwater inflows and outflows account for the movement of groundwater between different groundwater subbasins. Groundwater inflow is the main source of water to the subbasins utilized by TPWD, much larger than precipitation recharge.

Groundwater flow between basins is estimated based on local hydrogeological knowledge of the hydrologic flow system and flow estimates based on Darcy's Law. A discussion of the calculation methods is provided in Appendix D. This method calculated groundwater fluxes across basin boundaries using the changes in head across the boundaries over time. Several basins communicate water with the TPWD basins. The relationships of flow between the groundwater basins in the study area are outlined below.

- Indian Cove Subbasin: Receives inflow from the Joshua Tree Subbasin to the west, and discharges groundwater to the Mesquite Lake Subbasin to the north.

- Fortynine Palms Subbasin: Does not receive groundwater inflow from an adjacent basin, but discharges groundwater to the Mesquite Lake Subbasin to the north.

- Eastern Subbasin: Does not receive groundwater inflow from an adjacent basin, but discharges groundwater to the Mesquite Lake Subbasin to the north.

- Mesquite Lake Subbasin: Receives groundwater inflow from the Indian Cove, Fortynine Palms, and Eastern Subbasins to the south, Surprise Spring and Deadman Lake Subbasins to the north, and the Copper Mountain Subbasin to the west and discharges groundwater to the Dale Basin to the east.

A tabulation of the estimated groundwater inflow and outflow for each basin is provided in Tables 4-2 and 4-3. The Indian Cove Subbasin receives an average of 36 afy from the Joshua Tree Subbasin; the Mesquite Lake Subbasin receives an average of 52 afy from the Surprise Spring Subbasin, 566 afy from the Deadman Lake Subbasin, 97 afy from the Copper Mountain Subbasin, 10 afy from the Indian Cove Subbasin, and 5 afy from the Fortynine Palms Subbasin; and the Dale Basin receives 114 afy from the Mesquite Lake Subbasin.

No groundwater inflow or outflow is considered from the bedrock units in the surrounding highlands. This assumes that the mountain blocks bounding the study area are too restrictive to allow for significant inflow of groundwater through them.

4.6 Changes in Groundwater Storage

Hydrologic budgets are presented on a subbasin-by-subbasin and year-by-year basis from 1984 to 2008. The result of the water balance equation is the change in storage for a basin. A negative change in storage indicates that the amount of water in the basin is decreasing, which would result in lowered groundwater levels for wells in the basin.

The sum of all of the other water budget components is the change in storage. Under recharge Method 1 (Table 4-2), the Indian Cove Subbasin averages a loss of 1,205 afy, while the Fortynine Palms Subbasin loses 909 afy, the Eastern Subbasin loses 143 afy, and the Mesquite Lake Subbasin loses 442 afy. Under recharge Method 2 (Table 4-3), the Indian Cove Subbasin loses an average of 1,260 afy, the Fortynine Palms Subbasin 1,115 afy, the Eastern Subbasin 366 afy, and the Mesquite Lake Subbasin 518 afy. The losses in storage have generally been increasing over time with increasing groundwater pumping.

Section 5: Groundwater Model

The numerical groundwater is a computer simulation of groundwater flow that provides a predictive tool to evaluate changes in the basin hydrology. This includes quantifying recharge, groundwater exchanges between basins, and changes in storage. The setup, calibration, and application of a numerical model of the Mesquite, Indian Cove, Fortynine Palms, and Eastern Subbasins builds upon the comprehensive hydrogeologic investigation performed for the wider study area and presented in this report. A brief summary of the numerical model setup is provided here and a complete discussion of the model set is covered in Appendix E and the model calibration in Appendix F.

5.1 Purpose

The overall purpose of the hydrogeologic investigation and the numerical groundwater model is to provide a predictive tool for changes in the basin hydrology (especially groundwater levels and groundwater flow) due to changes in the amount and location of pumping in the study area. This includes quantifying recharge, groundwater exchanges between basins, and changes in storage, among other things.

The main objective of the numerical groundwater model is to simulate the long-term changes in groundwater elevation over time that could be expected due to increased pumping in the Mesquite Lake Subbasin, and concomitant decreased pumping in the Indian Cove, Fortynine Palms, and/or Eastern Subbasins. The subsidiary objective of the modeling effort is to refine uncertain components of the hydrologic budget, accomplished through the course of calibration of the numerical model.

5.2 General Approach

The numerical flow model uses the USGS MODFLOW-2000 software (Harbaugh et al., 2000), a finite-difference numerical model developed by the USGS. To facilitate construction and operation of the numerical model, the MODFLOW processor *Groundwater Vistas 5* (ESI, 2007) is used. The use of the industry standard modeling code MODFLOW-2000 along with a commercial processor supports future usability of the model.

The first step towards developing a sound, defensible numerical model is to ensure that consistency is maintained with the hydrogeological understanding or conceptual model of the study area. The conceptual model describes the geological setting and hydraulic processes for the study area basins based on a compilation and evaluation of the available data. It serves as the basis for constructing a numerical model.

Because of the complexity of a natural system, certain simplifying assumptions are necessary to define the aquifer properties and boundary conditions required for the numerical model. Although a model is a simplification of the natural system, the numerical model must be constructed in a manner that properly represents the key features of the groundwater basin in order to provide accurate and useful simulation results. In support of the numerical model development, a range of reasonable values for aquifer properties and the hydrologic budget are defined based on measured field data and hydrogeological analyses. For aquifer properties, this involves defining values for a representative elementary volume (REV) as described by Bear and Verruijt (1987). These values represent large-scale heterogeneity (i.e. between aquifers), and are not meant to capture heterogeneities on the scale of individual depositional beds or smaller. For the hydrologic budget, these values represent the major hydrologic interactions of the basin, including surface water-groundwater interactions and recharge and discharge components.

After construction is completed, model calibration is the next step towards developing a sound, defensible numerical model. Calibration is the process of comparing model simulation results to measured groundwater levels to evaluate the ability of the numerical model to accurately simulate historical conditions in the groundwater basin. The more extensive the calibration process, the more the potential uncertainty in the model simulation results is reduced, increasing confidence in the model's ability to simulate historical and future conditions. For the calibration process, aquifer properties and hydrologic balance data are varied within the range prescribed by the conceptual model until the best obtainable fit of simulated versus measured data is achieved. Areas where the numerical model is considered poorly calibrated may indicate locations where the initial estimates of input data are inadequate, or where some key component of the hydrogeological conceptual model is not adequately described. The former serves as a valuable quality assurance check, whereas the latter may provide guidance for future monitoring locations and frequencies where additional data evaluation is needed. Therefore, the numerical model can also provide useful guidance on how to allocate resources for data collection.

Once calibration is achieved, the model is considered capable of simulating future conditions with reasonable accuracy. Input parameters can be set to simulate a wide range of potential future groundwater management scenarios and other conditions, including natural or climatic variations such as variation in rainfall over time (i.e. drought scenarios). Future groundwater management changes can include changes in the amount and distribution of groundwater pumpage, the addition of groundwater recharge programs, or evaluation of the costs and benefits of water projects on groundwater conditions. The model can also be used to address water quality issues resulting from future changes. A numerical model also provides another method to estimate perennial yield through balancing the amount of water entering and exiting the basin and the rate of groundwater flow through the basin.

For the model calibration and subsequently for the evaluation of pumping, conservative assumptions for groundwater recharge are applied regarding the amount of annual groundwater recharge were applied for the evaluation of change in groundwater pumping because of the uncertainty of estimating the groundwater recharge. This is done to insure that the analysis gives a high degree of confidence that the results of the mitigation of groundwater level declines in the Indian Cove, Fortynine Palms, and Eastern Subbasins will be similar, and possibly, better than those presented in this analysis.

5.3 Numerical Model Setup Overview

A numerical model is a mathematical representation of a natural system. The approach to develop a numerical model capable of simulating historical and future conditions depends upon properly incorporating the hydrogeological data from the basin. The conceptual model describes the geological setting and hydraulic processes for the study area basins based on a compilation and evaluation of the available data. The numerical model is constructed using data presented in Sections 2 through 4. A brief summary of the model construction is provided below; however, a more detailed discussion of the model set is covered in Appendix E.

The model domain is the geographical area covered by the numerical model. The model domain is a square box that contains all of the areas of the Mesquite, Indian Cove, Fortynine Palms, and Eastern Subbasins (Figure 5-1). This area measures about 17 miles on each side for a total area of about 290 square miles (about 186,000 acres). The model domain is divided into a grid that provides the mathematical structure for developing and operating the numerical model. The MODFLOW Model uses a uniform grid spacing of 300 feet. However, much of the model domain does not actively participate in the groundwater flow system, being areas where bedrock is very close to or at the surface. The actual active area of the uppermost layer of the model is 82,000 acres, or 130 square miles.

Model layers provide vertical resolution for the model to simulate variations in groundwater elevation, aquifer stresses, and water quality with depth. The MODFLOW Model consists of three layers that simulate the primary water-bearing formations, consisting of Quaternary and Tertiary alluvium. Because the hydrologic properties of the alluvium vary with depth, the alluvium is divided into three model layers, following the convention of the USGS for another groundwater modeling study just to the west (Nishikawa et al., 2004).

To simulate changing conditions over time requires the definition of stress periods that represent the resolution of time into discrete intervals. For the MODFLOW Model, annual stress periods are used. Although the rainfall is highly seasonal in nature, the measured water levels in the basins do not show a pattern of seasonal variability. Therefore, an annual timestep is appropriate. To simulate the 25-year base period of 1984 to 2008, the model required 25 stress periods.

Aquifer properties represent the hydrogeologic characteristics that control groundwater flow. These primarily include hydraulic conductivity, specific yield, and specific storage. The numerical model requires that aquifer properties are defined for every active cell in the model. Extrapolation methods to define properties in areas with insufficient data are performed using science-based assumptions based on the conceptual model. Reasonable value ranges for each are defined and are used to guide model calibration.

Model boundary conditions define the hydrologic conditions represented by the hydrologic budget where groundwater enters and exits the basin. MODFLOW-2000 provides a number of different boundary condition options to numerically represent the different physical processes included in the hydrologic budget. The boundary conditions applied to the model include:

- Precipitation Recharge: Represents groundwater inflow resulting from rainfall percolating downward to the groundwater. In the Twentynine Palms area, this is primarily derived from runoff from the surrounding highlands after large rainfall events. Recharge occurs where the runoff enters the basin and percolates into the alluvial sediments.

- ET: Represents the component of groundwater outflow from evaporation to the atmosphere and uptake by plants (transpiration).

- Groundwater Pumpage: The most significant groundwater outflow component for the basin. This includes estimates of annual pumping from TPWD and other private wells.
- Groundwater Inflow and Outflow: Accounts for groundwater inflow and outflow into the model area from adjacent groundwater basins not included in the model domain.

The geographic distribution of and amount of inflow and outflow of each hydrologic budget component needs to be accounted for within the model domain. Boundary condition data must be entered for each stress period at each model grid cell where a boundary condition is defined in the model. A detailed discussion of the boundary condition setup is provided in Appendix E.

5.4 Calibration Summary

Model calibration is the step where the simulated results are compared to measured data. A constructed groundwater model must be calibrated to verify that the model setup is able to reproduce actual conditions before it can be used as a predictive tool. Reasonable values for aquifer properties and the hydrologic budget are defined using the information from previous sections of this report; during model calibration, these values are varied within the range prescribed by the conceptual model. The MODFLOW Model is calibrated by matching model results to observed data. An extensive calibration process is designed to better constrain the range of aquifer properties and boundary conditions for the model, thereby reducing uncertainty in the results. A summary of the model calibration is provided below; however, full documentation of the calibration process is provided in Appendix F.

There are multiple combinations of aquifer properties and boundary conditions that can be used to match a single set of groundwater elevation data. Calibrating to multiple data sets under differing recharge and discharge rates reduces this non-uniqueness, thereby reducing the uncertainty. Performing a comprehensive calibration over a 25-year base period infers the calibration has been performed over wet, dry, and normal years with varying degrees of pumping. The MODFLOW Model is calibrated using three separate criteria:

- Groundwater Elevation Maps
- Statistical Analysis
- Hydrographs

The first and most basic model calibration criterion is a direct comparison of simulated versus measured groundwater elevation maps for selected time periods. The primary purpose of this calibration is to compare hydraulic gradients for both magnitude and direction to ensure that the model is accurately simulating existing conditions. This visual comparison is a fast method to determine where additional model calibration efforts should be focused. Figure 5-2 shows the calculated groundwater elevations for Model Layer 1 for 2008. In general, the direction and magnitude of the hydraulic gradient as expressed by the contours is similar to the maps in Figure 3-3. A comparison of the contour locations shows some variability, but the overall contour patterns compare favorably between model and hand-drawn maps. Therefore, this preliminary calibration suggests that the groundwater flow field generated by the model is reasonable.

For the statistical analysis, the model calibration is evaluated using a measure of the difference or residual between the measured and simulated groundwater levels. This comparison of observed versus simulated groundwater elevations is based on data from 60 wells. The locations of these wells are shown on Figure 5-3. It should be noted that some degree of difference or residual between the observed and simulated groundwater elevations is expected. Residuals may be due in part to localized effects or data quality issues. Plotting these residuals indicates that the model is capable of simulating historical conditions (Figure 5-4). The absolute residual mean is the average difference between observed and measured water levels. For the model calibration, the absolute residual mean is just over 22 feet. To determine the significance of the absolute residual mean, the ratio between the standard deviation of residuals and the range of observed water levels is used to evaluate the absolute residual mean in regional context that looks at the total difference in groundwater elevations for the study area. For the model calibration, this ratio is 0.058, well below the threshold value of 0.15 required to consider a calibration to be acceptable (ESI, 2007).

Most of the residual occurs at relatively few specific locations within the basin. This indicates that the calibration over most of the basin is strong, and that most of the uncertainty is focused in a few specific locations. The general interpretation of these locations is that additional information is necessary to improve the hydrogeological conceptual model in these locations so that the model can be improved. Additional discussion of this is provided in Appendix F.

Hydrographs provide a detailed time history of groundwater elevations for specific wells. These time histories include the impact of varying climatic and pumping stresses on the groundwater basin. Comparing hydrographs of model results versus observed data provides a measure of how well the model handles these changing conditions through time. Hydrographs from 16 wells from different parts of the basin are included Appendix F. This representative sample includes 32 percent of the total wells. For calibration purposes, the hydrographs are inspected to evaluate how well the model results matched the overall magnitude and trend of the observed groundwater elevation data over time. For the transient model, it is considered more important to honor the overall trend of the data. A hydrograph is considered a good match if the model simulated the trend, even if the groundwater elevations are offset. Considering all of the hydrographs presented in Appendix F, the model does is considered a satisfactory calibration of matching observed water levels. The discrepancies that do exist are discussed in Appendix F, or are relatively small.

5.5 Model-Based Evaluation of Groundwater Flow

The 2008 groundwater elevation map for Model Layer 1 is presented on Figure 5-2. In general, the MODFLOW model indicates that groundwater generally flows from the furthest extents of the model domain toward the area of Mesquite Dry Lake. In the MODFLOW model, groundwater elevations are strongly controlled by the faults present within the model, and the two areas of evapotranspiration of groundwater. In general, groundwater elevations are nearly constant within individual fault-bounded blocks of the basin, with extremely steep gradients through the fault zones. The hydraulic gradient within individual basins is typically between 0.66 and 7.3 feet per 1,000 horizontal feet. The groundwater elevations and fluxes presented in this section are representative of 2008 conditions.

In the Indian Cove Subbasin, water generally flows from south to north in the southern part of the basin, while north of the Pinto Fault water flows from west to east. South of the Pinto Fault, the water level is about 2,410 feet asl, about 250 feet higher than in the northern area. In the northern part of the Indian Cove Subbasin, water levels are highest (about 2,170 feet asl) at the western end, generally decreasing to the east (to an elevation of about 2,150 feet asl at the eastern end). Water enters the Indian Cove Subbasin as recharge in the part of the basin above the Pinto Fault, and as groundwater inflow from the Joshua Tree Subbasin to the west. Water exits the basin both to the north across the Oasis Fault into the southwestern reaches of the Mesquite Lake Subbasin, and to the east into the western part of the Fortynine Palms Subbasin. For the 2008 timestep, about 22 af came into the Indian Cove Subbasin, 92 percent of it from the Joshua Tree Subbasin and the remaining 8 percent from recharge within the basin. Over the same timestep, about 26 af left the basin, with 22 percent going into the Mesquite Lake Subbasin and 78 percent going into the Fortynine Palms Subbasin.

Water in the Fortynine Palms Subbasin generally flows to the east. This flow regime is interrupted in the area of TPWD-13, TPWD-14, and TPWD-5, where groundwater production has caused a reversal in the gradient for the eastern part of the basin. Water levels in the western end of the basin are about 2,020 feet asl (130 feet lower than in the eastern part of the Indian Cove Subbasin), while water levels around the previously mentioned TPWD wells are about 1,880 feet asl and those along the eastern edge of the basin are about 1,900 feet asl. A small sliver of the basin exists to the south of the Pinto Fault in the western part of the basin, but there are no water level data or wells in this area. Water enters this basin as recharge along the Little San Bernardino Mountains, and as groundwater inflow from the Indian Cove Subbasin to the west, the Mesquite Lake Subbasin to the north, and the Eastern Subbasin to the east. Water exits the basin to the north, back into the Mesquite Lake Subbasin. For the 2008 timestep, about 124 af came into the Fortynine Palms Subbasin, with 6 percent being recharge, 63 percent coming in from the Indian Cove Subbasin, 15 percent coming in from the Eastern Subbasin, and the remaining 16 percent coming in from the Mesquite Lake Subbasin. For the same timestep, about 0.1 af left the Fortynine Palms Subbasin, going into the Mesquite Lake Subbasin. It should be noted that the movement of water from the Eastern Subbasin to the Fortynine Palms Subbasin seems to be a reversal of predevelopment conditions, when water flowed to the east rather than the west.

Water in the Eastern Subbasin generally flows to the north from recharge areas in the southern part of the basin. Water south of the Pinto Fault is about 2,040 feet asl, 100 feet higher than water north of the fault. North of the Pinto Fault, groundwater elevations range from about 1,940 feet asl in the southeast to 1,920 feet asl in the vicinity of TPWD-16. The area of the Oasis of Mara has groundwater elevations of about 1,940 feet asl. Groundwater enters the Eastern Subbasin as recharge and exits the basin as ET at the Oasis of Mara and groundwater flow into the Fortynine Palms Subbasin to the west and the Mesquite Lake Subbasin to the north. For the 2008 timestep, about 5 af came into the Eastern Subbasin as recharge. Over the same period, about 10 af left the basin, with no ET, 45 percent going into the Fortynine Palms Subbasin and the other 55 percent going into the Mesquite Lake Subbasin.

Water in the Mesquite Lake Subbasin tends to flow from all directions toward the Mesquite Dry Lake area. Water levels in the basin are as high as 2,180 feet asl in the northwestern corner of the basin and 2,100 feet asl in the southwestern corner, and as low as 1,750 feet asl in the Mesquite Dry Lake area. In the southern part of the basin, water flows east along the edge of the bedrock high that cuts through the basin from the west, eventually crossing the Bagley Fault and flowing north subparallel to the Mesquite Fault. Groundwater flow in the northern part of the basin is generally southeast to east, building up behind the barriers of the Surprise Spring and Elkins Faults before flowing directly toward Mesquite Dry Lake in the eastern half of the basin. Water enters the basin from the Indian Cove, Fortynine Palms, and Eastern Subbasins to the south, the Copper Mountain Subbasin to the west (via flow through the bedrock as represented by a general head boundary), and the Surprise Spring and Deadman Lake Subbasins to the north. Water exits the basin as ET in the Mesquite Dry Lake area and as groundwater flow into the Dale Basin to the east and the Fortynine Palms Subbasin to the south and the Deadman Lake Subbasin to the north, between the Surprise Spring and Elkins Faults. For the 2008 model timestep, 1,010 af entered the basin, with 1 percent from the Indian Cove Subbasin, less than 0.1 percent from the Fortynine Palms Subbasin, 1 percent from the Eastern Subbasin, 14 percent from the Copper Mountain Subbasin, 74 percent from the Surprise Spring Subbasin, and 11 percent from the Deadman Lake Subbasin. Over the same year, 2,232 af left the basin, with 74 percent being lost as ET, 23 percent flowing into the Dale Basin, 1 percent flowing north into the Deadman Lake Subbasin, and less than 1 percent flowing into the Fortynine Palms Subbasin.

5.6 Model-Based Hydrologic Budget

A water balance or hydrologic budget is a quantitative statement of the balance of the total water gains and losses from the basin for a given time period. Groundwater inflow to the Mesquite Lake Subbasin is derived from mountain-front recharge and groundwater inflow. Outflow from the basin occurs as well pumpage, evapotranspiration, and groundwater outflow. The difference between inflow and outflow is balanced by the change of groundwater in storage. The major components of the hydrologic budget evaluated for the Mesquite Lake Subbasin are detailed in Section 4.

The results of this groundwater flow evaluation correlate well with the conceptual model of the basin. Results also agree with the hydrologic budget quantification. The MODFLOW model used recharge estimates consistent with Method 2 (Section 4) of the hydrologic budget. Because data are sparse in the southern part of the Mesquite Lake Subbasin, the hydrologic budget is not set up to quantify fluxes back and forth between the southern TPWD basins and the Mesquite Lake Subbasin, and these fluxes may not be captured well by the hydrologic budget.

The year-by-year hydrologic budget results from the calibrated model are presented in Table 5-1. The model results produce a total recharge of approximately 210 af over the 25-year base period for an average annual recharge rate of 8.4 afy. The results show that 5 percent of the recharge occurred in the Indian Cove Subbasin, 62 percent in the Fortynine Palms Subbasin, and 33 percent in the Eastern Subbasin, with no recharge in the Mesquite Lake Subbasin; these amounts are specified as an input to the model. Recharge within the model domain represents only 0.9 percent of the total inflow to the model.

Subsurface inflow totals 22,200 af over the 25-year base period, for an average annual inflow of 889 afy (Table 5-1). This accounts for the other 99.1 percent of inflow to the model. Of this subsurface inflow, 2.5 percent (20 afy) comes in from the Joshua Tree Subbasin in the southwestern corner of the model. Another 82.6 percent (621 afy) comes into the model domain from the Deadman and Surprise Spring Subbasins across the Transverse Arch. The remaining

15.0 percent of the inflow (125 afy) entered the model domain from the Copper Mountain Subbasin through the western boundary of the model.

The year-by-year hydrologic budget results from the calibrated model for model outflow are also presented in Table 5-1. The model results produce a total discharge of 150,900 af over the 25-year base period, for an annual average discharge of 6,000 afy. Groundwater pumping accounts for the majority (63.0 percent, or 3,800 afy) of the groundwater outflow. Of this, TPWD wells accounted for 77.4 percent, other municipal wells for 15.2 percent, and domestic wells for 7.4 percent. The importance of TPWD pumping shifted over time as it increased (as municipal and domestic wells were assumed to have a constant pumping rate over the model period), rising from a low of 70.4 percent in 1984 to a high of 80.4 percent in 2002.

ET is also included in Table 5-1. Because the ET output depends on the depth to water, this outflow also changes over time. The total ET output for the entire 25-year base period is 41,300 af, for an annual average of 1,650 afy. This represents 27.3 percent of the total output. ET varies from a low of 17.7 percent in 1984 to a high of 26.5 percent in 1992. Most (99 percent) of the ET for the model occurs at the Mesquite Dry Lake area, with the remaining 1 percent lost around the Oasis of Mara. ET at Mesquite Dry Lake increases over the first half of the model (from 1,100 af in 1984 to 1,690 af in 1996), but then decreases over the second half of the model to a final value of 1,660 af in 2008. ET at the Oasis of Mara declines from about 50 afy at the start of the model to a value of 6 afy in 1997, then slowly decreases to 0 afy in 2001.

Subsurface outflow along the Mesquite Fault accounts for the remaining 9.6 percent of total outflow, 14,500 af over the entire model run, or an annual average of 580 afy. The difference in inflow and outflow is equal to the change in storage. The storage in the groundwater system decreases every year, and this decrease changes from a minimum of 4,000 af in 1984 to a maximum of 5,700 af in 2002 (Table 5-2). The change in storage is primarily impacted by the amount of groundwater pumping (Figure 4-2). As stated in Appendix D, recharge likely changes significantly from year to year, but this variability is not reflected in water levels within the basins, and so does not affect the annual water balance. Six of the last seven model years saw decreases in storage of at least 5,400 afy. The average annual decrease in storage for the individual basins ranges from 530 afy for the Eastern Subbasin to 2,110 afy for the Mesquite Lake Subbasin.

The hydrologic budget described in Section 4 (Tables 4-2 and 4-3) is compared to the model-based hydrologic budget (Table 5-1). Overall, the model-based hydrologic budget agrees reasonably well with the previous budget. The model recharge of 8.4 afy for the modeled area is substantially lower than the estimate of 597 afy obtained using Method 1 (Appendix D), but very close to the estimate of 9 afy obtained using Method 2. The groundwater inflow to the model totals 828 afy, also quite close to the hydrologic budget estimate of 752 afy. The total inflow of the numerical model is only 4.8 percent different from the total inflow determined by the hydrologic budget (Table 5-2).

5.7 Model-Based Insights to the Conceptual Model

One of the objectives of the numerical modeling work is to provide insights into the hydrogeologic conceptual model for the four modeled basins. This section documents the conceptual model insights that were developed during the process of model development and calibration.

One major insight derived from the MODFLOW model is the importance of the bedrock high southeast of Copper Mountain to flow in the Mesquite Lake Subbasin. From the numerical model, the southern part of the Mesquite Lake Subbasin does not easily communicate with the rest of the basin; instead, water in this area must flow east around the bedrock high, crossing the Chocolate Drop and Bagley Faults before flowing north again into the main part of the Mesquite Lake Subbasin.

Another insight is that a much greater volume of water is lost at the Mesquite Dry Lake and across the Mesquite Fault into the Dale Basin than was estimated using the hydrologic budget. This may indicate that the conceptual model does not allow for enough groundwater flow into the basin, or that the numerical model must have its ET parameters reduced to account for the generally sparse character of the vegetation. This discrepancy may be important to TPWD in developing groundwater resources in the Mesquite Lake Subbasin and could be investigated further in the future.

The MODFLOW model also shows much more water to be flowing through the western part of the Transverse Arch versus the eastern part. In many of the previous reports, this situation was considered reversed, with most of the flow coming through the eastern end. However, groundwater data indicate that water levels are very similar in the Deadman and Mesquite Lake Subbasins, particularly east of the Elkins Fault; this may preclude significant movement of water through this part of the Transverse Arch. On the other hand, some studies indicate that the Transverse Arch may plunge downward to the east, and the lack of a significant head gradient across the Arch in the eastern part of the Mesquite Lake Subbasin may simply be the result of there not being much resistance to flow here. This type of variation is not captured in the model, which only varied head along the Transverse Arch, not its ability to transmit water. The total amount of water crossing the Transverse Arch into the Mesquite Lake Subbasin is about 30 percent higher in the model than in the hydrologic budget, so the difference between the models indicate where the water comes in, and may not affect the final conclusions significantly.

The MODFLOW model also indicates that groundwater development south of the Pinto Fault is not likely to result in significant water production. Alluvial sediments in this area are very thin, and easily dry out even under fairly modest pumping. The thinness of the sediments and proximity to the mountain front also leave water levels in this area more prone to natural climatic variations compared to the main parts of the basins.

The MODFLOW model indicates that recharge needed to be shifted between basins south of the Oasis Fault. In particular, recharge is greatly reduced in the Fortynine Palms Subbasin, while it is increased in both the Indian Cove and Eastern Subbasins. This may show insufficiencies in the Maxey-Eakin Method for estimating recharge in individual subbasins within a larger groundwater basin, since the total recharge for these three basins is about equal in the Maxey-Eakin Method and in the numerical model.

5.8 Application of Model Results

The MODFLOW Model is designed as a basin-scale model to evaluate long-term trends in groundwater elevation within the modeled basins and groundwater inflows to and outflows from the modeled basins. Because small-scale heterogeneities are not included in the modeling effort, modeled conditions must be considered averaged, without site-specific details to evaluate some localized conditions that are due to geologic complexity or unique localized effects. For these areas, a more localized model may be required if such a detailed analysis is necessary. This basin-scale model can provide a broader regional context in which localized models would be imbedded. Special emphasis for this model is placed on accurately representing the effects on groundwater elevation of TPWD wells, as the predictive value of the model is as a simulator of water level changes due to alterations in the pumping regime of these wells.

When evaluating model results, it is important to consider the strengths and limitations of the numerical model. The horizontal and vertical resolution used to construct the model dictates the range of scales that the model can evaluate. The results can be evaluated for overall trends and more localized effects. For example, a regional or basin-scale model will not likely contain the site-specific details of a more localized model, but a regional model will better evaluate a local area within the broader regional context by accurately simulating conditions just outside and along the borders of the localized site.

Section 6: Evaluation of Long-Term Groundwater Pumping Scenarios

This section of the report summarizes the results of the evaluation of the effects of shifting TPWD's groundwater production to the Mesquite Lake Subbasin over the next 25 years, through year 2033. The geologic and hydrogeologic characterization work reported in preceding sections of this report provides the foundation for performing the analyses of anticipated future effects on basin groundwater levels.

6.1 Background

The overall purpose of this study is to evaluate the effects of moving future TPWD groundwater production from the Indian Cove, Fortynine Palms, and Eastern Subbasins to the Mesquite Lake Subbasin. Since the formation of TPWD in 1954, historical increases in pumping demand, coupled with the low natural groundwater recharge typical of arid environments, has resulted in steadily-decreasing groundwater levels in the Indian Cove, Fortynine Palms, and Eastern Subbasins. The Mesquite Lake Subbasin has been less utilized due to naturally high levels of fluoride which require additional treatment for use as a water supply. Water use projections for the TPWD service area indicate that demand will continue to rise, from 3,200 afy in 2004 to an estimated 4,680 afy in 2030 (Kennedy/Jenks 2005). The existing TPWD wells are projected to fall behind demand by 2012. Therefore, TPWD is considering shifting some of its groundwater production to the Mesquite Lake Subbasin.

In 2003, the first TPWD well in the Mesquite Lake Subbasin, TPWD-TP-1, was installed to expand the overall water supply. However, a new treatment plant was constructed to provide treatment of the fluoride-rich groundwater from TPWD-TP-1. In 2009, the treatment plant was capable of treating approximately 1.0 MGD of raw groundwater. At full build-out in 2015, the plant would be able to treat up to 3.0 MGD, or 3,360 afy, of groundwater pumped from the Mesquite Lake Subbasin.

6.2 Approach

The approach needs to provide an evaluation of the potential benefits of reducing pumping in the Indian Cove, Fortynine Palms, and Eastern Subbasins, and the potential impacts of increasing pumping in the Mesquite Lake Subbasin. For this, two approaches are used to evaluate the effects of shifting future TPWD groundwater production. These include:

- The first approach is based on the hydrologic budgets established in Section 4. Projected future pumping is applied to the hydrologic budget to estimate future annual changes in basin groundwater levels and basin storage. The approach provides a basin-scale analysis.

- The second approach uses the MODFLOW model described in Section 5. The model provides a tool to evaluate the spatial variability in the changes in basin groundwater levels and basin storage. The model is calibrated to historical conditions from 1984 to 2008; therefore, it is considered to provide a tool to evaluate the spatial variability in the changes in basin groundwater levels and basin storage the future under various possible pumping scenarios.

The MODFLOW model approach is much more complex, but yields results that are more area-specific, such as anticipated changes in groundwater levels near a pumping center. The hydrologic budget approach is useful, because it can be performed relatively, and it can be used to corroborate the model results.

6.3 Pumping Scenarios

For the analysis, a series of potential future pumping scenarios was developed for evaluating the response of groundwater levels to various potential future groundwater pumping scenarios. For this evaluation, eight model scenarios are simulated to evaluate a range of potential future conditions. These scenarios were developed to answer the following questions:

- Scenarios 1 and 2 provide the Baseline Scenarios that address the question “What are the impacts of continuing the current pumping distribution into the future?”
- Scenarios 3 and 4 provide the Mesquite Lake Pumping Scenarios that address the question “What are the impacts and benefits of shifting pumping to the Mesquite Lake Subbasin?”
- Scenarios 5 and 6 provide the Alternative Pumping Scenarios that address the question “Can the proposed pumping plan be optimized?”
- Scenarios7 and 7 provide sensitivity analyses that address the question “How does uncertainty in our understanding of the hydrogeology affect the conclusion?”

Because of the uncertainty of evaluating future conditions, multiple pumping scenarios are evaluated to define a reasonable range of potential future conditions. The actual future conditions would be considered to fall within this range. The hydrologic budget approach evaluates only the first four scenarios, whereas the MODFLOW model is used to evaluate all eight scenarios.

A summary of the setup of the eight scenarios setup is provided below.

- **Scenario 1 – Baseline Scenario with No Growth**: This scenario carries forward current conditions for another 25 years (until 2033). The pumping from TPWD-TP-1 is increased to the current maximum yield of 1 MGD. The pumping in all other TPWD wells remains constant from 2009 to 2033 at the rates measured in 2008. This scenario is designed to show the groundwater conditions after 25 more years of the current usage pattern, for the purpose of comparing the results at the end of the model run with the results of the other scenarios.
- **Scenario 2 – Baseline Scenario with Growth**: This scenario starts with the pumped volumes for each active TPWD well from the end of 2008, but increases pumping every year on a linear basis for another 25 years (until 2033). The percentage of the total pumping applied to each well is the same in every year, so pumping in every well is

increased each year, with no extra pumping applied to the Mesquite Lake Subbasin beyond the annual increase. This scenario is designed to show the groundwater conditions after 25 more years, assuming continued growth and extension of the current usage pattern.

- **Scenario 3 – Mesquite Lake Pumping Scenario with No Growth**: This scenario moves groundwater development to the Mesquite Lake Subbasin from the other basins using the planned production schedule. This scenario is designed to show the groundwater conditions after 25 years of pumping with increased production in the Mesquite Lake Subbasin and decreased production in the other basins.

- **Scenario 4 – Mesquite Lake Pumping Scenario with Growth**: This scenario moves groundwater development to the Mesquite Lake Subbasin as above, but allows for a linear annual increase in total pumping over the model duration. This scenario is designed to show the groundwater conditions after 25 years of pumping, assuming increased production in the Mesquite Lake Subbasin and continued growth in the total groundwater development in the other basins.

- **Scenario 5 – Alternative Pumping Scenario with No Growth**: This scenario moves groundwater development to the Mesquite Lake Subbasin as in Scenario 3, with total pumping remaining constant. The decrease in pumping in the other basins is distributed to minimize pumping in the Eastern Subbasin, with less of a decrease in pumping in the Indian Cove and Fortynine Palms Subbasins.

- **Scenario 6 – Alternative Pumping Scenario with Growth**: This scenario moves groundwater development to the Mesquite Lake Subbasin as in Scenario 4, with total pumping increasing linearly over the evaluated duration. As in Scenario 5, pumping in the Eastern Subbasin is minimized, with less of a decrease in pumping in the Indian Cove and Fortynine Palms Subbasins.

- **Scenario 7 – Sensitivity Analysis for variability of Hydraulic Conductivity**: This scenario tests the effect of modifying the hydraulic conductivity on the model results. The sensitivity analysis entails re-running the transient model with new hydraulic conductivity values, then subsequently running a predictive scenario. The pumping for this scenario is identical to that of Scenario 6.

- **Scenario 8 – Sensitivity Analysis for variability of Specific Yield**: This scenario tests the effect of modifying the specific yield on the model results. Again, the transient model is re-run, and then a predictive scenario is run. As with Scenario 7, the pumping for this scenario is identical to that of Scenario 6.

6.4 Evaluation of Pumping Using Hydraulic Budget Method

The hydrologic budget method consists of a tabulation of the total groundwater inflows and outflows from the basin enables estimates of the change in groundwater storage, and is based on the methodology discussed in Section 4. A reasonable estimate of a particular basin's response to future pumping demands can be made by comparing historic annual changes in basin groundwater storage to overall pumping withdrawals for that same annual period. Using the historical data, a correlation is developed that relates the change in groundwater storage to groundwater pumping for each basin. For the future pumping scenarios, this correlation factor is applied to the proposed groundwater pumping in each basin on an annual basis. Documentation for the development of the linear regression analysis used to develop this correlation factor is provided in Appendix G.

Changes in groundwater in storage are reflected in the change in groundwater elevations in the basin. In the hydrologic budget equation above, a negative change in storage means that the net amount of groundwater in a basin is decreasing over time, and would be reflected by decreasing water levels measured in area wells. Conversely, a positive change in storage means that the net amount of groundwater in a basin is increasing over time, and would be reflected by increasing water levels measured in area wells.

To estimate the change in groundwater levels is a function of both the specific yield and areal extent of the aquifer. Specific yield is the ratio of the volume of water that saturated sediment will yield by gravity drainage in proportion to the total volume of the sediments. Using sediment descriptions from area well logs, DWR suggested average specific yield estimates of 0.10 for the Indian Cove Subbasin and 0.20 for the Fortynine Palms and Eastern Subbasins (DWR, 1984). The values estimated by DWR are used for this analysis, with an average specific yield of 0.10 conservatively assumed for the Mesquite Lake Subbasin.

Groundwater level changes can be determined by dividing the change in groundwater storage for each basin by the product of the specific yield and the total basin area. Changes in groundwater levels calculated by this method are an average change over the entire basin. Local variations in groundwater levels due to geologic heterogeneities or localized effects of large-scale pumping are not considered. Evaluation of localized drawdowns due to changes in groundwater pumping requires a different analysis. Therefore, this method provides a general evaluation of basin impacts that can be used for comparative purposes. In general, larger basins would typically experience less change in groundwater levels due to pumping than smaller basins because the change in groundwater storage can be distributed over a larger area.

The hydrologic budget method is applied to Pumping Scenarios 1 through 4. For each of the four basins, the projected cumulative change in total groundwater storage volume over the 25-year future-case scenario is provided. The annual changes in storage are documented in Appendix G with summary tables of the projected annual basin pumping totals, changes in basin storage, and potential change in groundwater levels.

6.4.1 Scenario 1 Using Hydraulic Budget Method

Scenario 1 is the Baseline Scenario for estimating basin groundwater conditions after another 25 years of the pumping usage patterns established in 2008, except that pumping in the Mesquite Lake Subbasin from TPWD-TP-1 is increased to the well's current maximum yield of 1 MGD (1,120 afy). In addition to pumping from TPWD-TP-1, it is assumed that the existing pumping at the park and golf course in the Mesquite Lake Subbasin (approximately 580 afy) would also persist throughout the 25-year analysis period. For the Indian Cove, Fortynine Palms and Eastern Subbasins, the total annual basin pumping totals projected over the 25-year period are equal to the volumes experienced in 2008.

Using the hydrologic budget method, the annual change in groundwater storage and average change in groundwater levels for Scenario 1 are presented in more detail in Appendix G. A summary of the results concludes the following:

- Indian Cove Subbasin: Pumping remains steady at 691 afy. Cumulative groundwater levels decline by 25 to 28 feet and annual groundwater storage decreases to a loss of 584 to 664 afy over 25 years.

- Fortynine Palms Subbasin: Pumping remains steady at 1,024 afy. Cumulative groundwater levels decline by 56 to 69 feet and annual groundwater storage decreases to a loss of 822 to 1,022 afy over 25 years.

- Eastern Subbasin: Pumping remains steady at 737 afy. Cumulative groundwater levels decline by 10 to 13 feet and annual groundwater storage decreases to a loss of 542 to 737 afy over 25 years.

- Mesquite Lake Subbasin: Pumping remains steady at 1,121 afy (1 MGD). Cumulative groundwater levels decline by 6 to 8 feet and annual groundwater storage decreases to a loss of 1,110 to 1,418 afy over 25 years.

6.4.2 Scenario 2 Using Hydraulic Budget Method

Scenario 2 is the Baseline Scenario that evaluates effects of increasing pumping in each of the four basins every year from 2009 through 2033 on a linear basis relative to the 2008 pumping. The percentage of pumping increase applied to each well is the same in every year, with no extra pumping applied to the Mesquite Lake Subbasin beyond the annual increase. This scenario is designed to show the groundwater conditions after 25 more years with continued growth of the current usage pattern.

Using the hydrologic budget method, the annual change in groundwater storage and average change in groundwater levels for Scenario 2 are presented in more detail in Appendix G. A summary of the results concludes the following:

- Indian Cove Subbasin - Pumping increases from 691 to 833 afy after 25 years. Cumulative groundwater levels decline by 28 to 31 feet and annual groundwater storage decreases to a loss of 732 to 806 afy over 25 years.

- Fortynine Palms Subbasin - Pumping increases from 1,024 to 1,233 afy after 25 years. Cumulative groundwater levels decline by 62 to 76 feet and annual groundwater storage decreases to a loss of 1,019 to 1,231 afy over 25 years.

- Eastern Subbasin - Pumping increases from 737 to 888 afy after 25 years. Cumulative groundwater levels decline by 11 to 14 feet and annual groundwater storage decreases to a loss of 736 to 888 afy over 25 years.

- Mesquite Lake Subbasin - Pumping increases from 1,121 to 1,350 afy (1 MGD) after 25 years. Cumulative groundwater levels decline by 7 to 8 feet and annual groundwater storage decreases to a loss of 1,275 to 1,640 afy over 25 years.

Compared to Scenario 1, the projected changes for each basin are similar, showing additional decreases in both the amount of groundwater in storage and average water levels. However, because the pumping growth is applied linearly to each basin, the projected decreases after 25 more years compared to the no-growth scenario are moderate, ranging from approximately 7 percent in the Mesquite Lake Subbasin to about 15 percent in the Eastern Subbasin.

6.4.3 Scenario 3 Using Hydraulic Budget Method

Scenario 3 is a Mesquite Lake Pumping Scenario with no projected future growth in overall TPWD groundwater production. The majority of groundwater production is shifted to the Mesquite Lake Subbasin, using the planned production schedule, with the remaining demand met by reduced withdrawals from the three southern basins. For Scenario 3, pumping in the Mesquite Lake Subbasin is increased over time to reflect the planned expansion of the treatment plant capacity over time. The total TPWD pumping increases from 1.0 MGD to 1.3 MGD in 2010, then to 2.0 MGD in 2011, and then finally to the planned capacity of 3.0 MGD in 2015. Under this scenario, this final capacity treatment plant represents 94 percent of the total pumping from the TPWD well system. The increased pumping at the treatment plant is compensated for by decreasing the pumping from all of the other TPWD wells; each well is decreased by the same percentage, so each well takes up the same percentage of the non-treatment plant pumping every year.

Using the hydrologic budget method, the annual change in groundwater storage and average change in groundwater levels for Scenario 3 are presented in more detail in Appendix G. A summary of the results concludes the following:

- Indian Cove Subbasin: Pumping declines from 691 to 59 afy after 25 years. Cumulative groundwater levels decline by 1 to 6 feet and annual groundwater storage ranges from a loss of 32 afy to an increase of 76 afy over 25 years.

- Fortynine Palms Subbasin: Pumping declines from 1,024 to 88 afy after 25 years. Cumulative groundwater levels decline by 5 to 16 feet and annual groundwater storage ranges from a loss of 87 afy to an increase of 60 afy over 25 years.

- Eastern Subbasin: Pumping declines from 737 to 63 afy after 25 years. Cumulative groundwater levels range from a rise of 3 feet to a decline of 3 feet and annual groundwater storage ranges from a loss of 63 afy to an increase of 324 afy over 25 years.

- Mesquite Lake Subbasin: Pumping increases from 1,701 to 3,363 afy after 25 years. Cumulative groundwater levels decline by 14 to 18 feet and annual groundwater storage decreases to a loss of 2,724 to 3,593 afy over 25 years.

After 25 years, groundwater level declines in the Indian Cove and Fortynine Palms Subbasins are quite low, approximately 1 to 6 feet and 5 to 16 feet, respectively. Because the Eastern Subbasin receives relatively greater groundwater inflow and recharge, groundwater levels there are projected to either increase or decrease by about 3 feet by 2033, depending on the recharge values used for the analysis. This scenario apparently results in relatively modest reductions in groundwater levels in the Mesquite Lake Subbasin, with a projected lowering of about 14 to 18 feet after 25 years.

6.4.4 Scenario 4 Using Hydraulic Budget Method

Scenario 4 is a Mesquite Lake Pumping Scenario with a linearly increasing projected future growth in overall TPWD groundwater production. The majority of groundwater production is shifted to the Mesquite Lake Subbasin. However, a linear increase in total pumping is applied so that total pumping is identical to Scenario 2 for each year. The pumping at the treatment plant wells is identical to Scenario 3. The linear increase in pumping is applied to wells in Indian Cove, Fortynine Palms and Eastern Subbasins. At the end of this scenario, 78 percent of the total pumping comes from the treatment plant wells as compared to 94 percent for Scenario 3.

Using the hydrologic budget method, the annual change in groundwater storage and average change in groundwater levels for Scenario 4 are presented in more detail in Appendix G. A summary of the results concludes the following:

- Indian Cove Subbasin: Pumping declines from 691 to 265 afy after 25 years. Cumulative groundwater levels decline by 5 to 9 feet and annual groundwater storage decreases to a loss of 139 to 238 afy after 25 years.

- Fortynine Palms Subbasin: Pumping declines from 1,024 to 393 afy after 25 years. Cumulative groundwater levels decline by 5 to 16 feet and annual groundwater storage decreases to a loss of 228 to 393 afy over 25 years.

- Eastern Subbasin: Pumping declines from 737 to 283 afy after 25 years. Cumulative groundwater levels range from a rise of 3 feet to a decline of 3 feet and annual groundwater storage ranges from a loss of 283 afy to an increase of 41 afy over 25 years.

- Mesquite Lake Subbasin: Pumping increases from 1,701 to 3,363 afy after 25 years. Cumulative groundwater levels decline by 14 to 18 feet and annual groundwater storage decreases to a loss of 2,724 to 3,593 afy over 25 years.

Changes in storage and water level projections for the Mesquite Lake Subbasin are the same as for Scenario 3, because pumping in this basin is based on the planned schedule, with production there anticipated to be maximized by 2015. Projected impacts to water levels in the other three southern basins range from moderately negative to slightly positive. In the Indian Cove and Fortynine Palms Subbasins, water level declines are estimated to be about 5 to 9 feet and 14 to 25 feet, respectively. For the Eastern Subbasin, by 2033 the groundwater level is expected to either increase by about 1 foot or decrease by about 5 feet, again depending on the recharge values used for the analysis.

6.5 Evaluation of Pumping using MODFLOW Model

Based on the calibration to historical data and the quality assurance parameters, the MODFLOW model is considered capable of forecasting future case scenarios. Therefore, the model is able to evaluate the impact of potential future changes in pumping conditions on groundwater levels in the groundwater basin. The goal of shifting pumping from wells within the southern basins (Indian Cove, Fortynine Palms and Eastern Subbasins) into wells in the Mesquite Lake Subbasin is to mitigate the drawdown in the southern basins. Therefore, the various scenarios investigated in the numerical modeling portion of this project are considered for their ability to reduce drawdown in the southern basins while not producing unacceptable drawdown in the Mesquite Lake Subbasin.

The MODFLOW model is used to evaluate pumping Scenarios 1 through 6 using assumed future pumping conditions. Therefore, in evaluating the results of model scenarios, it is recommended to look more at the overall trends and the relative differences between the scenario and the baseline scenarios.

When considering the results of the model scenarios, it is important to note that conservative assumptions were applied in the MODFLOW model regarding the amount of annual groundwater recharge. This was necessary because of the uncertainty inherent in estimating the groundwater recharge (see Section 4.2). Additional details of these conservative assumptions are provided in Appendix F.

The results of the model scenarios include changes in the hydrologic budget, groundwater storage, and groundwater levels throughout the model domain. The modeling software automatically keeps track of the hydrologic budget over time. In order to track water levels throughout the basin, difference maps are developed to show the total change in groundwater levels over the 25-year model scenario.

6.5.1 Scenario 1 Using MODFLOW Model

Scenario 1 is a Baseline Scenario that evaluates potential future groundwater conditions for 25 years using the current distribution of pumping established in 2008, except that pumping in the Mesquite Lake Subbasin from TPWD-TP-1 is increased to the well's current maximum yield of 1 MGD (1,120 afy). In addition to pumping from TPWD-TP-1, it is assumed that the existing pumping at the park and golf course in the Mesquite Lake Subbasin (approximately 580 afy) would also persist throughout the 25-year analysis period. For the Indian Cove, Fortynine Palms and Eastern Subbasins, the total annual basin pumping totals projected over the 25-year period are equal to the volumes experienced in 2008.

Using the MODFLOW model, the annual change in groundwater storage and average change in groundwater levels for Scenario 1 are evaluated for each subbasin. Hydrographs of key monitoring points and additional detailed data for the model scenarios are included on Figures 6-1, 6-2, 6-3, and 6-4. Additional tables and graphs are presented in Appendix H to provide more detail. A summary of the results concludes the following:

- Indian Cove Subbasin: Pumping remains steady at 691 afy over 25 years. Cumulative groundwater levels decline an average of about 18 feet and annual groundwater storage decreases to a loss of 693 afy after 25 years.

- Fortynine Palms Subbasin: Pumping remains steady at 1,024 afy over 25 years. Cumulative groundwater levels decline an average of about 80 feet and annual groundwater storage decreases to a loss of 1,051 afy after 25 years.

- Eastern Subbasin: Pumping remains steady at 737 afy over 25 years. Cumulative groundwater levels decline an average of about 49 feet and annual groundwater storage decreases to a loss of 886 afy after 25 years.

- Mesquite Lake Subbasin: Pumping increases to 1,121 afy over 25 years. Cumulative groundwater levels decline an average of about 27 feet and annual groundwater storage decreases to a loss of 2,710 afy after 25 years.

Figure 6-5 provides a map that shows the difference in groundwater levels after 25 years under the Scenario 1 assumptions. The results indicate that continuing current pumping would result in significant additional drawdowns in the Indian Cove, Fortynine Palms and Eastern Subbasins for the areas between the Oasis and Pinto Faults. Drawdown in the Mesquite Lake Subbasin would be limited to the southeastern corner near well TPWD-TP-1.

The response of the hydrologic system to the changes in pumping simulated in these scenarios can also be studied by accounting for the fluxes into and out of the model. Additional tables summarizing the hydrologic budget are provided in Appendix H. In summary, as water levels drop in the model domain, groundwater inflow to the model is expected to increase, and outflow is expected to decrease. Groundwater inflow across the Transverse Arch increases from 810 af in 2009 to 900 af in 2033, an increase of 11 percent. Inflow from the Copper Mountain Subbasin increased from 130 af in 2009 to 140 af in 2033, an increase of 7 percent. Inflow from the Joshua Tree Subbasin in to the Indian Cove Subbasin initially increases from 26 af in 2009 to 29 af in 2019, but then decreases to 27 af by 2033, an increase of 3 percent over 2009 inflow. Groundwater outflow to the Dale Basin declines from 510 af in 2009 to 490 af in 2033, a decrease of 4 percent. ET at the Mesquite Dry Lake area decreases over time with the dropping water level, from 1,630 af in 2009 to 1,420 af in 2033, a drop of 13 percent. The groundwater pumping in the basin results in an additional 3.9 afy of inflow to the model domain, and a decrease of 9.3 afy of outflow (both groundwater outflow and ET).

The rate of decrease in groundwater elevation varies from basin to basin (rates are for groundwater elevations in Model Layer 1, which are not very different from those in Model Layers 2 and 3): 0.7 ft/yr for the Indian Cove Subbasin, 3.2 ft/yr for the Fortynine Palms Subbasin, 2.0 ft/yr for the Eastern Subbasin, and 1.1 ft/yr for the Mesquite Lake Subbasin (Figures 6-1, 6-2, 6-3, and 6-4). This compares to observed drawdown rates from 1984 through 2008 of 1.1 ft/yr for the Indian Cove Subbasin, 4.1 ft/yr for the Fortynine Palms Subbasin, 1.6 ft/yr for the Eastern Subbasin, and 1.1 ft/yr for the Mesquite Lake Subbasin (Figures 6-1, 6-2, 6-3, and 6-4).

6.5.2 Scenario 2 Using MODFLOW Model

Scenario 2 uses the same assumptions as Scenario 1, except that a linear growth rate is applied to the pumping. The percentage of pumping increase applied to each well is the same in every year, with no extra pumping applied to the Mesquite Lake Subbasin beyond the annual increase. This scenario is designed to show the groundwater conditions after 25 more years with continued growth of the current usage pattern.

Using the MODFLOW model, the annual change in groundwater storage and average change in groundwater levels for Scenario 2 are evaluated for each subbasin. Hydrographs of key monitoring points and additional detailed data for the model scenarios are included on Figures 6-1, 6-2, 6-3, and 6-4. Additional tables and graphs are presented in Appendix H to provide more detail. A summary of the results concludes the following:

- Indian Cove Subbasin: Pumping increases from 691 to 833 afy after 25 years. Cumulative groundwater levels decline an average of about 21 feet and annual groundwater storage decreases to a loss of 834 afy after 25 years.

- Fortynine Palms Subbasin: Pumping increases from 1,024 to 1,233 afy after 25 years. Cumulative groundwater levels decline an average of about 105 feet and annual groundwater storage decreases to a loss of 1,274 afy after 25 years.

- Eastern Subbasin: Pumping increases from 737 to 888 afy after 25 years. Cumulative groundwater levels decline an average of about 55 feet and annual groundwater storage decreases to a loss of 1,037 afy after 25 years.

- Mesquite Lake Subbasin: Pumping increases from 1,121 to 1,350 afy after 25 years. Cumulative groundwater levels decline an average of about 31 feet and annual groundwater storage decreases to a loss of 2,961 afy after 25 years.

Figure 6-6 provides a map that shows the difference in groundwater levels after 25 years under the Scenario 2 assumptions. The results are similar to Scenario 1 in distribution, but with slightly more drawdown in the Indian Cove, Fortynine Palms and Eastern Subbasins for the areas between the Oasis and Pinto Faults. Drawdown in the Mesquite Lake Subbasin would be limited to the southeastern corner near well TPWD-TP-1.

As with Scenario 1, the increase in pumping results in an increase in inflow to the basin, and a decrease in outflows (Appendix H). Because these scenarios are fairly similar, the starting and ending fluxes are also quite similar. ET at the Mesquite Dry Lake decreases to 1,410 af by 2033. Groundwater inflow from the Copper Mountain Subbasin increases by 6 percent in this scenario, and flow from the Joshua Tree Subbasin increases by 4 percent. Groundwater outflow to the Dale Basin declines by 5 percent. Total inflow to the model increases by 3.8 afy, and outflow decreases by 9.7 afy.

The response of the water level in the various basins is very similar to that of Scenario 1, with equal or slightly higher drawdowns in all wells. The annual drawdown rate for the Eastern Subbasin is 2.2 ft/yr in the southern part and -0.2 ft/yr (i.e. an increase in water levels of 0.2 ft/yr) in the northern part; in the Fortynine Palms Subbasin, it is 3.1 ft/yr in the west and 4.2 ft/yr in the east; in the Indian Cove Subbasin, it is 0.9 ft/yr in the south and 0.1 ft/yr in the north; and in the Mesquite Lake Subbasin, it varies from -0.1 ft/yr in the northwest to 1.0 ft/yr near the treatment plant (Figures 6-1, 6-2, 6-3, and 6-4).

6.5.3 Scenario 3 Using MODFLOW Model

Scenario 3 is a Mesquite Lake Pumping Scenario with no projected future growth in overall TPWD groundwater production. For Scenario 3, the majority of groundwater production is shifted to the Mesquite Lake Subbasin. Pumping in the Mesquite Lake Subbasin is increased from 1.0 MGD to 1.3 MGD in 2010, then to 2.0 MGD in 2011, then to a final planned capacity of

3.0 MGD in 2015. Under this scenario, this final capacity treatment plant represents 94 percent of the total pumping from the TPWD well system. The increased pumping at the treatment plant is compensated for by decreasing the pumping from all of the other TPWD wells; each well is decreased by the same percentage, so each well takes up the same percentage of the non-treatment plant pumping every year. This results in a net decrease in pumping in the Indian Cove, Fortynine Palms and Eastern Subbasins (Appendix H).

Using the MODFLOW model, the annual change in groundwater storage and average change in groundwater levels for Scenario 3 are evaluated for each subbasin. Hydrographs of key monitoring points and additional detailed data for the model scenarios are included on Figures 6-1, 6-2, 6-3, and 6-4. Additional tables and graphs are presented in Appendix H to provide more detail. A summary of the results concludes the following:

- Indian Cove Subbasin: Pumping declines from 691 to 59 afy after 25 years. Cumulative groundwater levels recover an average of about 3 feet and annual groundwater storage improves from to a loss of 65 afy after 25 years.

- Fortynine Palms Subbasin: Pumping declines from 1,024 to 88 afy after 25 years. Cumulative groundwater levels recover an average of about 24 feet and annual groundwater storage improves to 169 afy after 25 years.

- Eastern Subbasin: Pumping declines from 737 to 63 afy after 25 years. Cumulative groundwater levels decline an average of about 12 feet and annual groundwater storage decreases to a loss of 193 afy after 25 years.

- Mesquite Lake Subbasin: Pumping increases from 1,121 to 3,363 afy after 25 years. Cumulative groundwater levels decline an average of about 92 feet and annual groundwater storage decreases to 5,029 afy after 25 years.

Figure 6-7 provides a map that shows the difference in groundwater levels after 25 years under the Scenario 3 assumptions. The results show that groundwater levels in the Indian Cove, Fortynine Palms and Eastern Subbasins have significantly less drawdown than for Scenario 1. Areas near the pumping wells show increases in groundwater levels. The results show increased drawdown in the Mesquite Lake Subbasin in the vicinity of well TPWD-TP-1; however, the basin is over 1,000 feet thick here, so the overall drawdown is a low percentage of the saturated aquifer thickness.

Although the total pumping is the same as Scenario 1, the redistribution of pumping changes the hydrologic budget. Additional detail is provided in Appendix H. ET at the Mesquite Dry Lake declines by 22 percent over the 25 years of the model as compared to 13 percent for Scenario 1, from 1,630 af in 2009 to 1,280 af in 2033. Groundwater inflow from the Transverse Arch is nearly identical throughout the model run to that of Scenario 1. Inflow from the Copper Mountain Subbasin increases 10 percent, from about 130 af in 2009 to almost 150 af in 2033. Inflow across the Joshua Tree Subbasin initially increases as in Scenario 1, but returns to a flux almost identical to the 2009 flux by 2033. Groundwater outflow from the model decreases by 10 percent, from 510 af in 2009 to 460 af in 2033 (compared to 490 af in 2033 for Scenario 1). In total, groundwater inflow increases by 4 afy over the entire 25-year model duration, and groundwater outflow decreases by 16 afy.

In general, drawdown decreases greatly in the southern basins in this scenario (as compared to Scenario 1), and increases in the Mesquite Lake Subbasin. Drawdown rates for the various parts of the model domain are: -0.1 ft/yr in the southern part and -0.01 ft/yr in the northern part of the Indian Cove Subbasin; 2.1 ft/yr in the western part and -0.9 ft/yr in the eastern part of the Fortynine Palms Subbasin; -0.2 ft/yr in the southern part and 0.5 ft/yr in the northern part of the Eastern Subbasin; and between -0.1 ft/yr in the northwestern part and 3.8 ft/yr near the treatment plant in the Mesquite Lake Subbasin (Figures 6-1, 6-2, 6-3, and 6-4).

6.5.4 Scenario 4 Using MODFLOW Model

Scenario 4 is a Mesquite Lake Pumping Scenario with a linearly increasing projected future growth in overall TPWD groundwater production. Scenario 4 is similar to Scenario 3, expect that a linear increase in total pumping is applied for each year as was applied for Scenario 2. The linear increase in pumping is applied to wells in Indian Cove, Fortynine Palms and Eastern Subbasins. At the end of this scenario, 78 percent of the total pumping comes from the treatment plant wells as compared to 94 percent for Scenario 3.

Using the MODFLOW model, the annual change in groundwater storage and average change in groundwater levels for Scenario 4 are evaluated for each subbasin. Hydrographs of key monitoring points and additional detailed data for the model scenarios are included on Figures 6-1, 6-2, 6-3, and 6-4. Additional tables and graphs are presented in Appendix H to provide more detail. A summary of the results concludes the following:

- Indian Cove Subbasin: Pumping declines from 691 to 265 afy after 25 years. Cumulative groundwater levels decline an average of about 1 feet and annual groundwater storage improves from to a loss of 270 afy after 25 years.

- Fortynine Palms Subbasin: Pumping declines from 1,024 to 393 afy after 25 years. Cumulative groundwater levels recover an average of about 3 feet and annual groundwater storage improves to 459 afy after 25 years.

- Eastern Subbasin: Pumping declines from 737 to 283 afy after 25 years. Cumulative groundwater levels decline an average of about 19 feet and annual groundwater storage decreases to a loss of 429 afy after 25 years.

- Mesquite Lake Subbasin: Pumping increases from 1,121 to 3,363 afy after 25 years. Cumulative groundwater levels decline an average of about 92 feet and annual groundwater storage decreases to 5,034 afy after 25 years.

Figure 6-8 provides a map that shows the difference in groundwater levels after 25 years under the Scenario 4 assumptions. The results are similar to Scenario 1 in distribution, but with more drawdown in the Indian Cove, Fortynine Palms and Eastern Subbasins for the areas between the Oasis and Pinto Faults. Drawdown in the Mesquite Lake Subbasin also increases in the southeastern corner near well TPWD-TP-1.

The boundary fluxes for this scenario are similar to those from Scenario 3 since the overall pumping is the same. However, some variations do occur. ET at Mesquite Dry Lake decreases from 1,630 af in 2009 to 1,270 af in 2033. Groundwater inflow increases by 4.1 afy over the 25-year model duration, and groundwater outflow decreases by 16.5 afy.

Drawdown rates are similar to those of Scenario 3: 0.01 ft/yr in the southern part and 0.1 ft/yr in the northern part of the Indian Cove Subbasin; 2.2 ft/yr in the western part and -0.05 ft/yr in the eastern part of the Fortynine Palms Subbasin; -0.2 ft/yr in the southern part and 0.8 ft/yr in the northern part of the Eastern Subbasin; and between -0.1 ft/yr in the northwestern part and 3.8 ft/yr near the treatment plant in the Mesquite Lake Subbasin (Figures 6-1, 6-2, 6-3, and 6-4).

6.5.5 Scenario 5 Using MODFLOW Model

Scenario 5 is an Alternative Pumping Scenario with no projected future growth in overall TPWD groundwater production. Scenario 5 is an adaptation of Scenario 3 where most of the pumping in the Eastern Subbasin is redistributed to the Fortynine Palms and Indian Cove Subbasins. The results of Scenario 5 (Figure 6-9) show more drawdown in the Eastern Subbasin than in the Fortynine Palms and Indian Cove Subbasins. For Scenario 5, pumping is reduced from 710 af in 2009 to 410 af in 2010 in the Eastern Subbasin, then to zero in 2011. This pumping is distributed to the wells in the Fortynine Palms and Indian Cove Subbasins, excepting TPWD-15, which is south of the Pinto Fault in the Indian Cove Subbasin. At the end of the scenario, pumping from the treatment plant makes up 94 percent of the total TPWD pumping, the same as in Scenario 3.

Using the MODFLOW model, the annual change in groundwater storage and average change in groundwater levels for Scenario 5 are evaluated for each subbasin. Hydrographs of key monitoring points and additional detailed data for the model scenarios are included on Figures 6-1, 6-2, 6-3 and 6-4. Additional tables and graphs are presented in Appendix H to provide more detail. A summary of the results concludes the following:

- Indian Cove Subbasin: Pumping declines from 691 to 85 afy after 25 years. Cumulative groundwater levels recover an average of about 2 feet and annual groundwater storage improves from to a loss of 90 afy after 25 years.

- Fortynine Palms Subbasin: Pumping declines from 1,024 to 126 afy after 25 years. Cumulative groundwater levels recover an average of about 17 feet and annual groundwater storage improves to 203 afy after 25 years.

- Eastern Subbasin: Pumping declines from 737 to 0 afy after 25 years. Cumulative groundwater levels decline an average of about 5 feet and annual groundwater storage decreases to a loss of 148 afy after 25 years.

- Mesquite Lake Subbasin: Pumping increases from 1,121 to 3,363 afy after 25 years Cumulative groundwater levels decline an average of about 92 feet and annual groundwater storage decreases to 5,028 afy after 25 years.

Figure 6-9 provides a map that shows the difference in groundwater levels after 25 years under the Scenario 1 assumptions. The results indicate that continuing current pumping would result in significant additional drawdowns in the Indian Cove, Fortynine Palms and Eastern Subbasins for the areas between the Oasis and Pinto Faults. Drawdown in the Mesquite Lake Subbasin would be limited to the southeastern corner near well TPWD-TP-1.

The hydrologic budget for Scenario 5 is similar to those of Scenario 3. Total groundwater inflow increases by 4.1 afy over the duration of the scenario, and groundwater outflow decreases by 16.4 afy.

Compared to Scenario 3, drawdown rates are slightly higher in the Fortynine Palms and Indian Cove Subbasins, and lower in the Eastern Subbasin: -0.01 ft/yr in the southern part and -0.04 ft/yr in the northern part of the Indian Cove Subbasin; 2.2 ft/yr in the western part and -0.6 ft/yr in the eastern part of the Fortynine Palms Subbasin; -0.2 ft/yr in the southern part and 0.3 ft/yr in the northern part of the Eastern Subbasin; and between -0.1 ft/yr in the northwestern part and 3.8 ft/yr near the treatment plant in the Mesquite Lake Subbasin (Figures 6-1, 6-2, 6-3, and 6-4).

6.5.6 Scenario 6 Using MODFLOW Model

Scenario 6 is an Alternative Pumping Scenario with a linearly increasing projected future growth in overall TPWD groundwater production Scenario 6 is the same as Scenario 5, except that a linear growth rate is applied to production from the TPWD wells. As is the case in Scenario 5, the goal of changing the pumping regime is to minimize pumping in the Eastern Subbasin. The same approach as in Scenario 5 is taken to computing how much pumping to apply to each well in the Fortynine Palms and Indian Cove Subbasins.

Using the MODFLOW model, the annual change in groundwater storage and average change in groundwater levels for Scenario 6 are evaluated for each subbasin. Hydrographs of key monitoring points and additional detailed data for the model scenarios are included on Figures 6-1, 6-2, 6-3 and 6-4. Additional tables and graphs are presented in Appendix H to provide more detail. A summary of the results concludes the following:

- Indian Cove Subbasin: Pumping declines from 691 to 379 afy after 25 years. Cumulative groundwater levels recover an average of about 5 feet and annual groundwater storage improves from to a loss of 384 afy after 25 years.

- Fortynine Palms Subbasin: Pumping declines from 1,024 to 562 afy after 25 years. Cumulative groundwater levels recover an average of about 15 feet and annual groundwater storage improves to 617 afy after 25 years.

- Eastern Subbasin: Pumping declines from 737 to 0 afy after 25 years. Cumulative groundwater levels decline an average of about 5 feet and annual groundwater storage decreases to a loss of 151 afy after 25 years.

- Mesquite Lake Subbasin: Pumping increases from 1,121 to 3,363 afy after 25 years. Cumulative groundwater levels decline an average of about 92 feet and annual groundwater storage decreases to 5,037 afy after 25 years.

Figure 6-10 provides a map that shows the difference in groundwater levels after 25 years under the Scenario 1 assumptions. The results indicate that continuing current pumping would result in significant additional drawdowns in the Indian Cove, Fortynine Palms and Eastern Subbasins for the areas between the Oasis and Pinto Faults. Drawdown in the Mesquite Lake Subbasin would be limited to the southeastern corner near well TPWD-TP-1.

The hydrologic budget determined by the model for Scenario 6 is similar to Scenario 5. Groundwater inflow increases by only 4.1 afy, and groundwater outflow decreases by about 16.6 afy.

Drawdown rates are equal to or slightly higher than in Scenario 5 with about 0.01 ft/yr in the southern part and 0.2 ft/yr in the northern part of the Indian Cove Subbasin; 2.4 ft/yr in the western part and 0.6 ft/yr in the eastern part of the Fortynine Palms Subbasin; -0.2 ft/yr in the southern part and 0.3 ft/yr in the northern part of the Eastern Subbasin; and between -0.1 ft/yr in the northwestern part and 3.8 ft/yr near the treatment plant in the Mesquite Lake Subbasin (Figures 6-1, 6-2, 6-3, and 6-4).

6.6 Sensitivity Analysis

Scenarios 7 and 8 are a sensitivity analysis for hydraulic conductivity and specific yield. The purpose of the sensitivity analysis is to evaluate the sensitivity of the model results to the inherent uncertainty of key hydrogeologic properties including hydraulic conductivity and specific yield. The hydraulic conductivities and specific yield used in the MODFLOW model are considered as best estimates and the model is considered well calibrated. The purpose of the sensitivity analysis is to provide as assessment of the potential variability of model results due to the uncertainty of selecting aquifer properties. Additional data on the sensitivity analysis are provided in Appendix I.

6.6.1 Scenario 7 – Hydraulic Conductivity Sensitivity Analysis

Scenario 7 evaluates the variability of hydraulic conductivity by changing the hydraulic conductivity in the uppermost model layer. Two simulations are created for this analysis, one with hydraulic conductivity halved, and the other with hydraulic conductivity doubled. The hydraulic conductivity is not changed in the strip along the mountain front of the Little San Bernardino Mountains. The final horizontal hydraulic conductivities for Scenario 7A are 5 ft/d for the Mesquite and Fortynine Palms Subbasins, as well as the Indian Cove Subbasin south of the Pinto Fault, and 7.5 ft/d for the Eastern Subbasin and the Indian Cove Subbasin north of the Pinto Fault. For Scenario 7B, the horizontal hydraulic conductivity is 20 ft/d for the Mesquite and Fortynine Palms Subbasins and the southern part of the Indian Cove Subbasin, and 30 ft/d for the Eastern Subbasin and the northern part of the Indian Cove Subbasin. The vertical hydraulic conductivity is 1 percent of the horizontal hydraulic conductivity.

For Scenario 7A, the hydraulic conductivity is reduced by half in many parts of the model. This leads to greater hydraulic gradients across the individual basins. In the downgradient parts of the basins, water levels decreases by between 3.2 feet in the Eastern Subbasin and 33.2 feet in the Fortynine Palms Subbasin. In the upgradient parts of the basins, water levels increases by between 1.5 feet in the Indian Cove and Eastern Subbasins and 24.7 feet in the Fortynine Palms Subbasin. Most of the downgradient wells, where the water level is lower compared to the results of Scenario 6, are TPWD production wells.

Under reduced hydraulic conductivity (Scenario 7A), flow into the model across the Transverse Arch is reduced by an average of 140 afy, while flux into the model from the Copper Mountain Subbasin is reduced by about 8 afy, and flux from the Joshua Tree Subbasin is reduced by about 0.2 afy. Flux out of the model into the Dale Basin is also reduced by about 8 afy. However, the ET from the Mesquite Dry Lake area declines by 580 afy, far more than the changes in fluxes across the general head boundaries. This indicates that the amount of water in the model actually increases, rather than decreases, due to the change in hydraulic conductivity.

Figure 6-11 shows the difference in water levels between Scenarios 7A and 6 at the end of the respective scenarios. From this figure, the majority of the model domain shows a positive change in water level; the statistical result of an average drop in water levels at the wells and monitoring points is the result of underrepresentation in the water level measurements in the parts of the model where the water level actually rises.

For Scenario 7B, the hydraulic conductivity is doubled in many parts of the model. This leads to decreased hydraulic gradients across the individual basins. In the downgradient parts of the basins, water levels rise by between 2.0 feet in the Eastern Subbasin and 19.0 feet in the Fortynine Palms Subbasin. In the upgradient parts of the basin, water levels decrease by between 0.6 feet in the Eastern Subbasin and 19.0 feet in the Fortynine Palms Subbasin. In contrast to Scenario 7A, the water levels at the TPWD production wells are higher in Scenario 7B than in Scenario 6.

With the increased hydraulic conductivity in the model domain (Scenario 7B), flow into the model across the Transverse Arch increases by an average of 320 afy, while flux from the Copper Mountain Subbasin decreases by 56 afy and flux from the Joshua Tree Subbasin increases by 0.6 afy. Flux out of the model into the Dale Basin across the Mesquite Flux increases by 6 afy. The groundwater flux into and out of the model increases by 270 afy. In addition, the higher water level in the area of the Mesquite Dry Lake leads to a total ET flux of 840 afy more than in Scenario 6. The total increase in losses from the model of 1,110 afy means that the amount of water in the model is greatly reduced when hydraulic conductivity increases.

Figure 6-12 shows the difference in water levels between Scenarios 7B and 6 at the end of the respective scenarios. From this figure, the majority of the model domain shows dominantly reduced water levels, while most areas of water level rise are close to well clusters. The increased water levels at the TPWD wells (with no change in pumping rates) is due to the increased hydraulic conductivity, which increases the area of the aquifer that each well affects.

6.6.2 Scenario 8 –Specific Yield Sensitivity Analysis

Scenario 8 evaluates the variability of hydraulic conductivity by changing the specific yield of the aquifer. The sensitivity analysis on specific yield shows how uncertainty in the estimate of specific yield can affect the conclusions drawn from the model results. The change in specific yield results in a change in the water levels throughout the model domain, with little difference in hydraulic gradients from Scenario 6. The change in water levels reflects a change in the total amount of water in the model. Two simulations are created for this analysis, one with specific yield reduced to 0.12 (Scenario 8A), and the other with specific yield increased to 0.24

(Scenario 8B). It should be noted that the porosity in Scenario 8B had to be increased from 0.2 to 0.25 to accommodate that increase in specific yield.

For Scenario 8A, the specific yield is reduced to 0.12 in Model Layer 1 in many parts of the model. This leads to decreased water levels throughout the model domain. Groundwater levels in individual basins decreased by between 7.1 feet in the Mesquite Lake Subbasin and 28.3 feet in the Fortynine Palms Subbasin (Figure 6-13).

Under reduced specific yield (Scenario 8A), flux into the model across the Transverse Arch is increased by an average of 58 afy, while flux into the model from the Copper Mountain Subbasin is reduced by about 9 afy, and flux from the Joshua Tree Subbasin is increased by about 3 afy. Flux out of the model into the Dale Basin is also reduced by about 9 afy. In total, the groundwater flux into and out of the model increases by 43 afy. The ET from the Mesquite Dry Lake area is reduced by 129 afy, far more than the changes in fluxes across the general head boundaries. This indicates that the amount of water in the model actually increases by about 86 afy, rather than decreases, due to the change in specific yield.

Figure 6-13 shows the difference in water levels (in Model Layer 1) between Scenarios 8A and 6 at the end of the respective scenarios. From this figure, it appears that the majority of the model domain experiences a negative change in water level, with only the parts of the southern basins that lie south of the Pinto Fault showing very slight positive differences in water levels.

For Scenario 8B, the specific yield is increased to 0.24 in Model Layer 1 in many parts of the model. This leads to increased water levels in almost the entire model domain. Water levels in the individual basins are higher by between 4.2 feet in the Eastern and Mesquite Lake Subbasins and 16.8 feet in the Fortynine Palms Subbasin compared to Scenario 6.

With the increased specific yield in the model domain, flux into the model across the Transverse Arch decreases by an average of 41 afy, with flux from the Copper Mountain Subbasin decreases by 5 afy and flux from the Joshua Tree Subbasin decreases by 2 afy. Flux out of the model into the Dale Basin across the Mesquite Flux increases by 6 afy. The net groundwater flux for the model decreases by 42 afy. In addition, the higher water level in the area of the Mesquite Dry Lake led to a total ET flux of 76 afy more than in Scenario 6. The total increase in losses from the model of 34 afy means that the amount of water in the model is slightly reduced when specific yield is increased.

As with Scenario 8A, the average response of the wells (an increase in water levels) is reflected in the change in boundary conditions compared to Scenario 6. Again, a map of the change in Model Layer 1 water levels versus Scenario 6 (Figure 6-14) shows that almost all of the model domain exhibited higher water levels, except for the Fortynine Palms and Eastern Subbasins south of the Pinto Fault.

In summary, if estimations of the specific yield are too high, then the model results will indicate water levels that are too high, and drawdown will be greater than indicated in this analysis. Additionally, there will be less water stored in the modeled basins than indicated. If the specific yield estimates are too low, then the model results will indicate water levels in the TPWD wells that are too low, and the drawdown will not be as severe as indicated. There will be more water stored in the basins than indicated by the model.

6.7 Evaluation of Pumping Scenarios by Basin

In evaluating the results of model scenarios, it is recommended that TPWD look more at the overall trends and the relative differences between the scenario and a baseline scenario. Figures 6-15, 6-16, 6-17, and 6-18 show the relative difference in groundwater levels between the baseline scenario and the related pumping scenario. In these figures, positive values represent higher groundwater levels and negative numbers represent lower groundwater levels in the proposed pumping scenario relative to the baseline scenario.

In general, these maps show a similar pattern of the overall effect of shifting pumping to the Mesquite Lake Subbasin. In all cases, the groundwater levels are generally and significantly higher in Indian Cove, Fortynine Palms and Eastern Subbasins after pumping has been reduced. Increased pumping in the Mesquite Lake Subbasin does result in increased drawdown in the vicinity of TPWD-TP-1. However, the basin is over 1,200 feet thick at this location, and the overall drawdown is small relative to the overall aquifer thickness. In relation to continuing current pumping distribution as reflected in the baseline scenario, groundwater levels changes can be summarized as follows:

- Groundwater levels in the Indian Cove Subbasin under proposed future conditions would be 16 to 21 feet higher after 25 years.

- Groundwater levels in the Fortynine Palms Subbasin under proposed future conditions would be 90 to 108 feet higher after 25 years.

- Groundwater levels in the Eastern Subbasin under proposed future conditions would be 36 to 50 feet higher after 25 years.

- Average groundwater levels in the Mesquite Lake Subbasin after 25 years under proposed future conditions would be 60 to 70 feet lower near the proposed wellfield to 1 to 17 feet of lower over most of the basin.

Appendix H provides tables summarizing drawdown totals and drawdown rates for the 18 TPWD wells and 18 monitoring points throughout the basin for the eight different scenarios (from 2009 to 2033), as well as the observed drawdown and drawdown rates and the drawdown and drawdown rates computed by the transient model for the 18 TPWD wells. These tables can be used to compare the impact of shifting pumping from basin to basin.

For Scenarios 4 and 6, drawdown is about 3.8 ft/yr in the area of the treatment plant, for a total drawdown of about 95 feet over the period 2009 to 2033. Under these scenarios, which include growth in demand, drawdown in most other parts of the service area is under 1 ft/yr, with the exception of the western part of the Fortynine Palms Subbasin, where the water level drops by 2.2 to 2.4 ft/yr. This demonstrates that the Mesquite Lake Subbasin is able to handle the shifted pumping, while the shifting greatly mitigates the drawdown in the other TPWD basins.

The focus of Scenarios 5 and 6 is balancing the drawdowns in the Indian Cove, Fortynine Palms and Eastern Subbasins. These scenarios also reduce the drawdowns at the Oasis of Mara. The numerical model may not be capturing the exact groundwater elevation at the Oasis of Mara, but it is likely that the change in water levels is accurate, based on the ability of the model to capture historical drawdown at the TPWD wells in the basin.

Significant groundwater is lost from the Mesquite Lake Subbasin through ET in the area of Mesquite Dry Lake and as groundwater flow across the Mesquite Fault into the Dale Basin. Groundwater in this area could be developed to reduce these losses from the basin. Water quality in the area of ET losses is quite low due to the evaporation-driven concentration of mineral constituents, but water could be intercepted north, west, and south of the area to tap into better-quality water before it reaches the area of Mesquite Dry Lake.

The modeled drawdown in the area of the treatment plant is less than has been seen in some of the TPWD wells through the history of TPWD, but is still a significant amount. A well spacing of 600 feet and a total of 8 additional deep wells are assumed for the treatment plant area. If more wells are included, or the spacing between wells is greater, the amount of drawdown would be reduced, although the area affected by drawdown would expand. The numerical model created for this project could in the future be deployed as a tool to optimize the system of wells in the area of the treatment plant.

Section 7: Conclusions

This section of the report summarizes the results of the evaluation of the effects of shifting the TPWD's groundwater production to the Mesquite Lake Subbasin over the next 25 years, through year 2033. The geologic and hydrogeologic characterization work reported in preceding sections of this report provides the foundation for performing the analyses of anticipated future effects on subbasin groundwater levels.

7.1 Objective

The overall objective of the Mesquite Lake Subbasin Groundwater Study is to provide TPWD with an evaluation of the changes in groundwater conditions resulting from shifting of groundwater pumping from the Indian Cove, Fortynine Palms, and Eastern Subbasins to the Mesquite Lake Subbasin. To perform this evaluation, this groundwater study provides an analysis of the quantity of groundwater in the basin, the hydraulic movement of groundwater through the aquifer, and sources and volumes of natural recharge. A numerical groundwater model was developed to investigate the effect of moving groundwater production from the subbasins in the southern part of the district to the Mesquite Lake Subbasin.

Since the formation of TPWD in 1954, historic increases in pumping demand, coupled with the low natural groundwater recharge typical of arid environments, has resulted in steadily decreasing groundwater levels in the Indian Cove, Fortynine Palms, and Eastern Subbasins. The Mesquite Lake Subbasin has been less utilized due to naturally high levels of fluoride which require additional treatment for use as a water supply. Water use projections for the TPWD service area indicate that demand will continue to rise, from 3,200 afy in 2004 to an estimated 4,680 afy in 2030 (Kennedy/Jenks 2005). The existing TPWD wells are projected to fall behind demand by 2012. Therefore, TPWD is considering shifting most of their future groundwater production to the Mesquite Lake Subbasin.

7.2 Groundwater Pumping Evaluation

The objective of this analysis is to provide an evaluation of the potential impacts and benefits of the proposed shift in future pumping conditions. This shift consists of increasing groundwater pumping to the Mesquite Lake Subbasin up to 3.0 MGD with a concomitant decrease in pumping in the Indian Cove, Fortynine Palms and Eastern Subbasins). The purpose for the shift in groundwater pumping is to stabilize groundwater level declines in the Indian Cove, Fortynine Palms and Eastern Subbasins.

Historically, most of the TPWD's groundwater pumping was derived from the Indian Cove and Fortynine Palms Subbasins primarily due to the better water quality. Elevated levels of naturally occurring inorganic constituents, primarily fluoride, occurring in the Eastern and Mesquite Lake Subbasins require additional water treatment. Therefore, groundwater pumping from these subbasins was historically limited. However, the Indian Cove and Fortynine Palms Subbasins have experienced long-term groundwater level declines over the past 50 years.

For the analysis, a series of potential future pumping scenarios was developed for evaluating the effect on groundwater levels of various potential future groundwater pumping scenarios. Several scenarios were developed to answer the following questions:

- Baseline Scenarios address the question “What are the impacts of continuing the current pumping distribution into the future?”

- Mesquite Lake Pumping Scenarios address the question “What are the impacts and benefits of shifting pumping to the Mesquite Lake Subbasin?”

- Alternative Pumping Scenarios address the question “Can the proposed pumping plan be optimized?”

A summary of the results by scenario is provided below.

7.2.1 Baseline Scenarios

The purpose of the Baseline Scenarios is to provide a reference condition representing future conditions if current practices were continued into the future without change. The results of the baseline scenario indicate that historical patterns of groundwater level declines would continue into the future. The scenarios indicate that some of the TPWD wells in the Indian Cove and Fortynine Palms Subbasins may not be able to sustain these pumping rates and that new wells would need to be constructed in these subbasins to sustain these pumping rates. Groundwater pumping n the Mesquite Lake Subbasin is based on 2008 pumping rates, which are higher than the long-term historical average. Therefore, the Baseline Scenarios indicate some increased drawdown in this subbasin compared to historical patterns.

7.2.2 Mesquite Lake Pumping Scenarios

The purpose of the Mesquite Lake Pumping Scenarios is to evaluate the relative differences resulting from increasing groundwater pumping in the Mesquite Lake Subbasin from 0.95 million gallons per day (MGD) in 2008 to 3.0 MGD by 2015 while simultaneously decreasing pumping in the Indian Cove, Fortynine Palms, and Eastern Subbasins by a similar amount. The results of the Mesquite Lake Pumping Scenarios indicate that groundwater levels will stabilize in the Indian Cove, Fortynine Palms, and Eastern Subbasins. Relative to the Baseline Scenarios, the groundwater levels in Indian Cove, Fortynine Palms, and Eastern Subbasins are significantly higher. This demonstrates that there is a significant benefit from shifting groundwater pumping out of these subbasins.

In the Mesquite Lake Subbasin, the increased groundwater pumping would result in increased drawdown; however, this will be concentrated near the proposed pumping locations. Over most of the subbasin, groundwater level declines are less. Over 25 years, declines would range from 90 to 95 feet near the proposed wellfield to 6 to 25 feet of drawdown over most of the subbasin. The drawdown resulting from increased groundwater pumping is less than that historically observed in the Indian Cove, Fortynine Palms, and Eastern Subbasins because of the larger volume of alluvial sediments in the Mesquite Lake Subbasin.

7.2.3 Alternative Pumping Scenarios

The purpose of the Alternative Pumping Scenarios is to evaluate whether groundwater levels in the Indian Cove, Fortynine Palms, and Eastern Subbasins can be actively managed by shifting the remaining groundwater production (i.e. demand not supplied by the Mesquite Lake Subbasin) between them. For this analysis, pumping was eliminated from the Eastern Subbasin and shifted to existing wells in the Indian Cove and Fortynine Palms Subbasins, as water levels in the Eastern Subbasin continued to decline even in the Mesquite Lake Pumping Scenarios.

The results of the Alternative Pumping Scenarios indicate that groundwater levels in the Indian Cove and Fortynine Palms Subbasins can sustain this additional pumping with only minor variations while reducing groundwater level declines in the Eastern Subbasin. Relative to the Baseline Scenario, the groundwater levels in Indian Cove, Fortynine Palms, and Eastern Subbasins are significantly higher. These results demonstrate that there is the potential to move groundwater pumping around spatially to improve groundwater conditions.

7.2.4 Scenario Results by Subbasin

The potential future groundwater conditions in the groundwater subbasins are evaluated by two methods, a hydrologic budget analysis and a numerical MODFLOW groundwater model. The MODFLOW model provides a more comprehensive analysis that incorporates more of the hydrogeologic information of the groundwater subbasins whereas the hydrologic budget is a more simplified approach that is limited to a regional scale analysis. The hydrologic budget approach is useful because it is a more straightforward approach that can be use to corroborate the model results. A summary of the results is provided below by groundwater subbasin.

A summary of the pumping scenario results for the Indian Cove Subbasin includes the following:

- If current pumping conditions are projected into the future, groundwater level declines average 0.7 to 1.25 ft/yr. Over 25 years, an estimated 18 to 31 feet of drawdown would occur.

- Under proposed future conditions, groundwater pumping would decline. Multiple pumping conditions were evaluated, with pumping decreased between 632 and 568 afy. Under future pumping conditions, groundwater level changes would vary between a rises of 0.1 ft/yr to a decline of 0.2 ft/yr. Over 25 years, the change in groundwater levels would range between an average rise of 2 feet and a decline of 5 feet.

- Relative to the baseline conditions, groundwater levels in the Indian Cove Subbasin under proposed future conditions would be 16 to 21 feet higher after 25 years.

A summary of the pumping scenario results for the Fortynine Palms Subbasin include the following:

- If current pumping conditions are projected into the future, groundwater level declines average 2.2 to 4.2 ft/yr. Over 25 years, an estimated 56 to 105 feet of drawdown would occur.

- Under proposed future conditions, groundwater pumping would decline. Multiple pumping conditions were evaluated, with pumping decreased between 671 and 936 afy. Under future pumping conditions, groundwater level changes would vary between a rises of 1.0 ft/yr to a decline of 0.6 ft/yr. Over 25 years, the change in groundwater levels would range between an average rise of 24 feet and a decline of 15 feet.

- Relative to the baseline conditions, groundwater levels in the Fortynine Palms Subbasin under proposed future conditions would be 90 to 108 feet higher after 25 years.

A summary of the pumping scenario results for the Eastern Subbasin include the following:

- If current pumping conditions are projected into the future, groundwater level declines average 0.4 to 2.2 ft/yr. Over 25 years, an estimated 10 to 55 feet of drawdown would occur.

- Under proposed future conditions, groundwater pumping would decline. Multiple pumping conditions were evaluated, with pumping decreased between 605 and 888 afy. Under future pumping conditions, groundwater level changes would vary between a rises of 0.1 ft/yr to a decline of 0.8 ft/yr. Over 25 years, the change in groundwater levels would range between an average rise of 3 feet and a decline of 19 feet.

- Relative to the baseline conditions, groundwater levels in the Eastern Subbasin under proposed future conditions would be 36 to 50 feet higher after 25 years.

A summary of the pumping scenario results for the Mesquite Lake Subbasin include the following:

- If current pumping conditions are projected into the future, groundwater level declines average 1.0 to 1.3 ft/yr near the proposed wellfield and 0.2 to 0.3 ft/yr over most of the subbasin. Over 25 years, declines would range from 27 to 31 feet near the proposed wellfield to 5 to 8 feet of drawdown over most of the subbasin.

- Under proposed future conditions, groundwater pumping would increase. Multiple pumping conditions were evaluated, with pumping increased between 2,010 and 2,040 afy. Under future pumping conditions, groundwater levels would decline by about 3.7 ft/yr near the proposed wellfield and 0.2 to 1.0 ft/yr over most of the subbasin. Over 25 years, declines would range from 90 to 95 feet near the proposed wellfield to 6 to 25 feet of drawdown over most of the subbasin.

Relative to the baseline conditions, average groundwater levels in the Mesquite Lake Subbasin after 25 years under proposed future conditions would be 60 to 70 feet lower near the proposed wellfield to 1 to 17 feet lower over most of the subbasin.

7.3 Summaries

The overall conclusion of this study is that shifting pumping to the Mesquite Lake Subbasin will mitigate the decline in groundwater levels in Indian Cove, Fortynine Palms, and Eastern Subbasins. In the Indian Cove, Fortynine Palms, and Eastern Subbasins, groundwater levels tend to stabilize. Groundwater levels in these basins are projected to be approximately 20 to 100 feet higher relative to the baseline condition of continuation of current pumping practices.

Groundwater pumping in the Mesquite Lake Subbasin will produce localized drawdowns near the proposed wellfield; however, subbasin-wide groundwater level declines are much less than in the southern subbasins because of the large size and volume of the Mesquite Lake Subbasin. Over 25 years, groundwater level declines would range from 90 to 95 feet near the proposed wellfield, representing less than 10 percent of the total saturated thickness of the aquifer at this location. If more wells were included, or the spacing between wells was greater, the amount of drawdown would be reduced, although the area affected by drawdown would expand.

The numerical model created for this project could in the future be deployed as a tool to optimize the system of wells in the area of the treatment plant, or to provide support as a predictive tool to support operations management decisions.

References

Akers, J.P., 1986. Geohydrology and potential for artificial recharge in the western part of the U.S. Marine Corps Base, Twentynine Palms, California, 1982-83, *U.S. Geological Survey Water-Resources Investigations Report 84-4119*, U.S. Geological Survey, Sacramento, CA, 22pp.

Avon, L. and T.J. Durbin, 1994. Evaluation of the Maxey-Eakin Method for estimating recharge to ground-water basins in Nevada, *Water Resources Bulletin*, 30(1), pp.99-111.

Bader, J.S. and W.R. Moyle, Jr., 1958. Data on water wells and springs in Morongo Valley and vicinity, San Bernardino and Riverside Counties, California, *U.S. Geological Survey Open-File Report 58-7*, U.S. Geological Survey, Long Beach, CA, 31pp.

Bear, J. and A. Verruijt, 1987. *Modeling Groundwater Flow and Pollution*, D. Reidel Publishing Company, Boston, MA, 414pp.

Bedford, D.R. and D.M. Miller, compilers, 1997. Bedrock geology database for the Mojave Desert Ecoregion, in Arc/INFO data layers CD-ROM, Mojave Desert Ecosystem Program, Utah State University Press, Logan, UT.

Bisdorf, R.J., 1993. Schlumberger soundings near Twentynine Palms, California, *U.S. Geological Survey Open-File Report 93-279*, U.S. Geological Survey, Denver, CO, 73pp.

California Department of Water Resources (DWR), 1984. Twentynine Palms Ground Water Study, California Department of Water Resources, Southern District, Los Angeles, CA, 109pp.

California Department of Water Resources (DWR), 2003. *California's Groundwater, Bulletin 118*, Update 2003, California Department of Water Resources, Sacramento, CA, 265pp.

Canadell, J., R.B. Jackson, J.R. Ehleringer, H.A. Mooney, O.E. Sala, and E.-D. Schulze, 1996. Maximum rooting depth of vegetation types at the global scale, *Oecologia*, 108, pp.583-595.

Darcy, H., 1856. Les fontaines publiques de la ville de Dijon, Victor Dalmont, Paris, France.

Dibblee, T.W. Jr., 1968. Geologic map of the Twentynine Palms quadrangle, San Bernardino and Riverside Counties, California, *U.S. Geological Survey Miscellaneous Geologic Investigations Map I-561*, U.S. Geological Survey, 1pl.

Dutcher, L.C., 1960. Ground-water conditions during 1959 at the Twentynine Palms Marine Corps Training Center, California, *U.S. Geological Survey Open-File Report 60-39*, U.S. Geological Survey, Long Beach, CA, 29pp.

Dyer, H.B., 1961. Ground-water conditions during 1960 at the Marine Corps Base, Twentynine Palms, California, *U.S. Geological Survey Open-File Report 61-43*, U.S. Geological Survey, Long Beach, CA, 32pp.

Eakin, T.E., G.B. Maxey, T.W. Robinson, J.C. Fredericks, and O.J. Loeltz, 1951. Contributions to the hydrology of eastern Nevada, *Water Resources Bulletin No. 12*, State of Nevada Office of the State Engineer, Carson City, NV, 171pp.

Environmental Simulations Incorporated (ESI), 2007. Guide to Using Groundwater Vistas Version 5, ESI, Reinholds, PA, 381pp.

Environmental Systems Research Institute, Inc. (ESRI), 2008. ArcGIS: Release 9.3, ESRI, Redlands, CA.

Everett, D.E., 1964. Ground-water appraisal of Edwards Creek Valley, Churchill County, Nevada, *Ground-Water Resources-Reconnissance Series, Report 26*, State of Nevada Department of Conservation and Natural Resources, Carson City, NV, 18pp.

Fetter, C.W., 1994. Applied Hydrogeology, Third Edition, Prentice Hall, Upper Saddle River, NJ, 691pp.

Freckleton, J.R., 1982. Ground water in the Twenty-Nine Palms Indian Reservation and vicinity, San Bernardino, County, California, *U.S. Geological Survey Water-Resources Investigations Report 82-4060*, U.S. Geological Survey, Sacramento, CA, 50pp.

Freeze, R.A. and J.A. Cherry, 1979. Groundwater, Prentice Hall, Upper Saddle River, NJ, 604pp.

Friedman, I., G.I. Smith, J.D. Gleason, A. Warden, and J.M Harris, 1992. Stable isotope composition of water in southeastern California: 1. Modern precipitation, *Journal of Geophysical Research*, 97(D5), pp.5,795-5,812.

Geissner, F.W., 1965. Ground-water conditions for 1964 at the Marine Corps Base, Twentynine Palms, California, *U.S. Geological Survey Open-File Report 65-61*, U.S. Geological Survey, Long Beach, CA, 30pp.

Geissner, F.W. and S.G. Robson, 1966. Ground-water conditions for 1965 at the Marine Corps Base, Twentynine Palms, California, *U.S. Geological Survey Open-File Report 66-48*, U.S. Geological Survey, Long Beach, CA, 27pp.

Gesch, D.B., 2007. The National Elevation Dataset, in D. Maune, ed., *Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition*, American Society for Photogrammetry and Remote Sensing, Bethesda, MD, pp.99-118.

Gesch, D.B., M. Oimoen, S. Greenlee, C. Nelson, M. Steuck, and D. Tyler, 2002. The National Elevation Dataset, Photogrammetric Engineering and Remote Sensing, 68(1), pp.5-11.

Gleason, J.D., G. Veronda, G.I. Smith, I. Friedman, and P. Martin, 1994. Deuterium content of water from wells and perennial springs, southeastern California, U.S. Geological Survey Hydrologic Investigations Atlas HA-727, *U.S. Geological Survey*, Sacramento, CA, 1pl.

Haley & Aldrich, Baseline Report, 2000, Compilation of Groundwater and Wells Information within the Twentynine Palms Water District Service Area, December 2000.

Harbaugh, A.W., E.R. Banta, M.C. Hill, and M.G. McDonald, 2000. MODFLOW-2000, the U.S. Geological Survey modular ground-water model – user guide to modularization concepts and the ground-water flow process, *U.S. Geological Survey Open-File Report 00-92*, U.S. Geological Survey, Reston, VA, 121pp.

Hardman, G., 1936. Nevada precipitation and acreages of land by rainfall zones, mimeographed report, University of Nevada, Reno Agricultural Experiment Station, Reno, NV, 10pp.

Hardman, G. and H.G. Mason, 1949. *Irrigated lands of Nevada, Bulletin No. 183*, University of Nevada, Reno Agricultural Experiment Station, Reno, NV, 57pp.

Hill, M.C., 1990. Preconditioned Conjugate-Gradient 2 (PCG2), a computer program for solving ground-water flow equations, *U.S. Geological Survey Water-Resources Investigations Report 90-4048*, U.S. Geological Survey, Denver, CO, 47pp.

Hofstra, A.H., D.L. Fey, J.M. Motooka, and D.A. Hopkins, 1994. Reconnaissance stream-sediment geochemistry of Twentynine Palms Marine Corps Base, California, *U.S. Geological Survey Open-File Report 95-13*, U.S. Geological Survey, Denver, CO, 107pp.

Hsieh, P.A. and J.R. Freckleton, 1993. Documentation of a computer program to simulate horizontal-flow barriers using the U.S. Geological Survey's modular three-dimensional finite-difference ground-water flow model, *U.S. Geological Survey Open-File Report 92-477*, U.S. Geological Survey, Reston, VA, 37pp.

Izbicki, J.A., J. Radyk, and R.L. Michel, 2002. Movement of water through the thick unsaturated zone underlying Oro Grande and Sheep Creek Washes in the western Mojave Desert, USA, *Hydrogeology Journal*, v.10, pp.409-427.

Johnston, P.M., 1963. Ground-water conditions during 1963 at the Marine Corps Base, Twentynine Palms, California, *U.S. Geological Survey Open-File Report (Sequence Unknown)*, U.S. Geological Survey, Long Beach, CA, 37pp.

Kennedy/Jenks Consultants, 2001. Final Groundwater Management Plan, Kennedy/Jenks, Ventura, CA, 50pp.

Kennedy/Jenks Consultants, 2005. 2005 Urban Water Management Plan Update, Kennedy/Jenks, Ventura, CA, 131pp.

Kennedy/Jenks Consultants, 2008. Groundwater Management Plan Update, Kennedy/Jenks, Los Angeles, CA, 126pp.

Kennedy/Jenks/Todd LLC, 2007. Basin Conceptual Model and Assessment of Water Supply and Demand for the Ames Valley, Johnson Valley, and Means Valley Groundwater Basins, Emeryville, CA, 251pp.

Koehler, J.H., 1983. Ground water in the northeast part of Twentynine Palms Marine Corps Base, Bagdad area, California, *U.S. Geological Survey Water-Resources Investigations Report 83-4053*, U.S. Geological Survey, Sacramento, CA, 19pp.

Lewis, R.E., 1972. Ground-water resources of the Yucca Valley-Joshua Tree area, San Bernardino County, California, *U.S. Geological Survey Open-File Report 72-234*, U.S. Geological Survey, Menlo Park, CA, 51pp.

Londquist, C.J. and P.R. Martin, 1991. Geohydrology and ground-water-flow simulation of the Surprise Spring basin aquifer system, San Bernardino County, California, *U.S. Geological Survey Water-Resources Investigations Report 89-4099*, U.S. Geological Survey, Sacramento, CA, 48pp.

Ludington, S., B.C. Moring, R.J. Miller, K. Flynn, M.J. Hopkins, P. Stone, D.R. Bedford, and G.A. Haxel, 2005. Preliminary integrated geologic map databases for the United States – western states: California, Nevada, Arizona, and Washington, *U.S. Geological Survey Open-File Report 2005-1305*, U.S. Geological Survey, Reston, VA.

Maxey, G.B. and T.E. Eakin, 1949. Ground water in White River Valley, White Pine, Nye, and Lincoln Counties, Nevada, *Water Resources Bulletin No. 8*, State of Nevada Office of the State Engineer, Carson City, NV, 60pp.

McDonald, M.G. and A.W. Harbaugh, 1984. A modular three-dimensional finite-difference ground-water flow model, U.S. Geological Survey Open-File Report 83-875, U.S. Geological Survey, Reston, VA, 528pp.

Mojave Water Agency (MWA), 2004. 2004 Regional Water Management Plan, Mojave Water Agency, Apple Valley, CA, 252pp.

Moyle, W.R., Jr., 1984. Bouguer anomaly map of Twentynine Palms Marine Corps Base and vicinity, California, *U.S. Geological Survey Water-Resources Investigations Report 84-4005*, U.S. Geological Survey, Reston, VA, 1 map.

Nishikawa, T., J.N. Densmore, P. Martin, and J. Matti, 2003. Evaluation of the source and transport of high nitrate concentrations in ground water, Warren subbasin, California, *U.S. Geological Survey Water-Resources Investigations Report 03-4009*, U.S. Geological Survey, Reston, VA, 133pp.

Nishikawa, T., J.A. Izbicki, J.A. Hevesi, C.L. Stamos, and P. Martin, 2004. Evaluation of geohydrologic framework, recharge estimates, and ground-water flow of the Joshua Tree area, San Bernardino County, California, *U.S. Geological Survey Science Investigations Report 2004-5267*, U.S. Geological Survey, Reston, VA, 127pp.

Ott, L., 1988. An Introduction to Statistical Methods and Data Analysis, Third Edition, PWS-KENT Publishing Company, Boston, MA, 945pp.

Riley, F.S. and G.F. Worts, Jr., 1952 [Retyped 2001]. Geologic reconnaissance and test-well drilling program, Marine Corps Training Center, Twentynine Palms, California, *U.S. Geological Survey Open-File Report 98-166*, U.S. Geological Survey, Long Beach, CA, 71pp.

Riley, F.S. and G.F. Worts, Jr., 1953 [Retyped 2001]. Geology and ground-water appraisal of the Twentynine Palms Marine Corps Training Center, California, *U.S. Geological Survey Open-File Report 98-167*, U.S. Geological Survey, Long Beach, CA, 131pp.

Riley, F.S. and J.S. Bader, 1961. Data on water wells on Marine Corps Base, Twentynine Palms, California, *U.S. Geological Survey Open-File Report 61-128*, U.S. Geological Survey, Long Beach, CA, 18pp.

Roberts, C., R. Jachens, A. Katzenstein, G. Smith, and R. Johnson, 2002. Gravity map and data of the eastern half of the Big Bear Lake, 100,000 scale quadrangle, California and analysis of the depths of several basins*, U.S. Geological Survey Open-File Report 02-353*, U.S. Geological Survey, Reston, VA, 1 map.

Rogers, T.H., 1967. Geologic map of California: San Bernardino sheet, California Division of Mines and Geology, scale 1:250,000, 1 map.

Schaefer, D.H., 1978. Ground-water resources of the Marine Corps Base, Twentynine Palms, San Bernardino County, California, *U.S. Geological Survey Water-Resources Investigations Report 77-37*, U.S. Geological Survey, Sacramento, CA, 29pp.

Smith, G.I., I. Friedman, J.D. Gleason, and A. Warden, 1992. Stable isotope composition of water in southeastern California: 2. Groundwaters and their relation to modern precipitation, *Journal of Geophysical Research*, v.97, no.D5, pp.5,813-5,823.

Snyder, R.L., W.O. Pruitt, and D.A. Shaw, 1992. Determining daily reference evapotranspiration (ETo), *U.C. Publication 21426*, University of California Division of Agriculture and Natural Resources (ANR) Publications, Oakland, CA, 22pp.

Sterrett, R.J., ed., 2007. Groundwater and Wells, Johnson Screens, New Brighton, MN, 812pp.

Stone, D.B., C.L. Moomaw, and A. Davis, 2001. Estimating recharge distribution by incorporating runoff from mountainous areas in an alluvial basin in the Great Basin Region of the Southwestern United States, *Ground Water*, 39(6), pp.807-818.

Thompson, D.G., 1921. Routes to desert watering places in the Mohave Desert region, California, *U.S. Geological Survey Water-Supply Paper 490-B*, U.S. Government Printing Office, Washington, D.C., 206pp.

Thompson, D.G., 1929. The Mohave Desert Region, California: a geographic, geologic, and hydrologic reconnaissance, U*.S. Geological Survey Water-Supply Paper 578*, U.S. Government Printing Office, Washington, D.C., 817pp.

Troxell, H.C. and others, 1954. Hydrology of the San Bernardino and eastern San Gabriel Mountains, California, U.S. Geological Survey Hydrologic Atlas HA 1, *U.S. Geological Survey*, Washington, D.C., 30pp.

U.S. Department of Agriculture (USDA), 1970. Report and General Soil Map of the Southwestern Desert Area of San Bernardino County, California, U.S. Department of Agriculture, Fort Worth, TX.

U.S. Department of Agriculture (USDA), 1994. State Soil Geogrphic (STATSGO) Data Base – Data Use Information, *Miscellaneous Publication No. 1492*, U.S. Department of Agriculture, Fort Worth, TX.

Walton, W.C., 1970. Groundwater Resource Evaluation, McGraw-Hill Book Company, New York, NY, 576pp.

Watson, P., P. Sinclair, and R. Waggoner, 1976. Quantitative evaluation of a method for estimating recharge to the desert basins of Nevada, *Journal of Hydrology*, 31, pp.335-357.

Weir, J.E. Jr., 1962a. Ground-water conditions during 1961 at the Marine Corps Base, Twentynine Palms, California, *U.S. Geological Survey Open-File Report 62-153*, U.S. Geological Survey, Long Beach, CA, 50pp.

Weir, J.E. Jr., 1962b. Ground-water conditions during 1962 at the Marine Corps Base, Twentynine Palms, California, *U.S. Geological Survey Open-File Report 62-151*, U.S. Geological Survey, Long Beach, CA, 42pp.

Weir, J.E. Jr. and J.S. Bader, 1963. Ground-water and related geology of Joshua Tree National Monument, California, *U.S. Geological Survey Open-File Report 63-137*, U.S. Geological Survey, Long Beach, CA, 103pp.

Whitt, A. and K.L. Jonker, 1998. Groundwater survey of the Joshua Tree and Copper Mountain subbasins, Joshua Tree, California, Western Water Surveys report prepared for the Joshua Tree Water District.

Wilson, J.L. and H. Guan, 2004. Mountain-block hydrology and mountain-front recharge, in Groundwater Recharge in a Desert Environment: the Southwestern United States, *Water Science and Application Series*, v.9, ed. by J.F. Hogan, F.M. Phillips, and B.R. Scanlon, American Geophysical Union, Washington, D.C., pp.113-137.

Zhang, L., I.H. Hume, M.G. O'Connell, D.C. Mitchell, P.L. Milthorpe, M. Yee, W.R. Dawes, and T.J. Hatton, 1999. Estimating episodic recharge under different crop/pasture rotations in the Mallee region. Part 1. Experiments and model calibration, *Agricultural Water Management, 42*, pp. 219-235.

Tables

Table 3-1 – Water quality summary for TPWD Production Wells

	Total Dissolved Solids (TDS) (mg/L)			*Fluoride Concentrations (mg/L)*			*Years of Well Sampling History*	
Well	Average	Maximum	Minimum	Average	Maximum	Minimum	Well first sampled[a]	Well last sampled[b]
Indian Cove Subbasin								
TPWD-6	123	157	101	0.76	1.91	0.30	1958	present
TPWD-7	118	140	102	0.65	2.09	0.27	1962	2003
TPWD-8	163	242	123	1.24	2.60	0.45	1964	1993
TPWD-9	160	257	120	2.25	4.00	0.84	1968	present
TPWD-10	163	192	140	1.51	2.25	0.55	1968	2006
TPWD-11	171	202	149	2.08	3.40	0.22	1978	present
TPWD-12	144	180	129	1.52	2.59	0.40	1983	present
TPWD-15	145	178	126	0.34	1.10	0.34	1987	present
Summary[c]	**149**	**257**	**101**	**1.42**	**4.00**	**0.20**		
Fortynine Palms Subbasin								
TPWD-3	151	173	135	1.47	2.30	0.42	1953	1992
TPWD-3B	132	151	121	2.05	3.63	0.37	1992	2006
TPWD-4	170	220	135	1.66	2.60	0.56	1951	present
TPWD-5	149	173	121	1.50	2.70	0.79	1951	1996
TPWD-13	166	215	142	1.08	2.01	0.26	1985	2003
TPWD-14	131	150	100	0.66	1.51	0.42	1993	present
Summary[c]	**153**	**220**	**100**	**1.45**	**3.63**	**0.26**		
Eastern Subbasin								
TPWD-1	250	304	198	5.72	7.22	1.80	1955	1998
TPWD-2	176	190	154	2.59	5.90	1.20	1951	1993
TPWD-16	160	173	145	1.65	2.14	0.39	1991	present
Summary[c]	**191**	**304**	**145**	**3.43**	**7.22**	**0.39**		
Mesquite Lake Subbasin								
TPWD-TP-1	335	350	320	6.10	6.30	5.90	2006	present

Notes: a) Well first sampled is based on TPWD records
b) Well last sampled is based on TPWD records. Wells marked *"present"* are currently operating.
c) Summary provides the average, maximum and minimum of all samples in each subbasin.

Table 4-1 – Rainfall zones and recharge estimates for the Maxey-Eakin method of recharge quantification (from Maxey and Eakin, 1949).

Rainfall (inches)		*Recharge Percentage*
Maximum	**Minimum**	
0	8	0%
8	12	3%
12	15	7%
15	20	15%
20	24	25%

Table 4-2a – Water budget summary for the Indian Cove Subbasin under Recharge Method 1[a]

	Groundwater Inflow (acre-feet)			*Groundwater Outflow (acre-feet)*				*Storage (acre-feet)*
Year	**Precip Recharge**[b]	**GW Inflow**[c]	**Total Inflow**	**GW Pumping**[d]	**ET**[e]	**GW Outflow**[f]	**Total Outflow**	**Change in Storage**[g]
1984	0	34	34	1,845	0	10	1,856	-1,822
1985	0	35	35	2,076	0	10	2,086	-2,050
1986	0	35	35	1,927	0	10	1,937	-1,902
1987	0	36	36	1,525	0	10	1,535	-1,499
1988	119	36	155	1,453	0	10	1,463	-1,308
1989	0	35	35	1,558	0	10	1,568	-1,532
1990	0	36	36	1,904	0	10	1,914	-1,879
1991	10	35	45	1,628	0	10	1,638	-1,592
1992	101	37	139	1,560	0	10	1,569	-1,431
1993	159	37	196	1,262	0	10	1,272	-1,076
1994	0	37	37	1,074	0	9	1,083	-1,046
1995	87	37	123	1,006	0	10	1,016	-893
1996	0	37	37	1,130	0	10	1,140	-1,103
1997	0	37	37	991	0	10	1,001	-964
1998	331	36	368	1,028	0	10	1,037	-670
1999	0	36	36	1,009	0	10	1,018	-982
2000	0	36	36	1,113	0	10	1,122	-1,087
2001	0	35	35	1,065	0	10	1,075	-1,039
2002	0	36	36	1,120	0	9	1,129	-1,093
2003	36	36	72	817	0	9	827	-755
2004	29	36	66	1,172	0	9	1,181	-1,115
2005	486	37	522	1,150	0	9	1,160	-637
2006	0	37	37	1,193	0	9	1,202	-1,165
2007	0	35	35	854	0	9	863	-828
2008	0	34	34	691	0	10	701	-667
Average[h]	54	36	90	1,286	0	10	1,296	-1,205

Notes: a) Recharge Method 1 is the classical application of the Maxey-Eakin method
b) Precipitation Recharge estimated using Maxey-Eakin method
c) Groundwater Inflow from adjacent groundwater basins
d) Groundwater Pumping is estimated based on TPWD records and other sources
e) Evapotranspiration (ET) from groundwater only, does not include soil moisture ET
f) Groundwater Outflow to adjacent groundwater basins
g) Change in Groundwater Storage based on water balance equation
h) Averages calculated from 1984 through 2008

Table 4-2b – Water budget summary for the Fortynine Palms Subbasin under Recharge Method 1[a]

	Groundwater Inflow (acre-feet)			*Groundwater Outflow (acre-feet)*				*Storage (acre-feet)*
Year	**Precip Recharge**[b]	**GW Inflow**[c]	**Total Inflow**	**GW Pumping**[d]	**ET**[e]	**GW Outflow**[f]	**Total Outflow**	**Change in Storage**[g]
1984	25	0	25	217	0	6	223	-198
1985	0	0	0	285	0	6	291	-291
1986	0	0	0	485	0	6	490	-490
1987	0	0	0	605	0	6	610	-610
1988	443	0	443	1,205	0	6	1,211	-767
1989	0	0	0	1,203	0	5	1,209	-1,209
1990	0	0	0	850	0	6	856	-856
1991	159	0	159	1,020	0	5	1,025	-866
1992	390	0	390	1,010	0	5	1,016	-626
1993	573	0	573	1,200	0	5	1,205	-632
1994	0	0	0	1,596	0	5	1,601	-1,601
1995	359	0	359	1,581	0	5	1,586	-1,226
1996	0	0	0	1,481	0	5	1,486	-1,486
1997	95	0	95	1,406	0	5	1,411	-1,316
1998	975	0	975	1,481	0	4	1,486	-511
1999	0	0	0	1,513	0	4	1,517	-1,517
2000	0	0	0	1,474	0	4	1,478	-1,478
2001	0	0	0	1,516	0	4	1,520	-1,520
2002	0	0	0	1,620	0	4	1,623	-1,623
2003	235	0	235	1,152	0	3	1,156	-921
2004	209	0	209	947	0	3	951	-741
2005	1,845	0	1,845	949	0	3	952	893
2006	0	0	0	1,021	0	3	1,025	-1,025
2007	0	0	0	1,073	0	3	1,076	-1,076
2008	0	0	0	1,024	0	3	1,027	-1,027
Average	212	0	212	1,117	0	5	1,121	-909

Notes: a) Recharge Method 1 is the classical application of the Maxey-Eakin method
b) Precipitation Recharge estimated using Maxey-Eakin method
c) Groundwater Inflow from adjacent groundwater basins
d) Groundwater Pumping is estimated based on TPWD records and other sources
e) Evapotranspiration (ET) from groundwater only, does not include soil moisture ET
f) Groundwater Outflow to adjacent groundwater basins
g) Change in Groundwater Storage based on water balance equation
h) Averages calculated from 1984 through 2008

Table 4-2c – Water budget summary for the Eastern Subbasin under Recharge Method 1[a]

	Groundwater Inflow (acre-feet)			Groundwater Outflow (acre-feet)				Storage (acre-feet)
Year	Precip Recharge[b]	GW Inflow[c]	Total Inflow	GW Pumping[d]	ET[e]	GW Outflow[f]	Total Outflow	Change in Storage[g]
1984	8	0	8	0	8	0	8	0
1985	0	0	0	6	0	0	6	-6
1986	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0
1988	428	0	428	0	75	0	75	353
1989	0	0	0	0	0	0	0	0
1990	0	0	0	33	0	0	33	-33
1991	102	0	102	81	75	0	156	-54
1992	395	0	395	353	75	0	428	-33
1993	511	0	511	551	75	0	626	-115
1994	0	0	0	463	0	0	463	-463
1995	368	0	368	427	75	0	502	-134
1996	0	0	0	533	0	0	533	-533
1997	59	0	59	586	75	0	661	-602
1998	843	0	843	521	75	0	596	247
1999	0	0	0	556	0	0	556	-556
2000	0	0	0	659	0	0	659	-659
2001	0	0	0	527	0	0	527	-527
2002	0	0	0	829	0	0	829	-829
2003	154	0	154	290	75	0	365	-211
2004	128	0	128	470	75	0	545	-417
2005	1,762	0	1,762	416	75	0	491	1,271
2006	0	0	0	483	0	0	483	-483
2007	0	0	0	634	0	0	634	-634
2008	0	0	0	737	0	0	737	-737
Average	190	0	190	366	30	0	397	-206

Notes: a) Recharge Method 1 is the classical application of the Maxey-Eakin method
b) Precipitation Recharge estimated using Maxey-Eakin method
c) Groundwater Inflow from adjacent groundwater basins
d) Groundwater Pumping is estimated based on TPWD records and other sources
e) Evapotranspiration (ET) from groundwater only, does not include soil moisture ET
f) Groundwater Outflow to adjacent groundwater basins
g) Change in Groundwater Storage based on water balance equation
h) Averages calculated from 1984 through 2008

Table 4-2d – Water budget summary for the Mesquite Lake Subbasin under Recharge Method 1[a]

	Groundwater Inflow (acre-feet)			*Groundwater Outflow (acre-feet)*				*Storage (acre-feet)*
Year	**Precip Recharge**[b]	**GW Inflow**[c]	**Total Inflow**	**GW Pumping**[d]	**ET**[e]	**GW Outflow**[f]	**Total Outflow**	**Change in Storage**[g]
1984	0	720	720	580	385	113	1,078	-358
1985	0	720	720	580	383	113	1,076	-355
1986	0	720	720	580	381	113	1,074	-353
1987	0	720	720	580	379	113	1,072	-351
1988	1	723	724	580	377	113	1,070	-346
1989	0	725	725	580	374	113	1,068	-343
1990	0	727	727	580	372	113	1,066	-338
1991	0	729	729	580	370	113	1,064	-334
1992	0	731	731	580	368	113	1,062	-330
1993	7	735	742	580	366	113	1,060	-318
1994	0	737	737	580	364	113	1,057	-321
1995	0	737	737	580	362	114	1,056	-318
1996	0	737	737	580	360	114	1,054	-317
1997	0	737	737	580	358	114	1,052	-316
1998	48	736	783	580	356	114	1,050	-267
1999	0	736	736	580	354	115	1,049	-313
2000	0	736	736	580	352	115	1,047	-311
2001	0	732	732	580	350	115	1,045	-313
2002	0	731	731	580	348	116	1,043	-312
2003	0	730	730	1,192	346	116	1,654	-924
2004	0	726	726	1,373	344	116	1,833	-1,108
2005	136	728	864	1,410	342	116	1,868	-1,004
2006	0	726	726	1,394	340	117	1,851	-1,124
2007	0	742	742	1,429	338	114	1,881	-1,139
2008	0	731	731	1,530	336	116	1,981	-1,250
Average	8	730	738	774	360	114	1,248	-511

Notes: a) Recharge Method 1 is the classical application of the Maxey-Eakin method
b) Precipitation Recharge estimated using Maxey-Eakin method
c) Groundwater Inflow from adjacent groundwater basins
d) Groundwater Pumping is estimated based on TPWD records and other sources
e) Evapotranspiration (ET) from groundwater only, does not include soil moisture ET
f) Groundwater Outflow to adjacent groundwater basins
g) Change in Groundwater Storage based on water balance equation
h) Averages calculated from 1984 through 2008

Table 4-3a – Water budget summary for the Indian Cove Subbasin under Recharge Method 2[a]

	Groundwater Inflow (acre-feet)			*Groundwater Outflow (acre-feet)*				*Storage (acre-feet)*
Year	**Precip Recharge**[b]	**GW Inflow**[c]	**Total Inflow**	**GW Pumping**[d]	**ET**[e]	**GW Outflow**[f]	**Total Outflow**	**Change in Storage**[g]
1984	0	34	34	1,845	0	10	1,856	-1,822
1985	0	35	35	2,076	0	10	2,086	-2,050
1986	0	35	35	1,927	0	10	1,937	-1,902
1987	0	36	36	1,525	0	10	1,535	-1,499
1988	0	36	36	1,453	0	10	1,463	-1,427
1989	0	35	35	1,558	0	10	1,568	-1,532
1990	0	36	36	1,904	0	10	1,914	-1,879
1991	0	35	35	1,628	0	10	1,638	-1,602
1992	0	37	37	1,560	0	10	1,569	-1,532
1993	0	37	37	1,262	0	10	1,272	-1,235
1994	0	37	37	1,074	0	9	1,083	-1,046
1995	0	37	37	1,006	0	10	1,016	-979
1996	0	37	37	1,130	0	10	1,140	-1,103
1997	0	37	37	991	0	10	1,001	-964
1998	0	36	36	1,028	0	10	1,037	-1,001
1999	0	36	36	1,009	0	10	1,018	-982
2000	0	36	36	1,113	0	10	1,122	-1,087
2001	0	35	35	1,065	0	10	1,075	-1,039
2002	0	36	36	1,120	0	9	1,129	-1,093
2003	0	36	36	817	0	9	827	-790
2004	0	36	36	1,172	0	9	1,181	-1,145
2005	0	37	37	1,150	0	9	1,160	-1,123
2006	0	37	37	1,193	0	9	1,202	-1,165
2007	0	35	35	854	0	9	863	-828
2008	0	34	34	691	0	10	701	-667
Average	0	36	36	1,286	0	10	1,296	-1,260

Notes: a) Recharge Method 2 uses a modified version of the Maxey-Eakin method
b) Precipitation Recharge estimated using Maxey-Eakin method
c) Groundwater Inflow from adjacent groundwater basins
d) Groundwater Pumping is estimated based on TPWD records and other sources
e) Evapotranspiration (ET) from groundwater only, does not include soil moisture ET
f) Groundwater Outflow to adjacent groundwater basins
g) Change in Groundwater Storage based on water balance equation
h) Averages calculated from 1984 through 2008

Table 4-3b – Water budget summary for the Fortynine Palms Subbasin under Recharge Method 2[a]

	Groundwater Inflow (acre-feet)			*Groundwater Outflow (acre-feet)*				*Storage (acre-feet)*
Year	**Precip Recharge**[b]	**GW Inflow**[c]	**Total Inflow**	**GW Pumping**[d]	**ET**[e]	**GW Outflow**[f]	**Total Outflow**	**Change in Storage**[g]
1984	7	0	7	217	141	0	358	-351
1985	5	0	5	285	141	0	426	-422
1986	6	0	6	485	141	0	626	-620
1987	5	0	5	605	141	0	746	-740
1988	10	0	10	1,205	141	0	1,346	-1,336
1989	4	0	4	1,203	141	0	1,344	-1,340
1990	3	0	3	850	141	0	991	-988
1991	8	0	8	1,020	141	0	1,161	-1,153
1992	10	0	10	1,010	141	0	1,151	-1,141
1993	11	0	11	1,200	141	0	1,341	-1,330
1994	5	0	5	1,596	141	0	1,737	-1,732
1995	10	0	10	1,581	141	0	1,722	-1,712
1996	3	0	3	1,481	141	0	1,622	-1,620
1997	8	0	8	1,406	141	0	1,547	-1,539
1998	12	0	12	1,481	141	0	1,622	-1,610
1999	5	0	5	1,513	141	0	1,654	-1,649
2000	4	0	4	1,474	141	0	1,615	-1,611
2001	5	0	5	1,516	141	0	1,657	-1,651
2002	1	0	1	1,620	141	0	1,761	-1,760
2003	8	0	8	1,152	141	0	1,293	-1,285
2004	8	0	8	947	141	0	1,088	-1,080
2005	14	0	14	949	141	0	1,090	-1,076
2006	4	0	4	1,021	141	0	1,162	-1,159
2007	4	0	4	1,073	141	0	1,214	-1,210
2008	6	0	6	1,024	141	0	1,165	-1,159
Average	7	0	7	1,117	141	0	1,258	-1,251

Notes: a) Recharge Method 2 uses a modified version of the Maxey-Eakin method
b) Precipitation Recharge estimated using Maxey-Eakin method
c) Groundwater Inflow from adjacent groundwater basins
d) Groundwater Pumping is estimated based on TPWD records and other sources
e) Evapotranspiration (ET) from groundwater only, does not include soil moisture ET
f) Groundwater Outflow to adjacent groundwater basins
g) Change in Groundwater Storage based on water balance equation
h) Averages calculated from 1984 through 2008

Table 4-3c – Water budget summary for the Eastern Subbasin under Recharge Method 2[a]

	Groundwater Inflow (acre-feet)			Groundwater Outflow (acre-feet)				Storage (acre-feet)
Year	**Precip Recharge**[b]	**GW Inflow**[c]	**Total Inflow**	**GW Pumping**[d]	**ET**[e]	**GW Outflow**[f]	**Total Outflow**	**Change in Storage**[g]
1984	2	0	2	0	2	0	2	0
1985	2	0	2	6	2	0	8	-6
1986	2	0	2	0	2	0	2	0
1987	2	0	2	0	2	0	2	0
1988	3	0	3	0	3	0	3	0
1989	1	0	1	0	1	0	1	0
1990	1	0	1	33	1	0	34	-33
1991	2	0	2	81	2	0	83	-81
1992	3	0	3	353	3	0	356	-353
1993	3	0	3	551	3	0	554	-551
1994	1	0	1	463	1	0	464	-463
1995	3	0	3	427	3	0	430	-427
1996	1	0	1	533	1	0	534	-533
1997	2	0	2	586	2	0	589	-586
1998	4	0	4	521	4	0	525	-521
1999	1	0	1	556	1	0	557	-556
2000	1	0	1	659	1	0	661	-659
2001	2	0	2	527	2	0	528	-527
2002	0	0	0	829	0	0	829	-829
2003	3	0	3	290	3	0	293	-290
2004	3	0	3	470	3	0	472	-470
2005	4	0	4	416	4	0	420	-416
2006	1	0	1	483	1	0	484	-483
2007	1	0	1	634	1	0	636	-634
2008	2	0	2	737	2	0	739	-737
Average	2	0	2	366	2	0	368	-366

Notes: a) Recharge Method 2 uses a modified version of the Maxey-Eakin method
b) Precipitation Recharge estimated using Maxey-Eakin method
c) Groundwater Inflow from adjacent groundwater basins
d) Groundwater Pumping is estimated based on TPWD records and other sources
e) Evapotranspiration (ET) from groundwater only, does not include soil moisture ET
f) Groundwater Outflow to adjacent groundwater basins
g) Change in Groundwater Storage based on water balance equation
h) Averages calculated from 1984 through 2008

Table 4-3d – Water budget summary for the Mesquite Lake Subbasin under Recharge Method 2[a]

	Groundwater Inflow (acre-feet)			*Groundwater Outflow (acre-feet)*				*Storage (acre-feet)*
Year	**Precip Recharge[b]**	**GW Inflow[c]**	**Total Inflow**	**GW Pumping[d]**	**ET[e]**	**GW Outflow[f]**	**Total Outflow**	**Change in Storage[g]**
1984	0	720	720	580	385	113	1,078	-358
1985	0	720	720	580	383	113	1,076	-355
1986	0	720	720	580	381	113	1,074	-353
1987	0	720	720	580	379	113	1,072	-351
1988	0	723	723	580	377	113	1,070	-347
1989	0	725	725	580	374	113	1,068	-343
1990	0	727	727	580	372	113	1,066	-338
1991	0	729	729	580	370	113	1,064	-334
1992	0	731	731	580	368	113	1,062	-331
1993	0	735	735	580	366	113	1,060	-325
1994	0	737	737	580	364	113	1,057	-321
1995	0	737	737	580	362	114	1,056	-319
1996	0	737	737	580	360	114	1,054	-317
1997	0	737	737	580	358	114	1,052	-316
1998	0	736	736	580	356	114	1,050	-315
1999	0	736	736	580	354	115	1,049	-313
2000	0	736	736	580	352	115	1,047	-311
2001	0	732	732	580	350	115	1,045	-313
2002	0	731	731	580	348	116	1,043	-312
2003	0	730	730	1,192	346	116	1,654	-924
2004	0	726	726	1,373	344	116	1,833	-1,108
2005	0	728	728	1,410	342	116	1,868	-1,140
2006	0	726	726	1,394	340	117	1,851	-1,124
2007	0	742	742	1,429	338	114	1,881	-1,139
2008	0	731	731	1,530	336	116	1,981	-1,250
Average	0	730	730	774	360	114	1,248	-518

Notes: a) Recharge Method 2 uses a modified version of the Maxey-Eakin method
b) Precipitation Recharge estimated using Maxey-Eakin method
c) Groundwater Inflow from adjacent groundwater basins
d) Groundwater Pumping is estimated based on TPWD records and other sources
e) Evapotranspiration (ET) from groundwater only, does not include soil moisture ET
f) Groundwater Outflow to adjacent groundwater basins
g) Change in Groundwater Storage based on water balance equation
h) Averages calculated from 1984 through 2008

Table 5-1 – Comparison between hydrologic budget and numerical model budget (average annual values over the model period, in afy).

	Groundwater Inflow (acre-feet)					*Groundwater Outflow (acre-feet)*				*Storage (acre-feet)*
Method	**Joshua Tree**[a]	**Copper Mtn**[b]	**Trans Arch**[c]	**Precip**[d]	**Total Inflow**	**GW Pump**[e]	**ET**[f]	**Dale**[g]	**Total Outflow**	**Change in Storage**[h]
Hydrologic Budget	36	97	618	9	760	3,543	362	114	4,019	-3,259
Numerical Model	20	124	684	8	837	3,806	1,651	519	5,976	-5,137
Net Difference	-16	27	66	1	77	264	1,289	405	1,957	-1,879
Percent Difference	27.9%	12.1%	5.0%	1.4%	4.8%	3.5%	64.0%	63.9%	19.6%	-22.4%

Notes: a) Groundwater Inflow from the Joshua Tree Subbasin to the Indian Cove Subbasin
b) Groundwater Inflow from the Copper Mountain Subbasin to the Mesquite Lake Subbasin
c) Groundwater Inflow across the Transverse Arch to the Mesquite Lake Subbasin
a) Precipitation-based recharge from runoff from surrounding highlands
e) Groundwater Pumping from TPWD and other private wells
f) Evapotranspiration (ET) from groundwater only, does not include soil moisture ET
g) Groundwater Outflow from the Mesquite Lake Subbasin to the Dale Basin
h) Change in Groundwater Storage is difference between total inflow and total outflow and reflected by change in groundwater levels

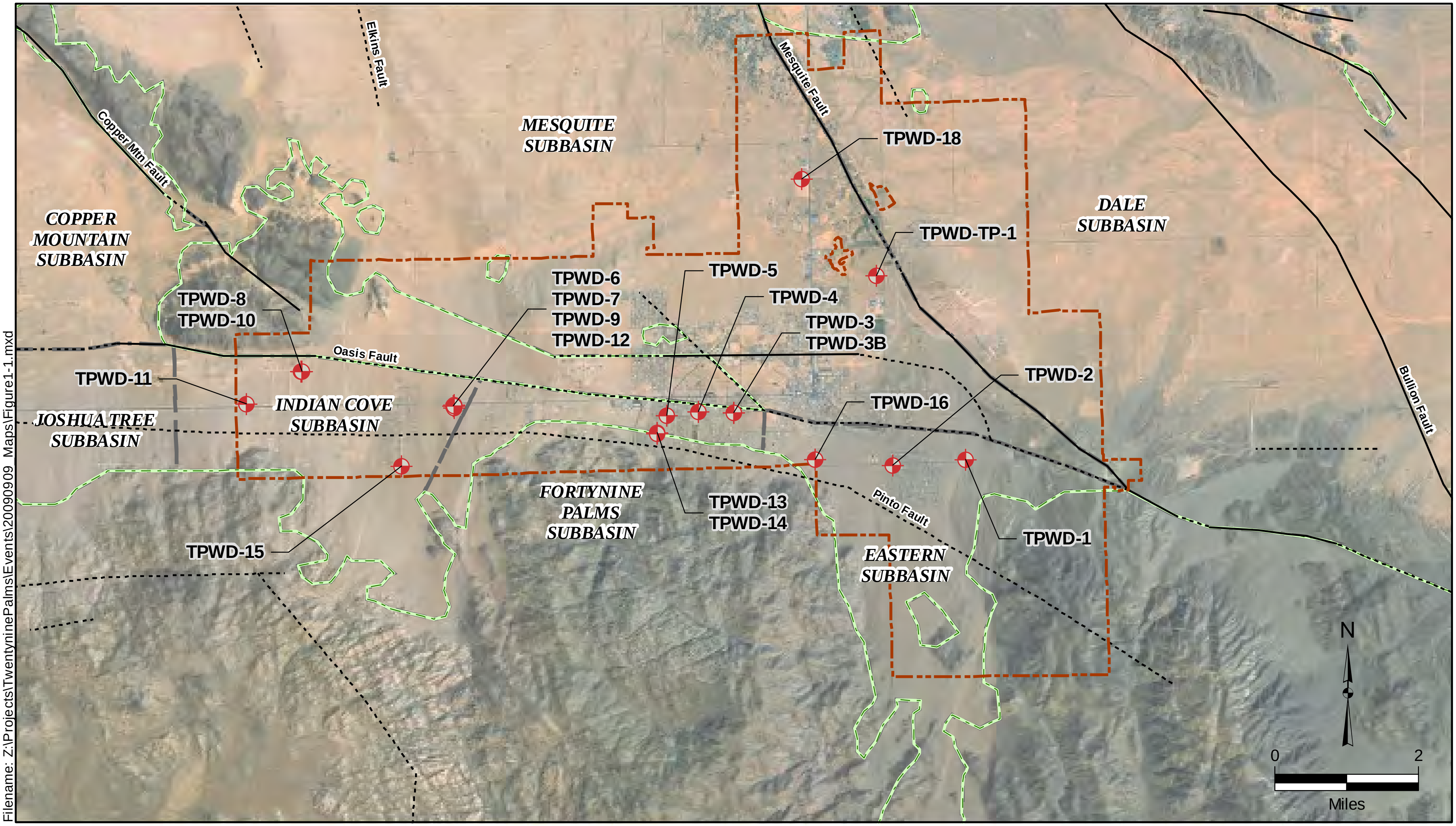
Table 5-2 – Summary of the hydrologic budget derived from MODFLOW Model of Indian Cove, Fortynine Palms, Eastern and Mesquite Lake Subbasins.

	Groundwater Inflow (acre-feet)					*Groundwater Outflow (acre-feet)*				*Storage (acre-feet)*
Year	**Joshua Tree[a]**	**Copper Mtn[b]**	**Trans Arch[c]**	**Pre-cip[d]**	**Total Inflow**	**GW Pump[e]**	**ET[f]**	**Dale[g]**	**Total Outflow**	**Change in Storage[h]**
1984	20	117	433	8	578	2,906	1,145	524	4,575	-3,996
1985	20	116	492	8	636	3,211	1,438	523	5,173	-4,536
1986	20	115	531	8	675	3,255	1,565	523	5,343	-4,667
1987	20	115	562	8	705	2,973	1,630	523	5,126	-4,419
1988	20	116	586	8	730	3,501	1,668	522	5,691	-4,960
1989	20	116	608	8	752	3,605	1,692	522	5,818	-5,063
1990	20	117	626	8	772	3,632	1,706	521	5,859	-5,083
1991	20	118	643	8	790	3,572	1,714	521	5,807	-5,015
1992	20	119	659	8	806	3,766	1,717	521	6,004	-5,193
1993	20	120	673	8	822	3,857	1,715	520	6,091	-5,268
1994	20	121	686	8	836	3,976	1,711	520	6,207	-5,370
1995	20	123	698	8	849	3,857	1,707	520	6,084	-5,232
1996	20	124	709	8	862	3,988	1,703	519	6,210	-5,346
1997	20	125	720	8	873	3,827	1,698	519	6,044	-5,167
1998	21	126	730	8	885	3,874	1,696	519	6,088	-5,201
1999	21	127	739	8	895	3,921	1,693	518	6,132	-5,236
2000	20	128	748	8	905	4,090	1,690	518	6,297	-5,391
2001	20	129	756	8	915	3,951	1,686	517	6,155	-5,239
2002	20	130	765	8	924	4,413	1,684	517	6,614	-5,689
2003	20	131	772	8	933	3,715	1,681	516	5,913	-4,974
2004	20	132	780	8	941	4,225	1,678	515	6,419	-5,471
2005	20	133	787	8	949	4,188	1,674	515	6,377	-5,423
2006	20	134	793	8	956	4,355	1,670	514	6,538	-5,580
2007	20	135	800	8	964	4,253	1,664	513	6,430	-5,466
2008	20	136	806	8	971	4,246	1,658	512	6,416	-5,443
Total	506	3,106	17,100	210	20,923	95,157	41,282	12,973	149,412	-128,432
Average	20	124	684	8	837	3,806	1,651	519	5,976	-5,137

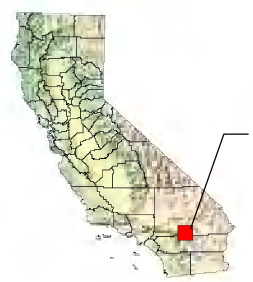
Notes: a) Groundwater Inflow from the Joshua Tree Subbasin to the Indian Cove Subbasin
b) Groundwater Inflow from the Copper Mountain Subbasin to the Mesquite Lake Subbasin
c) Groundwater Inflow across the Transverse Arch to the Mesquite Lake Subbasin
a) Precipitation-based recharge from runoff from surrounding highlands
e) Groundwater Pumping from TPWD and other private wells
f) Evapotranspiration (ET) from groundwater only, does not include soil moisture ET
g) Groundwater Outflow from the Mesquite Lake Subbasin to the Dale Basin
h) Change in Groundwater Storage is difference between total inflow and total outflow and reflected by change in groundwater levels

Figures

Filename: Z:\Projects\TwentyninePalms\Events\20090909_Maps\Figure1-1.mxd



Source: (c)2009 Microsoft Corporation.



TPWD Well

Site Boundary

Subbasin Boundary

Twentynine Palms City Boundary

Faults

Known

Inferred

Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Site Location Map

K/J 0964003*00
March 2010

Figure 1-1

Filename: Z:\Projects\TwentyninePalms\Events\20090914_SiteLocationMxd\Figure2-1.mxd

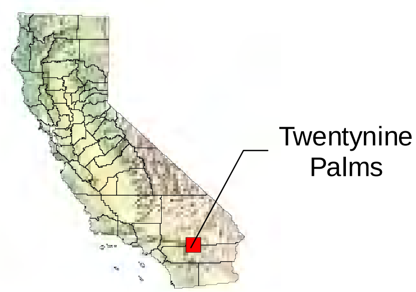
Source: (c)2009 Microsoft Corporation.

Legend

Site Boundary

Marine Corps Air Ground Combat Center

USA Prime Imagery



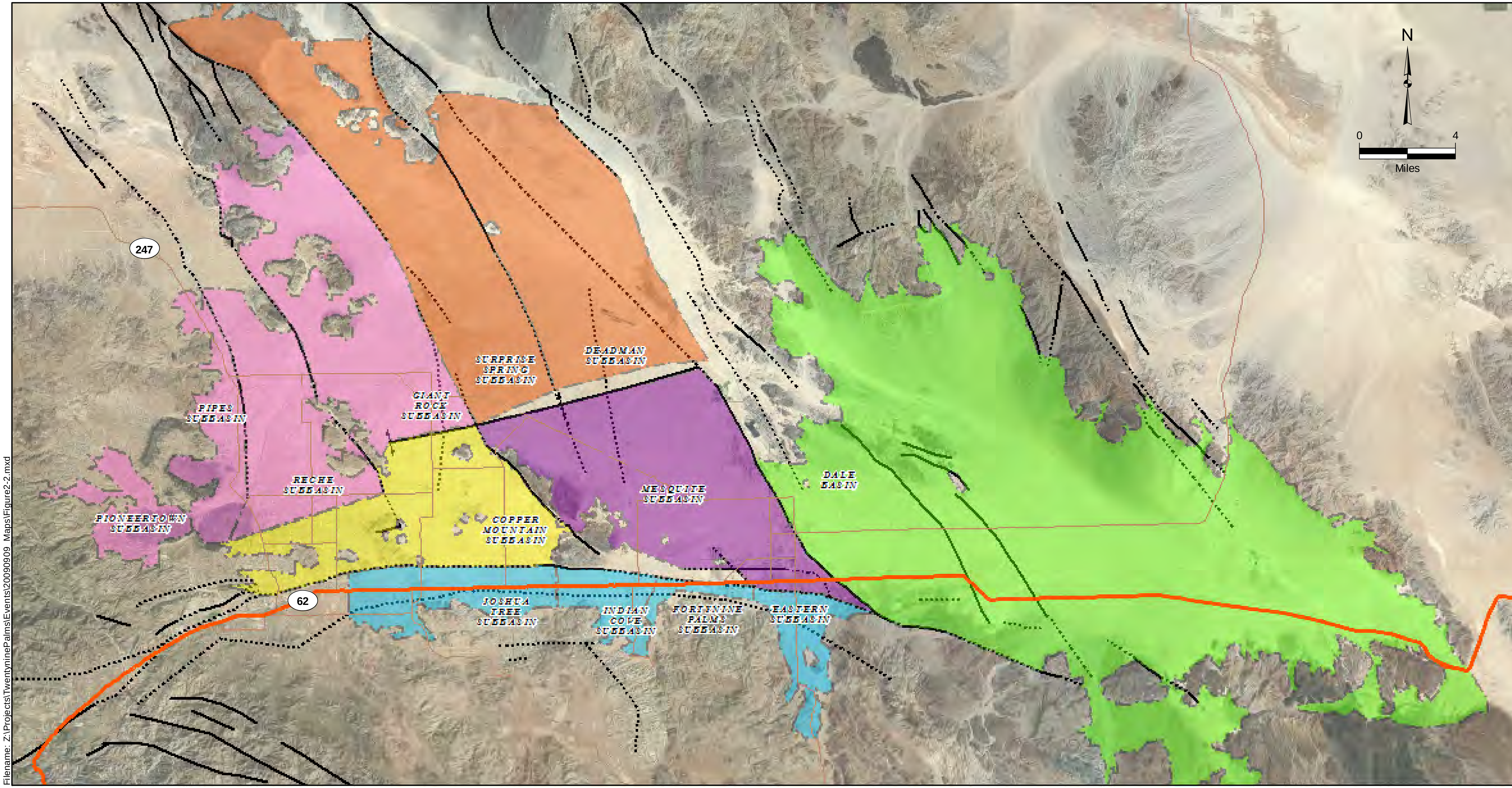
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Regional Map

K/J 0964003.00
March 2010

Figure 2-1



Filename: Z:\Projects\TwentyninePalms\Events\20090909_Maps\Figure2-2.mxd

Source: (c) 2009 Microsoft Corporation

Explanation

Faults
- Known
- Inferred
- Anticline

DWR Groundwater Basin
- Ames Valley Basin
- Copper Mountain Valley Basin
- Dale Valley Basin
- Deadman Valley Basin
- Joshua Tree Basin
- Twentynine Palms Valley Basin

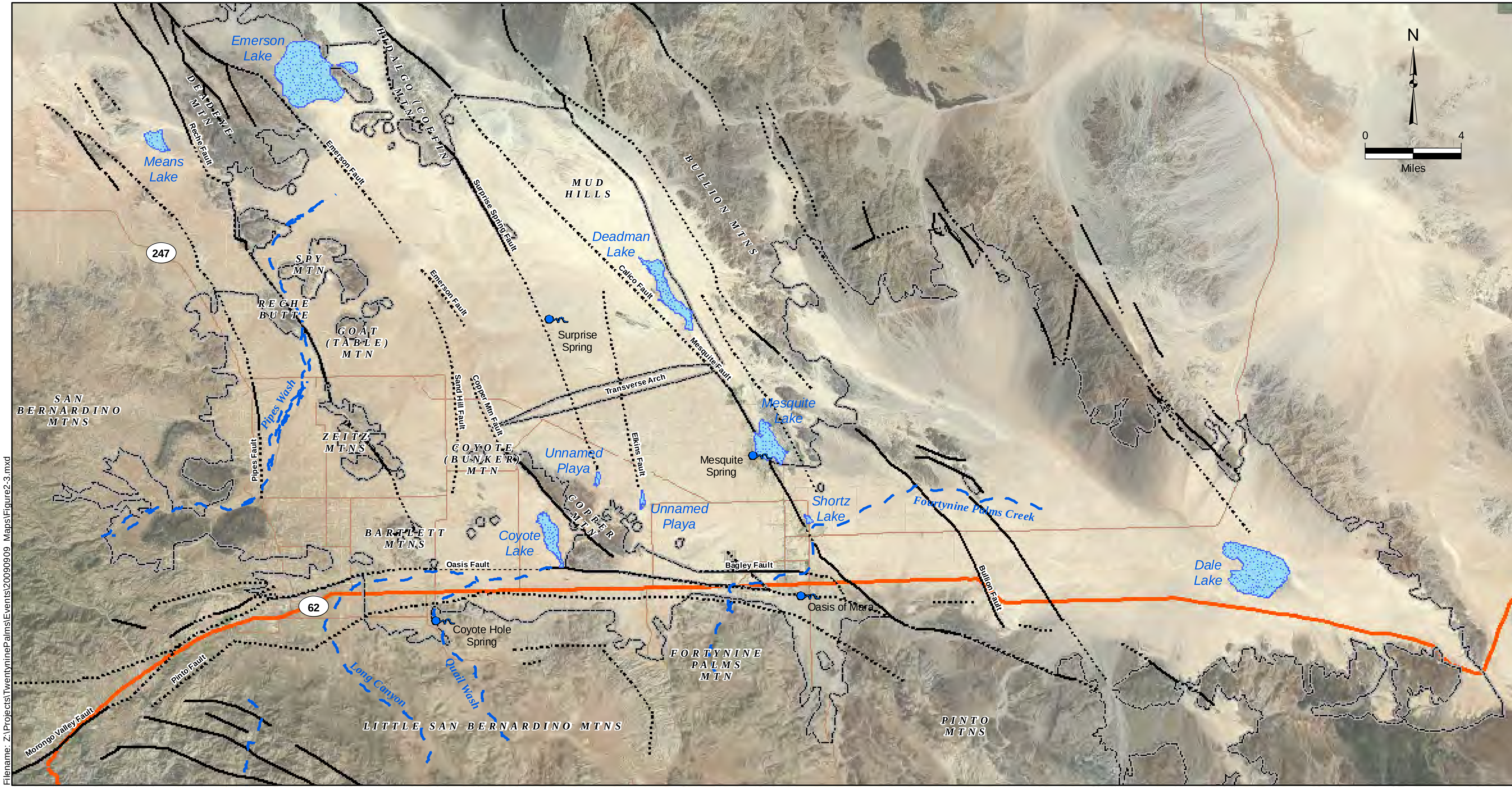
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Groundwater Basins and Subbasins

K/J 0964003.00
March 2010

Figure 2-2



Filename: Z:\Projects\TwentyninePalms\Events\20090909_Maps\Figure2-3.mxd

Source: (c) 2009 Microsoft Corporation

Explanation

Surface Water Features
- Springs
- Streams
- Playas

Faults
- Known
- Inferred

Study Area

Kennedy/Jenks Consultants

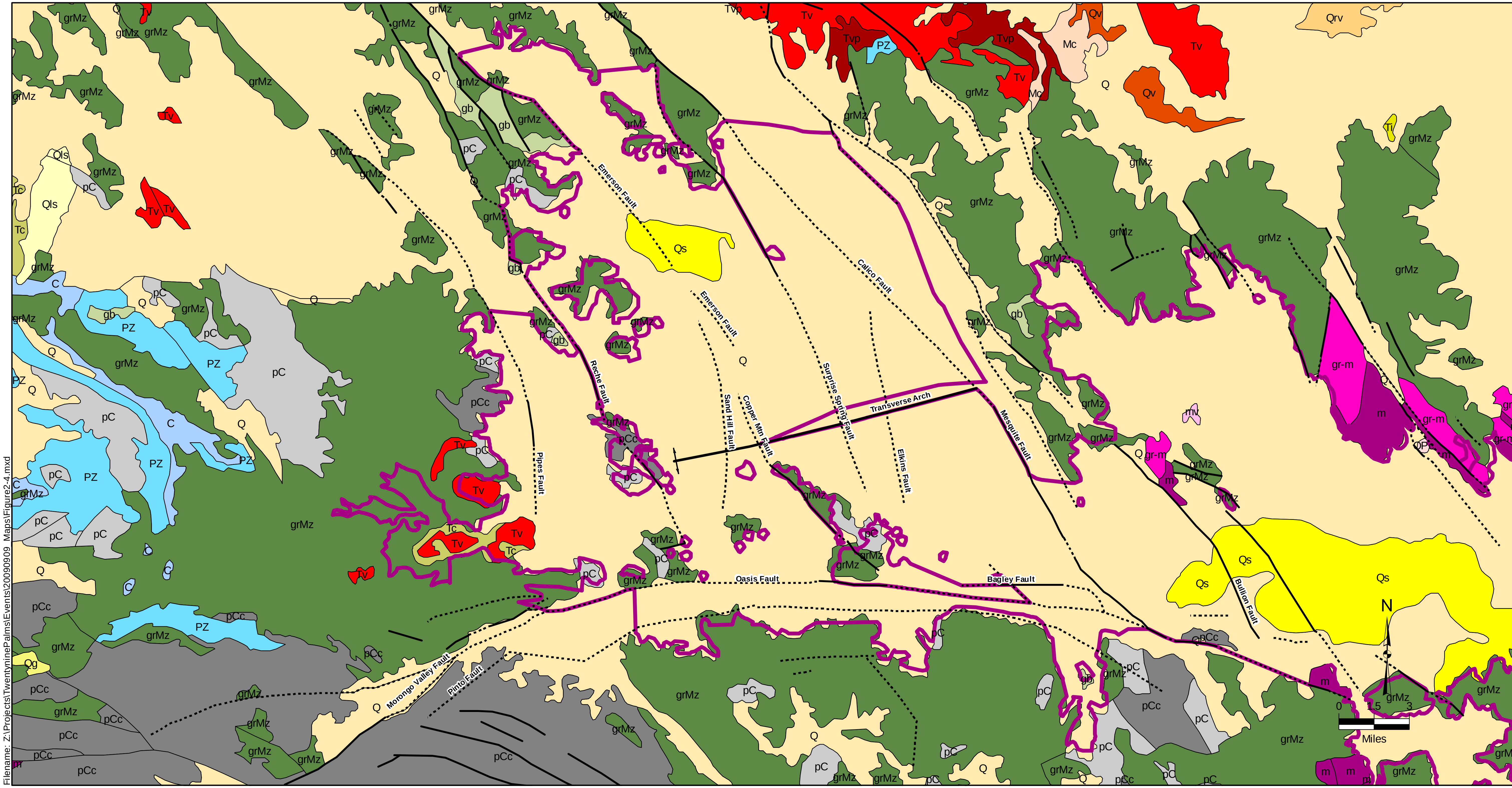
Twentynine Palms
San Bernardino County, California

Map of Landforms

K/J 0964003.00
March 2010

Figure 2-3

Filename: Z:\Projects\TwentyninePalms\Events\20090909 Maps\Figure2-4.mxd



Explanation

Faults

- Known
- Inferred
- Anticline

Study Area

Geologic Units

- Qrv: Recent volcanics
- Qls: Quaternary landslide deposits
- Qs: Quaternary sand deposits
- Qv: Quaternary volcanics
- Q: Quaternary alluvium
- Qg: Quaternary glacial deposits
- QPc: Plio-Pleistocene alluvium
- Mc: Miocene nonmarine rocks
- Tv: Tertiary volcanics
- Tvp: Tertiary pyroclastics
- Tc: Tertiary nonmarine rocks
- Ti: Tertiary intrusive rocks
- gb: Mesozoic gabbroic rocks
- grMz: Mesozoic granitic rocks
- C: Carboniferous marine rocks
- PZ: Paleozoic marine rocks
- mv: Pre-Cenozoic metavolcanic rocks
- gr-m: Pre-Cenozoic granitic and metamorphic rocks
- m: Pre-Cenozoic metasedimentary and metavolcanic rocks
- pC: Precambrian undivided rocks
- pCc: Precambrian igneous and metamorphic rocks

Notes:

See Section 2.7.3 for geologic unit descriptions

The Oasis Fault is also known as the Pinto Mountain Fault.

Kennedy/Jenks Consultants

Twentynine Palms

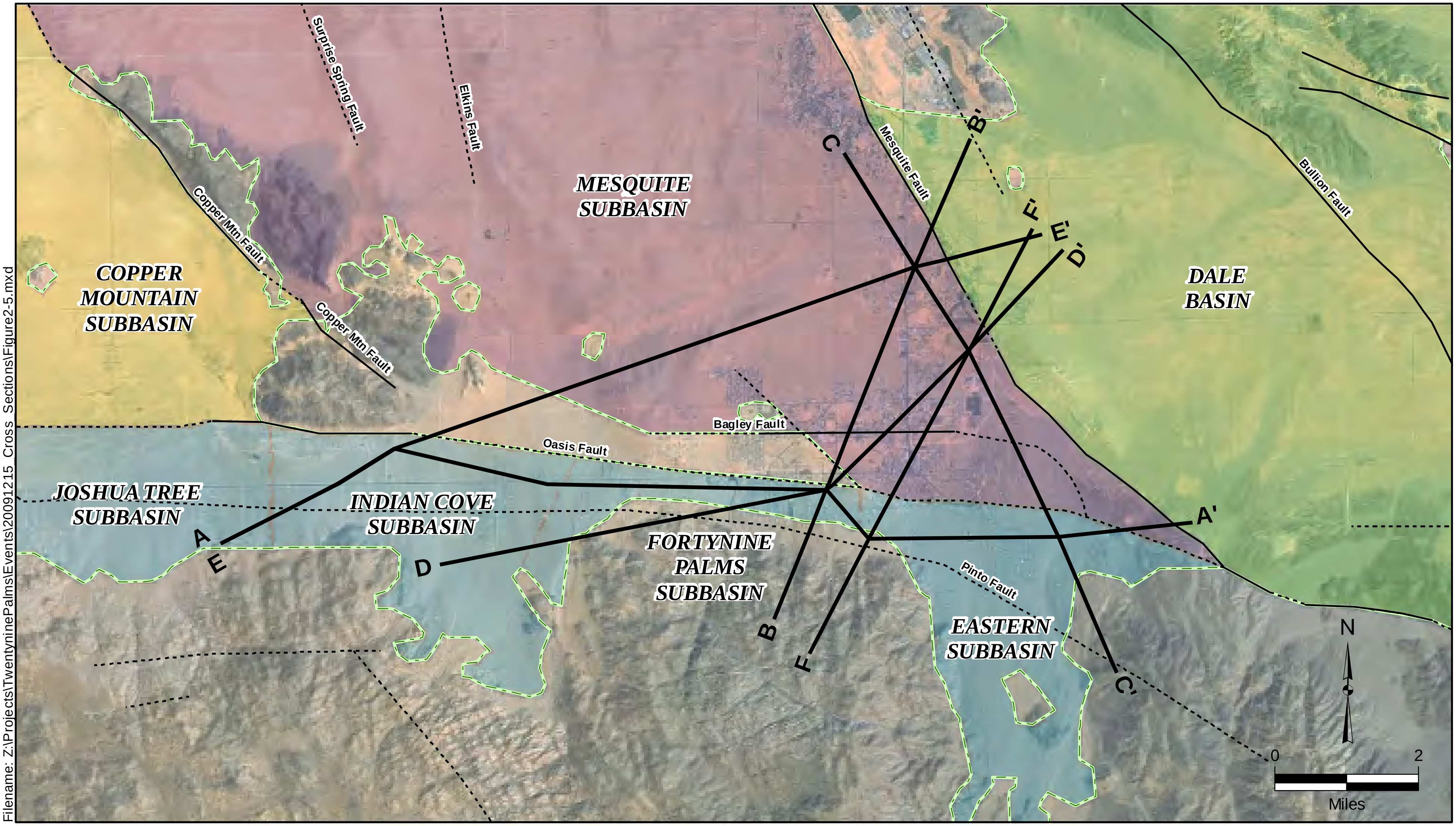
San Bernardino County, California

Study Area Geologic Map

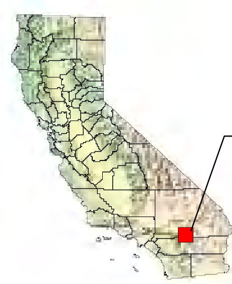
K/J 0964003*00

March 2010

Figure 2-4



Source: (c)2009 Microsoft Corporation.



Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Cross Section Location Map

K/J 0964003*00
March 2010

Figure 2-5

Cross Section Trace

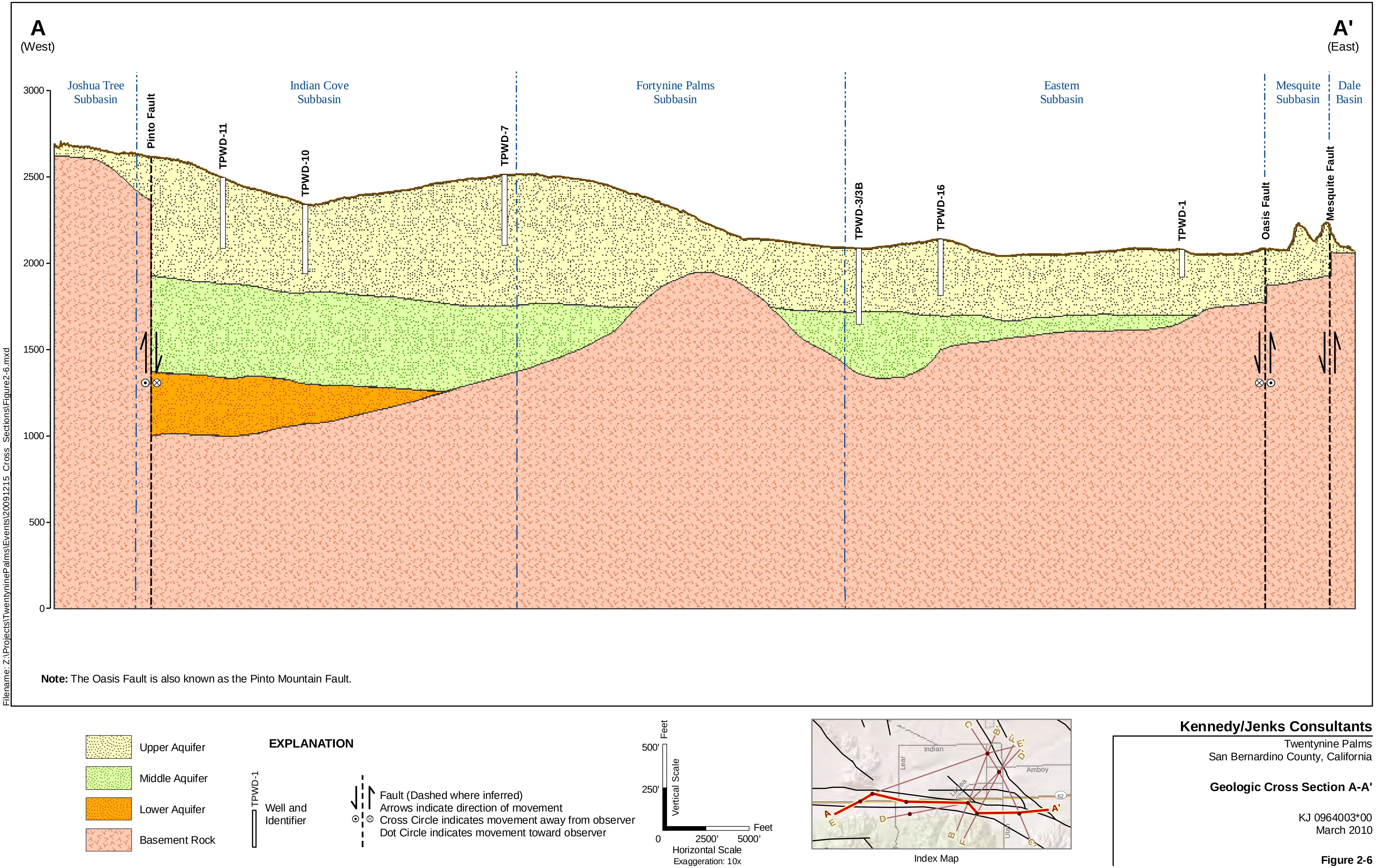
Site Boundary

Faults

Known

Inferred

Note:
The Oasis Fault is also known as the Pinto Mountain Fault.



Note: The Oasis Fault is also known as the Pinto Mountain Fault.

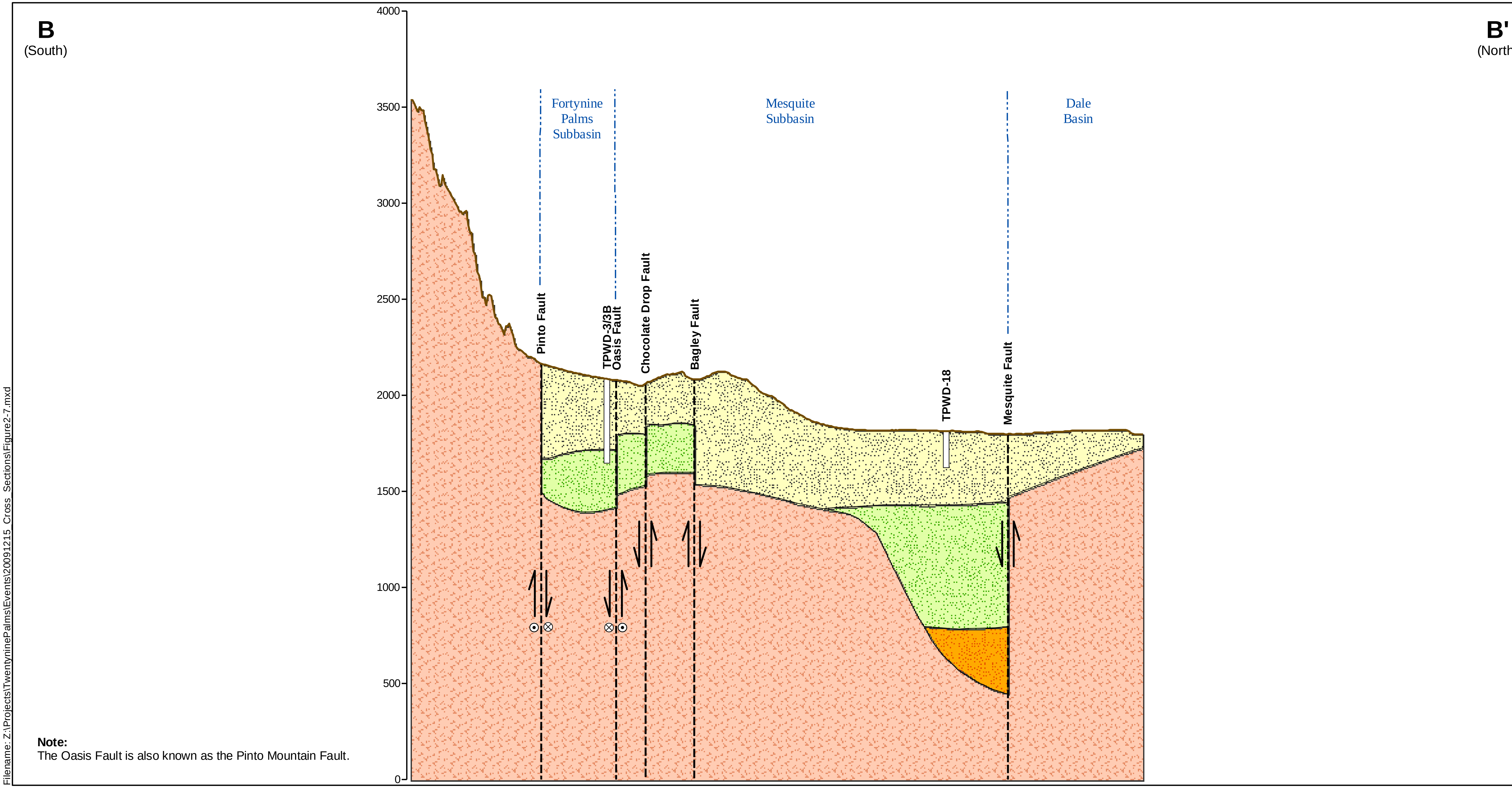
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Geologic Cross Section A-A'

KJ 0964003*00
March 2010

Figure 2-6



Filename: Z:\Projects\TwentyninePalms\Events\20091215_Cross_Sections\Figure2-7.mxd

EXPLANATION

Upper Aquifer

Middle Aquifer

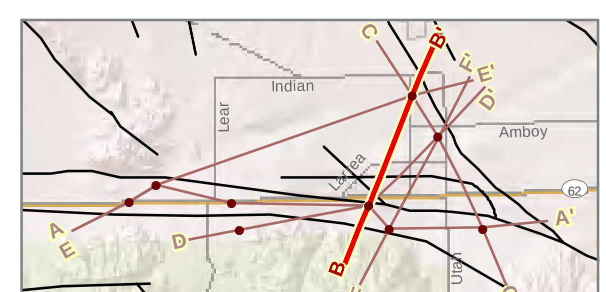
Lower Aquifer

Basement Rock

TPWD-1 Well and Identifier

Fault (Dashed where inferred)
Arrows indicate direction of movement
Cross Circle indicates movement away from observer
Dot Circle indicates movement toward observer

Feet
500'
250'
Vertical Scale
0 2500' 5000' Feet
Horizontal Scale
Exaggeration: 10x



Index Map

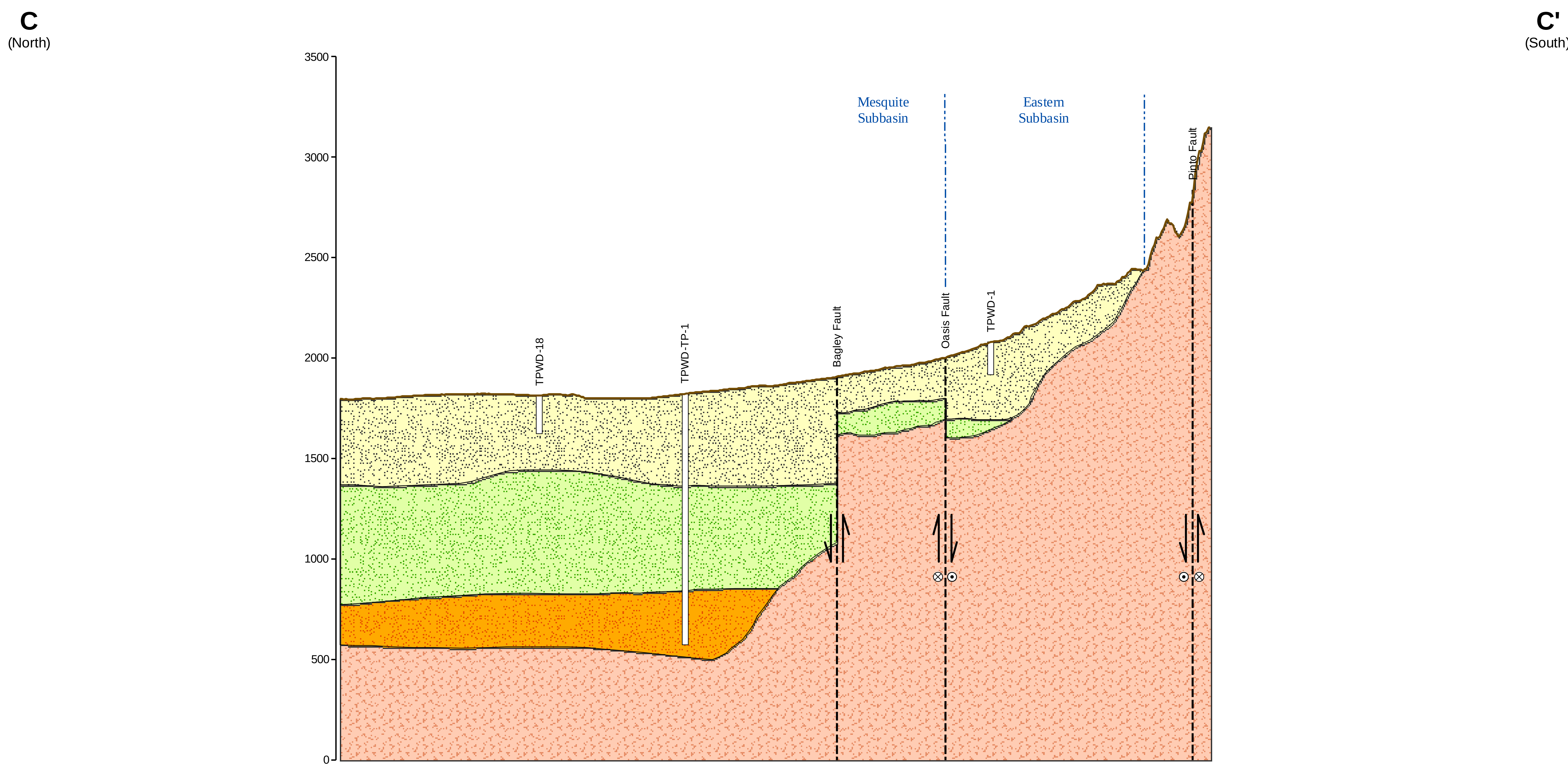
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Geologic Cross Section B-B'

KJ 0964003*00
March 2010

Figure 2-7



Note: The Oasis Fault is also known as the Pinto Mountain Fault.

Filename: Z:\Projects\TwentyninePalms\Events\20091215_Cross_Sections\Figure2-8.mxd

EXPLANATION

Upper Aquifer

Middle Aquifer

Lower Aquifer

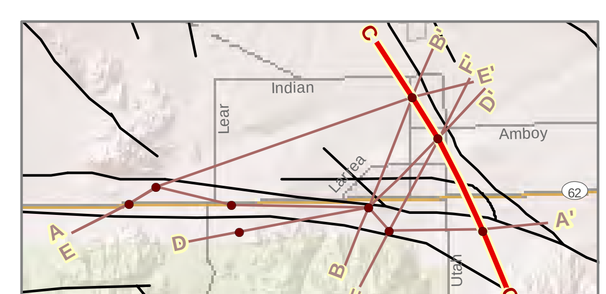
Basement Rock

TPWD-1 Well and Identifier

Fault (Dashed where inferred)
Arrows indicate direction of movement
Cross Circle indicates movement away from observer
Dot Circle indicates movement toward observer

Feet 500' 250' Vertical Scale

0 2500' 5000' Feet
Horizontal Scale
Exaggeration: 10x



Index Map

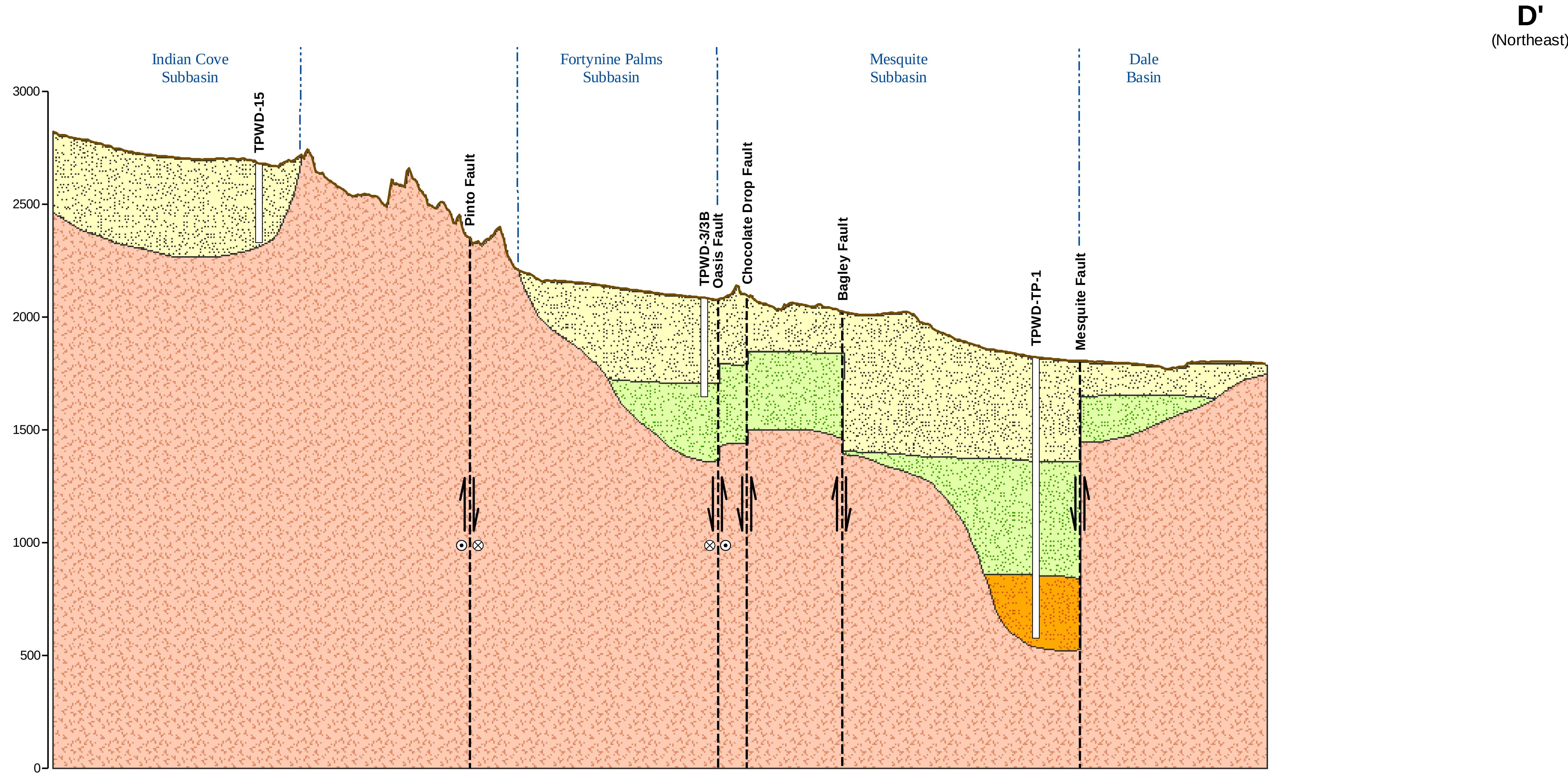
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

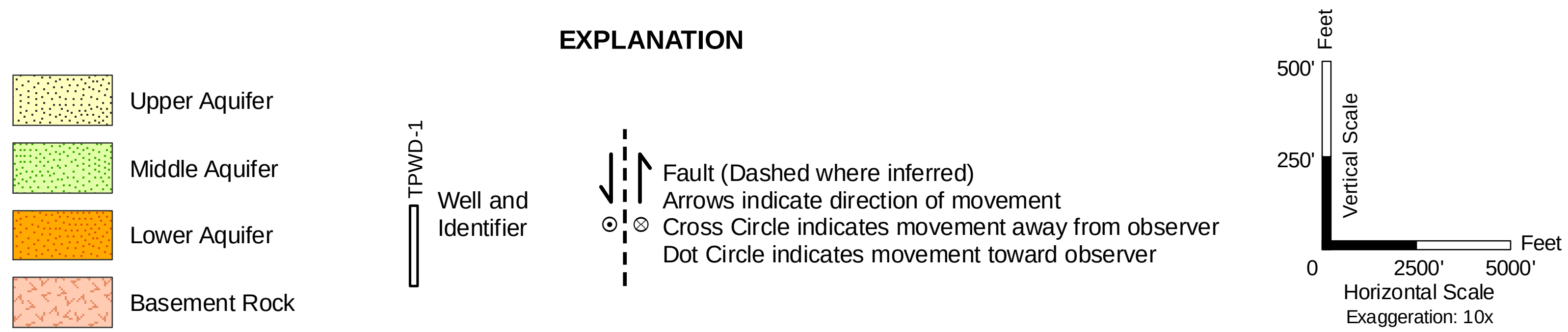
Geologic Cross Section C-C'

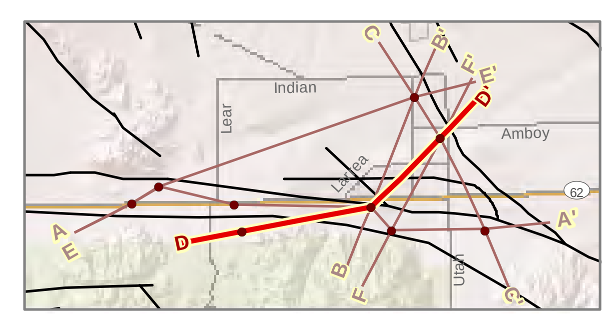
KJ 0964003*00
March 2010

Figure 2-8



Note: The Oasis Fault is also known as the Pinto Mountain Fault.





Index Map

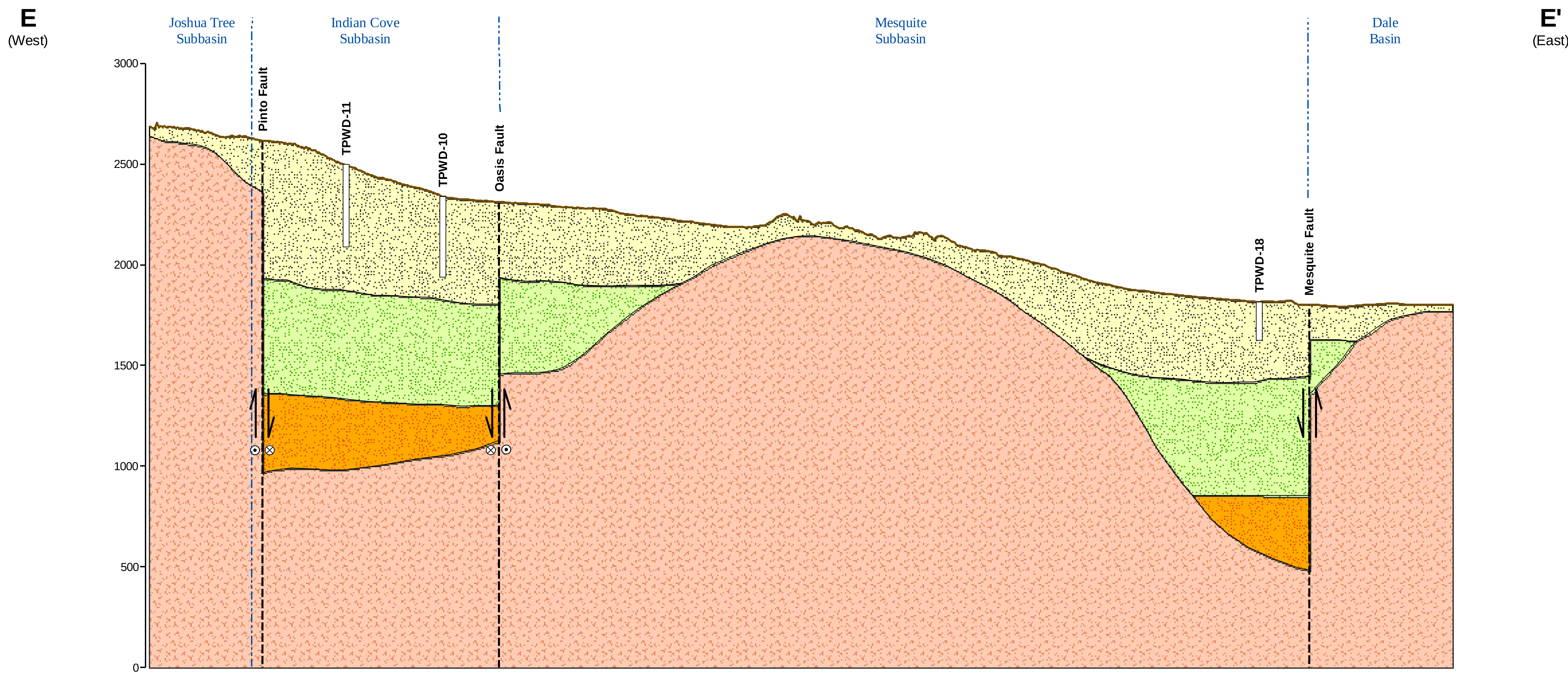
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Geologic Cross Section D-D'

KJ 0964003*00
March 2010

Figure 2-9



Note: The Oasis Fault is also known as the Pinto Mountain Fault.

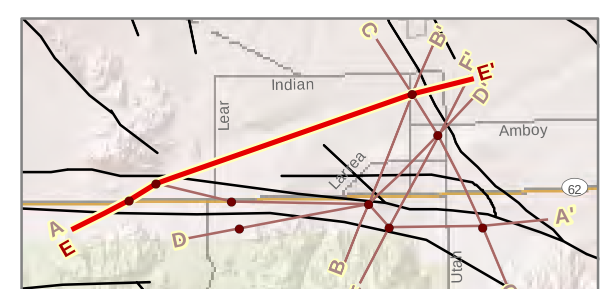
EXPLANATION

- Upper Aquifer
- Middle Aquifer
- Lower Aquifer
- Basement Rock

TPWD-1 — Well and Identifier

Fault (Dashed where inferred)
Arrows indicate direction of movement
Cross Circle indicates movement away from observer
Dot Circle indicates movement toward observer

Feet
500'
250'
Vertical Scale
0 2500' 5000' Feet
Horizontal Scale
Exaggeration: 10x



Index Map

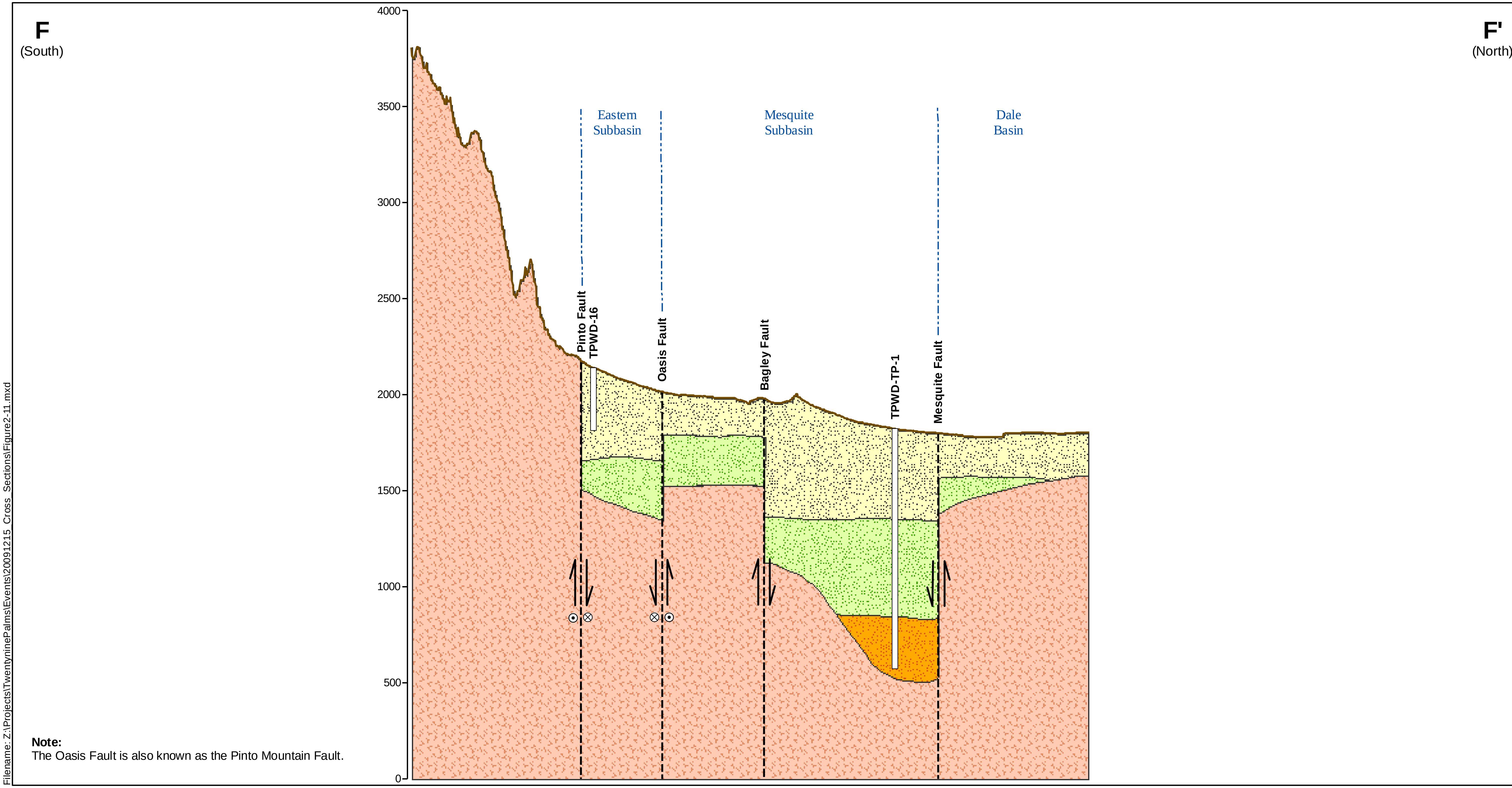
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Geologic Cross Section E-E'

KJ 0964003*00
March 2010

Figure 2-10



Filename: Z:\Projects\TwentyninePalms\Events\20091215_Cross_Sections\Figure2-11.mxd

EXPLANATION

- Upper Aquifer
- Middle Aquifer
- Lower Aquifer
- Basement Rock

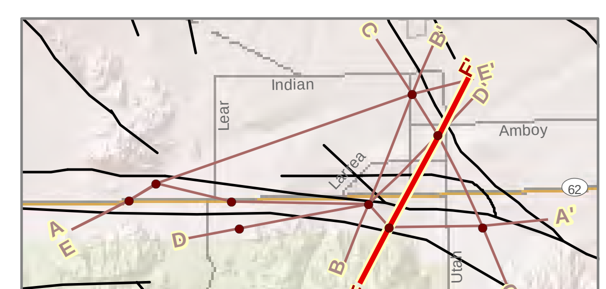
TPWD-1 — Well and Identifier

Selected Fault (Dashed where inferred)
Arrows indicate direction of movement
Cross Circle indicates movement away from observer
Dot Circle indicates movement toward observer

Vertical Scale (Feet): 500', 250'

Horizontal Scale (Feet): 0, 2500', 5000'

Exaggeration: 10x



Index Map

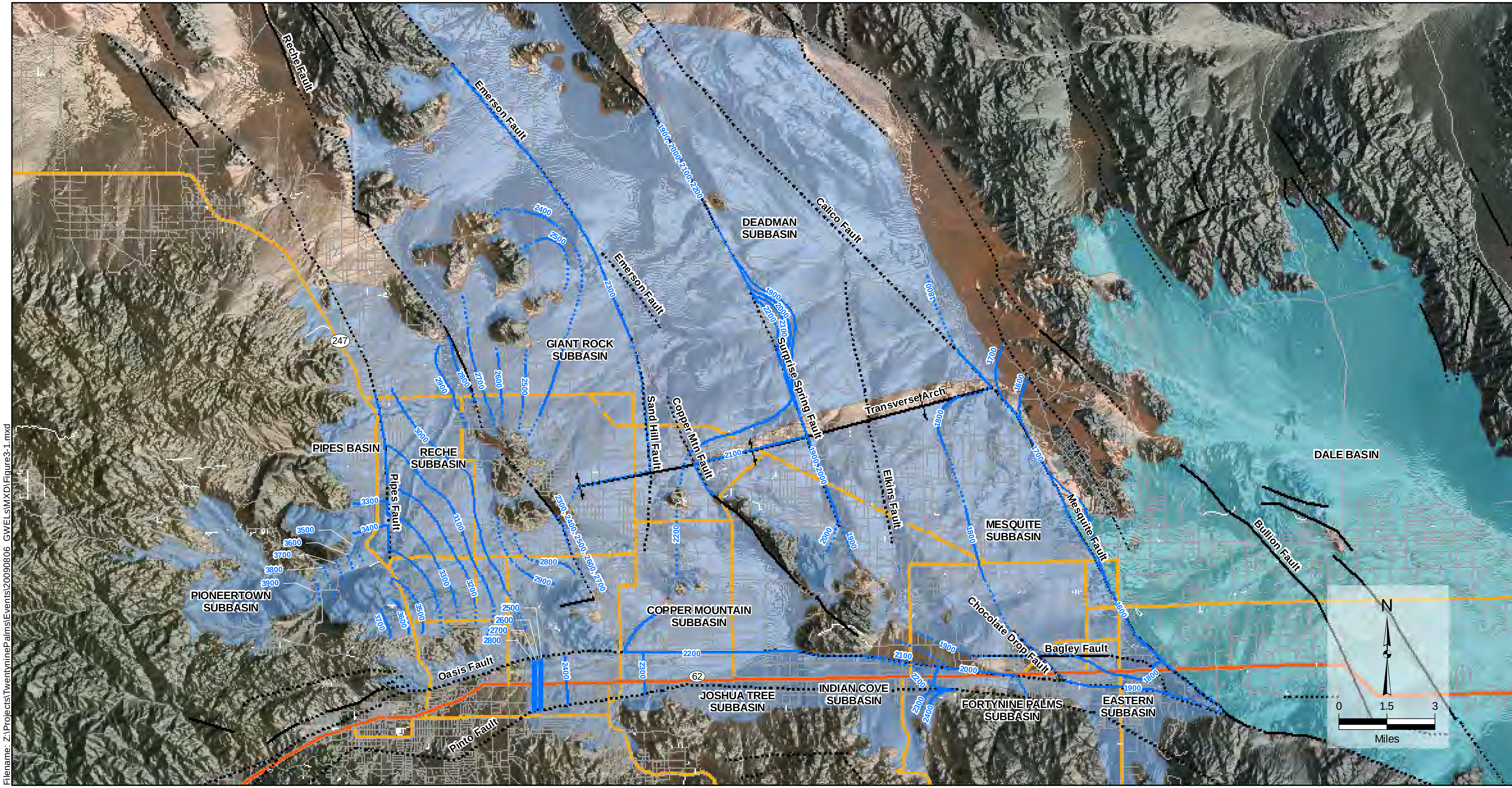
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Geologic Cross Section F-F'

KJ 0964003*00
March 2010

Figure 2-11



Filename: Z:\Projects\TwentyninePalms\Events\20090806_GWELs\MXD\Figure3-1.mxd

Source: (c) 2009 Microsoft Corporation

Explanation

Groundwater Subbasins

Groundwater Elevation (ft AMSL)

Known

Inferred

Faults

Known

Inferred

Anticline

Notes:
Contour Interval = 100 feet.
The Oasis Fault is also known as the Pinto Mountain Fault.

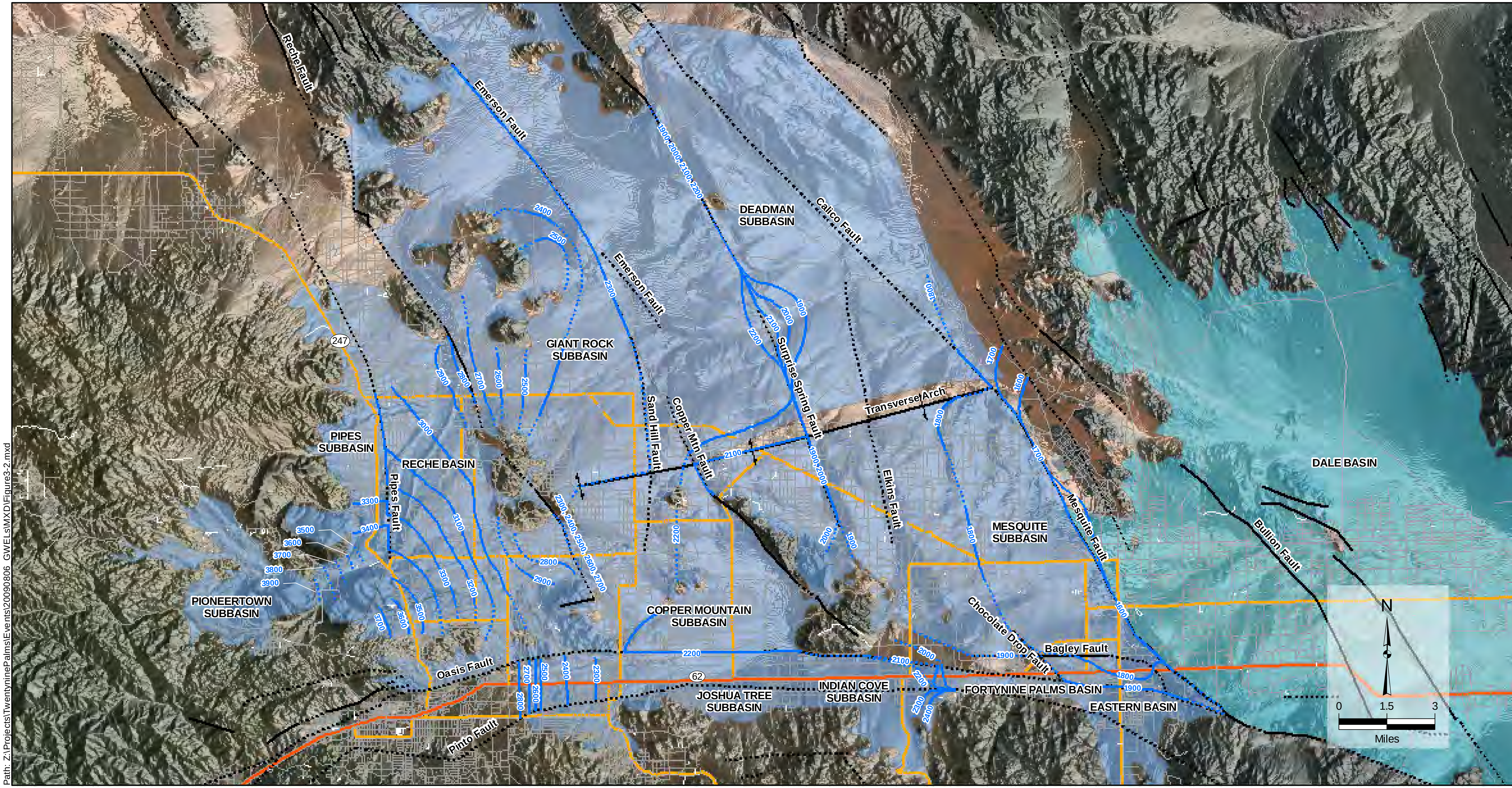
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Groundwater Elevation Contours 1947

K/J 0964003*00
March 2010

Figure 3-1



Source: (c) 2009 Microsoft Corporation

Explanation

Groundwater Subbasins

Groundwater Elevation (ft AMSL)

Known

Inferred

Faults

Known

Inferred

Anticline

Notes:
Contour Interval = 100 feet.
The Oasis Fault is also known as the Pinto Mountain Fault.

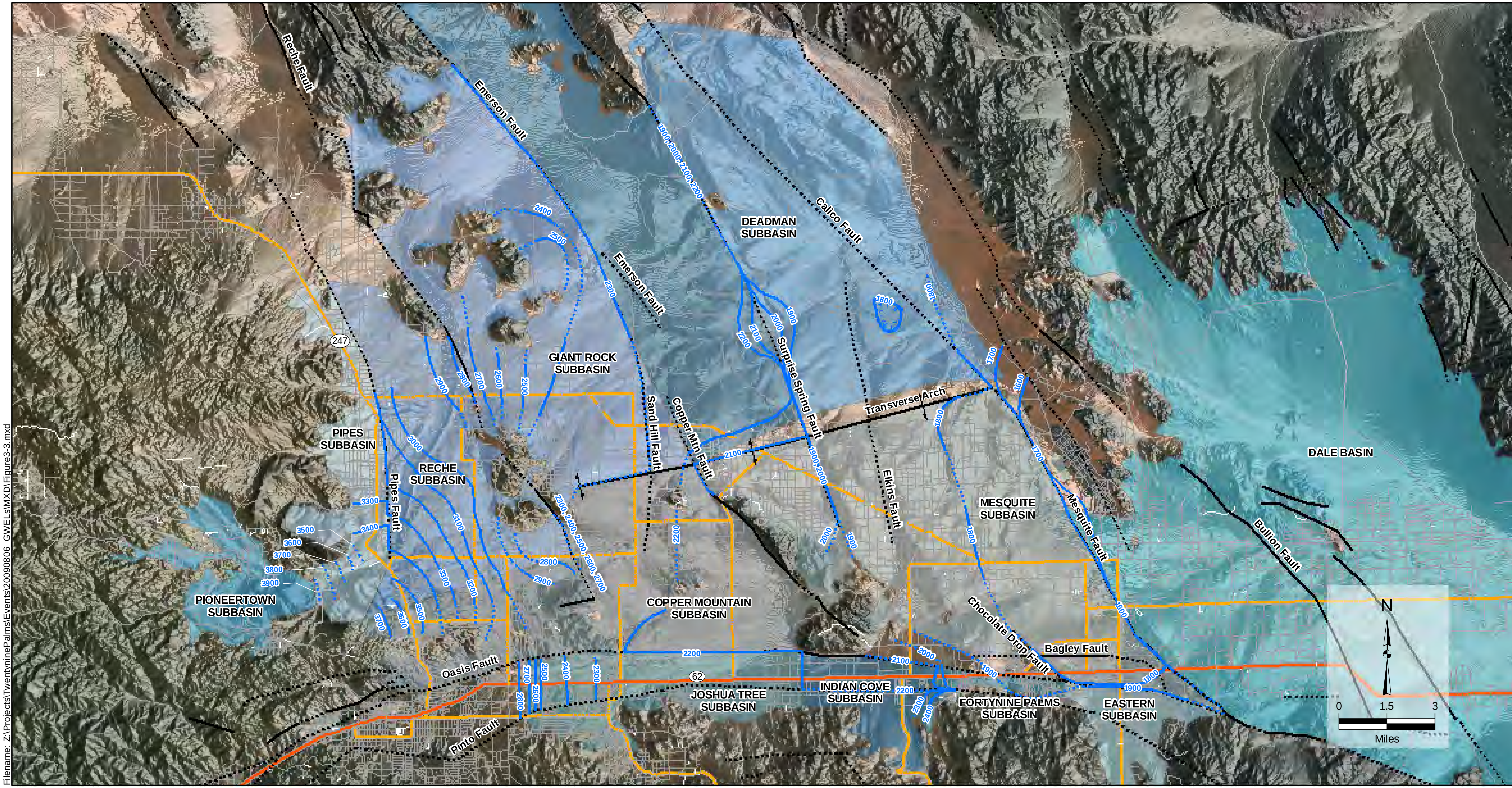
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Groundwater Elevation Contours 1982

K/J 0964003*00
March 2010

Figure 3-2



Filename: Z:\Projects\TwentyninePalms\Events\20090806_GWELs\MXD\Figure3-3.mxd

Source: (c) 2009 Microsoft Corporation

Explanation

Groundwater Subbasins

Groundwater Elevation (ft AMSL)

Known

Inferred

Faults

Known

Inferred

Anticline

Notes:
Contour Interval = 100 feet.
The Oasis Fault is also known as the Pinto Mountain Fault.

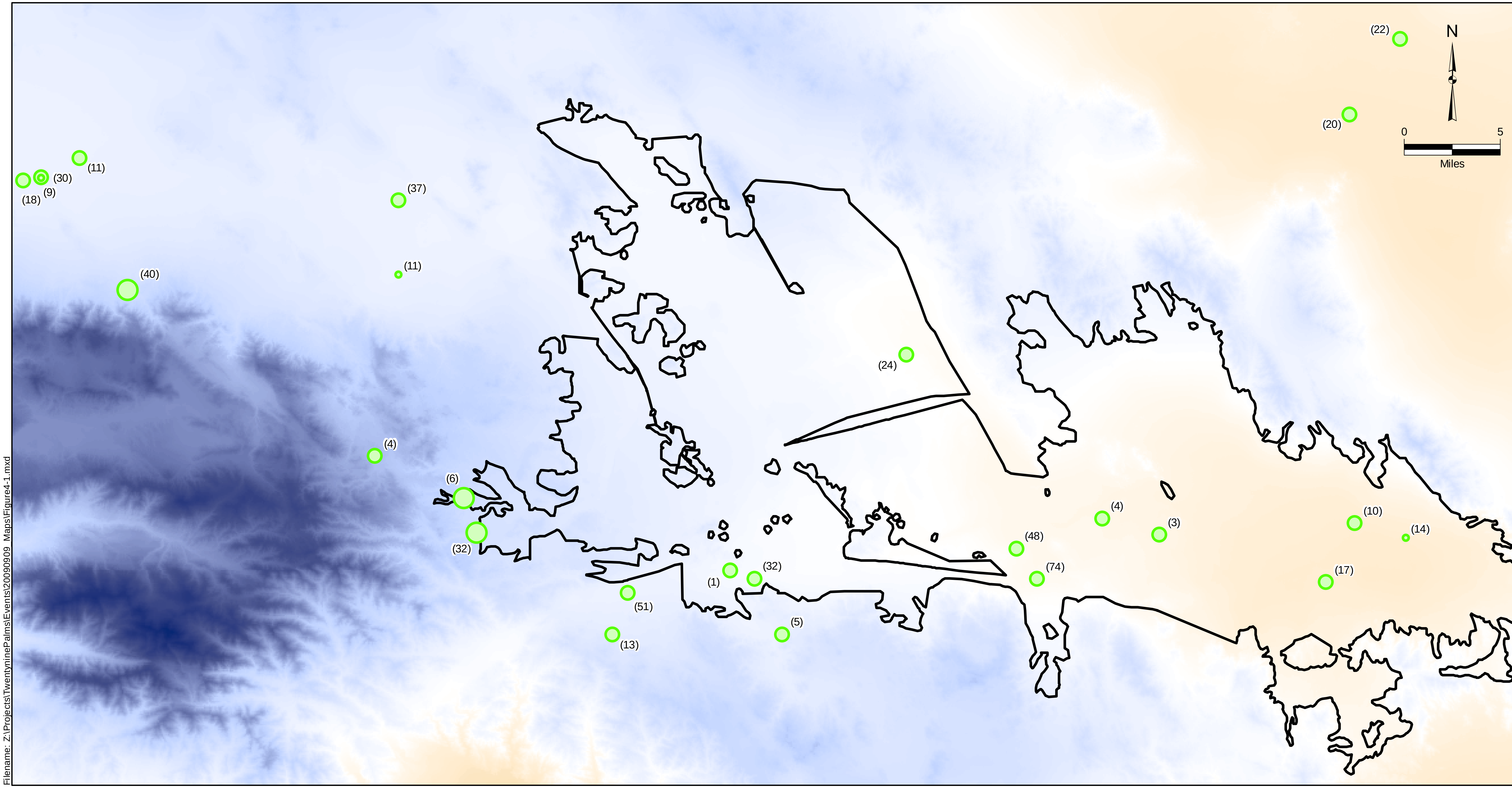
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Groundwater Elevation Contours 2008

K/J 0964003*00
March 2010

Figure 3-3



Filename: Z:\Projects\TwentyninePalms\Events\20090909_Maps\Figure4-1.mxd

Source: (c) 2009 Microsoft Corporation

Precipitation Stations

Annual Precipitation (inches)

- <3.0
- 3.0-6.0
- 6.0-9.0
- >9.0

Annual Rainfall

High : 16.0

Low : 0.3

Study Area

(8.4) Number of years of record

Note:
The size of the station markers corresponds to the average annual rainfall (inches).
The associated number of years of record for that station are shown in parentheses.

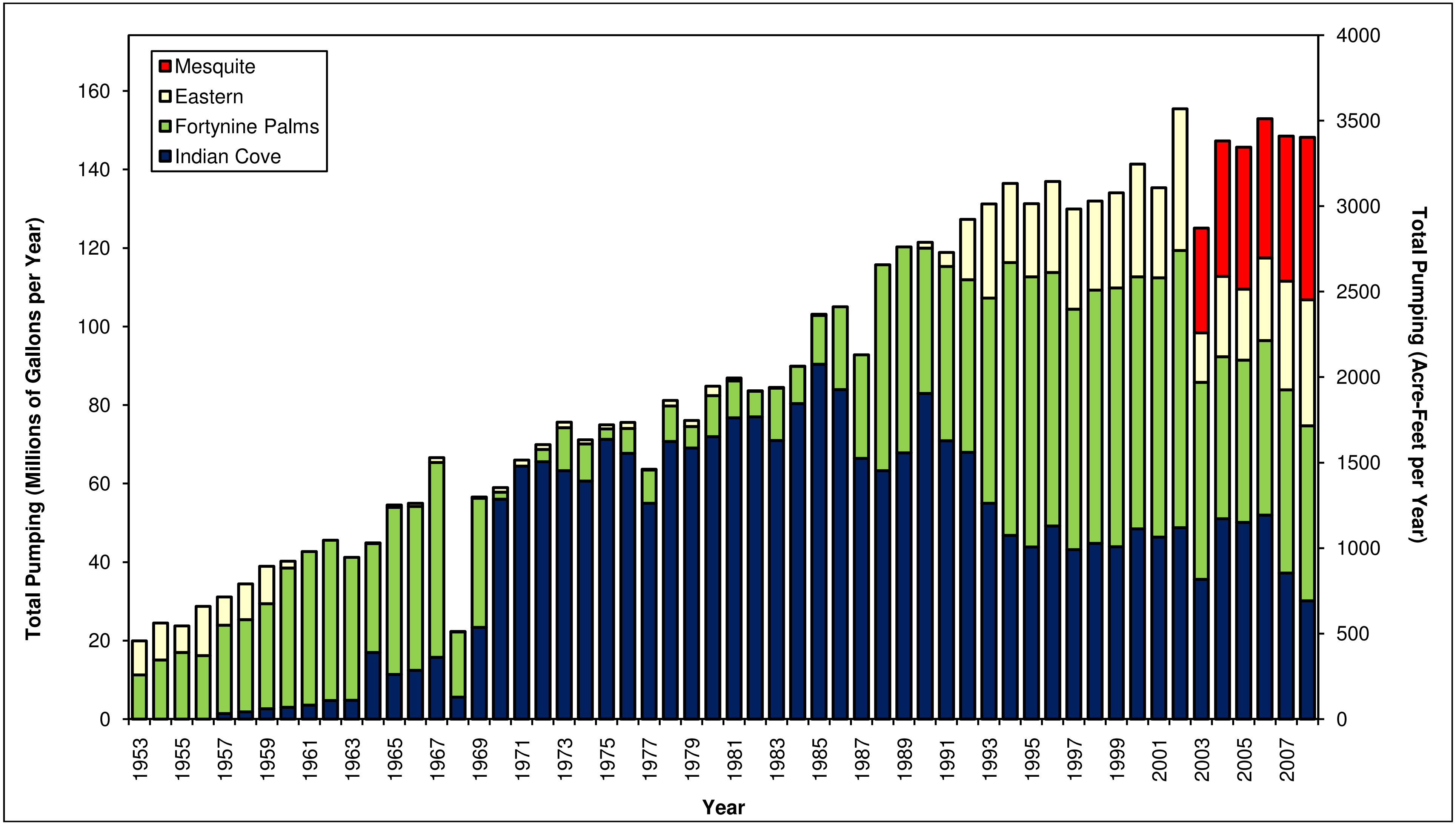
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Map of Interpolated Annual Rainfall

K/J 0964003.00
March 2010

Figure 4-1



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure4-2.pptx

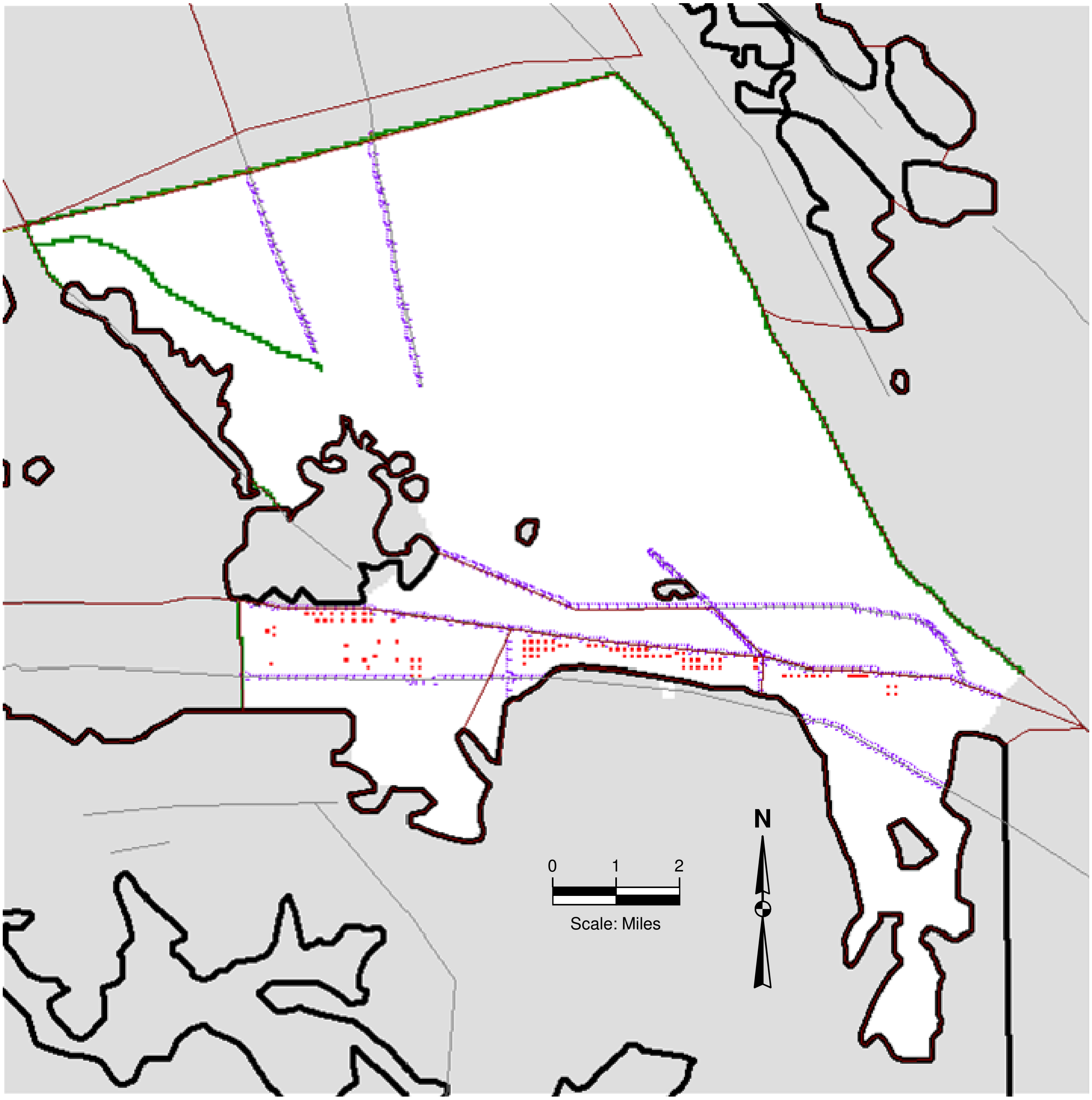
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Annual Pumping from TPWD Wells by Subbasin

K/J 0964003*00
March 2010

Figure 4-2



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure5-1.pptx

Legend

- No-flow (inactive) cell
- General Head Boundary
- Well (Boundary Condition)
- Fault (Hydrologic Flow Barrier)

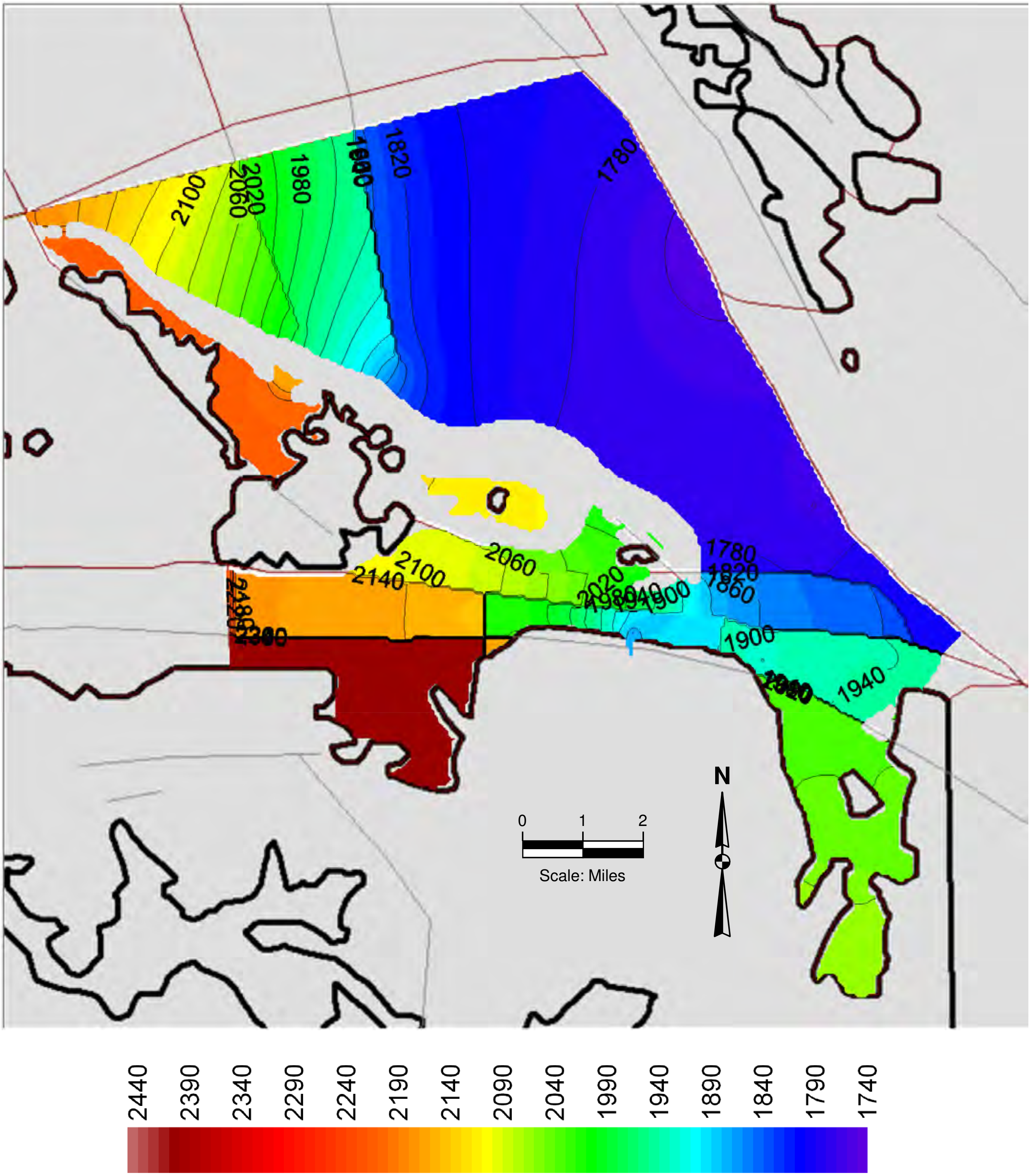
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Model Domain Map for Mesquite Lake Groundwater Model

K/J 0964003*00
March 2010

Figure 5-1



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure5-2.pptx

Contour Interval = 20 feet.

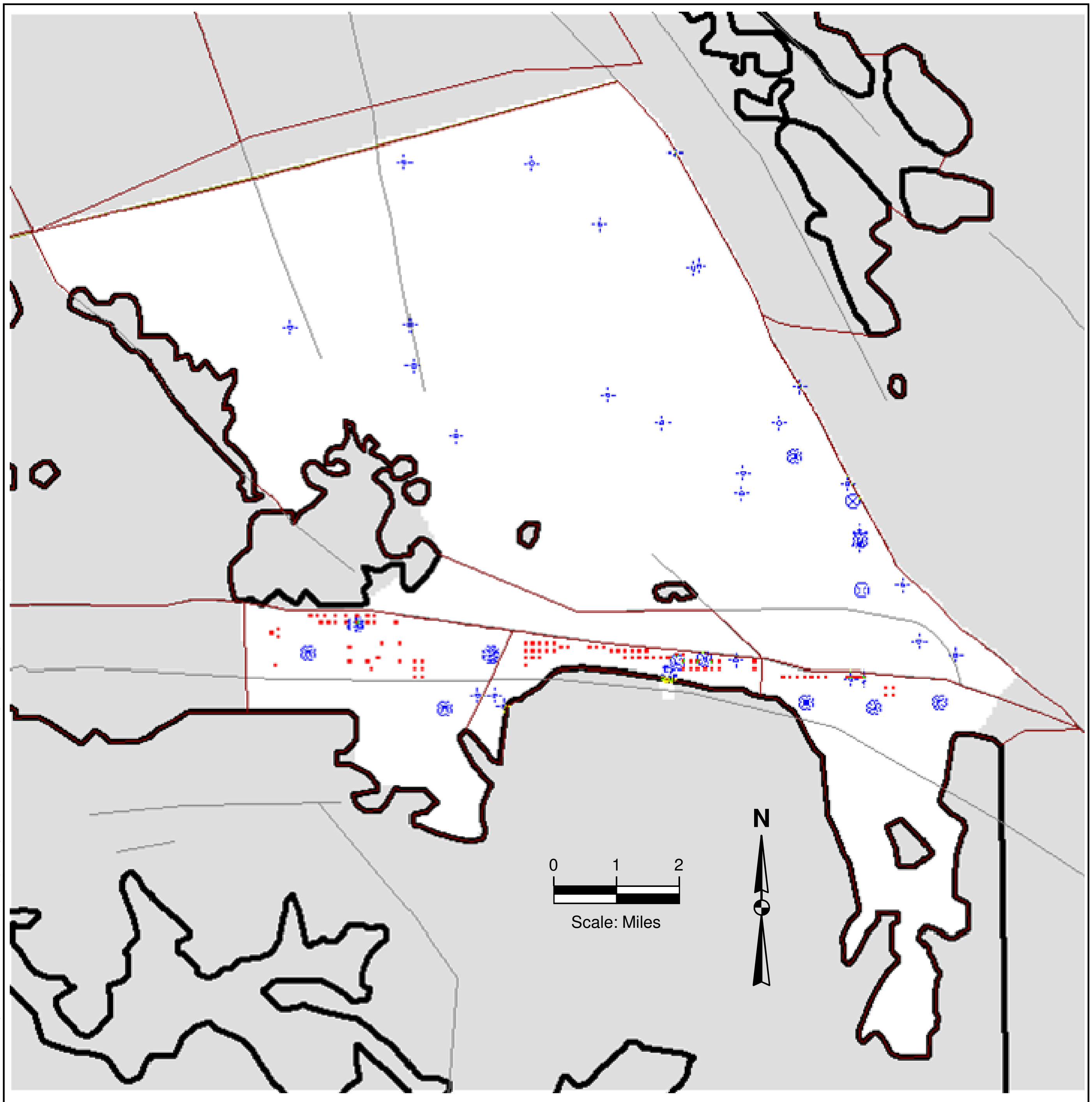
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

2008 Groundwater Elevations for Model Layer 1, Transient Simulation, Mesquite Lake Groundwater Model

K/J 0964003*00
March 2010

Figure 5-2



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure5-3.pptx

Legend

- No-flow (inactive) cell
- Well (Analytical Element)
- Well (Boundary Condition)
- Groundwater Elevation Target

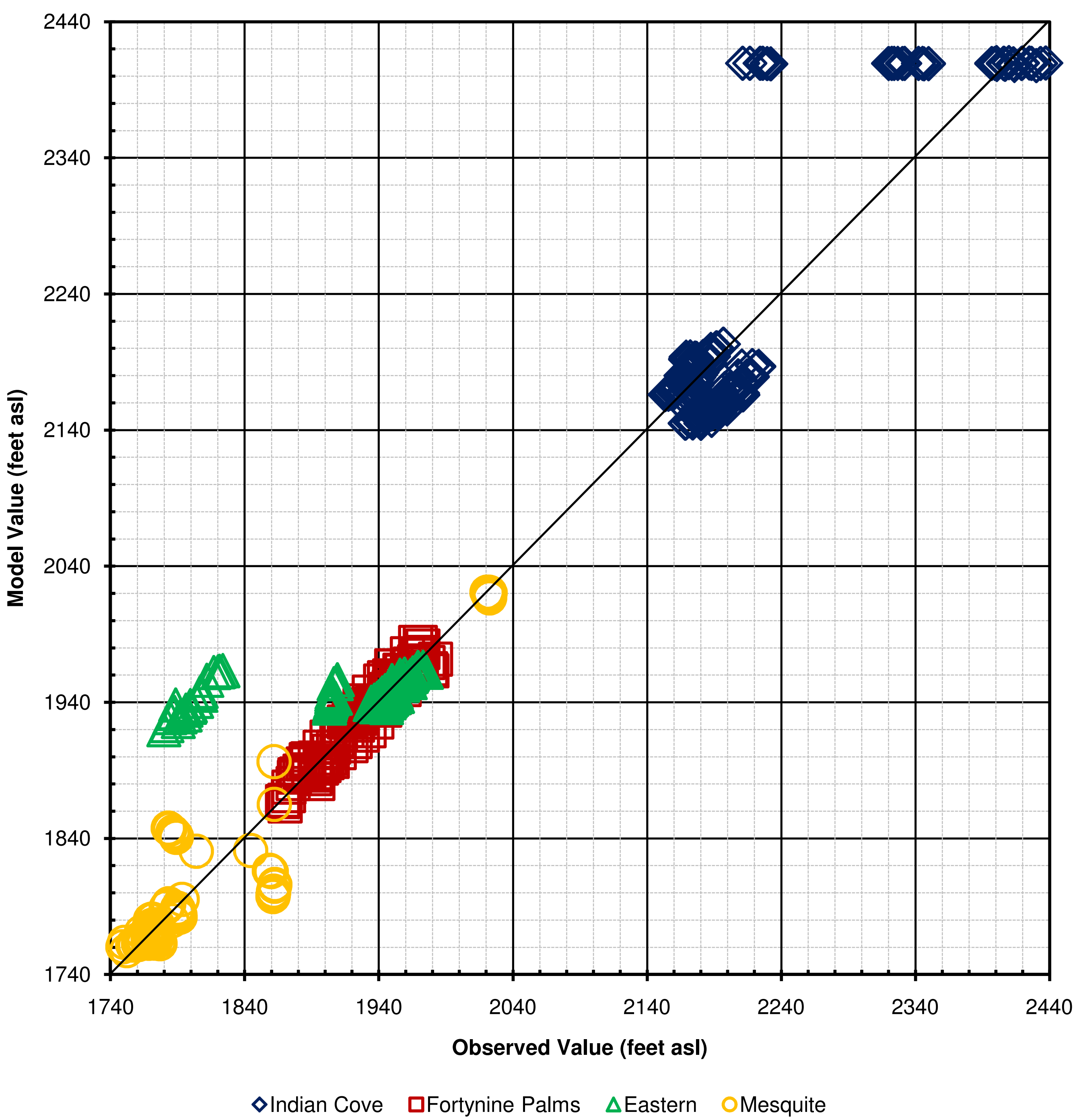
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Wells in Mesquite Lake Groundwater Model

K/J 0964003*00
March 2010

Figure 5-3



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure5-4.pptx

Kennedy/Jenks Consultants

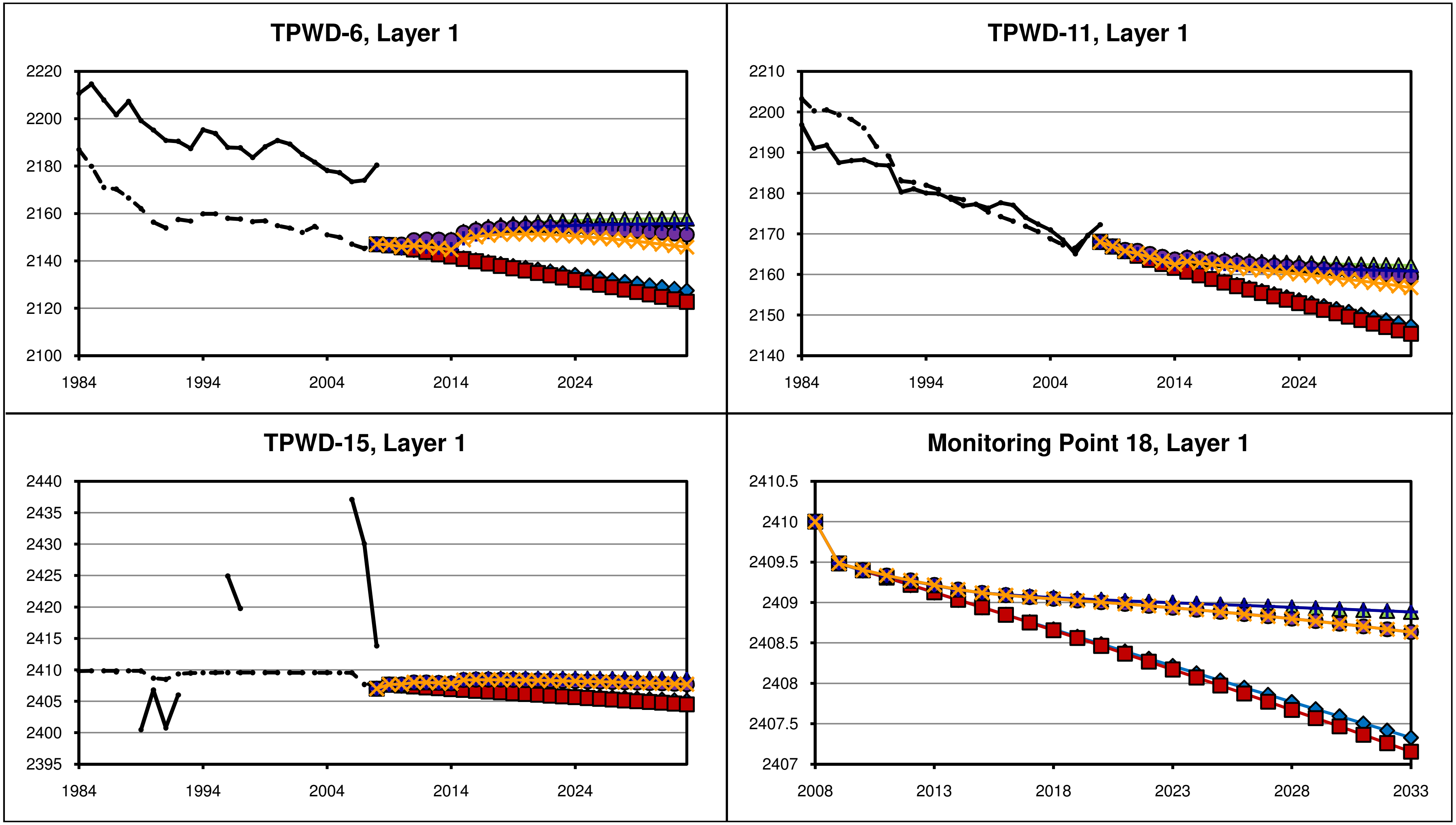
Twentynine Palms
San Bernardino County, California

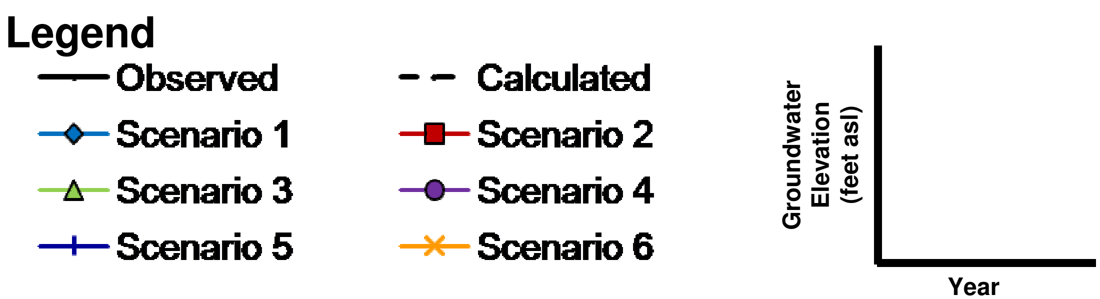
Observed versus Computed Target Values for Transient Calibration

K/J 0964003*00
March 2010

Figure 5-4

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-1.pptx





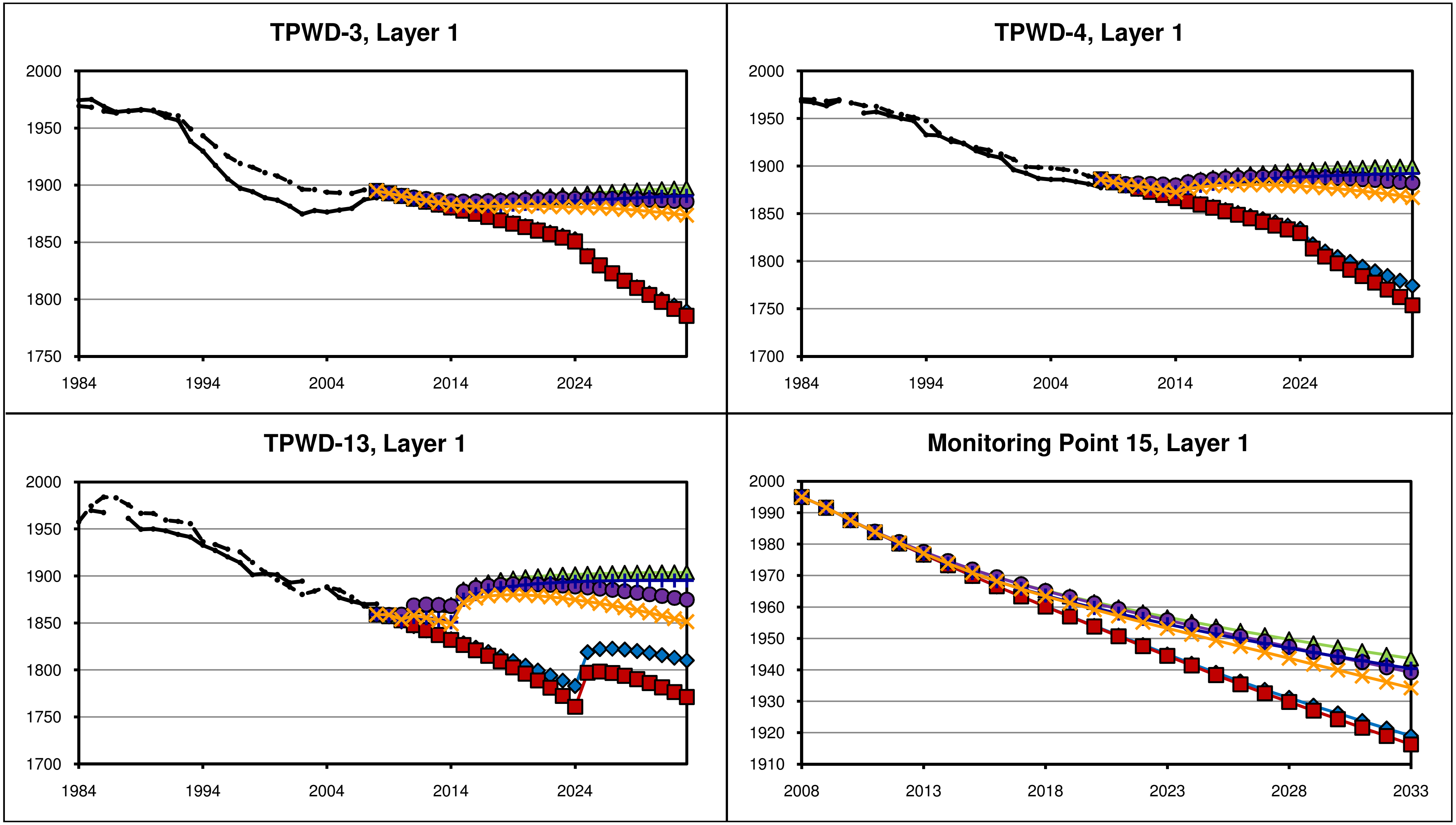
Kennedy/Jenks Consultants

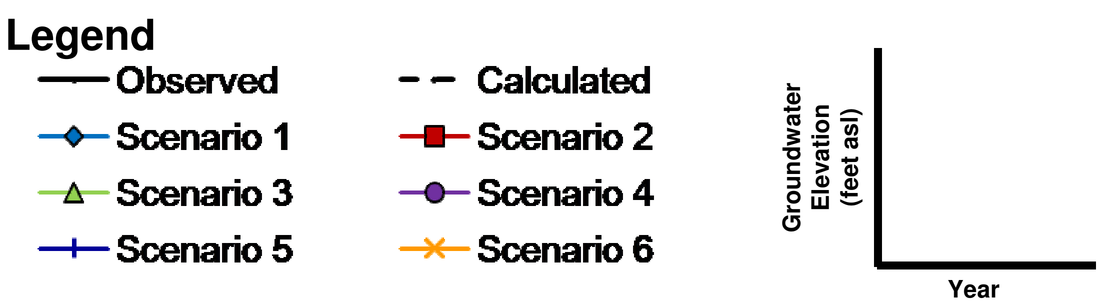
Twentynine Palms
San Bernardino County, California

Hydrographs for Wells in the Indian Cove Subbasin

K/J 0964003*00
March 2010

Figure 6-1





Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-2.pptx

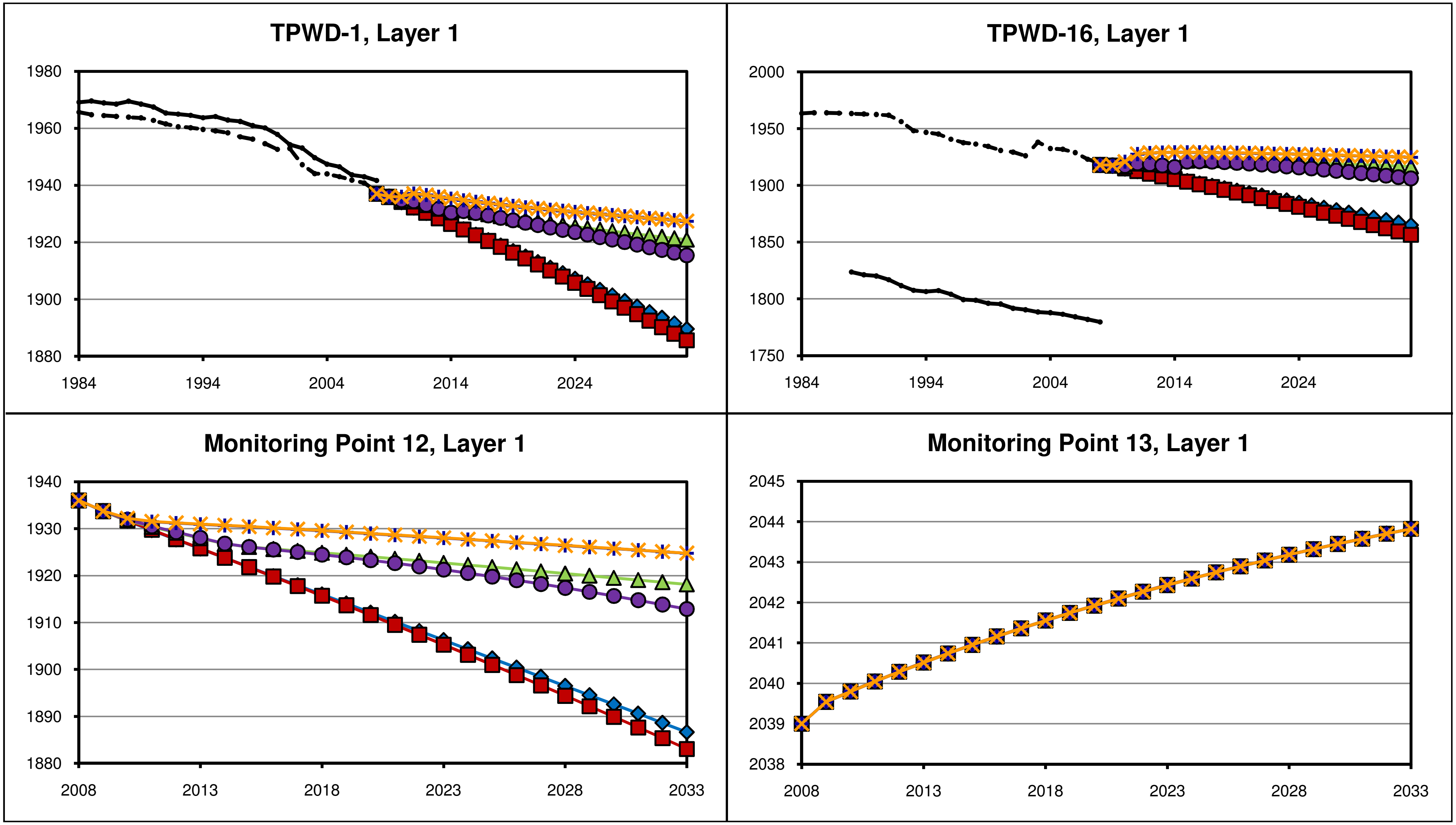
Kennedy/Jenks Consultants

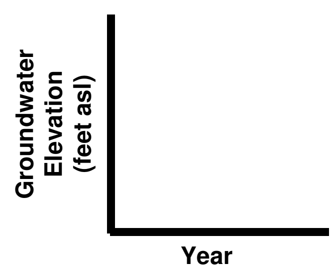
Twentynine Palms
San Bernardino County, California

Hydrographs for Wells in the Fortynine Palms Subbasin

K/J 0964003*00
March 2010

Figure 6-2





Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

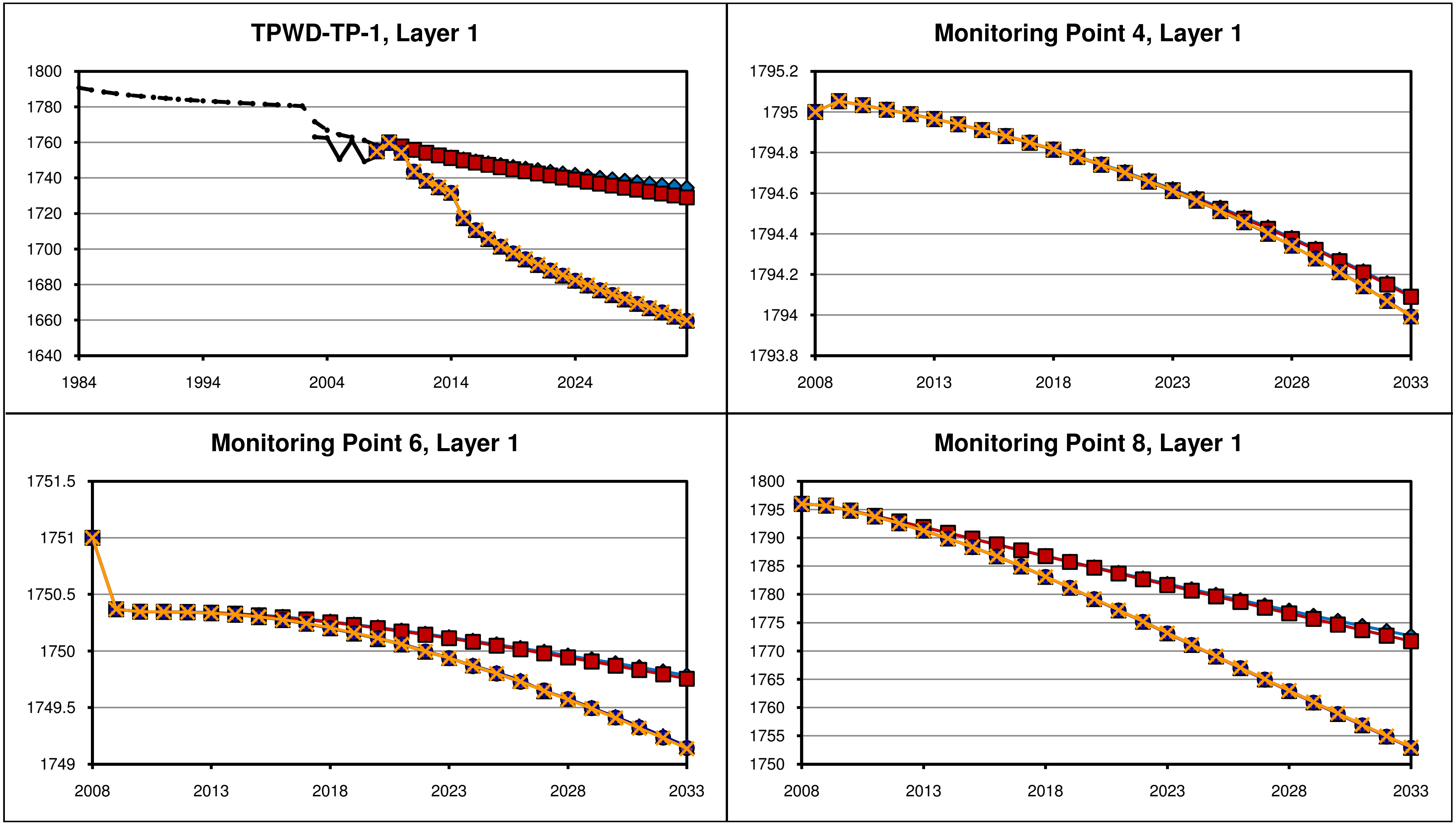
Hydrographs for Wells in the Eastern Subbasin

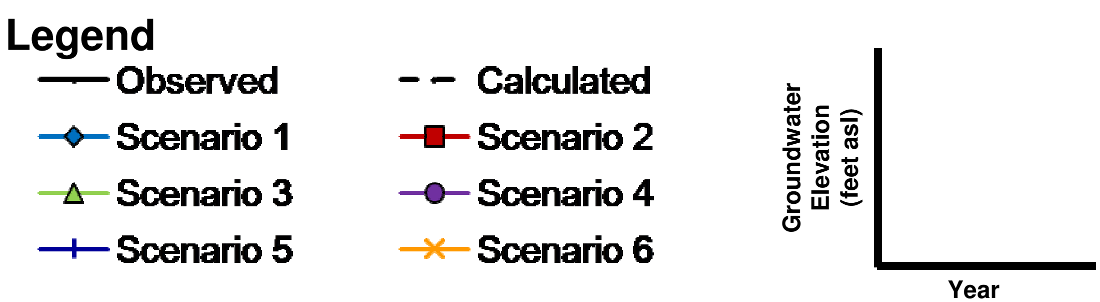
K/J 0964003*00
March 2010

Figure 6-3

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-3.pptx

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-4.pptx





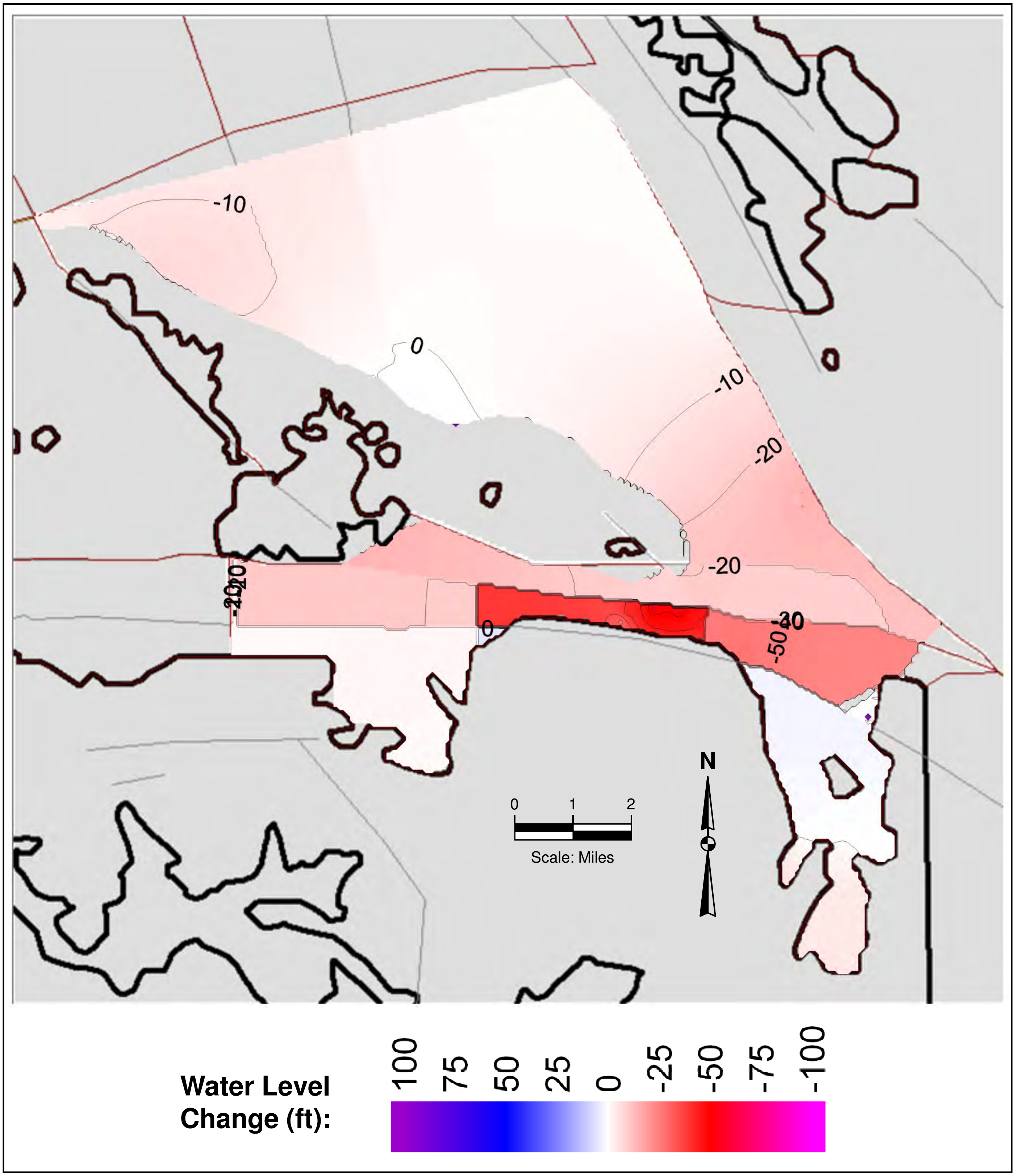
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for Wells in the Mesquite Subbasin

K/J 0964003*00
March 2010

Figure 6-4



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-5.pptx

Contour Interval = 10 feet.

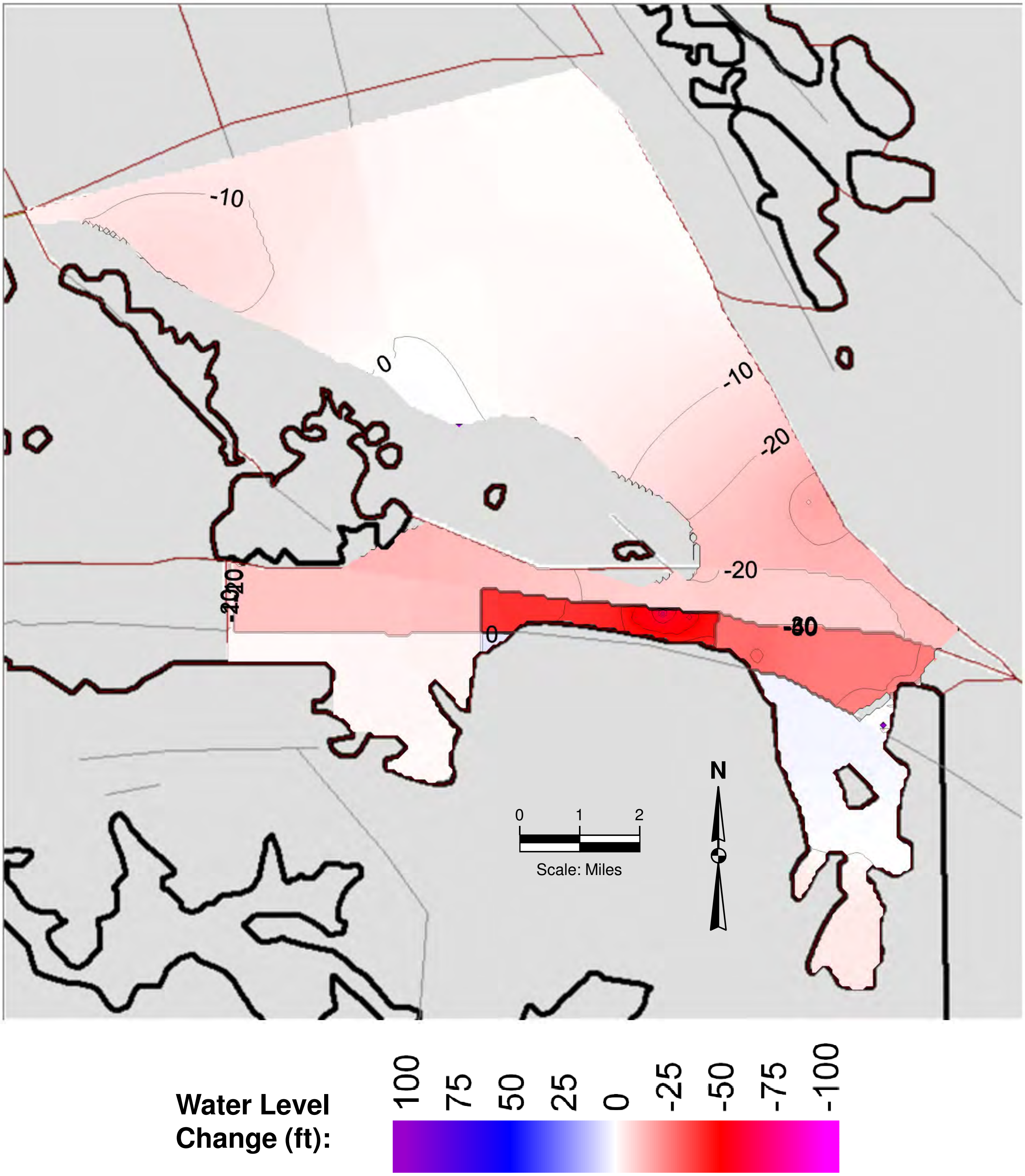
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Change in Water Levels from 2008 to 2033 for Scenario 1

K/J 0964003*00
March 2010

Figure 6-5



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-6.pptx

Contour Interval = 10 feet.

Kennedy/Jenks Consultants

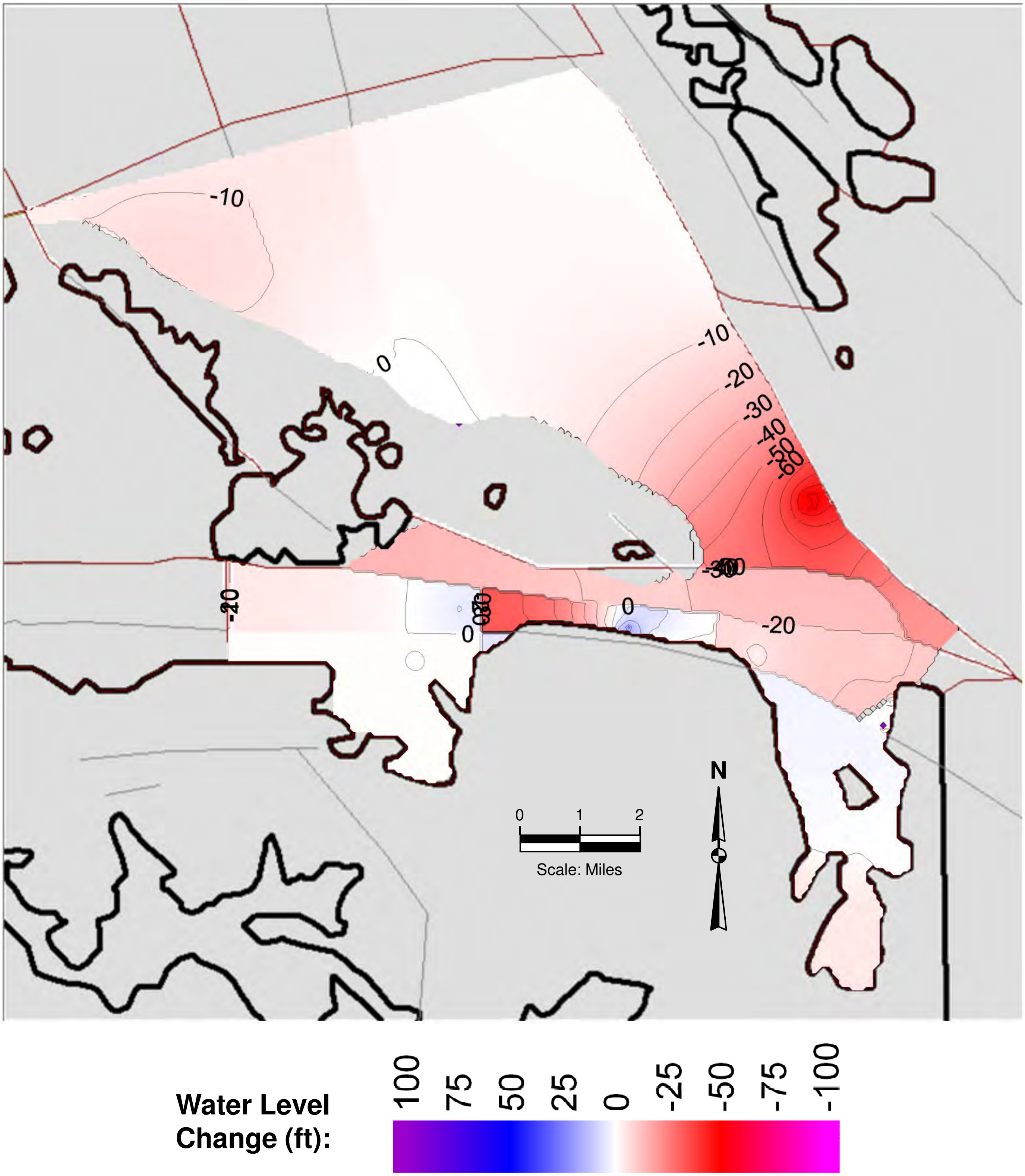
Twentynine Palms
San Bernardino County, California

Change in Water Levels from 2008 to 2033 for Scenario 2

K/J 0964003*00
March 2010

Figure 6-6

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-7.pptx



Contour Interval = 10 feet.

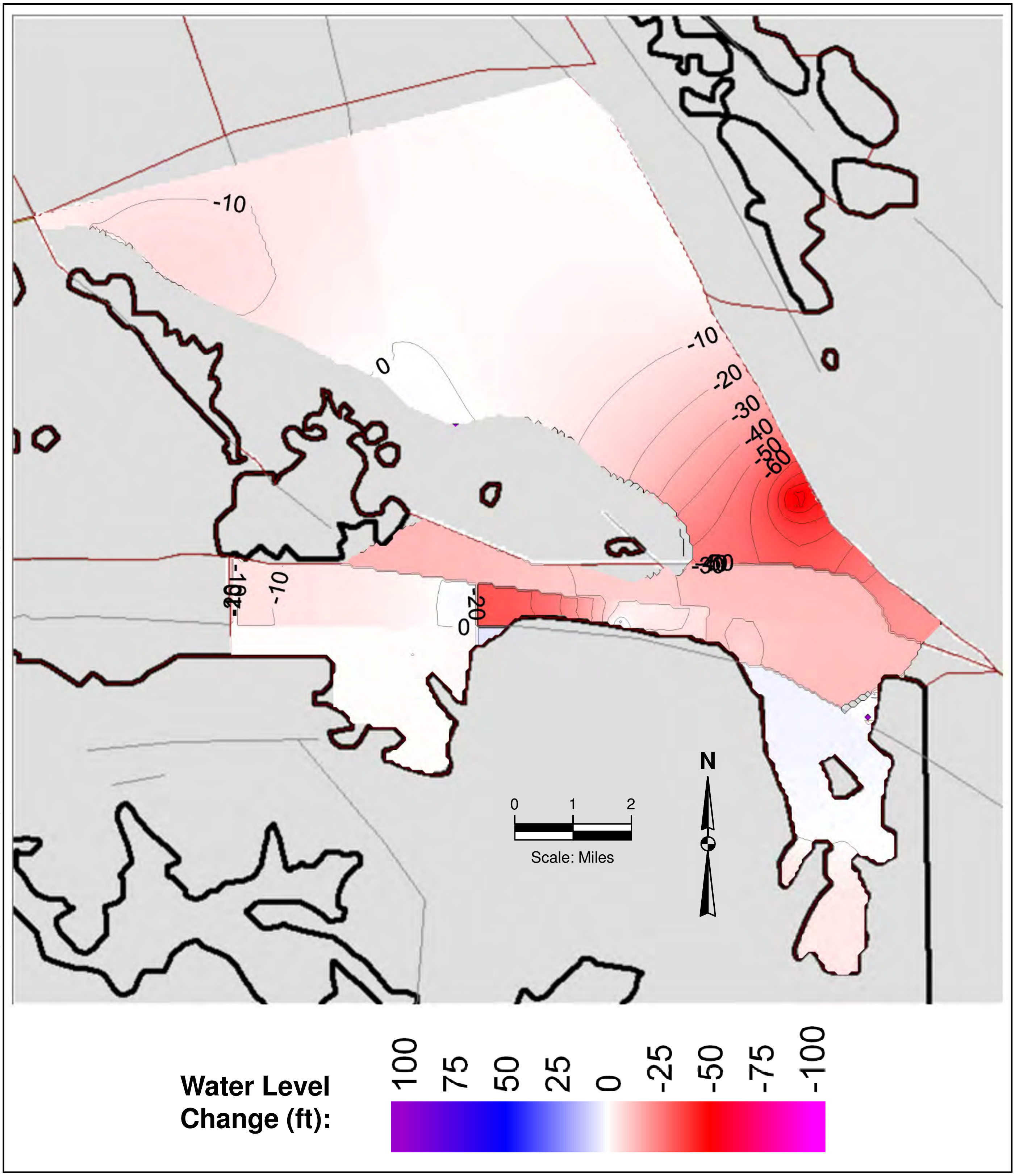
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Change in Water Levels from 2008 to 2033 for Scenario 3

K/J 0964003*00
March 2010

Figure 6-7



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-8.pptx

Contour Interval = 10 feet.

Kennedy/Jenks Consultants

Twentynine Palms

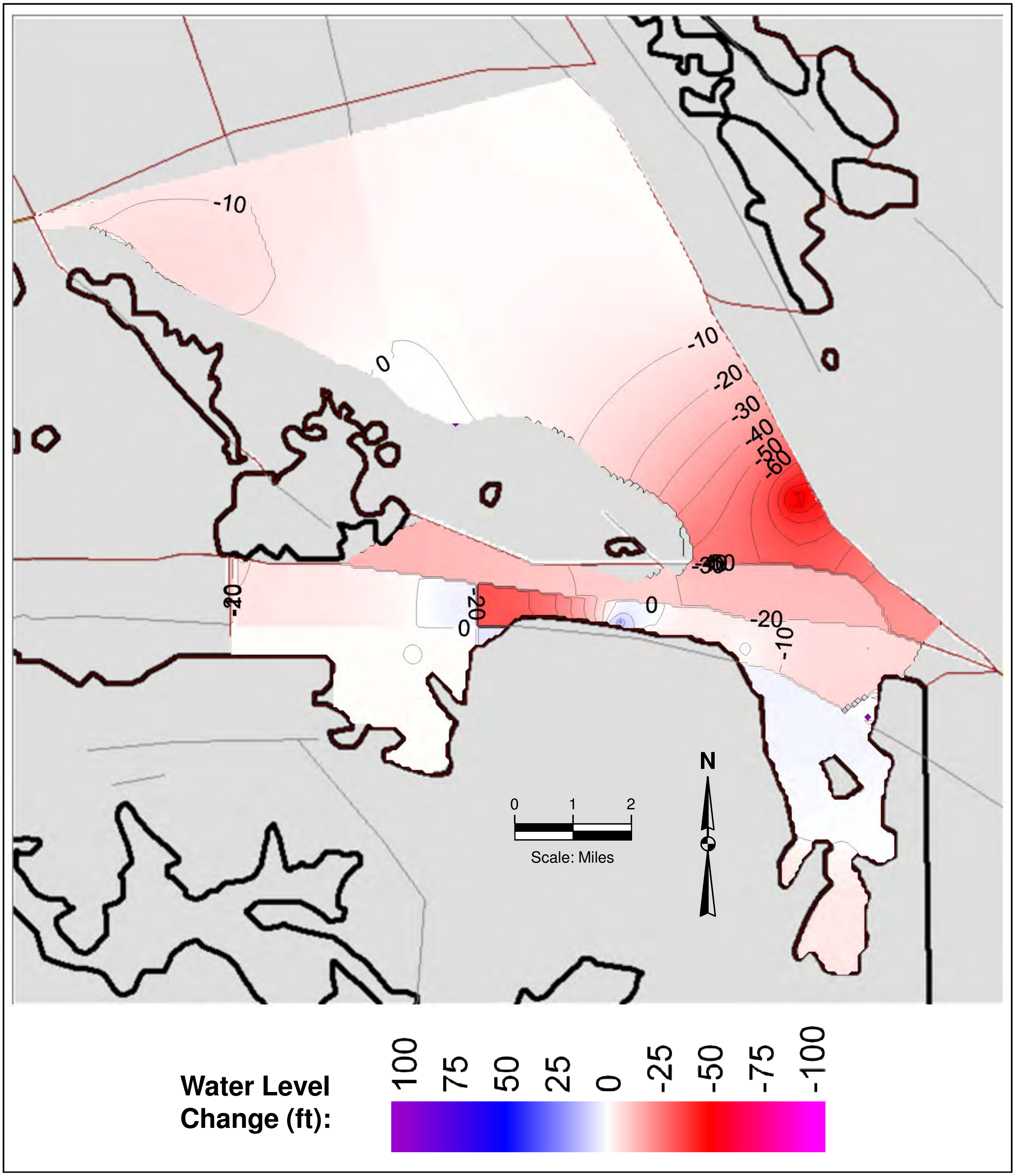
San Bernardino County, California

Change in Water Levels from 2008 to 2033 for Scenario 4

K/J 0964003*00

March 2010

Figure 6-8



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-9.pptx

Contour Interval = 10 feet.

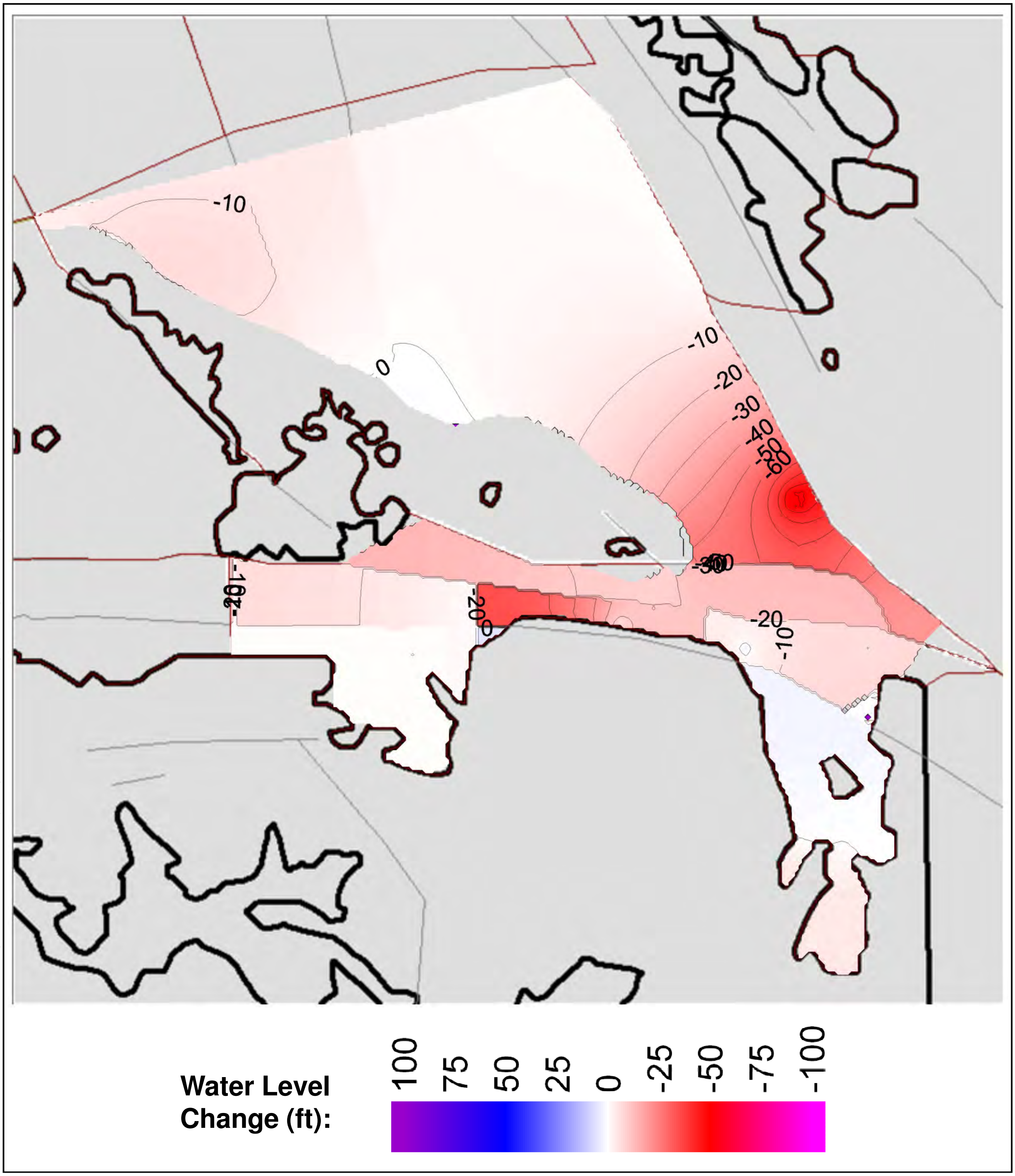
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Change in Water Levels from 2008 to 2033 for Scenario 5

K/J 0964003*00
March 2010

Figure 6-9



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-10.pptx

Contour Interval = 10 feet.

Kennedy/Jenks Consultants

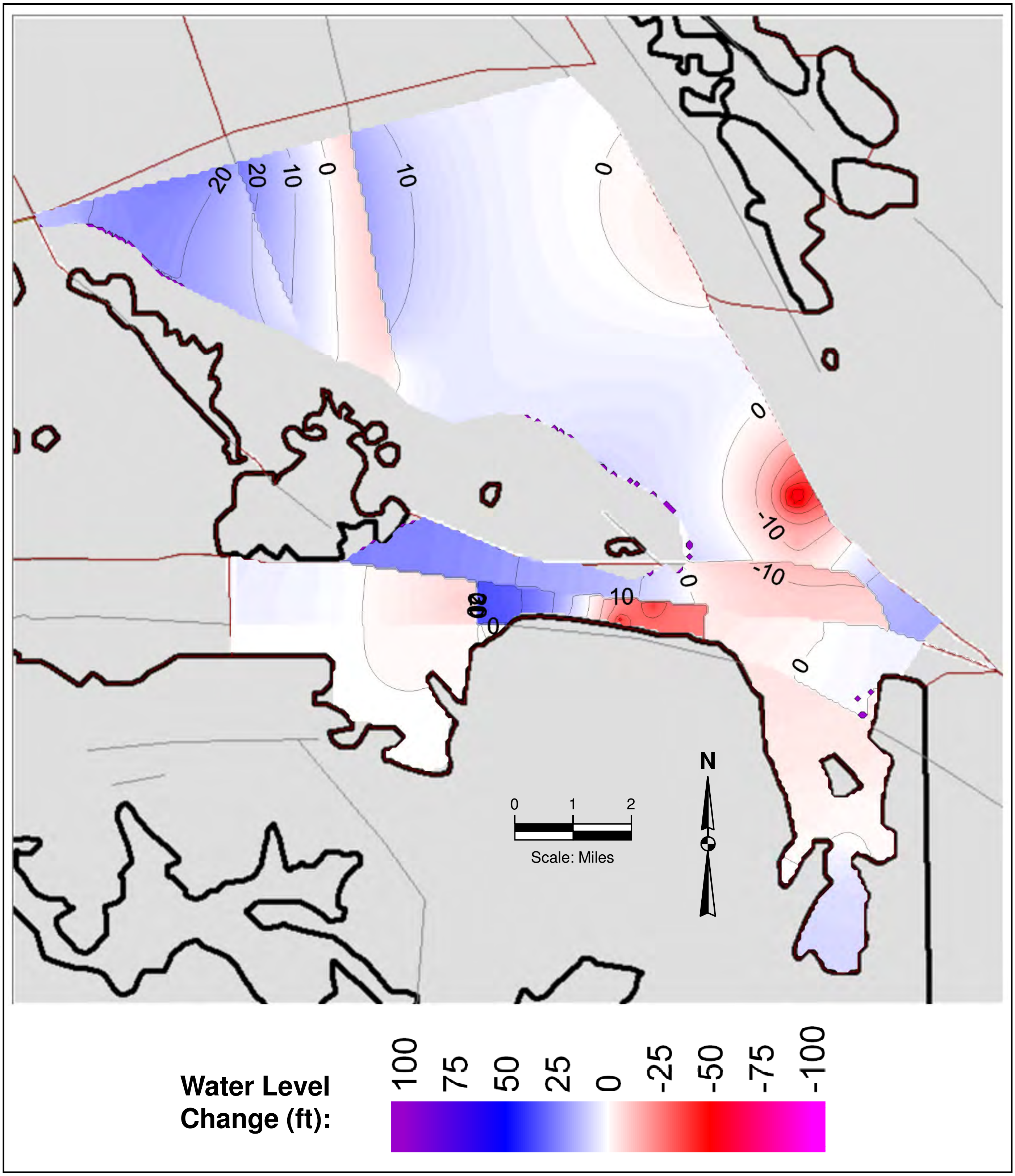
Twentynine Palms
San Bernardino County, California

Change in Water Levels from 2008 to 2033 for Scenario 6

K/J 0964003*00
March 2010

Figure 6-10

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-11.pptx



Contour Interval = 10 feet.

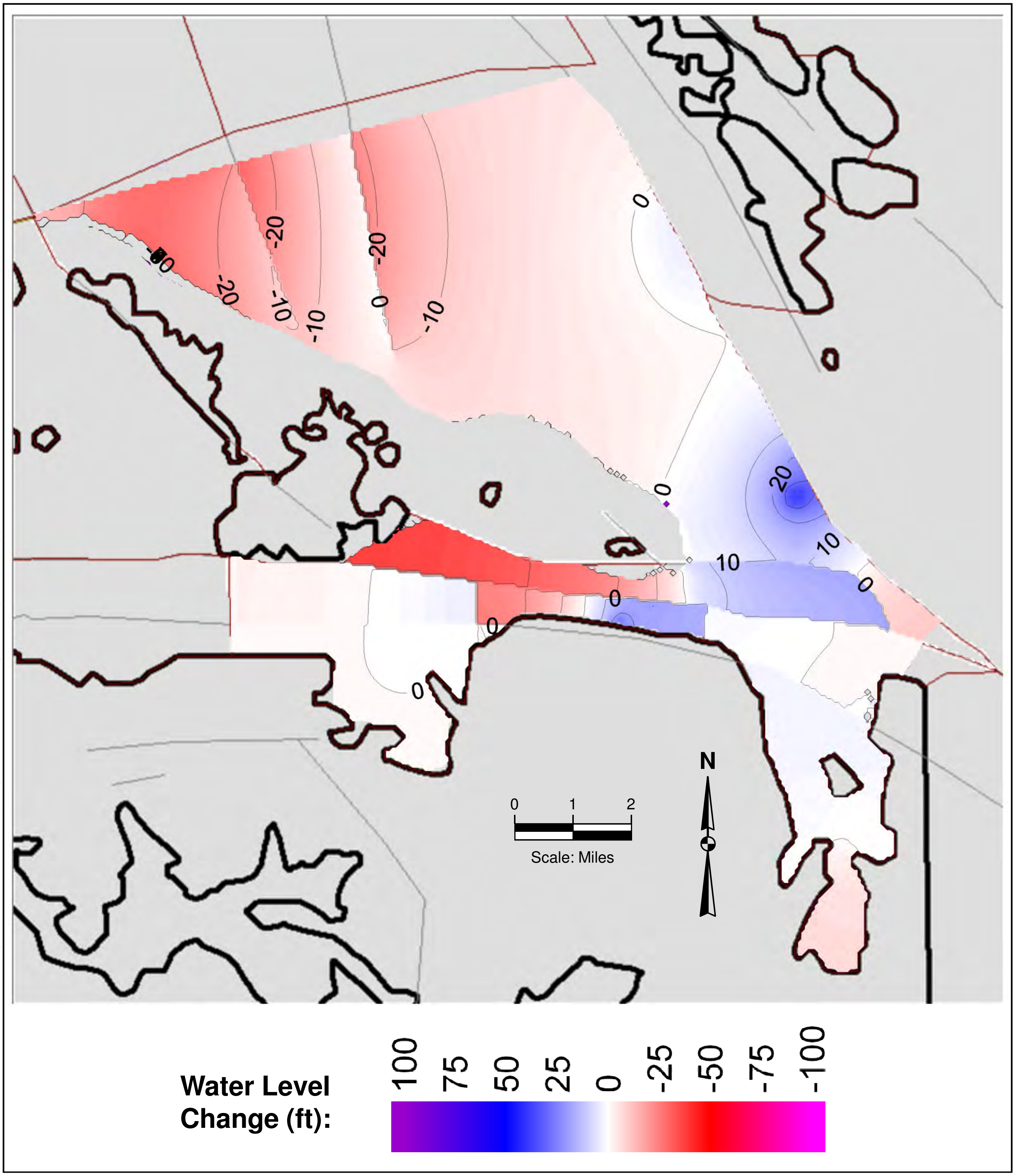
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Change in Water Levels in 2033 from Scenario 6 to Sensitivity Scenario 7A

K/J 0964003*00
March 2010

Figure 6-11



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-12.pptx

Contour Interval = 10 feet.

Kennedy/Jenks Consultants

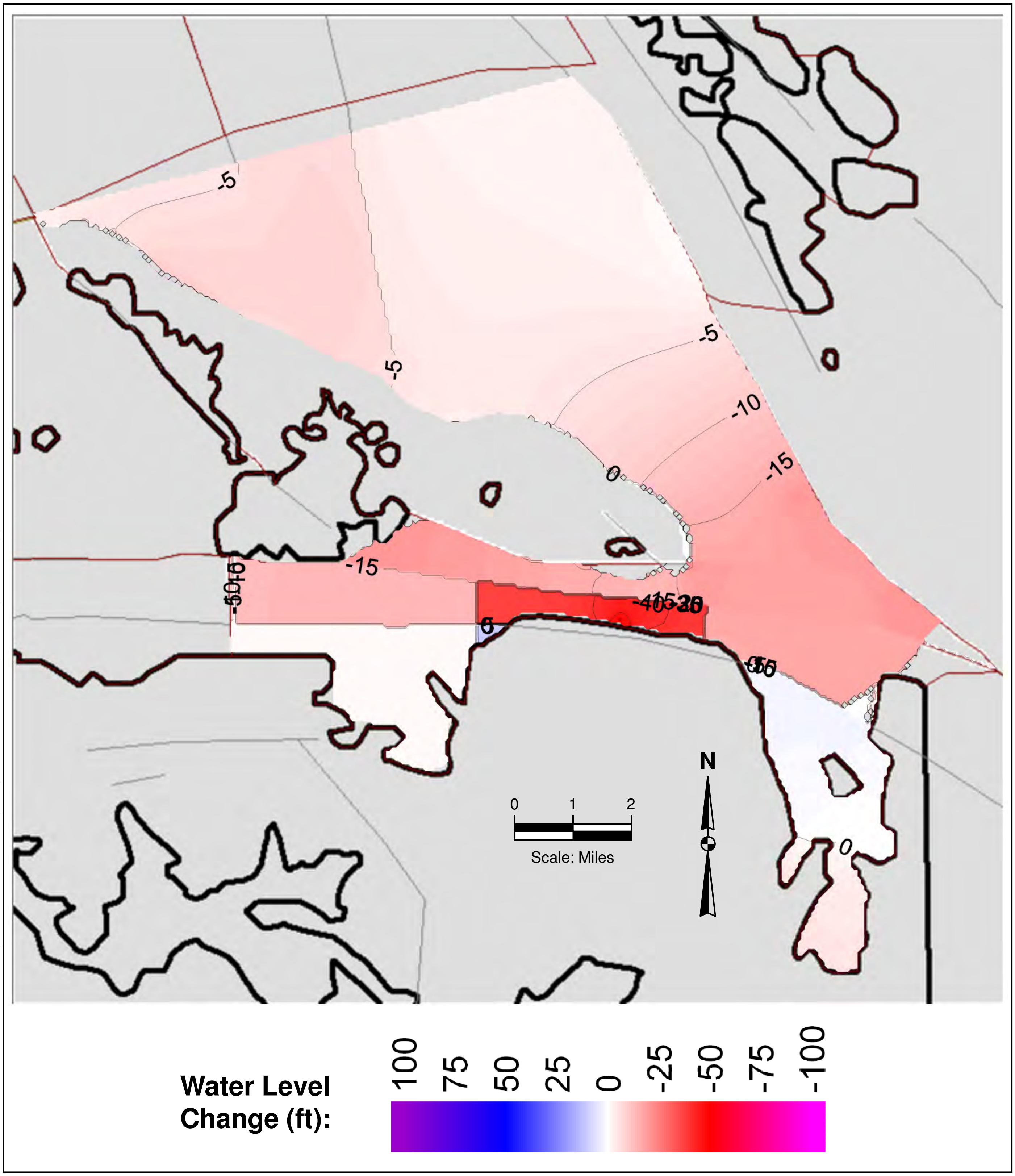
Twentynine Palms
San Bernardino County, California

Change in Water Levels in 2033 from Scenario 6 to Sensitivity Scenario 7B

K/J 0964003*00
March 2010

Figure 6-12

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-13.pptx



Contour Interval = 5 feet.

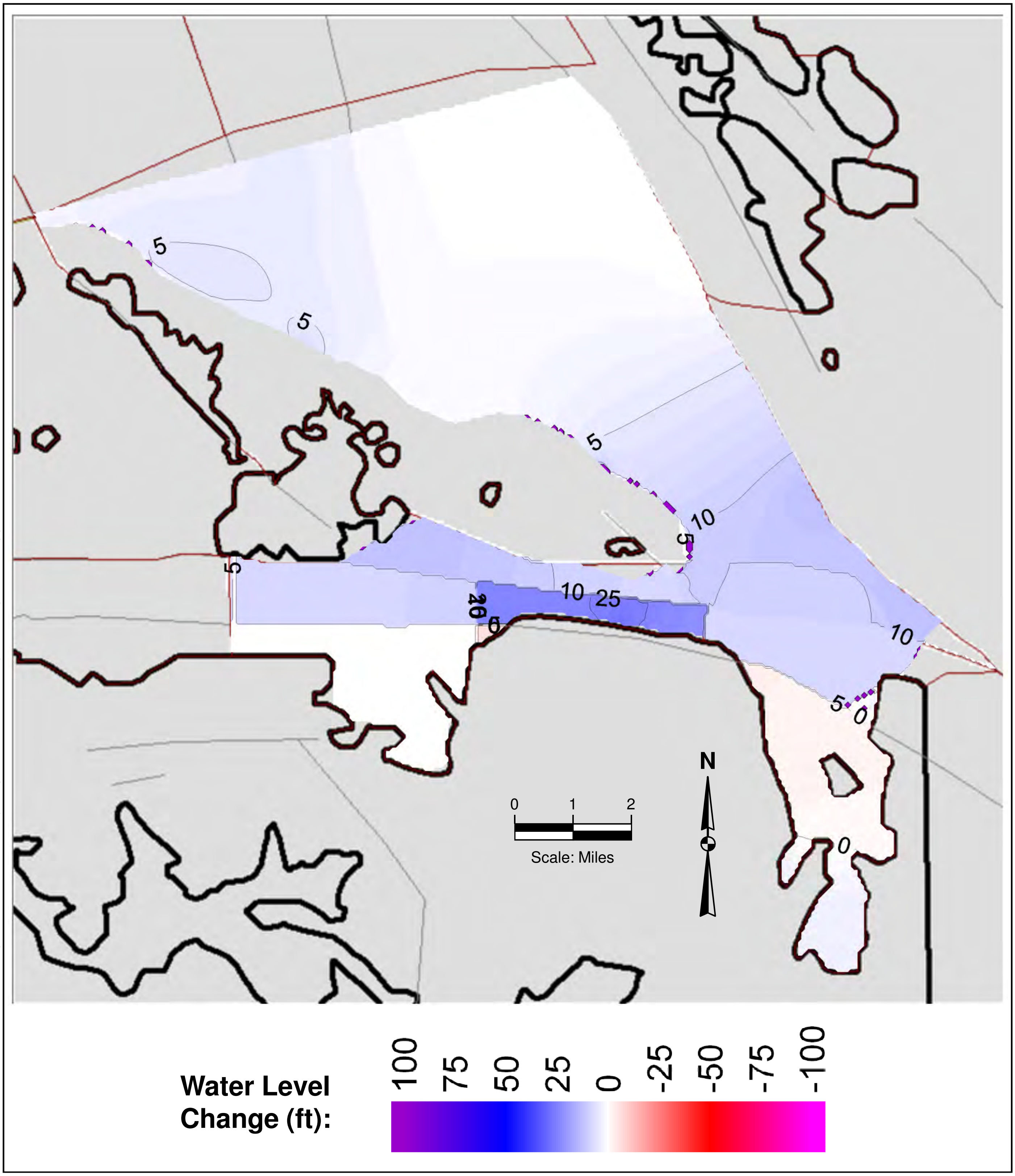
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Change in Water Levels in 2033 from Scenario 6 to Sensitivity Scenario 8A

K/J 0964003*00
March 2010

Figure 6-13



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-14.pptx

Contour Interval = 5 feet.

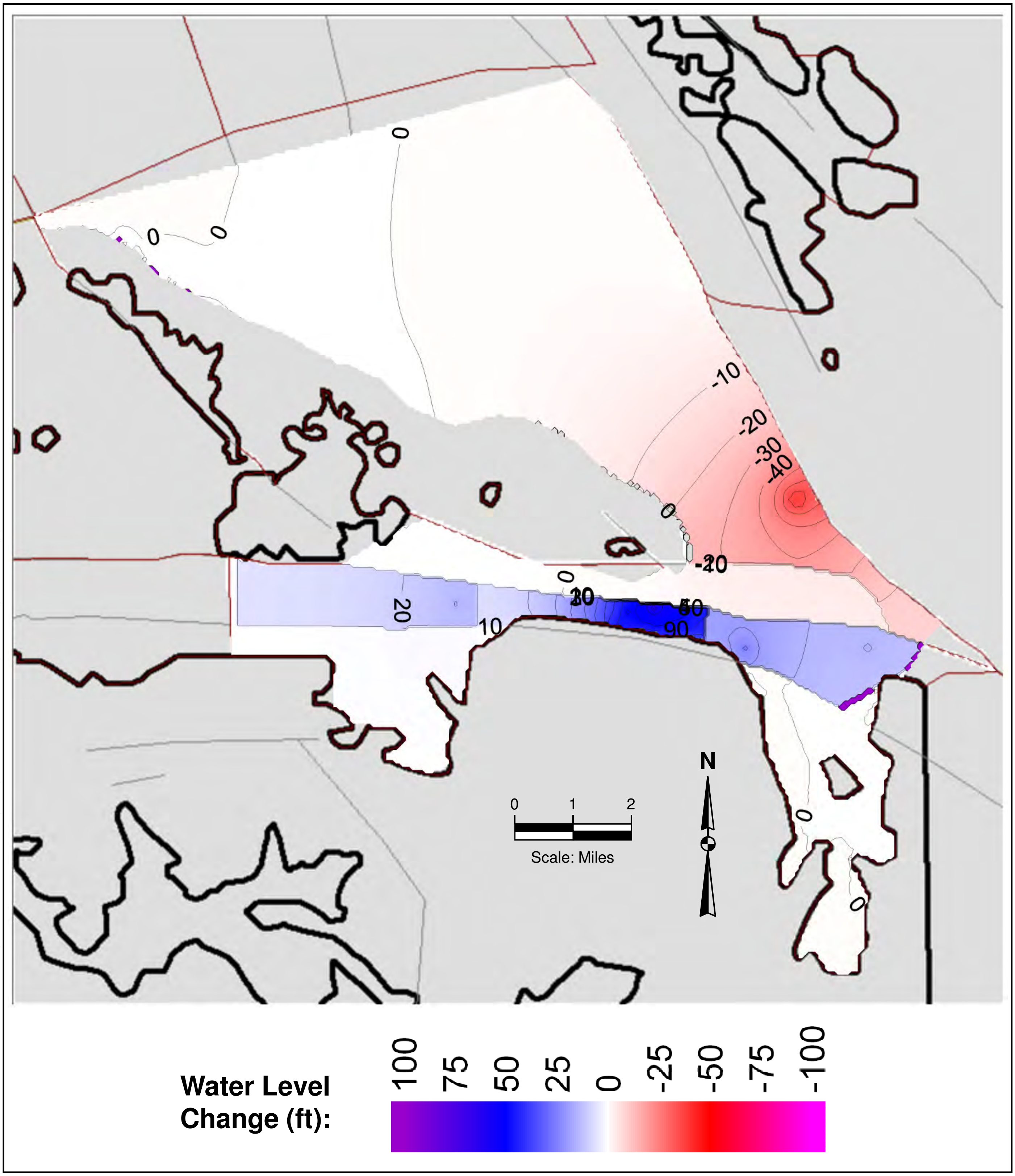
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Change in Water Levels in 2033 from Scenario 6 to Sensitivity Scenario 8B

K/J 0964003*00
Match 2010

Figure 6-14



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-15.pptx

Contour Interval = 10 feet.

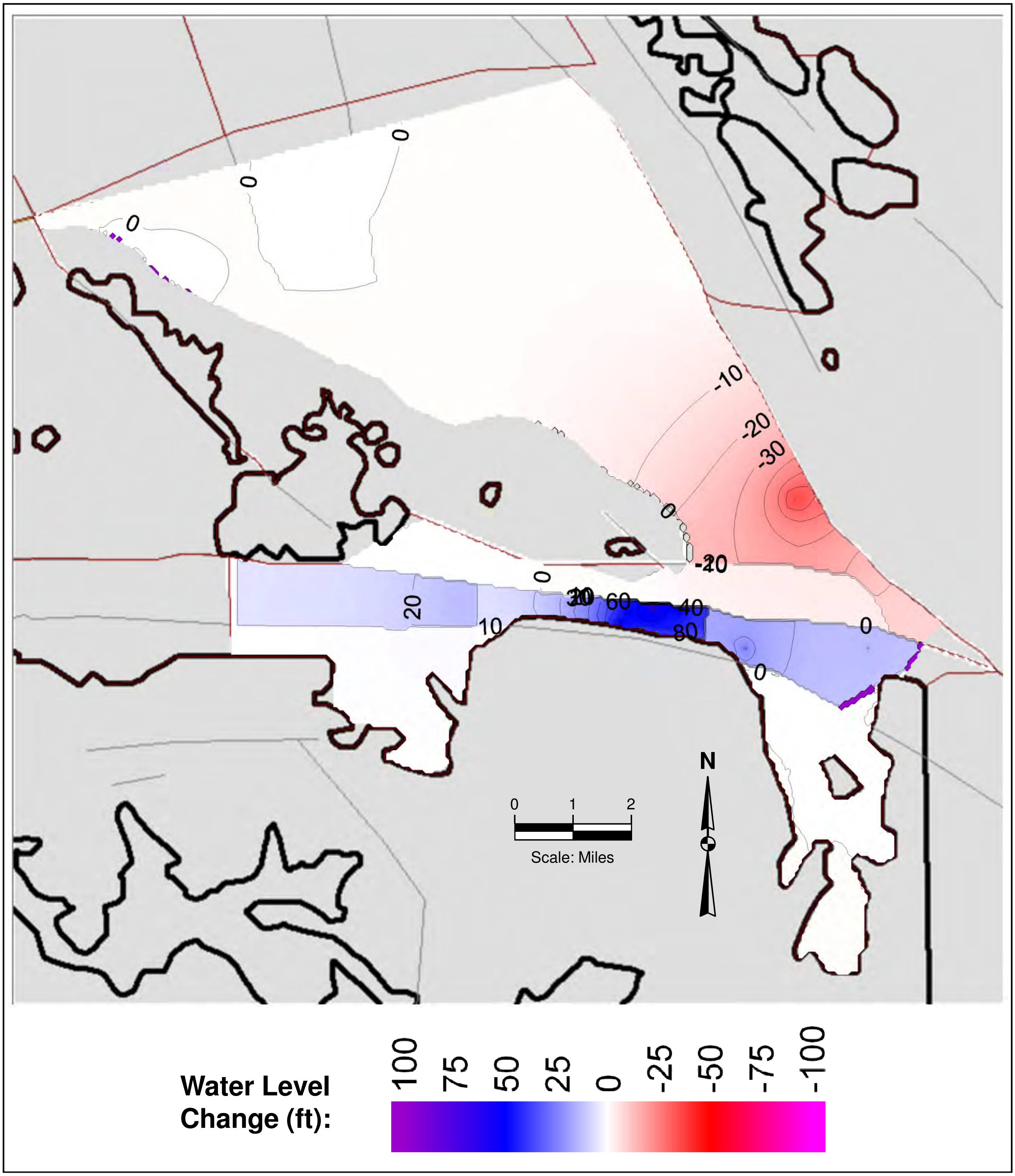
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Difference in 2033 Water Levels Between Scenarios 1 and 3

K/J 0964003*00
March 2010

Figure 6-15



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-16.pptx

Contour Interval = 10 feet.

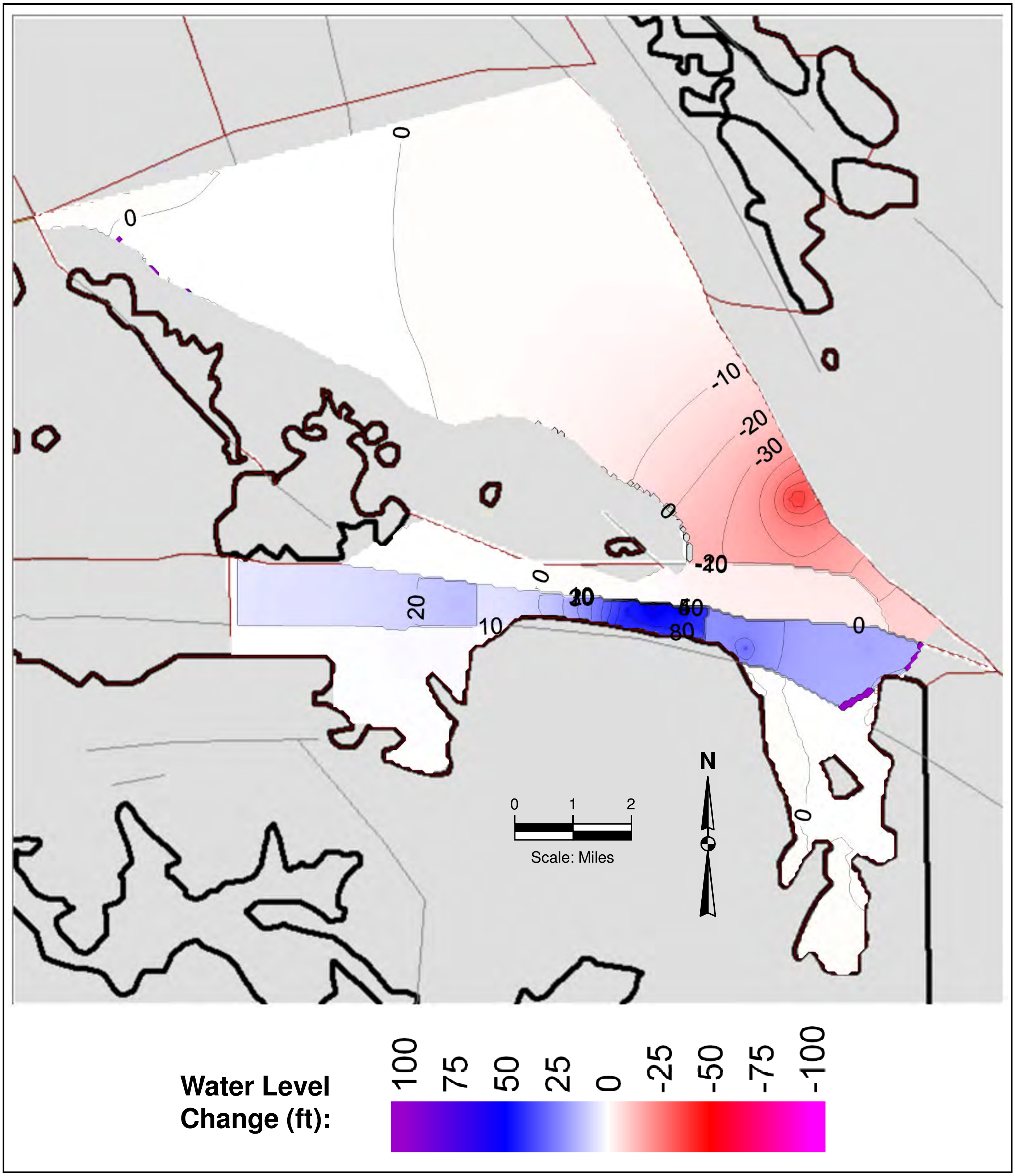
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Difference in 2033 Water Levels Between Scenarios 2 and 4

K/J 0964003*00
March 2010

Figure 6-16



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-17.pptx

Contour Interval = 10 feet.

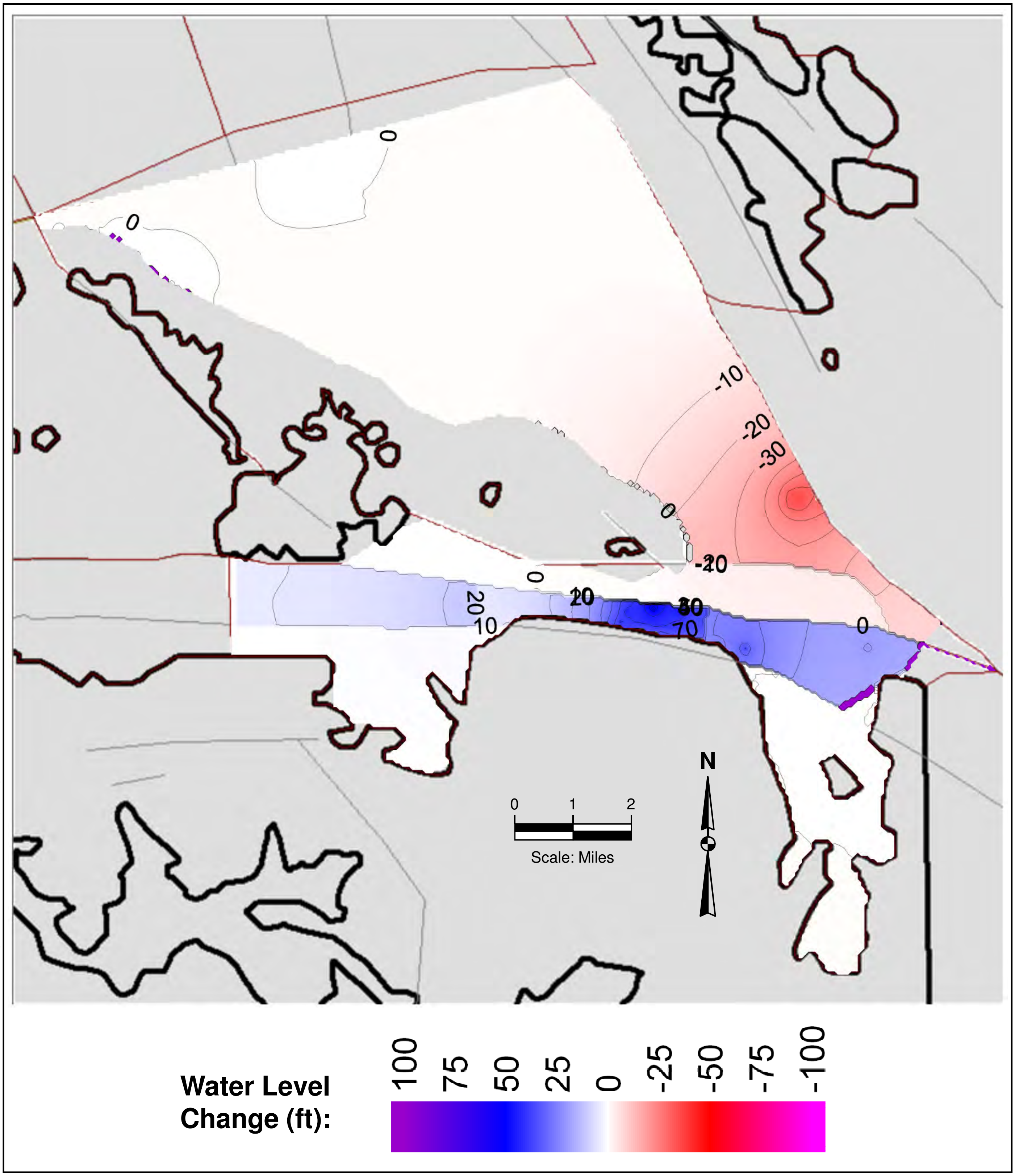
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Difference in 2033 Water Levels Between Scenarios 1 and 5

K/J 0964003*00
March 2010

Figure 6-17



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\Figure6-18.pptx

Contour Interval = 10 feet.

Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Difference in 2033 Water Levels Between Scenarios 2 and 6

K/J 0964003*00
March 2010

Figure 6-18

Appendix A: Geology and Hydrogeology

Appendix A: Geology and Hydrogeology

Appendix A provides additional description and data on the geologic units and groundwater aquifers in the study area.

A.1 Geologic Data

The geological conceptual model for the study area was developed from four sources of information. Well logs from nineteen TPWD production wells formed the basis for further analysis. The hard data provided by these well logs was supplemented with soft data derived from geologic maps, gravity surveys, and previous groundwater modeling studies conducted in adjacent basins.

A.1.1 Well Logs

Nineteen well logs from TPWD production wells were provided by the TPWD, with drilling dates ranging from 1956 to 1993. Several different drilling companies performed the work, each with their own style for completing the well logs. Nine of these well logs were sufficiently detailed for use in the development of geologic cross-sections.

The well logs obtained from TPWD show that various proportions of gravel, sand, silt, and clay are present at each location, but quantitative descriptions of particle-size distribution and geophysical logs were not available. However, Riley and Worts (1952) noted that medium to coarse sand with intermixed gravel probably makes up about half the total alluvium in the Twentynine Palms Basin.

Most of the wells in the present study area were completed in the alluvium, although two wells appear to have reached bedrock. The well log for TPWD-15 (in the southern Indian Cove Subbasin) describes a color change and a significant reduction of the penetration rate between 317 and 352 feet of depth. Furthermore, it is noted on the log that the material encountered appeared to be granite (black and white chips). The well log for TPWD-16 (in the western Eastern Subbasin) appears to describe a reduction in penetration rate at around 310 feet of depth. It is noted on the log that the on-site geologist determined bedrock had been penetrated.

It should be pointed out that both TPWD-15 (total depth 352 feet) and TPWD-16 (total depth 325 feet) are relatively shallow when compared the alluvial thicknesses reported by Riley and Worts (1952, 1953) and others. In contrast, TPWD-TP1 was drilled to a total depth of 1,250 feet in the eastern Mesquite Lake Subbasin, but did not encounter bedrock.

A.1.2 Gravity Surveys

The U.S. Geological Survey conducted two gravity surveys in the area to estimate depth to bedrock and sediment thickness (Moyle, 1984; Roberts et al., 2002). The earlier study (Moyle, 1984) was focused on the area surrounding the Twentynine Palms Marine Corps Base and had a fairly sparse network of points. The sediment thickness interpretations from Moyle (1984) terminate near the northern portion of the present study area.

The area encompassed by Roberts et al. (2002) is larger than Moyle (1984) and includes the present study area. Furthermore, Roberts et al. (2002) used a significantly denser network of points than Moyle (1984), and known bedrock depths were used explicitly in their numerical inversion to constrain the solution. Moreover, the Roberts et al. (2002) study is fully three-dimensional, which provides significantly more detail than does Moyle (1984) in the interpretations of sediment thickness and geometry of the basement rock. While both the Moyle (1984) and Roberts et al. (2002) maps were considered when interpreting depth to bedrock and sediment thickness for the present study, preference was given to the results and conclusions of Roberts et al. (2002).

A.2 Previous Hydrogeological Studies

Previous work in the general area includes two U.S. Geological Survey studies that included groundwater modeling components. Londquist and Martin (1991) conducted groundwater flow simulations in the Surprise Spring Subbasin, which is located immediately north of the study area. In their study, Londquist and Martin (1991) described much of the surface geology and near-surface primary water-bearing units as being Late Tertiary alluvial deposits, following the work of Riley and Worts (1953). The primary water-bearing material was divided into upper and lower Late Tertiary units that together are approximately 1,850 feet thick. Quaternary deposits were reported to be 50 to 150 feet thick, of limited extent, and generally above the water table.

Nishikawa et al. (2004) conducted a fairly comprehensive study of the hydrogeology in the Joshua Tree area, including groundwater flow simulations of the Copper Mountain and Joshua Tree basins. In the Nishikawa et al. study, the near-surface primary water-bearing units were considered to be Quaternary, based on the work of Bedford and Miller (1997). The Quaternary primary water-bearing units were divided into an upper, less indurated unit and an underlying, more indurated unit. The two units together have a maximum thickness of approximately 1,000 feet. Quaternary sedimentary deposits beneath active washes are described as being 0 to 100 feet thick. Tertiary sedimentary deposits were reported to be restricted to much deeper levels and considered to be of minor importance in terms of their water-transmitting properties, although a geologic map in Nishikawa et al. (2004) indicates that the undifferentiated surface deposits throughout their study area were given an age of Quaternary/Pliocene. The deeper, less-permeable Tertiary sediments were reported by Nishikawa et al. to reach a maximum thickness of approximately 2,000 feet.

Numerous previous studies exist for the study area, mostly performed by the USGS. These studies stretch back as far as 1921, when Thompson (1921) included Twentynine Palms in his report on watering places in the Mohave Desert, mentioning the Oasis of Mara and other springs in the area. Thompson (1929) later produced a more complete assessment of the various hydrological features in the study area, including some speculation on the movement of groundwater through the basins and mentioning the importance of faults to the hydrologic system. These two reports mostly covered the area around what is now Highway 62, in the southern end of the study area.

The most important early study on the area was performed by the USGS in cooperation with the USN, which then controlled the military base in the basin, now operated by the U.S. Marine Corps (USMC) and called the MCAGCC. This study was published in two parts by Riley and Worts (1952, 1953). These researchers for the first time produced a comprehensive hydrogeological study of the area from the San Bernardino Mountains in the west to the Bullion Mountains in the east, and from the Oasis (or Pinto Mountain) Fault and Copper Mountain and related bedrock highs to the west in the south to Hidalgo (or Coffin) Mountain, the Mud Hills, Deadeye Mountain, and other bedrock highs in the north. This study covered the occurrence and extent of groundwater and surface water, as well as initial estimates of recharge and ET in the various basins within the study area. It also gave a first look at the subsurface through documentation and testing of USN supply and test wells throughout the Surprise Spring, Deadman, and Mesquite Lake Subbasins. This study also provided the first information on groundwater chemistry in the basins.

Troxell et al. (1954) performed a study on the hydrology of the San Bernardino Mountains, focusing on climatology. This report deals mostly with areas west of the study area, but does provide details on the general climatological setting of the study area itself.

In-depth analysis of the hydrology of the area lulled in the next several decades. Bader and Moyle (1958) studied wells and springs in the area of the Morongo Valley, in the southwestern part of the study area. From 1959 through 1965, short annual reports (Dutcher, 1960; Dyer, 1961; Weir, 1962a; Weir, 1962b; Johnston, 1963; Geissner, 1965; and Geissner and Robson, 1966) were produced detailing the groundwater conditions at the USMC base, including total pumping, groundwater chemistry, and changes in groundwater level. During this time, Riley and Bader (1961) produced a short report on the wells at the USMC base.

Weir and Bader (1963) performed a more extensive study on the geology and groundwater hydrology of Joshua Tree National Monument (now Joshua Tree National Park) bordering the southern end of the study area. At the end of the 1960’s, two geologic maps were produced: one by the California Division of Mines and Geology (Rogers, 1967), and the other for the USGS (Dibblee, 1968). These two maps are still important guides to the geology of the study area.

Lewis (1972) wrote an important report on the hydrology of the section of the study area west of Surprise Spring Fault, including estimates of recharge, pumping, and groundwater fluxes on a basin-by-basin basis. Schaefer (1978) wrote on the groundwater resources of the USMC base, summarizing the changes over the previous ten years since the annual series stopped. Freckleton (1982), in cooperation with the U.S. Bureau of Indian Affairs, performed a brief analysis of the groundwater hydrology of the 160-acre Twenty-Nine Palms Indian Reservation in the Eastern Subbasin. Koehler (1983) produced a short study on the groundwater hydrology of the northeastern part of the USMC base, which is on the other side of the Bullion Mountains from the study area.

The DWR produced a report in 1984 on the groundwater hydrology of the four basins in the TPWD area (the Indian Cove, Fortynine Palms, Eastern, and Mesquite Lake Subbasins), detailing groundwater production, changes in water levels, and especially the occurrence of fluoride in the area and its possible sources. This report was the first to look at the TPWD area in isolation from the rest of the basins in the study area.

Moyle (1984) performed a gravity survey, a tool to indicate depth to bedrock, in the northeastern part of the study area. Akers (1986) produced a short study on the hydrology of the western part of the USMC base, in the Surprise Spring and Deadman Lake Subbasins, quantifying the amount of water in storage in these basins. Londquist and Martin (1991) produced a follow-up report, discussing a numerical groundwater model that they created for just the Surprise Spring Subbasin, giving numbers for fluxes across the bounding faults and changes in storage due to pumping.

A series of three reports (Friedman, 1992; Smith, 1992; and Gleason, 1994) was written on the stable isotope chemistry of water in the general area of southeastern California, including some wells, springs, and precipitation in the study area.

Bisdorf (1993) presented the results of 52 Schlumberger soundings in the area of the MCAGCC, which are done to help determine depth to bedrock and geologic structure in an area. Hofstra (1994) studied the geochemistry of stream sediments in the MCAGCC area. Whitt and Jonker (1998, as cited in Nishikawa et al., 2004) provided an estimate of recharge to the area of the Joshua Tree Subbasin in the southwestern part of the study area.

Recently, Roberts et al. (2002) produced an updated gravity map of most of the study area, from the eastern San Bernardino Mountains in the west to the Bullion Mountains in the east, and covering almost all of the study area from south to north. Finally, Nishikawa et al. (2003, 2004) performed a very extensive study on the hydrology of the Warren, Joshua Tree, and Copper Mountain Subbasins in the southwestern part of the study area. This study included a geochemical study of nitrate concentrations, and also a hydrogeological analysis of the area, including a numerical groundwater model. Importantly, the eastern boundary of this groundwater model abuts the western boundary of the Indian Cove Subbasin, providing information on the inputs into the TPWD from the west.

A.3 Bedrock Hydrogeology

Bedrock in the study area is mostly present at the surface along the basin margins, in the mountain ranges that bound the alluvial basins. Minor outcrops exist in the midst of some basins (e.g. the Mesquite Lake Subbasin). The bedrock in the area can be divided into pre-Tertiary and Tertiary units (the Cretaceous-Tertiary boundary is set at about 65.5 million years ago); most of the bedrock is pre-Tertiary. It can be assumed that the unseen bedrock, that which lies below the alluvial sediments, is made up of the same pre-Tertiary units as make up the mountain ranges. This section describes the geology and hydrogeology of the bedrock in the study area.

The San Bernardino and Little San Bernardino Mountains to the west are made up mostly of Mesozoic granite (Figure 2-4) and Precambrian igneous and metamorphic rocks, with significant Mesozoic marine rocks in the central parts of the range (Ludington et al., 2005). The mountain ranges that bound the study area to the north and east are dominated by Mesozoic granite, accompanied by Mesozoic gabbro (gb) in the Deadeye Mountain area to the northwest, various Tertiary to Quaternary volcanics (Tvp, Tv, and Qv) in the northern Bullion Mountains to the northeast, and some undifferentiated pre-Tertiary granitic, metamorphic, metasedimentary, and metavolcanic rocks (m and gr-m) in the Sheep Hole Mountains on the eastern boundary.

Because the bedrock in the study area is almost all crystalline (i.e. not clastic), the bedrock matrix is basically non-transmissive of groundwater. Riley and Worts (1952, 1953) note that water is present in joints, fractures, and highly weathered areas. However, these storage areas generally do not transmit quantities of water that could support any kind of development. Londquist and Martin (1991) characterized the pre-Tertiary bedrock as “nearly impermeable,” while Nishikawa et al. (2004) consider the bedrock to have low permeability and Riley and Worts (1952) note that the units are basically non-water bearing. Fracture zones are most important in the mountains, where they allow for recharge of precipitation and surface runoff into the mountain as mountain block recharge (Kennedy/Jenks, 2001, 2008). Because they do not transmit much water, the hydrologic properties of the pre-Tertiary bedrock are unknown.

A.4 Alluvial Hydrogeology

The basins in the study area are filled with alluvium from the bedrock surface to the land surface. Alluvium naturally contains significant pore space, and so can transmit groundwater fairly efficiently; these deposits form all of the important aquifers in the area, transmitting to the wells the water that supports stakeholders in the basins. This section details the geology and hydrogeology of the various alluvial units that exist in the study area, and provides information on the known aquifer properties.

A.4.1 Introduction

The total thickness of sediments in the basins is highly variable although these thicknesses are speculative due to the murky knowledge that currently exists on the depth to bedrock. Sediment thickness in the northern half of the Mesquite Lake Subbasin ranges from 0 to 3,800 feet (Akers, 1986); the southern half is not mapped. The thickness of the sediments in the Indian Cove, Fortynine Palms, and Eastern Subbasins are not shown in previous reports, but based on the gravity map of Roberts et al. (2002), the bedrock is likely quite a bit shallower in these basins than in the Joshua Tree Subbasin. In these basins, the alluvial sediments pinch out near the bounding mountain ranges, and reach unknown thicknesses (up to 2,500 feet) in the graben between the Oasis and Pinto Faults.

In the surrounding basins, Riley and Worts (1953) reported a thickness of at least 2,500 feet of uplifted sediments in the area of Mud Hills, on the northern boundary of the basin, dipping downward toward Deadman Lake and diminishing in thickness toward the west. Akers (1986) noted a maximum thickness of sediments of 10,500 feet in the Deadman Dry Lake area, based on the results of gravity surveys presented in Moyle (1984). A later gravity model by Roberts et al. (2002) indicated that the sediments may actually be more than 15,000 feet thick in this area. This is by far the greatest thickness of sediments in the study area. In the Surprise Spring Subbasin to the west, sediment thickness is much less, ranging from 0 to 2,000 feet (Akers, 1986). The basins in the northwestern part of the study area (the Pioneertown, Pipes, Reche, and Giant Rock Subbasins) do not have published sediment thicknesses, but the alluvium is likely thinner than those found in the Surprise Spring Subbasin. Nishikawa et al. (2004) indicate that the depth to bedrock may be 2,000 feet or more in the Copper Mountain Subbasin and 4,500 feet or more in the Joshua Tree Subbasin.

A.4.2 Differentiation of the Alluvial Units

Few analyses exist of the characteristics of the alluvial sediments in bulk. Riley and Worts (1952) described the makeup of the alluvial sediments in the northern part of the study area in bulk as being made up of about 55% massive beds of moderately to well sorted fine to medium sand, 30% beds of poorly sorted medium to very coarse sand with lenses of pebble- to large cobble-sized gravel, 10% very fine, silty sand, and 5% silty, sandy clay. This and the other descriptions of the stratigraphy of sediments are based on a tilted and exposed section located in the area of the Mud Hills, along the northern boundary of the Deadman Lake Subbasin (Riley and Worts, 1952).

In the study area outside the graben between the Oasis and Pinto Faults, the sediment thickness is likely less than in the graben, so the alluvial units may not be as well-defined in these other areas. In fact, other than the Nishikawa et al. (2004) study, almost all other studies defined only two thick alluvial units (i.e. Riley and Worts, 1953; Londquist and Martin, 1991). This difference may result from the combining of the two Quaternary units of Nishikawa et al. (2004) into a single Quaternary unit in these other studies, although this is not known for sure. Riley and Worts (1952) indicate that there is a quite sudden change between their two Tertiary units, just as indicated by the hydrologic properties of the corresponding Tertiary and lower Quaternary units of Nishikawa et al. (2004).

The vertical variation of the alluvial units has led previous investigators to divide the sediments into several specific ages. However, there has been some difference between previous reports regarding the age of these various units. For this discussion of the sediments and aquifers, the convention of Nishikawa et al. (2004) was followed.

The Nishikawa et al. (2004) convention was applied to other areas, so that, for example, the lower Tertiary unit of Londquist and Martin (1991) becomes the Tertiary unit in this report, while the Londquist and Martin (1991) upper Tertiary unit is described here as the lower Quaternary unit. The Quaternary alluvium mentioned in Riley and Worts (1952, 1953) is described here with the upper Quaternary unit, although, as noted above, the upper Quaternary unit of Nishikawa et al. (2004) may simply be part of the upper Tertiary unit of previous investigators.

A.4.3 Tertiary Sediments

Tertiary sediments represent the lowermost alluvial unit in the basin, forming in the early period of extension in the study area. These deposits directly overlie the pre-Tertiary bedrock, and are in turn overlain by the lower Quaternary unit. These sediments are made up somewhat consolidated fanglomerates containing clasts of granite and gneiss (Nishikawa et al., 2004). This unit is more poorly sorted and more massive (i.e. less bedding) than are the Quaternary units above it, with many solid rock fragments and interstitial clay (Londquist and Martin, 1991). The sediments are also more consolidated than are the upper units (Nishikawa et al., 2004). Riley and Worts (1953) classify the sediments of this unit as clayey sand.

In addition to the sediments deposited during the Tertiary in this study area, Nishikawa et al. (2004) note some Tertiary volcanic in this part of the aquifer in the Joshua Tree and Copper Mountain Subbasins. These units are presumably similar to the volcanic outcrops described in Section A.3.

The thickness of the Tertiary sediments is more variable than for the other units. As the first alluvial unit was laid down in the study area, this unit filled the deepest bedrock lows, reducing the variability of the land surface topography in the basins. Nishikawa et al. (2004) state that the maximum thickness of Tertiary sediments in the Joshua Tree Subbasin is about 2,000 feet, and nearly 600 feet in the Copper Mountain Subbasin. In the TPWD basins, the Tertiary sediments reach a thickness of about 400 feet in the westernmost Indian Cove Subbasin, and about

300 feet in the easternmost part of the Mesquite Lake Subbasin. Further north, the Tertiary sediments attain a thickness of at least 1,560 feet in the area of the Mud Hills (Riley and Worts, 1953). Londquist and Martin (1991) indicate a maximum thickness of about 1,000 feet for this unit in the Surprise Spring Subbasin. The thickness of this unit is unknown in the other basins in the study area.

Due to the diagenetic alteration of these sediments likely due to the presence of interstitial clay, they are relatively impermeable to water relative to the upper alluvial units. In fact, Londquist and Martin (1991) state that the Quaternary sediments above this Tertiary unit can be considered to be the only water-bearing unit in the Surprise Spring basin, and Nishikawa et al. (2004) indicate that the Tertiary alluvium likely provides little water, even to wells that tap it directly.

According to Londquist and Martin (1991), only one well in the Surprise Spring area is perforated in this lower unit. Nishikawa et al. (2004) show no wells completed in the Tertiary alluvium. Only one TPWD well (TPWD-TP-1) is perforated in this unit. Because of this paucity of development of this unit, very few data are available on the hydrologic properties of this unit.

For the most part, the thickness of this unit is likely the same as the saturated thickness, as the water table does not dip below the top of this unit, although Nishikawa et al. (2004) state that the maximum saturated thickness is about 1,500 feet, 500 feet less than the maximum sediment thickness. Londquist and Martin (1991) and Nishikawa et al. (2004) both state that this unit is a confined aquifer.

The hydraulic conductivity, K, of this unit was reported as 0.5 ft/d (Nishikawa et al., 2004) to 1 ft/d (Londquist and Martin, 1991). Nishikawa et al. (2004) also provided an estimate of 750 ft^2/d for the transmissivity (T) of the aquifer. These estimates were based on specific capacity derived from pumping tests on wells within the basin, or in the adjacent Warren Valley in the case of Nishikawa et al. (2004). Nishikawa et al. (2004) and Londquist and Martin (1991) both provide an estimate of 1×10^{-6} ft^{-1} for the specific storage (S_s) of this unit; Londquist and Martin (1991) further state that the specific yield (S_y) of these sediments would be 0.05 if unconfined.

A.4.4 Quaternary Alluvium

The Quaternary alluvium, which is divided into two separate units, provides the bulk of the water discharged by wells in the study area. Its thickness varies from zero along the basin edges to maxima of about 730 feet in the Mud Hills area (Riley and Worts, 1953), about 700 feet in the Surprise Spring Subbasin (Londquist and Martin, 1991), more than 1,000 feet near the center of the Joshua Tree Subbasin (Nishikawa et al., 2004), and about 1,000 feet in the TPWD basins. These units are thickest in the downdropped graben between the Oasis and Pinto Faults.

On the whole, these deposits are coarse, poorly sorted sand and gravel alluvial fan deposits that interfinger with finer, silt- and clay-dominated lenses and streambed deposits (Kennedy/Jenks, 2001, 2008; Nishikawa et al., 2004). The alluvial fan deposits are dominated by sand, and are coarsest and most heterogeneous near the mountain front, becoming finer and more homogeneous further away (Kennedy/Jenks, 2001, 2008). In the upland areas, soils are thin and medium- to coarse-grained, with a high percentage of sand, and bedrock outcrops in many places (Nishikawa et al., 2004). The Quaternary deposits are most permeable in the active washes (Nishikawa et al., 2004), where sediments are not only coarse, but also well-sorted. These streambed deposits vary from 0 to 100 feet in thickness, and are located above the water table (Nishikawa et al., 2004), indicating that these deposits are not important to the movement of groundwater (although they may be critical locations for recharge to the water table).

The Quaternary sediments are divided into three units, a lower Quaternary Alluvium (the "middle aquifer" of Nishikawa et al., 2004), an upper Quaternary Alluvium (the "upper aquifer"), and Quaternary Playa Deposits that exist in the areas of the several dry lakes of the study area. In this section, the upper Tertiary unit of Riley and Worts (1952, 1953) and other studies will be considered to be equal to the lower Quaternary unit, while the thin Quaternary alluvium of these earlier studies will be considered analogous to the upper Quaternary unit here.

A.4.4.1 Lower Quaternary Alluvium

The lower of the two Quaternary alluvial units is made up mostly of mainly sand, silt, and clay, with some few gravel layers interspersed, and is less indurated than the Tertiary sediments, but still more indurated than the upper Quaternary deposits (Nishikawa et al., 2004). Riley and Worts (1953) give a composition of about 60% well-sorted coarse sand layers and 40% finer-grained layers of fine sand to clay in the Mud Hills area. The composition of this layer is not described in the TPWD basins, although a zone of low specific yield described in DWR (1984) may correspond to this layer. The geologic map of Rogers (1967) labels this unit as Qc (lumped in with Q on Figure 2-4), and indicates that somewhere on the order of 75% of the basin floor is covered by this unit as no upper Quaternary alluvium is present; in these areas, this unit is the only important water-bearing unit.

The thickness of this layer varies from about 1,000 feet in the Mud Hills area (Riley and Worts, 1953), to about 450 feet in the Joshua Tree Subbasin (Nishikawa et al., 2004). In the TPWD basins, the thickness of this layer is assumed to be about 400 feet; this correlates both with the estimates of Nishikawa et al. (2004) to the west, and the indication of a 400-foot thick low specific yield zone described in DWR (1984).

The values of T estimated by Londquist and Martin (1991) for this unit varied from 3,930 to 36,360 ft^2/d, based on specific capacity derived from pumping tests in production wells in the Surprise Spring Subbasin. These values correspond to K values ranging from 11.2 to 60.6 ft/d. Nishikawa et al. (2004) estimate T values between 38,000 and 98,000 ft^2/d in the Joshua Tree and Copper Mountain Subbasins. S_y values for this unit have been variously reported as 0.12 to 0.13 in the Deadman Lake Subbasin (Riley and Worts, 1953) and 0.12 to 0.14 in the Surprise Spring Subbasin (Riley and Worts, 1953; Akers, 1986; Londquist and Martin, 1991) based on well logs. S_s in the Joshua Tree and Copper Mountain Subbasins was reported as 1×10^{-6} ft^{-1} (Nishikawa et al., 2004).

A.4.4.2 Upper Quaternary Alluvium

Where present, the upper Quaternary unit is the uppermost alluvial unit, except for the few locations where it is overlain by playa deposits. This unit was deposited as alluvial fans near the mountain fronts, broad alluvial plains on the basin floor, and fluvial deposits along the ephemeral washes in the basin (Riley and Worts, 1952). This unit is made up mainly of poorly sorted sands and gravels, with interbedded finer-grained sediments, except in active washes, where materials are more uniformly coarse (Nishikawa et al., 2004). These sediments are much more permeable than are the underlying Tertiary sediments (Nishikawa et al., 2004). These deposits tend to be fairly coarse-grained, although that varies from place to place.

Alluvial fans are composed of poorly sorted, angular clasts of local provenance, with sizes ranging from boulders to clay. Within the basin, fans are present along the northern boundary of the Little San Bernardino Mountains, along the western boundary of the Bullion Mountains, and along the eastern boundary of the San Bernardino Mountains. Minor deposits of Quaternary alluvium surround most of the other bedrock outcrops in the basin, aside from the Zeitz Mountains and the Bartlett Mountains. Alluvial plains exist in the northwestern corner of the basin, stretching from this area northwest into the next basin.

Fluvial deposits fill many of the beds of the ephemeral streams in the basin. There are also fairly extensive deposits of Quaternary alluvium that may be fluvial in origin near some of the dry lakes in the area, for example at Deadman Lake and Emerson Dry Lake (where Pipes Wash empties; Riley and Worts, 1952). These deposits are generally more coarse near the mountain front, becoming finer further out into the basin, although the exact progression depends largely upon the frequency and amount of flow in the individual washes; those that flow more regularly and reach farther into the basin likely carry sands further from the mountain source areas than those relatively minor washes that do not extend far into the basin.

As is typical of very arid areas, this basin also has some areas of dune sand (Qs on Figure 2-4) that are of relatively minor importance. The largest is directly south of Hidalgo Mountain, with other large expanses of dune sands around Deadman Lake and Mesquite Lake.

In addition to the horizontal variation noted above, there is some vertical variability in the aquifer properties. DWR (1984) notes a zone of low specific yield within the basins south of the Oasis Fault in the TPWD area, likely corresponding to a zone of finer deposits. This unit varies in thickness from 20 to 40 feet in the Indian Cove Subbasin and 10 to 20 feet in the Fortynine Palms and Eastern Subbasins, and its top ranges from 220 to 350 feet below land surface from east to west across the area.

Upper Quaternary alluvium units are generally thin throughout most of the basin north of the Oasis Fault. The descriptions of the Quaternary unit by Nishikawa et al. (2004) are carried into the TPWD basins, including the Mesquite Lake Subbasin. Therefore, the Quaternary alluvium is described here as being both very thin (Riley and Worts, 1953) to quite thick (Nishikawa et al., 2004).

These deposits are generally 50 to 150 feet thick north of the Oasis Fault; in the Mesquite Lake Subbasin, the Quaternary alluvium is at least 50 feet thick in the lowest parts of the basin closest to Mesquite Dry Lake; however, they rapidly thinning west of the playa (Riley and Worts, 1953). Some parts of the Copper Mountain Subbasin have Quaternary alluvium in excess of 700 feet thick (Nishikawa et al., 2004). The upper Quaternary unit is as much as 1,000 feet thick in the Joshua Tree Subbasin (Nishikawa et al., 2004), although it is on the order of about 500 feet throughout the TPWD basins.

The saturated thickness (*b*) of the upper unit varies from place to place. Nishikawa et al. (2004) report values of *b* of 175 feet in the Copper Mountain Subbasin and up to 300 feet in the Joshua

Tree Subbasin. In the Indian Cove Subbasin, the saturated thickness varies from about 300 to 500 feet. In the Fortynine Palms *b* is about 170 feet, while in the Eastern Subbasin, it is on the order of 230 feet.

Most of the production wells in the Joshua Tree and Copper Mountain Subbasins are screened in the upper aquifer, and based on specific capacity and pumping tests from these wells, the transmissivity (*T*) varies from 580 to 55,580 ft^2/d, with a mean of 6,183 ft^2/d (Nishikawa et al., 2004). Based on tests of the TPWD wells in these basins, the specific capacity varies from 2.4 to 124 gallons per minute per foot (gpm/ft), although the basin in which each value was derived was not indicated (DWR, 1984). A value of *T* of 10,000 gallons per day per foot (gpd/ft), or about 1,340 ft^2/d, was derived for one well in the Indian Cove Subbasin (Kennedy/Jenks, 2001, 2008).

In an effort to quantify recharge to the Joshua Tree and Copper Mountain Subbasins, Nishikawa et al. (2004) extensively studied the near-surface sediments and estimated hydrologic properties for them. It should be noted that these hydrologic properties are not necessarily directly comparable to deeper deposits. At sites in and near active streambeds, most of the deposits were sand with some gravel and silt, and no clay layers. The saturated hydraulic conductivity (K_{sat}) of core material from several boreholes mostly ranged from about 6 to 0.3 ft/d; one sample at the base of one site had a K_{sat} value of about 0.01 ft/d, and may represent a value more typical of finer-grained layers. Izbicki et al. (2002; as cited in Nishikawa et al., 2004) indicate that the geomorphic processes dictating the movement of streambeds over time likely prevents the formation of uniformly coarse-grained conduits of flow downward toward the water table, which is located at depths hundreds of feet in most areas of the study area. Nishikawa et al. (2004) also performed infiltrometer tests in the streambed sediments, with measure the rate of water movement into the surface. The infiltration rates determined by these tests were greatest near the mountain front, and lower away from it. Infiltration rates varied from 2.0 to 3.4 feet per hour (ft/hr) in active stream washes, and 1.5 to 2.8 ft/hr outside of the washes (Nishikawa et al., 2004). Locations of higher infiltration rates likely have a higher value of K_z than do sites with lower infiltration rates.

S_y of the upper Quaternary aquifer is estimated to range from 0.12 to 0.21 (average of 0.15) in the Joshua Tree Subbasin and from 0.08 to 0.23 (average of 0.14) in the Copper Mountain Subbasin, based on known relationships between S_y and the types of deposits encountered in the subsurface (Lewis, 1972). The average value of S_y is 0.1 in the Indian Cove Subbasin, and 0.2 in the Fortynine Palms and Eastern Subbasins (DWR, 1984). Both confined and unconfined conditions exist in the alluvium of these basins, due to the heterogeneity of the deposits (Kennedy/Jenks, 2001, 2008).

A.4.4.3 Quaternary Playa Deposits

Quaternary-aged fine-grained sediments have been deposited around the various dry lakes in the area (Nishikawa et al., 2004). These deposits are visually obvious due to the presence of very fine sediments (silts and clays). Quaternary playa deposits (lumped into Q on Figure 2-4, but given as Ql on the map of Rogers, 1967) are present at Deadman, Mesquite, Coyote, Ames, and Emerson Dry Lakes, as well as several more unnamed playas throughout the basin. These sediments generally rest directly on Quaternary sediments (Riley and Worts, 1952).

These deposits are generally thin; Riley and Worts (1953) noted that the playa deposits reach a thickness of 45 to 50 feet underneath Mesquite Dry Lake, and they speculate that similar thicknesses occur under Deadman and Coyote Dry Lakes. The smaller playa lakes likely contain thinner deposits. As climate has dried out since the late Pleistocene, these dry lakes have become less and less important as locations of deposition; indeed, Riley and Worts (1952) speculate that any addition of sediment that has occurred in recent times has been nullified by the action of wind erosion.

These deposits are nearly impermeable (Riley and Worts, 1953), which is significant for two reasons. First, although they may be saturated in some places, they do not represent transmissive aquifers to any degree, and cannot be relied upon to produce any significant amount of water. Second, these deposits may act as confining layers to underlying aquifers, as is seen in the western half of Mesquite Dry Lake (Riley and Worts, 1952); this leads to artesian pressure in the underlying aquifers (Riley and Worts, 1953) wherever the water table rises into the playa sediments.

Appendix B: Climatological Analysis

Appendix B: Climatological Analysis

Appendix B provides details on the statistical analysis of precipitation and an assessment of evapotranspiration in the area of Twentynine Palms, California. This analysis was performed in order to determine whether trends exist in these climatological variables; these trends could be over time or space, and be manifested for measurements on monthly to annual timescales.

B.1 Precipitation

The distribution of precipitation in the study area is an important determinant to the hydrologic budget, as almost the entirety of input to the basin results from precipitation within the basin area. This area is near the intersection of two different seasonal precipitation regimes (Friedman et al., 1992), resulting in a bimodal distribution of monthly average rainfall. Rainy seasons exist in the summer (the North American monsoon) and in the winter.

Precipitation data are available from several sources in the area. The Desert Research Institute (DRI) Western Regional Climate Center (WRCC) publishes monthly average maximum and minimum temperatures for National Climate Data Center (NCDC) cooperative network stations throughout the west, including a few in the area (Table B-1). San Bernardino County (SBCO) maintains records from many stations within the county, with many more precipitation records than temperature records; 30 stations in or near the study area were analyzed here (Table B-1).

B.1.1 Climatological Setting

The study area varies from arid in the basins to semiarid in some of the highest mountain ranges, for example along the Little San Bernardino Mountains (Troxell et al., 1954; Nishikawa et al., 2004). Most of the precipitation falls as rain, although the amount of snow varies from more or less negligible on the basins floor to very important in the uppermost reaches of the mountain ranges.

The actual amount of precipitation and its seasonal distribution is dependent on location and elevation, and so the existing literature reports a wide range of values. Riley and Worts (1952) reported an average of 4.54 inches per year at Twentynine Palms, and stated that most rainfall occurs during the fall and winter months, with “occasional” thunderstorms in August. Weir and Bader (1963) give a total of 4.19 inches per year at the Joshua Tree National Monument (JTNM) headquarters, without indicating where that is located (currently just south of Highway 62 on Utah Trail within the town of Twentynine Palms), and they state that precipitation occurs mostly in the winter. Freckleton (1982) gives the rainfall total as 4.01 inches per year (over the period of record 1936 through 1979) at JTNM headquarters, with most of the rainfall occurring as summer thunderstorms. Koehler (1983) gives precipitation in the Bagdad area, just northeast of the study area, as 3.3 inches per year. A DWR study in the area (1984) gave an average of 4.11 inches of precipitation per year at JTNM (period of record 1936-1982), with average precipitation at the crest of the Little San Bernardino Mountains of 8 inches.

Nishikawa et al. (2004) analyzed five different NCDC stations in the area in more detail. Kee Ranch (Station #44467) and Morongo Valley (Station #45863) are in the more mountainous southwestern part of the area. The annual average precipitation is 8.32 inches at Kee Ranch and 7.84 inches at Morongo Valley. January is the wettest month, averaging over 2 inches per month, and May and June are the driest months, averaging less than 0.1 inches per month. At these stations, about 50% of precipitation falls in the winter (January through March), and 10% falls during the summer (July through September). The station at Twentynine Palms (Station #49099; period of record 1948-2002) is on the desert floor. Annual precipitation averages 4.07 inches. July and August are the wettest months, averaging 0.59 inches per month in July and 0.69 inches per month in August. June is the driest month, averaging just 0.01 inches per month. 30% of precipitation falls in the winter, with 44% falling in the summer. The station at Joshua Tree (Station #44405; period of record 1959-1974) is on the higher desert floor. Annual average rainfall is 4.83 inches. The bimodal distribution is more subtle than at Twentynine Palms, with the wettest month in December (0.76 inches per month), and the driest month in June (0.01 inches per month). Finally, the average annual precipitation at Palm Springs (Station #46635; period of record 1927-2002), southwest of the San Bernardino Mountains, is 5.64 inches per year. The wettest month is January, with 1.14 inches per month; the driest month is May, with only 0.05 inches per month. Most of the precipitation at this location occurs in the winter.

As implied by the variety of information provided on the distribution of precipitation, this area sits at the interface between two climatological regimes (Friedman et al., 1992), leading to a bimodal precipitation distribution. These two regimes are divided approximately along the California-Arizona border east of the site. East of this divide, precipitation is dominated by summer precipitation; west of the divide, winter precipitation dominates. This divide is a manifestation of the study area’s location at the intersection of air masses coming from two different source areas. Figure B-1 shows monthly precipitation distributions at various places in the study area, showing the differences in seasonal precipitation amounts from west to east.

Winter, spring, and fall precipitation result from frontal storms coming east from the Pacific Ocean (Nishikawa et al., 2004). These storms have durations on the order of one or more days, at a fairly low intensity. Rainfall from these storms is greatest in the winter, with the fall and spring being relatively dry. Precipitation falls out of these storms due to orographic lifting (Friedman et al., 1992), which occurs when the fronts encounter mountains and are lifted higher into the atmosphere; therefore, we would expect winter precipitation amounts to increase with increasing elevation. Because this study area is just east of the high San Bernardino Mountains, their rain shadow effect keeps the basin dry compared to more coastal zones.

Summer precipitation occurs as the result of isolated convective thunderstorms or mesoscale clusters of convective storms (Nishikawa et al., 2004), typical of the North American summertime monsoon. These storms are of short duration (one to several hours), with much higher intensities than is typical of the winter storms. Because precipitation falls as a result of lifting by convection, we might not expect as strong of an effect of elevation on the amount of precipitation as for winter storms. The moisture source areas for these summer storms are both the Gulf of Mexico and the Gulf of California (Friedman et al., 1992).

In addition to the two major precipitation regimes, some hurricane moisture reaches the area from the late summer through fall, with larger precipitation amounts and high intensities (Nishikawa et al., 2004). However, the occurrence of hurricane-driven rainfall in this region depends strongly on the year-to-year variability in the number of hurricanes, their intensity, the track they take overland, and their source area. This means that some years can see no hurricane moisture, while significant hurricane rainfall can occur in others.

B.1.2 Precipitation Data

The following discussion of precipitation relies on the data reported by SBCO on their website (http://www.sbcounty.gov/trnsprtn/pwg/Online_Data/Online_Data_Intro.htm). The earliest data available are from October 1934 at Twentynine Palms. Thirty of the stations in the SBCO system were used, with their criteria for use being that they are north and east of the crests of the San Bernardino and Little San Bernardino Mountains, and west of the California-Arizona border region (Figure B-2). Stations were not limited to within the study basin, as that would have resulted in only twelve stations being used in the analysis, with little data on the precipitation in high-elevation areas. Because of the highly episodic nature of precipitation in this area (particularly in the summer), months were not used in this analysis if more than a few days' data were missing.

Because the study area is so arid, spatial and temporal variations in precipitation can be very important. In particular, the variability in precipitation leads to variability (in both space and time) in recharge. Therefore, gaining insight into the quantitative variation of precipitation will aid the later quantification of other components of the hydrologic budget. A statistical analysis was undertaken to examine this variability.

B.1.3 Precipitation Regression Analysis

Because precipitation amounts, source areas, intensities, and other factors in this area are highly seasonal the regressions on the annual average precipitation were extended to a monthly timestep. Precipitation data from the same month in all years of record (i.e. all Octobers) were averaged together at each station to attain an average monthly precipitation amount (Table B-1). Average monthly precipitation ranged from zero at several stations and several months to 4.18 inches for February at the Joshua Tree Water District (Station #6384), although this value is based on only one month of record. All other monthly average precipitation totals are less than 2 inches. Monthly average precipitation amounts are presented for a selection of stations in Figure B-3.

Because storm tracks for winter precipitation generally run from west to east, latitude was not expected to have a strong effect on precipitation amount in the winter. However, moisture generally comes from the southwest and southeast in the summer, so some relationship between latitude and monthly precipitation was expected for the summer months. Figure B-4 and Table B-2 show linear regressions and regression statistics for each month versus latitude (in these analyses, separate regressions were not performed against a dataset not including the higher-elevation stations). The regression statistics indicate that significant relationships (i.e. $p < 0.05$) exist between latitude and monthly precipitation from April through October, inclusive. Interestingly, the slopes of these regressions are all positive, indicating greater precipitation with increasing latitude.

Longitude would be expected to have the strongest effect on precipitation amount in the winter, as moisture travels west-to-east over the basin. Figure B-5 and Table B-2 show linear regressions and regression statistics for each month versus longitude. The regression statistics indicate that significant relationships ($p < 0.05$) exist between longitude and monthly precipitation for July and August only, with increasing precipitation toward the east. This indicates that there is, in fact, no relationship between west-east position and winter precipitation. Further, these results indicate that, nearer to the California-Arizona border (the interface between the frontal and monsoonal climate regimes of Friedman et al., 1992) more precipitation falls during the summer. This likely implicates the Gulf of Mexico as the dominant precipitation source for monsoonal moisture for this area, although a definitive statement is beyond this report.

Elevation is expected to have strong control on precipitation through much of the year. However, as stated above, frontal storms are expected to be affected more by orographic lifting than are the convective storms of the monsoon season. Therefore, elevation is expected to be a more significant determinant of precipitation amount in the winter than in the summer. Figure B-6 and Table B-2 give linear regressions and regression statistics for each month versus altitude. The regression statistics indicate that significant relationships ($p < 0.05$) exist between elevation and monthly precipitation for November through May, inclusive. These relationships are very strong, with p-values less than 0.001. R^2 values are also the highest of all the regressions, varying from 0.34 (May) to 0.62 (December). In all months, the regressions have positive slopes, showing that precipitation amounts increase with elevation. These data confirm that elevation is only an important determinant of precipitation amount while frontal storms dominate precipitation.

B.1.4 Precipitation Isohytel Maps

The statistical regression analysis added insight to the variation due to the different seasonal precipitation processes. With these regressions, we can gain a much better understanding of the spatial variability of precipitation. We can predict the amount of monthly precipitation based on the latitude, longitude, and elevation of a location.

The statistically significant regressions presented in the previous section were used to create formulas for precipitation based on latitude, longitude, and elevation. Where no significant relationship exists, a spatial variable was not used to vary precipitation. In ArcGIS (ESRI, 2008), the raster calculator was used to apply the weighted linear regressions to the spatial parameters of a 30-m Digital Elevation Model (DEM) from the National Elevation Dataset (NED; Gesch et al., 2002; Gesch, 2007). For example, rainfall is significantly correlated with elevation in November, and no other spatial parameters; therefore, the elevations throughout the study area were multiplied by the slope and intercept of the weighted linear regression to create a map of average monthly rainfall for November. For June and September through March, only one spatial parameter is significantly correlated with rainfall, so this single transformation of the DEM determines the rainfall for each month. For April, May, July, and August, two spatial parameters are significantly correlated with rainfall. In these months, the DEMs are modified twice, once for each spatial parameter, and then the two transformations are summed. Then, the rainfall at the station with the least error is used to adjust the monthly rainfall by adding or subtracting a constant from the whole rainfall map. After determining the average monthly rainfall throughout the study area, the twelve months of rainfall were summed together to determine the average annual rainfall throughout the study area (Figure 4-1).

List of Tables

B-1 Mean Rainfall and Station Statistics

B-2 Statistics for Precipitation Regressions

List of Figures

B-1 Monthly Precipitation Distributions

B-2 San Bernardino County Precipitation and Temperature Stations

B-3 Average Monthly Precipitation from Selected SBCO Stations

B-4 Average Monthly Precipitation versus Latitude in SBCO Stations with Weighted Linear Regressions

B-5 Average Monthly Precipitation versus Longitude in SBCO Stations with Weighted Linear Regressions

B-6 Average Monthly Precipitation versus Elevation in SBCO Stations with Weighted Linear Regressions

Table B-1: Mean rainfall (p, in inches) and number of records (n) for each month, as well as annually, for 30 SBCO precipitation stations used in weighted linear regression analysis. Note that high-elevation stations were removed from some analyses.

Station Name	Station Number	Latitude	Longitude	Elevation	Period of Record		October		November		December		January		February		March		April		May		June		July		August		September		Annual	
		Decimal Degrees		Feet ASL	Start	End	p	n	p	n	p	n	p	n	p	n	p	n	p	n	p	n	p	n	p	n	p	n	p	n	p	n
Baine Ranch Baker Hill	4733	34.23004	-116.63673	2700	Oct-79	Sep-83	0.00	4	0.00	4	0.00	4	1.24	4	1.16	4	0.50	4	0.09	4	0.06	4	0.03	4	0.16	4	0.00	4	0.01	4	3.24	4
Lucerne Valley Cemetery	6001	34.44154	-116.95433	2946	Oct-91	Apr-09	0.21	18	0.35	18	0.48	18	0.57	18	0.96	18	0.40	18	0.16	18	0.03	17	0.01	17	0.17	17	0.17	17	0.15	17	3.66	17.58
Yucca Valley - Alta Loma Tank	6006	34.09265	-116.42316	3740	Oct-95	Feb-09	0.24	14	0.46	14	0.56	14	0.74	14	1.35	14	0.58	13	0.21	13	0.05	13	0.01	13	0.26	13	0.20	12	0.31	12	4.97	13.25
Twentynine Palms	6048A	34.12907	-116.03672	1975	Oct-34	Aug-09	0.29	74	0.29	74	0.47	73	0.47	74	0.41	73	0.35	74	0.12	74	0.07	74	0.01	74	0.60	74	0.74	74	0.42	73	4.25	73.75
Lucerne Valley	6057B	34.44356	-116.93787	2957	Oct-48	Sep-78	0.10	30	0.44	30	0.50	29	0.53	30	0.41	30	0.34	30	0.18	30	0.05	28	0.01	30	0.20	30	0.23	30	0.23	30	3.22	29.75
Joshua Tree	6134B	34.13303	-116.29371	2760	Oct-52	Sep-84	0.31	32	0.51	32	0.57	32	0.85	32	0.76	32	0.78	32	0.18	32	0.14	32	0.01	32	0.26	32	0.51	32	0.43	32	5.31	32
Kee Ranch[a]	6139	34.17126	-116.54531	4325	Oct-50	Apr-84	0.24	33	1.22	33	1.20	33	1.93	33	1.03	33	1.26	32	0.43	32	0.10	30	0.05	30	0.11	32	0.46	32	0.48	32	8.51	32.08
Goffs	6179	34.91957	-115.06181	2587	Oct-61	Sep-68	0.19	6	0.04	5	0.10	4	0.10	4	0.06	4	0.21	4	0.06	4	0.08	4	0.00	4	0.61	4	0.20	4	0.65	4	2.28	4.25
Mitchell Caverns[a]	6215	34.94426	-115.51375	4330	Oct-57	Feb-09	0.64	51	0.68	52	1.03	52	1.36	51	1.59	52	1.41	50	0.54	51	0.23	50	0.09	51	0.78	51	1.42	49	0.81	51	10.59	50.92
Ivanpah County Yard	6223	34.38803	-115.25765	2927	Oct-60	Mar-87	0.21	20	0.18	20	0.32	22	0.28	22	0.34	22	0.52	21	0.11	18	0.19	18	0.05	18	0.90	19	1.03	19	0.29	19	4.42	19.83
Cushenberry Springs[a]	6224	34.35805	-116.85978	4250	Oct-60	May-01	0.29	41	0.62	41	0.95	41	1.37	40	1.77	41	1.22	41	0.40	41	0.20	40	0.09	39	0.52	40	0.57	40	0.42	40	8.44	40.42
Dale Dry Lake - Barnett's Trading Post	6245	34.15402	-115.70135	1220	Oct-64	Sep-78	0.05	14	0.14	14	0.24	14	0.18	14	0.14	14	0.12	14	0.05	14	0.06	13	0.05	13	0.33	13	0.50	14	0.48	14	2.34	13.75
Johnson Valley - W. C. Shehorn	6255	34.42278	-116.61209	2794	Oct-60	Sep-97	0.21	37	0.25	36	0.48	37	0.51	36	0.45	36	0.43	37	0.13	36	0.15	36	0.04	37	0.22	37	0.41	37	0.34	37	3.63	36.58
Amboy - Saltus #1	6298	34.53102	-115.69568	625	Oct-66	Sep-88	0.30	22	0.20	22	0.35	22	0.39	22	0.30	22	0.36	22	0.15	22	0.09	22	0.05	22	0.47	22	0.49	22	0.26	21	3.40	21.92
Amboy - Saltus #2	6300	34.47502	-115.74368	595	Oct-71	Sep-93	0.20	19	0.19	19	0.27	20	0.51	20	0.55	20	0.57	20	0.12	20	0.08	20	0.04	20	0.36	20	0.43	20	0.38	19	3.68	19.75
Lucerne Valley Fire District	6324	34.44308	-116.93795	2957	Oct-73	Sep-89	0.17	9	0.12	9	0.37	8	0.21	9	0.29	10	0.24	10	0.06	9	0.18	10	0.00	10	0.48	9	0.22	10	0.57	10	2.91	9.42
Dale Lake - Craine	6336	34.12208	-115.77481	1315	Oct-74	Sep-95	0.15	17	0.18	17	0.37	17	0.66	17	0.50	17	0.68	17	0.10	17	0.11	17	0.04	17	0.58	17	0.76	17	0.50	17	4.63	17
Rimrock[a]	6366	34.19723	-116.55672	4520	Oct-80	Sep-86	0.10	6	0.31	6	0.48	6	0.80	6	0.41	6	1.65	6	0.27	6	0.31	6	0.01	6	0.09	6	1.39	6	0.53	6	6.34	6
Lucerne Valley Midway Park	6372	34.45802	-116.90275	2910	Oct-81	Sep-93	0.24	10	0.46	10	0.46	11	0.48	11	0.30	11	0.68	11	0.10	12	0.08	11	0.02	10	0.31	10	0.36	10	0.09	10	3.58	10.58
Joshua Tree Water District	6384	34.13942	-116.31542	2710	Aug-88	Sep-92	0.01	2	0.00	1	0.00	1	0.04	2	4.18	1	0.00	1	0.00	1	0.00	1	0.00	1	0.00	1	0.17	2	0.00	2	4.39	1.33
Shadow Mountain	6397	34.17363	-115.97669	1360	Oct-89	Sep-93	0.22	4	0.00	4	0.30	4	0.70	4	0.78	4	0.69	4	0.04	4	0.07	4	0.03	4	0.14	4	0.29	4	0.08	4	3.32	4
Wonder Valley	6401	34.16053	-115.92528	1250	Oct-90	Sep-93	0.26	3	0.00	3	0.38	3	1.15	3	1.01	3	1.15	3	0.03	3	0.03	3	0.00	3	0.06	3	0.09	3	0.04	3	4.20	3
Twentynine Palms U.S.M.C.	6402	34.30005	-116.15180	2004	Oct-77	May-01	0.14	24	0.11	24	0.37	24	0.37	24	0.42	24	0.36	24	0.04	24	0.08	24	0.05	23	0.29	23	0.44	23	0.34	23	3.01	23.67
Iron Mountain	7114	34.14880	-115.12207	938	Oct-40	Sep-90	0.35	49	0.23	50	0.43	50	0.48	50	0.26	50	0.32	49	0.14	50	0.05	49	0.03	50	0.29	50	0.40	50	0.20	50	3.19	49.75
Yucca Valley C.D.F.	9002	34.12373	-116.40914	3420	Oct-57	Apr-09	0.28	51	0.46	52	0.59	51	0.86	52	1.07	52	0.62	51	0.22	51	0.09	51	0.02	51	0.18	50	0.43	50	0.24	50	5.03	51
Twentynine Palms County Yard	9004	34.15224	-116.05524	1895	Oct-60	Apr-09	0.20	48	0.19	48	0.28	48	0.29	49	0.32	49	0.27	49	0.09	49	0.06	48	0.01	48	0.42	47	0.76	46	0.34	46	3.22	47.92
Johnson Valley - Mojave Water Agency	9012	34.36678	-116.61284	2950	Oct-97	Apr-09	0.17	12	0.36	11	0.47	12	0.22	12	0.58	12	0.19	12	0.14	12	0.01	11	0.01	11	0.38	10	0.22	10	0.25	11	2.99	11.33
Wonder Valley F.S. - East	9016	34.16597	-115.74708	1224	Oct-98	Apr-09	0.15	11	0.30	10	0.29	10	0.30	10	0.63	10	0.09	11	0.08	11	0.00	10	0.03	10	0.09	10	0.63	10	0.63	10	3.22	10.25
Joshua Tree-Quail Springs	9018	34.09065	-116.26948	3568	Oct-09	Apr-09	0.50	5	0.63	6	0.80	6	0.72	6	0.84	6	0.27	5	0.09	6	0.00	5	0.00	5	0.20	5	0.30	5	0.08	5	4.44	5.42
Essex Cal Trans Yard	9020	34.73177	-115.25021	1720	Oct-94	Apr-09	0.24	14	0.35	14	0.39	13	0.57	13	0.72	14	0.20	14	0.15	14	0.03	12	0.03	12	0.30	12	0.37	12	0.46	13	3.80	13.08
Average	--	--	--	--	--	--	0.22	--	0.31	--	0.45	--	0.63	--	0.79	--	0.55	--	0.15	--	0.09	--	0.03	--	0.33	--	0.47	--	0.33	--	4.34	--

[a]High-elevation stations, over 4,000 feet above mean sea level.

Table B-2: Regression statistics for weighted linear regressions of latitude, longitude, and altitude versus monthly and annual precipitation. Given ± errors on slope and intercept are 95% confidence intervals.

	Latitude					**Longitude**					**Altitude**				
	m[a]	**b**[b]	**MSE**[c]	**R^2**[d]	**p-value**[e]	**m**	**b**	**MSE**	**R^2**	**p-value**	**m**	**b**	**MSE**	**R^2**	**p-value**
October	0.28 ± 0.09	-9.24 ± 3.00	0.30	0.24	0.0074	0.09 ± 0.04	10.65 ± 4.77	0.35	0.11	0.076	0.04 ± 0.02	0.16 ± 0.06	0.36	0.09	0.12
November	0.17 ± 0.20	-5.47 ± 6.83	1.56	-0.01	0.80	-0.14 ± 0.08	-15.79 ± 9.76	1.46	0.06	0.22	0.16 ± 0.03	-0.04 ± 0.08	0.72	0.54	0.0000051
December	0.36 ± 0.20	-11.70 ± 6.88	1.56	0.07	0.17	-0.11 ± 0.09	-12.22 ± 10.39	1.65	0.02	0.46	0.18 ± 0.03	0.07 ± 0.08	0.64	0.62	0.00000031
January	0.41 ± 0.34	-13.49 ± 11.75	4.53	0.02	0.47	-0.18 ± 0.15	-20.67 ± 17.17	4.52	0.02	0.45	0.28 ± 0.05	-0.03 ± 0.14	2.22	0.52	0.0000092
February	0.71 ± 0.37	-23.77 ± 12.54	5.23	0.09	0.12	-0.22 ± 0.16	-25.27 ± 18.96	5.57	0.03	0.36	0.32 ± 0.05	-0.10 ± 0.15	2.67	0.54	0.0000053
March	0.64 ± 0.29	-21.40 ± 9.90	3.19	0.12	0.069	-0.10 ± 0.13	-10.66 ± 15.50	3.68	-0.02	0.95	0.25 ± 0.04	-0.06 ± 0.12	1.67	0.54	0.0000049
April	0.31 ± 0.09	-10.34 ± 3.21	0.34	0.25	0.0055	-0.02 ± 0.05	-1.73 ± 5.54	0.47	-0.03	1.46	0.09 ± 0.01	-0.04 ± 0.04	0.20	0.56	0.0000022
May	0.14 ± 0.04	-4.56 ± 1.50	0.07	0.23	0.0084	0.00 ± 0.02	-0.40 ± 2.56	0.10	-0.03	1.69	0.03 ± 0.01	0.02 ± 0.02	0.06	0.34	0.00085
June	0.07 ± 0.02	-2.39 ± 0.59	0.01	0.35	0.00063	0.01 ± 0.01	1.14 ± 1.08	0.02	0.00	0.63	0.01 ± 0.00	0.01 ± 0.01	0.02	0.11	0.080
July	0.39 ± 0.15	-13.02 ± 5.11	0.85	0.17	0.028	0.16 ± 0.07	19.49 ± 7.58	0.86	0.16	0.035	0.01 ± 0.03	0.35 ± 0.10	1.05	-0.03	1.39
August	0.57 ± 0.23	-18.88 ± 7.94	2.00	0.15	0.042	0.24 ± 0.10	28.66 ± 11.60	2.01	0.14	0.044	0.08 ± 0.05	0.38 ± 0.14	2.24	0.04	0.27
September	0.38 ± 0.11	-12.71 ± 3.93	0.50	0.26	0.0049	0.07 ± 0.06	9.00 ± 6.62	0.66	0.02	0.41	0.05 ± 0.03	0.24 ± 0.07	0.60	0.11	0.089
Annual	4.44 ± 1.60	-147.54 ± 54.92	98.70	0.19	0.019	-0.18 ± 0.78	-16.27 ± 91.01	125.60	-0.03	1.64	1.51 ± 0.24	0.96 ± 0.68	51.89	0.57	0.0000016
Annual[f]	-1.81 ± 0.85	65.76 ± 29.00	11.55	0.12	0.086	-0.22 ± 0.29	-21.86 ± 34.05	13.43	-0.02	0.92	0.41 ± 0.16	2.94 ± 0.37	10.67	0.19	0.029

[a]Slope of the line of regression

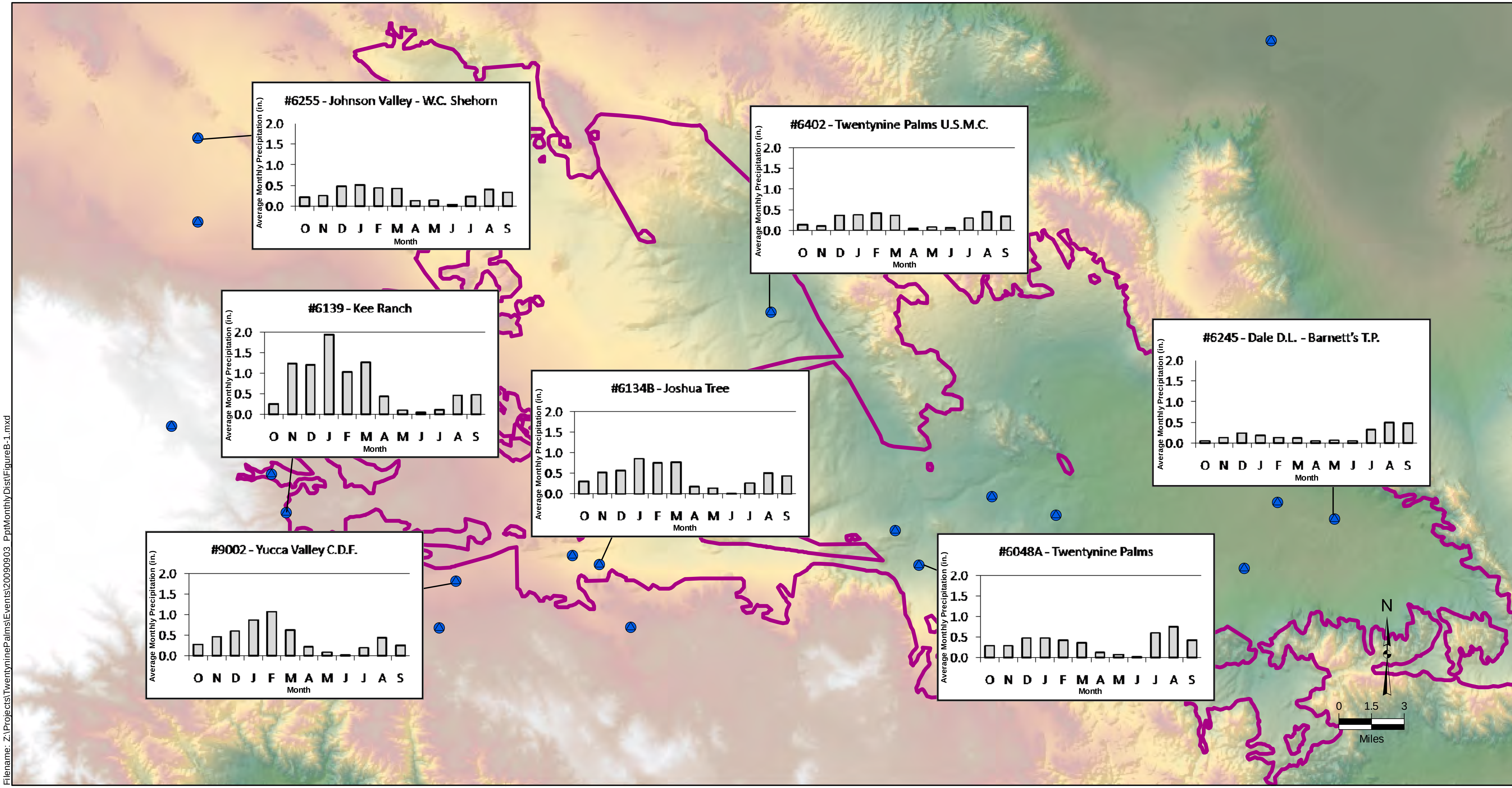
[b]y-intercept of line of regression (i.e. precipitation amount at latitude, longitude, or altitude equal to zero)

[c]Mean standard error of regression

[d]Regression coefficient of line of regression, indicating goodness of fit

[e]p-value, where any value $p < 0.05$ indicates statistical significance

[f]Values in this row are for regressions for which the high-elevation data were removed



Filename: Z:\Projects\TwentyninePalms\Events\20090903_PptMonthlyDist\FigureB-1.mxd

Source: (c) 2009 Microsoft Corporation

Explanation

SBCO Precipitation Station

Study Area Boundary

Elevation (ft asl)

High : 11,500

Low : 0

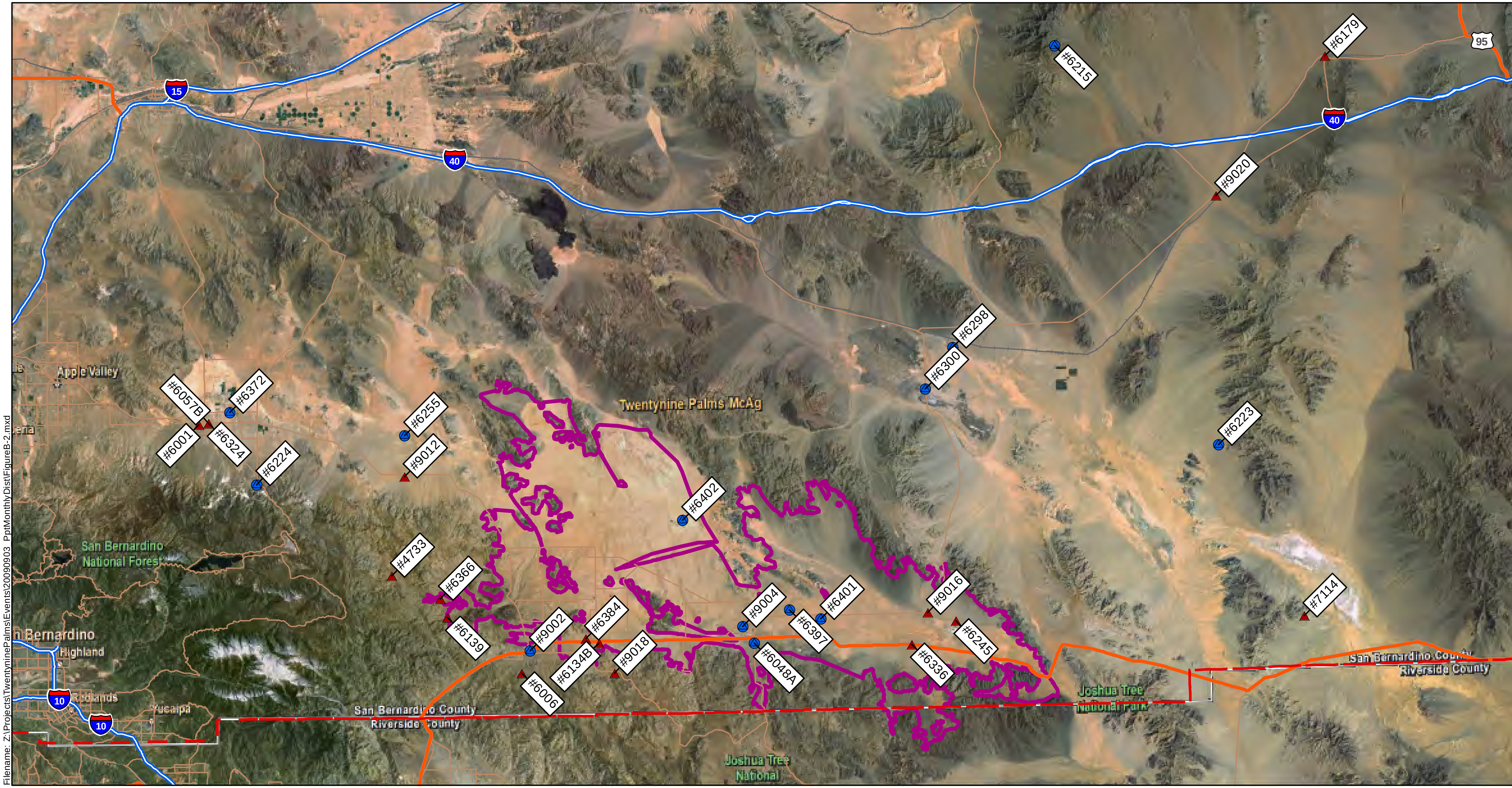
Kennedy/Jenks Consultants

Twentynine Palms
San Bernadino County, California

Monthly Precipitation Distributions

K/J 0964003*00
March 2010

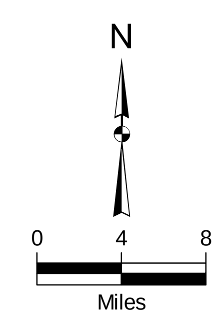
Figure B-1



Source: (c) 2009 Microsoft Corporation

Explanation

- ▲ SBCO Precipitation Station
- ● SBCO Temperature and Precipitation Station
- Study Area Boundary
- County Boundaries



Kennedy/Jenks Consultants

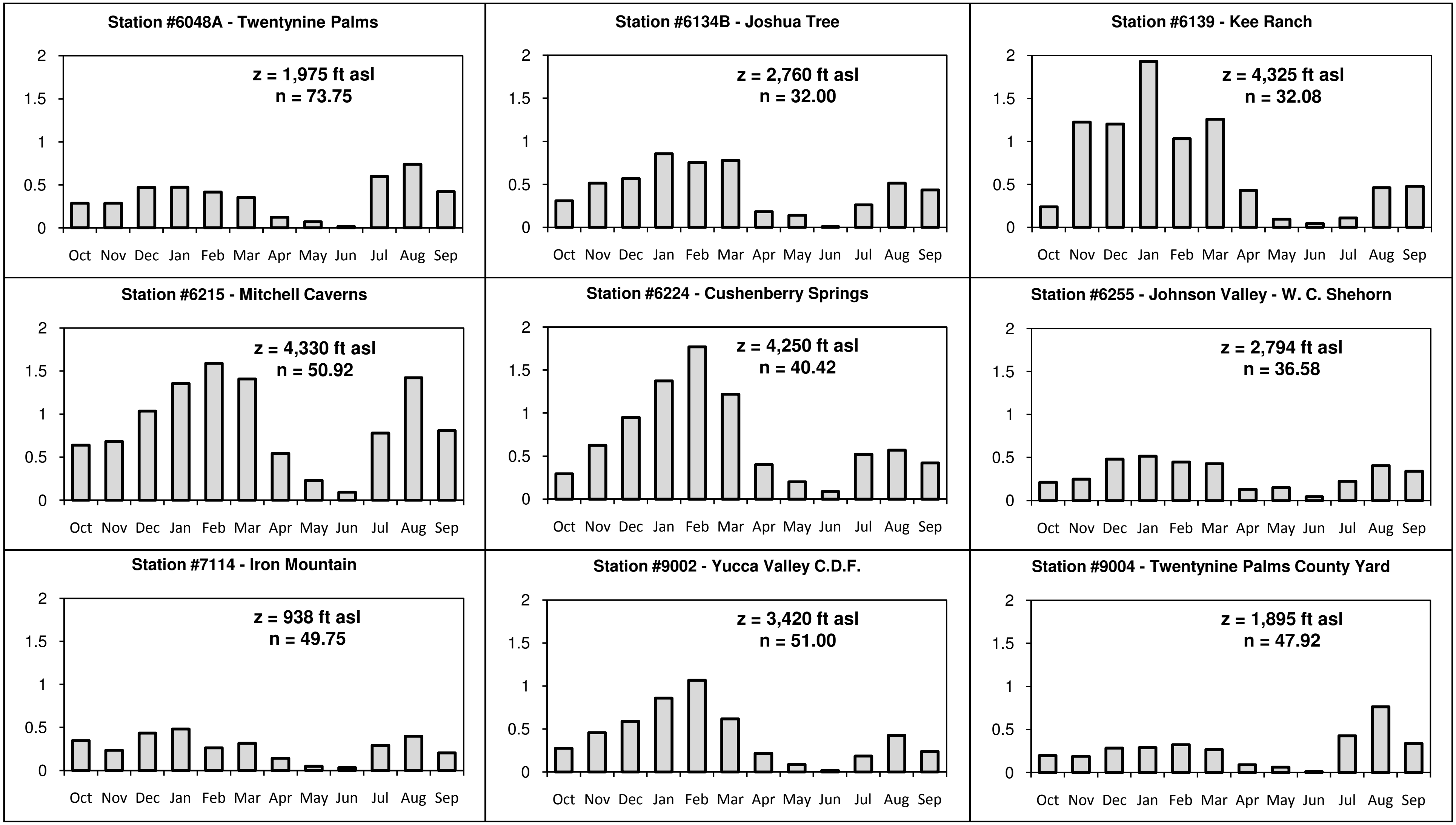
Twentynine Palms
San Bernadino County, California

San Bernardino County Precipitation and Temperature Stations

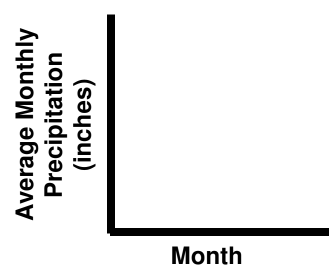
K/J 0964003*00
March 2010

Figure B-2

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureB-3.pptx



Note: z is the elevation of the station, and n is the number of years of records; months with insufficient data are not counted, leading to fractional years of record (i.e. n is equal to the months of record divided by 12).



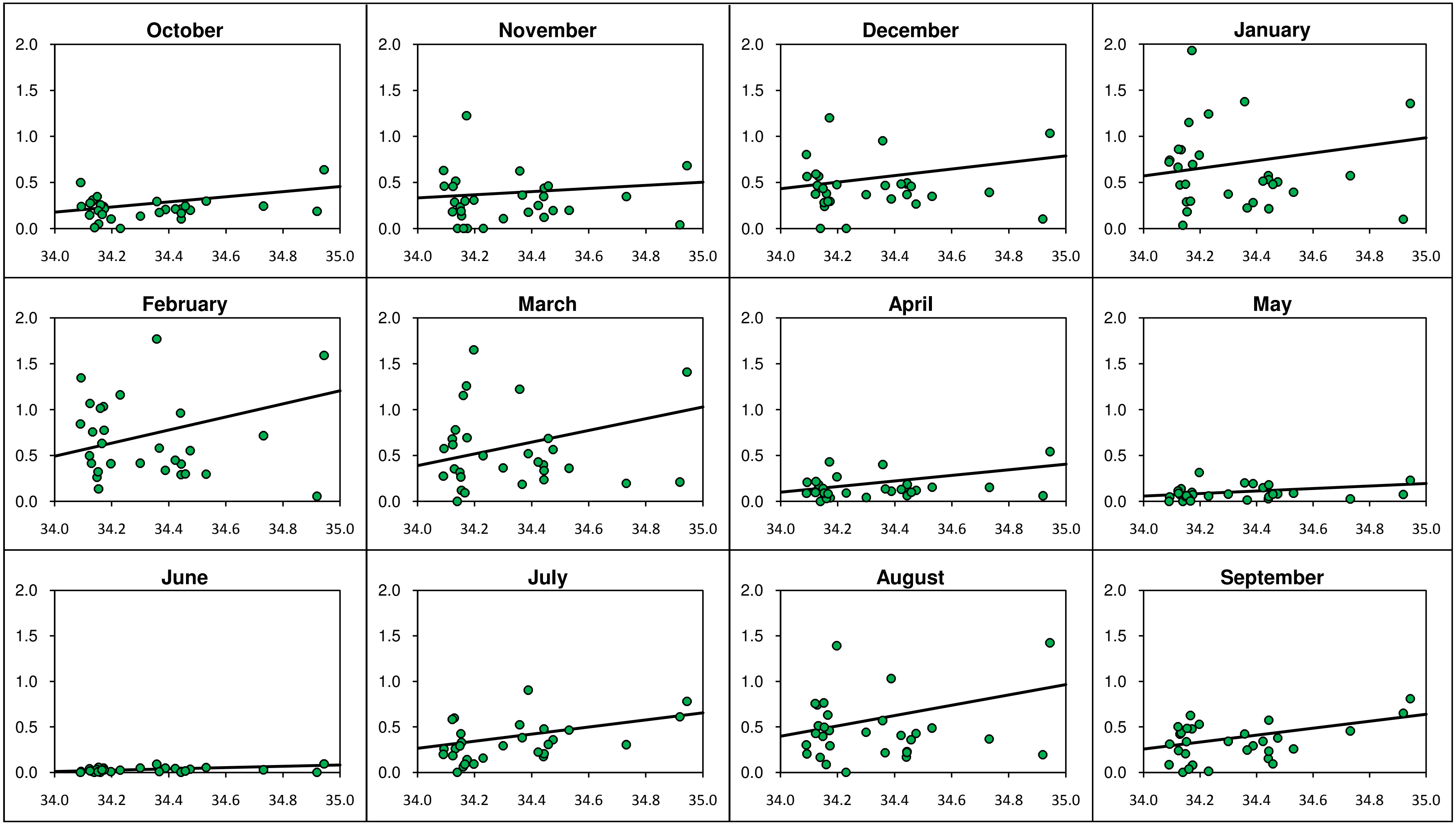
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

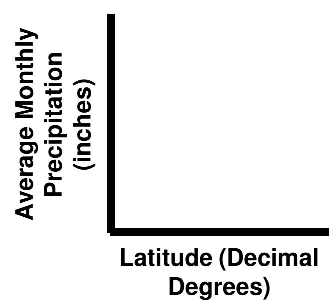
Average Monthly Precipitation from Selected SBCO Stations

K/J 0964003*00
March 2010
Figure B-3

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Figures for draft\FigureB-4.pptx



Note: One station (Joshua Tree Water District, #6384; latitude 34.139°N) had an average value of 4.18 inches in February, but this is based on just one month of record; all other average values were below 2 inches. Parameters of the weighted linear regressions can be found in Table B-2.



Kennedy/Jenks Consultants

Twentynine Palms

San Bernardino County, California

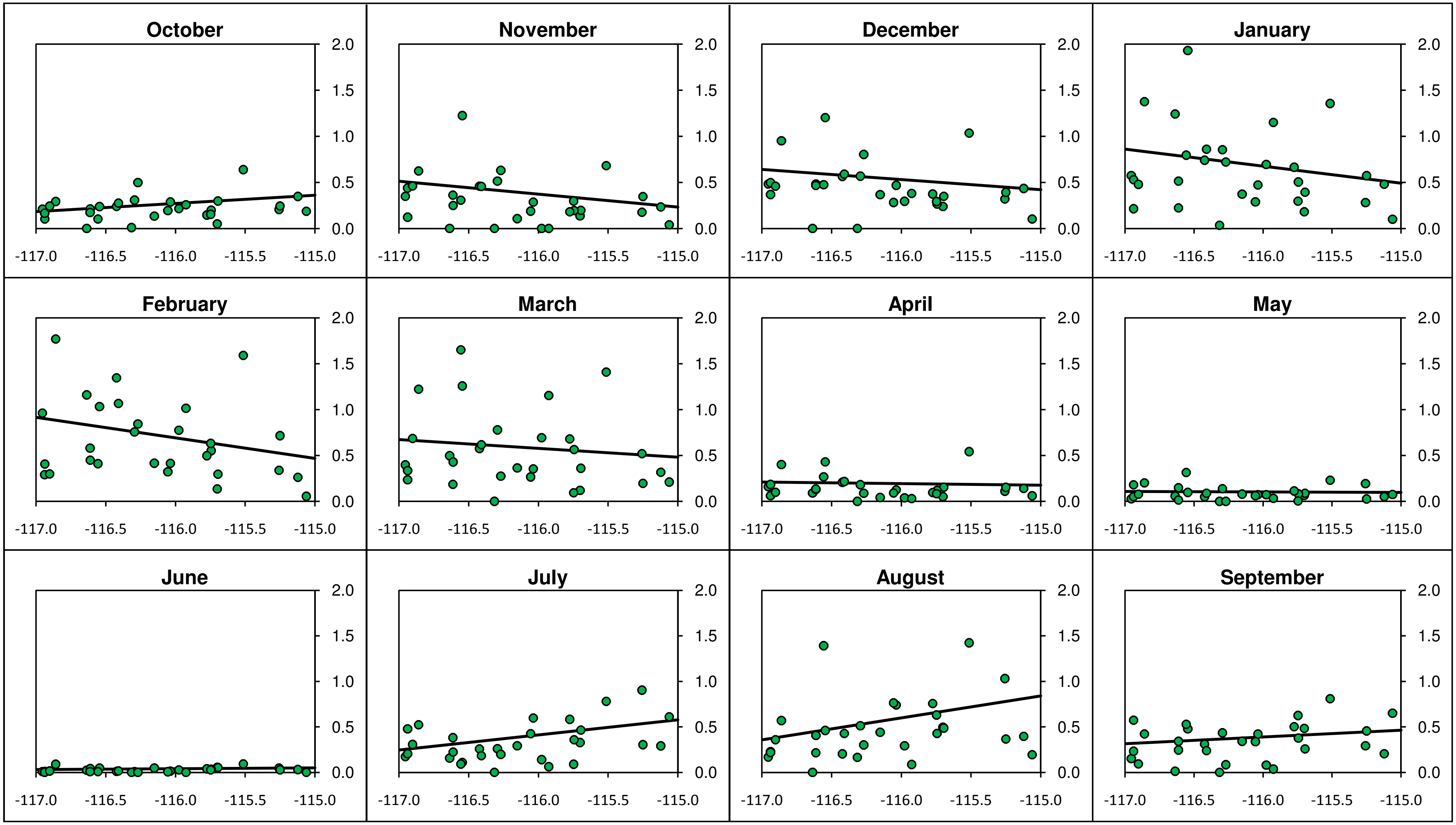
Average Monthly Precipitation versus Latitude in SBCO Stations with Weighted Linear Regressions

K/J 0964003*00

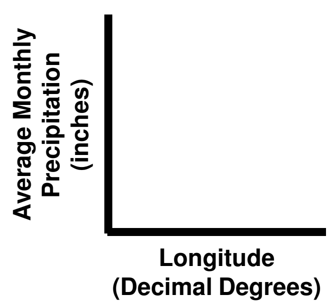
March 2010

Figure B-4

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureB-5.pptx



Note: One station (Joshua Tree Water District, #6384; latitude 34.139°N) had an average value of 4.18 inches in February, but this is based on just one month of record; all other average values were below 2 inches. Parameters of the weighted linear regressions can be found in Table B-2.



Kennedy/Jenks Consultants

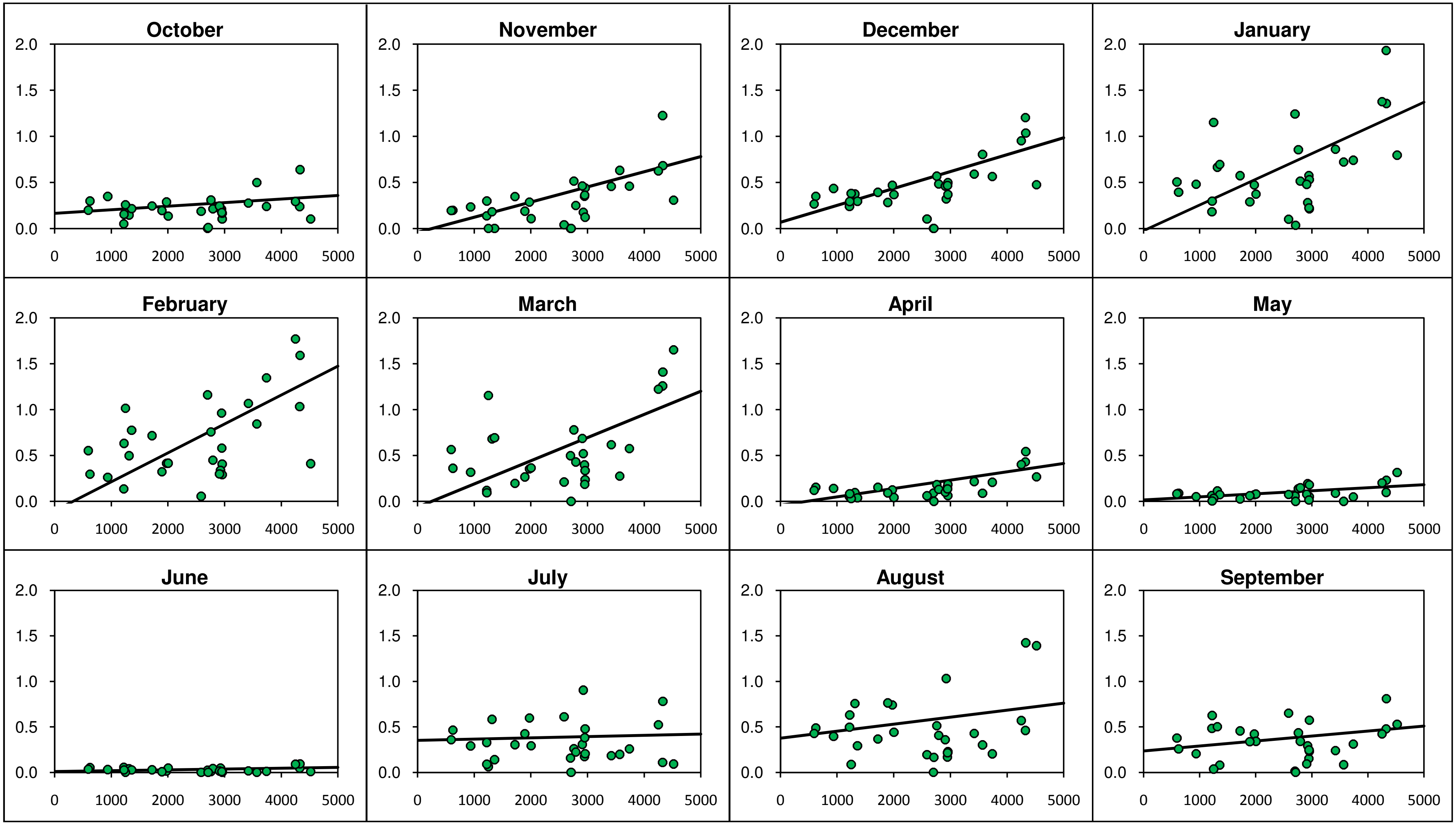
Twentynine Palms
San Bernardino County, California

Average Monthly Precipitation versus Longitude in SBCO Stations with Weighted Linear Regressions

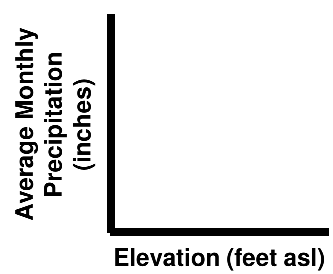
K/J 0964003*00
March 2010

Figure B-5

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureB-6.pptx



Note: One station (Joshua Tree Water District, #6384; latitude 34.139°N) had an average value of 4.18 inches in February, but this is based on just one month of record; all other average values were below 2 inches. Parameters of the weighted linear regressions can be found in Table B-2.



Kennedy/Jenks Consultants

Twentynine Palms

San Bernardino County, California

Average Monthly Precipitation versus Elevation in SBCO Stations with Weighted Linear Regressions

K/J 0964003*00

March 2010

Figure B-6

Appendix C: Regional Groundwater Basin Data

Appendix C: Regional Groundwater Basin Data

Appendix C contains additional tables and graphs from the groundwater basins in the region.

List of Tables

C-1 Details of Study Area Groundwater Subbasins

List of Figures

C-1 Hydrographs for Wells in the Joshua Tree Subbasin

C-2 Hydrographs for Wells in the Copper Mountain Subbasin

C-3 Hydrographs for Wells in the Pipes Subbasin

C-4 Hydrographs for Wells in the Reche Subbasin

C-5 Hydrographs for Wells in the Giant Rock Subbasin

C-6 Hydrographs for Wells in the Surprise Spring Subbasin

C-7 Hydrographs for Wells in the Deadman Subbasin

C-8 Hydrographs for Wells in the Dale Basin

C-9 Hydrographs for Wells in the Mesquite Subbasin

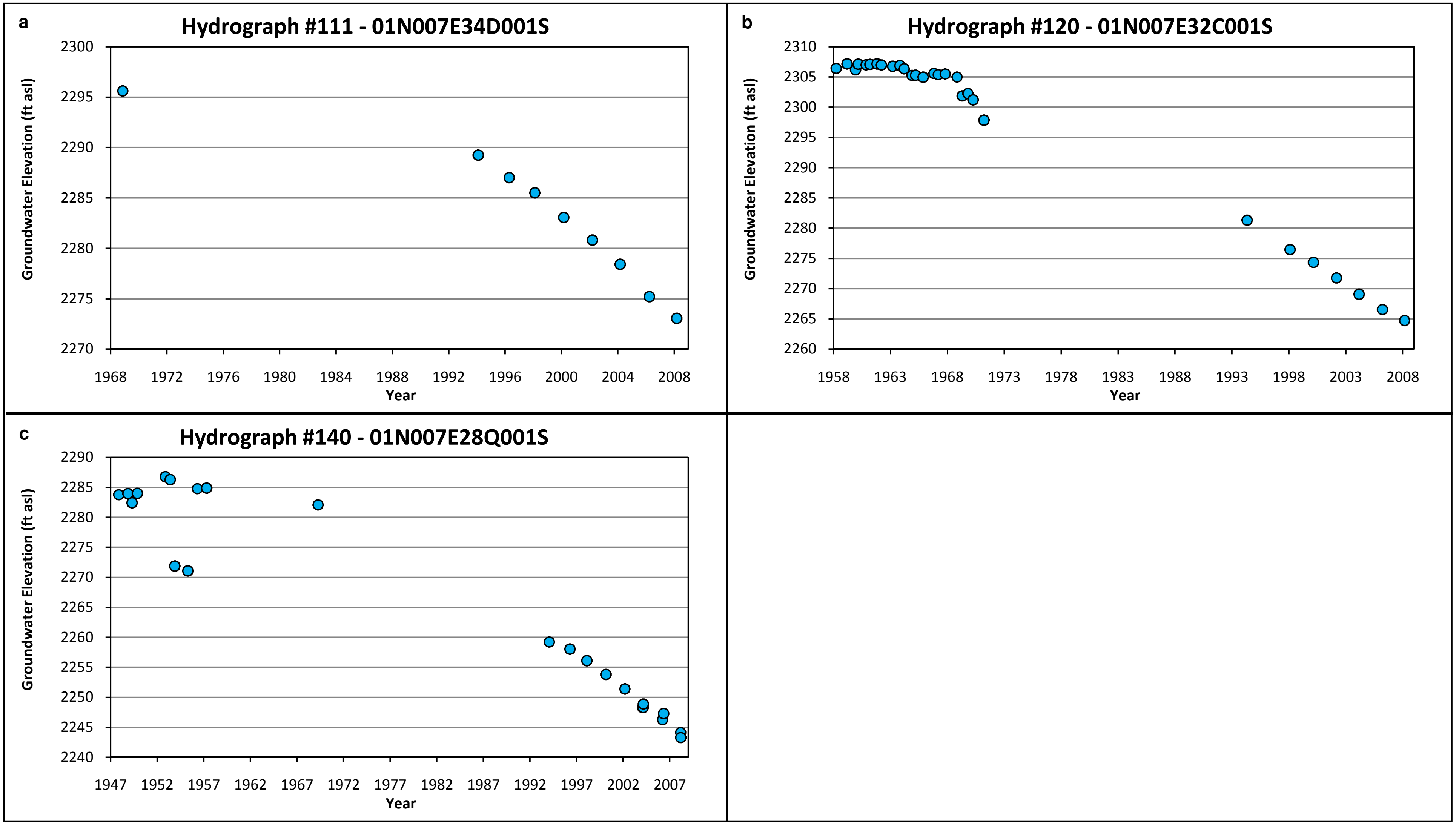
Table C-1: Subbasins in the study area, along with their extents and names used in other reports.

Subbasin Name	North		East		South		West		Area (acres)	DWR Basin[a]	Alternate Names	Sources[b]
	Barrier	Subbasin	Barrier	Subbasin	Barrier	Subbasin	Barrier	Subbasin				
Warren										7	Warren Valley (Lewis, 1972)	3,8
Joshua Tree	Oasis Fault[c]	Copper Mountain	Unnamed fault	Indian Cove	Little San Bernardino Mtns	None	Yucca Barrier	Warren	11,700	5,7	Subbasin of Copper Mountain Valley Basin (Lewis, 1972)	3,4,8
Copper Mountain	Transverse Arch	Giant Rock	Copper Mtn Fault and Copper Mtn	None	Pinto Mtn Fault	Joshua Tree	San Bernardino Mtns	None	30,700	2	Coyote Lake, Subbasin of Copper Mountain Valley Basin (Lewis, 1972); Included in Giant Rock Basin (Londquist and Martin, 1991)	3,8
Pioneertown	San Bernardino Mtns	None	San Bernardino Mtns and Pipes Wash	Pipes	San Bernardino Mtns	None	San Bernardino Mtns	None	7,600	1	Included in Pipes Basin (Riley and Worts, 1953); Subbasin of Means Valley Basin (Lewis, 1972)	2,3
Pipes	San Bernardino Mtns	None	Pipes Fault	Reche	San Bernardino Mtns	None	San Bernardino Mtns and Pipes Wash	Pioneer-town	10,600	1	Subbasin of Means Valley Basin (Lewis, 1972); Subbasin of Twentynine Palms Basin (Riley and Worts, 1953)	2,3,6
Reche	Reche Butte	None	Reche Fault	Giant Rock	None	Copper Mountain	Pipes Fault	Pipes	20,900	1	Subbasin of Means Valley Basin (Lewis, 1972); Subbasin of Twentynine Palms Basin (Riley and Worts, 1953)	2,3,6
Giant Rock	Deadeye Mtn	None	Emerson, Sand Hill, and Copper Mtn Faults	Surprise Spring	Transverse Arch	Copper Mountain	Reche Fault	Reche	37,400	1	Included in Surprise Spring Basin (Riley and Worts, 1952 and 1953); Subbasin of Copper Mountain Valley Basin (Lewis, 1972)	3,6,8
Surprise Spring	Hidalgo Mtn/Emerson Dry Lake	None	Surprise Spring Fault	Deadman	Transverse Arch	Mesquite	Emerson, Sand Hill, and Copper Mtn Faults	Giant Rock	46,700	4	Subbasin of Twentynine Palms Basin (Riley and Worts, 1952 and 1953); Subbasin of Deadman Valley Basin (Lewis, 1972)	1,2,3,4, 6,8
Deadman	Mud Hills	None	Mesquite Fault	None	Transverse Arch	Mesquite	Surprise Spring Fault	Surprise Spring	46,100	4	Subbasin of Twentynine Palms Basin (Riley and Worts, 1952 and 1953)	1,2,3,4,6
Mesquite	Transverse Arch	Deadman, Surprise Spring	Mesquite Fault	Dale	Oasis, Bagley, and Chocolate Drop Faults	Indian Cove, Fortynine Palms, Eastern	Copper Mtn	Copper Mtn	44,900	6	Mesquite Lake (DWR, 1984; Kennedy/Jenks, 2001); Subbasin of Twentynine Palms Basin (Riley and Worts, 1952 and 1953; Kennedy/Jenks, 2001)	1,2,4,6,7, 9
Indian Cove	Oasis Fault	Mesquite	None	Fortynine Palms	Little San Bernardino Mtns	None	Unnamed fault	Joshua Tree	5,900	5	Subbasin of Twentynine Palms Valley Basin (DWR, 1984); Subbasin of Twentynine Palms Basin (Kennedy/Jenks, 2001)	4,7,8,9
Fortynine Palms	Oasis Fault	Mesquite	None	Eastern	Little San Bernardino Mtns	None	None	Indian Cove	1,800	5	Subbasin of Twentynine Palms Valley Basin (DWR, 1984); Subbasin of Twentynine Palms Basin (Kennedy/Jenks, 2001)	4,7,9
Eastern	Oasis Fault	Mesquite	Little San Bernardino Mtns	None	Little San Bernardino Mtns	None	None	Fortynine Palms	7,000	5	Subbasin of Twentynine Palms Valley Basin (DWR, 1984); Subbasin of Twentynine Palms Basin (Kennedy/Jenks, 2001)	4,7,9
Dale	Bullion Mtns	None	Sheep Hole Mtns	None	Pinto Mtns	None	Mesquite Fault	Mesquite	201,100	3	None	2,3,6

[a]DWR Basins:
1: Ames Valley
2: Copper Mountain Valley
3: Dale Valley
4: Deadman Valley
5: Joshua Tree
6: Twentynine Palms Valley
7: Warren Valley

[b]Sources:
1: Riley and Worts, 1952
2: Riley and Worts, 1953
3: Lewis, 1972
4: DWR, 1984
5: Akers, 1986
6: Londquist and Martin, 1991
7: Kennedy/Jenks, 2001
8: Nishikawa et al., 2004
9: Kennedy/Jenks, 2005

[c]Note that the Oasis Fault is commonly known as the Pinto Mountain Fault in most studies.



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureC-1.pptx

Note: Data from USGS NWIS (http://waterdata.usgs.gov/nwis/). The title block of each hydrograph contains a hydrograph number (unique to this study) and the USGS identifier for each well.

Kennedy/Jenks Consultants

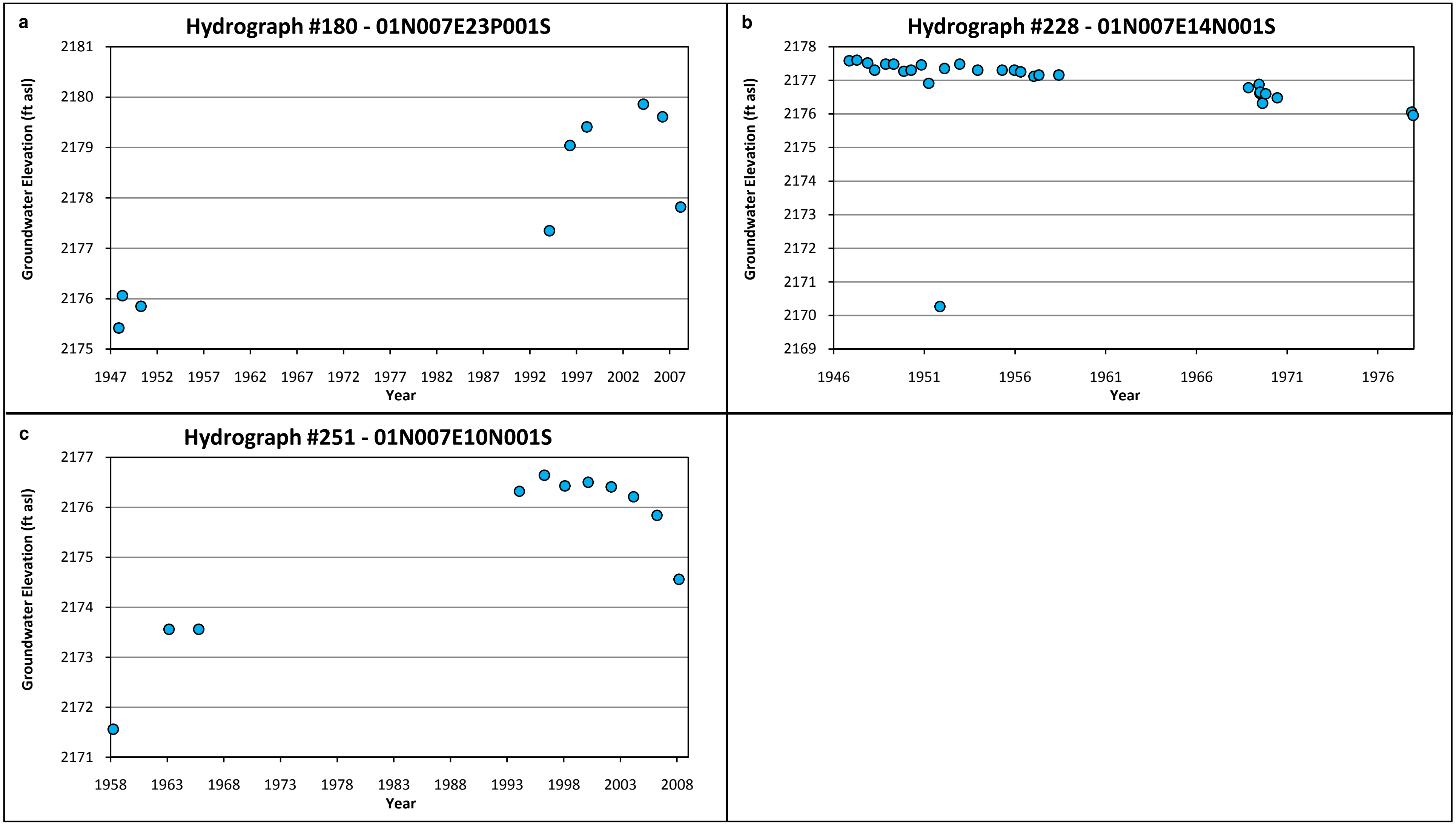
Twentynine Palms
San Bernardino County, California

Hydrographs for Wells in the Joshua Tree Basin

K/J 0964003*00
March 2010

Figure C-1

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureC-2.pptx



Note: Data from USGS NWIS (http://waterdata.usgs.gov/nwis/). The title block of each hydrograph contains a hydrograph number (unique to this study) and the USGS identifier for each well.

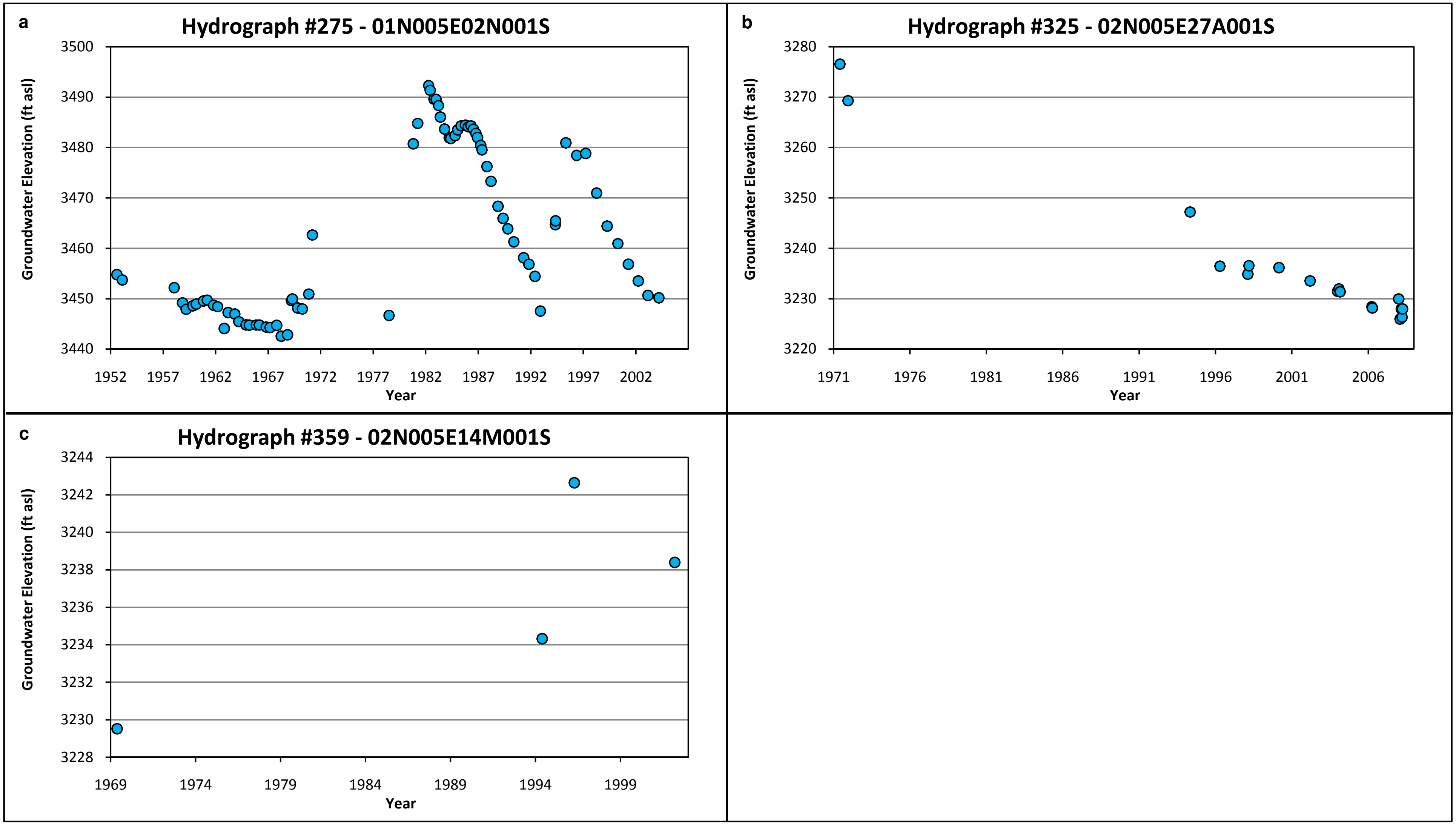
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for Wells in the Copper Mountain Subbasin

K/J 0964003*00
March 2010

Figure C-2



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureC-3.pptx

Note: Data from USGS NWIS (http://waterdata.usgs.gov/nwis/). The title block of each hydrograph contains a hydrograph number (unique to this study) and the USGS identifier for each well.

Kennedy/Jenks Consultants

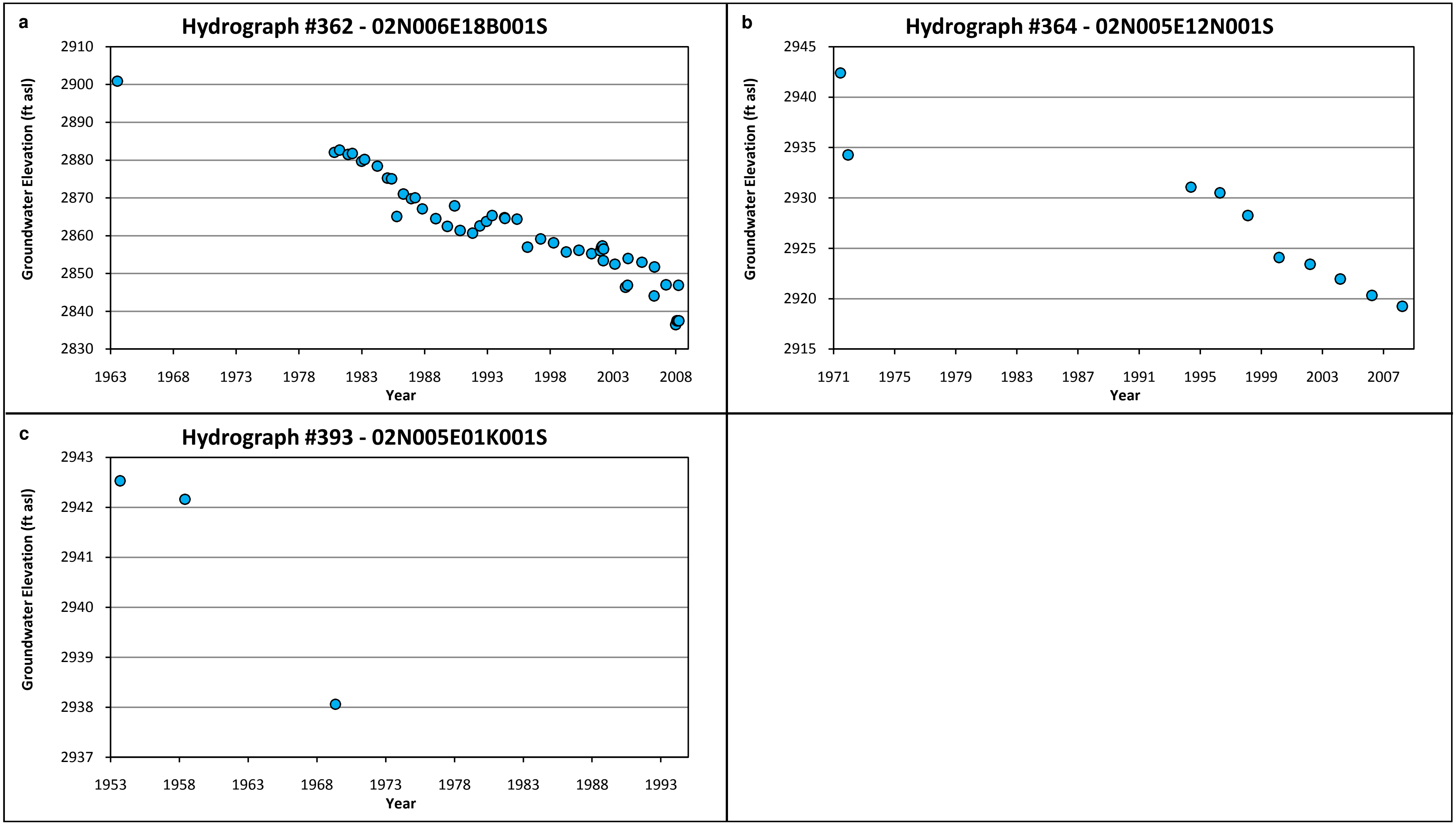
Twentynine Palms
San Bernardino County, California

Hydrographs for Wells in the Pipes Subbasin

K/J 0964003*00
March 2010

Figure C-3

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureC-4.pptx



Note: Data from USGS NWIS (http://waterdata.usgs.gov/nwis/). The title block of each hydrograph contains a hydrograph number (unique to this study) and the USGS identifier for each well.

Kennedy/Jenks Consultants

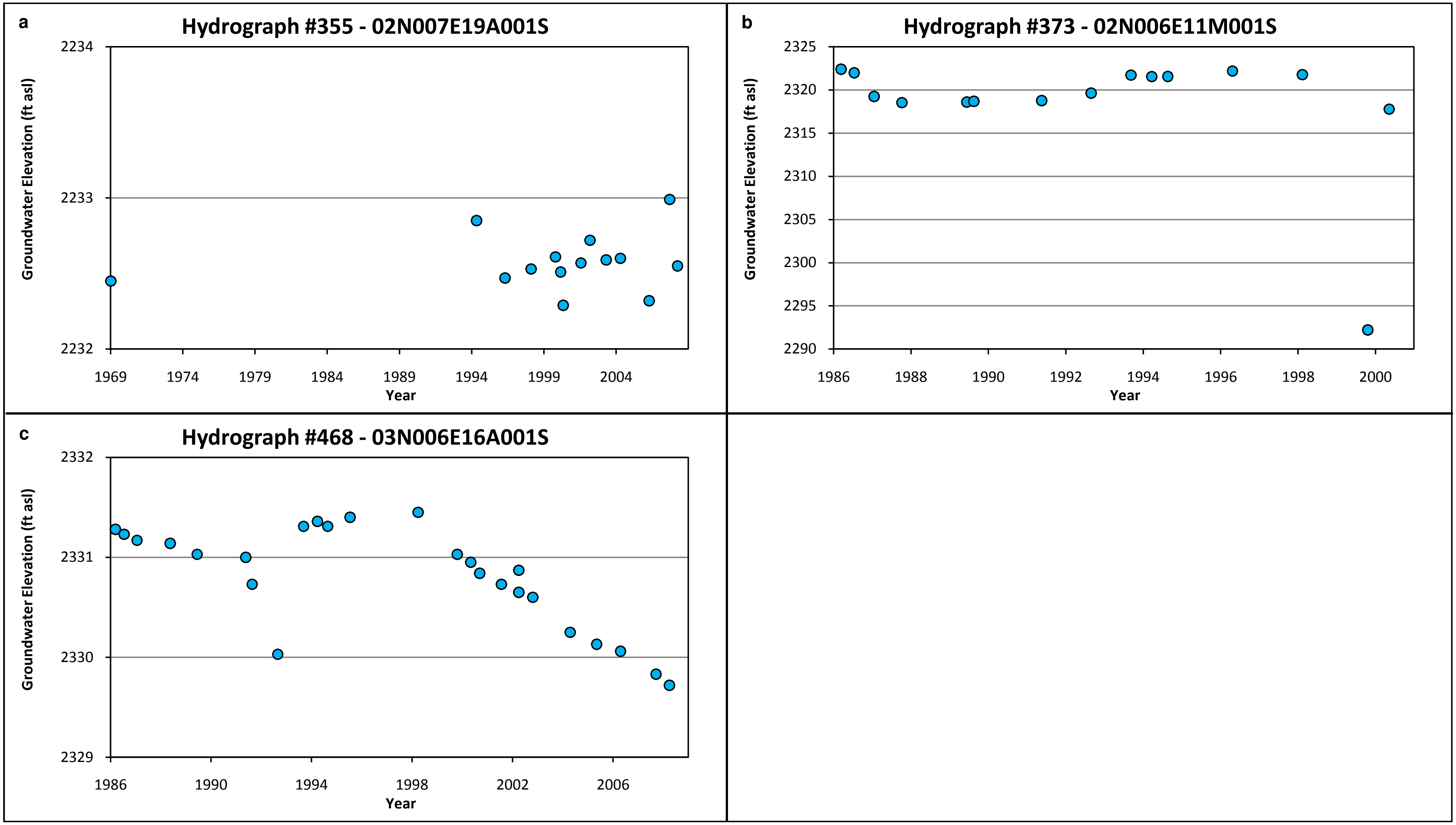
Twentynine Palms
San Bernardino County, California

Hydrographs for Wells in the Reche Subbasin

K/J 0964003*00
March 2010

Figure C-4

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureC-5.pptx



Note: Data from USGS NWIS (http://waterdata.usgs.gov/nwis/). The title block of each hydrograph contains a hydrograph number (unique to this study) and the USGS identifier for each well.

Kennedy/Jenks Consultants

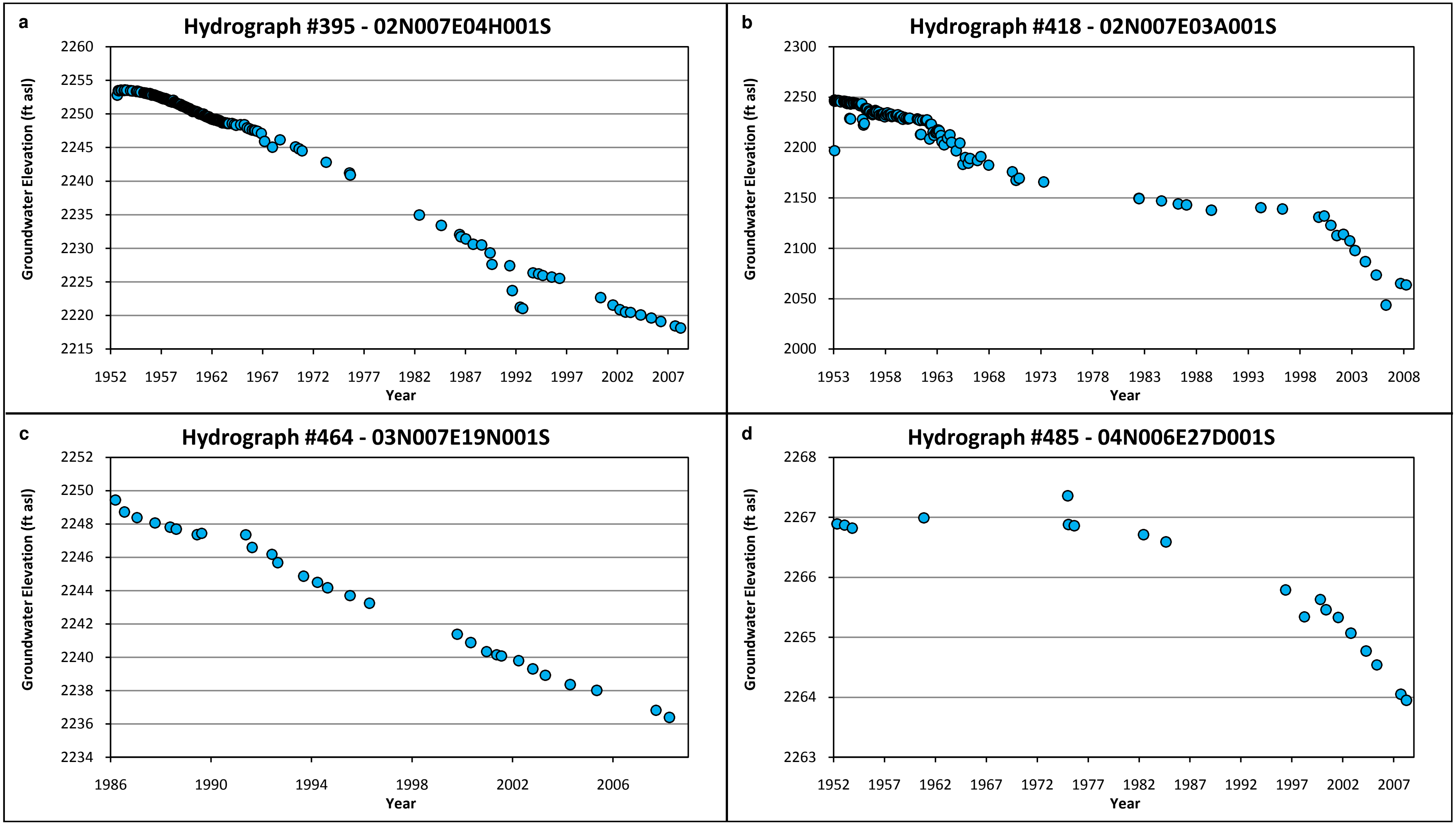
Twentynine Palms
San Bernardino County, California

Hydrographs for Wells in the Giant Rock Subbasin

K/J 0964003*00
March 2010

Figure C-5

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureC-6.pptx



Note: Data from USGS NWIS (http://waterdata.usgs.gov/nwis/). The title block of each hydrograph contains a hydrograph number (unique to this study) and the USGS identifier for each well.

Kennedy/Jenks Consultants

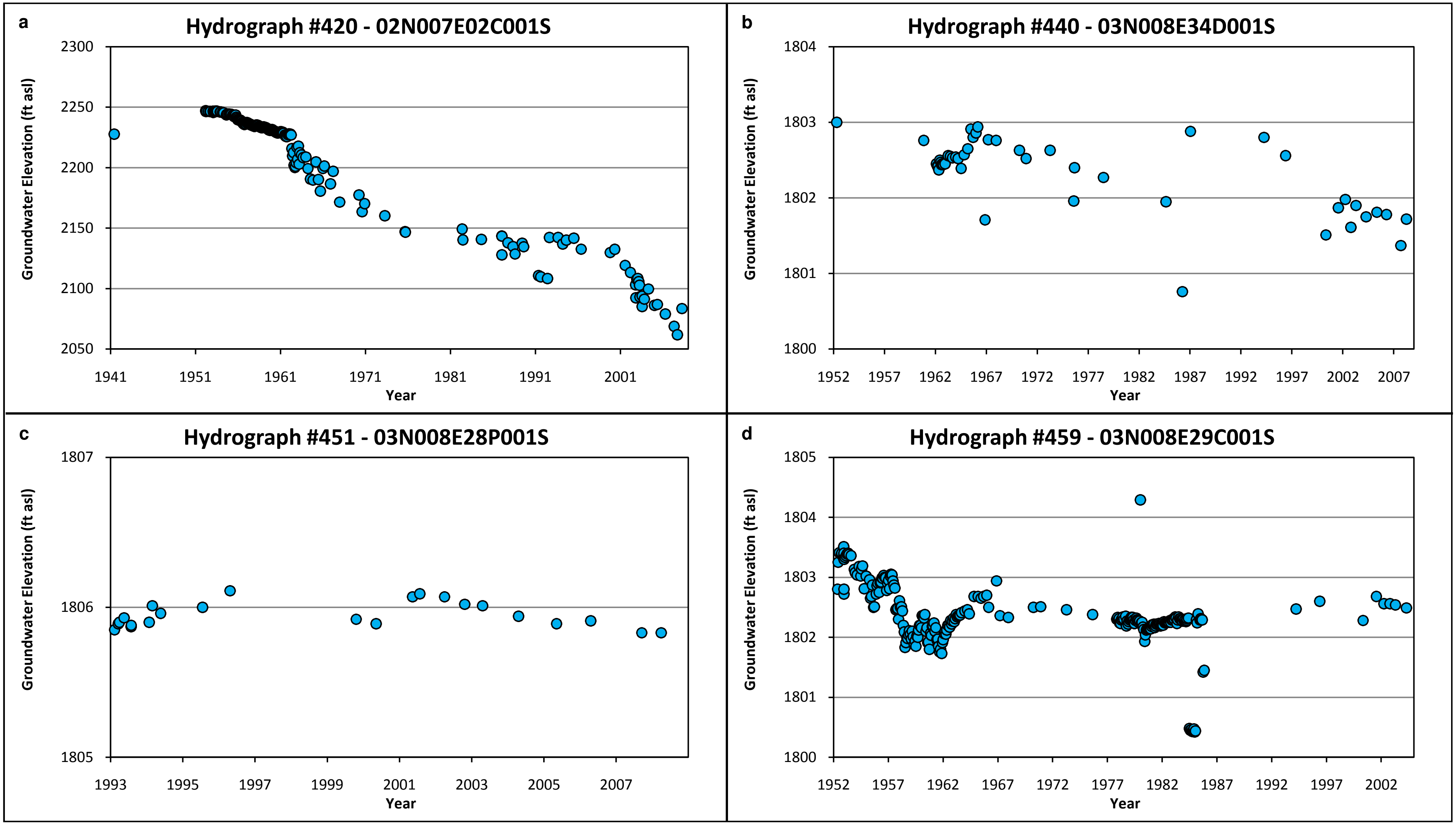
Twentynine Palms
San Bernardino County, California

Hydrographs for Wells in the Surprise Spring Subbasin

K/J 0964003*00
March 2010

Figure C-6

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureC-7.pptx



Note: Data from USGS NWIS (http://waterdata.usgs.gov/nwis/). The title block of each hydrograph contains a hydrograph number (unique to this study) and the USGS identifier for each well.

Kennedy/Jenks Consultants

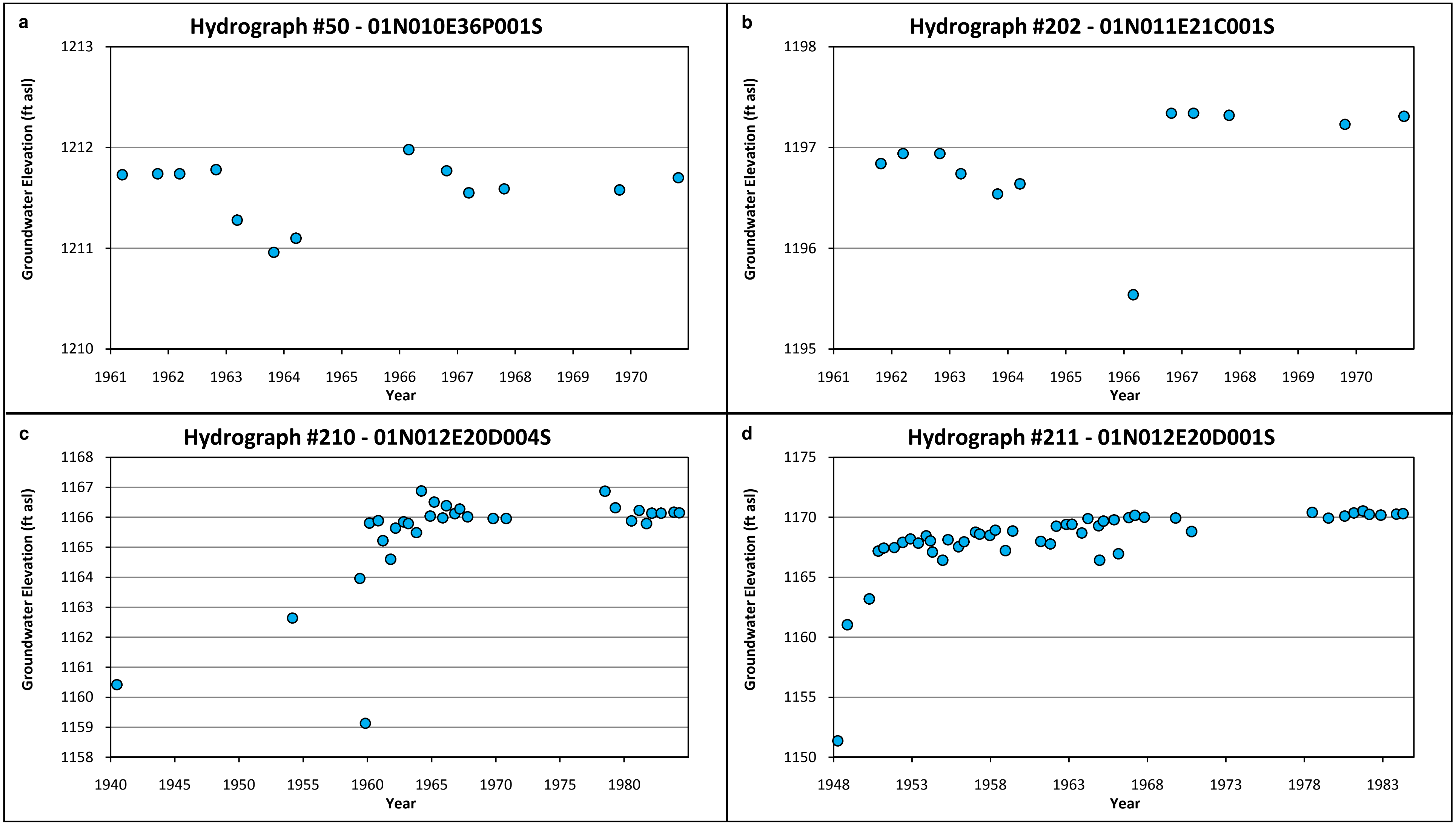
Twentynine Palms
San Bernardino County, California

Hydrographs for Wells in the Deadman Subbasin

K/J 0964003*00
March 2010

Figure C-7

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureC-8.pptx



Note: Data from USGS NWIS (http://waterdata.usgs.gov/nwis/). The title block of each hydrograph contains a hydrograph number (unique to this study) and the USGS identifier for each well.

Kennedy/Jenks Consultants

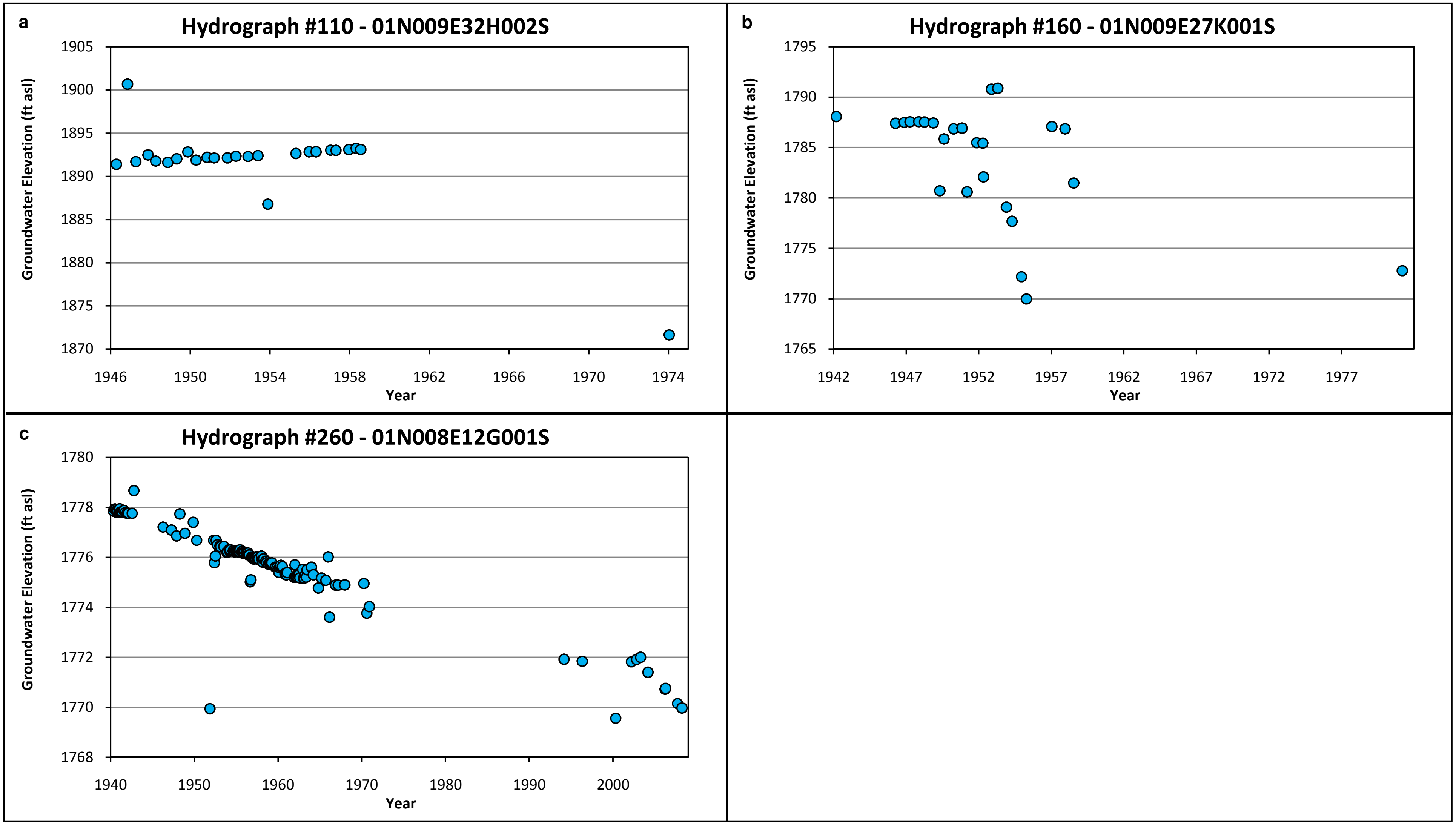
Twentynine Palms
San Bernardino County, California

Hydrographs for Wells in the Dale Basin

K/J 0964003*00
March 2010

Figure C-8

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureC-9.pptx



Note: Data from USGS NWIS (http://waterdata.usgs.gov/nwis/). The title block of each hydrograph contains a hydrograph number (unique to this study) and the USGS identifier for each well.

Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for Wells in the Mesquite Subbasin

K/J 0964003*00
March 2010

Figure C-9

Appendix D: Hydrologic Budget Calculations

Appendix D: Hydrologic Budget Calculations

Appendix D contains additional tables and graphs to support the hydrologic budget calculations used for this report.

List of Tables

D-1 Annual Maxey-Eakin Recharge in the Study Area Subbasins

D-2 Annual Evapotranspiration in the Study Area Subbasins

D-3 Annual Well Discharge in the Study Area Subbasins

D-4 Annual Pumping from TPWD Production Wells

D-5 Annual Groundwater Flow Between Study Area Subbasins

D-6 Annual Groundwater Head Differences Between Study Area Subbasins

D-7 Annual Calculated Change in Storage in Study Area Subbasins

Table D-1a: Maxey-Eakin recharge (in afy) to each of the study area subbasins on an annual basis using computed annual rainfall amounts (Recharge Method 1).

Subbasin / Year	%Mean	Joshua Tree	Copper Mountain	Pioneer-town	Pipes	Reche	Giant Rock	Surprise Spring	Deadman	Indian Cove	Fortynine Palms	Eastern	Mesquite	Dale	Total
Steady-State	--	27	0	633	57	0	0	0	1	0	7	2	0	0	727
1984	104%	98	0	776	110	3	0	0	5	0	25	8	0	0	1,026
1985	76%	0	0	110	0	0	0	0	0	0	0	0	0	0	110
1986	89%	0	0	315	6	0	0	0	0	0	0	0	0	0	321
1987	80%	0	0	153	0	0	0	0	0	0	0	0	0	0	153
1988	157%	3,250	415	3,983	1,160	777	616	653	1,641	119	443	571	1	916	14,545
1989	57%	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1990	47%	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	121%	1,209	2	1,496	394	36	2	19	182	10	159	135	0	43	3,687
1992	153%	3,009	352	3,640	1,076	746	406	548	1,511	101	390	527	0	747	13,054
1993	166%	4,040	579	4,990	1,389	852	1,118	1,539	1,989	159	573	682	67	1,305	19,283
1994	69%	0	0	50	0	0	0	0	0	0	0	0	0	0	50
1995	149%	2,832	287	3,348	999	703	234	463	1,394	87	359	490	0	614	11,809
1996	39%	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	116%	789	0	1,217	295	27	1	11	109	0	95	79	0	13	2,635
1998	186%	6,908	993	7,661	2,312	1,010	1,259	1,942	3,296	331	975	1,123	476	2,581	30,866
1999	69%	0	0	48	0	0	0	0	0	0	0	0	0	0	48
2000	60%	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	84%	0	0	225	0	0	0	0	0	0	0	0	0	0	225
2002	15%	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	128%	1,760	40	1,949	581	61	7	81	394	36	235	206	0	126	5,475
2004	125%	1,542	20	1,748	490	49	4	39	284	29	209	170	0	84	4,669
2005	219%	13,917	1,579	12,235	4,587	2,407	1,703	3,016	6,710	486	1,845	2,349	1,362	6,264	58,460
2006	57%	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	57%	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008	96%	2	0	497	35	0	0	0	0	0	0	0	0	0	534
Average	--	1,574	171	1,778	537	267	214	332	701	54	212	254	76	508	6,678

Table D-1b: Maxey-Eakin recharge (in afy) to each of the study area subbasins on an annual basis using percent of average annual rainfall (Recharge Method 2).

Subbasin / Year	%Mean	Joshua Tree	Copper Mountain	Pioneer-town	Pipes	Reche	Giant Rock	Surprise Spring	Deadman	Indian Cove	Fortynine Palms	Eastern	Mesquite	Dale	Total
Steady-State	--	27	0	633	57	0	0	0	1	0	7	2	0	0	727
1984	104%	28	0	661	59	1	0	0	1	0	7	2	0	0	758
1985	76%	20	0	483	43	0	0	0	1	0	5	2	0	0	554
1986	89%	24	0	563	50	0	0	0	1	0	6	2	0	0	646
1987	80%	21	0	504	45	0	0	0	1	0	5	2	0	0	578
1988	157%	42	0	993	89	1	0	0	2	0	10	3	0	0	1,139
1989	57%	15	0	360	32	0	0	0	1	0	4	1	0	0	413
1990	47%	13	0	300	27	0	0	0	0	0	3	1	0	0	344
1991	121%	32	0	765	68	1	0	0	1	0	8	2	0	0	878
1992	153%	41	0	967	87	1	0	0	2	0	10	3	0	0	1,110
1993	166%	44	0	1,052	94	1	0	0	2	0	11	3	0	0	1,207
1994	69%	18	0	438	39	0	0	0	1	0	5	1	0	0	503
1995	149%	40	0	946	85	1	0	0	2	0	10	3	0	0	1,085
1996	39%	10	0	249	22	0	0	0	0	0	3	1	0	0	286
1997	116%	31	0	736	66	1	0	0	1	0	8	2	0	0	844
1998	186%	49	0	1,177	105	1	0	0	2	0	12	4	0	0	1,350
1999	69%	18	0	437	39	0	0	0	1	0	5	1	0	0	501
2000	60%	16	0	377	34	0	0	0	1	0	4	1	0	0	432
2001	84%	22	0	532	48	0	0	0	1	0	5	2	0	0	610
2002	15%	4	0	98	9	0	0	0	0	0	1	0	0	0	112
2003	128%	34	0	811	72	1	0	0	1	0	8	3	0	0	930
2004	125%	33	0	789	71	1	0	0	1	0	8	3	0	0	906
2005	219%	58	0	1,385	124	1	0	0	2	0	14	4	0	0	1,589
2006	57%	15	0	364	33	0	0	0	1	0	4	1	0	0	417
2007	57%	15	0	364	33	0	0	0	1	0	4	1	0	0	417
2008	96%	25	0	607	54	0	0	0	1	0	6	2	0	0	696
Average	--	27	0	638	57	1	0	0	1	0	7	2	0	0	732

Table D-2a: Evapotranspiration discharge (in afy) from each of the study area subbasins on an annual basis using recharges from Table D-1a (Recharge Method 1).

Subbasin / Year	Joshua Tree	Copper Mountain	Pioneer-town	Pipes	Reche	Giant Rock	Surprise Spring	Deadman	Indian Cove	Fortynine Palms	Eastern	Mesquite	Dale	Total
Steady-State	0	0	10	0	0	0	75	30	0	0	2	550	144	811
1984	0	0	10	0	0	0	2	30	0	0	8	385	103	537
1985	0	0	10	0	0	0	0	30	0	0	0	383	103	526
1986	0	0	10	0	0	0	0	30	0	0	0	381	103	524
1987	0	0	10	0	0	0	0	30	0	0	0	379	103	522
1988	0	0	10	0	0	0	0	30	0	0	75	377	1,019	1,510
1989	0	0	10	0	0	0	0	30	0	0	0	374	103	518
1990	0	0	10	0	0	0	0	30	0	0	0	372	103	516
1991	0	0	10	0	0	0	0	30	0	0	75	370	146	631
1992	0	0	10	0	0	0	0	30	0	0	75	368	851	1,334
1993	0	0	10	0	0	0	0	30	0	0	75	366	1,409	1,890
1994	0	0	10	0	0	0	0	30	0	0	0	364	103	507
1995	0	0	10	0	0	0	0	30	0	0	75	362	718	1,195
1996	0	0	10	0	0	0	0	30	0	0	0	360	104	504
1997	0	0	10	0	0	0	0	30	0	0	75	358	117	590
1998	0	0	10	0	0	0	0	30	0	0	75	356	2,685	3,156
1999	0	0	10	0	0	0	0	30	0	0	0	354	105	499
2000	0	0	10	0	0	0	0	30	0	0	0	352	105	497
2001	0	0	10	0	0	0	0	30	0	0	0	350	105	495
2002	0	0	10	0	0	0	0	30	0	0	0	348	106	493
2003	0	0	10	0	0	0	0	30	0	0	75	346	232	693
2004	0	0	10	0	0	0	0	30	0	0	75	344	190	649
2005	0	0	10	0	0	0	0	30	0	0	75	342	6,370	6,827
2006	0	0	10	0	0	0	0	30	0	0	0	340	107	486
2007	0	0	10	0	0	0	0	30	0	0	0	338	104	482
2008	0	0	10	0	0	0	0	30	0	0	0	336	106	482
Average	0	0	10	0	0	0	0	30	0	0	30	360	612	1,043

Table D-2b: Evapotranspiration discharge (in afy) from each of the study area subbasins on an annual basis using recharges from Table D-1b (Recharge Method 2).

Subbasin / Year	Joshua Tree	Copper Mountain	Pioneer-town	Pipes	Reche	Giant Rock	Surprise Spring	Deadman	Indian Cove	Fortynine Palms	Eastern	Mesquite	Dale	Total
Steady-State	0	0	10	0	0	0	75	30	0	0	2	550	144	811
1984	0	0	10	0	0	0	2	30	0	0	2	385	103	532
1985	0	0	10	0	0	0	0	30	0	0	2	383	103	527
1986	0	0	10	0	0	0	0	30	0	0	2	381	103	525
1987	0	0	10	0	0	0	0	30	0	0	2	379	103	523
1988	0	0	10	0	0	0	0	30	0	0	3	377	103	523
1989	0	0	10	0	0	0	0	30	0	0	1	374	103	519
1990	0	0	10	0	0	0	0	30	0	0	1	372	103	516
1991	0	0	10	0	0	0	0	30	0	0	2	370	103	516
1992	0	0	10	0	0	0	0	30	0	0	3	368	103	515
1993	0	0	10	0	0	0	0	30	0	0	3	366	103	513
1994	0	0	10	0	0	0	0	30	0	0	1	364	103	509
1995	0	0	10	0	0	0	0	30	0	0	3	362	104	509
1996	0	0	10	0	0	0	0	30	0	0	1	360	104	505
1997	0	0	10	0	0	0	0	30	0	0	2	358	104	505
1998	0	0	10	0	0	0	0	30	0	0	4	356	104	504
1999	0	0	10	0	0	0	0	30	0	0	1	354	105	500
2000	0	0	10	0	0	0	0	30	0	0	1	352	105	498
2001	0	0	10	0	0	0	0	30	0	0	2	350	105	497
2002	0	0	10	0	0	0	0	30	0	0	0	348	106	494
2003	0	0	10	0	0	0	0	30	0	0	3	346	106	494
2004	0	0	10	0	0	0	0	30	0	0	3	344	106	493
2005	0	0	10	0	0	0	0	30	0	0	4	342	106	493
2006	0	0	10	0	0	0	0	30	0	0	1	340	107	487
2007	0	0	10	0	0	0	0	30	0	0	1	338	104	483
2008	0	0	10	0	0	0	0	30	0	0	2	336	106	484
Average	0	0	10	0	0	0	0	30	0	0	2	360	104	507

Table D-3: Estimated well discharge (in afy) from each subbasin on an annual basis.

Subbasin / Year	Joshua Tree	Copper Mountain	Pioneer-town	Pipes	Reche	Giant Rock	Surprise Spring	Deadman	Indian Cove	Fortynine Palms	Eastern	Mesquite	Dale	Total
Steady-State	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	1,236	92	25	60	75	10	2,700	30	1,845	217	0	580	10	6,880
1985	1,299	97	25	60	75	10	2,900	30	2,076	285	6	580	10	7,453
1986	1,362	102	25	60	75	10	2,500	30	1,927	485	0	580	10	7,165
1987	1,425	106	25	60	75	10	2,500	30	1,525	605	0	580	10	6,951
1988	1,488	111	25	60	75	10	2,500	30	1,453	1,205	0	580	10	7,546
1989	1,551	116	25	60	75	10	2,500	30	1,558	1,203	0	580	10	7,717
1990	1,614	120	25	60	75	10	2,500	30	1,904	850	33	580	10	7,812
1991	1,489	111	25	60	75	10	2,500	30	1,628	1,020	81	580	10	7,618
1992	1,489	111	25	60	75	10	2,500	30	1,560	1,010	353	580	10	7,813
1993	1,489	111	25	60	75	10	2,500	30	1,262	1,200	551	580	10	7,903
1994	1,489	111	25	60	75	10	2,500	30	1,074	1,596	463	580	10	8,022
1995	1,489	111	25	60	75	10	2,500	30	1,006	1,581	427	580	10	7,904
1996	1,489	111	25	60	75	10	2,500	30	1,130	1,481	533	580	10	8,035
1997	1,489	111	25	60	75	10	2,500	30	991	1,406	586	580	10	7,873
1998	1,489	111	25	60	75	10	2,500	30	1,028	1,481	521	580	10	7,920
1999	1,489	111	25	60	75	10	2,500	30	1,009	1,513	556	580	10	7,967
2000	1,489	111	25	60	75	10	2,500	30	1,113	1,474	659	580	10	8,136
2001	1,489	111	25	60	75	10	2,500	30	1,065	1,516	527	580	10	7,998
2002	1,489	111	25	60	75	10	2,500	30	1,120	1,620	829	580	10	8,459
2003	1,489	111	25	60	75	10	2,500	30	817	1,152	290	1,192	10	7,761
2004	1,489	111	25	60	75	10	2,500	30	1,172	947	470	1,373	10	8,272
2005	1,489	111	25	60	75	10	2,500	30	1,150	949	416	1,410	10	8,235
2006	1,489	111	25	60	75	10	2,500	30	1,193	1,021	483	1,394	10	8,401
2007	1,489	111	25	60	75	10	2,500	30	854	1,073	634	1,429	10	8,300
2008	1,489	111	25	60	75	10	2,500	30	691	1,024	737	1,530	10	8,292
Average	1,471	110	25	60	75	10	2,524	30	1,286	1,117	366	774	10	7,857

Table D-4: Annual (calendar year) pumping (in acre-feet) from TPWD production wells, as well as totals for the four subbasins from which water is withdrawn. Note that the numbers are rounded to the nearest acre-foot, but the totals are based on unrounded amounts.

TPWD Well ID[a]	1	2	3	3B	4	5	6	7	8	9	10	11	12	13	14	15	16	TP-1	Subbasin Totals			
Subbasin[b]	E	E	49	49	49	49	IC	IC	IC	IC	IC	IC	IC	49	49	IC	E	M	IC	49	E	M
1953	--	199	70	--	76	113	--	--	--	--	--	--	--	--	--	--	--	--	--	259	199	--
1954	--	216	147	--	44	155	--	--	--	--	--	--	--	--	--	--	--	--	--	346	216	--
1955	36	119	163	--	37	190	--	--	--	--	--	--	--	--	--	--	--	--	--	390	155	--
1956	124	164	130	--	60	182	--	--	--	--	--	--	--	--	--	--	--	--	--	371	288	--
1957	131	34	207	--	116	195	32	--	--	--	--	--	--	--	--	--	--	--	32	517	165	--
1958	71	138	230	--	91	218	43	--	--	--	--	--	--	--	--	--	--	--	43	539	209	--
1959	86	132	249	--	131	235	61	--	--	--	--	--	--	--	--	--	--	--	61	615	218	--
1960	0	40	326	--	108	381	69	--	--	--	--	--	--	--	--	--	--	--	69	815	40	--
1961	0	0	299	--	185	414	81	--	--	--	--	--	--	--	--	--	--	--	81	898	0	--
1962	0	0	371	--	234	333	109	--	--	--	--	--	--	--	--	--	--	--	109	937	0	--
1963	0	0	403	--	142	291	54	57	--	--	--	--	--	--	--	--	--	--	110	835	0	--
1964	4	0	259	--	193	185	18	372	--	--	--	--	--	--	--	--	--	--	390	637	4	--
1965	13	0	549	--	204	224	5	255	--	--	--	--	--	--	--	--	--	--	261	978	13	--
1966	18	0	222	--	294	443	1	283	--	--	--	2	--	--	--	--	--	--	285	959	18	--
1967	29	0	275	--	290	575	134	226	--	--	--	0	--	--	--	--	--	--	361	1,140	29	--
1968	2	0	138	--	72	170	20	109	--	--	--	0	--	--	--	--	--	--	129	381	2	--
1969	8	0	272	--	221	262	102	327	74	--	34	0	--	--	--	--	--	--	537	755	8	--
1970	26	0	42	--	0	0	61	161	317	356	391	0	--	--	--	--	--	--	1,286	42	26	--
1971	34	0	0	--	0	0	65	176	300	354	585	0	--	--	--	--	--	--	1,480	0	34	--
1972	29	0	23	--	6	42	70	99	354	364	618	0	--	--	--	--	--	--	1,505	71	29	--
1973	33	0	92	--	47	113	27	89	377	345	615	0	--	--	--	--	--	--	1,453	251	33	--
1974	24	0	37	--	8	173	54	173	165	429	571	0	--	--	--	--	--	--	1,392	218	24	--
1975	24	0	31	--	16	14	87	247	295	426	581	0	--	--	--	--	--	--	1,636	61	24	--
1976	36	0	54	--	48	44	105	190	332	308	619	0	--	--	--	--	--	--	1,554	145	36	--
1977	5	0	82	--	66	47	45	89	312	379	437	0	--	--	--	--	--	--	1,263	194	5	--
1978	32	0	75	--	63	70	93	263	296	284	471	217	--	--	--	--	--	--	1,623	208	32	--
1979	35	0	3	--	82	40	1	189	163	288	395	551	--	--	--	--	--	--	1,586	125	35	--
1980	54	0	104	--	111	26	167	232	62	424	206	561	--	--	--	--	--	--	1,652	240	54	--
1981	16	0	102	--	69	46	45	325	73	582	207	531	--	--	--	--	--	--	1,762	216	16	--
1982	2	0	13	--	60	78	100	195	191	464	265	553	--	--	--	--	--	--	1,768	150	2	--
1983	4	0	45	--	75	187	109	181	249	325	245	492	28	--	--	--	--	--	1,629	307	4	--
1984	0	0	105	--	64	48	78	199	286	85	291	492	414	--	--	--	--	--	1,845	217	0	--
1985	6	0	108	--	99	78	184	356	279	89	340	467	361	0	--	--	--	--	2,076	285	6	--
1986	0	0	198	--	191	95	173	210	133	324	255	220	612	1	--	--	--	--	1,927	485	0	--
1987	0	0	218	--	135	36	50	223	207	279	177	143	446	216	--	--	--	--	1,525	605	0	--
1988	0	0	96	--	108	842	223	219	0	159	338	82	432	159	--	--	--	--	1,453	1,205	0	--
1989	0	0	15	--	73	888	260	223	0	215	312	105	443	228	--	--	--	--	1,558	1,203	0	--
1990	33	0	0	--	55	660	284	199	0	262	287	281	549	135	--	43	--	--	1,904	850	33	--
1991	76	0	58	--	174	412	234	193	100	266	1	291	504	376	--	40	5	--	1,628	1,020	81	--
1992	90	36	29	--	186	525	120	58	137	337	76	538	293	270	--	2	227	--	1,560	1,010	353	--
1993	62	1	0	333	145	450	100	134	0	186	85	379	378	165	107	0	488	--	1,262	1,200	551	--
1994	53	0	0	334	70	437	51	137	0	202	220	295	169	91	664	0	410	--	1,074	1,596	463	--
1995	37	0	0	411	301	226	136	44	0	282	144	269	131	133	510	0	390	--	1,006	1,581	427	--
1996	30	0	0	455	302	15	87	45	0	313	131	304	250	117	591	0	503	--	1,130	1,481	533	--
1997	56	0	0	440	289	0	102	10	0	291	103	252	233	106	571	0	530	--	991	1,406	586	--
1998	37	0	0	361	249	0	105	11	0	268	126	251	267	111	760	0	484	--	1,028	1,481	521	--
1999	64	0	0	368	172	0	96	10	0	174	161	296	273	132	841	0	492	--	1,009	1,513	556	--
2000	103	0	0	318	150	0	95	15	0	278	165	282	277	135	871	0	557	--	1,113	1,474	659	--
2001	3	0	0	341	163	0	90	20	0	265	146	275	267	134	879	0	524	--	1,065	1,516	527	--
2002	253	0	0	369	217	0	91	21	0	285	154	278	291	173	860	0	576	--	1,120	1,620	829	--
2003	290	0	0	239	121	0	89	22	0	0	134	288	284	97	695	0	0	612	817	1,152	290	612
2004	177	0	0	239	87	0	91	1	0	290	161	322	306	59	562	0	293	793	1,172	947	470	793
2005	153	0	0	180	83	0	91	3	0	263	185	331	277	0	686	0	263	830	1,150	949	416	830
2006	144	0	0	145	74	0	107	0	0	265	163	294	364	0	803	0	338	814	1,193	1,021	483	814
2007	126	0	0	0	154	0	107	0	0	274	0	50	354	0	919	69	508	849	854	1,073	634	849
2008	214	0	0	0	143	0	53	0	0	215	0	143	232	0	881	49	523	950	691	1,024	737	950
Total	2,885	1,079	5,837	4,532	6,951	10,156	4,857	6,588	4,704	11,191	10,393	9,834	8,436	2,838	11,202	203	7,110	4,848	56,205	41,517	11,074	4,848

[a]TPWD ID is the well name; for example, well 3B is TPWD-3B.

[b]IC = Indian Cove; 49 = Fortynine Palms; E = Eastern; M = Mesquite.

Table D-5a: Groundwater flow (in afy) between subbasins under steady-state and annual conditions using Table D-1a recharge numbers (Recgarge Method 1).

Subbasin / Year	Joshua Tree to Copper Mountain	Joshua Tree to Indian Cove	Pioneertown to Pipes	Pipes to Reche	Reche to Giant Rock	Giant Rock to Surprise Spring	Surprise Spring to Deadman	Surprise Spring to Mesquite	Deadman to Mesquite	Copper Mountain to Mesquite	Indian Cove to Mesquite	Fortynine Palms to Mesquite	Eastern to Mesquite	Mesquite to Dale	Total
Steady-State	100	11	623	680	680	680	545	61	516	100	11	7	0	144	4,156
1984	101	34	741	423	667	794	411	55	550	99	10	6	0	113	4,003
1985	101	35	75	422	659	788	414	55	551	98	10	6	0	113	3,328
1986	100	35	280	422	654	854	416	55	551	98	10	6	0	113	3,595
1987	100	36	118	421	656	792	409	54	552	98	10	6	0	113	3,366
1988	99	36	3,948	421	651	796	400	54	555	98	10	6	0	113	7,187
1989	98	35	-35	420	649	808	406	54	558	98	10	5	0	113	3,219
1990	98	36	-35	420	651	812	390	53	560	98	10	6	0	113	3,212
1991	96	35	1,461	419	646	816	374	53	563	98	10	5	0	113	4,691
1992	96	37	3,605	419	648	825	395	52	566	98	10	5	0	113	6,869
1993	95	37	4,955	419	648	843	412	53	569	98	10	5	0	113	8,258
1994	95	37	15	418	648	851	407	53	572	98	9	5	0	113	3,321
1995	93	37	3,313	404	647	878	411	52	573	98	10	5	0	114	6,634
1996	92	37	-35	391	638	865	400	52	573	97	10	5	0	114	3,237
1997	91	37	1,182	390	641	872	398	52	573	97	10	5	0	114	4,461
1998	90	36	7,626	389	640	879	397	52	574	97	10	4	0	114	10,907
1999	89	36	13	385	639	871	395	51	574	97	10	4	0	115	3,279
2000	88	36	-35	382	642	863	399	51	574	97	10	4	0	115	3,225
2001	87	35	190	401	637	899	382	51	571	97	10	4	0	115	3,480
2002	86	36	-35	420	638	897	365	51	570	97	9	4	0	116	3,254
2003	85	36	1,914	422	634	896	354	51	569	97	9	3	0	116	5,187
2004	84	36	1,713	424	630	899	357	51	565	97	9	3	0	116	4,985
2005	83	37	12,200	425	635	902	341	51	568	97	9	3	0	116	15,466
2006	82	37	-35	426	628	904	331	50	566	97	9	3	0	117	3,216
2007	82	35	-35	427	627	919	313	50	583	96	9	3	0	114	3,225
2008	81	34	462	428	618	921	336	50	572	96	10	3	0	116	3,728
Average	92	36	1,743	414	643	858	385	52	566	97	10	5	0	114	5,013

Table D-5b: Groundwater flow (in afy) between subbasins under steady-state and annual conditions using Table D-1b recharge numbers (Recharge Method 2).

Subbasin / Year	Joshua Tree to Copper Mountain	Joshua Tree to Indian Cove	Pioneertown to Pipes	Pipes to Reche	Reche to Giant Rock	Giant Rock to Surprise Spring	Surprise Spring to Deadman	Surprise Spring to Mesquite	Deadman to Mesquite	Copper Mountain to Mesquite	Indian Cove to Mesquite	Fortynine Palms to Mesquite	Eastern to Mesquite	Mesquite to Dale	Total
Steady-State	100	11	623	680	680	680	545	61	516	100	11	7	0	144	4,156
1984	101	34	626	423	667	794	411	55	550	99	10	6	0	113	3,888
1985	101	35	448	422	659	788	414	55	551	98	10	6	0	113	3,700
1986	100	35	528	422	654	854	416	55	551	98	10	6	0	113	3,842
1987	100	36	469	421	656	792	409	54	552	98	10	6	0	113	3,716
1988	99	36	958	421	651	796	400	54	555	98	10	6	0	113	4,197
1989	98	35	325	420	649	808	406	54	558	98	10	5	0	113	3,579
1990	98	36	265	420	651	812	390	53	560	98	10	6	0	113	3,511
1991	96	35	730	419	646	816	374	53	563	98	10	5	0	113	3,960
1992	96	37	932	419	648	825	395	52	566	98	10	5	0	113	4,197
1993	95	37	1,017	419	648	843	412	53	569	98	10	5	0	113	4,320
1994	95	37	403	418	648	851	407	53	572	98	9	5	0	113	3,709
1995	93	37	911	404	647	878	411	52	573	98	10	5	0	114	4,231
1996	92	37	214	391	638	865	400	52	573	97	10	5	0	114	3,486
1997	91	37	701	390	641	872	398	52	573	97	10	5	0	114	3,980
1998	90	36	1,142	389	640	879	397	52	574	97	10	4	0	114	4,423
1999	89	36	402	385	639	871	395	51	574	97	10	4	0	115	3,668
2000	88	36	342	382	642	863	399	51	574	97	10	4	0	115	3,602
2001	87	35	497	401	637	899	382	51	571	97	10	4	0	115	3,786
2002	86	36	63	420	638	897	365	51	570	97	9	4	0	116	3,352
2003	85	36	776	422	634	896	354	51	569	97	9	3	0	116	4,048
2004	84	36	754	424	630	899	357	51	565	97	9	3	0	116	4,026
2005	83	37	1,350	425	635	902	341	51	568	97	9	3	0	116	4,616
2006	82	37	329	426	628	904	331	50	566	97	9	3	0	117	3,580
2007	82	35	329	427	627	919	313	50	583	96	9	3	0	114	3,589
2008	81	34	572	428	618	921	336	50	572	96	10	3	0	116	3,838
Average	92	36	603	414	643	858	385	52	566	97	10	5	0	114	3,874

Table D-6: Groundwater head differences (in feet) between subbasins under steady-state and annual conditions.

Subbasin / Year	Joshua Tree to Copper Mountain	Joshua Tree to Indian Cove	Pioneertown to Pipes	Pipes to Reche	Reche to Giant Rock	Giant Rock to Surprise Spring	Surprise Spring to Deadman	Surprise Spring to Mesquite	Deadman to Mesquite	Copper Mountain to Mesquite	Indian Cove to Mesquite	Fortynine Palms to Mesquite	Eastern to Mesquite	Mesquite to Dale
Steady-State	121	34	--	275	570	77	431	236	40	158	485	218	212	83
1984	124	104	--	171	559	90	325	215	43	157	449	195	200	65
1985	123	109	--	171	552	90	327	214	43	156	446	194	200	65
1986	122	107	--	171	548	97	329	213	43	156	439	191	200	65
1987	122	111	--	170	550	90	324	212	43	156	432	196	200	65
1988	121	110	--	170	546	90	317	211	43	156	439	190	200	65
1989	120	109	--	170	544	92	321	209	44	156	428	183	200	65
1990	119	109	--	170	546	92	309	207	44	156	427	185	199	65
1991	118	108	--	170	542	93	296	206	44	156	422	181	203	65
1992	118	114	--	169	544	94	312	201	44	156	424	178	187	65
1993	116	113	--	169	544	96	326	206	45	156	422	176	184	65
1994	116	113	--	169	543	97	322	206	45	156	394	161	186	65
1995	114	112	--	164	543	100	325	204	45	155	425	161	185	66
1996	112	112	--	158	535	98	316	203	45	155	419	154	183	66
1997	111	113	--	158	537	99	315	202	45	154	423	153	184	66
1998	110	112	--	157	536	100	314	201	45	153	418	145	181	66
1999	108	112	--	156	536	99	313	201	45	154	423	141	179	66
2000	107	109	--	154	538	98	316	200	45	154	424	139	179	66
2001	106	108	--	162	534	102	302	199	45	154	422	126	174	67
2002	105	110	--	170	535	102	289	198	45	154	416	121	171	67
2003	103	111	--	171	532	102	280	198	45	154	415	115	170	67
2004	102	111	--	172	528	102	283	198	44	154	414	115	169	67
2005	101	112	--	172	532	102	270	197	44	154	413	115	168	67
2006	100	114	--	172	527	103	262	197	44	153	410	113	166	67
2007	99	109	--	173	526	104	248	196	46	153	410	111	164	66
2008	99	105	--	173	518	105	266	196	45	152	418	107	164	67
Average	112	110	--	167	539	97	304	204	44	155	423	154	184	66

Table D-7a: Calculated change in storage (in afy) in each subbasin on an annual basis, based on recharge numbers from Table D-1a (Recharge Method 1).

Subbasin / Year	Joshua Tree	Copper Mountain	Pioneer-town	Pipes	Reche	Giant Rock	Surprise Spring	Deadman	Indian Cove	Fortynine Palms	Eastern	Mesquite	Dale	Total
Steady-State	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	-1,189	-89	0	254	-316	-137	-2,374	-194	-1,822	-198	0	-358	0	-6,423
1985	-1,351	-94	0	-34	-312	-140	-2,580	-197	-2,050	-291	-6	-355	0	-7,412
1986	-1,413	-100	0	52	-307	-211	-2,116	-195	-1,902	-490	0	-353	0	-7,036
1987	-1,476	-105	0	-13	-309	-147	-2,171	-203	-1,499	-610	0	-351	0	-6,885
1988	1,711	304	0	1,637	472	461	-1,505	1,426	-1,308	-767	496	-346	0	2,583
1989	-1,600	-116	0	-155	-303	-169	-2,152	-212	-1,532	-1,209	0	-343	0	-7,791
1990	-1,663	-121	0	-215	-306	-171	-2,131	-230	-1,879	-856	-33	-338	0	-7,944
1991	-328	-111	0	644	-266	-177	-2,092	-67	-1,592	-866	-20	-334	0	-5,210
1992	1,470	240	0	1,529	441	220	-1,574	1,279	-1,431	-626	99	-330	0	1,318
1993	2,503	465	0	1,927	547	914	-583	1,772	-1,076	-632	56	-257	0	5,636
1994	-1,537	-114	0	-75	-305	-214	-2,109	-225	-1,046	-1,601	-463	-321	0	-8,008
1995	1,297	171	0	1,446	385	-7	-1,624	1,173	-893	-1,226	-12	-318	0	392
1996	-1,533	-117	0	-237	-322	-237	-2,087	-234	-1,103	-1,486	-533	-317	0	-8,206
1997	-744	-117	0	546	-299	-241	-2,068	-126	-964	-1,316	-582	-316	0	-6,226
1998	5,377	875	0	3,004	684	1,009	-127	3,059	-670	-511	528	161	0	13,390
1999	-1,530	-119	0	-44	-329	-242	-2,076	-239	-982	-1,517	-556	-313	0	-7,945
2000	-1,528	-120	0	-100	-335	-230	-2,088	-235	-1,087	-1,478	-659	-311	0	-8,172
2001	-1,527	-121	0	36	-311	-272	-2,034	-249	-1,039	-1,520	-527	-313	0	-7,877
2002	-1,527	-122	0	-417	-293	-269	-2,019	-265	-1,093	-1,623	-829	-312	0	-8,771
2003	235	-84	0	874	-226	-265	-1,928	119	-755	-921	-159	-924	0	-4,033
2004	17	-105	0	760	-232	-274	-1,971	16	-1,115	-741	-374	-1,108	0	-5,127
2005	12,392	1,454	0	5,452	2,123	1,426	1,026	6,424	-637	893	1,859	222	0	32,632
2006	-1,524	-126	0	-157	-277	-285	-1,977	-296	-1,165	-1,025	-483	-1,124	0	-8,440
2007	-1,522	-126	0	-159	-275	-301	-1,945	-330	-828	-1,076	-634	-1,139	0	-8,334
2008	-1,518	-125	0	119	-265	-313	-1,965	-296	-667	-1,027	-737	-1,250	0	-8,045
Average	60	55	0	667	-37	-11	-1,771	459	-1,205	-909	-143	-442	0	-3,277

Table D-7b: Calculated change in storage (in afy) in each subbasin on an annual basis, based on recharge numbers from Table D-1b (Recharge Method 2).

Subbasin / Year	Joshua Tree	Copper Mountain	Pioneer-town	Pipes	Reche	Giant Rock	Surprise Spring	Deadman	Indian Cove	Fortynine Palms	Eastern	Mesquite	Dale	Total
Steady-State	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	-1,259	-89	0	317	-319	-137	-2,374	-198	-1,822	-216	0	-358	0	-6,455
1985	-1,331	-94	0	-364	-311	-140	-2,580	-196	-2,050	-286	-6	-355	0	-7,715
1986	-1,389	-100	0	-151	-307	-211	-2,116	-194	-1,902	-485	0	-353	0	-7,208
1987	-1,455	-105	0	-318	-309	-147	-2,171	-202	-1,499	-605	0	-351	0	-7,162
1988	-1,497	-110	0	3,556	-304	-156	-2,158	-213	-1,427	-1,200	0	-347	0	-3,855
1989	-1,585	-116	0	-483	-303	-169	-2,152	-211	-1,532	-1,205	0	-343	0	-8,099
1990	-1,650	-121	0	-488	-306	-171	-2,131	-230	-1,879	-853	-33	-338	0	-8,200
1991	-1,504	-113	0	1,050	-301	-180	-2,111	-248	-1,602	-1,017	-81	-334	0	-6,442
1992	-1,498	-113	0	3,213	-304	-186	-2,122	-230	-1,532	-1,006	-353	-331	0	-4,460
1993	-1,493	-114	0	4,571	-304	-205	-2,122	-215	-1,235	-1,194	-551	-325	0	-3,187
1994	-1,518	-114	0	-424	-304	-214	-2,109	-224	-1,046	-1,596	-463	-321	0	-8,333
1995	-1,495	-115	0	2,933	-317	-241	-2,086	-220	-979	-1,576	-427	-319	0	-4,841
1996	-1,523	-117	0	-463	-322	-237	-2,087	-233	-1,103	-1,483	-533	-317	0	-8,419
1997	-1,502	-117	0	798	-325	-241	-2,078	-234	-964	-1,403	-586	-316	0	-6,968
1998	-1,482	-118	0	7,282	-325	-250	-2,069	-235	-1,001	-1,474	-521	-315	0	-506
1999	-1,512	-119	0	-394	-328	-242	-2,076	-238	-982	-1,512	-556	-313	0	-8,271
2000	-1,512	-120	0	-443	-335	-230	-2,088	-234	-1,087	-1,475	-659	-311	0	-8,495
2001	-1,505	-121	0	-223	-311	-272	-2,034	-248	-1,039	-1,514	-527	-313	0	-8,107
2002	-1,522	-122	0	-506	-293	-269	-2,019	-265	-1,093	-1,622	-829	-312	0	-8,854
2003	-1,492	-123	0	1,504	-286	-272	-2,009	-274	-790	-1,147	-290	-924	0	-6,103
2004	-1,491	-124	0	1,300	-280	-279	-2,010	-266	-1,145	-943	-470	-1,108	0	-6,816
2005	-1,466	-125	0	11,839	-283	-277	-1,990	-284	-1,123	-938	-416	-1,140	0	3,797
2006	-1,508	-126	0	-489	-277	-285	-1,977	-295	-1,165	-1,021	-483	-1,124	0	-8,751
2007	-1,507	-126	0	-490	-275	-301	-1,945	-329	-828	-1,072	-634	-1,139	0	-8,645
2008	-1,495	-125	0	28	-265	-313	-1,965	-295	-667	-1,021	-737	-1,250	0	-8,106
Average	-1,488	-116	0	1,326	-304	-225	-2,103	-240	-1,260	-1,115	-366	-518	0	-6,408

Appendix E: Groundwater Model Development

Appendix E: Groundwater Model Development

Appendix E presents additional detail on the development of the numerical groundwater model for the Twentynine Palms area. The basic components of the conceptual model required to construct a numerical model describe how groundwater enters and exits a defined system and the geologic factors that control groundwater flow.

E.1 Numerical Model Setup

The numerical model was constructed using the groundwater flow model MODFLOW-2000 (Harbaugh et al., 2000), an update to the original MODFLOW model (McDonald and Harbaugh, 1984), a finite-difference numerical model developed by the USGS. To facilitate model development, the MODFLOW processor Groundwater Vistas 5 (GWV5; ESI, 2007) was used. The use of the industry standard modeling code MODFLOW 2000 along with a commercial processor supports future usability of the model.

E.1.1 Model Domain

The model domain is the geographical area covered by the numerical model. The model domain for the MODFLOW Model includes the Mesquite Lake, Indian Cove, Fortynine Palms, and Eastern Subbasins. The model domain is a square box that contains all of the areas of these four basins, measuring about 17 miles on each side, for a total area of about 290 square miles (about 186,000 acres). However, much of the model domain does not actively participate in the groundwater flow system, being areas where bedrock is very close to or at the surface. The actual active area of the uppermost layer of the model is 82,000 acres, or 130 square miles.

The model grid provides the mathematical structure for developing and operating the numerical model. The MODFLOW Model used a uniform grid spacing of 300 feet. The model grid is composed of 300 rows and 300 columns; therefore, each model layer contains 90,000 cells (Figure E-1). The entire three-layer model contains a total of 270,000 cells. As noted above, not all of these cells are active; in fact, only 46,890 cells are active. The rest are no-flow cells, meaning simply that they do not participate in the groundwater model. The actual number of active cells varies depending upon the model layer, as will be discussed below.

E.1.2 Model Layers

Model layers provide vertical resolution for the model to simulate variations in groundwater elevation, aquifer stresses, and water quality with depth. The MODFLOW Model consists of three layers that simulate the primary water-bearing formations, consisting of Quaternary and Tertiary alluvium. Because the hydrologic properties of the alluvium vary with depth, the alluvium was divided into three model layers, following the convention of the USGS for another groundwater modeling study just to the west (Nishikawa et al., 2004).

The upper surface of the model represents the basin topography, and is based on a DEM from the National Elevation Dataset (NED; Gesch et al., 2002; Gesch, 2007) with a 30-meter spatial resolution. The top and bottom elevations of each model layer were derived from the basin cross-sections (Figures E-2, E-3, E-4, and E-5). To create the model layers, a digital structure contour map was developed for each layer interface. These layers were terminated at the bedrock surface. These maps were then directly imported into the numerical model. It should be noted that, within any individual fault-bounded section of the basin, the interfaces between the layers were mostly assumed to be flat.

Model Layer 1 represents the most recent Quaternary alluvium (Nishikawa et al., 2004) which is the most transmissive aquifer unit. This layer is distributed throughout the non-bedrock areas of the model (Figure E-6). It was assumed that the maximum thickness of this layer was upwards of 750 feet in the area of the boundary between the Indian Cove and Fortynine Palms Subbasins. In general, the thickness varies from 300 to 400 feet in the deepest parts of the basins to zero at the bedrock outcrops. The thickness of this model layer was widely variable throughout the model both because of the topography of the bedrock surface, and because of the presence of numerous faults, along which parts of the basin have dropped or risen tectonically.

Model Layer 2 represents a lower aquifer of Quaternary age (Nishikawa et al., 2004). This layer is less transmissive than is Layer 1. It is present chiefly in the eastern part of the Mesquite Lake Subbasin, as well as within the down-dropped graben between the Oasis and Pinto Faults in the southern part of the model domain (Figure E-7). The maximum thickness of this layer is about 600 feet in the western part of the Indian Cove Subbasin. The model thickness drops to zero where it intersects with the bedrock.

Model Layer represents the lowest aquifer, which is of Tertiary age (Nishikawa et al., 2004). This layer represents the lowest alluvium, directly overlying the bedrock wherever present. This layer is chiefly present along the Mesquite Fault in the Mesquite Lake Subbasin, and in the down-dropped graben in the Indian Cove Subbasin (Figure E-8). The thickness of this layer is 400 feet along the western border of the Indian Cove Subbasin. This layer is considered the least transmissive of the three alluvial layers.

E.1.3 Stress Periods

To simulate changing conditions over time requires the definition of stress periods that represent the resolution of time into discrete intervals. For the MODFLOW Model, annual stress periods were used. Although the rainfall is highly seasonal in nature, the water levels measured in wells, even those quite close to the edges of the basin, do not respond to this seasonality, indicating that an annual timestep can be used. To simulate the 25-year base period of 1984 to 2008, the model required 25 stress periods.

E.2 Boundary Conditions

Model boundary conditions define the hydrologic conditions at the edges of the model domain, representing the hydrologic budget by simulating where groundwater enters and exits the basin. Boundary condition data must be entered for each stress period at each model grid cell where a boundary condition is defined in the model. MODFLOW-2000 provides a number of different boundary condition options to numerically represent the different physical processes included in the hydrologic budget.

The geographic distribution of and amount of inflow and outflow of each water budget component needs to be accounted for within the model domain. Some of the model input parameters depend on geology, others on location, and others on vegetation. A discussion of each component of the hydrologic budget that is represented by a boundary condition is provided below.

E.2.1 Precipitation Recharge

Precipitation recharge represents groundwater inflow resulting from rainfall percolating downward to the groundwater. Precipitation recharge is dependent upon multiple factors including amount of precipitation, land use, surface topography, and soil moisture conditions. Recharge only occurs where there is an excess of water, a rare occurrence in this arid climate. Within the model domain, the water budget only calculates recharge for the Fortynine Palms and Eastern Subbasins, as these basins are located at the outlets of streams that reach into the highest parts of the Little San Bernardino Mountains.

Precipitation recharge was incorporated into the model using the MODFLOW recharge package. Recharge cells were created in a strip two cells wide along the bedrock-alluvium interface, except where major streams indicated that recharge should be extended further into the basin (Figure E-9). The total recharge for a basin was then divided up between all of the active recharge cells. The total recharge for the model was 210 af over the entire model period, for an annual average of 8.4 afy (Table 5-2). Of this, 5% was applied to the Indian Cove Subbasin, 62% was applied to the Fortynine Palms Subbasin, and 33% was applied to the Eastern Subbasin. No recharge occurred in the Mesquite Lake Subbasin.

Because the alluvial basins of the study area do not respond to year-to-year changes in precipitation, recharge was applied as a steady-state condition. Recharge was only applied to the uppermost model layer.

E.2.2 Evapotranspiration

ET represents the component of groundwater outflow from evaporation to the atmosphere and uptake by plants (transpiration). ET only is important to the groundwater budget in a few places within the study area. Two of these exist within the model domain, at the area around Mesquite Springs and Mesquite Dry Lake, and the area of the Oasis of Mara (Figure E-10).

The MODFLOW evapotranspiration package was used to input ET data into the model. The reference ET (ET_0 – the amount of ET that would be expected from a reference grass crop with ample water) applied to both ET zones was 83 inches per year, based on information from the University of California (Snyder et al., 1992). ET is also a head dependent boundary condition; when the groundwater elevation is closer to the surface, ET increases. The ET depth limit was set at 15 feet (6 meters) in the area around Mesquite Dry Lake, and 16.4 feet (5 meters) around the Oasis of Mara. These values are based on general information about the maximum rooting depth of types of vegetation present in these areas (Canadell et al., 1996): mesquite around Mesquite Dry Lake, and a variety of plants (including mesquite, willows, palms, and others) around the Oasis of Mara (Riley and Worts, 1953). The ET depth limit around Mesquite Dry Lake is shallower than indicated by Canadell et al. (1996), due to the fact that the mesquite in this area is quite scattered. Because the uppermost model layer is so thick, ET was only applied to this layer.

Evapotranspiration totaled 41,300 af over the 25-year period of the model, for an average of 1,650 afy (Table 5-2). The vast majority (98.8%) of this occurred around Mesquite Dry Lake, with the remaining 1.2% being lost around the Oasis of Mara.

E.2.3 Groundwater Pumpage

Groundwater pumpage is the most significant groundwater outflow component for the basin. Groundwater pumpage is represented in the MODFLOW model using two different methods: as boundary conditions and analytical elements. Analytical elements were used to represent individual production wells, including those operated by TPWD, while boundary conditions were used to represent domestic wells, whose locations and discharges are unknown.

For analytical elements, the location and amount of pumping are both specified, as well as the layers from which groundwater is extracted. MODFLOW automatically apportions the well pumping to all layers across which the well is screened, based on layer thicknesses and hydrologic properties. Model layer assignments were based on well screen intervals for each individual well. For the boundary conditions (which are applied using the MODFLOW well package), the amount of pumping is specified for each well location. In the model, pumpage comes from a combination of TPWD wells, municipal wells, and rural domestic wells. Below is a more detailed discussion of each. Total pumping varied from year to year in the model; the total water pumped was 95,200 af, for an annual average of 3,800 afy (Table 5-2).

There are 19 production wells that have been drilled in the study area by TPWD. Of these, three are in the Eastern Subbasin, six are in the Fortynine Palms Subbasin, eight are in the Indian Cove Subbasin, and two are in the Mesquite Lake Subbasin. It should be noted that not all of these wells are active any more, but all were at some point during the model period (1984 to 2008). Pumping was applied to each well based on measurements provided by TPWD the amount of pumping for each timestep was the sum of reported pumping for that year. Pumping from individual wells varied from 0.02 to 950 afy. The total pumping from all wells ranged from 460 to 3600 afy (Figure 4-2).

In addition to the TPWD wells, there are two areas irrigated by locally-extracted groundwater in the Mesquite Lake Subbasin: the park at Utah Trail and 2 Mile Road, and the Roadrunner Dunes Golf Course. It was assumed that each is supplied by a single pumping well that pumps at steady state. No information is available for pumping rates and screened intervals for the wells that provide water to these areas. Each well was assigned a pumping rate of 290 afy (Mike Wright, Personal Communication, 10/29/2009), and this amount was assumed not to change over the model period. The wells only exist in Model Layer 1, as are most other wells in the model.

In addition to the production wells mentioned above, there are numerous domestic wells throughout the model area that supply single or multiple homes. Records for these wells are not available, so there is no information on the number, location, pumping rates, or screened intervals of domestic wells. Domestic wells were placed in the model using the MODFLOW well package. Wells were placed only in areas that have existing structures, and where the model showed that pumping from TPWD wells alone did not seem to account for all pumping from a basin. No wells were placed among the higher-density housing areas in the southern part of the Mesquite Lake Subbasin, as there are few data available for groundwater levels in this area, particularly toward the west. Groundwater level data indicate that there are few domestic wells in the Indian Cove Subbasin, where population is sparse. The number of cells used in the Fortynine Palms and Eastern Subbasins, as well as the pumping rates applied, are included in Table E-1.

E.2.4 Subsurface Inflow

Subsurface inflow accounts for groundwater inflow into the model area from other basins. This subsurface inflow is simulated in MODFLOW using the general head boundary (GHB). This type of boundary condition allows flow into and out of the model, based on the groundwater head at the boundary and several parameters (hydraulic conductivity of the boundary, width of the boundary, distance to the specified head, and saturated thickness at the boundary) that are combined together into a single parameter, the conductance, according to the equation:

$$C = \frac{wbK}{d}$$

where C is the conductance [L^2/T], w is the cell width [L], b is the saturated thickness [L], K is the hydraulic conductivity [L/T], and d is the distance to the head measurement [L]. The conductance is multiplied by the specified head [L] to determine the volume of water flowing through the boundary.

Inflow to the basin was modeled along the Transverse Arch at the north end of the Mesquite Lake Subbasin, from the Deadman and Surprise Spring Subbasins; along the western boundary of the Mesquite Lake Subbasin, from the Copper Mountain Subbasin; along the western boundary of the Indian Cove Subbasin, from the Joshua Tree Subbasin; and along the eastern boundary of the Copper Mountain bedrock block in northwestern Mesquite Lake Subbasin (Figure E-11). Because of the presence of faults that cross the Transverse Arch, the head difference along this boundary changes; therefore, this boundary is actually divided into three GHBs. The parameters for the various GHBs are given in Table E-2. It should be noted that the saturated thickness is not included in this table, as the saturated thickness is highly variable along the length of a given GHB (due to changes in the thicknesses of layers); the saturated thickness is calculated based on the boundary head and the depth to the bottom of the layer. The table also includes the actual flux (annual average) across each GHB. The inflows to the model are 684 afy along the Transverse Arch, 20 afy from the Joshua Tree Subbasin, and 124 afy along Copper Mountain, mostly through the bedrock (Table 5-2).

E.2.5 Subsurface Outflow

Water leaves the model along the Mesquite Fault, flowing into the Dale Basin to the east (Figure E-11). This interaction is modeled as a MODFLOW general head boundary, as discussed above. The parameters for this GHB are included in Table E-2. The average annual flux across this GHB is 519 afy (Table 5-2).

E.3 Aquifer Properties

Aquifer properties represent the hydrogeologic characteristics within the basin. Specifically, aquifer properties describe the physical characteristics of the aquifer and the hydraulic properties that control groundwater flow. As discussed in the conceptual model, the numerical model consists of three model layers that correlate with the alluvial stratigraphy and are representative of the hydrogeological conditions.

The numerical model requires that these properties are defined for every active cell in the model. Extrapolation methods to define properties in areas with insufficient data have been performed using science-based assumptions based on the conceptual model. Reasonable value ranges for each have been defined and have been used to guide model calibration. Specific aquifer properties are summarized below.

E.3.1 Hydraulic Conductivity

For the numerical model, hydraulic conductivity is defined horizontally within a model layer and vertically between adjacent model layers. Rather than attempting to model individual sand and gravel zones, the model layers define thicker intervals that represent subdivisions of the basin aquifer system. The hydraulic conductivity for these layers represents an average value for the entire interval. For example, the hydraulic conductivity of Model Layer 1 represents the overall conductivity across the entire thickness of that aquifer, rather than for a specified sand and gravel zone.

Because no data are available on the spatial variability of hydraulic conductivity, it was set equal throughout all of a given model layer, except near the mountain front in Model Layer 1. Hydraulic conductivity values were set based on the model results of Nishikawa et al. (2004), although the hydraulic conductivity of Model Layer 1 is lower than their estimate. The hydraulic conductivity zones for Model Layer 1 are shown on Figure E-12 (hydraulic conductivity is uniform in Model Layers 2 and 3). The horizontal and vertical hydraulic conductivities for each zone are given in Table E-3.

The horizontal hydraulic conductivity (K_h) is 0.6 ft/d in the zone bounding the mountain front in Model Layer 1, while it is assumed that the vertical hydraulic conductivity (K_z) is 10% of this value, a common assumption. K_h was set to 15 ft/d in the Indian Cove Subbasin between the Oasis and Pinto Faults, and throughout the Eastern Subbasin, with K_z set to 1% of this value (due to the likely highly stratified nature of the alluvial sediments). K_h was set to 10 ft/d (with K_z set to 1% of this value) for the Mesquite and Fortynine Palms basins, as well as the Indian Cove Subbasin south of the Pinto Fault. K_h for Model Layer 2 is 1 ft/d, and K_z is 1% of this value, except in the same mountain-front zone, where K_h is 0.6 ft/d and K_z is 0.06 ft/d. K_h for Model Layer 3 is 0.5 ft/d, and K_z is 1% of this value.

E.3.2 Storage Coefficient and Specific Yield

Specific yield is the volume of water that is released by a unit volume of aquifer under gravity drainage. No data are available for specific yield in the four study basins, so it is instead based on values determined by Nishikawa et al. (2004). The specific yield of Model Layer 1 is 0.18. The porosity is 0.2. The specific yield value for this layer is typical of alluvial deposits dominated by sand and gravel (Walton, 1970). The porosity is within the range of typical values for a mixture of sand and gravel (Sterrett, 2007).

Because the lower aquifers are confined, they do not dewater, so in their cases the storage coefficient is used. The storage coefficient represents the volume of water released by a unit area of an aquifer due to a unit drop in head. The actual mechanisms leading to this release of water are compression of the aquifer skeleton and expansion of the water, both the result of the loss of water pressure. The storage coefficient in Model Layer 2 is 3×10^{-4}, and that in Model Layer 3 is 1×10^{-5}. These values are within the typical range for confined aquifers (Sterrett, 2007). The porosities for Model Layers 2 and 3 are 0.15 and 0.1, respectively; these are on the lower end of the range of typical values for a sand and gravel mixture, reflecting the increasing amount of compaction and cementation typical of alluvial sediments with increasing depth.

E.3.3 Internal Faults

There are several faults that are within the model domain, and these represent important structural controls on the movement of groundwater (Riley and Worts, 1952). The faults within the model are the Oasis, Pinto, Bagley, Chocolate Drop, Elkins, and Surprise Spring Faults, as well as the boundaries between the Indian Cove and Fortynine Palms Subbasins and between the Fortynine Palms and Eastern Subbasins, which may represent unnamed faults (Figure E-13). Faults are simulated using the MODFLOW Horizontal Flow Barrier (HFB) package (Hsieh and Freckleton, 1993). The ability of a fault plane to allow groundwater flow is measured by its hydraulic characteristic, which has units of per day. When multiplied by the width of the barrier, this equates to the hydraulic conductivity, and can further be multiplied by the head gradient to determine a one-dimensional flux through the fault plane.

All fault planes in the model are also assumed to be vertical, as no information is available on their dips in the subsurface.

Previous estimates of fault conductances range from 3.8×10^{-7} to 4.3×10^{-1} ft/d (Londquist and Martin, 1991; Nishikawa et al., 2004). The faults in this model have conductances ranging from 1×10^{-9} to 6.5×10^{-1} ft/d. No direct measurements have been taken on fault conductivity; these values are based on calibration of the model to historical water levels.

List of Tables

E-1	Domestic Well Cells and Pumping Rates for Mesquite Lake Groundwater Model
E-2	General Head Boundary Parameters for Mesquite Lake Groundwater Model
E-3	Horizontal and Vertical Hydraulic Conductivities for Mesquite Lake Groundwater Model

List of Figures

E-1	Finite Difference Grid for Mesquite Lake Groundwater Model
E-2	Model Layer 1 Top Elevation, Mesquite Lake Groundwater Model
E-3	Model Layer 1 Bottom/Layer 2 Top, Mesquite Lake Groundwater Model
E-4	Model Layer 2 Bottom/Layer 3 Top, Mesquite Lake Groundwater Model
E-5	Model Layer 3 Bottom, Mesquite Lake Groundwater Model
E-6	Extent of Model Layer 1 of Mesquite Lake Groundwater Model
E-7	Extent of Model Layer 2 of Mesquite Lake Groundwater Model
E-8	Extent of Model Layer 3 of Mesquite Lake Groundwater Model
E-9	Model Recharge Zones for Mesquite Lake Groundwater Model
E-10	Evapotranspiration Zones for Mesquite Lake Groundwater Model
E-11	General Head Boundaries in Mesquite Lake Groundwater Model
E-12	Hydraulic Conductivity Zones in Mesquite Lake Groundwater Model

Table E-1: Number of domestic well cells and pumping rates in each model subbasin

Subbasin	**Number of cells**	**Pumping Rate (ft^3/d)**	**Total Pumping (afy)**
Fortynine Palms	56	300	141
Eastern	17	1000	143

Table E-2: General Head Boundary parameters for the Mesquite Lake Groundwater Model

Inflow Subbasin	Outflow Subbasin	Area	GHB Head (*h* , ft)	Width (*w* , ft)	Saturated Thickness (*b* , ft)	Hydraulic Conductivity (*K* , ft/d)	Distance to GHB (*d* , ft)	Conductance (*C* , ft^2/d)
Joshua Tree	Indian Cove	--	Variable	300	Variable	3.5×10^{-6}	1	Variable
Copper Mountain	Mesquite	North	2177	300	Variable	1.0×10^{-4}	1	Variable
Copper Mountain	Mesquite	South	2177	300	Variable	1.0×10^{-5}	1	Variable
Copper Mountain	Mesquite	Mountain Block	2177	300	100	1.0×10^{0}	20,000	1.5
Surprise Spring	Mesquite	--	2200	300	Variable	3.0×10^{-4}	1	Variable
Deadman	Mesquite	West	1822	300	Variable	3.0×10^{-4}	1	Variable
Deadman	Mesquite	East	1800	300	Variable	3.0×10^{-4}	1	Variable
Mesquite	Dale	--	1537	300	Variable	4.0×10^{-6}	1	Variable

Table E-3: Horizontal and vertical hydraulic conductivities and storage parameters for the Mesquite Lake Groundwater Model

Model Layer	Zone	Horizontal Hydraulic Conductivity (K_h, ft/d)	Vertical Hydraulic Conductivity (K_z, ft/d)	Specific Yield (S_y)	Specific Storage (S_s, ft^{-1})	Porosity (n)
1	Alluvium[a]	15	0.15	0.18	0.18	0.2
1	Alluvium[b]	10	0.1	0.18	0.18	0.2
1	Mountain Front	0.6	0.06	0.18	0.18	0.2
2	--	1	0.01	0.0003	0.0003	0.15
3	--	0.5	0.005	0.00001	0.00001	0.1

[a]In the Indian Cove Subbasin between the Oasis and Pinto Faults, as well as all of the Eastern Subbasin.

[b]In the Mesquite and Fortynine Palms Subbasins, and in the Indian Cove Subbasin south of the Pinto Fault.

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureE-1.pptx

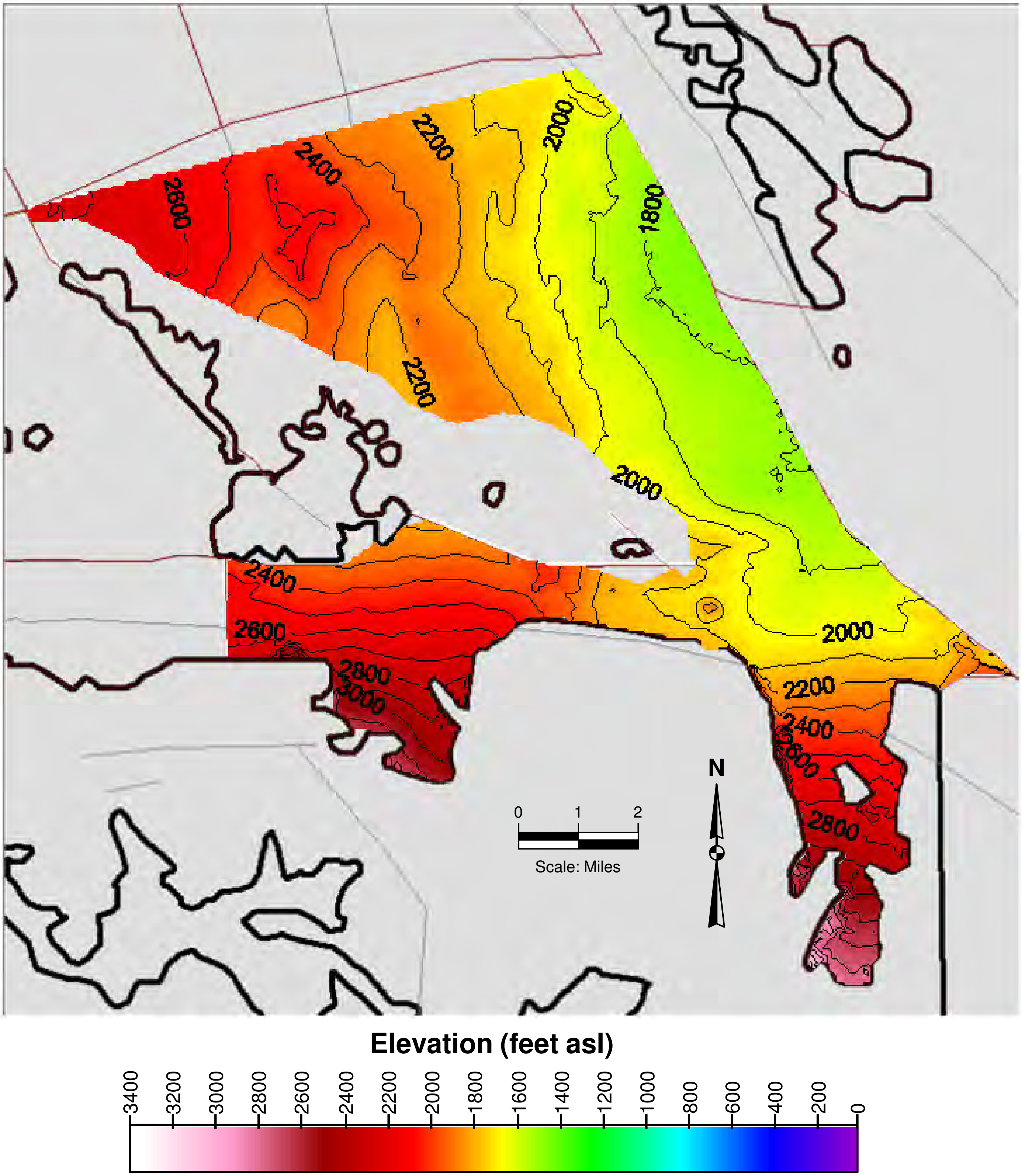
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Finite Difference Grid for Mesquite Lake Groundwater Model

K/J 0964003*00
March 2010

Figure E-1



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureE-2.pptx

Contour Interval = 100 feet.

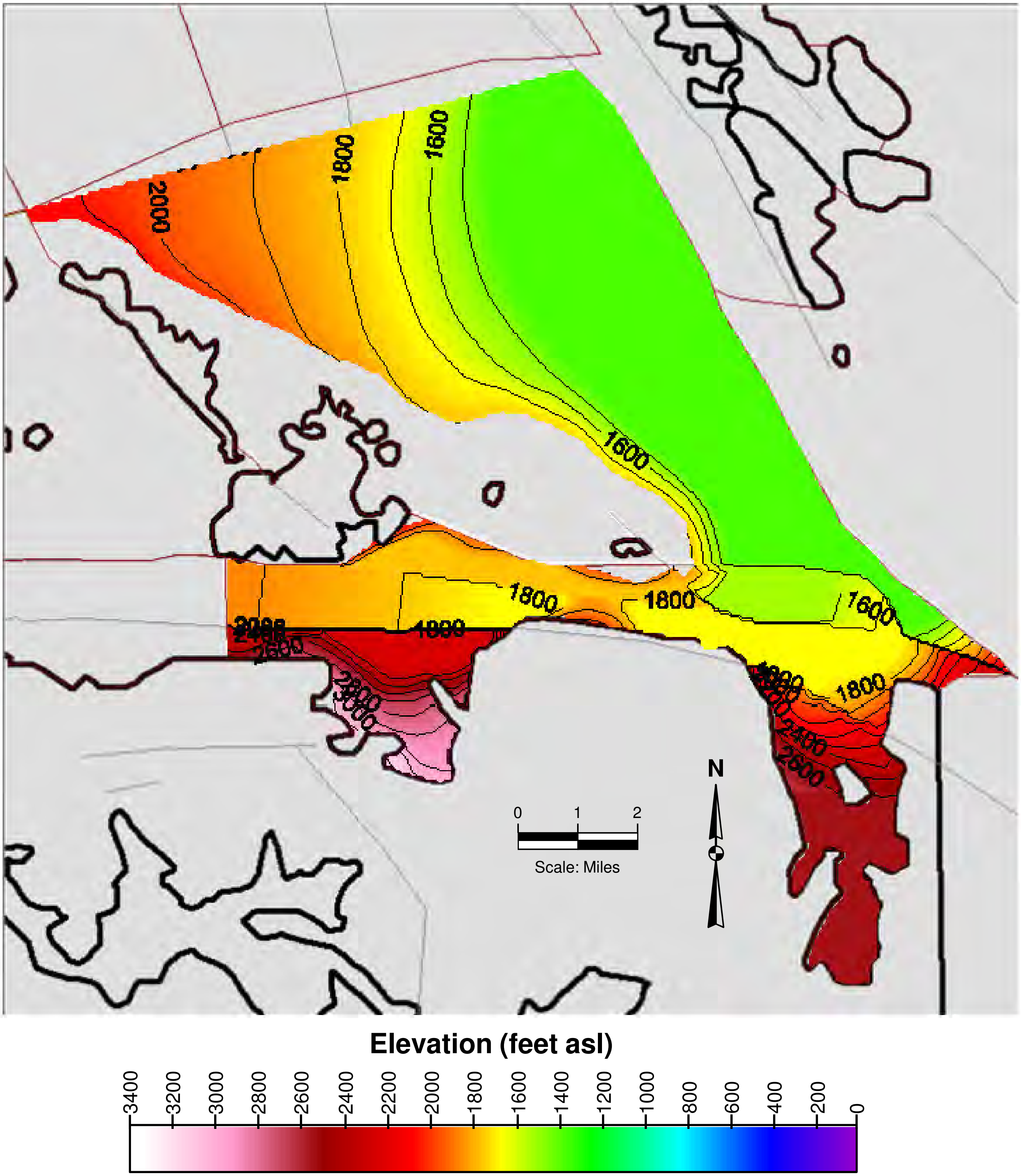
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Model Layer 1 Top Elevation, Mesquite Lake Groundwater Model

K/J 0964003*00
March 2010

Figure E-2



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureE-3.pptx

Contour Interval = 100 feet.

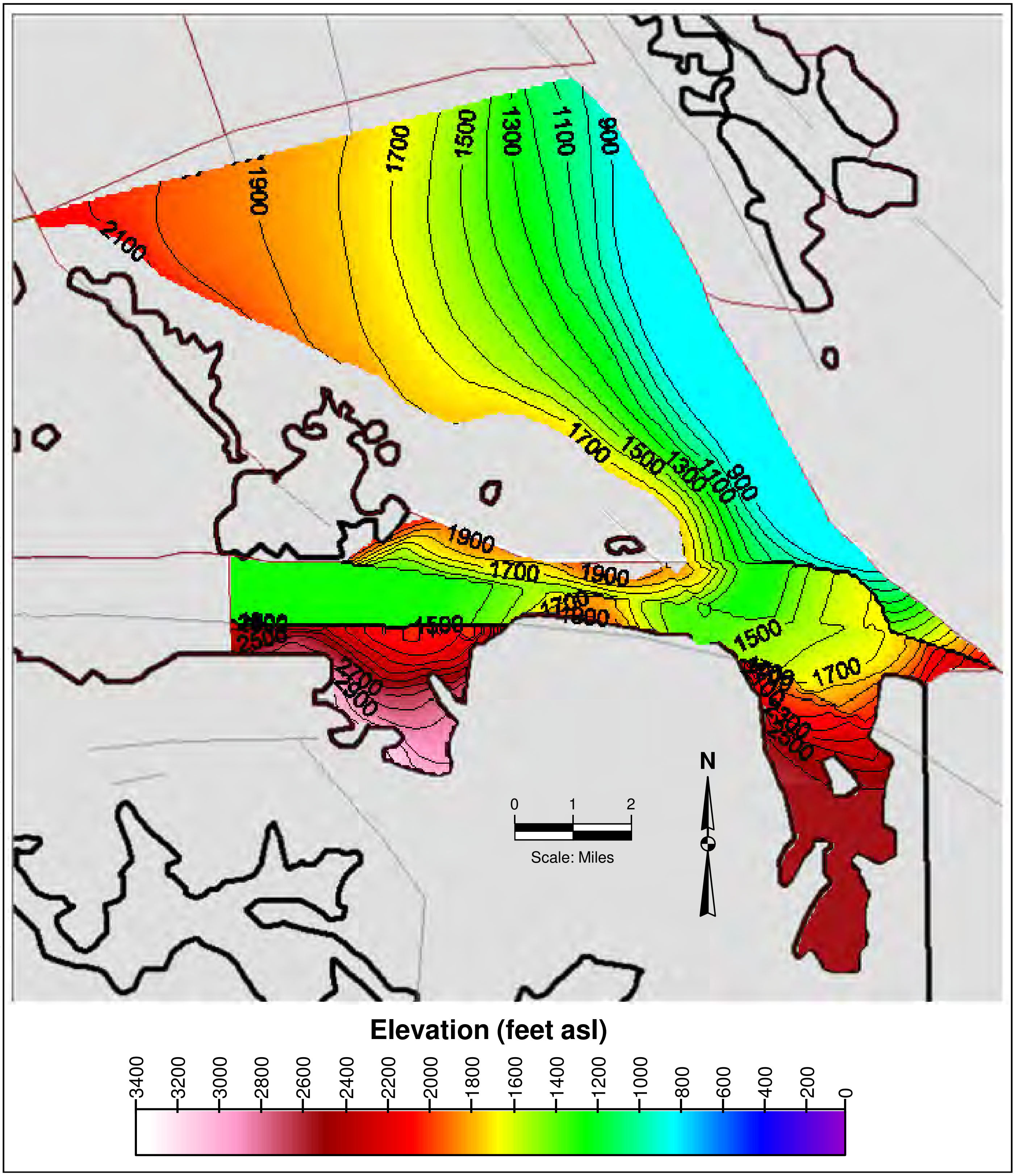
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Model Layer 1 Bottom/Layer 2 Top, Mesquite Lake Groundwater Model

K/J 0964003*00
March 2010

Figure E-3



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureE-4.pptx

Contour Interval = 100 feet.

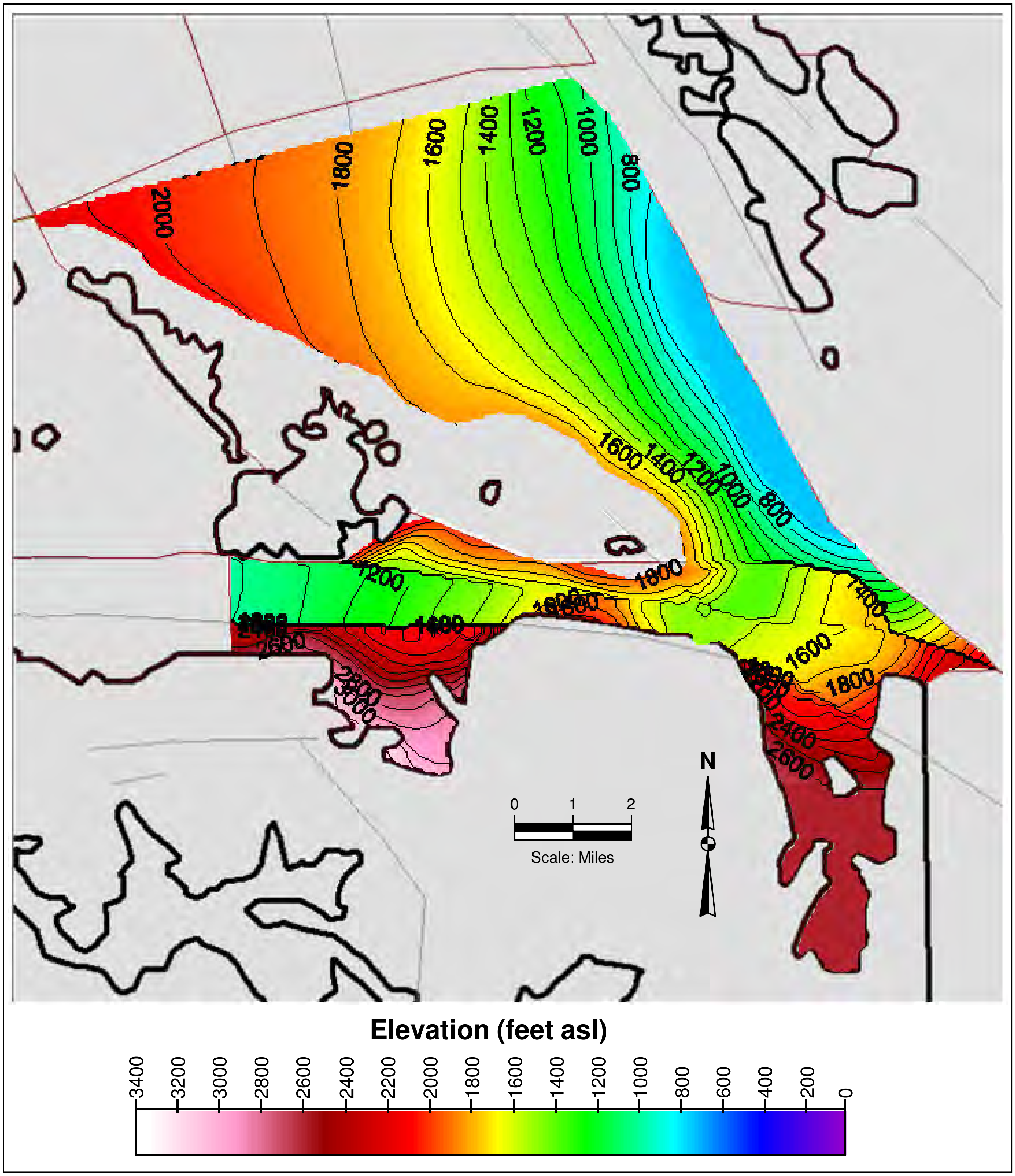
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Model Layer 2 Bottom/Layer 3 Top, Mesquite Lake Groundwater Model

K/J 0964003*00
March 2010

Figure E-4



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureE-5.pptx

Contour Interval = 100 feet.

Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Model Layer 3 Bottom, Mesquite Lake Groundwater Model

K/J 0964003*00
March 2010

Figure E-5

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureE-6.pptx

Legend

No-flow (inactive) cell

Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Extent of Model Layer 1 of Mesquite Lake Groundwater Model

K/J 0964003*00
March 2010

Figure E-6

Legend

No-flow (inactive) cell

Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Extent of Model Layer 2 of Mesquite Lake Groundwater Model

K/J 0964003*00
March 2010

Figure E-7

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureE-8.pptx

Legend

No-flow (inactive) cell

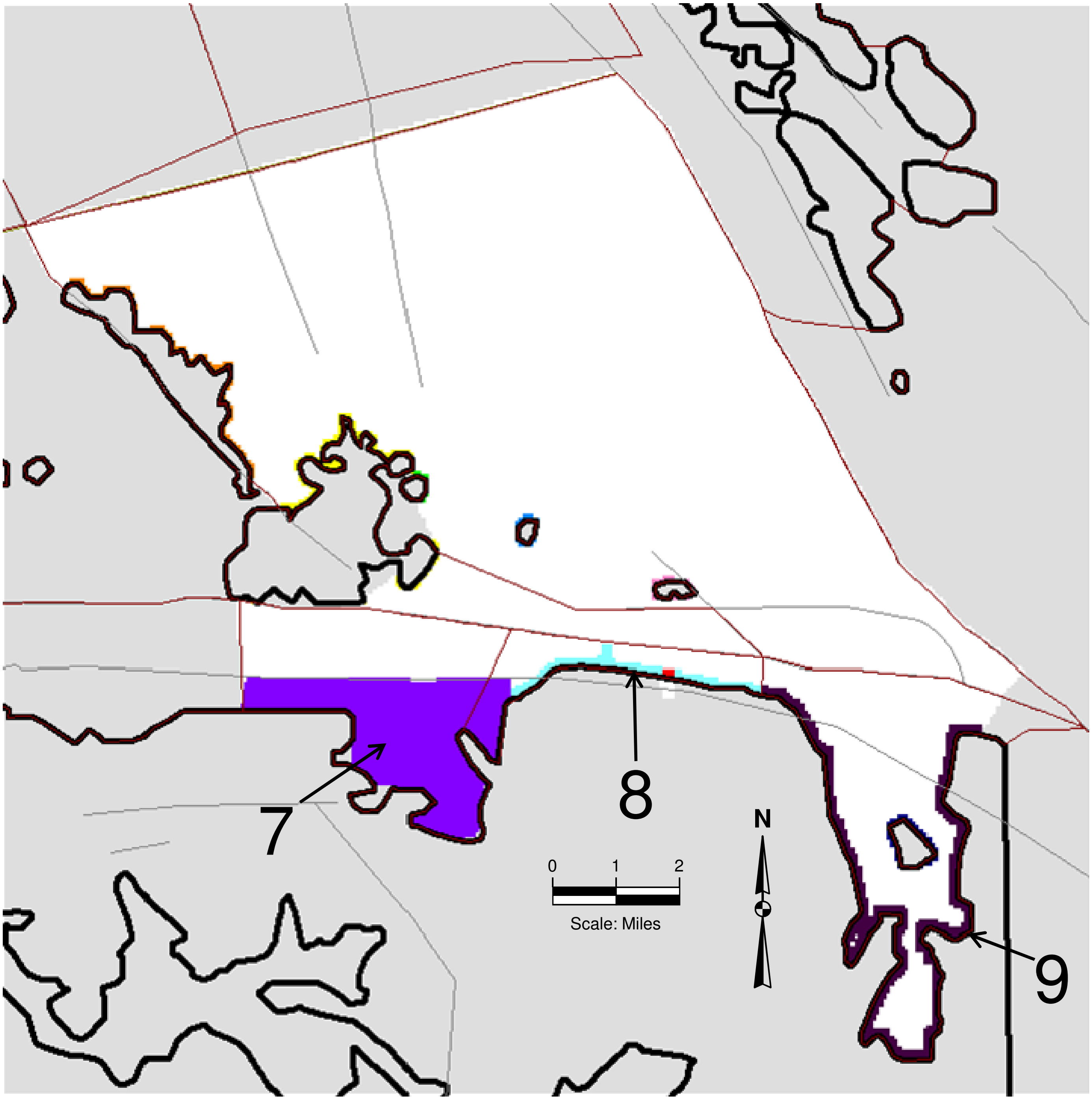
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Extent of Model Layer 3 of Mesquite Lake Groundwater Model

K/J 0964003*00
March 2010

Figure E-8



Recharge Zones:

Zone 7: 1.4 × 10^{-6} ft/d.
Zone 8: 16 × 10^{-6} ft/d.
Zone 9: 8.6 × 10^{-6} ft/d.

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureE-9.pptx

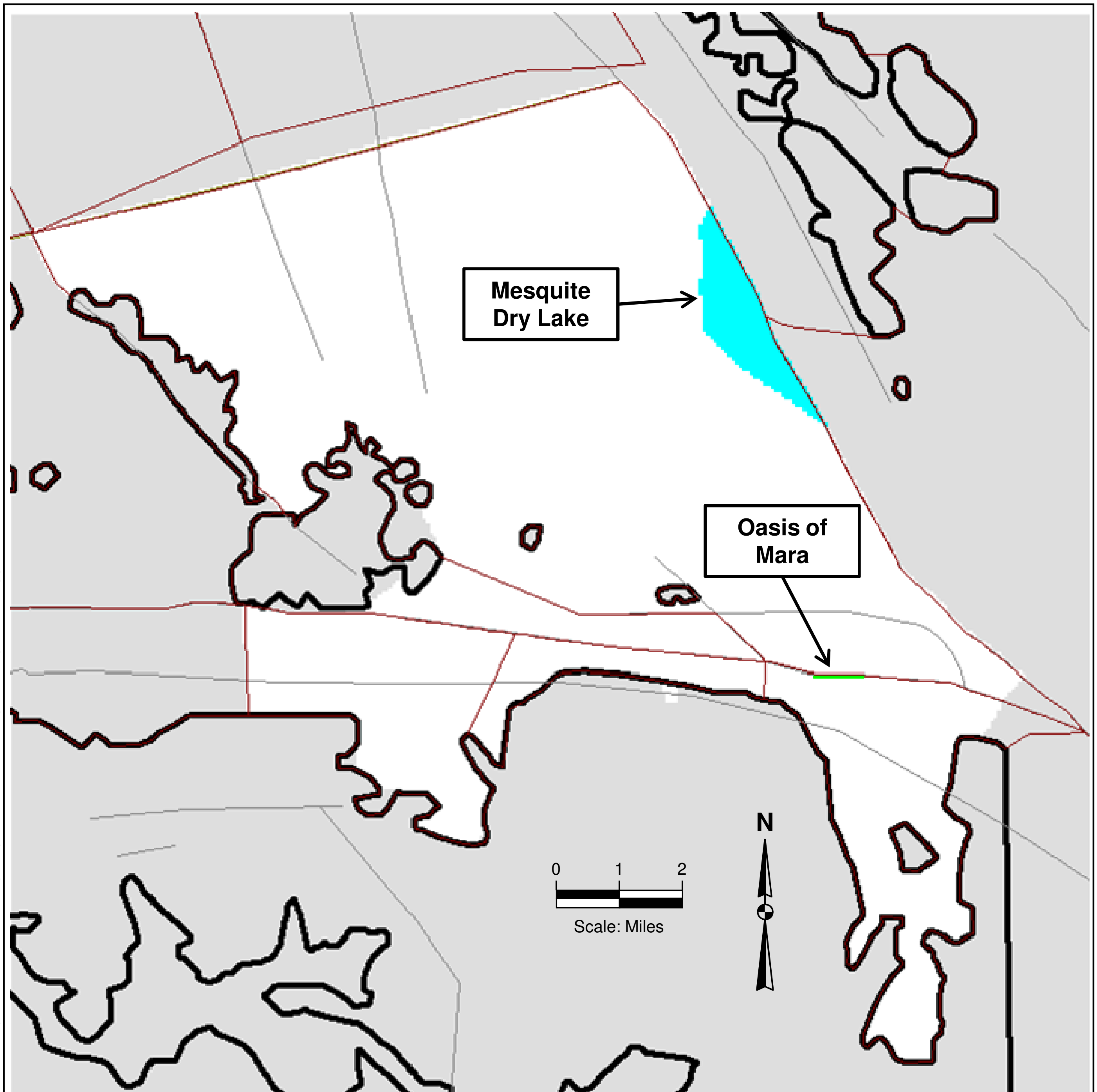
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Model Recharge Zones for Mesquite Lake Groundwater Model

K/J 0964003*00
March 2010

Figure E-9



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureE-10.pptx

Legend

No-flow (inactive) cell

Kennedy/Jenks Consultants

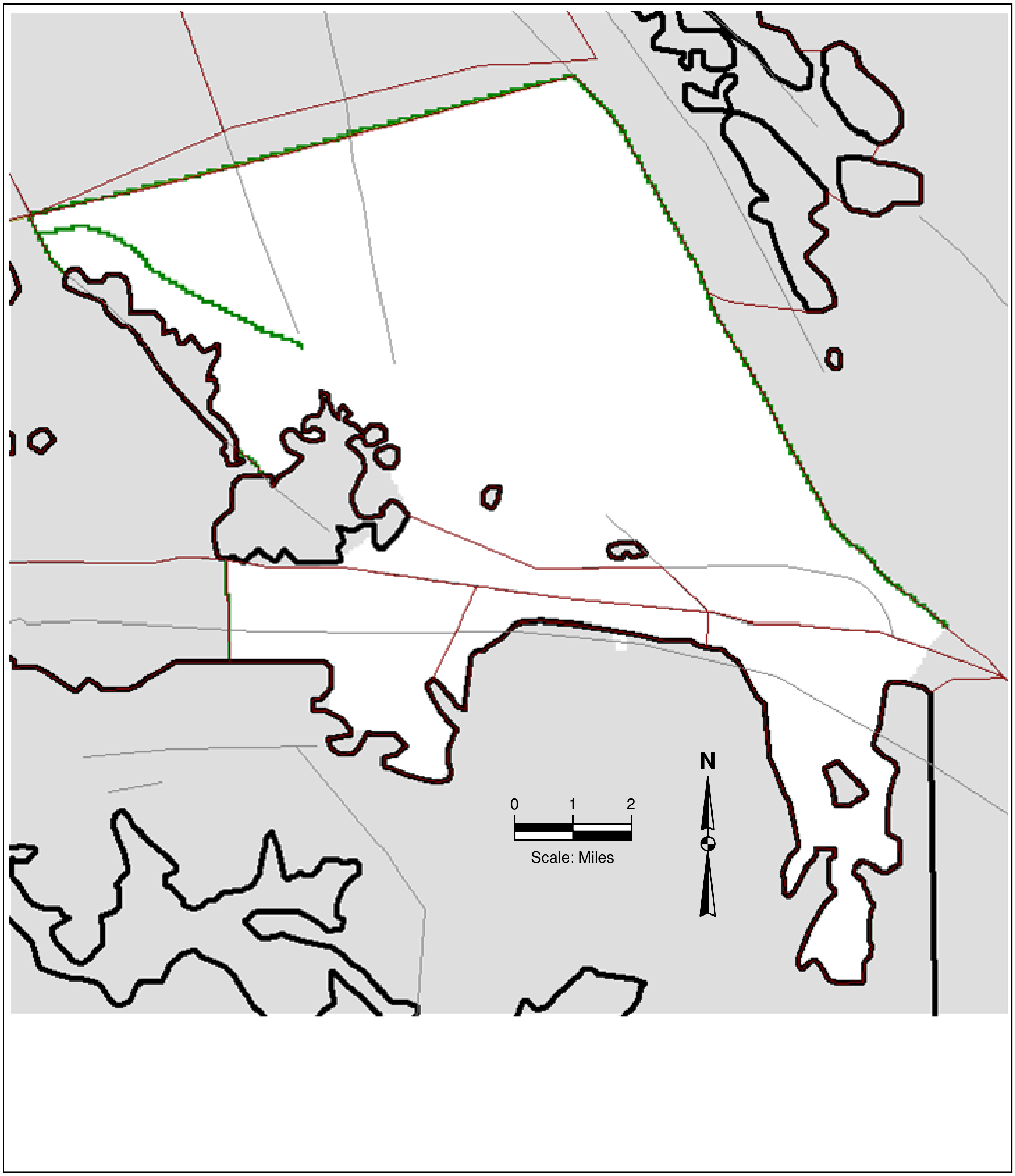
Twentynine Palms
San Bernardino County, California

Evapotranspiration Zones for Mesquite Lake Groundwater Model

K/J 0964003*00
March 2010

Figure E-10

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureE-11.pptx



Legend

No-flow (inactive) cell

General Head Boundary

Kennedy/Jenks Consultants

Twentynine Palms

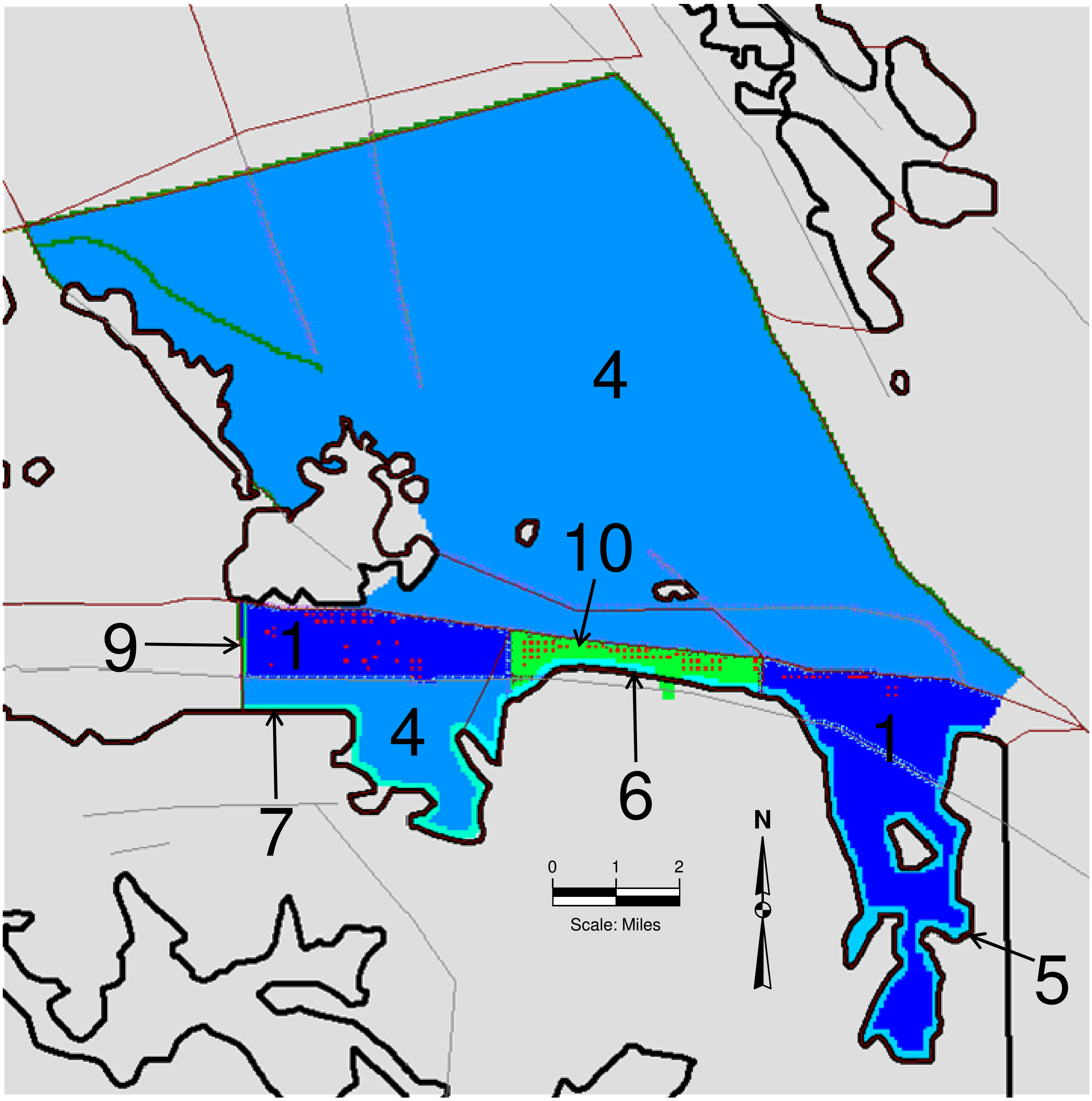
San Bernardino County, California

General Head Boundaries in Mesquite Lake Groundwater Model

K/J 0964003*00

March 2010

Figure E-11



Hydraulic Conductivity Zones:

Zone 1: K_h = 15 ft/d, K_z = 0.15 ft/d.
Zone 4: K_h = 10 ft/d, K_z = 0.10 ft/d.
Zone 5: K_h = 0.6 ft/d, K_z = 0.06 ft/d.
Zone 6: K_h = 0.6 ft/d, K_z = 0.06 ft/d.
Zone 7: K_h = 0.6 ft/d, K_z = 0.06 ft/d.
Zone 9: K_h = 10^{-6} ft/d, K_z = 10^{-8} ft/d.
Zone 10: K_h = 10 ft/d, K_z = 0.1 ft/d.

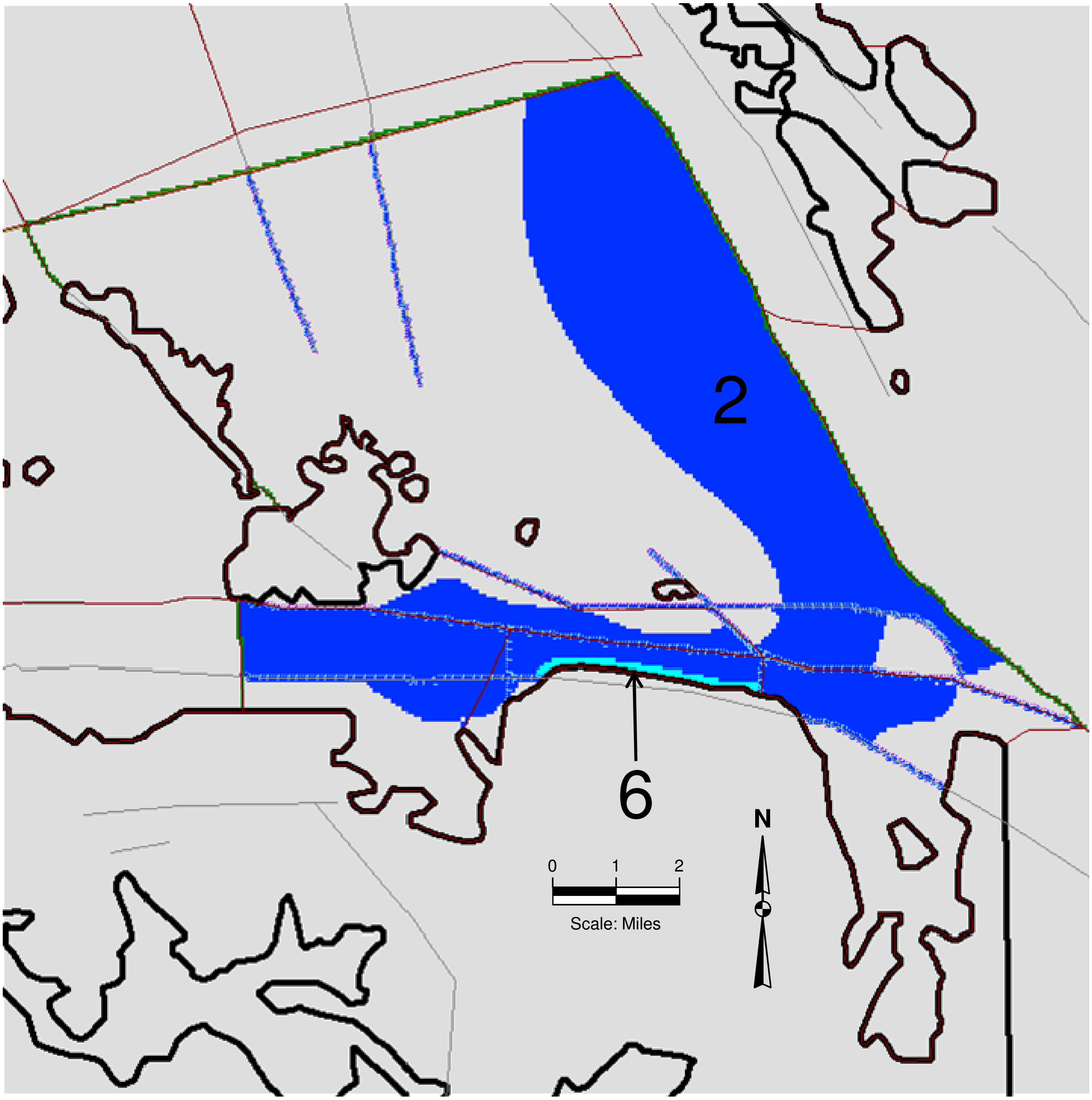
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Model Layer 1 Hydraulic Conductivity Zones in Mesquite Lake Groundwater Model

K/J 0964003*00
March 2010

Figure E-12a



Hydraulic Conductivity Zones:

Zone 2: K_h = 1.0 ft/d, K_z = 0.01 ft/d.
Zone 6: K_h = 0.6 ft/d, K_z = 0.06 ft/d.

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureE-12.pptx

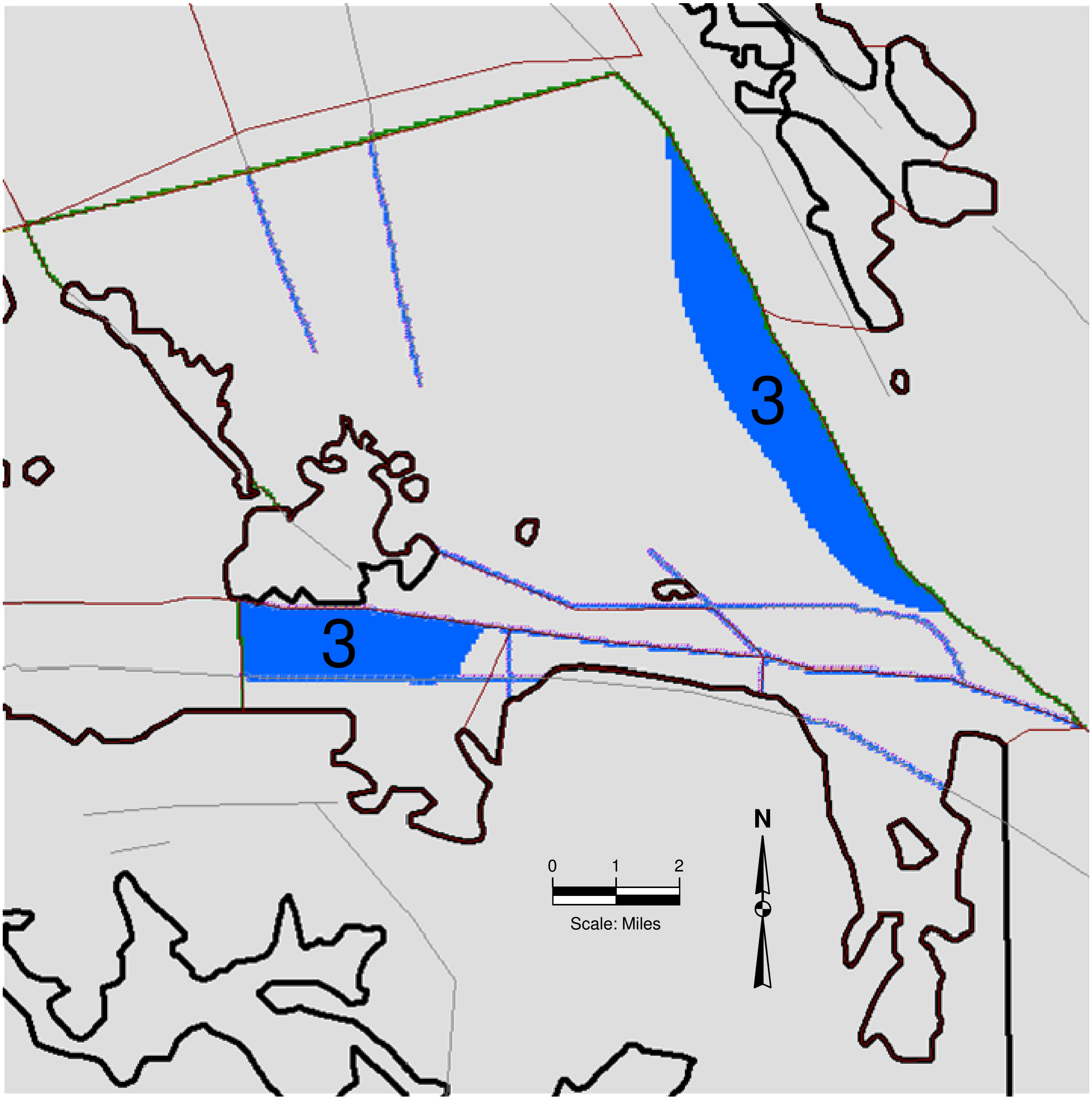
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Model Layer 2 Hydraulic Conductivity Zones in Mesquite Lake Groundwater Model

K/J 0964003*00
March 2010

Figure E-12b



Hydraulic Conductivity Zones:

Zone 3: K_h = 0.5 ft/d, K_z = 0.005 ft/d.

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureE-12.pptx

Kennedy/Jenks Consultants

Twentynine Palms

San Bernardino County, California

Model Layer 3 Hydraulic Conductivity Zones in Mesquite Lake Groundwater Model

K/J 0964003*00

March 2010

Figure E-12c

Appendix F: Groundwater Model Calibration Data

Appendix F: Groundwater Model Calibration Data

Model calibration is the process of testing the accuracy of the model results by comparing the model simulated groundwater elevations to measured groundwater data from the basin. During the calibration process, the aquifer properties and boundary conditions are varied within an acceptable range until the closest fit of the simulated versus measured data is achieved. This comparison of observed versus simulated groundwater elevations is based on data from 60 wells. The locations of these wells are shown on Figure 5-3.

For the MODFLOW Model, an extensive calibration process was designed to better constrain the range of aquifer properties and boundary conditions for the model, thereby improving the accuracy and reliability of the model results.

F.1 Calibration Results

The transient calibration includes the simulation of changes in groundwater elevations over time. For the MODFLOW Model, the period is the 25-year base period from 1984 to 2008. This aspect of the calibration is important to demonstrate that the model has the capability to simulate historical changes in groundwater elevations, and is therefore capable of forecasting future changes in groundwater elevations. This capability is necessary for the model to serve as a useful groundwater management tool.

F.1.1 Calibration Criteria

The MODFLOW Model was calibrated using the developed calibration criteria to reduce uncertainty by matching model results to observed data. An extensive calibration process was designed to better constrain the range of aquifer properties and boundary conditions for the model, thereby reducing uncertainty in the results.

There are multiple combinations of aquifer properties and boundary conditions that can be used to match a single set of groundwater elevation data. Calibrating to multiple data sets under differing stresses (i.e. recharge and discharge rates) reduces this non-uniqueness, thereby reducing the uncertainty. Performing a comprehensive calibration over a 25-year base period infers the calibration has been performed over wet, dry, and normal years with varying degrees of pumping (although, as noted above, the study basin does not respond to annual changes in precipitation amount). To that end, the MODFLOW Model was calibrated using three separate criteria:

- Groundwater Elevation Maps
- Statistical Analysis
- Hydrographs

It should be noted that some degree of difference or residual between the observed and simulated groundwater elevations is expected. Residuals may be due in part to localized effects or data quality issues. For example, residuals can result from using groundwater elevations from pumping wells as calibration targets. MODFLOW calculates the groundwater elevation for the center of a model cell rather than at the well location itself. MODFLOW also does not take into account the impact of well efficiency on groundwater elevations at pumping wells. In addition, the timing of the observed groundwater elevations does not exactly match the model stress periods.

F.1.2 Groundwater Elevation Map Calibration

The first and most basic model calibration criterion is a direct comparison of simulated versus measured groundwater elevation maps for selected time periods. The primary purpose of this calibration is to compare hydraulic gradients for both magnitude and direction to ensure that the model is accurately simulating existing conditions. This visual comparison is a fast method to determine where additional model calibration efforts should be focused.

A series of hand-drawn groundwater elevation maps was developed based on the measured groundwater elevation data. Maps were constructed for 1947, 1953, 1958, 1969, 1975, 1982, 1994, 2002, and 2008 (Figures F-1 through F-9). Figures F-7, F-8 and F-9 show calculated water levels for 1984 (initial conditions), 1994, 2002, and 2008, respectively, for Model Layer 1.

Figures 5-2, F-10 and F-11 show the calculated groundwater elevations for 2008, the last timestep in the simulation. These figures show that the steeper hydraulic gradients are observed along the basin margin, and the gradients flatten toward the center of the basin. In general, groundwater flow is to the north on the south side of the Pinto Fault. Between the Pinto and Oasis Faults, groundwater flow is to the north or east, except where pumping causes local disturbances in the flow regime. North of the Oasis Fault, groundwater flows from all parts of the Mesquite Lake Subbasin toward the topographic low in the area of Mesquite Springs and Mesquite Dry Lake. Pumping in the Mesquite Lake Subbasin (especially the production of TPWD-TP-1) has led to changes in the flow regime, with local reversals in flow direction from predevelopment conditions.

In general, the direction and magnitude of the hydraulic gradient as expressed by the contours is very similar to the maps in Figures F-1 through F-9. A comparison of the contour locations shows some variability, but the overall contour patterns compare favorably between model and hand-drawn maps. Therefore, this preliminary calibration suggests that the groundwater flow field generated by the model is reasonable.

F.1.3 Statistical Calibration

Next, a more rigorous calibration was performed involving a statistical analysis to compare the difference, or residual, between measured and simulated groundwater elevations. Calibration statistics for the transient analysis are included in Table F-1. A scatter plot of observed versus simulated groundwater elevations (Figure 5-4) depicts this relationship. As indicated on Figure 5-4, the scatter along the correlation line is minor in comparison to the range of the data. The correlation coefficient (r^2) ranges from 0 to 1 and is a measure of the closeness of fit of the data to a 1-to-1 correlation. A correlation of 1 is a perfect correlation. The correlation coefficient of 0.952 for the data on this figure indicates a very strong correlation between simulated and observed groundwater elevations. This correlation is based on 566 groundwater elevation measurements over the 25-year base period from 60 basin wells.

Figure 5-4 also includes a list of other statistical measures of calibration. The residual mean is computed by dividing the sum of the residuals by the number of residual data values. The closer this value is to zero, the better the calibration. The residual mean for the model is -3.97 feet. The absolute residual mean is a measure of the overall error of the model, and is computed by dividing the sum of the absolute values of the residuals by the number of residual data values. The absolute residual mean for the model is 22.16 feet. Another statistical measure of calibration is the ratio of the standard deviation of the mean error divided by the range of observed groundwater elevations. This ratio shows how the model error relates to the overall hydraulic gradient across the model. Typically, a calibration is considered good when this ratio is below 0.15 (ESI, 2007); the ratio for the MODFLOW Model is 0.058. Based on the statistical analysis, the model is well calibrated.

As mentioned above, the model does not perform well in certain areas, and does not match a few targets. These problems are discussed here, along with their effects on the overall calibration of the model.

F.1.3.1 Indian Cove Subbasin

In the southeastern Indian Cove Subbasin, east of well TPWD-15, three wells (Figure F-12) exist with a total of 24 groundwater elevation measurements. These three wells are all within 2,400 feet of each other, but their groundwater elevations are separated by 200 feet. The extremely steep hydraulic gradient in this area could be due to several factors, including the high bedrock here, or a series of parallel faults, or even a perched zone of groundwater, but the actual reason is unknown. Removing this set of three wells changes the residual mean to -0.70 feet, the absolute residual mean to 18.70 feet, and the ratio between the standard deviation of the mean error and the range of observed groundwater elevations to 0.049.

Another group of wells exists in the eastern end of the Indian Cove Subbasin, between the Oasis and Pinto Faults. The four wells in this group are all TPWD production wells (TPWD-6, TPWD-7, TPWD-9, and TPWD-12), and all have water levels very similar to one another. The groundwater elevation in these wells is also about 45 feet too high (compared to water levels in the rest of the basin) at all times. Hydrographs (F-13) indicate that the model captures the relative changes in groundwater elevations over time, but not the absolute magnitude of the groundwater elevation. Removing this set of four wells changes the residual mean to -9.85 feet, the absolute residual mean to 16.27 feet, and the ratio between the standard deviation of the mean error and the range of observed groundwater elevations to 0.053.

F.1.3.2 Eastern Subbasin

One well in the western end of the Eastern Subbasin (TPWD-16) is not matched well by the model. Actual measurements are about 130 too low compared to the model results, and to the water levels measured in other wells throughout the basin. As with the wells in the eastern end of the Indian Cove Subbasin, the model captures the trend in groundwater elevations over time, but fails to produce the absolute magnitude (Figure F-14). If these wells is removed from the statistics, the residual mean for the whole model improves to 1.26 feet, the absolute residual mean to 16.93 feet, and the ratio between the standard deviation of the mean error and the range of observed groundwater elevations to 0.043.

F.1.3.3 Mesquite Lake Subbasin

Simulated water levels at two wells (Figure F-15) in the southeastern corner of the Mesquite Lake Subbasin also do not match real observations. One of these wells (Figure F-15) is about 60 feet lower than observed data, while the other (Figure F-15) is about 55 feet higher than observed data. The inability of the model to capture the water levels in these two wells could have something to do with the wells' proximity to the Bagley Fault, which (according to the geologic map) runs between them. Removing these two wells changes the residual mean to -4.13 feet, the absolute residual mean to 20.39 feet, and the ratio between the standard deviation of the mean error and the range of observed groundwater elevations to 0.056.

Removing all four of the sets of "problem" wells changes the residual mean to -1.53 feet, the absolute residual mean to 5.82 feet, and the ratio between the standard deviation of the mean error and the range of observed groundwater elevations to 0.015. This leaves 405 groundwater elevation measurements in 50 wells.

F.1.4 Hydrograph Calibration

Hydrographs provide a detailed time history of groundwater elevations for specific wells. These time histories include the impact of varying climatic and pumping stresses on the groundwater basin. Comparing hydrographs of model results versus observed data provides a measure of how well the model handles these changing conditions through time. Of the 60 wells with groundwater elevation data, 16 hydrographs from different parts of the basin are included on Figures F-13 through F-15 for the hydrograph evaluation. This representative sample includes 32% of the total wells. For calibration purposes, the hydrographs were inspected to evaluate how well the model results matched the overall magnitude and trend of the observed groundwater elevation data over time. For the transient model, it was considered more important to honor the overall trend of the data. A hydrograph was considered a good match if the model simulated the trend, even if the groundwater elevations were offset.

In the Indian Cove Subbasin, four hydrographs are presented (Figure F-13). The hydrographs show a strong correlation between the modeled and observed water levels in TPWD-10 and TPWD-11. As discussed above, TPWD-12 shows the correct trend, but water levels are offset by about 45 feet. The modeled water levels in TPWD-15 do not vary as much as do the actual measurements. Because the actual observations vary rather extremely, it could be that this well taps a restricted water source, for example a perched zone that is not spatially extensive.

In the Fortynine Palms Subbasin, four hydrographs are presented (Figure F16). The hydrographs show a strong correlation between modeled and observed water levels in TPWD-3, TPWD-4, and TPWD-13. In TPWD-5, the actual water levels drop much more slowly than do the modeled levels. This may indicate that the modeled well is artificially affected by its proximity to the Oasis Fault, which would act as a barrier to recharge. In all four hydrographs, there is an increase in modeled groundwater elevation starting in year 2002, when total water pumping in this basin decreased from over 1,600 afy to around 1,000 afy for the rest of the model period. The increase in modeled groundwater levels, not reflected in the actual groundwater levels, may indicate that recharge is too high in the model, or that the model allows too much water in from Model Layer 2. It should be noted that MODFLOW is unable to simulate wells that only partially penetrate a model layer; all of the TPWD wells in this part of the basin only partially penetrate

Model Layer 1, so one would not expect any significant communication with Model Layer 2 in reality.

In the Eastern Subbasin, four hydrographs are presented (Figure F-14). The hydrographs show a mostly good correlation between modeled and observed water levels, especially in TPWD-1 and TPWD-2. As discussed above, modeled water levels in TPWD-16 are too high by about 130 feet, and the reason for this is unclear. Well #88 is in the vicinity of the Oasis of Mara. Modeled water levels drop more than do the observed water levels, indicating that the model may not fully capture the behavior of the water table in this area. Namely, the modeled aquifer does not provide enough water to the area of the Oasis, which may indicate that recharge is too low, or that there is a problem with the modeling of the hydrology of the actual area around the Oasis. The actual discrepancy in the area of the Oasis is only about 10 feet at most, so this is not a significant modeling issue.

In the Mesquite Lake Subbasin, four hydrographs are presented (Figure F-15). Considering the small vertical change scale, water levels in this basin are matched very well by the model. TPWD-TP-1, which is the large production well in the basin, shows more extreme variability in reality than in the model; this may be a result of the measurement system, which could chiefly measure water levels while the well is pumping, or it could indicate that the aquifer responds more quickly to changes in pumping than is shown in the model. The greatest discrepancy between the model and actual measurements is about 15 feet, which again is well within a reasonable amount of error. In the three other hydrographs, the trend of groundwater changes is matched quite well, even if the absolute water levels are off by one or two feet.

Considering all of the hydrographs presented in Figures F-13 through F-16, the model does quite a good job of matching observed water levels. The discrepancies that do exist were either discussed above, or are relatively small. The overall results of the model calibration to the various calibration criteria indicate that the model is well calibrated.

F.2 Quality Assurance

The first step towards the developing a sound, defensible numerical model is to ensure consistency with the hydrogeological conceptual model of the basin. The previous discussions regarding the model calibration and comparison of the hydrologic budget results demonstrate that the model is consistent with the conceptual model. The calibration correlation coefficient of 0.952 demonstrates a strong comparison between measured and simulated groundwater elevations.

A numerical model mathematically describes the conceptual model by solving the mass balance and motion equations that govern groundwater flow and chemical transport (Bear and Verruijt, 1987). To solve these equations, an iterative method is used to solve the matrix equations. For these iterative techniques, the procedure is repeated until the convergence criteria are met. The convergence criteria may be groundwater elevation change, mass balance difference, or both. Convergence defines whether the model is mathematically stable and capable of producing reliable results.

For this model, the MODFLOW preconditioned conjugate-gradient 2 (PCG2) package was used (Hill, 1990). The convergence criteria for PCG2 included both a maximum change in groundwater elevation and a maximum mass balance differential for a cell. For this model, the convergence parameter for groundwater elevation was set at 1.0 foot and the mass balance differential was set to 200 cubic feet per day. Convergence is evaluated at the grid cell level. If a single cell does not meet the requirement, then the solution procedure is repeated. The model was able to successfully converge using the set convergence parameters.

The primary method to check whether the model is numerically stable is to evaluate the differential in mass balance. Iterative techniques provide an approximate solution for the model; therefore, there is always a mass balance differential. This differential should be small, and typically a solution with a differential of less than 1% is considered good. The mass balance differential for the MODFLOW Model is 0.03%. Table F-2 provides the mass balance differential for each year. The maximum mass differential is 0.10% in 2004. These values further indicate that this is a high-quality numerical model that is accurately simulating the flow of groundwater in the Mesquite Lake Groundwater Basin.

List of Tables

F-1 Calibration Statistics for Mesquite Lake Groundwater Model

F-2 Annual Mass Balance Error for Mesquite Lake Groundwater Model

List of Figures

F-1 Groundwater Elevation Contours: 1953

F-2 Groundwater Elevation Contours: 1958

F-3 Groundwater Elevation Contours: 1969

F-4 Groundwater Elevation Contours: 1975

F-5 Groundwater Elevation Contours: 1994

F-6 Groundwater Elevation Contours: 2002

F-7 1984 Groundwater Elevations for Model Layer 1, Transient Simulation, Mesquite Lake Groundwater Model

F-8 1994 Groundwater Elevations for Model Layer 1, Transient Simulation, Mesquite Lake Groundwater Model

F-9 2002 Groundwater Elevations for Model Layer 1, Transient Simulation, Mesquite Lake Groundwater Model

F-10 2008 Groundwater Elevations for Model Layer 2, Transient Simulation, Mesquite Lake Groundwater Model

F-11 2008 Groundwater Elevations for Model Layer 3, Transient Simulation, Mesquite Lake Groundwater Model

F-12 Hydrographs from Indian Cove Subbasin, Transient Calibration

F-13 Hydrographs from Indian Cove Subbasin, Transient Calibration

F-14 Hydrographs from Eastern Subbasin, Transient Calibration

F-15 Hydrographs from Mesquite Subbasin, Transient Calibration

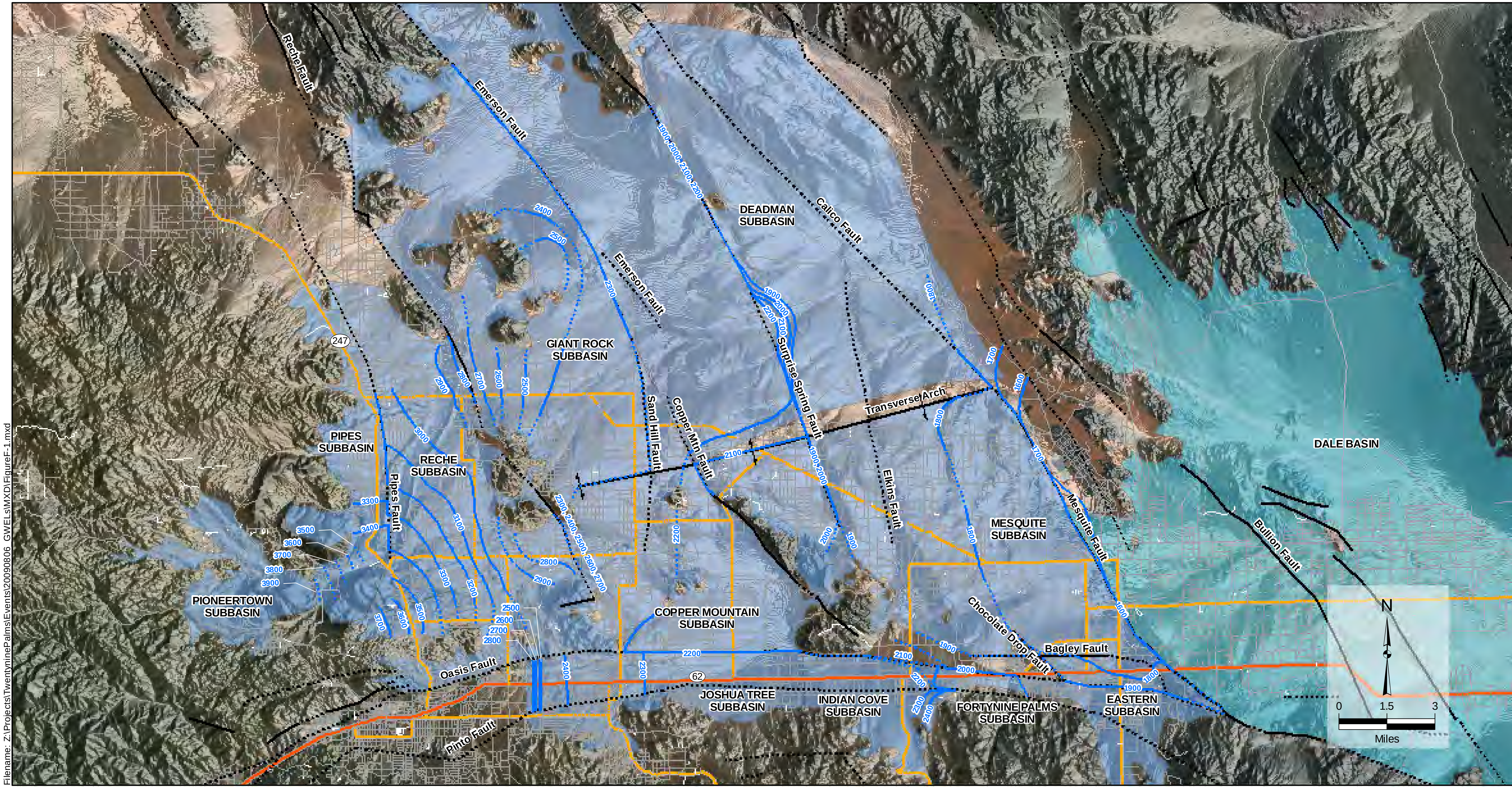
F-16 Hydrographs from Fortynine Palms Subbasin, Transient Calibration

Table F-1: Calibration statistics and average residuals for TPWD wells and for each modeled subbasin. Note that the subbasin averages are calculated based just on the TPWD wells present in those subbasins.

	Calibrated	Scenario			
Calibration Statistics	**Transient**	**7A**	**7B**	**8A**	**8B**
Correlation Coefficient	0.952	0.944	0.952	0.949	0.953
Residual Mean	-3.97	4.73	-10.17	2.71	-3.97
Residual Standard Deviation	40.06	43.65	40.40	41.58	40.06
Sum of Squares	917,437	1,090,880	982,324	982,630	917,437
Absolute Residual Mean	22.16	28.05	24.26	25.27	22.16
Minimum Residual	-198.15	-197.91	-198.31	-197.98	-198.15
Maximum Residual	63.80	85.54	70.12	68.77	63.80
Range in Target Values	687.89	687.89	687.89	687.89	687.89
Standard Deviation/Range	0.0582	0.0634	0.0587	0.0604	0.0582
Average Residuals					
TPWD-1	4.28	3.93	4.94	8.46	2.08
TPWD-2	-0.07	-0.82	0.38	4.65	-2.64
TPWD-3	7.50	23.37	-11.58	20.13	0.43
TPWD-4	-6.11	14.17	-26.44	7.65	-13.81
TPWD-5	-4.77	17.81	-23.27	1.38	-7.75
TPWD-6	32.22	47.74	22.90	41.09	26.63
TPWD-7	36.03	51.92	26.55	45.02	30.34
TPWD-8	-14.53	-13.31	-14.62	-7.13	-19.00
TPWD-9	33.34	48.67	24.09	42.21	27.74
TPWD-10	-11.79	-11.19	-11.69	-3.49	-17.02
TPWD-11	-2.03	-2.03	-1.01	6.44	-7.45
TPWD-12	33.08	48.76	23.67	41.95	27.48
TPWD-13	-6.06	36.60	-32.76	10.38	-15.01
TPWD-14	-1.57	47.27	-31.67	21.99	-15.04
TPWD-15	5.91	6.41	5.60	6.10	5.80
TPWD-16	-140.74	-132.03	-145.82	-135.41	-143.76
TPWD-18	1.58	1.76	1.21	3.21	0.46
TPWD-TP-1	-7.14	1.61	-12.69	-3.40	-9.72
Subbasin Average Residuals					
Indian Cove Subbasin	14.03	22.12	9.44	21.52	9.32
Fortynine Palms Subbasin	-2.20	27.84	-25.14	12.31	-10.23
Eastern Subbasin	-45.51	-42.97	-46.83	-40.77	-48.10
Mesquite Subbasin	-2.78	1.69	-5.74	-0.09	-4.63

Table F-2: Annual mass balance error for the Mesquite Lake Groundwater Model

Year	Mass Balance Inflow (afy)	Mass Balance Outflow (afy)	Error (afy)	% Error
1984	16,834.21	16,835.23	-1.02	-0.0061%
1985	10,283.51	10,284.43	-0.92	-0.0089%
1986	8,533.27	8,534.47	-1.20	-0.0141%
1987	7,263.27	7,264.72	-1.45	-0.0200%
1988	7,250.38	7,251.49	-1.11	-0.0153%
1989	7,090.75	7,093.00	-2.26	-0.0318%
1990	6,936.25	6,939.33	-3.08	-0.0443%
1991	6,737.28	6,739.37	-2.09	-0.0310%
1992	6,859.86	6,864.62	-4.76	-0.0694%
1993	6,813.95	6,815.72	-1.77	-0.0260%
1994	6,929.12	6,930.34	-1.23	-0.0177%
1995	6,661.88	6,664.94	-3.07	-0.0460%
1996	6,733.06	6,735.21	-2.16	-0.0320%
1997	6,522.03	6,525.63	-3.60	-0.0551%
1998	6,530.44	6,532.13	-1.69	-0.0259%
1999	6,544.53	6,545.62	-1.10	-0.0167%
2000	6,682.62	6,683.74	-1.12	-0.0168%
2001	6,517.92	6,518.91	-1.00	-0.0153%
2002	6,955.60	6,956.58	-0.98	-0.0141%
2003	6,486.86	6,493.05	-6.19	-0.0954%
2004	6,740.99	6,748.01	-7.02	-0.1040%
2005	6,664.00	6,668.73	-4.73	-0.0710%
2006	6,813.84	6,815.15	-1.31	-0.0192%
2007	6,765.08	6,766.31	-1.23	-0.0182%
2008	6,698.13	6,699.78	-1.66	-0.0247%



Source: (c) 2009 Microsoft Corporation

Explanation

Groundwater Subbasins

Groundwater Elevation (ft AMSL)

Known

Inferred

Faults

Known

Inferred

Anticline

Notes:
Contour Interval = 100 feet.
The Oasis Fault is also known as the Pinto Mountain Fault.

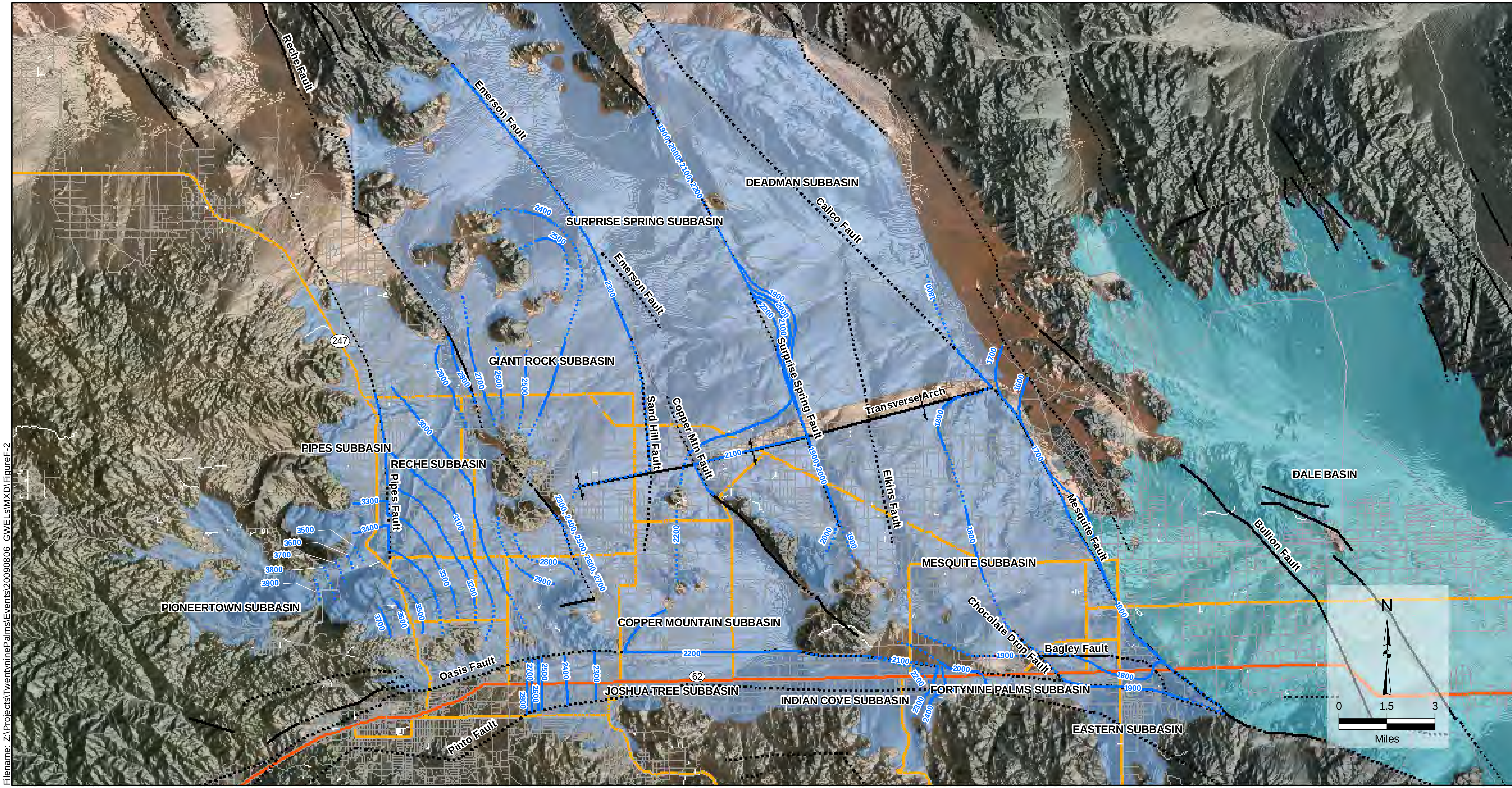
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Groundwater Elevation Contours
1953

K/J 0964003*00
March 2010

Figure F-1



Filename: Z:\Projects\TwentyninePalms\Events\20090806_GWELS\MXD\FigureF-2

Source: (c) 2009 Microsoft Corporation

Explanation

Groundwater Subbasins

Groundwater Elevation (ft AMSL)

Known

Inferred

Faults

Known

Inferred

Anticline

Notes:
Contour Interval = 100 feet.
The Oasis Fault is also known as the Pinto Mountain Fault.

Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Groundwater Elevation Contours
1958

K/J 0964003*00
March 2010

Figure F-2

Source: (c) 2009 Microsoft Corporation

Path: Z:\Projects\TwentyninePalms\Events\20090806_GWELs\MXD\FigureF-3.mxd

Explanation

Groundwater Subbasins

Groundwater Elevation (ft AMSL)

Known

Inferred

Faults

Known

Inferred

Anticline

Notes:
Contour Interval = 100 feet.
The Oasis Fault is also known as the Pinto Mountain Fault.

Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Groundwater Elevation Contours
1969

K/J 0964003*00
March 2010

Figure F-3

Path: Z:\Projects\TwentyninePalms\Events\20090806_GWELs\MXD\FigureF-4.mxd

Source: (c) 2009 Microsoft Corporation

Explanation

Groundwater Subbasins

Groundwater Elevation (ft AMSL)

Known

Inferred

Faults

Known

Inferred

Anticline

Notes:
Contour Interval = 100 feet.
The Oasis Fault is also known as the Pinto Mountain Fault.

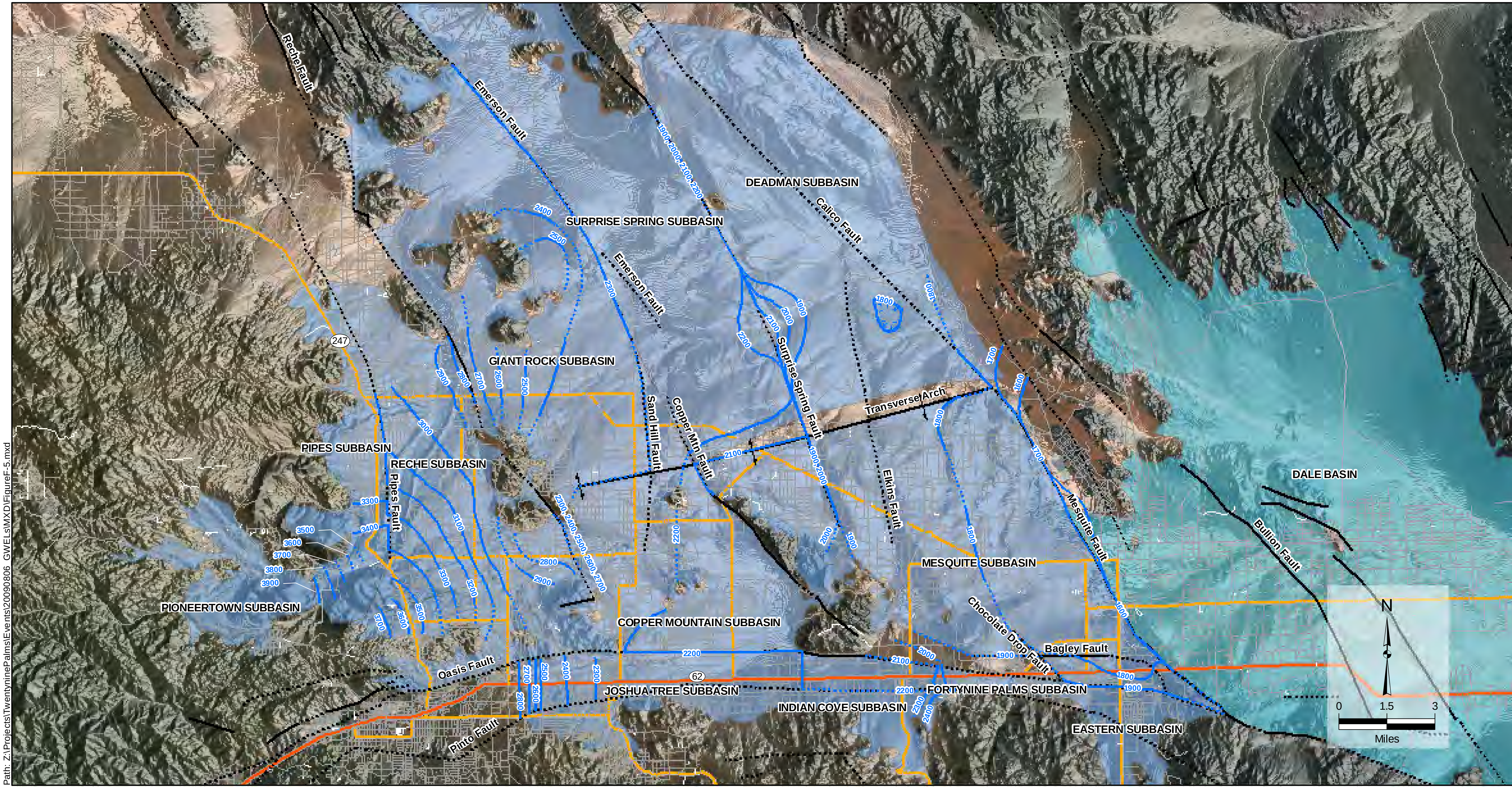
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Groundwater Elevation Contours 1975

K/J 0964003*00
March 2010

Figure F-4



Source: (c) 2009 Microsoft Corporation

Path: Z:\Projects\TwentyninePalms\Events\20090806_GWELs\MXD\FigureF-5.mxd

Explanation

Groundwater Subbasins

Groundwater Elevation (ft AMSL)

Known

Inferred

Faults

Known

Inferred

Anticline

Notes:
Contour Interval = 100 feet.
The Oasis Fault is also known as the Pinto Mountain Fault.

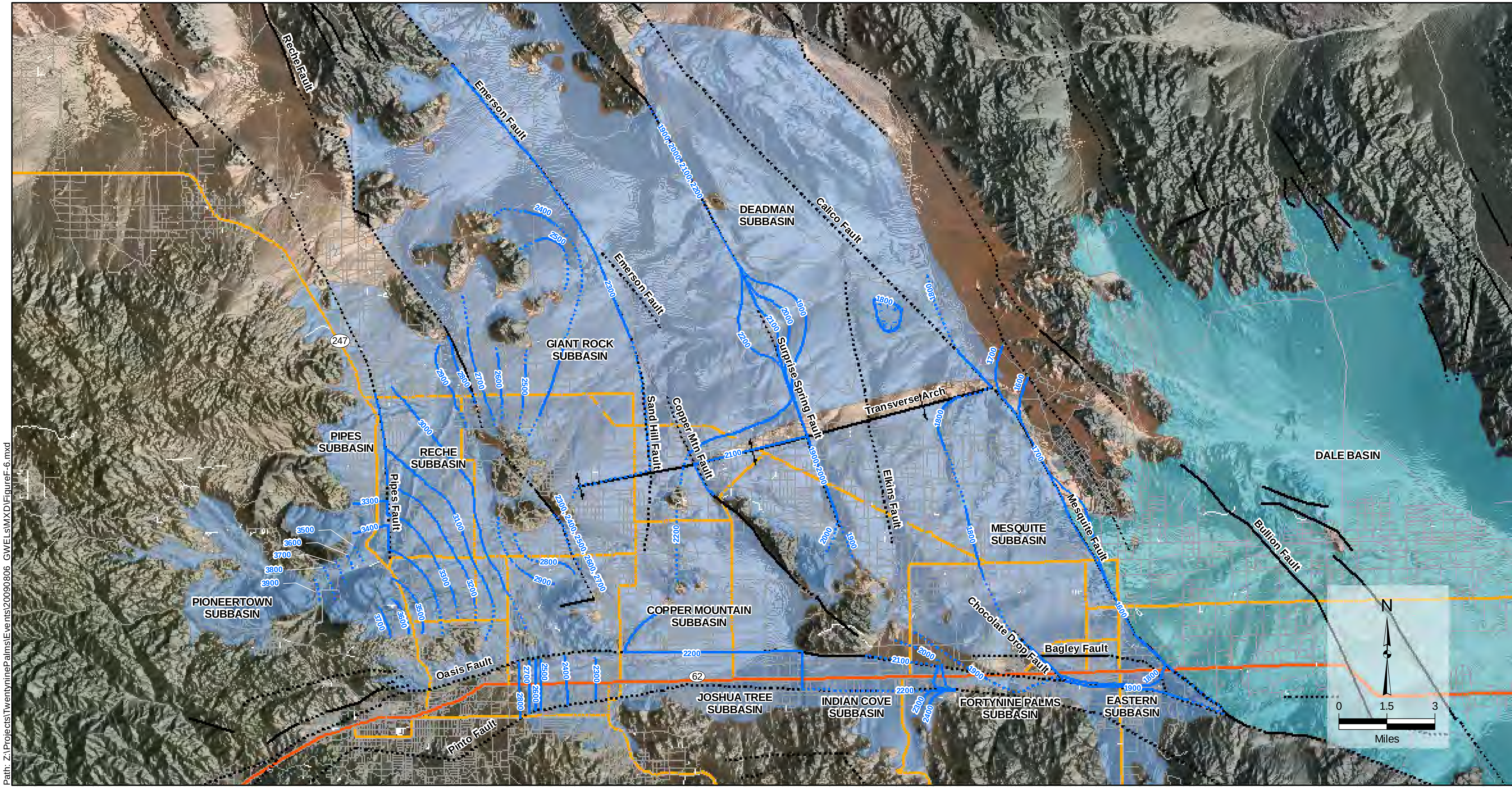
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Groundwater Elevation Contours
1994

K/J 0964003*00
March 2010

Figure F-5



Path: Z:\Projects\TwentyninePalms\Events\20090806_GWELs\MXD\FigureF-6.mxd

Source: (c) 2009 Microsoft Corporation

Explanation

Groundwater Subbasins

Groundwater Elevation (ft AMSL)

Known

Inferred

Faults

Known

Inferred

Anticline

Notes:
Contour Interval = 100 feet.
The Oasis Fault is also known as the Pinto Mountain Fault.

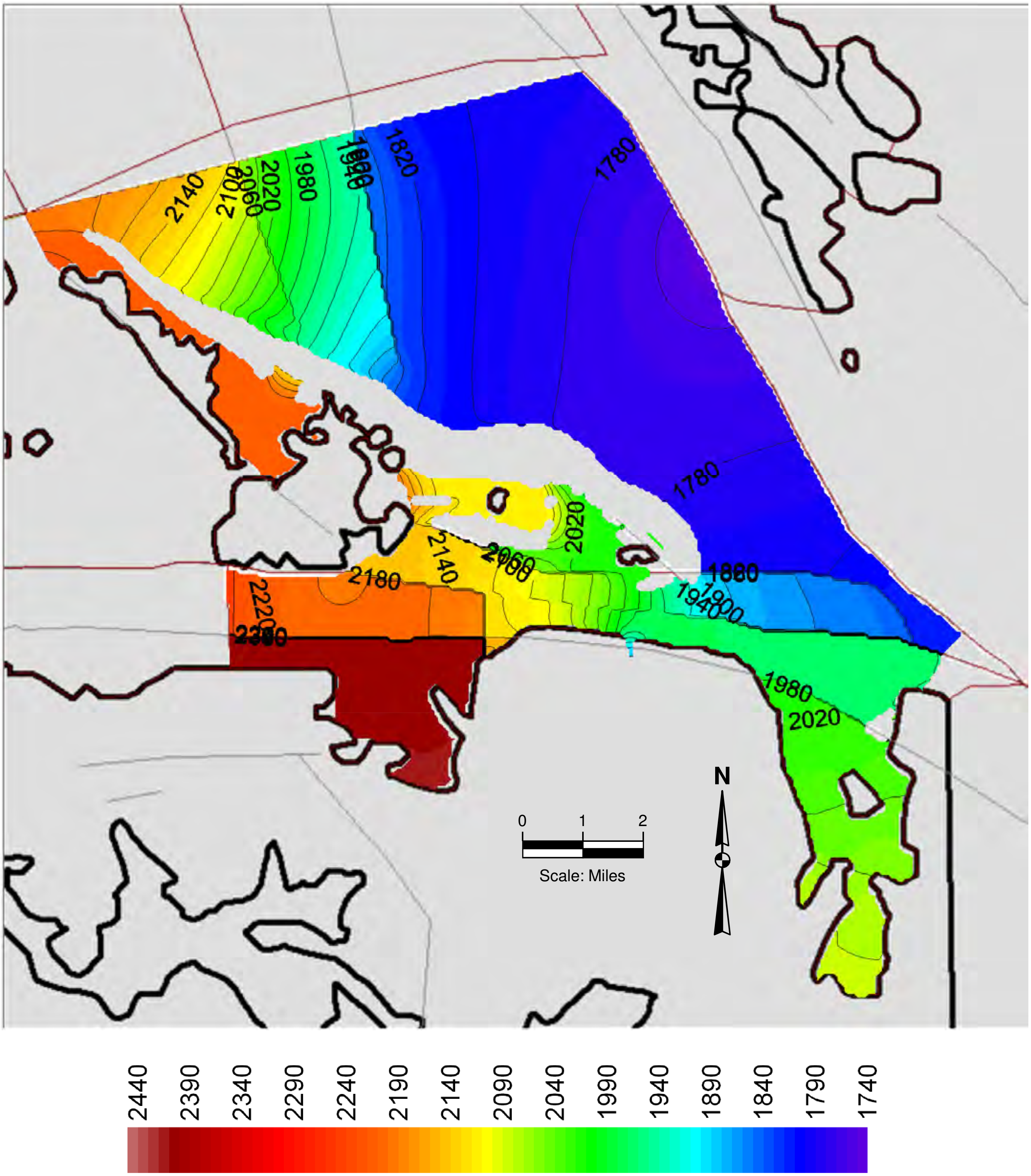
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Groundwater Elevation Contours 2002

K/J 0964003*00
March 2010

Figure F-6



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureF-7.pptx

Contour Interval = 20 feet.

Kennedy/Jenks Consultants

Twentynine Palms

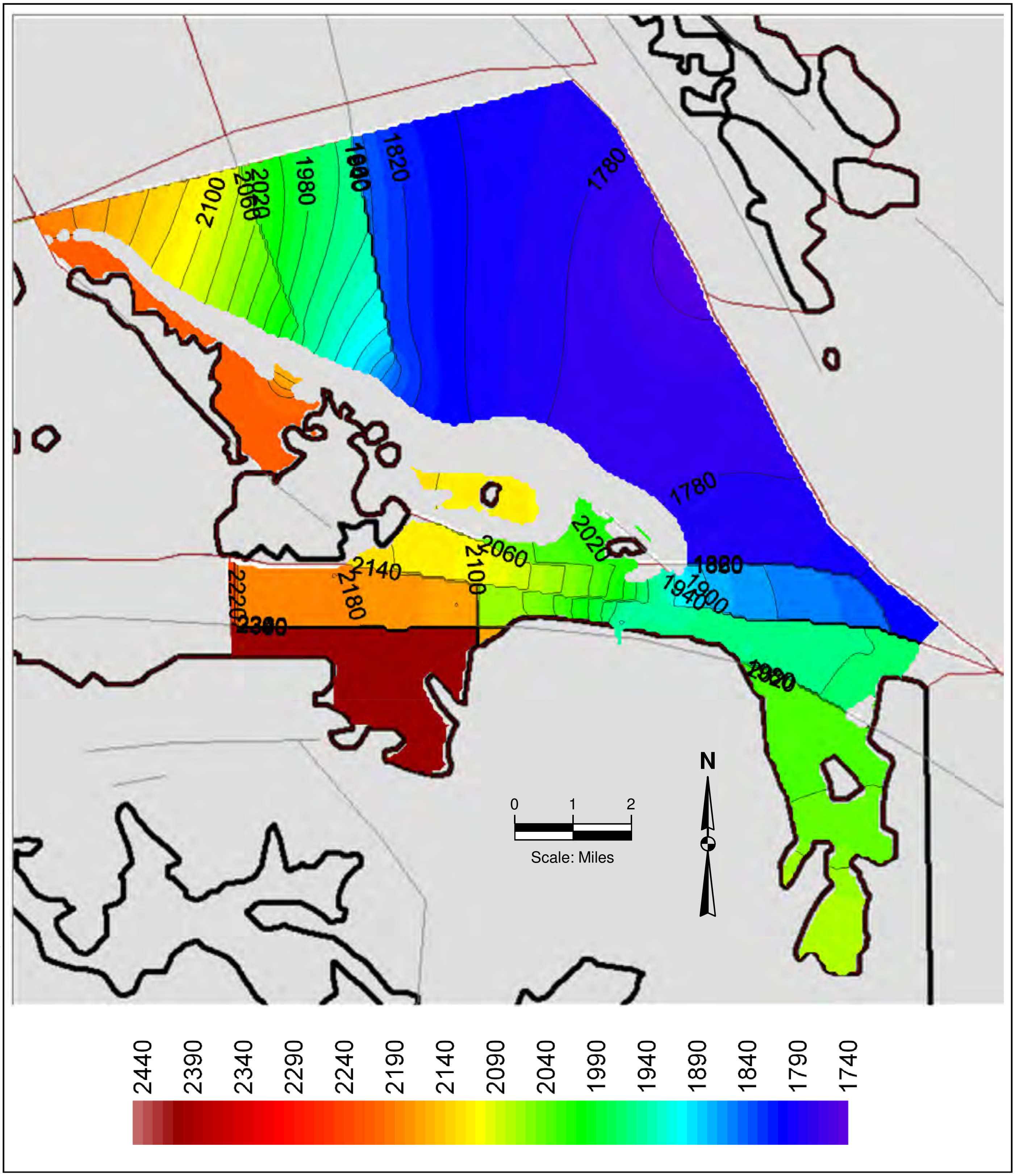
San Bernardino County, California

1984 Groundwater Elevations for Model Layer 1, Transient Simulation, Mesquite Lake Groundwater Model

K/J 0964003*00

March 2010

Figure F-7



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureF-8.pptx

Contour Interval = 20 feet.

Kennedy/Jenks Consultants

Twentynine Palms

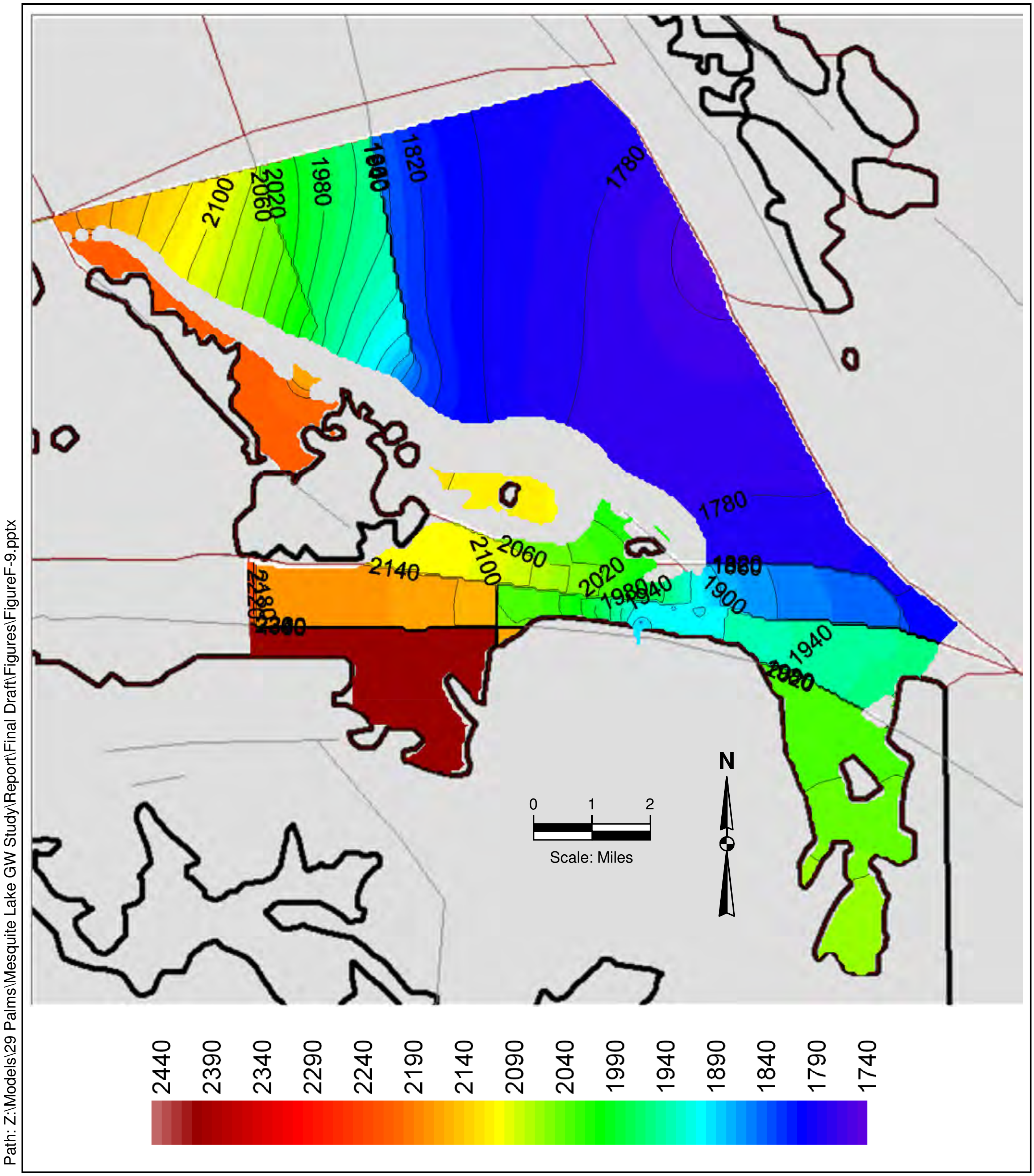
San Bernardino County, California

1994 Groundwater Elevations for Model Layer 1, Transient Simulation, Mesquite Lake Groundwater Model

K/J 0964003*00

March 2010

Figure F-8



Contour Interval = 20 feet.

Kennedy/Jenks Consultants

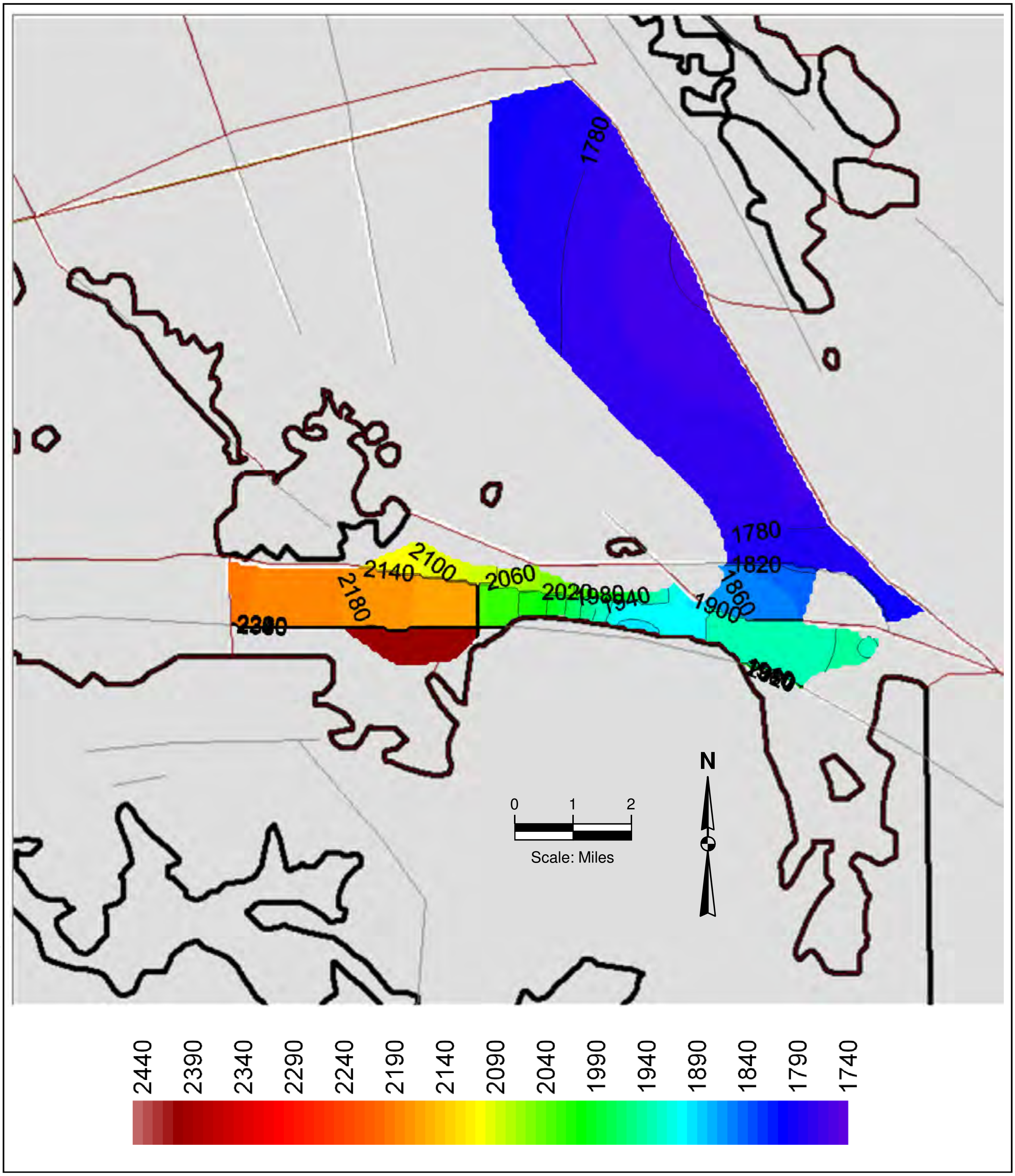
Twentynine Palms
San Bernardino County, California

2002 Groundwater Elevations for Model Layer 1, Transient Simulation, Mesquite Lake Groundwater Model

K/J 0964003*00
March 2010

Figure F-9

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureF-10.pptx



Contour Interval = 20 feet.

Kennedy/Jenks Consultants

Twentynine Palms

San Bernardino County, California

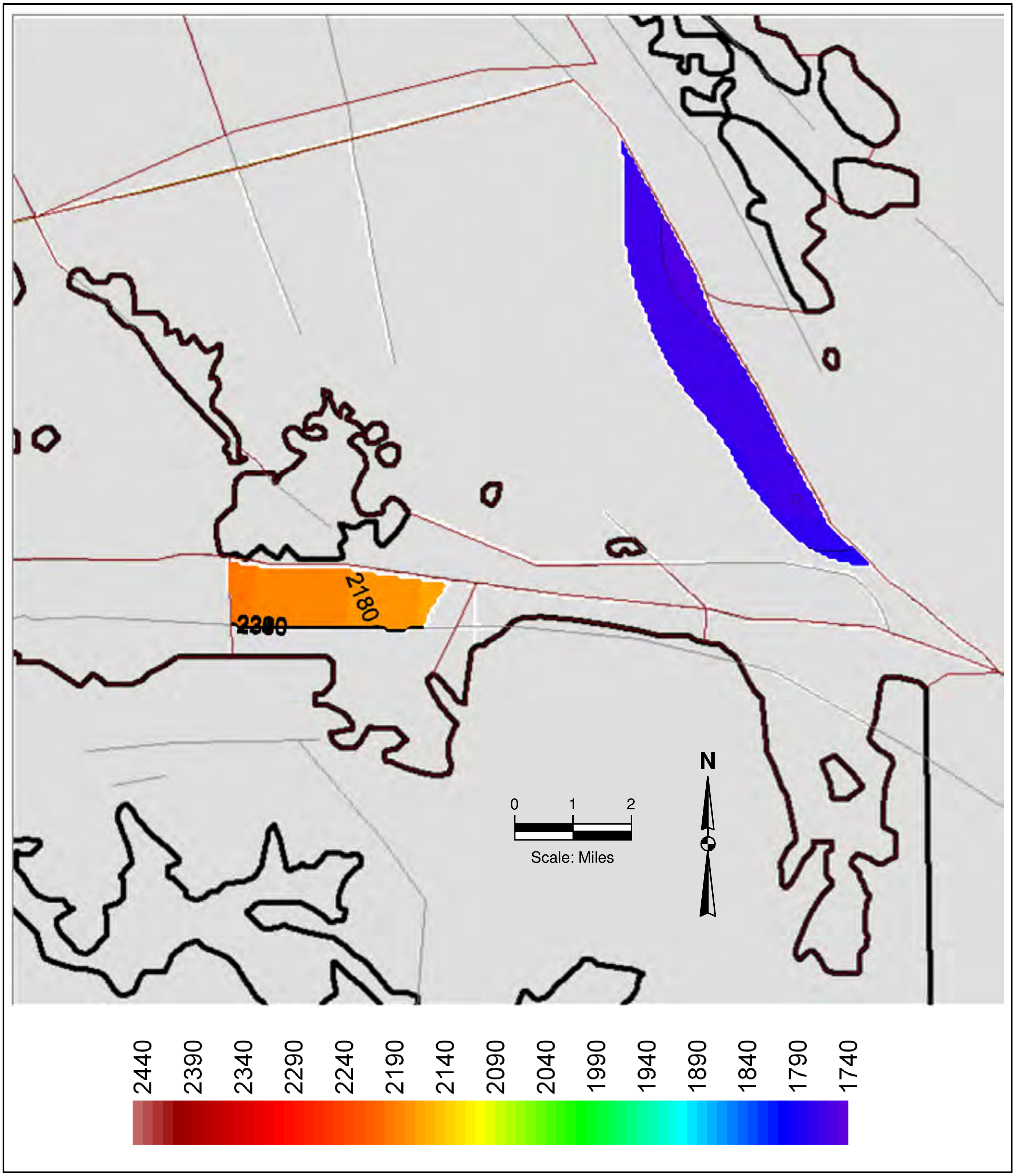
2008 Groundwater Elevations for Model Layer 2, Transient Simulation, Mesquite Lake Groundwater Model

K/J 0964003*00

March 2010

Figure F-10

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureF-11.pptx



Contour Interval = 20 feet.

Kennedy/Jenks Consultants

Twentynine Palms

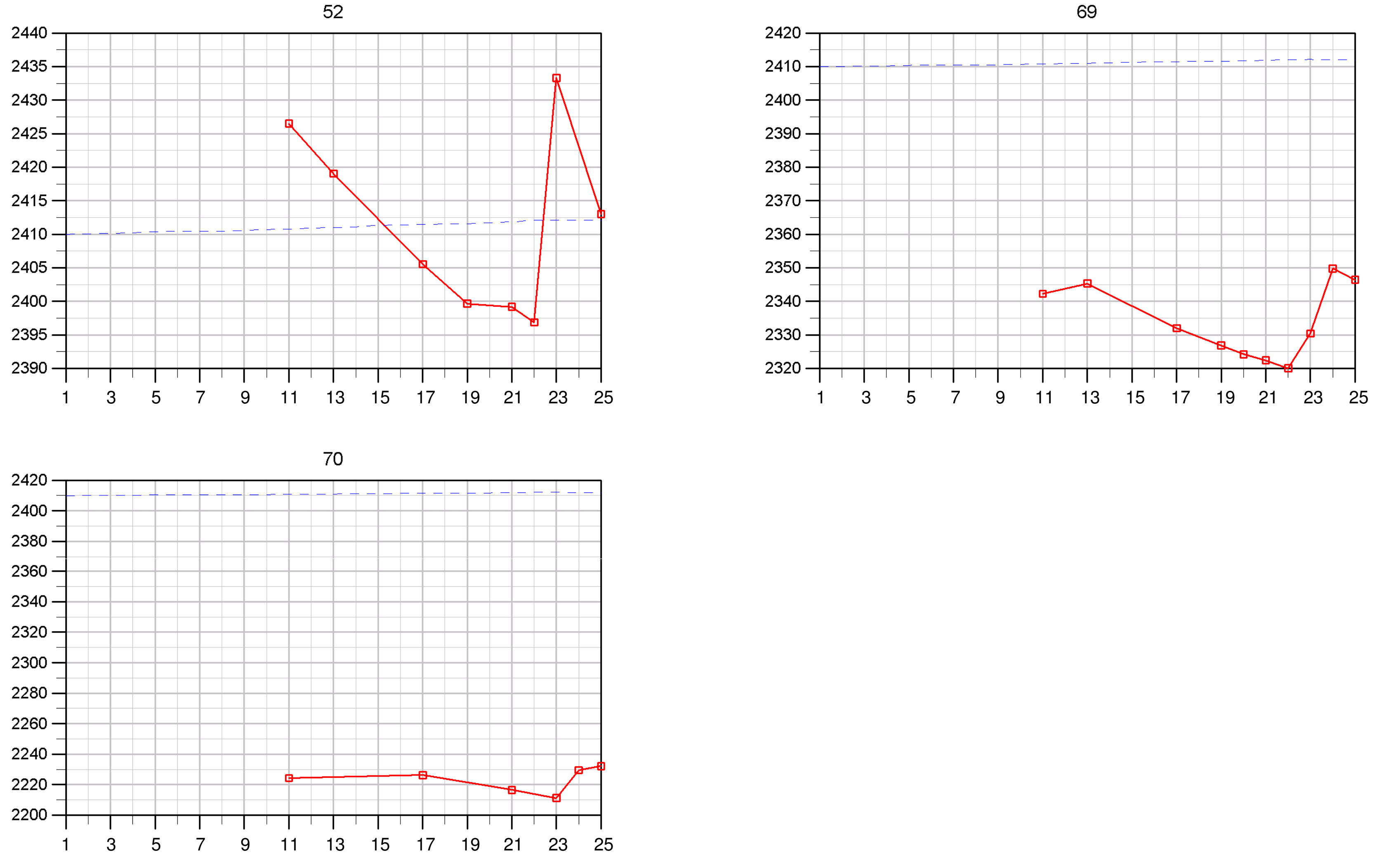
San Bernardino County, California

2008 Groundwater Elevations for Model Layer 3, Transient Simulation, Mesquite Lake Groundwater Model

K/J 0964003*00

March 2010

Figure F-11

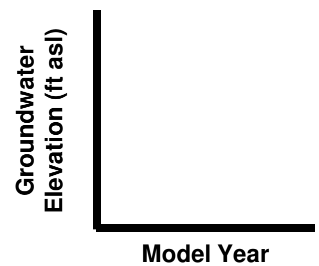


Note: The title block of each hydrograph is a hydrograph number unique to this study, as well as the TPWD well name of the well, if applicable. Model year 1 is 1984, model year 25 is 2008.

Legend

Observed head

(Model) calculated head



Kennedy/Jenks Consultants

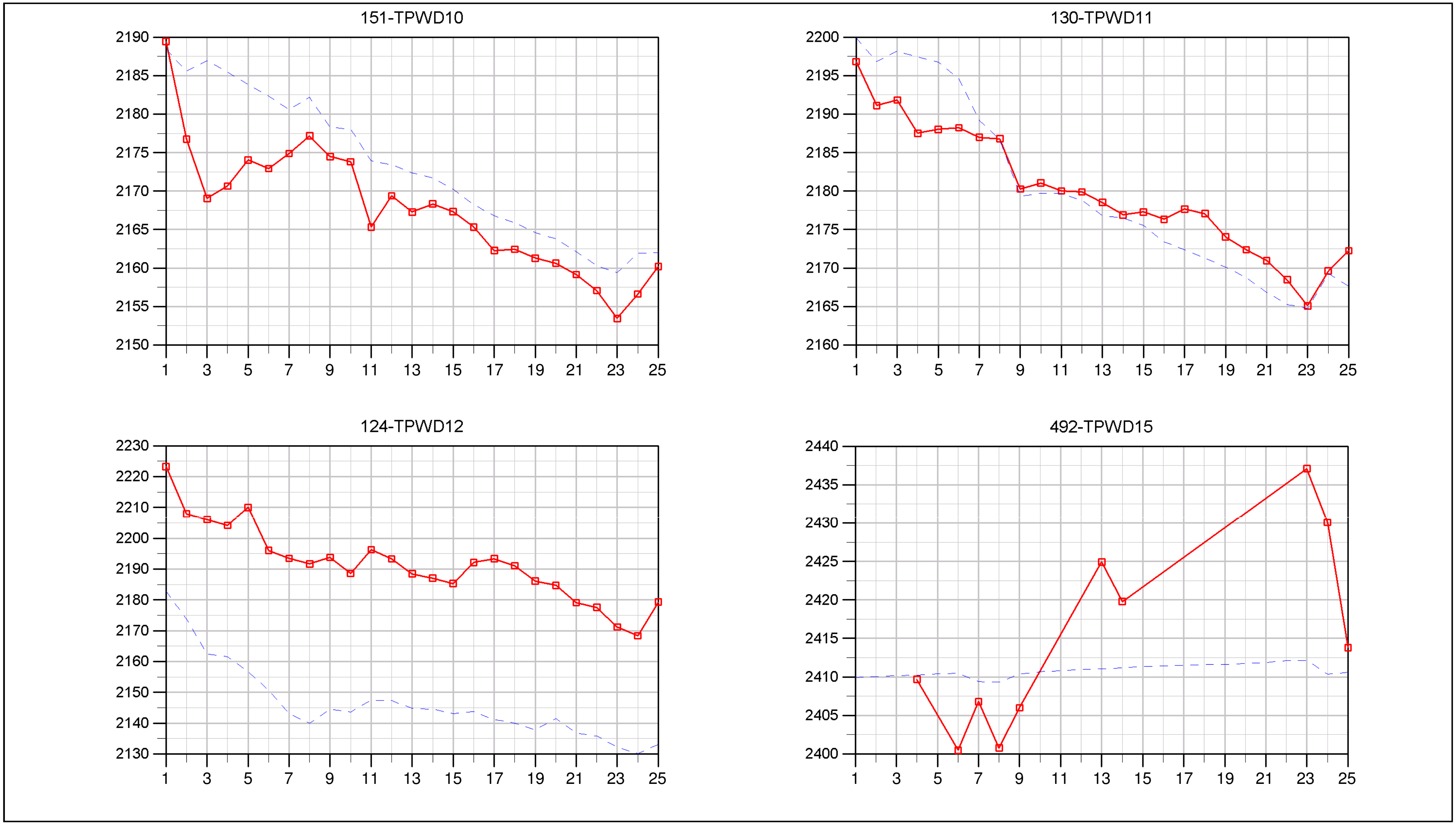
Twentynine Palms
San Bernardino County, California

Hydrographs from Indian Cove Subbasin, Transient Calibration

0964003*00
March 2010

Figure F-12

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureF-13.pptx

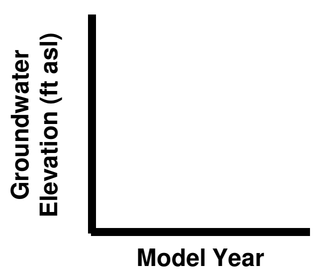


Note: The title block of each hydrograph is a hydrograph number unique to this study, as well as the TPWD well name of the well, if applicable. Model year 1 is 1984, model year 25 is 2008.

Legend

Observed head

(Model) calculated head



Kennedy/Jenks Consultants

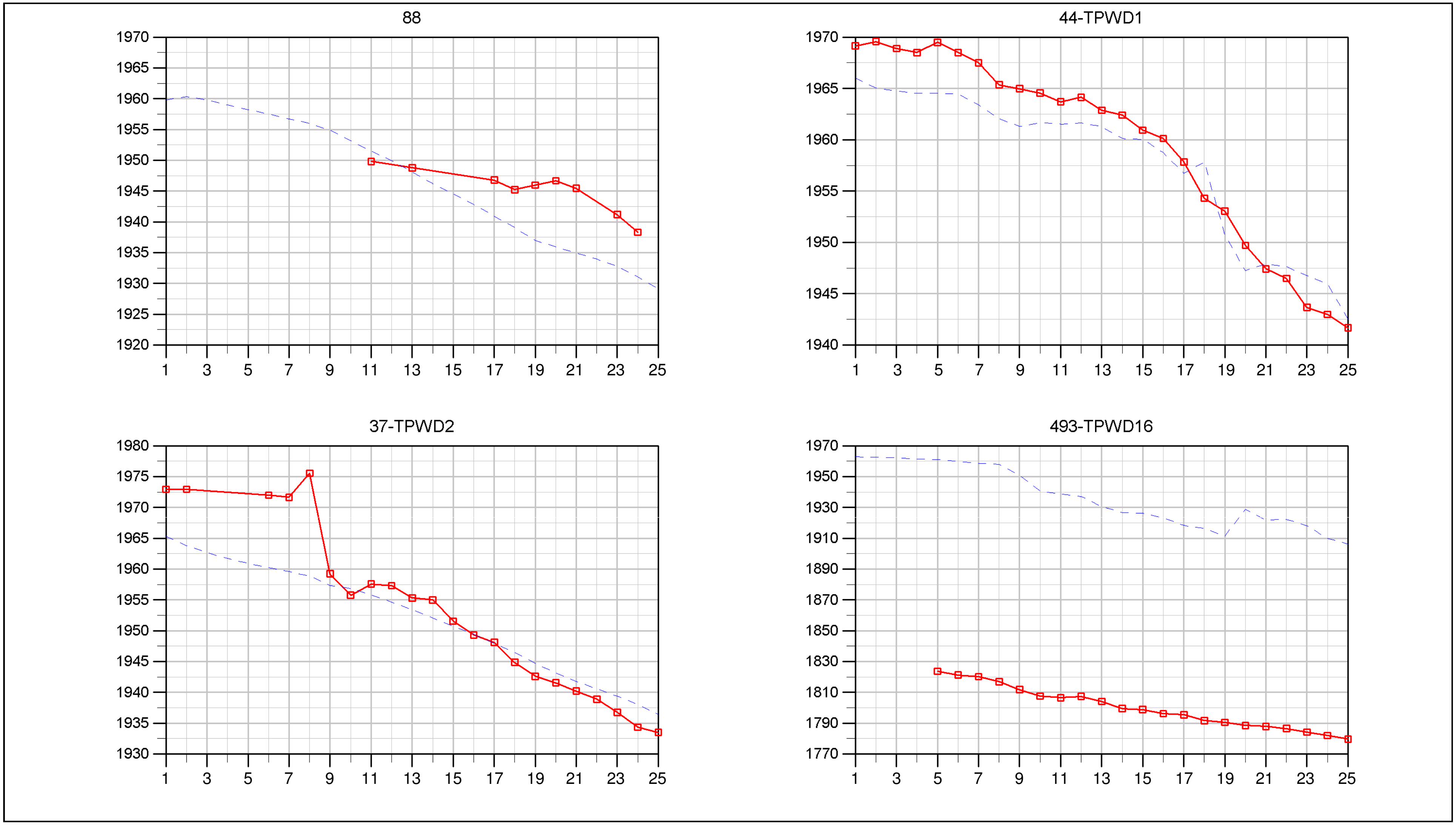
Twentynine Palms
San Bernardino County, California

Hydrographs from Indian Cove Subbasin, Transient Calibration

0964003*00
March 2010

Figure F-13

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureF-14.pptx



Note: The title block of each hydrograph is a hydrograph number unique to this study, as well as the TPWD well name of the well, if applicable. Model year 1 is 1984, model year 25 is 2008.

Legend

Observed head

(Model) calculated head

Groundwater Elevation (ft asl)

Model Year

Kennedy/Jenks Consultants

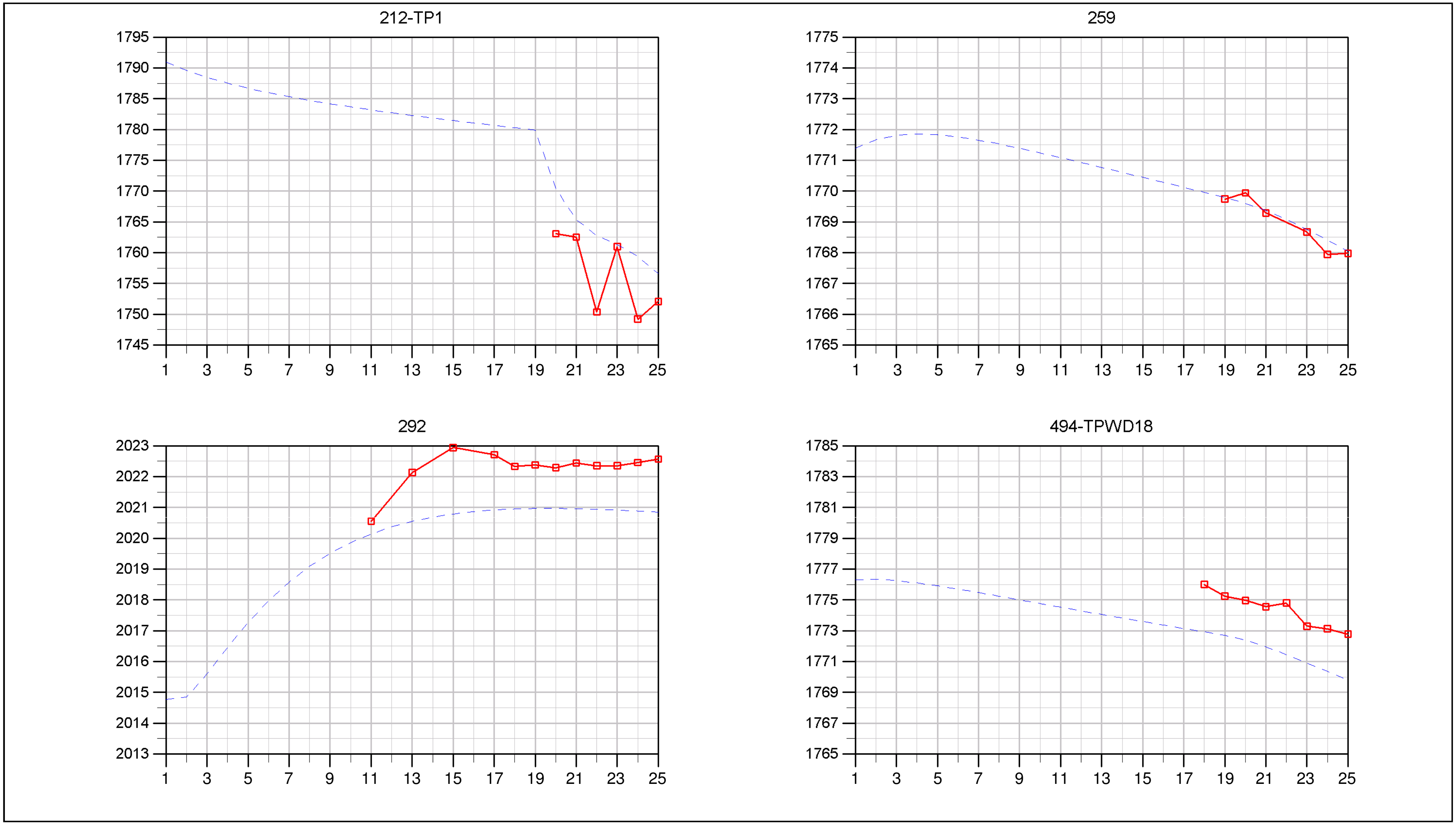
Twentynine Palms
San Bernardino County, California

Hydrographs from Eastern Subbasin, Transient Calibration

0964003*00
March 2010

Figure F-14

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureF-15.pptx

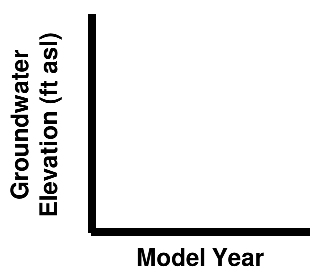


Note: The title block of each hydrograph is a hydrograph number unique to this study, as well as the TPWD well name of the well, if applicable. Model year 1 is 1984, model year 25 is 2008.

Legend

Observed head

(Model) calculated head



Kennedy/Jenks Consultants

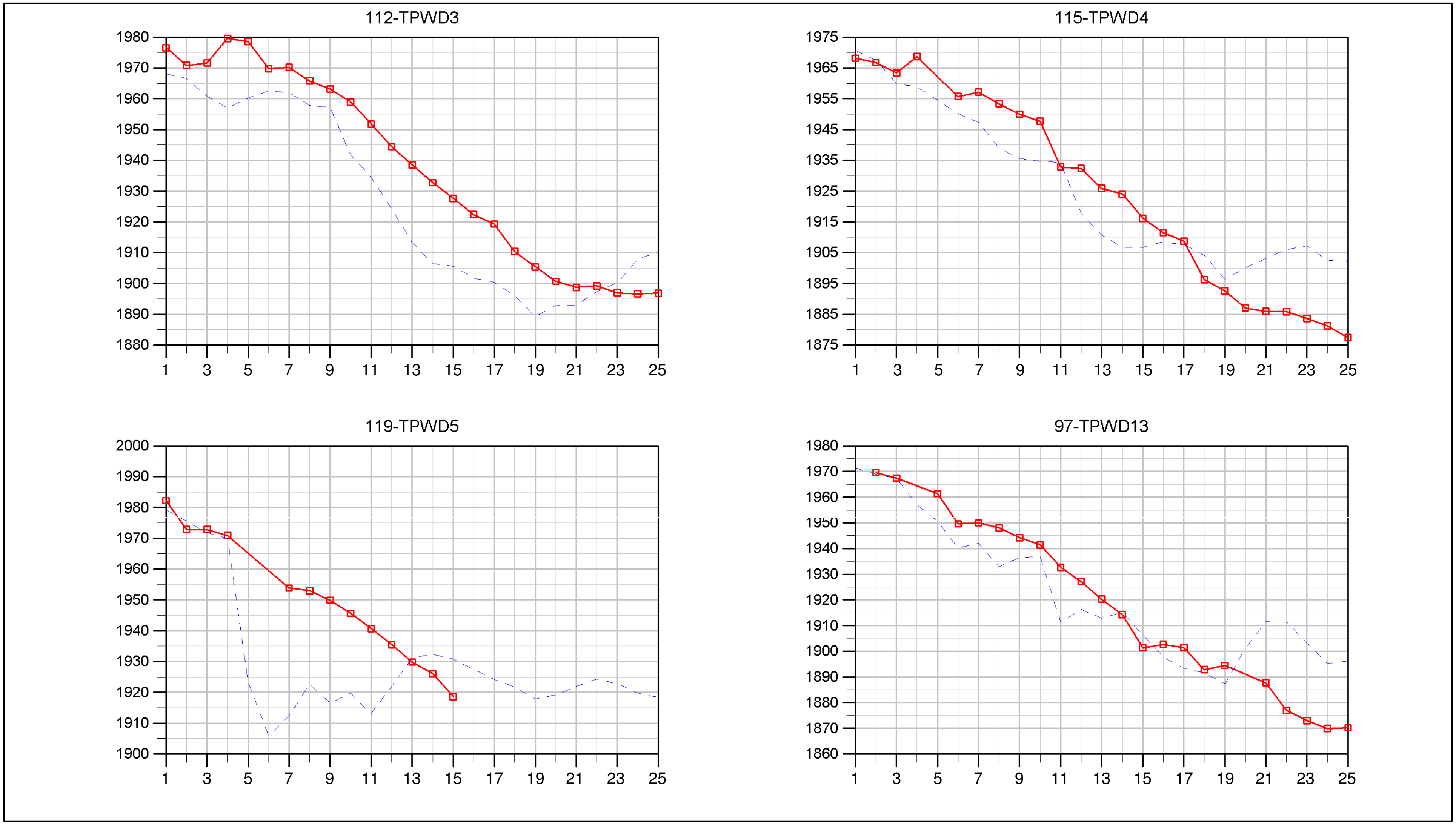
Twentynine Palms
San Bernardino County, California

Hydrographs from Mesquite Subbasin, Transient Calibration

0964003*00
March 2010

Figure F-15

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureF-16.pptx

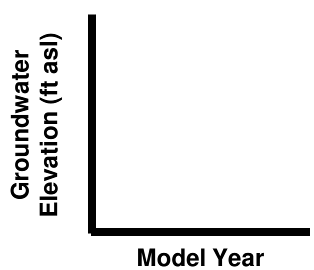


Note: The title block of each hydrograph is a hydrograph number unique to this study, as well as the TPWD well name of the well, if applicable. Model year 1 is 1984, model year 25 is 2008.

Legend

Observed head

(Model) calculated head



Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs from Fortynine Palms Subbasin, Transient Calibration

0964003*00
March 2010

Figure F-16

Appendix G: Hydraulic Budget Evaluation of Pumping Results

Appendix G: Hydraulic Budget Evaluation of Pumping Results

Appendix G contains additional tables and graphs to support the evaluation of future groundwater pumping using the hydrologic budget method.

List of Tables

G-1 Annual Estimated Changes in Groundwater Storage and Water Levels, Pumping Scenario 1

G-2 Annual Estimated Changes in Groundwater Storage and Water Levels, Pumping Scenario 2

G-3 Annual Estimated Changes in Groundwater Storage and Water Levels, Pumping Scenario 3

G-4 Annual Estimated Changes in Groundwater Storage and Water Levels, Pumping Scenario 4

List of Figures

G-1 Mesquite Subbasin, Annual Total Subbasin Well Discharge versus Change in Storage, Pumping Scenario 1

G-2 Indian Cove Subbasin, Annual Total Subbasin Well Discharge versus Change in Storage, Pumping Scenario 1

G-3 Fortynine Palms Subbasin, Annual Total Subbasin Well Discharge versus Change in Storage, Pumping Scenario 1

G-4 Eastern Subbasin, Annual Total Subbasin Well Discharge versus Change in Storage, Pumping Scenario 1

Table G-1a: Annual Estimated Changes in Groundwater Storage and Water Levels, Pumping Scenario 1 (using Method 1 subbasin recharge estimates)												
	Mesquite Subbasin			Indian Cove Subbasin			Fortynine Palms Subbasin			Eastern Subbasin		
Year	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)
2009	1,701	-1,110	-0.25	691	-584	-1.00	1,024	-822	-2.23	737	-542	-0.39
2010	1,701	-1,110	-0.49	691	-584	-1.99	1,024	-822	-4.47	737	-542	-0.78
2011	1,701	-1,110	-0.74	691	-584	-2.99	1,024	-822	-6.70	737	-542	-1.17
2012	1,701	-1,110	-0.99	691	-584	-3.98	1,024	-822	-8.93	737	-542	-1.56
2013	1,701	-1,110	-1.24	691	-584	-4.98	1,024	-822	-11.16	737	-542	-1.95
2014	1,701	-1,110	-1.48	691	-584	-5.97	1,024	-822	-13.40	737	-542	-2.34
2015	1,701	-1,110	-1.73	691	-584	-6.97	1,024	-822	-15.63	737	-542	-2.73
2016	1,701	-1,110	-1.98	691	-584	-7.96	1,024	-822	-17.86	737	-542	-3.12
2017	1,701	-1,110	-2.23	691	-584	-8.96	1,024	-822	-20.10	737	-542	-3.51
2018	1,701	-1,110	-2.47	691	-584	-9.95	1,024	-822	-22.33	737	-542	-3.90
2019	1,701	-1,110	-2.72	691	-584	-10.95	1,024	-822	-24.56	737	-542	-4.29
2020	1,701	-1,110	-2.97	691	-584	-11.94	1,024	-822	-26.79	737	-542	-4.68
2021	1,701	-1,110	-3.21	691	-584	-12.94	1,024	-822	-29.03	737	-542	-5.07
2022	1,701	-1,110	-3.46	691	-584	-13.94	1,024	-822	-31.26	737	-542	-5.46
2023	1,701	-1,110	-3.71	691	-584	-14.93	1,024	-822	-33.49	737	-542	-5.85
2024	1,701	-1,110	-3.96	691	-584	-15.93	1,024	-822	-35.73	737	-542	-6.24
2025	1,701	-1,110	-4.20	691	-584	-16.92	1,024	-822	-37.96	737	-542	-6.63
2026	1,701	-1,110	-4.45	691	-584	-17.92	1,024	-822	-40.19	737	-542	-7.02
2027	1,701	-1,110	-4.70	691	-584	-18.91	1,024	-822	-42.43	737	-542	-7.41
2028	1,701	-1,110	-4.95	691	-584	-19.91	1,024	-822	-44.66	737	-542	-7.80
2029	1,701	-1,110	-5.19	691	-584	-20.90	1,024	-822	-46.89	737	-542	-8.19
2030	1,701	-1,110	-5.44	691	-584	-21.90	1,024	-822	-49.12	737	-542	-8.58
2031	1,701	-1,110	-5.69	691	-584	-22.89	1,024	-822	-51.36	737	-542	-8.97
2032	1,701	-1,110	-5.93	691	-584	-23.89	1,024	-822	-53.59	737	-542	-9.36
2033	1,701	-1,110	-6.18	691	-584	-24.89	1,024	-822	-55.82	737	-542	-9.75
Total Change in Storage, 2009-2033		-27,743			-14,608			-20,543			-13,557	
Total Estimated Storage (upper 100 ft of aquifer)		448,800			58,700			36,800			139,000	

Table G-1b: Annual Estimated Changes in Groundwater Storage and Water Levels, Pumping Scenario 1 (using Method 2 subbasin recharge estimates)

	Mesquite Subbasin			Indian Cove Subbasin			Fortynine Palms Subbasin			Eastern Subbasin		
Year	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)
2009	1,701	-1,418	-0.32	691	-664	-1.13	1,024	-1,022	-2.78	737	-737	-0.53
2010	1,701	-1,418	-0.63	691	-664	-2.26	1,024	-1,022	-5.55	737	-737	-1.06
2011	1,701	-1,418	-0.95	691	-664	-3.39	1,024	-1,022	-8.33	737	-737	-1.59
2012	1,701	-1,418	-1.26	691	-664	-4.52	1,024	-1,022	-11.11	737	-737	-2.12
2013	1,701	-1,418	-1.58	691	-664	-5.66	1,024	-1,022	-13.89	737	-737	-2.65
2014	1,701	-1,418	-1.90	691	-664	-6.79	1,024	-1,022	-16.66	737	-737	-3.18
2015	1,701	-1,418	-2.21	691	-664	-7.92	1,024	-1,022	-19.44	737	-737	-3.71
2016	1,701	-1,418	-2.53	691	-664	-9.05	1,024	-1,022	-22.22	737	-737	-4.24
2017	1,701	-1,418	-2.84	691	-664	-10.18	1,024	-1,022	-25.00	737	-737	-4.77
2018	1,701	-1,418	-3.16	691	-664	-11.31	1,024	-1,022	-27.77	737	-737	-5.30
2019	1,701	-1,418	-3.47	691	-664	-12.44	1,024	-1,022	-30.55	737	-737	-5.83
2020	1,701	-1,418	-3.79	691	-664	-13.57	1,024	-1,022	-33.33	737	-737	-6.36
2021	1,701	-1,418	-4.11	691	-664	-14.71	1,024	-1,022	-36.11	737	-737	-6.89
2022	1,701	-1,418	-4.42	691	-664	-15.84	1,024	-1,022	-38.88	737	-737	-7.42
2023	1,701	-1,418	-4.74	691	-664	-16.97	1,024	-1,022	-41.66	737	-737	-7.95
2024	1,701	-1,418	-5.05	691	-664	-18.10	1,024	-1,022	-44.44	737	-737	-8.48
2025	1,701	-1,418	-5.37	691	-664	-19.23	1,024	-1,022	-47.22	737	-737	-9.01
2026	1,701	-1,418	-5.69	691	-664	-20.36	1,024	-1,022	-49.99	737	-737	-9.54
2027	1,701	-1,418	-6.00	691	-664	-21.49	1,024	-1,022	-52.77	737	-737	-10.07
2028	1,701	-1,418	-6.32	691	-664	-22.62	1,024	-1,022	-55.55	737	-737	-10.60
2029	1,701	-1,418	-6.63	691	-664	-23.76	1,024	-1,022	-58.33	737	-737	-11.13
2030	1,701	-1,418	-6.95	691	-664	-24.89	1,024	-1,022	-61.10	737	-737	-11.66
2031	1,701	-1,418	-7.27	691	-664	-26.02	1,024	-1,022	-63.88	737	-737	-12.19
2032	1,701	-1,418	-7.58	691	-664	-27.15	1,024	-1,022	-66.66	737	-737	-12.73
2033	1,701	-1,418	-7.90	691	-664	-28.28	1,024	-1,022	-69.44	737	-737	-13.26
Total Change in Storage, 2009-2033		-35,444			-16,600			-25,553			-18,425	
Total Estimated Storage (upper 100 ft of aquifer)		448,800			58,700			36,800			139,000	

Table G-2a: Annual Estimated Changes in Groundwater Storage and Water Levels, Pumping Scenario 2 (using Method 1 subbasin recharge estimates)

	Mesquite Subbasin			Indian Cove Subbasin			Fortynine Palms Subbasin			Eastern Subbasin		
Year	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)
2009	1,673	-1,089	-0.24	674	-566	-0.96	998	-797	-2.17	719	-519	-0.37
2010	1,683	-1,097	-0.49	680	-573	-1.94	1,008	-807	-4.36	726	-528	-0.75
2011	1,694	-1,105	-0.73	687	-580	-2.93	1,018	-816	-6.58	733	-537	-1.14
2012	1,705	-1,112	-0.98	694	-587	-3.93	1,028	-825	-8.82	740	-546	-1.53
2013	1,715	-1,120	-1.23	700	-594	-4.94	1,037	-834	-11.08	747	-555	-1.93
2014	1,726	-1,128	-1.48	707	-601	-5.97	1,047	-843	-13.38	754	-564	-2.34
2015	1,737	-1,136	-1.74	713	-608	-7.00	1,057	-853	-15.69	761	-573	-2.75
2016	1,748	-1,143	-1.99	720	-615	-8.05	1,067	-862	-18.04	768	-582	-3.17
2017	1,758	-1,151	-2.25	727	-622	-9.11	1,077	-871	-20.40	775	-591	-3.59
2018	1,769	-1,159	-2.50	733	-629	-10.18	1,086	-880	-22.80	782	-600	-4.02
2019	1,780	-1,166	-2.76	740	-635	-11.26	1,096	-890	-25.21	789	-609	-4.46
2020	1,791	-1,174	-3.03	747	-642	-12.35	1,106	-899	-27.66	796	-618	-4.91
2021	1,801	-1,182	-3.29	753	-649	-13.46	1,116	-908	-30.12	803	-628	-5.36
2022	1,812	-1,190	-3.55	760	-656	-14.58	1,126	-917	-32.62	810	-637	-5.82
2023	1,823	-1,197	-3.82	766	-663	-15.71	1,135	-927	-35.13	817	-646	-6.28
2024	1,833	-1,205	-4.09	773	-670	-16.85	1,145	-936	-37.68	824	-655	-6.75
2025	1,844	-1,213	-4.36	780	-677	-18.00	1,155	-945	-40.24	832	-664	-7.23
2026	1,855	-1,221	-4.63	786	-684	-19.17	1,165	-954	-42.84	839	-673	-7.71
2027	1,866	-1,228	-4.91	793	-691	-20.34	1,175	-963	-45.46	846	-682	-8.21
2028	1,876	-1,236	-5.18	800	-698	-21.53	1,184	-973	-48.10	853	-691	-8.70
2029	1,887	-1,244	-5.46	806	-705	-22.73	1,194	-982	-50.77	860	-700	-9.21
2030	1,898	-1,251	-5.74	813	-712	-23.95	1,204	-991	-53.46	867	-709	-9.72
2031	1,909	-1,259	-6.02	819	-718	-25.17	1,214	-1,000	-56.18	874	-718	-10.23
2032	1,919	-1,267	-6.30	826	-725	-26.41	1,224	-1,010	-58.92	881	-727	-10.76
2033	1,930	-1,275	-6.58	833	-732	-27.65	1,233	-1,019	-61.69	888	-736	-11.29
Total Change in Storage, 2009-2033		-29,548			-16,233			-22,702			-15,688	
Total Estimated Storage (upper 100 ft of aquifer)		448,800			58,700			36,800			139,000	

Table G-2b:	Annual Estimated Changes in Groundwater Storage and Water Levels, Pumping Scenario 2 (using Method 2 subbasin recharge estimates)											
	Mesquite Subbasin			Indian Cove Subbasin			Fortynine Palms Subbasin			Eastern Subbasin		
Year	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)
2009	1,673	-1,390	-0.31	674	-647	-1.10	998	-996	-2.71	719	-719	-0.52
2010	1,683	-1,401	-0.62	680	-653	-2.21	1,008	-1,006	-5.44	726	-726	-1.04
2011	1,694	-1,411	-0.94	687	-660	-3.34	1,018	-1,016	-8.20	733	-733	-1.57
2012	1,705	-1,421	-1.25	694	-667	-4.47	1,028	-1,026	-10.99	740	-740	-2.10
2013	1,715	-1,432	-1.57	700	-673	-5.62	1,037	-1,035	-13.80	747	-747	-2.64
2014	1,726	-1,442	-1.89	707	-680	-6.78	1,047	-1,045	-16.64	754	-754	-3.18
2015	1,737	-1,453	-2.22	713	-687	-7.95	1,057	-1,055	-19.51	761	-761	-3.73
2016	1,748	-1,463	-2.54	720	-693	-9.13	1,067	-1,065	-22.40	768	-768	-4.28
2017	1,758	-1,473	-2.87	727	-700	-10.32	1,077	-1,075	-25.32	775	-775	-4.84
2018	1,769	-1,484	-3.20	733	-706	-11.53	1,086	-1,084	-28.27	782	-782	-5.40
2019	1,780	-1,494	-3.53	740	-713	-12.74	1,096	-1,094	-31.24	789	-789	-5.97
2020	1,791	-1,505	-3.87	747	-720	-13.97	1,106	-1,104	-34.24	796	-796	-6.54
2021	1,801	-1,515	-4.21	753	-726	-15.20	1,116	-1,114	-37.27	803	-803	-7.12
2022	1,812	-1,526	-4.55	760	-733	-16.45	1,126	-1,124	-40.32	810	-810	-7.70
2023	1,823	-1,536	-4.89	766	-740	-17.71	1,135	-1,133	-43.40	817	-817	-8.29
2024	1,833	-1,546	-5.23	773	-746	-18.98	1,145	-1,143	-46.51	824	-824	-8.88
2025	1,844	-1,557	-5.58	780	-753	-20.27	1,155	-1,153	-49.64	832	-832	-9.48
2026	1,855	-1,567	-5.93	786	-759	-21.56	1,165	-1,163	-52.80	839	-839	-10.08
2027	1,866	-1,578	-6.28	793	-766	-22.86	1,175	-1,173	-55.99	846	-846	-10.69
2028	1,876	-1,588	-6.64	800	-773	-24.18	1,184	-1,182	-59.20	853	-853	-11.30
2029	1,887	-1,598	-6.99	806	-779	-25.51	1,194	-1,192	-62.44	860	-860	-11.92
2030	1,898	-1,609	-7.35	813	-786	-26.85	1,204	-1,202	-65.71	867	-867	-12.55
2031	1,909	-1,619	-7.71	819	-793	-28.20	1,214	-1,212	-69.00	874	-874	-13.18
2032	1,919	-1,630	-8.07	826	-799	-29.56	1,224	-1,222	-72.32	881	-881	-13.81
2033	1,930	-1,640	-8.44	833	-806	-30.93	1,233	-1,231	-75.67	888	-888	-14.45
Total Change in Storage, 2009-2033		-37,877			-18,157			-27,845			-20,082	
Total Estimated Storage (upper 100 ft of aquifer)		448,800			58,700			36,800			139,000	

Table G-3a: Annual Estimated Changes in Groundwater Storage and Water Levels, Pumping Scenario 3 (using Method 1 subbasin recharge estimates)

	Mesquite Subbasin			Indian Cove Subbasin			Fortynine Palms Subbasin			Eastern Subbasin		
Year	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)
2009	1,701	-1,110	-0.25	691	-585	-1.00	1,024	-822	-2.23	737	-543	-0.39
2010	2,037	-1,352	-0.55	596	-485	-1.82	884	-690	-4.11	636	-413	-0.69
2011	2,822	-1,917	-0.98	375	-254	-2.26	556	-381	-5.14	400	-109	-0.77
2012	2,822	-1,917	-1.40	375	-254	-2.69	556	-381	-6.18	400	-109	-0.84
2013	2,822	-1,917	-1.83	375	-254	-3.12	556	-381	-7.21	400	-109	-0.92
2014	2,822	-1,917	-2.26	375	-254	-3.56	556	-381	-8.25	400	-109	-1.00
2015	3,943	-2,724	-2.86	59	76	-3.43	88	60	-8.09	63	324	-0.77
2016	3,943	-2,724	-3.47	59	76	-3.30	88	60	-7.92	63	324	-0.54
2017	3,943	-2,724	-4.08	59	76	-3.17	88	60	-7.76	63	324	-0.30
2018	3,943	-2,724	-4.68	59	76	-3.04	88	60	-7.60	63	324	-0.07
2019	3,943	-2,724	-5.29	59	76	-2.91	88	60	-7.44	63	324	0.16
2020	3,943	-2,724	-5.90	59	76	-2.78	88	60	-7.28	63	324	0.40
2021	3,943	-2,724	-6.50	59	76	-2.65	88	60	-7.12	63	324	0.63
2022	3,943	-2,724	-7.11	59	76	-2.52	88	60	-6.95	63	324	0.86
2023	3,943	-2,724	-7.72	59	76	-2.39	88	60	-6.79	63	324	1.09
2024	3,943	-2,724	-8.33	59	76	-2.26	88	60	-6.63	63	324	1.33
2025	3,943	-2,724	-8.93	59	76	-2.13	88	60	-6.47	63	324	1.56
2026	3,943	-2,724	-9.54	59	76	-2.00	88	60	-6.31	63	324	1.79
2027	3,943	-2,724	-10.15	59	76	-1.87	88	60	-6.15	63	324	2.03
2028	3,943	-2,724	-10.75	59	76	-1.75	88	60	-5.98	63	324	2.26
2029	3,943	-2,724	-11.36	59	76	-1.62	88	60	-5.82	63	324	2.49
2030	3,943	-2,724	-11.97	59	76	-1.49	88	60	-5.66	63	324	2.73
2031	3,943	-2,724	-12.57	59	76	-1.36	88	60	-5.50	63	324	2.96
2032	3,943	-2,724	-13.18	59	76	-1.23	88	60	-5.34	63	324	3.19
2033	3,943	-2,724	-13.79	59	76	-1.10	88	60	-5.17	63	324	3.42
Total Change in Storage, 2009-2033		-61,876			-645			-1,904			4,760	
Total Estimated Storage (upper 100 ft of aquifer)		448,800			58,700			36,800			139,000	

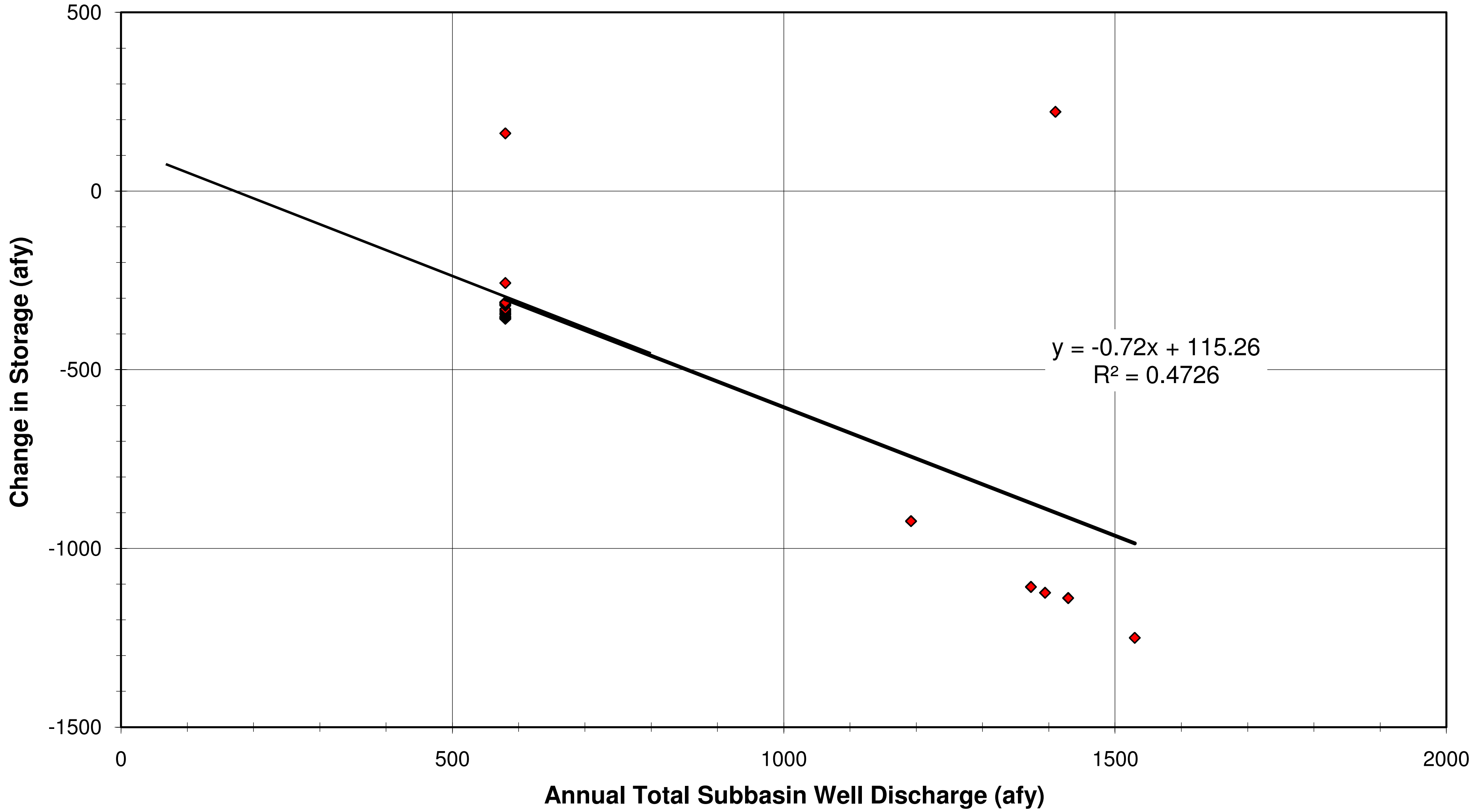
Table G-3b:	Annual Estimated Changes in Groundwater Storage and Water Levels, Pumping Scenario 3 (using Method 2 subbasin recharge estimates)											
	Mesquite Subbasin			Indian Cove Subbasin			Fortynine Palms Subbasin			Eastern Subbasin		
Year	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)
2009	1,701	-1,418	-0.32	691	-664	-1.13	1,024	-1,022	-2.78	737	-737	-0.53
2010	2,037	-1,744	-0.70	596	-569	-2.10	884	-882	-5.17	636	-636	-0.99
2011	2,822	-2,505	-1.26	375	-348	-2.69	556	-554	-6.68	400	-400	-1.28
2012	2,822	-2,505	-1.82	375	-348	-3.29	556	-554	-8.19	400	-400	-1.56
2013	2,822	-2,505	-2.38	375	-348	-3.88	556	-554	-9.69	400	-400	-1.85
2014	2,822	-2,505	-2.94	375	-348	-4.47	556	-554	-11.20	400	-400	-2.14
2015	3,943	-3,593	-3.74	59	-32	-4.53	88	-87	-11.43	63	-63	-2.19
2016	3,943	-3,593	-4.54	59	-32	-4.58	88	-87	-11.67	63	-63	-2.23
2017	3,943	-3,593	-5.34	59	-32	-4.63	88	-87	-11.91	63	-63	-2.28
2018	3,943	-3,593	-6.14	59	-32	-4.69	88	-87	-12.14	63	-63	-2.32
2019	3,943	-3,593	-6.94	59	-32	-4.74	88	-87	-12.38	63	-63	-2.37
2020	3,943	-3,593	-7.74	59	-32	-4.80	88	-87	-12.61	63	-63	-2.41
2021	3,943	-3,593	-8.54	59	-32	-4.85	88	-87	-12.85	63	-63	-2.46
2022	3,943	-3,593	-9.34	59	-32	-4.90	88	-87	-13.08	63	-63	-2.50
2023	3,943	-3,593	-10.14	59	-32	-4.96	88	-87	-13.32	63	-63	-2.55
2024	3,943	-3,593	-10.94	59	-32	-5.01	88	-87	-13.55	63	-63	-2.60
2025	3,943	-3,593	-11.74	59	-32	-5.07	88	-87	-13.79	63	-63	-2.64
2026	3,943	-3,593	-12.54	59	-32	-5.12	88	-87	-14.03	63	-63	-2.69
2027	3,943	-3,593	-13.34	59	-32	-5.17	88	-87	-14.26	63	-63	-2.73
2028	3,943	-3,593	-14.14	59	-32	-5.23	88	-87	-14.50	63	-63	-2.78
2029	3,943	-3,593	-14.94	59	-32	-5.28	88	-87	-14.73	63	-63	-2.82
2030	3,943	-3,593	-15.75	59	-32	-5.34	88	-87	-14.97	63	-63	-2.87
2031	3,943	-3,593	-16.55	59	-32	-5.39	88	-87	-15.20	63	-63	-2.91
2032	3,943	-3,593	-17.35	59	-32	-5.44	88	-87	-15.44	63	-63	-2.96
2033	3,943	-3,593	-18.15	59	-32	-5.50	88	-87	-15.67	63	-63	-3.01
Total Change in Storage, 2009-2033		-81,444			-3,227			-5,768			-4,178	
Total Estimated Storage (upper 100 ft of aquifer)		448,800			58,700			36,800			139,000	

Table G-4a: Annual Estimated Changes in Groundwater Storage and Water Levels, Pumping Scenario 4 (using Method 1 subbasin recharge estimates)

	Mesquite Subbasin			Indian Cove Subbasin			Fortynine Palms Subbasin			Eastern Subbasin		
Year	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)
2009	1,701	-1,110	-0.25	666	-558	-0.95	986	-786	-2.14	710	-508	-0.37
2010	2,037	-1,352	-0.55	581	-469	-1.75	860	-667	-3.95	619	-391	-0.65
2011	2,822	-1,917	-0.98	369	-248	-2.17	547	-372	-4.96	394	-101	-0.72
2012	2,822	-1,917	-1.40	379	-258	-2.61	561	-386	-6.01	404	-114	-0.80
2013	2,822	-1,917	-1.83	388	-268	-3.07	575	-399	-7.10	414	-127	-0.89
2014	2,822	-1,917	-2.26	398	-278	-3.54	590	-413	-8.22	425	-141	-0.99
2015	3,943	-2,724	-2.86	92	42	-3.47	136	14	-8.18	98	279	-0.79
2016	3,943	-2,724	-3.47	101	32	-3.42	150	1	-8.18	108	266	-0.60
2017	3,943	-2,724	-4.08	111	22	-3.38	165	-13	-8.21	118	253	-0.42
2018	3,943	-2,724	-4.68	121	12	-3.36	179	-26	-8.28	129	240	-0.25
2019	3,943	-2,724	-5.29	130	2	-3.36	193	-39	-8.39	139	226	-0.08
2020	3,943	-2,724	-5.90	140	-8	-3.37	207	-53	-8.53	149	213	0.07
2021	3,943	-2,724	-6.50	150	-18	-3.40	222	-66	-8.71	160	200	0.21
2022	3,943	-2,724	-7.11	159	-29	-3.45	236	-80	-8.93	170	187	0.35
2023	3,943	-2,724	-7.72	169	-39	-3.52	250	-93	-9.18	180	174	0.47
2024	3,943	-2,724	-8.33	179	-49	-3.60	265	-107	-9.47	190	160	0.59
2025	3,943	-2,724	-8.93	188	-59	-3.70	279	-120	-9.80	201	147	0.69
2026	3,943	-2,724	-9.54	198	-69	-3.82	293	-134	-10.16	211	134	0.79
2027	3,943	-2,724	-10.15	208	-79	-3.95	307	-147	-10.56	221	121	0.88
2028	3,943	-2,724	-10.75	217	-89	-4.10	322	-161	-11.00	232	107	0.95
2029	3,943	-2,724	-11.36	227	-99	-4.27	336	-174	-11.47	242	94	1.02
2030	3,943	-2,724	-11.97	236	-109	-4.46	350	-187	-11.98	252	81	1.08
2031	3,943	-2,724	-12.57	246	-119	-4.66	365	-201	-12.53	262	68	1.13
2032	3,943	-2,724	-13.18	256	-129	-4.88	379	-214	-13.11	273	55	1.17
2033	3,943	-2,724	-13.79	265	-139	-5.12	393	-228	-13.73	283	41	1.20
Total Change in Storage, 2009-2033		-61,876			-3,004			-5,052			1,665	
Total Estimated Storage (upper 100 ft of aquifer)		448,800			58,700			36,800			139,000	

Table G-4b: Annual Estimated Changes in Groundwater Storage and Water Levels, Pumping Scenario 4 (using Method 2 subbasin recharge estimates)

	Mesquite Subbasin			Indian Cove Subbasin			Fortynine Palms Subbasin			Eastern Subbasin		
Year	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)	Annual Subbasin Pumping (afy)	Change in Storage (afy)	Cumulative Change in Groundwater Level (ft)
2009	1,701	-1,418	-0.32	666	-639	-1.09	986	-984	-2.68	710	-710	-0.51
2010	2,037	-1,744	-0.70	581	-554	-2.03	860	-858	-5.01	619	-619	-0.96
2011	2,822	-2,505	-1.26	369	-342	-2.61	547	-545	-6.49	394	-394	-1.24
2012	2,822	-2,505	-1.82	379	-351	-3.21	561	-560	-8.01	404	-404	-1.53
2013	2,822	-2,505	-2.38	388	-361	-3.83	575	-574	-9.57	414	-414	-1.83
2014	2,822	-2,505	-2.94	398	-371	-4.46	590	-588	-11.17	425	-425	-2.13
2015	3,943	-3,593	-3.74	92	-64	-4.57	136	-135	-11.53	98	-98	-2.20
2016	3,943	-3,593	-4.54	101	-74	-4.69	150	-149	-11.94	108	-108	-2.28
2017	3,943	-3,593	-5.34	111	-83	-4.84	165	-163	-12.38	118	-118	-2.37
2018	3,943	-3,593	-6.14	121	-93	-4.99	179	-177	-12.86	129	-129	-2.46
2019	3,943	-3,593	-6.94	130	-103	-5.17	193	-192	-13.38	139	-139	-2.56
2020	3,943	-3,593	-7.74	140	-112	-5.36	207	-206	-13.94	149	-149	-2.67
2021	3,943	-3,593	-8.54	150	-122	-5.57	222	-220	-14.54	160	-160	-2.78
2022	3,943	-3,593	-9.34	159	-132	-5.79	236	-235	-15.18	170	-170	-2.90
2023	3,943	-3,593	-10.14	169	-141	-6.03	250	-249	-15.86	180	-180	-3.03
2024	3,943	-3,593	-10.94	179	-151	-6.29	265	-263	-16.57	190	-190	-3.17
2025	3,943	-3,593	-11.74	188	-161	-6.57	279	-277	-17.33	201	-201	-3.32
2026	3,943	-3,593	-12.54	198	-170	-6.86	293	-292	-18.12	211	-211	-3.47
2027	3,943	-3,593	-13.34	208	-180	-7.16	307	-306	-18.95	221	-221	-3.63
2028	3,943	-3,593	-14.14	217	-190	-7.48	322	-320	-19.82	232	-232	-3.79
2029	3,943	-3,593	-14.94	227	-199	-7.82	336	-335	-20.73	242	-242	-3.97
2030	3,943	-3,593	-15.75	236	-209	-8.18	350	-349	-21.68	252	-252	-4.15
2031	3,943	-3,593	-16.55	246	-219	-8.55	365	-363	-22.66	262	-262	-4.34
2032	3,943	-3,593	-17.35	256	-228	-8.94	379	-377	-23.69	273	-273	-4.53
2033	3,943	-3,593	-18.15	265	-238	-9.35	393	-392	-24.75	283	-283	-4.74
Total Change in Storage, 2009-2033		-81,444			-5,487			-9,109			-6,585	
Total Estimated Storage (upper 100 ft of aquifer)		448,800			58,700			36,800			139,000	



Kennedy/Jenks Consultants

Twentynine Palms

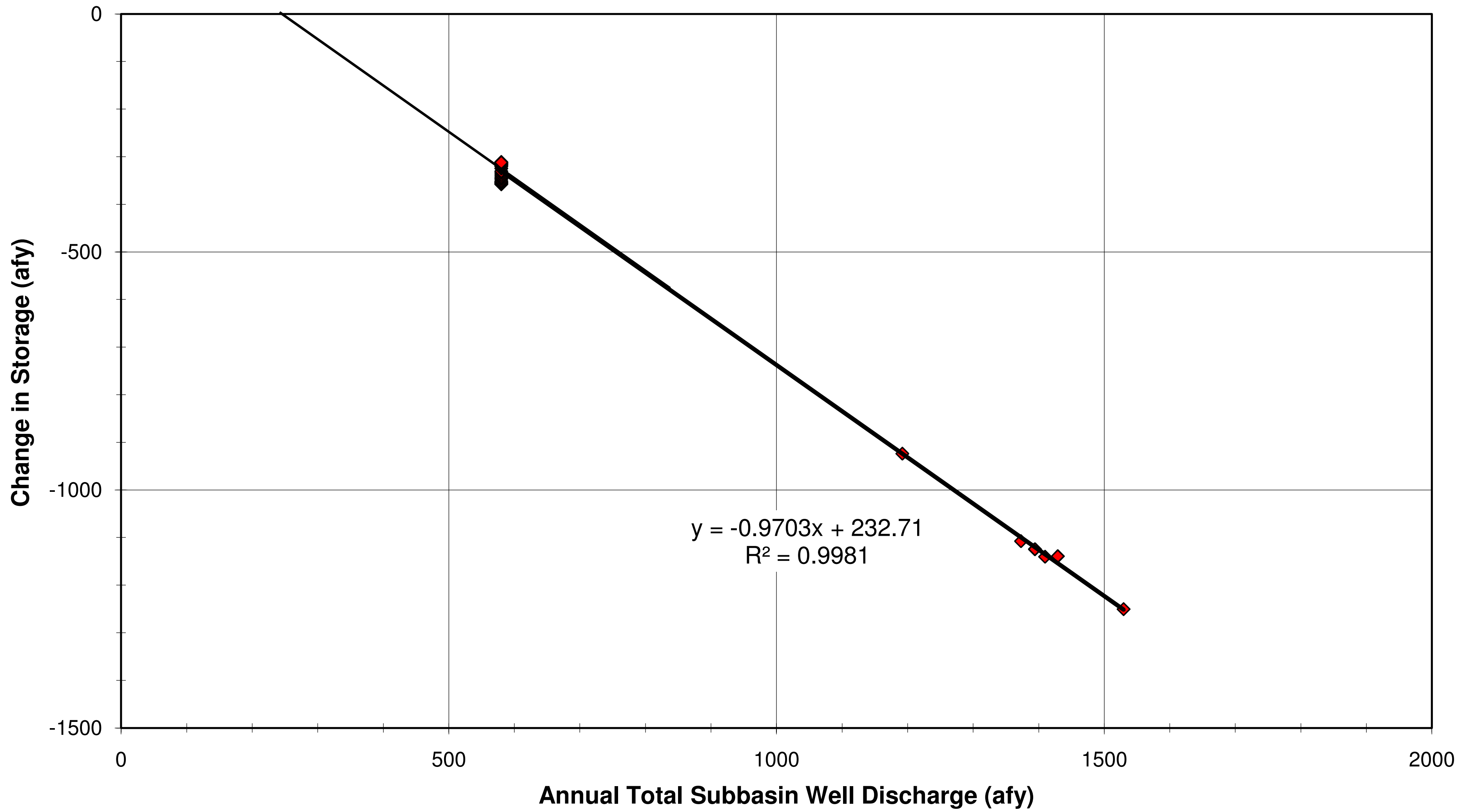
San Bernardino County, California

Annual Well Discharge versus Change in Storage (Scenario 1, Recharge Method 1) for Mesquite Subbasin

K/J 0964003*00

March 2010

Figure G-1a



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureG-1.pptx

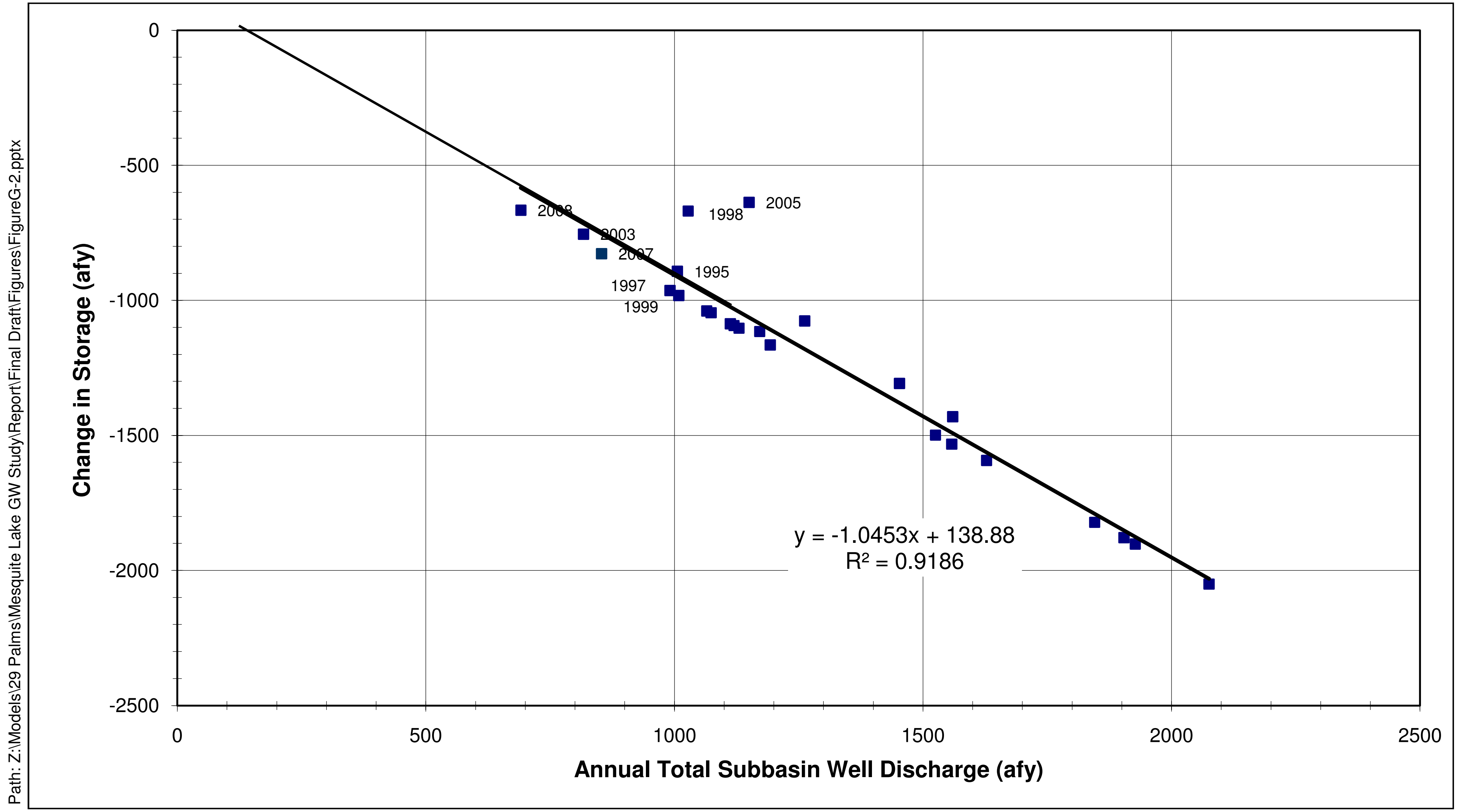
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Annual Well Discharge versus Change in Storage (Scenario 1, Recharge Method 2) for Mesquite Subbasin

K/J 0964003*00
March 2010

Figure G-1b



Kennedy/Jenks Consultants

Twentynine Palms

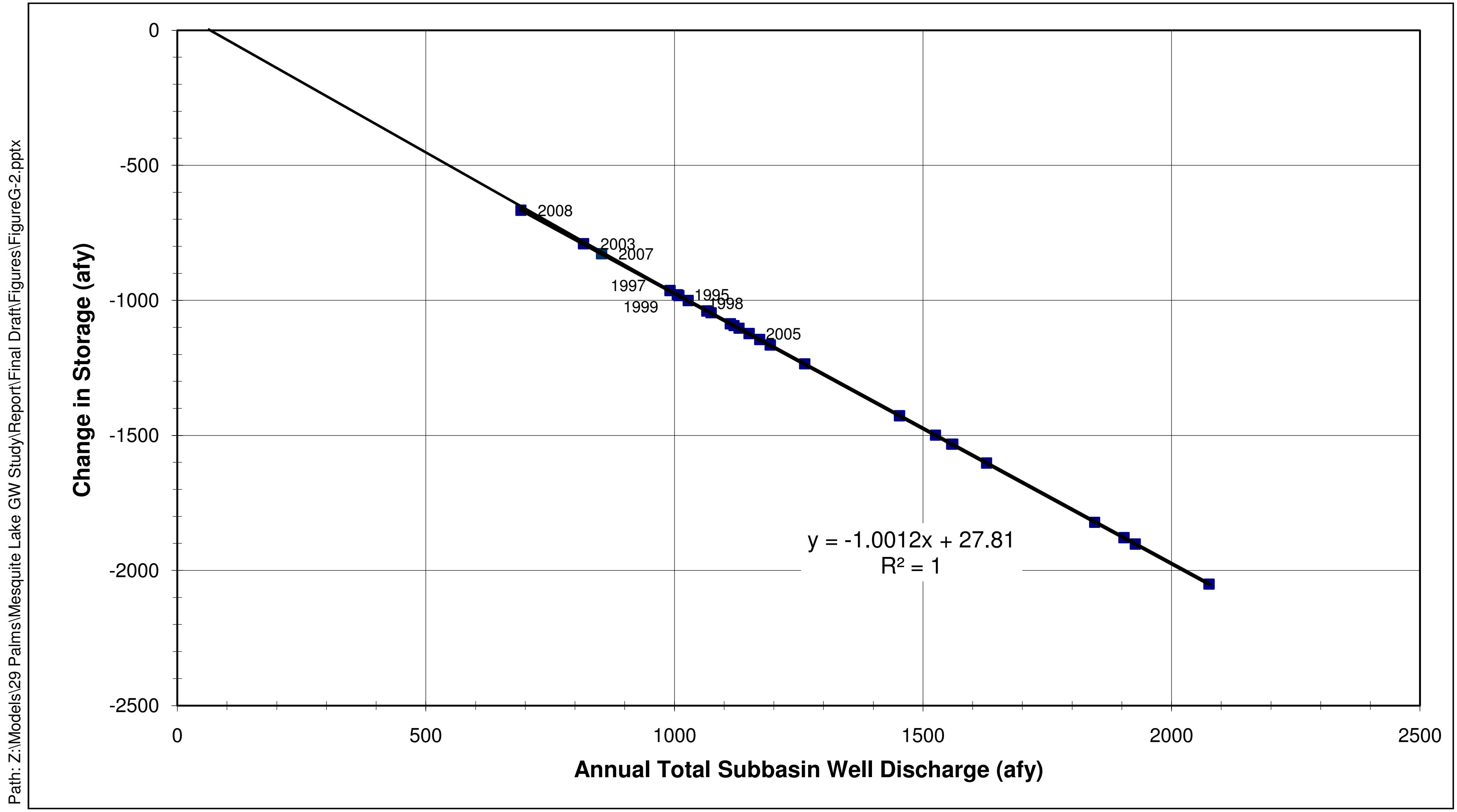
San Bernardino County, California

Annual Well Discharge versus Change in Storage (Scenario 1, Recharge Method 1) for Indian Cove Subbasin

K/J 0964003*00

March 2010

Figure G-2a



Kennedy/Jenks Consultants

Twentynine Palms

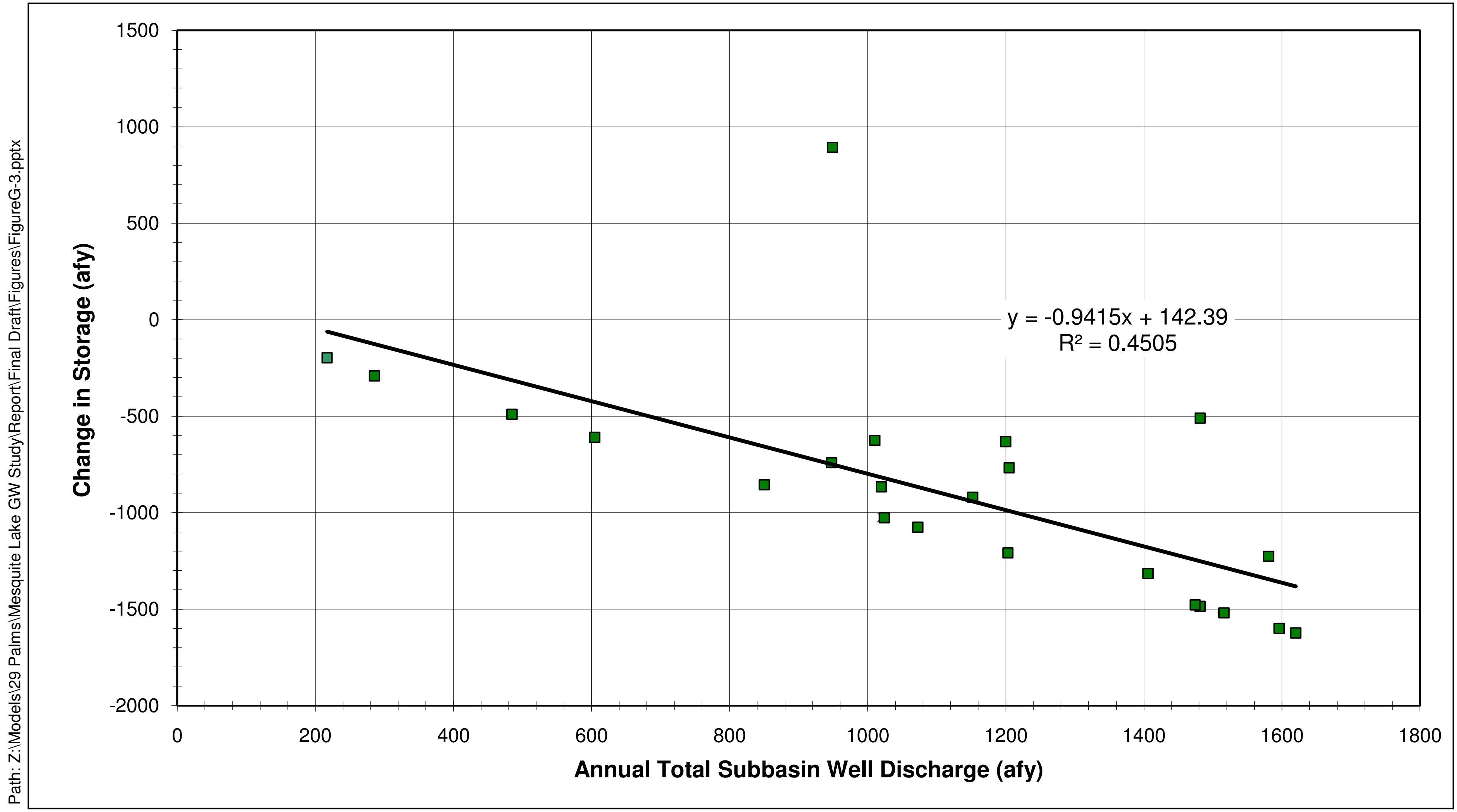
San Bernardino County, California

Annual Well Discharge versus Change in Storage (Scenario 1, Recharge Method 2) for Indian Cove Subbasin

K/J 0964003*00

March 2010

Figure G-2b



Kennedy/Jenks Consultants

Twentynine Palms

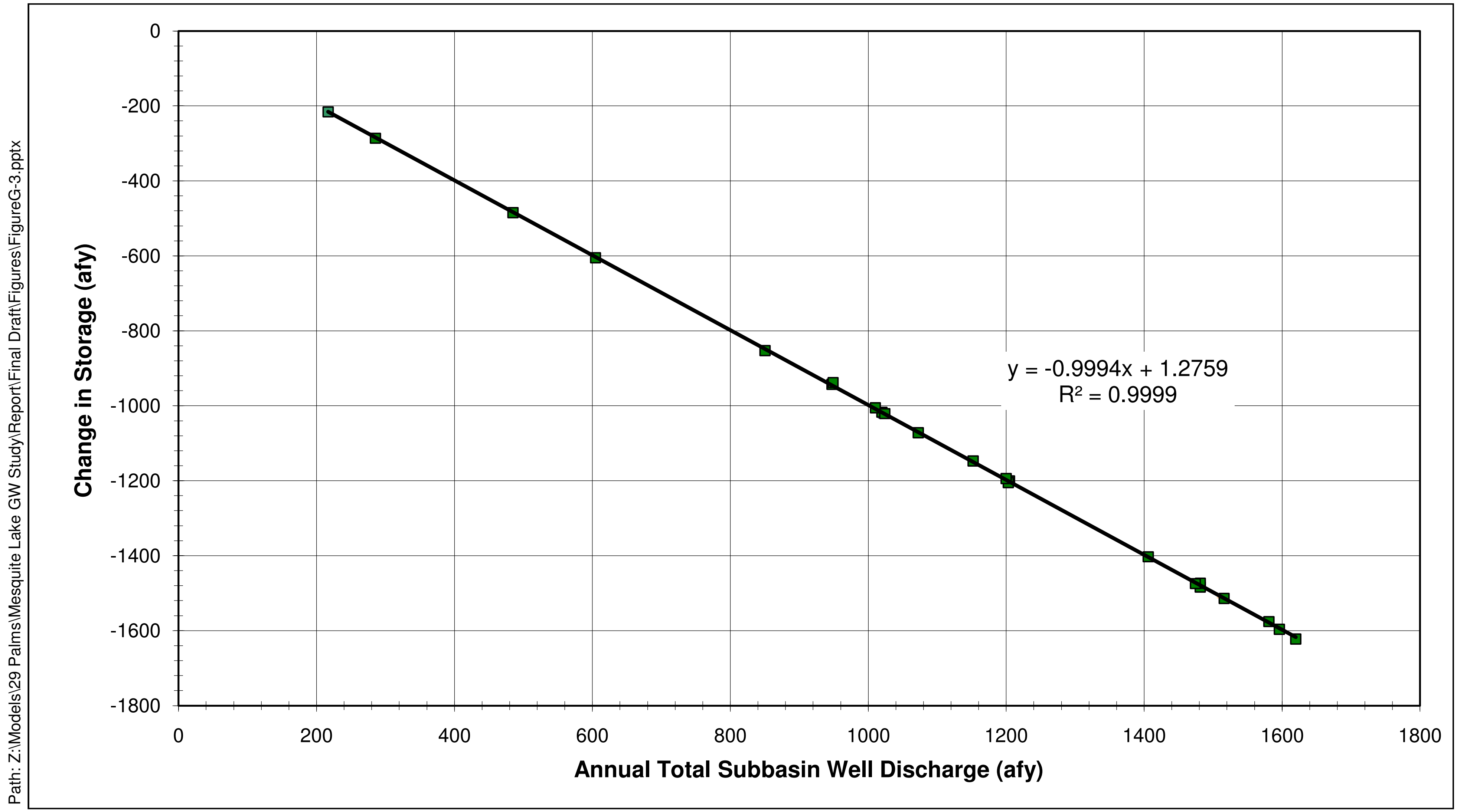
San Bernardino County, California

Annual Well Discharge versus Change in Storage (Scenario 1, Recharge Method 1) for Fortynine Palms Subbasin

K/J 0964003*00

March 2010

Figure G-3a



Kennedy/Jenks Consultants

Twentynine Palms

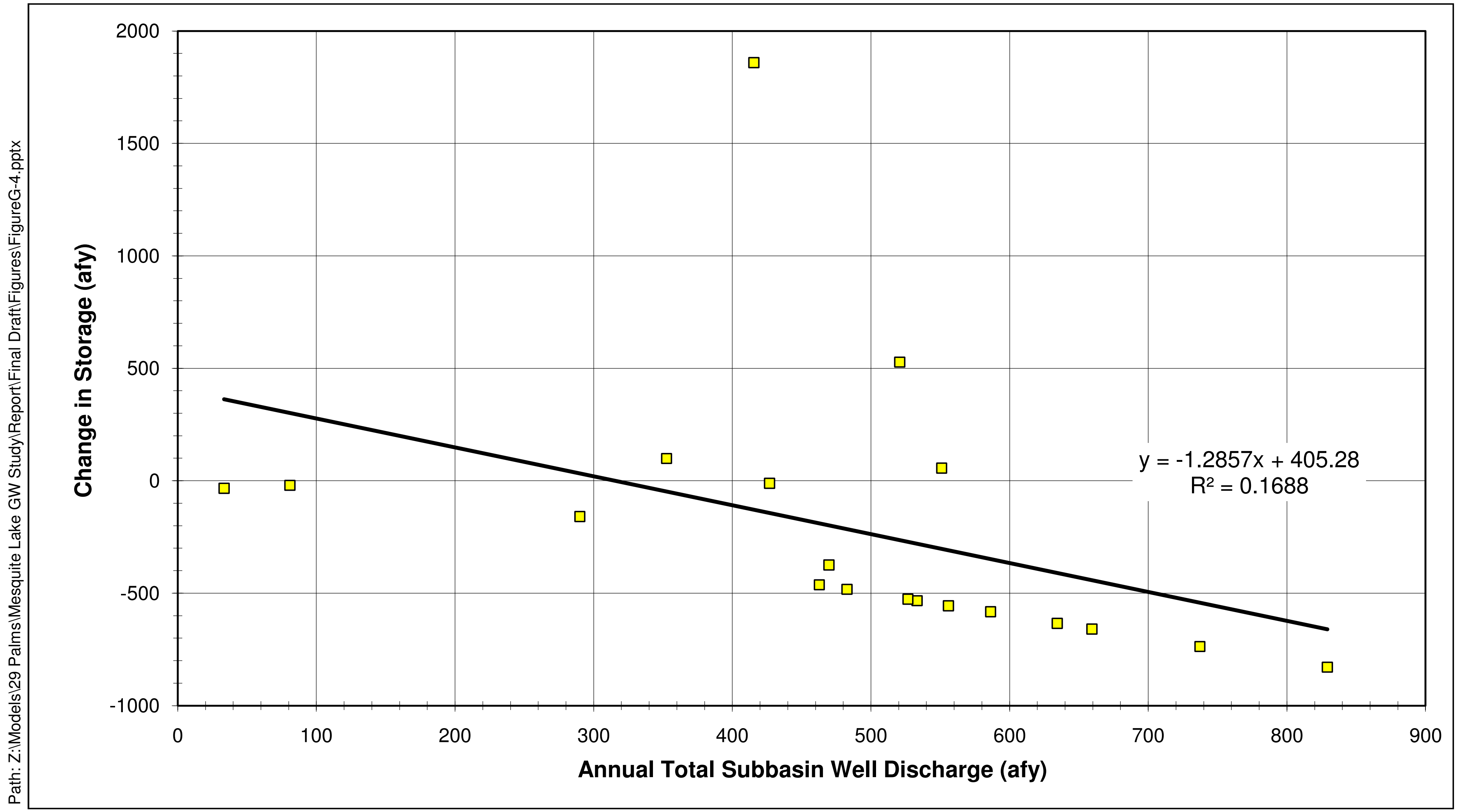
San Bernardino County, California

Annual Well Discharge versus Change in Storage (Scenario 1, Recharge Method 2) for Fortynine Palms Subbasin

K/J 0964003*00

March 2010

Figure G-3b



Kennedy/Jenks Consultants

Twentynine Palms

San Bernardino County, California

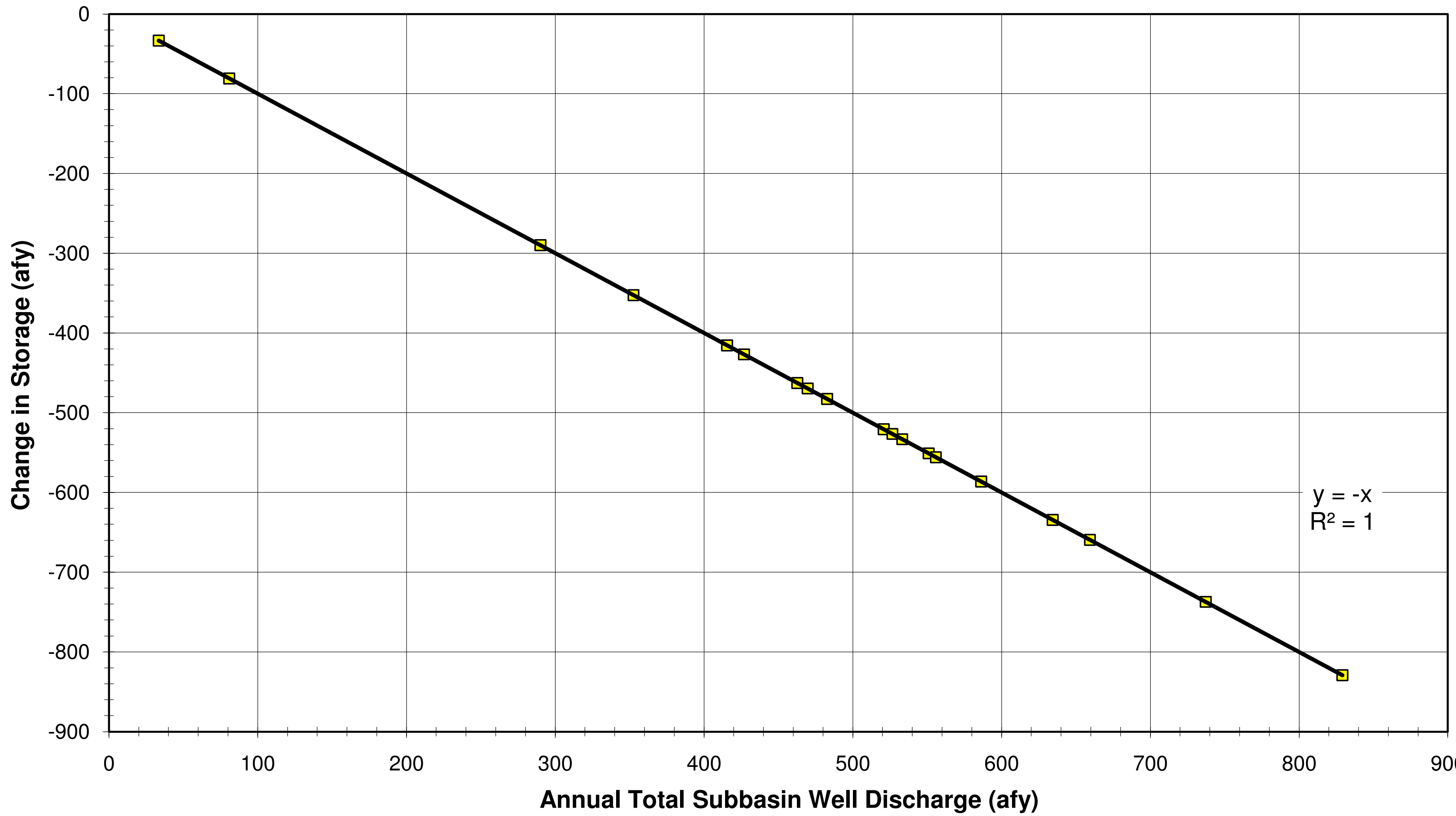
Annual Well Discharge versus Change in Storage (Scenario 1, Recharge Method 1) for Eastern Subbasin

K/J 0964003*00

March 2010

Figure G-4a

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureG-4.pptx



Kennedy/Jenks Consultants

Twentynine Palms

San Bernardino County, California

Annual Well Discharge versus Change in Storage (Scenario 1, Recharge Method 2) for Eastern Subbasin

K/J 0964003*00

March 2010

Figure G-4b

Appendix H: MODFLOW Model Evaluation of Pumping Results

Appendix H: MODFLOW Model Evaluation of Pumping Results

Appendix H contains additional tables and graphs to support the evaluation of future groundwater pumping using the MODFLOW model.

List of Tables

H-1	Annual Pumping from TPWD Production Wells, Scenario 1
H-2	Annual Pumping from TPWD Production Wells, Scenario 2
H-3	Annual Pumping from TPWD Production Wells, Scenario 3
H-4	Annual Pumping from TPWD Production Wells, Scenario 4
H-5	Annual Pumping from TPWD Production Wells, Scenario 5
H-6	Annual Pumping from TPWD Production Wells, Scenario 6
H-7	Drawdown and Drawdown Rate for TPWD Wells and Monitoring Points
H-8	2033 Groundwater Levels for TPWD Wells and Monitoring Points
H-9	Annual Boundary Fluxes, Scenario 1
H-10	Annual Boundary Fluxes, Scenario 2
H-11	Annual Boundary Fluxes, Scenario 3
H-12	Annual Boundary Fluxes, Scenario 4
H-13	Annual Boundary Fluxes, Scenario 5
H-14	Annual Boundary Fluxes, Scenario 6

List of Figures

H-1	Pumping Wells and Monitoring Points for Model Scenarios
H-2	Model Well Setup in Treatment Plant Area
H-3	Annual Pumping by Subbasin for Model Scenario 1
H-4	Annual Pumping by Subbasin for Model Scenario 2
H-5	Annual Pumping by Subbasin for Model Scenario 3
H-6	Annual Pumping by Subbasin for Model Scenario 4

H-7	Annual Pumping by Subbasin for Model Scenario 5
H-8	Annual Pumping by Subbasin for Model Scenario 6
H-9	Hydrographs for TPWD-2 in the Eastern Subbasin
H-10	Hydrographs for TPWD-5 in the Fortynine Palms Subbasin
H-11	Hydrographs for TPWD-7 in the Indian Cove Subbasin
H-12	Hydrographs for TPWD-8 in the Indian Cove Subbasin
H-13	Hydrographs for TPWD-9 in the Indian Cove Subbasin
H-14	Hydrographs for TPWD-10 in the Indian Cove Subbasin
H-15	Hydrographs for TPWD-12 in the Indian Cove Subbasin
H-16	Hydrographs for TPWD-14 in the Fortynine Palms Subbasin
H-17	Hydrographs for TPWD-18 in the Mesquite Subbasin
H-18	Hydrographs for Monitoring Point 1 in the Mesquite Subbasin
H-19	Hydrographs for Monitoring Point 2 in the Mesquite Subbasin
H-20	Hydrographs for Monitoring Point 3 in the Mesquite Subbasin
H-21	Hydrographs for Monitoring Point 5 in the Mesquite Subbasin
H-22	Hydrographs for Monitoring Point 7 in the Mesquite Subbasin
H-23	Hydrographs for Monitoring Point 9 in the Mesquite Subbasin
H-24	Hydrographs for Monitoring Point 10 in the Mesquite Subbasin
H-25	Hydrographs for Monitoring Point 11 in the Mesquite Subbasin
H-26	Hydrographs for Monitoring Point 14 in the Fortynine Palms Subbasin
H-27	Hydrographs for Monitoring Point 16 in the Indian Cove Subbasin
H-28	Hydrographs for Monitoring Point 17 in the Indian Cove Subbasin

Table H-1: Annual (calendar year) pumping (in acre-feet) from TPWD production wells for Model Scenario 1, with totals for the four subbasins from which water is withdrawn. Note that the numbers are rounded to the nearest acre-foot, but the totals are based on unrounded amounts.

TPWD Well ID[a]	1	2	3	3B	4	5	6	7	8	9	10	11	12	13	14	15	16	TP-1	Subbasin Totals			
Subbasin[b]	E	E	49	49	49	49	IC	IC	IC	IC	IC	IC	IC	49	49	IC	E	M	IC	49	E	M
2008	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	950	691	1,024	737	950
2009	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2010	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2011	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2012	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2013	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2014	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2015	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2016	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2017	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2018	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2019	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2020	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2021	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2022	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2023	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2024	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2025	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2026	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2027	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2028	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2029	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2030	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2031	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2032	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2033	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
Total	5,568	--	--	--	3,709	--	1,376	--	--	5,581	--	3,706	6,023	--	22,914	1,285	13,599	28,971	17,972	26,623	19,168	28,971

[a]TPWD ID is the well name; for example, well 3B is TPWD-3B.

[b]IC = Indian Cove; 49 = Fortynine Palms; E = Eastern; M = Mesquite.

Table H-2: Annual (calendar year) pumping (in acre-feet) from TPWD production wells for Model Scenario 2, with totals for the four subbasins from which water is withdrawn. Note that the numbers are rounded to the nearest acre-foot, but the totals are based on unrounded amounts.

TPWD Well ID[a]	1	2	3	3B	4	5	6	7	8	9	10	11	12	13	14	15	16	TP-1	Subbasin Totals			
Subbasin[b]	E	E	49	49	49	49	IC	IC	IC	IC	IC	IC	IC	49	49	IC	E	M	IC	49	E	M
2008	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	950	691	1,024	737	950
2009	209	--	--	--	139	--	52	--	--	209	--	139	226	--	859	48	510	1,093	674	998	719	1,093
2010	211	--	--	--	140	--	52	--	--	211	--	140	228	--	867	49	515	1,103	680	1,008	726	1,103
2011	213	--	--	--	142	--	53	--	--	213	--	142	230	--	876	49	520	1,114	687	1,018	733	1,114
2012	215	--	--	--	143	--	53	--	--	215	--	143	232	--	884	50	525	1,125	694	1,028	740	1,125
2013	217	--	--	--	145	--	54	--	--	217	--	144	235	--	893	50	530	1,135	700	1,037	747	1,135
2014	219	--	--	--	146	--	54	--	--	220	--	146	237	--	901	51	535	1,146	707	1,047	754	1,146
2015	221	--	--	--	147	--	55	--	--	222	--	147	239	--	910	51	540	1,157	713	1,057	761	1,157
2016	223	--	--	--	149	--	55	--	--	224	--	148	241	--	918	51	545	1,168	720	1,067	768	1,168
2017	225	--	--	--	150	--	56	--	--	226	--	150	244	--	927	52	550	1,178	727	1,077	775	1,178
2018	227	--	--	--	151	--	56	--	--	228	--	151	246	--	935	52	555	1,189	733	1,086	782	1,189
2019	229	--	--	--	153	--	57	--	--	230	--	153	248	--	943	53	560	1,200	740	1,096	789	1,200
2020	231	--	--	--	154	--	57	--	--	232	--	154	250	--	952	53	565	1,211	747	1,106	796	1,211
2021	233	--	--	--	155	--	58	--	--	234	--	155	252	--	960	54	570	1,221	753	1,116	803	1,221
2022	235	--	--	--	157	--	58	--	--	236	--	157	255	--	969	54	575	1,232	760	1,126	810	1,232
2023	237	--	--	--	158	--	59	--	--	238	--	158	257	--	977	55	580	1,243	766	1,135	817	1,243
2024	240	--	--	--	160	--	59	--	--	240	--	159	259	--	986	55	585	1,253	773	1,145	824	1,253
2025	242	--	--	--	161	--	60	--	--	242	--	161	261	--	994	56	590	1,264	780	1,155	832	1,264
2026	244	--	--	--	162	--	60	--	--	244	--	162	264	--	1,003	56	595	1,275	786	1,165	839	1,275
2027	246	--	--	--	164	--	61	--	--	246	--	163	266	--	1,011	57	600	1,286	793	1,175	846	1,286
2028	248	--	--	--	165	--	61	--	--	248	--	165	268	--	1,019	57	605	1,296	800	1,184	853	1,296
2029	250	--	--	--	166	--	62	--	--	250	--	166	270	--	1,028	58	610	1,307	806	1,194	860	1,307
2030	252	--	--	--	168	--	62	--	--	252	--	168	272	--	1,036	58	615	1,318	813	1,204	867	1,318
2031	254	--	--	--	169	--	63	--	--	254	--	169	275	--	1,045	59	620	1,329	819	1,214	874	1,329
2032	256	--	--	--	170	--	63	--	--	257	--	170	277	--	1,053	59	625	1,339	826	1,224	881	1,339
2033	258	--	--	--	172	--	64	--	--	259	--	172	279	--	1,062	60	630	1,350	833	1,233	888	1,350
Total	6,048	--	--	--	4,029	--	1,495	--	--	6,062	--	4,025	6,542	--	24,889	1,396	14,772	31,482	19,521	28,918	20,820	31,482

[a]TPWD ID is the well name; for example, well 3B is TPWD-3B.

[b]IC = Indian Cove; 49 = Fortynine Palms; E = Eastern; M = Mesquite.

Table H-3: Annual (calendar year) pumping (in acre-feet) from TPWD production wells for Model Scenario 3, with totals for the four subbasins from which water is withdrawn. Note that the numbers are rounded to the nearest acre-foot, but the totals are based on unrounded amounts.

TPWD Well ID[a]	1	2	3	3B	4	5	6	7	8	9	10	11	12	13	14	15	16	TP-1	Subbasin Totals			
Subbasin[b]	E	E	49	49	49	49	IC	IC	IC	IC	IC	IC	IC	49	49	IC	E	M	IC	49	E	M
2008	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	950	691	1,024	737	950
2009	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2010	185	--	--	--	123	--	46	--	--	185	--	123	200	--	760	43	451	1,457	596	884	636	1,457
2011	116	--	--	--	77	--	29	--	--	117	--	77	126	--	479	27	284	2,242	375	556	400	2,242
2012	116	--	--	--	77	--	29	--	--	117	--	77	126	--	479	27	284	2,242	375	556	400	2,242
2013	116	--	--	--	77	--	29	--	--	117	--	77	126	--	479	27	284	2,242	375	556	400	2,242
2014	116	--	--	--	77	--	29	--	--	117	--	77	126	--	479	27	284	2,242	375	556	400	2,242
2015	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2016	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2017	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2018	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2019	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2020	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2021	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2022	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2023	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2024	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2025	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2026	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2027	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2028	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2029	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2030	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2031	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2032	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
2033	18	--	--	--	12	--	5	--	--	18	--	12	20	--	76	4	45	3,363	59	88	63	3,363
Total	1,428	--	--	--	951	--	353	--	--	1,431	--	950	1,545	--	5,876	330	3,487	76,382	4,609	6,827	4,915	76,382

[a]TPWD ID is the well name; for example, well 3B is TPWD-3B.

[b]IC = Indian Cove; 49 = Fortynine Palms; E = Eastern; M = Mesquite.

Table H-4: Annual (calendar year) pumping (in acre-feet) from TPWD production wells for Model Scenario 4, with totals for the four subbasins from which water is withdrawn. Note that the numbers are rounded to the nearest acre-foot, but the totals are based on unrounded amounts.

TPWD Well ID[a]	1	2	3	3B	4	5	6	7	8	9	10	11	12	13	14	15	16	TP-1	Subbasin Totals			
Subbasin[b]	E	E	49	49	49	49	IC	IC	IC	IC	IC	IC	IC	49	49	IC	E	M	IC	49	E	M
2008	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	950	691	1,024	737	950
2009	206	--	--	--	137	--	51	--	--	207	--	137	223	--	849	48	504	1,121	666	986	710	1,121
2010	180	--	--	--	120	--	44	--	--	180	--	120	195	--	740	42	439	1,457	581	860	619	1,457
2011	114	--	--	--	76	--	28	--	--	115	--	76	124	--	471	26	279	2,242	369	547	394	2,242
2012	117	--	--	--	78	--	29	--	--	118	--	78	127	--	483	27	287	2,242	379	561	404	2,242
2013	120	--	--	--	80	--	30	--	--	121	--	80	130	--	495	28	294	2,242	388	575	414	2,242
2014	123	--	--	--	82	--	30	--	--	124	--	82	133	--	508	28	301	2,242	398	590	425	2,242
2015	28	--	--	--	19	--	7	--	--	29	--	19	31	--	117	7	69	3,363	92	136	98	3,363
2016	31	--	--	--	21	--	8	--	--	32	--	21	34	--	129	7	77	3,363	101	150	108	3,363
2017	34	--	--	--	23	--	9	--	--	35	--	23	37	--	142	8	84	3,363	111	165	118	3,363
2018	37	--	--	--	25	--	9	--	--	37	--	25	40	--	154	9	91	3,363	121	179	129	3,363
2019	40	--	--	--	27	--	10	--	--	40	--	27	44	--	166	9	99	3,363	130	193	139	3,363
2020	43	--	--	--	29	--	11	--	--	43	--	29	47	--	179	10	106	3,363	140	207	149	3,363
2021	46	--	--	--	31	--	11	--	--	46	--	31	50	--	191	11	113	3,363	150	222	160	3,363
2022	49	--	--	--	33	--	12	--	--	49	--	33	53	--	203	11	121	3,363	159	236	170	3,363
2023	52	--	--	--	35	--	13	--	--	52	--	35	57	--	215	12	128	3,363	169	250	180	3,363
2024	55	--	--	--	37	--	14	--	--	55	--	37	60	--	228	13	135	3,363	179	265	190	3,363
2025	58	--	--	--	39	--	14	--	--	58	--	39	63	--	240	13	142	3,363	188	279	201	3,363
2026	61	--	--	--	41	--	15	--	--	61	--	41	66	--	252	14	150	3,363	198	293	211	3,363
2027	64	--	--	--	43	--	16	--	--	64	--	43	70	--	265	15	157	3,363	208	307	221	3,363
2028	67	--	--	--	45	--	17	--	--	67	--	45	73	--	277	16	164	3,363	217	322	232	3,363
2029	70	--	--	--	47	--	17	--	--	70	--	47	76	--	289	16	172	3,363	227	336	242	3,363
2030	73	--	--	--	49	--	18	--	--	73	--	49	79	--	301	17	179	3,363	236	350	252	3,363
2031	76	--	--	--	51	--	19	--	--	76	--	51	82	--	314	18	186	3,363	246	365	262	3,363
2032	79	--	--	--	53	--	20	--	--	79	--	53	86	--	326	18	194	3,363	256	379	273	3,363
2033	82	--	--	--	55	--	20	--	--	82	--	55	89	--	338	19	201	3,363	265	393	283	3,363
Total	2,127	--	--	--	1,417	--	526	--	--	2,132	--	1,416	2,301	--	8,754	491	5,195	76,382	6,866	10,171	7,322	76,382

[a]TPWD ID is the well name; for example, well 3B is TPWD-3B.

[b]IC = Indian Cove; 49 = Fortynine Palms; E = Eastern; M = Mesquite.

Table H-5: Annual (calendar year) pumping (in acre-feet) from TPWD production wells for Model Scenario 5, with totals for the four subbasins from which water is withdrawn. Note that the numbers are rounded to the nearest acre-foot, but the totals are based on unrounded amounts.

TPWD Well ID[a]	1	2	3	3B	4	5	6	7	8	9	10	11	12	13	14	15	16	TP-1	Subbasin Totals			
Subbasin[b]	E	E	49	49	49	49	IC	IC	IC	IC	IC	IC	IC	49	49	IC	E	M	IC	49	E	M
2008	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	950	691	1,024	737	950
2009	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	1,121	691	1,024	737	1,121
2010	116	--	--	--	143	--	53	--	--	217	--	144	234	--	881	43	284	1,457	691	1,024	401	1,457
2011	--	--	--	--	111	--	42	--	--	171	--	113	184	--	684	27	--	2,242	537	795	--	2,242
2012	--	--	--	--	111	--	42	--	--	171	--	113	184	--	684	27	--	2,242	537	795	--	2,242
2013	--	--	--	--	111	--	42	--	--	171	--	113	184	--	684	27	--	2,242	537	795	--	2,242
2014	--	--	--	--	111	--	42	--	--	171	--	113	184	--	684	27	--	2,242	537	795	--	2,242
2015	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2016	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2017	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2018	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2019	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2020	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2021	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2022	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2023	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2024	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2025	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2026	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2027	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2028	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2029	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2030	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2031	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2032	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
2033	--	--	--	--	18	--	7	--	--	27	--	18	29	--	108	4	--	3,363	85	126	--	3,363
Total	545	--	--	--	1,204	--	454	--	--	1,841	--	1,222	1,987	--	7,438	330	1,331	76,382	5,834	8,642	1,875	76,382

[a]TPWD ID is the well name; for example, well 3B is TPWD-3B.

[b]IC = Indian Cove; 49 = Fortynine Palms; E = Eastern; M = Mesquite.

Table H-6: Annual (calendar year) pumping (in acre-feet) from TPWD production wells for Model Scenario 6, with totals for the four subbasins from which water is withdrawn. Note that the numbers are rounded to the nearest acre-foot, but the totals are based on unrounded amounts.

TPWD Well ID[a]	1	2	3	3B	4	5	6	7	8	9	10	11	12	13	14	15	16	TP-1	Subbasin Totals			
Subbasin[b]	E	E	49	49	49	49	IC	IC	IC	IC	IC	IC	IC	49	49	IC	E	M	IC	49	E	M
2008	214	--	--	--	143	--	53	--	--	215	--	143	232	--	881	49	523	950	691	1,024	737	950
2009	206	--	--	--	137	--	51	--	--	207	--	137	223	--	849	48	504	1,121	666	986	710	1,121
2010	119	--	--	--	137	--	51	--	--	209	--	139	225	--	849	42	290	1,457	666	986	408	1,457
2011	--	--	--	--	109	--	41	--	--	168	--	111	181	--	673	26	--	2,242	528	782	--	2,242
2012	--	--	--	--	112	--	42	--	--	172	--	114	186	--	691	27	--	2,242	542	802	--	2,242
2013	--	--	--	--	115	--	44	--	--	176	--	117	190	--	708	28	--	2,242	555	823	--	2,242
2014	--	--	--	--	117	--	45	--	--	181	--	120	195	--	726	28	--	2,242	569	843	--	2,242
2015	--	--	--	--	27	--	10	--	--	42	--	28	45	--	167	7	--	3,363	131	194	--	3,363
2016	--	--	--	--	30	--	11	--	--	46	--	31	50	--	185	7	--	3,363	145	215	--	3,363
2017	--	--	--	--	33	--	12	--	--	50	--	34	54	--	203	8	--	3,363	159	235	--	3,363
2018	--	--	--	--	36	--	14	--	--	55	--	36	59	--	220	9	--	3,363	173	256	--	3,363
2019	--	--	--	--	38	--	15	--	--	59	--	39	64	--	238	9	--	3,363	186	276	--	3,363
2020	--	--	--	--	41	--	16	--	--	64	--	42	69	--	255	10	--	3,363	200	297	--	3,363
2021	--	--	--	--	44	--	17	--	--	68	--	45	73	--	273	11	--	3,363	214	317	--	3,363
2022	--	--	--	--	47	--	18	--	--	72	--	48	78	--	290	11	--	3,363	228	337	--	3,363
2023	--	--	--	--	50	--	19	--	--	77	--	51	83	--	308	12	--	3,363	242	358	--	3,363
2024	--	--	--	--	53	--	20	--	--	81	--	54	88	--	326	13	--	3,363	255	378	--	3,363
2025	--	--	--	--	56	--	21	--	--	86	--	57	92	--	343	13	--	3,363	269	399	--	3,363
2026	--	--	--	--	58	--	22	--	--	90	--	60	97	--	361	14	--	3,363	283	419	--	3,363
2027	--	--	--	--	61	--	23	--	--	94	--	63	102	--	378	15	--	3,363	297	440	--	3,363
2028	--	--	--	--	64	--	24	--	--	99	--	66	106	--	396	16	--	3,363	311	460	--	3,363
2029	--	--	--	--	67	--	25	--	--	103	--	68	111	--	413	16	--	3,363	324	480	--	3,363
2030	--	--	--	--	70	--	26	--	--	107	--	71	116	--	431	17	--	3,363	338	501	--	3,363
2031	--	--	--	--	73	--	28	--	--	112	--	74	121	--	449	18	--	3,363	352	521	--	3,363
2032	--	--	--	--	75	--	29	--	--	116	--	77	125	--	466	18	--	3,363	366	542	--	3,363
2033	--	--	--	--	78	--	30	--	--	121	--	80	130	--	484	19	--	3,363	379	562	--	3,363
Total	539	--	--	--	1,872	--	707	--	--	2,869	--	1,905	3,096	--	11,563	491	1,316	76,382	9,069	13,435	1,855	76,382

[a]TPWD ID is the well name; for example, well 3B is TPWD-3B.

[b]IC = Indian Cove; 49 = Fortynine Palms; E = Eastern; M = Mesquite.

Table H-7a: Drawdown (DD, ft) and drawdown rate (DD/yr, ft/yr) for TPWD wells for observed measurements and the calibrated transient model (1984 through 2008), and for the 8 scenarios (2008 through 2033).

Scenario		TPWD-1	TPWD-2	TPWD-3	TPWD-4	TPWD-5	TPWD-6	TPWD-7	TPWD-8	TPWD-9	TPWD-10	TPWD-11	TPWD-12	TPWD-13	TPWD-14	TPWD-15	TPWD-16	TPWD-18	TPWD-TP-1
Observed	DD	27.5	39.5	85.5	90.7	63.7	30.2	34.2	26.2	39.0	29.2	24.6	44.0	99.4	80.2	-4.1	44.0	3.2	11.0
	DD/yr	1.1	1.6	3.4	3.6	4.2	1.2	1.4	1.1	1.6	1.2	1.0	1.8	4.1	5.0	-0.2	2.1	0.4	1.8
Transient	DD	27.9	27.4	74.1	83.5	40.1	39.6	39.0	27.9	40.2	26.6	35.1	39.3	110.7	91.8	2.1	43.3	2.8	13.2
	DD/yr	1.1	1.1	3.0	3.3	2.7	1.6	1.6	1.2	1.6	1.1	1.4	1.6	4.6	5.7	0.1	2.1	0.4	2.2
Scenario 1	DD	47.5	47.8	105.5	111.6	87.3	19.5	19.5	21.0	19.6	20.0	20.7	19.7	48.8	47.8	1.9	52.9	14.2	20.5
	DD/yr	1.9	1.9	4.2	4.5	3.5	0.8	0.8	0.8	0.8	0.8	0.8	0.8	2.0	1.9	0.1	2.1	0.6	0.8
Scenario 2	DD	51.4	51.1	109.5	132.4	109.7	24.3	24.3	22.6	24.4	21.7	22.6	24.5	87.8	84.0	2.5	61.5	15.2	25.9
	DD/yr	2.1	2.0	4.4	5.3	4.4	1.0	1.0	0.9	1.0	0.9	0.9	1.0	3.5	3.4	0.1	2.5	0.6	1.0
Scenario 3	DD	16.1	18.5	-2.5	-13.7	-16.6	-10.8	-10.8	6.6	-10.8	5.6	5.8	-10.8	-44.8	-44.9	-1.5	1.4	32.0	95.4
	DD/yr	0.6	0.7	-0.1	-0.5	-0.7	-0.4	-0.4	0.3	-0.4	0.2	0.2	-0.4	-1.8	-1.8	-0.1	0.1	1.3	3.8
Scenario 4	DD	21.6	23.2	9.5	3.7	4.4	-4.1	-4.1	9.0	-4.1	8.0	8.6	-4.0	-15.7	-16.9	-0.7	11.9	32.0	95.4
	DD/yr	0.9	0.9	0.4	0.1	0.2	-0.2	-0.2	0.4	-0.2	0.3	0.3	-0.2	-0.6	-0.7	0.0	0.5	1.3	3.8
Scenario 5	DD	9.6	12.0	4.4	-6.2	-8.9	-8.7	-8.7	8.0	-8.7	7.0	7.2	-8.7	-36.2	-36.4	-1.5	-6.7	31.8	94.9
	DD/yr	0.4	0.5	0.2	-0.2	-0.4	-0.3	-0.3	0.3	-0.3	0.3	0.3	-0.3	-1.4	-1.5	-0.1	-0.3	1.3	3.8
Scenario 6	DD	9.6	12.0	21.3	19.0	21.7	1.2	1.2	11.5	1.3	10.6	11.2	1.3	7.7	5.7	-0.7	-6.7	31.8	95.1
	DD/yr	0.4	0.5	0.9	0.8	0.9	0.0	0.0	0.5	0.1	0.4	0.4	0.1	0.3	0.2	0.0	-0.3	1.3	3.8
Scenario 7A	DD	8.5	13.8	29.6	29.0	18.8	-4.6	-4.7	11.9	-4.7	11.9	11.8	-4.8	-23.8	-28.6	-0.5	-17.7	30.9	141.1
	DD/yr	0.3	0.6	1.2	1.2	0.8	-0.2	-0.2	0.5	-0.2	0.5	0.5	-0.2	-1.0	-1.1	0.0	-0.7	1.2	5.6
Scenario 7B	DD	10.5	11.4	26.2	26.1	28.1	5.5	5.4	10.5	5.4	10.5	10.8	5.4	24.3	23.5	0.4	2.5	29.3	67.3
	DD/yr	0.4	0.5	1.0	1.0	1.1	0.2	0.2	0.4	0.2	0.4	0.4	0.2	1.0	0.9	0.0	0.1	1.2	2.7
Scenario 8A	DD	15.0	17.4	33.9	32.6	34.7	3.7	3.7	13.6	3.6	13.6	14.0	3.6	25.3	22.4	0.4	-0.5	40.1	112.9
	DD/yr	0.6	0.7	1.4	1.3	1.4	0.1	0.1	0.5	0.1	0.5	0.6	0.1	1.0	0.9	0.0	0.0	1.6	4.5
Scenario 8B	DD	7.7	9.7	13.7	12.4	14.5	0.1	0.1	9.5	0.1	9.4	9.8	0.0	5.4	3.7	-0.1	-6.9	26.4	87.7
	DD/yr	0.3	0.4	0.5	0.5	0.6	0.0	0.0	0.4	0.0	0.4	0.4	0.0	0.2	0.1	0.0	-0.3	1.1	3.5

Table H-7b: Drawdown (DD, ft) and drawdown rate (DD/yr, ft/yr) for the monitoring points for the 8 scenarios (2008 through 2033).

Scenario		MP-1	MP-2	MP-3	MP-4	MP-5	MP-6	MP-7	MP-8	MP-9	MP-10	MP-11	MP-12	MP-13	MP-14	MP-15	MP-16	MP-17	MP-18
Scenario 1	DD	11.8	8.0	-2.6	0.9	3.0	1.2	18.3	23.3	18.0	15.3	26.6	49.4	-4.8	96.4	76.0	20.0	20.7	2.7
	DD/yr	0.5	0.3	-0.1	0.0	0.1	0.0	0.7	0.9	0.7	0.6	1.1	2.0	-0.2	3.9	3.0	0.8	0.8	0.1
Scenario 2	DD	11.8	8.0	-2.8	0.9	3.0	1.2	19.5	24.3	18.3	15.3	26.6	53.0	-4.8	105.4	78.7	23.4	22.5	2.8
	DD/yr	0.5	0.3	-0.1	0.0	0.1	0.0	0.8	1.0	0.7	0.6	1.1	2.1	-0.2	4.2	3.1	0.9	0.9	0.1
Scenario 3	DD	11.8	7.9	-2.8	1.0	4.6	1.8	40.5	43.1	24.5	15.8	26.5	17.9	-4.8	-6.6	51.4	-3.7	5.1	1.1
	DD/yr	0.5	0.3	-0.1	0.0	0.2	0.1	1.6	1.7	1.0	0.6	1.1	0.7	-0.2	-0.3	2.1	-0.1	0.2	0.0
Scenario 4	DD	11.8	7.9	-2.8	1.0	4.6	1.9	40.5	43.1	24.6	15.8	26.5	23.1	-4.8	7.7	55.8	1.1	7.8	1.4
	DD/yr	0.5	0.3	-0.1	0.0	0.2	0.1	1.6	1.7	1.0	0.6	1.1	0.9	-0.2	0.3	2.2	0.0	0.3	0.1
Scenario 5	DD	11.7	7.9	-2.9	1.0	4.6	1.8	40.3	43.0	24.5	15.8	26.5	11.2	-4.8	0.5	54.7	-1.9	6.6	1.1
	DD/yr	0.5	0.3	-0.1	0.0	0.2	0.1	1.6	1.7	1.0	0.6	1.1	0.4	-0.2	0.0	2.2	-0.1	0.3	0.0
Scenario 6	DD	11.8	8.0	-2.7	1.0	4.6	1.9	40.3	43.0	24.5	15.8	26.5	11.2	-4.8	21.0	60.8	5.2	10.5	1.4
	DD/yr	0.5	0.3	-0.1	0.0	0.2	0.1	1.6	1.7	1.0	0.6	1.1	0.4	-0.2	0.8	2.4	0.2	0.4	0.1
Scenario 7A	DD	7.7	3.8	-4.4	-0.5	1.0	0.9	39.4	35.2	26.4	10.5	17.3	11.7	-5.1	29.2	57.6	2.8	11.9	1.3
	DD/yr	0.3	0.2	-0.2	0.0	0.0	0.0	1.6	1.4	1.1	0.4	0.7	0.5	-0.2	1.2	2.3	0.1	0.5	0.1
Scenario 7B	DD	17.9	14.6	5.8	4.0	7.9	3.2	35.2	44.0	23.3	23.9	37.1	10.4	-3.4	26.9	56.0	7.0	10.0	1.4
	DD/yr	0.7	0.6	0.2	0.2	0.3	0.1	1.4	1.8	0.9	1.0	1.5	0.4	-0.1	1.1	2.2	0.3	0.4	0.1
Scenario 8A	DD	11.7	11.2	2.4	2.8	7.5	2.8	50.2	57.1	37.0	21.7	31.1	16.3	-3.9	34.4	71.8	7.7	12.7	1.1
	DD/yr	0.5	0.4	0.1	0.1	0.3	0.1	2.0	2.3	1.5	0.9	1.2	0.7	-0.2	1.4	2.9	0.3	0.5	0.0
Scenario 8B	DD	11.7	5.0	-5.5	0.3	2.5	1.3	33.6	34.9	17.9	12.2	22.5	8.6	-5.0	14.0	52.2	4.1	8.6	1.0
	DD/yr	0.5	0.2	-0.2	0.0	0.1	0.1	1.3	1.4	0.7	0.5	0.9	0.3	-0.2	0.6	2.1	0.2	0.3	0.0

Table H-8: Final groundwater levels at the end of the model run (2033) for all 8 scenarios at TPWD wells and monitoring points, as well as the final heads (2008) for both the observed measurements and the calibrated transient model. Observed heads in italics indicate that the last measurement was not performed in 2008: for TPWD-5, the observed measurement is from 1998; for TPWD-8, the observed measurement is from 2006.

Scenario	**TPWD-1**	**TPWD-2**	**TPWD-3**	**TPWD-4**	**TPWD-5**	**TPWD-6**	**TPWD-7**	**TPWD-8**	**TPWD-9**	**TPWD-10**	**TPWD-11**	**TPWD-12**	**TPWD-13**	**TPWD-14**	**TPWD-15**	**TPWD-16**	**TPWD-18**	**TPWD-TP-1**
Observed	1,941.7	1,933.5	1,888.9	1,877.4	*1,918.5*	2,180.4	2,188.1	*2,155.8*	2,179.4	2,160.2	2,172.2	2,179.3	1,870.2	1,868.2	2,413.8	1,779.7	1,772.8	1,752.1
Transient	1,937.8	1,938.4	1,895.1	1,886.9	1,888.3	2,147.4	2,147.3	2,167.6	2,147.2	2,167.5	2,168.2	2,147.1	1,863.8	1,863.8	2,407.8	1,919.9	1,771.1	1,758.4
Scenario 1	1,889.5	1,890.2	1,789.5	1,774.4	1,800.7	2,127.5	2,127.5	2,147.0	2,127.4	2,147.0	2,147.3	2,127.3	1,810.2	1,811.2	2,405.1	1,865.1	1,756.8	1,734.5
Scenario 2	1,885.6	1,886.9	1,785.5	1,753.6	1,778.3	2,122.7	2,122.7	2,145.4	2,122.6	2,145.3	2,145.4	2,122.5	1,771.2	1,775.0	2,404.5	1,856.5	1,755.8	1,729.1
Scenario 3	1,920.9	1,919.5	1,897.5	1,899.7	1,904.6	2,157.8	2,157.8	2,161.4	2,157.8	2,161.4	2,162.2	2,157.8	1,903.8	1,903.9	2,408.5	1,916.6	1,739.0	1,659.6
Scenario 4	1,915.4	1,914.8	1,885.5	1,882.3	1,883.6	2,151.1	2,151.1	2,159.0	2,151.1	2,159.0	2,159.4	2,151.0	1,874.7	1,875.9	2,407.7	1,906.1	1,739.0	1,659.6
Scenario 5	1,927.4	1,926.0	1,890.6	1,892.2	1,896.9	2,155.7	2,155.7	2,160.0	2,155.7	2,160.0	2,160.8	2,155.7	1,895.2	1,895.4	2,408.5	1,924.7	1,739.2	1,660.1
Scenario 6	1,927.4	1,926.0	1,873.7	1,867.0	1,866.3	2,145.8	2,145.8	2,156.5	2,145.7	2,156.4	2,156.8	2,145.7	1,851.3	1,853.3	2,407.7	1,924.7	1,739.2	1,659.9
Scenario 7A	1,929.4	1,925.9	1,846.9	1,829.1	1,839.2	2,137.3	2,137.2	2,158.0	2,137.1	2,158.0	2,158.7	2,137.0	1,808.4	1,813.3	2,406.9	1,922.6	1,740.4	1,604.9
Scenario 7B	1,926.8	1,926.1	1,890.9	1,886.7	1,885.1	2,150.0	2,150.0	2,155.6	2,150.0	2,155.5	2,155.7	2,149.9	1,878.2	1,879.0	2,408.1	1,925.6	1,742.1	1,697.8
Scenario 8A	1,911.3	1,909.9	1,834.6	1,824.8	1,822.2	2,132.1	2,132.1	2,143.4	2,132.0	2,143.3	2,143.7	2,132.0	1,800.9	1,803.9	2,407.0	1,908.7	1,728.8	1,640.3
Scenario 8B	1,936.1	1,934.6	1,896.9	1,891.8	1,892.4	2,155.0	2,154.9	2,165.3	2,154.9	2,165.3	2,165.6	2,154.8	1,879.8	1,881.5	2,408.1	1,933.3	1,746.2	1,672.8

	MP-1	**MP-2**	**MP-3**	**MP-4**	**MP-5**	**MP-6**	**MP-7**	**MP-8**	**MP-9**	**MP-10**	**MP-11**	**MP-12**	**MP-13**	**MP-14**	**MP-15**	**MP-16**	**MP-17**	**MP-18**
Scenario 1	2,063.2	1,960.0	1,848.6	1,794.1	1,779.0	1,749.8	1,757.7	1,772.7	1,829.0	1,946.7	2,065.4	1,886.6	2,043.8	1,795.6	1,919.0	2,135.0	2,145.3	2,407.3
Scenario 2	2,063.2	1,960.0	1,848.8	1,794.1	1,779.0	1,749.8	1,756.5	1,771.7	1,828.7	1,946.7	2,065.4	1,883.0	2,043.8	1,786.6	1,916.3	2,131.6	2,143.5	2,407.2
Scenario 3	2,063.2	1,960.1	1,848.8	1,794.0	1,777.4	1,749.2	1,735.5	1,752.9	1,822.5	1,946.2	2,065.5	1,918.1	2,043.8	1,898.6	1,943.6	2,158.7	2,160.9	2,408.9
Scenario 4	2,063.2	1,960.1	1,848.8	1,794.0	1,777.4	1,749.1	1,735.5	1,752.9	1,822.4	1,946.2	2,065.5	1,912.9	2,043.8	1,884.3	1,939.2	2,153.9	2,158.2	2,408.6
Scenario 5	2,063.3	1,960.1	1,848.9	1,794.0	1,777.4	1,749.2	1,735.7	1,753.0	1,822.5	1,946.2	2,065.5	1,924.8	2,043.8	1,891.5	1,940.3	2,156.9	2,159.4	2,408.9
Scenario 6	2,063.2	1,960.0	1,848.7	1,794.0	1,777.4	1,749.1	1,735.7	1,753.0	1,822.5	1,946.2	2,065.5	1,924.8	2,043.8	1,871.0	1,934.2	2,149.8	2,155.5	2,408.6
Scenario 7A	2,080.3	1,964.2	1,847.4	1,797.5	1,781.0	1,747.1	1,738.6	1,766.8	1,813.6	1,956.5	2,088.7	1,923.3	2,040.1	1,841.8	1,958.4	2,145.2	2,156.1	2,408.7
Scenario 7B	2,042.1	1,949.4	1,844.2	1,787.0	1,773.1	1,751.8	1,738.8	1,746.0	1,837.7	1,931.1	2,030.9	1,925.6	2,046.4	1,889.1	1,918.0	2,152.0	2,155.0	2,408.6
Scenario 8A	2,056.3	1,952.8	1,843.6	1,792.2	1,773.5	1,748.2	1,722.8	1,733.9	1,805.0	1,932.3	2,046.9	1,908.7	2,045.9	1,830.6	1,897.2	2,136.3	2,142.3	2,407.9
Scenario 8B	2,068.3	1,964.0	1,850.5	1,794.7	1,779.5	1,749.7	1,744.4	1,765.1	1,832.1	1,954.8	2,077.5	1,933.4	2,042.0	1,895.0	1,958.8	2,158.9	2,164.4	2,409.0

Table H-9: Annual (calendar year) boundary fluxes (Q, in acre-feet) from the model domain for Model Scenario 1. Note that the annual fluxes are rounded to the nearest acre-foot, but the averages are based on unrounded amounts. Negative numbers indicate fluxes out of the model domain. 2008 fluxes are the results of the calibrated transient model, and are not included in the averages at the bottom of this table.

			Evapotranspiration		General Head Boundary Flux			
Year	**Well Discharge**	**Recharge**	**Mesquite Dry Lake**	**Oasis of Mara**	**Across Transverse Arch**	**From Copper Mountain Subbasin**	**From Joshua Tree Subbasin**	**To Dale Basin**
2008	-4,246	8	-1,658	0	806	136	20	-512
2009	-4,557	8	-1,632	0	813	133	26	-510
2010	-4,557	8	-1,625	0	815	134	27	-509
2011	-4,557	8	-1,621	0	818	135	28	-508
2012	-4,557	8	-1,617	0	822	136	28	-507
2013	-4,557	8	-1,612	0	826	137	28	-506
2014	-4,557	8	-1,606	0	830	137	28	-505
2015	-4,557	8	-1,599	0	835	138	28	-504
2016	-4,557	8	-1,591	0	839	139	28	-503
2017	-4,557	8	-1,583	0	843	140	28	-502
2018	-4,557	8	-1,575	0	847	141	28	-501
2019	-4,557	8	-1,565	0	852	141	29	-500
2020	-4,557	8	-1,556	0	856	142	28	-500
2021	-4,557	8	-1,546	0	859	143	28	-499
2022	-4,557	8	-1,535	0	863	143	28	-498
2023	-4,557	8	-1,525	0	867	142	28	-497
2024	-4,557	8	-1,515	0	871	143	28	-496
2025	-4,532	8	-1,505	0	874	142	28	-495
2026	-4,532	8	-1,494	0	878	143	28	-494
2027	-4,532	8	-1,484	0	881	143	28	-493
2028	-4,532	8	-1,474	0	885	143	28	-492
2029	-4,532	8	-1,463	0	888	144	28	-491
2030	-4,532	8	-1,453	0	891	142	28	-491
2031	-4,532	8	-1,443	0	894	143	27	-490
2032	-4,532	8	-1,432	0	897	142	27	-489
2033	-4,532	8	-1,422	0	900	142	27	-488
Average	-4,548	8	-1,539	0	858	140	28	-499

Table H-10: Annual (calendar year) boundary fluxes (Q, in acre-feet) from the model domain for Model Scenario 2, along with percent differences from Scenario 1 results. Note that the annual fluxes are rounded to the nearest acre-foot, but the averages are based on unrounded amounts. Negative numbers indicate fluxes out of the model domain. 2008 fluxes are the results of the calibrated transient model, and are not included in the averages at the bottom of this table.

			Evapotranspiration				General Head Boundary Flux							
			Mesquite Dry Lake		Oasis of Mara		Across Transverse Arch		From Copper Mountain Subbasin		From Joshua Tree Subbasin		To Dale Basin	
Year	Well Discharge	Recharge	Q	+/-	Q	+/-	Q	+/-	Q	+/-	Q	+/-	Q	+/-
2008	-4,246	8	-1,658	--	0	--	806	--	136	--	20	--	-512	--
2009	-4,463	8	-1,632	0.0%	0	0.0%	813	0.0%	133	0.0%	26	0.0%	-510	0.0%
2010	-4,499	8	-1,625	0.0%	0	0.0%	815	0.0%	134	0.0%	27	0.0%	-509	0.0%
2011	-4,534	8	-1,621	0.0%	0	0.0%	818	0.0%	135	0.1%	28	0.0%	-508	0.0%
2012	-4,570	8	-1,616	0.0%	0	0.0%	822	0.0%	136	0.2%	28	0.0%	-507	0.0%
2013	-4,605	8	-1,611	0.0%	0	0.0%	826	0.0%	137	0.2%	28	0.0%	-506	0.0%
2014	-4,641	8	-1,605	0.0%	0	0.0%	830	0.0%	138	0.6%	28	0.0%	-505	0.0%
2015	-4,676	8	-1,598	-0.1%	0	0.0%	835	0.0%	138	0.0%	28	0.0%	-504	0.0%
2016	-4,712	8	-1,590	-0.1%	0	0.0%	839	0.0%	139	-0.1%	28	0.0%	-503	0.0%
2017	-4,748	8	-1,582	-0.1%	0	0.0%	843	0.0%	140	-0.1%	28	0.0%	-502	0.0%
2018	-4,783	8	-1,573	-0.1%	0	0.0%	847	0.0%	140	-0.1%	28	0.0%	-501	0.0%
2019	-4,819	8	-1,563	-0.1%	0	0.0%	852	0.0%	141	-0.1%	29	0.0%	-500	0.0%
2020	-4,854	8	-1,553	-0.1%	0	0.0%	856	0.0%	142	-0.1%	28	0.0%	-499	-0.1%
2021	-4,890	8	-1,543	-0.2%	0	0.0%	860	0.0%	141	-1.2%	28	0.0%	-498	-0.1%
2022	-4,925	8	-1,533	-0.2%	0	0.0%	863	0.0%	141	-1.2%	28	0.0%	-497	-0.1%
2023	-4,961	8	-1,522	-0.2%	0	0.0%	867	0.0%	142	0.0%	28	0.0%	-496	-0.1%
2024	-4,996	8	-1,512	-0.2%	0	0.0%	871	0.0%	143	0.0%	28	0.0%	-495	-0.1%
2025	-5,032	8	-1,501	-0.2%	0	0.0%	874	0.0%	143	0.7%	28	0.1%	-494	-0.1%
2026	-5,068	8	-1,491	-0.3%	0	0.0%	878	0.0%	143	0.6%	28	0.1%	-493	-0.2%
2027	-5,103	8	-1,480	-0.3%	0	0.0%	881	0.0%	144	0.6%	28	0.1%	-492	-0.2%
2028	-5,139	8	-1,469	-0.3%	0	0.0%	885	0.0%	144	0.6%	28	0.1%	-491	-0.2%
2029	-5,174	8	-1,458	-0.4%	0	0.0%	888	0.0%	144	-0.1%	28	0.2%	-490	-0.2%
2030	-5,210	8	-1,447	-0.4%	0	0.0%	891	0.0%	142	0.0%	28	0.2%	-489	-0.3%
2031	-5,245	8	-1,436	-0.5%	0	0.0%	894	0.0%	140	-2.1%	27	0.2%	-488	-0.3%
2032	-5,281	8	-1,425	-0.5%	0	0.0%	897	0.0%	140	-1.2%	27	0.3%	-487	-0.3%
2033	-5,316	8	-1,414	-0.6%	0	0.0%	901	0.0%	141	-1.2%	27	0.3%	-486	-0.4%
Average	-4,890	8	-1,536	-0.2%	0	0.0%	858	0.0%	140	-0.2%	28	0.1%	-498	-0.1%

Table H-11: Annual (calendar year) boundary fluxes (Q, in acre-feet) from the model domain for Model Scenario 3, along with percent differences from Scenario 1 results. Note that the annual fluxes are rounded to the nearest acre-foot, but the averages are based on unrounded amounts. Negative numbers indicate fluxes out of the model domain. 2008 fluxes are the results of the calibrated transient model, and are not included in the averages at the bottom of this table.

			Evapotranspiration				General Head Boundary Flux							
Year	Well Discharge	Recharge	Mesquite Dry Lake		Oasis of Mara		Across Transverse Arch		From Copper Mountain Subbasin		From Joshua Tree Subbasin		To Dale Basin	
			Q	+/-	Q	+/-	Q	+/-	Q	+/-	Q	+/-	Q	+/-
2008	-4,246	8	-1,658	--	0	--	806	--	136	--	20	--	-512	--
2009	-4,557	8	-1,632	0.0%	0	0.0%	813	0.0%	133	0.0%	26	0.0%	-510	0.0%
2010	-4,599	8	-1,625	0.0%	0	0.0%	815	0.0%	134	0.0%	27	0.0%	-509	-0.1%
2011	-4,697	8	-1,620	0.0%	0	0.0%	818	0.0%	135	-0.1%	28	0.0%	-507	-0.3%
2012	-4,697	8	-1,615	-0.1%	0	0.0%	822	0.0%	136	-0.1%	28	0.0%	-505	-0.4%
2013	-4,697	8	-1,609	-0.2%	0	0.0%	826	0.0%	137	0.0%	28	0.0%	-503	-0.6%
2014	-4,697	8	-1,600	-0.3%	0	0.0%	830	0.0%	138	0.3%	28	-0.1%	-502	-0.7%
2015	-4,837	8	-1,591	-0.5%	0	0.0%	835	0.0%	139	0.3%	28	-0.1%	-499	-1.1%
2016	-4,837	8	-1,580	-0.7%	0	0.0%	839	0.0%	139	0.3%	28	-0.2%	-496	-1.4%
2017	-4,837	8	-1,567	-1.1%	0	0.0%	843	0.0%	140	0.2%	28	-0.3%	-494	-1.7%
2018	-4,837	8	-1,552	-1.5%	0	0.0%	848	0.0%	140	-0.3%	28	-0.3%	-492	-2.0%
2019	-4,837	8	-1,535	-1.9%	0	0.0%	852	0.0%	140	-0.8%	28	-0.5%	-489	-2.3%
2020	-4,837	8	-1,519	-2.4%	0	0.0%	856	0.0%	140	-1.3%	28	-0.6%	-487	-2.6%
2021	-4,837	8	-1,503	-2.8%	0	0.0%	860	0.0%	141	-1.2%	28	-0.7%	-484	-2.9%
2022	-4,837	8	-1,484	-3.4%	0	0.0%	863	0.0%	141	-1.2%	28	-0.9%	-482	-3.1%
2023	-4,837	8	-1,467	-3.8%	0	0.0%	867	0.0%	142	0.0%	28	-1.1%	-480	-3.4%
2024	-4,837	8	-1,448	-4.4%	0	0.0%	871	0.0%	143	0.0%	28	-1.3%	-477	-3.7%
2025	-4,837	8	-1,430	-5.0%	0	0.0%	874	0.0%	143	0.7%	28	-1.5%	-475	-4.0%
2026	-4,837	8	-1,411	-5.5%	0	0.0%	878	0.0%	143	0.7%	28	-1.7%	-473	-4.3%
2027	-4,837	8	-1,389	-6.4%	0	0.0%	882	0.0%	144	0.6%	27	-2.0%	-471	-4.6%
2028	-4,837	8	-1,372	-6.9%	0	0.0%	885	0.0%	144	0.7%	27	-2.2%	-468	-4.9%
2029	-4,837	8	-1,352	-7.6%	0	0.0%	888	0.1%	145	0.7%	27	-2.5%	-466	-5.2%
2030	-4,837	8	-1,332	-8.3%	0	0.0%	892	0.1%	145	1.8%	27	-2.8%	-464	-5.5%
2031	-4,837	8	-1,313	-9.0%	0	0.0%	895	0.1%	145	1.8%	27	-3.2%	-462	-5.7%
2032	-4,837	8	-1,294	-9.6%	0	0.0%	898	0.1%	146	2.7%	26	-3.5%	-459	-6.0%
2033	-4,837	8	-1,275	-10.3%	0	0.0%	901	0.1%	146	2.7%	26	-3.8%	-457	-6.3%
Average	-4,794	8	-1,485	-3.5%	0	0.0%	858	0.0%	141	0.3%	28	-1.2%	-484	-2.9%

Table H-12: Annual (calendar year) boundary fluxes (Q, in acre-feet) from the model domain for Model Scenario 4, along with percent differences from Scenario 1 results. Note that the annual fluxes are rounded to the nearest acre-foot, but the averages are based on unrounded amounts. Negative numbers indicate fluxes out of the model domain. 2008 fluxes are the results of the calibrated transient model, and are not included in the averages at the bottom of this table.

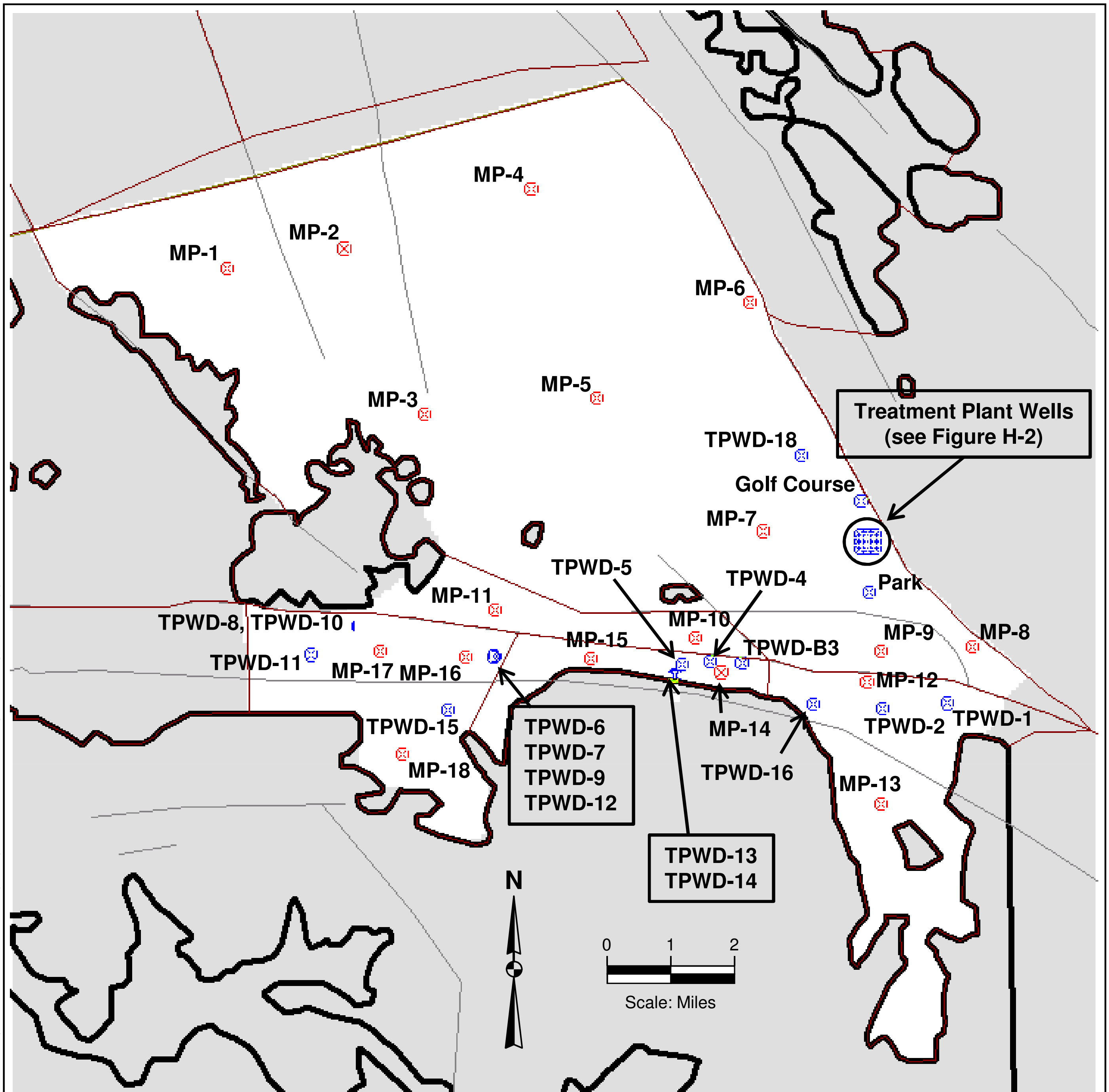
			Evapotranspiration				General Head Boundary Flux							
Year	Well Discharge	Recharge	Mesquite Dry Lake		Oasis of Mara		Across Transverse Arch		From Copper Mountain Subbasin		From Joshua Tree Subbasin		To Dale Basin	
			Q	+/-	Q	+/-	Q	+/-	Q	+/-	Q	+/-	Q	+/-
2008	-4,246	8	-1,658	--	0	--	806	--	136	--	20	--	-512	--
2009	-4,467	8	-1,632	0.0%	0	0.0%	813	0.0%	133	0.0%	26	0.0%	-510	0.0%
2010	-4,543	8	-1,625	0.0%	0	0.0%	815	0.0%	134	0.0%	27	0.0%	-509	-0.1%
2011	-4,675	8	-1,620	0.0%	0	0.0%	818	0.0%	135	-0.1%	28	0.0%	-507	-0.3%
2012	-4,709	8	-1,615	-0.1%	0	0.0%	822	0.0%	136	-0.1%	28	0.0%	-505	-0.4%
2013	-4,744	8	-1,609	-0.2%	0	0.0%	826	0.0%	137	-0.1%	28	0.0%	-503	-0.6%
2014	-4,778	8	-1,601	-0.3%	0	0.0%	830	0.0%	138	0.3%	28	-0.1%	-502	-0.7%
2015	-4,952	8	-1,591	-0.5%	0	0.0%	835	0.0%	138	0.0%	28	-0.1%	-499	-1.1%
2016	-4,986	8	-1,580	-0.7%	0	0.0%	839	0.0%	139	-0.1%	28	-0.2%	-496	-1.4%
2017	-5,021	8	-1,567	-1.0%	0	0.0%	843	0.0%	140	-0.2%	28	-0.3%	-494	-1.7%
2018	-5,055	8	-1,552	-1.4%	0	0.0%	847	0.0%	140	-0.1%	28	-0.3%	-492	-2.0%
2019	-5,089	8	-1,536	-1.9%	0	0.0%	852	0.0%	141	-0.1%	28	-0.4%	-489	-2.3%
2020	-5,123	8	-1,521	-2.2%	0	0.0%	856	0.0%	142	-0.1%	28	-0.6%	-487	-2.6%
2021	-5,157	8	-1,504	-2.7%	0	0.0%	860	0.0%	142	0.0%	28	-0.7%	-484	-2.9%
2022	-5,192	8	-1,484	-3.3%	0	0.0%	863	0.0%	143	-0.1%	28	-0.9%	-482	-3.1%
2023	-5,226	8	-1,467	-3.8%	0	0.0%	867	0.0%	143	0.6%	28	-1.0%	-480	-3.4%
2024	-5,260	8	-1,447	-4.5%	0	0.0%	871	0.0%	143	0.0%	28	-1.2%	-477	-3.7%
2025	-5,294	8	-1,429	-5.0%	0	0.0%	875	0.0%	143	0.7%	28	-1.4%	-475	-4.0%
2026	-5,329	8	-1,410	-5.7%	0	0.0%	878	0.0%	143	0.7%	28	-1.6%	-473	-4.3%
2027	-5,363	8	-1,391	-6.3%	0	0.0%	882	0.0%	144	0.7%	27	-1.8%	-471	-4.6%
2028	-5,397	8	-1,371	-6.9%	0	0.0%	885	0.0%	144	0.7%	27	-2.1%	-468	-4.9%
2029	-5,431	8	-1,352	-7.6%	0	0.0%	888	0.1%	145	0.7%	27	-2.3%	-466	-5.2%
2030	-5,465	8	-1,331	-8.4%	0	0.0%	892	0.1%	145	1.9%	27	-2.6%	-464	-5.5%
2031	-5,500	8	-1,311	-9.1%	0	0.0%	895	0.1%	146	1.9%	27	-2.9%	-462	-5.7%
2032	-5,534	8	-1,292	-9.8%	0	0.0%	898	0.1%	146	2.8%	26	-3.1%	-459	-6.0%
2033	-5,568	8	-1,272	-10.5%	0	0.0%	902	0.1%	146	2.8%	26	-3.4%	-457	-6.3%
Average	-5,114	8	-1,484	-3.5%	0	0.0%	858	0.0%	141	0.5%	28	-1.1%	-484	-2.9%

Table H-13: Annual (calendar year) boundary fluxes (Q, in acre-feet) from the model domain for Model Scenario 5, along with percent differences from Scenario 1 results. Note that the annual fluxes are rounded to the nearest acre-foot, but the averages are based on unrounded amounts. Negative numbers indicate fluxes out of the model domain. 2008 fluxes are the results of the calibrated transient model, and are not included in the averages at the bottom of this table.

			Evapotranspiration				**General Head Boundary Flux**							
			Mesquite Dry Lake		**Oasis of Mara**		**Across Transverse Arch**		**From Copper Mountain Subbasin**		**From Joshua Tree Subbasin**		**To Dale Basin**	
Year	**Well Discharge**	**Recharge**	**Q**	**+/-**	**Q**	**+/-**	**Q**	**+/-**	**Q**	**+/-**	**Q**	**+/-**	**Q**	**+/-**
2008	-4,246	8	-1,658	--	0	--	806	--	136	--	20	--	-512	--
2009	-4,557	8	-1,633	0.0%	0	0.0%	813	0.0%	133	0.0%	26	0.0%	-510	-0.1%
2010	-4,599	8	-1,625	0.0%	0	0.0%	815	0.0%	134	0.0%	27	0.0%	-508	-0.1%
2011	-4,697	8	-1,621	0.0%	0	0.0%	818	0.0%	135	-0.1%	28	0.0%	-506	-0.3%
2012	-4,697	8	-1,616	-0.1%	0	0.0%	822	0.0%	136	-0.1%	28	0.0%	-504	-0.5%
2013	-4,697	8	-1,609	-0.2%	0	0.0%	826	0.0%	137	-0.1%	28	0.0%	-503	-0.7%
2014	-4,697	8	-1,601	-0.3%	0	0.0%	830	0.0%	138	0.3%	28	0.0%	-501	-0.8%
2015	-4,837	8	-1,592	-0.5%	0	0.0%	835	0.0%	138	-0.1%	28	0.0%	-498	-1.2%
2016	-4,837	8	-1,580	-0.7%	0	0.0%	839	0.0%	139	-0.1%	28	-0.1%	-496	-1.5%
2017	-4,837	8	-1,567	-1.0%	0	0.0%	843	0.0%	140	-0.1%	28	-0.1%	-493	-1.8%
2018	-4,837	8	-1,552	-1.4%	0	0.0%	847	0.0%	140	-0.2%	28	-0.2%	-491	-2.1%
2019	-4,837	8	-1,536	-1.9%	0	0.0%	852	0.0%	141	-0.2%	28	-0.3%	-488	-2.4%
2020	-4,837	8	-1,521	-2.2%	0	0.0%	856	0.0%	142	-0.1%	28	-0.4%	-486	-2.7%
2021	-4,837	8	-1,505	-2.7%	0	0.0%	860	0.0%	142	-0.1%	28	-0.5%	-484	-3.0%
2022	-4,837	8	-1,485	-3.3%	0	0.0%	863	0.0%	143	-0.1%	28	-0.6%	-481	-3.3%
2023	-4,837	8	-1,467	-3.8%	0	0.0%	867	0.0%	144	1.1%	28	-0.8%	-479	-3.6%
2024	-4,837	8	-1,448	-4.4%	0	0.0%	871	0.0%	144	1.1%	28	-1.0%	-477	-3.9%
2025	-4,837	8	-1,431	-4.9%	0	0.0%	874	0.0%	143	0.6%	28	-1.2%	-474	-4.2%
2026	-4,837	8	-1,412	-5.5%	0	0.0%	878	0.0%	143	0.6%	28	-1.4%	-472	-4.5%
2027	-4,837	8	-1,389	-6.4%	0	0.0%	881	0.0%	144	0.6%	27	-1.6%	-470	-4.8%
2028	-4,837	8	-1,372	-6.9%	0	0.0%	885	0.0%	144	0.6%	27	-1.8%	-467	-5.1%
2029	-4,837	8	-1,352	-7.6%	0	0.0%	888	0.0%	145	0.6%	27	-2.1%	-465	-5.4%
2030	-4,837	8	-1,332	-8.3%	0	0.0%	892	0.1%	145	1.8%	27	-2.4%	-463	-5.6%
2031	-4,837	8	-1,313	-9.0%	0	0.0%	895	0.1%	145	1.8%	27	-2.6%	-461	-5.9%
2032	-4,837	8	-1,294	-9.7%	0	0.0%	898	0.1%	146	2.7%	27	-2.9%	-459	-6.2%
2033	-4,837	8	-1,275	-10.3%	0	0.0%	901	0.1%	146	2.6%	26	-3.3%	-456	-6.5%
Average	-4,794	8	-1,485	-3.5%	0	0.0%	858	0.0%	141	0.5%	28	-0.9%	-484	-3.0%

Table H-14: Annual (calendar year) boundary fluxes (Q, in acre-feet) from the model domain for Model Scenario 6, along with percent differences from Scenario 1 results. Note that the annual fluxes are rounded to the nearest acre-foot, but the averages are based on unrounded amounts. Negative numbers indicate fluxes out of the model domain. 2008 fluxes are the results of the calibrated transient model, and are not included in the averages at the bottom of this table.

			Evapotranspiration				General Head Boundary Flux							
Year	Well Discharge	Recharge	Mesquite Dry Lake		Oasis of Mara		Across Transverse Arch		From Copper Mountain Subbasin		From Joshua Tree Subbasin		To Dale Basin	
			Q	+/-	Q	+/-	Q	+/-	Q	+/-	Q	+/-	Q	+/-
2008	-4,246	8	-1,658	--	0	--	806	--	136	--	20	--	-512	--
2009	-4,467	8	-1,633	0.0%	0	0.0%	813	0.0%	133	0.0%	26	0.0%	-510	-0.1%
2010	-4,543	8	-1,625	0.0%	0	0.0%	815	0.0%	134	-0.1%	27	0.0%	-508	-0.1%
2011	-4,675	8	-1,621	0.0%	0	0.0%	818	0.0%	135	-0.1%	28	0.0%	-506	-0.3%
2012	-4,709	8	-1,616	-0.1%	0	0.0%	822	0.0%	136	-0.1%	28	0.0%	-504	-0.5%
2013	-4,744	8	-1,609	-0.1%	0	0.0%	826	0.0%	137	-0.4%	28	0.0%	-503	-0.7%
2014	-4,778	8	-1,601	-0.3%	0	0.0%	830	0.0%	138	0.0%	28	0.0%	-501	-0.8%
2015	-4,952	8	-1,592	-0.4%	0	0.0%	835	0.0%	138	-0.1%	28	-0.1%	-498	-1.2%
2016	-4,986	8	-1,581	-0.7%	0	0.0%	839	0.0%	139	-0.1%	28	-0.1%	-496	-1.5%
2017	-5,021	8	-1,568	-1.0%	0	0.0%	843	0.0%	140	-0.1%	28	-0.1%	-493	-1.8%
2018	-5,055	8	-1,553	-1.4%	0	0.0%	848	0.0%	141	0.0%	28	-0.2%	-491	-2.1%
2019	-5,089	8	-1,537	-1.8%	0	0.0%	852	0.0%	141	0.0%	28	-0.3%	-488	-2.4%
2020	-5,123	8	-1,521	-2.2%	0	0.0%	856	0.0%	142	0.0%	28	-0.4%	-486	-2.7%
2021	-5,157	8	-1,504	-2.7%	0	0.0%	860	0.0%	143	0.0%	28	-0.5%	-484	-3.0%
2022	-5,192	8	-1,485	-3.3%	0	0.0%	863	0.0%	142	-0.7%	28	-0.6%	-481	-3.3%
2023	-5,226	8	-1,467	-3.8%	0	0.0%	867	0.0%	142	0.0%	28	-0.7%	-479	-3.6%
2024	-5,260	8	-1,448	-4.4%	0	0.0%	871	0.0%	143	0.0%	28	-0.9%	-477	-3.9%
2025	-5,294	8	-1,429	-5.0%	0	0.0%	875	0.0%	143	0.7%	28	-1.0%	-474	-4.2%
2026	-5,329	8	-1,410	-5.6%	0	0.0%	878	0.0%	144	0.7%	28	-1.2%	-472	-4.5%
2027	-5,363	8	-1,390	-6.4%	0	0.0%	882	0.0%	144	0.7%	28	-1.4%	-470	-4.8%
2028	-5,397	8	-1,371	-7.0%	0	0.0%	885	0.1%	144	0.7%	27	-1.6%	-467	-5.1%
2029	-5,431	8	-1,351	-7.7%	0	0.0%	888	0.1%	145	0.7%	27	-1.8%	-465	-5.4%
2030	-5,465	8	-1,331	-8.4%	0	0.0%	892	0.1%	145	1.8%	27	-2.0%	-463	-5.6%
2031	-5,500	8	-1,310	-9.2%	0	0.0%	895	0.1%	145	1.8%	27	-2.2%	-461	-5.9%
2032	-5,534	8	-1,291	-9.9%	0	0.0%	898	0.1%	146	2.7%	27	-2.4%	-458	-6.2%
2033	-5,568	8	-1,272	-10.6%	0	0.0%	902	0.1%	146	2.7%	27	-2.7%	-456	-6.5%
Average	-5,114	8	-1,485	-3.5%	0	0.0%	858	0.0%	141	0.4%	28	-0.8%	-484	-3.0%



Legend

No-flow (inactive) cell

Pumping well

Monitoring point (MP)

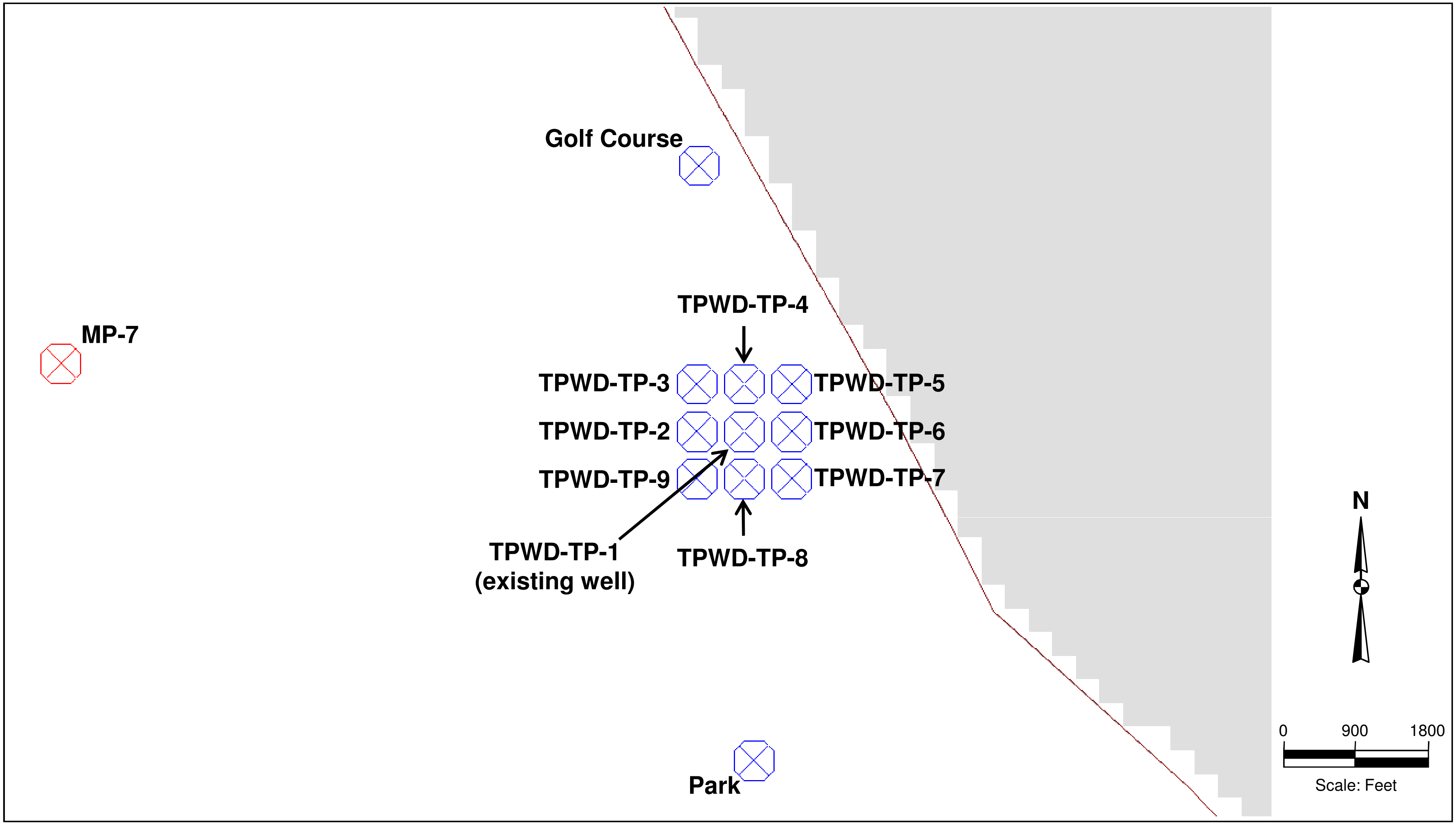
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Pumping Wells and Monitoring Points for Model Scenarios

K/J 0964003*00
March 2010

Figure H-1



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureH-2.pptx

Legend

- No-flow (inactive) cell
- Pumping well
- Monitoring point (MP)

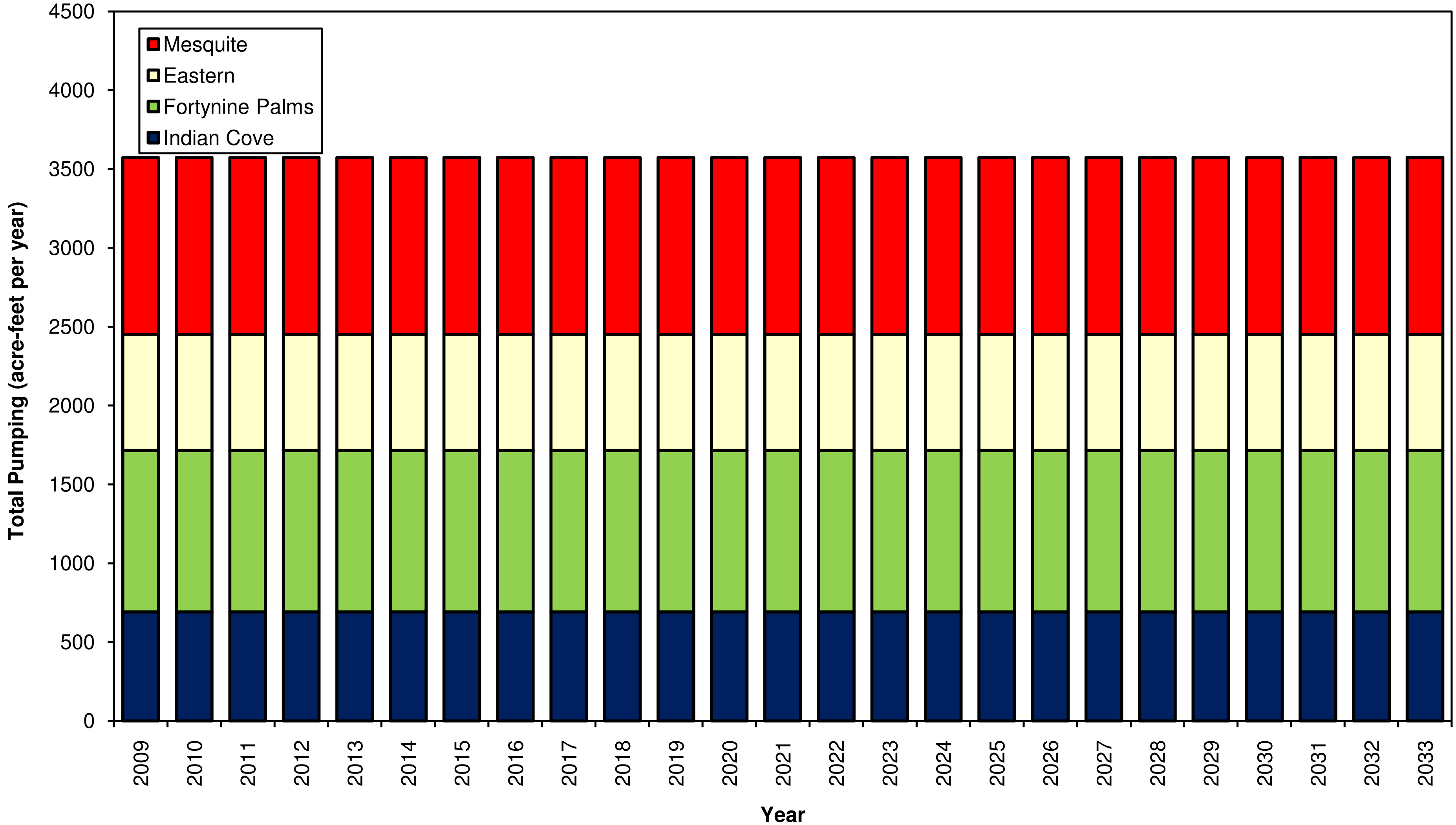
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Model Well Setup in Treatment Plant Area

K/J 0964003*00
March 2010

Figure H-2



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureH-3.pptx

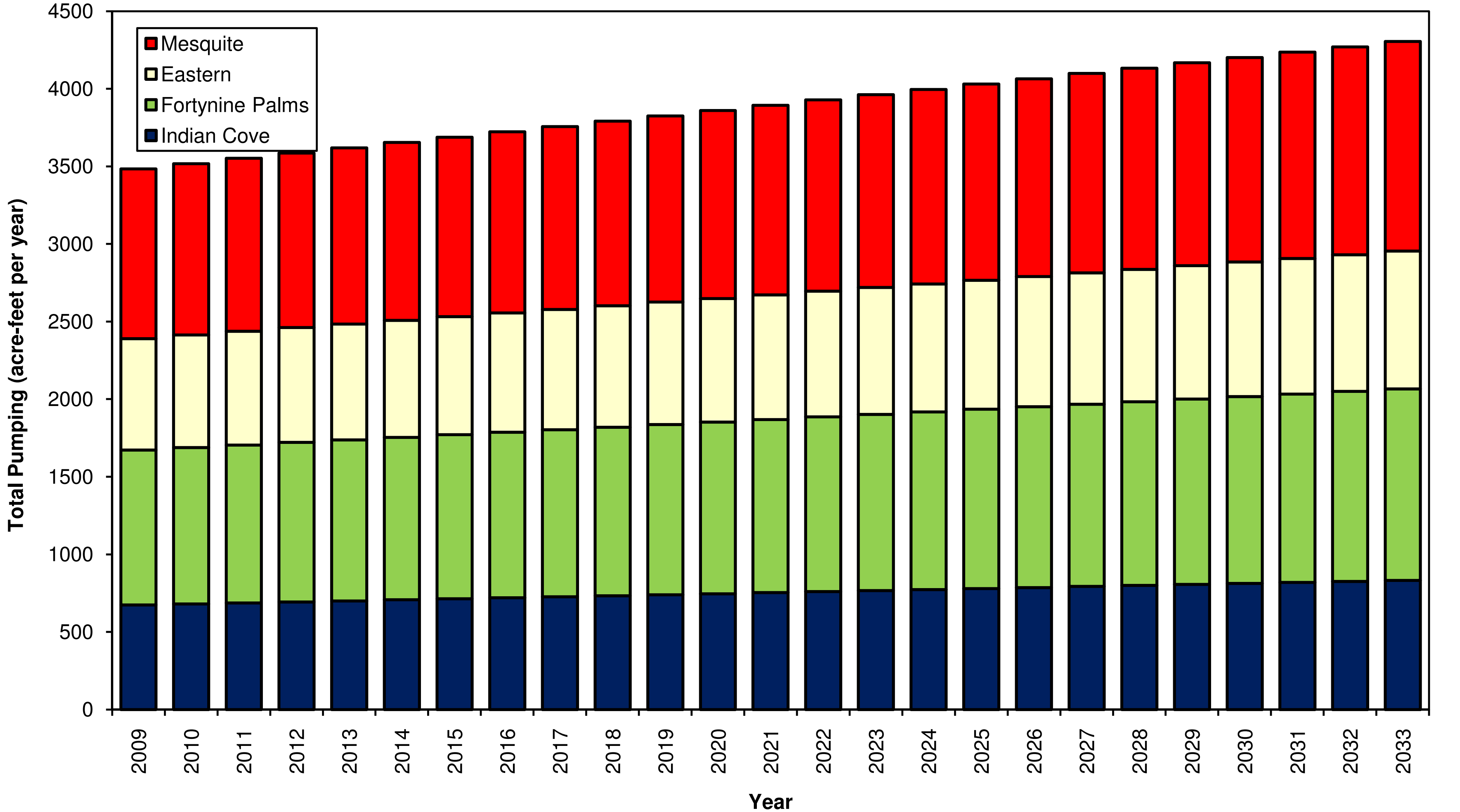
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Annual Pumping by Subbasin for Model Scenario 1

K/J 0964003*00
March 2010

Figure H-3



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureH-4.pptx

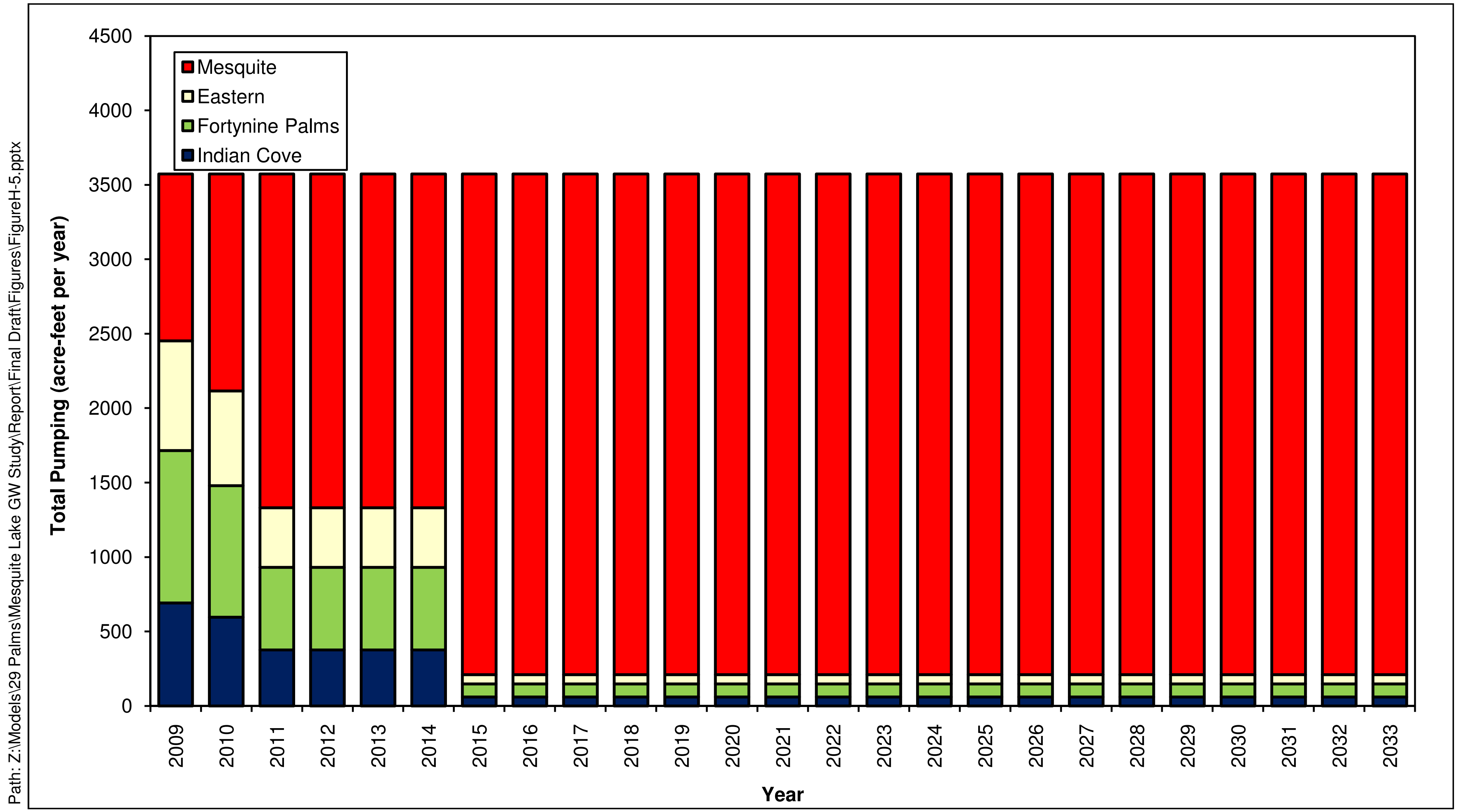
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Annual Pumping by Subbasin for Model Scenario 2

K/J 0964003*00
March 2010

Figure H-4



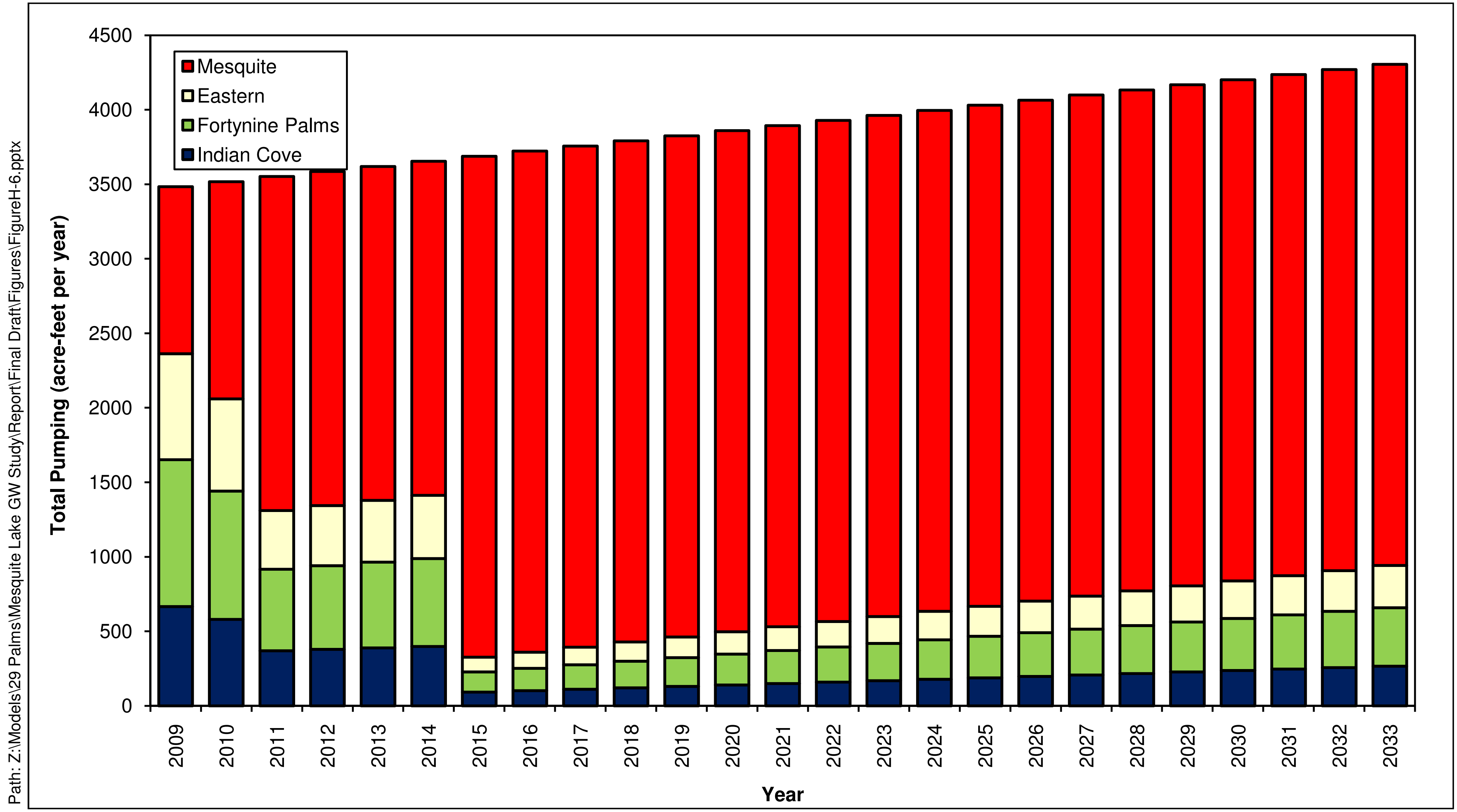
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Annual Pumping by Subbasin for Model Scenario 3

K/J 0964003*00
March 2010

Figure H-5



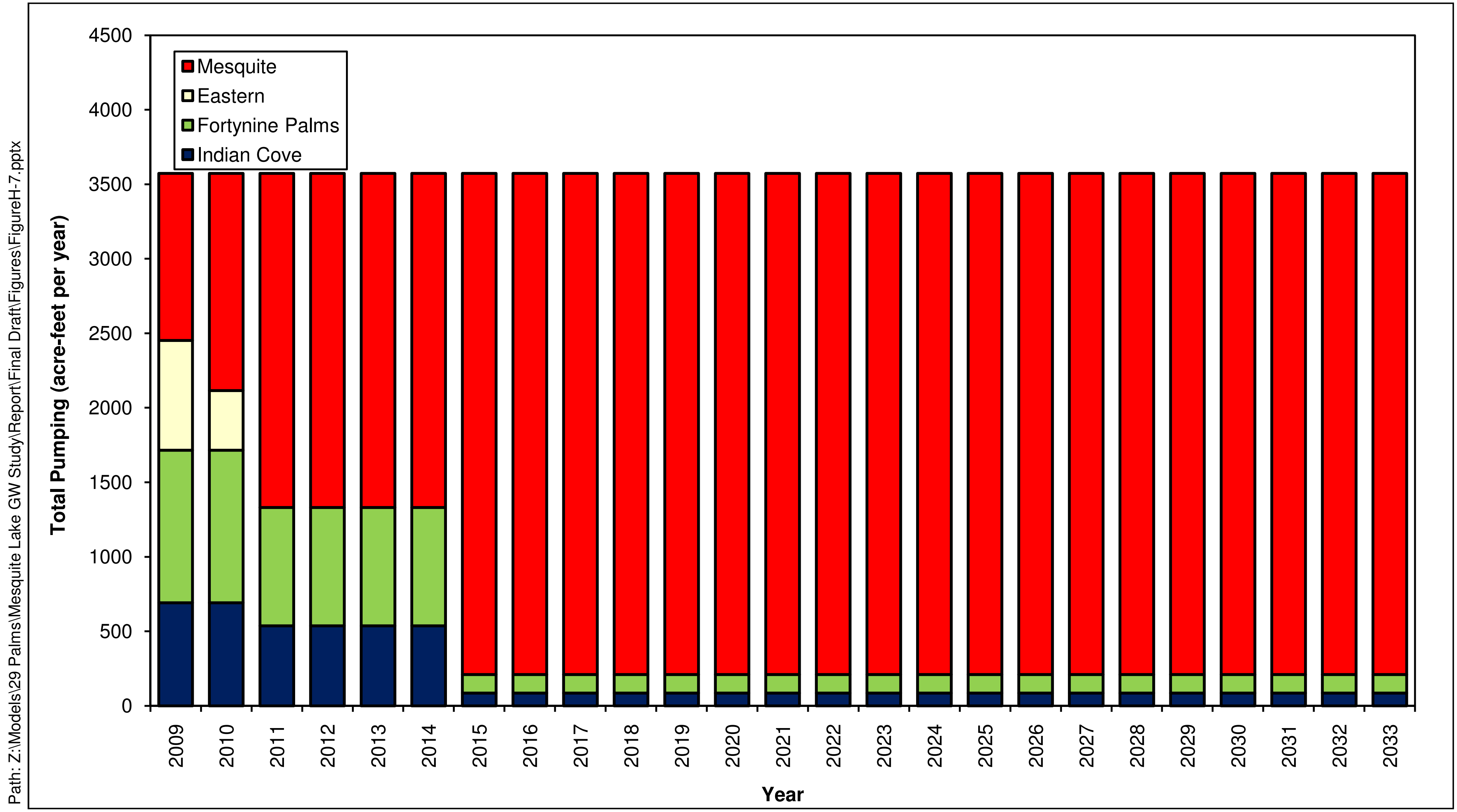
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Annual Pumping by Subbasin for Model Scenario 4

K/J 0964003*00
March 2010

Figure H-6



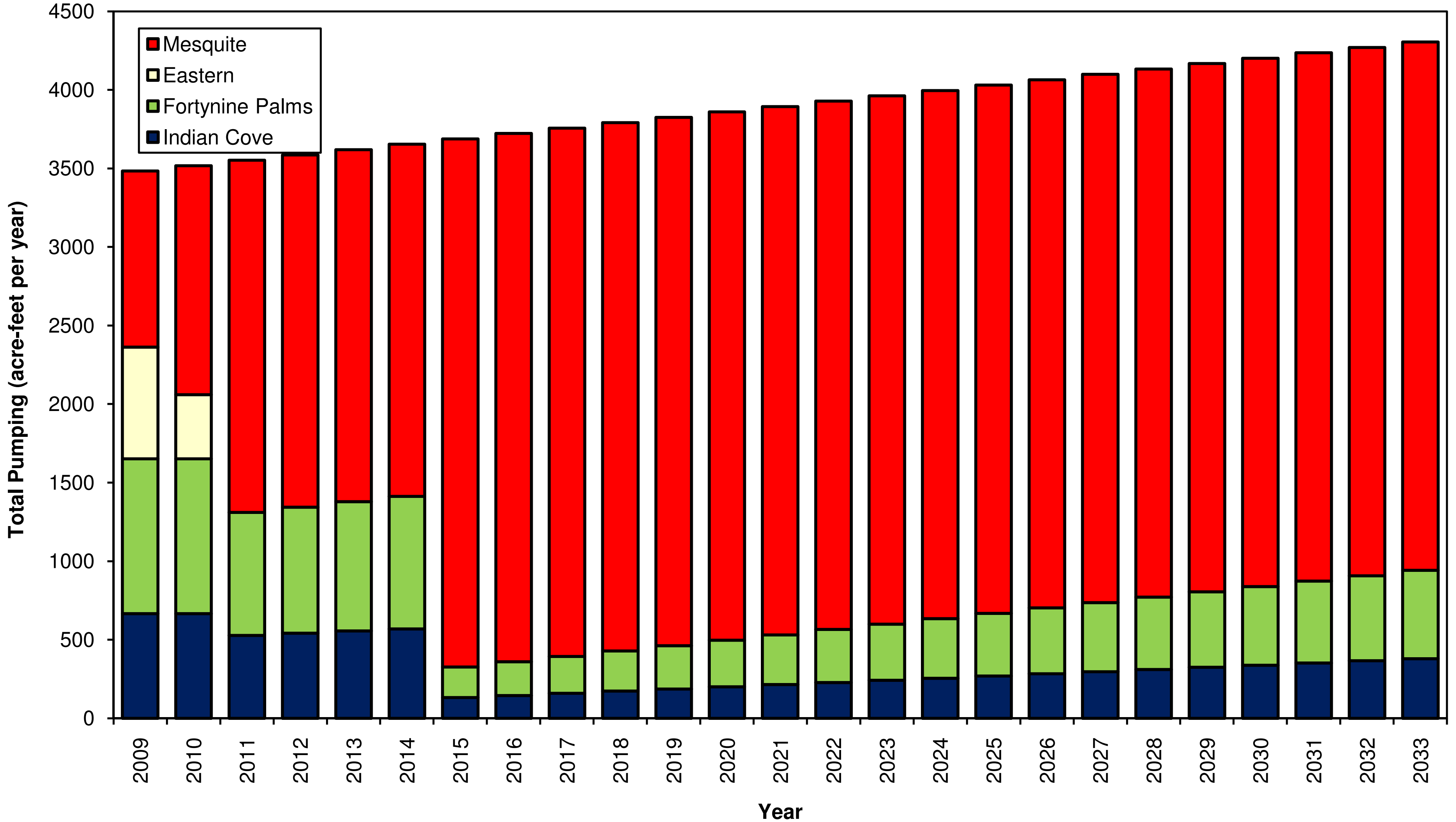
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Annual Pumping by Subbasin for Model Scenario 5

K/J 0964003*00
March 2010

Figure H-7



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureH-8.pptx

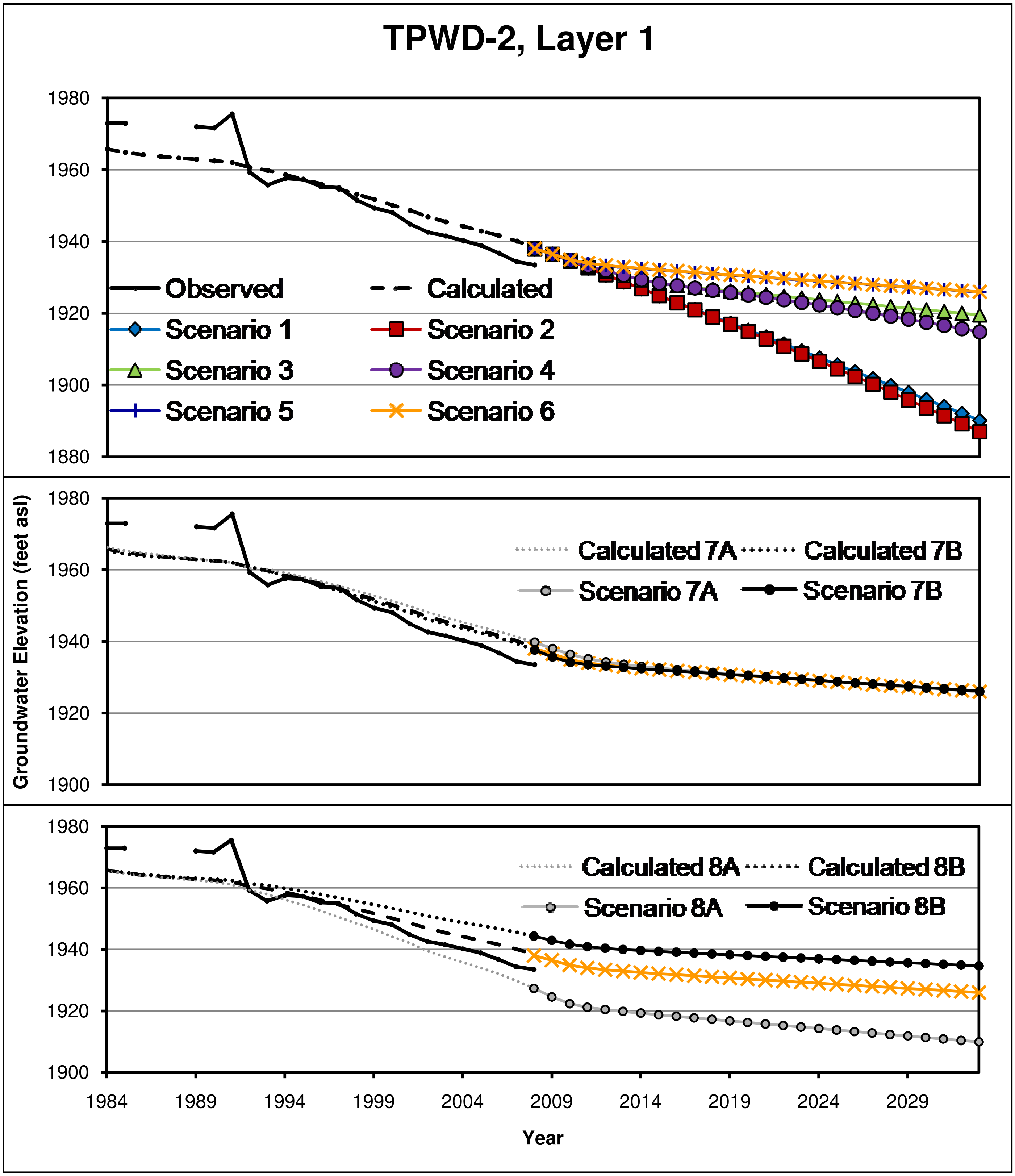
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Annual Pumping by Subbasin for Model Scenario 6

K/J 0964003*00
March 2010

Figure H-8



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureH-9.pptx

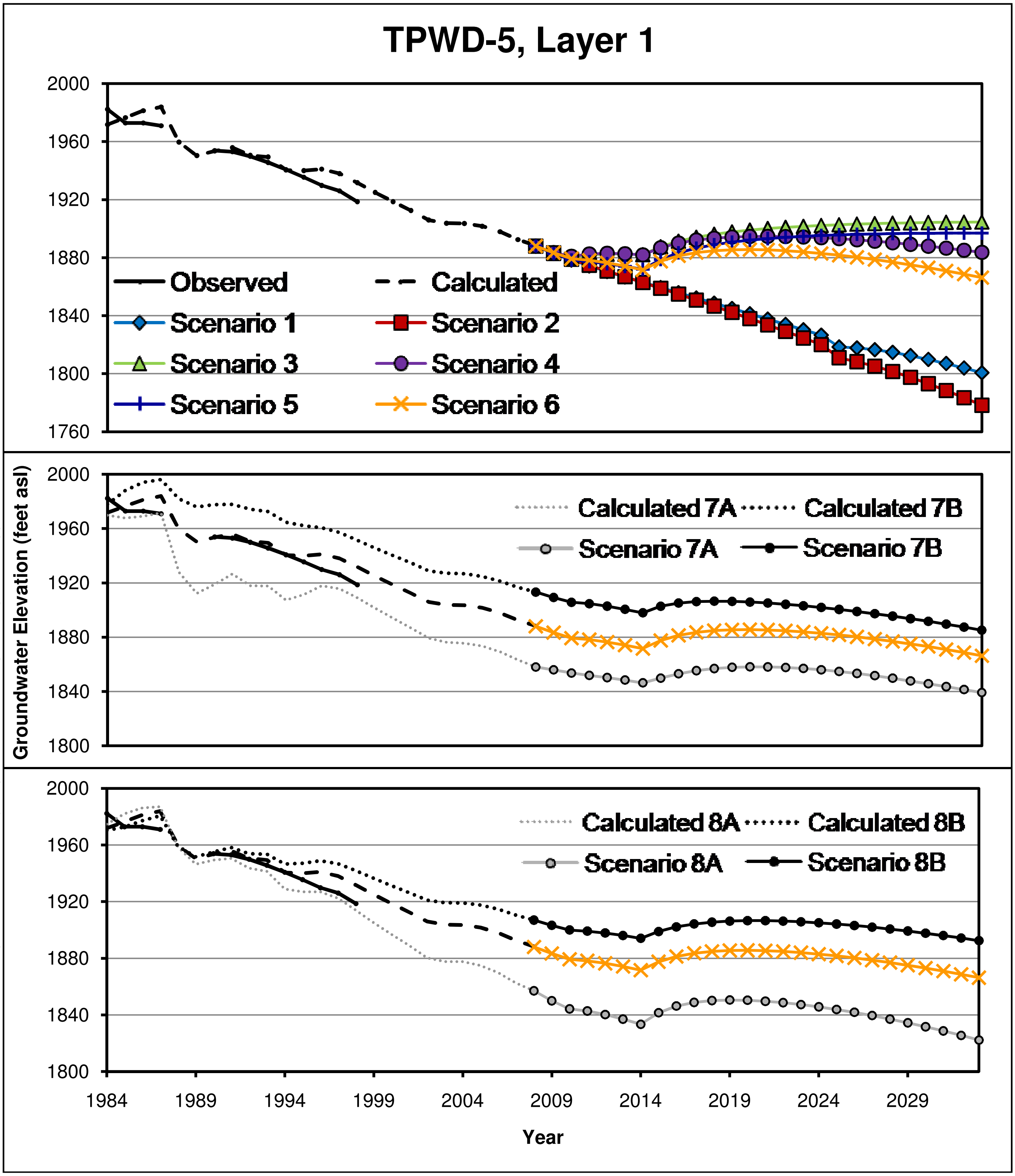
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for TPWD-2 in the Eastern Subbasin

K/J 0964003*00
March 2010

Figure H-9



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureH-10.pptx

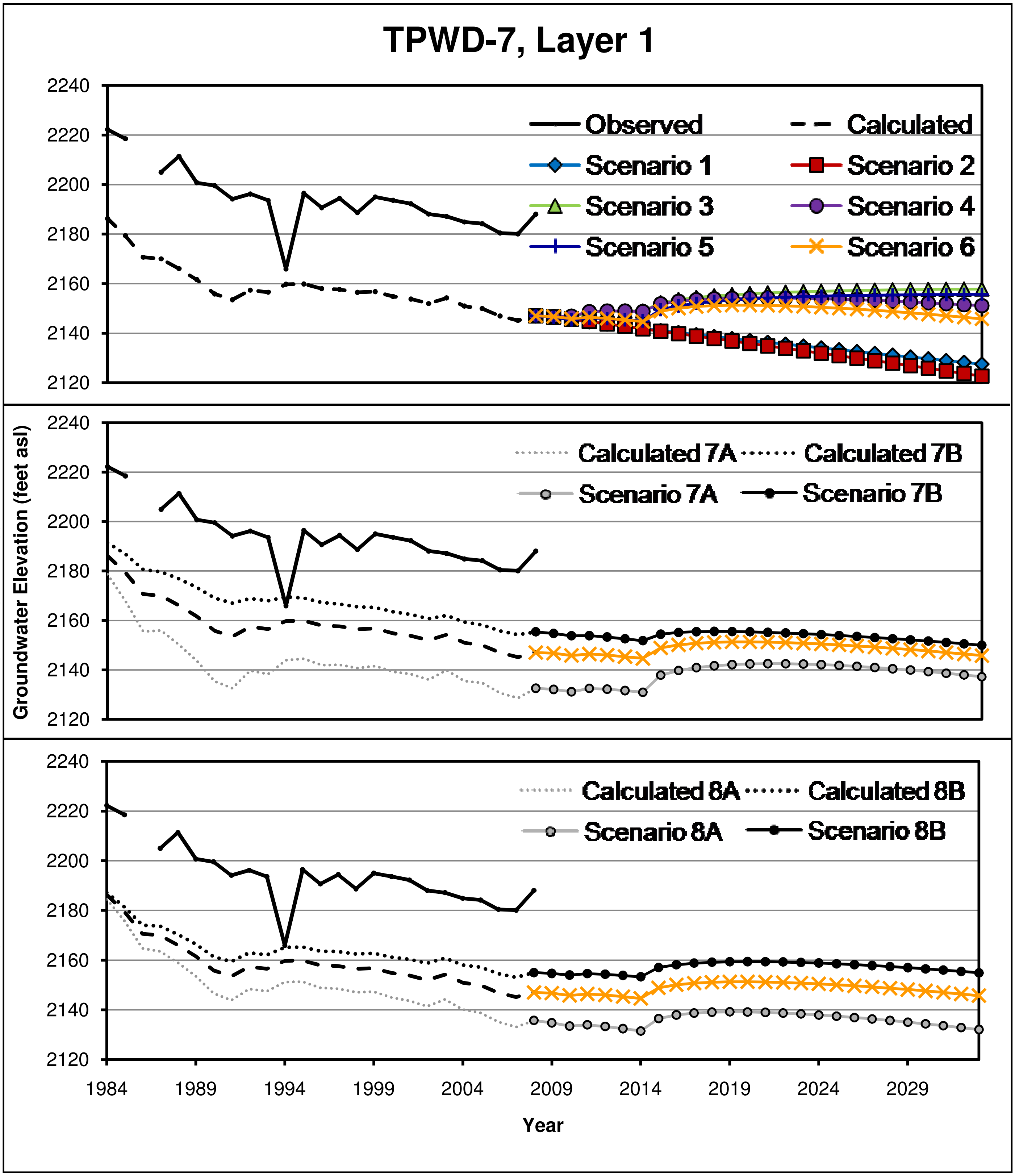
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for TPWD-5 in the Fortynine Palms Subbasin

K/J 0964003*00
March 2010

Figure H-10



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureH-11.pptx

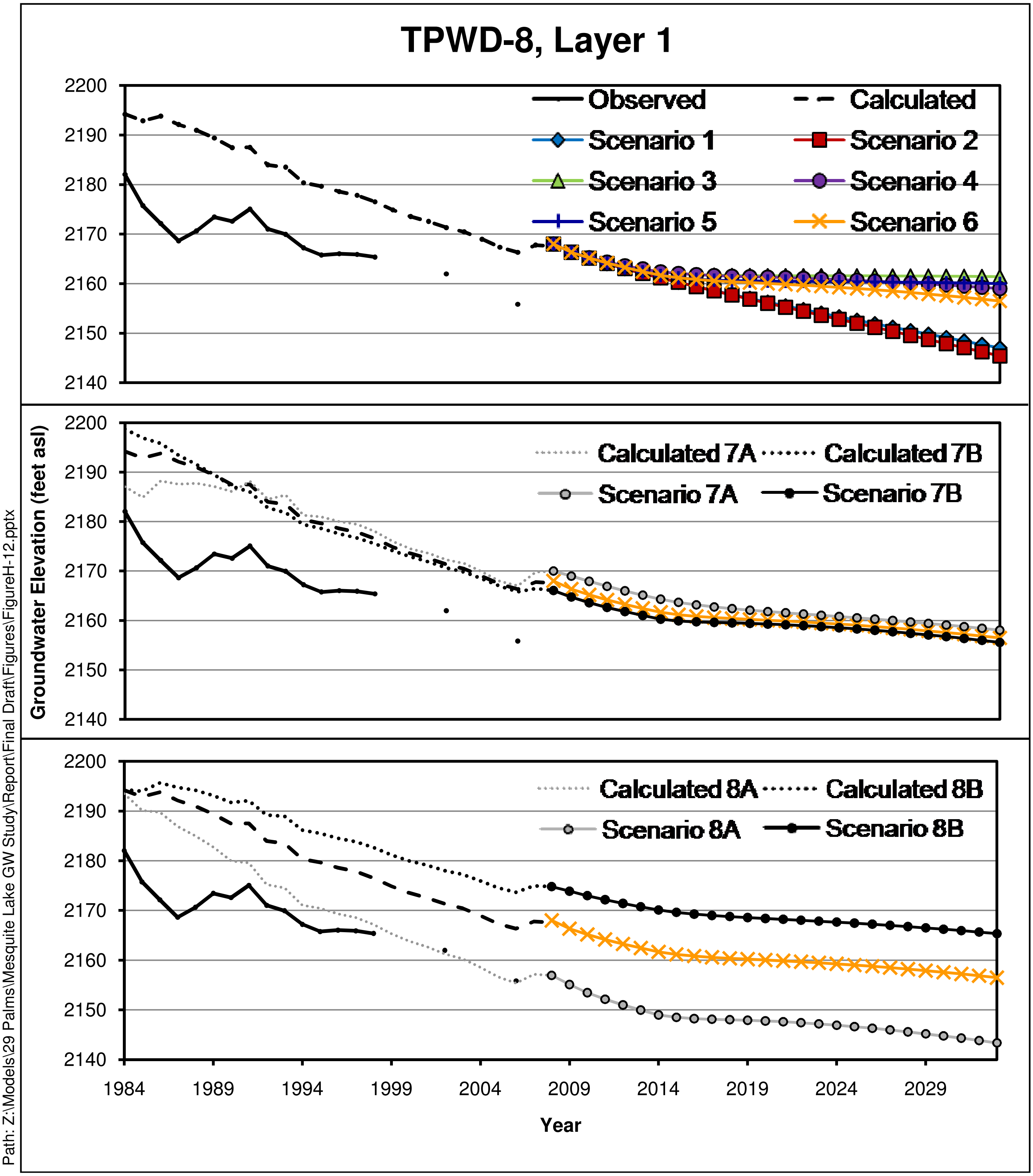
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for TPWD-7 in the Indian Cove Subbasin

K/J 0964003*00
March 2010

Figure H-11



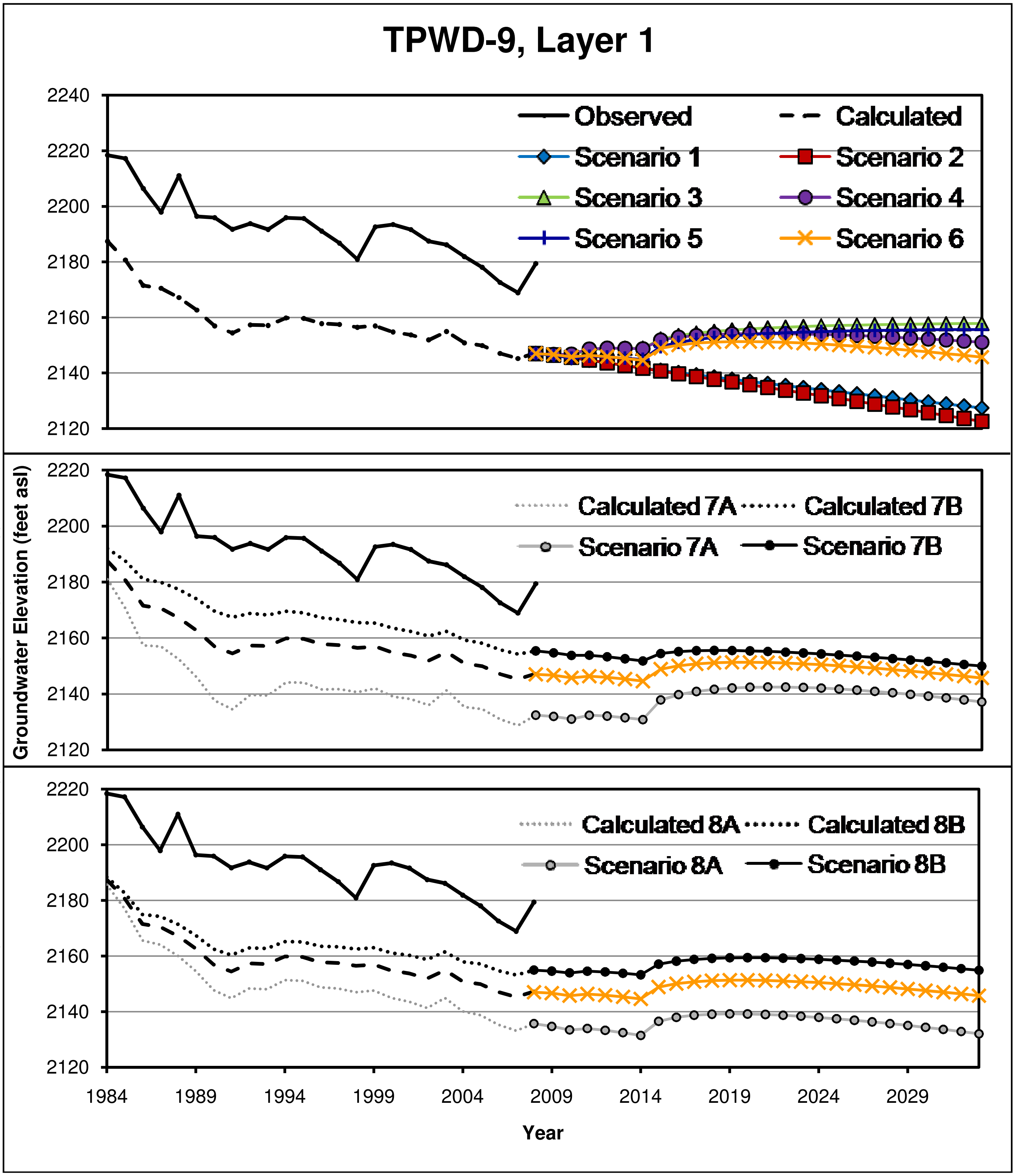
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for TPWD-8 in the Indian Cove Subbasin

K/J 0964003*00
March 2010

Figure H-12



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureH-13.pptx

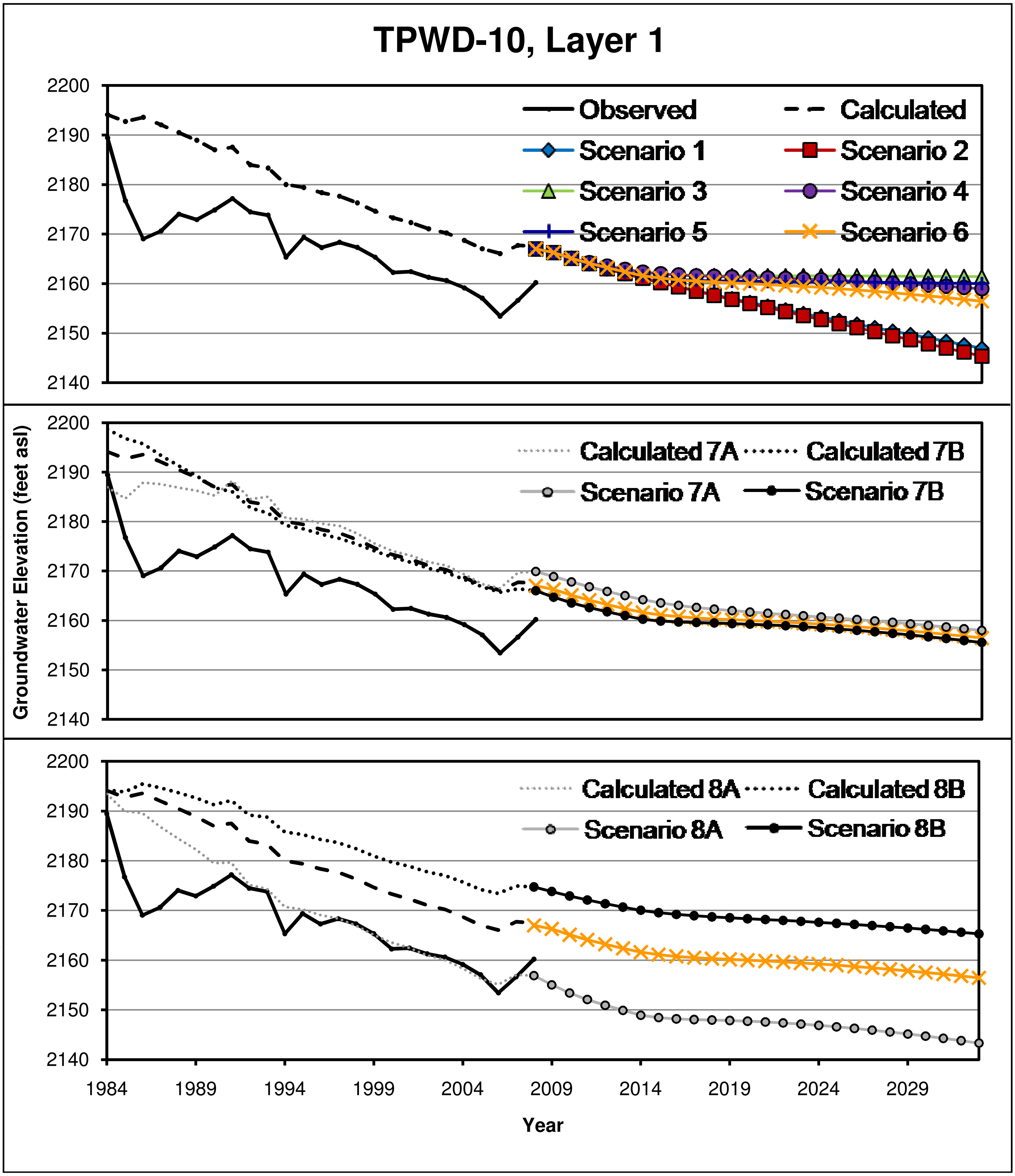
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for TPWD-9 in the Indian Cove Subbasin

K/J 0964003*00
March 2010

Figure H-13



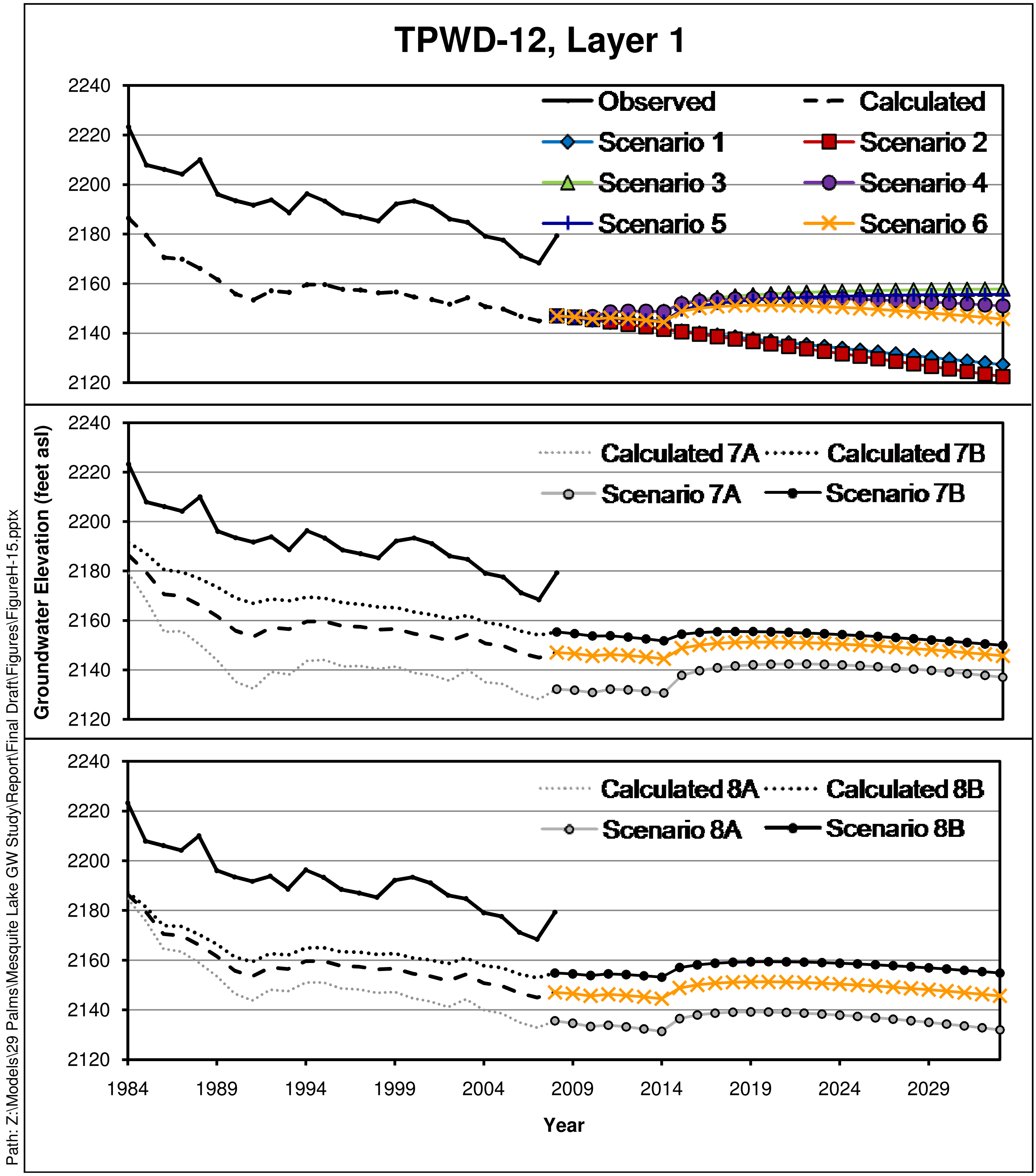
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for TPWD-10 in the Indian Cove Subbasin

K/J 0964003*00
March 2010

Figure H-14



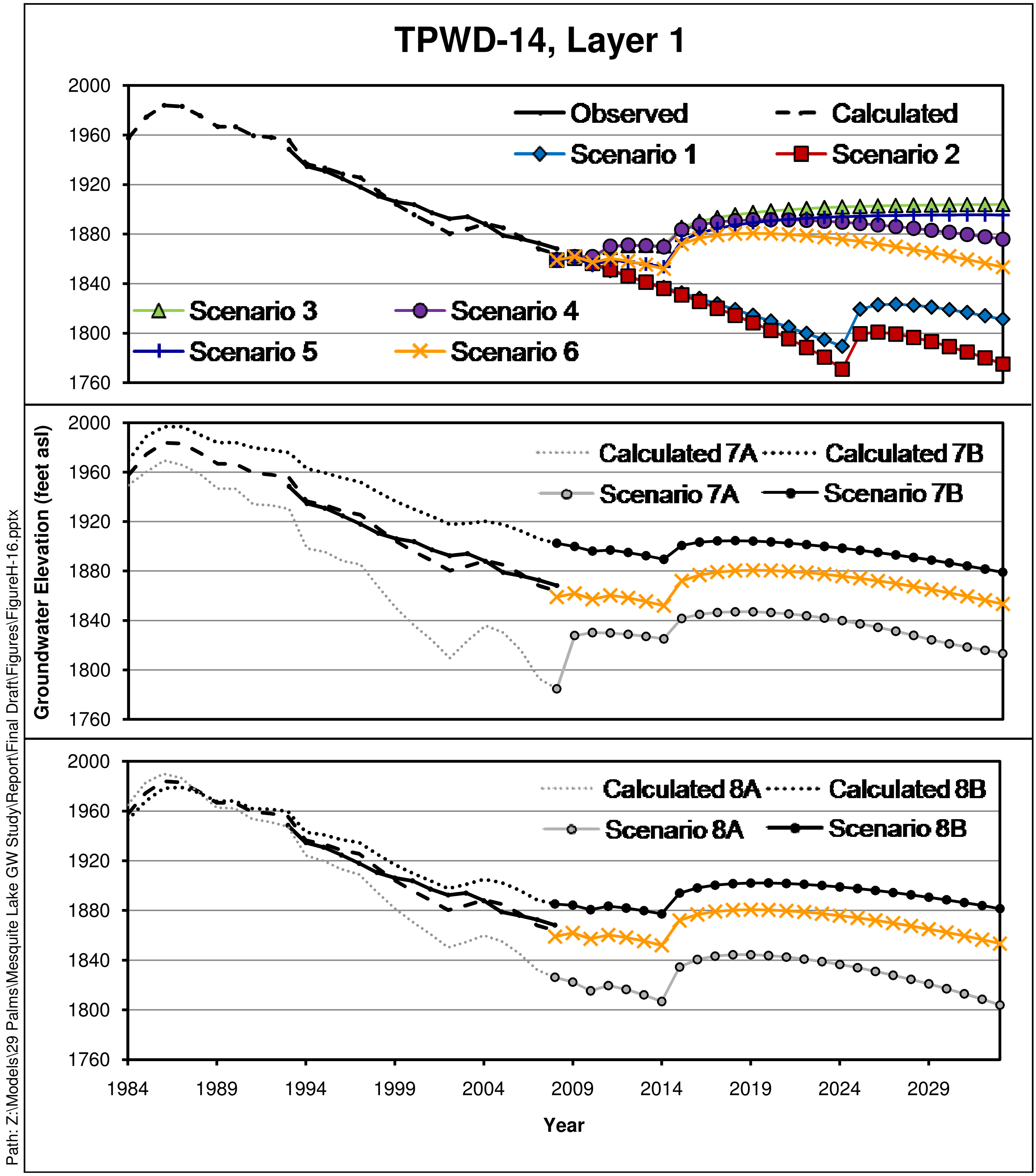
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for TPWD-12 in the Indian Cove Subbasin

K/J 0964003*00
March 2010

Figure H-15



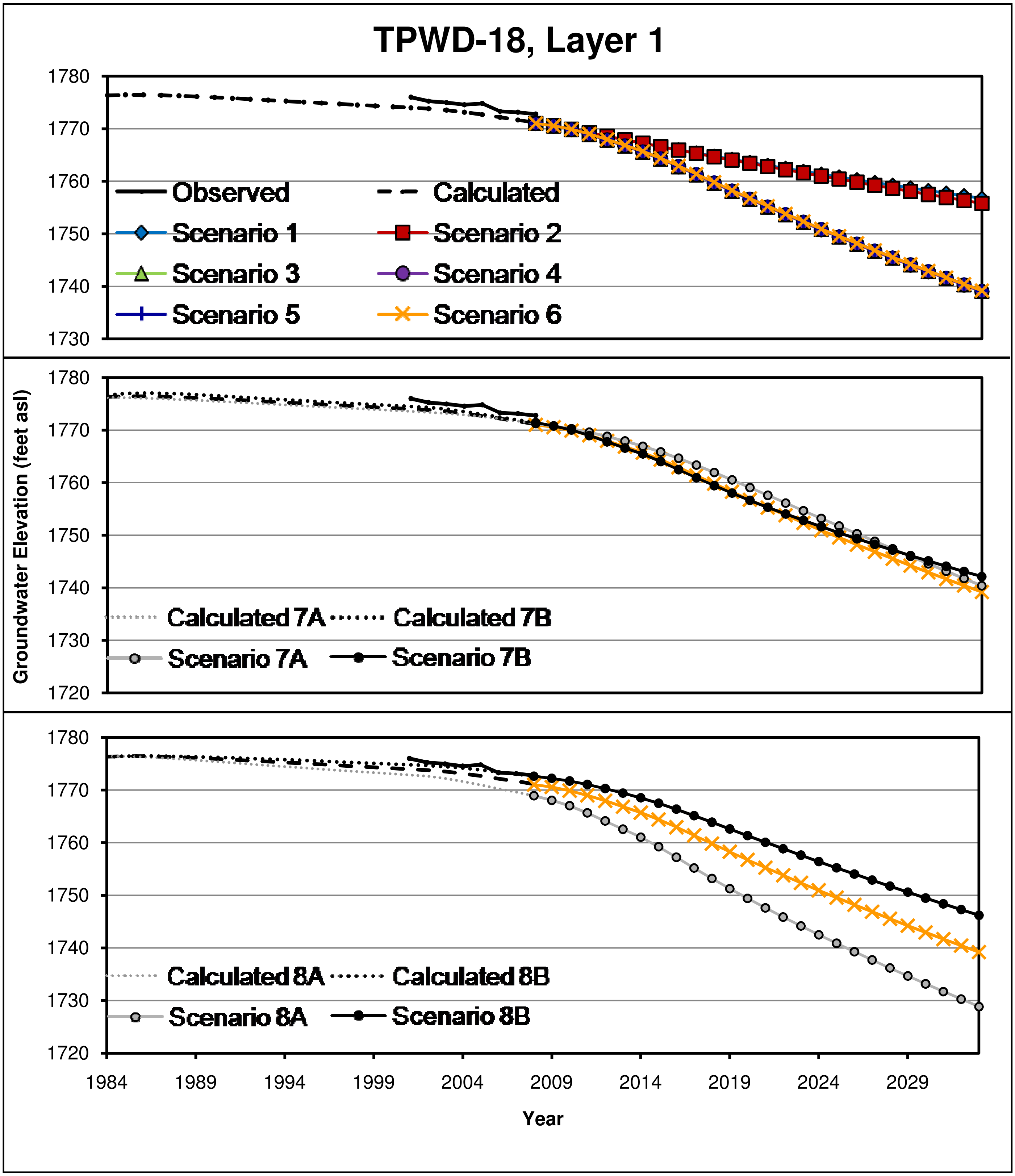
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for TPWD-14 in the Fortynine Palms Subbasin

K/J 0964003*00
March 2010

Figure H-16



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureH-17.pptx

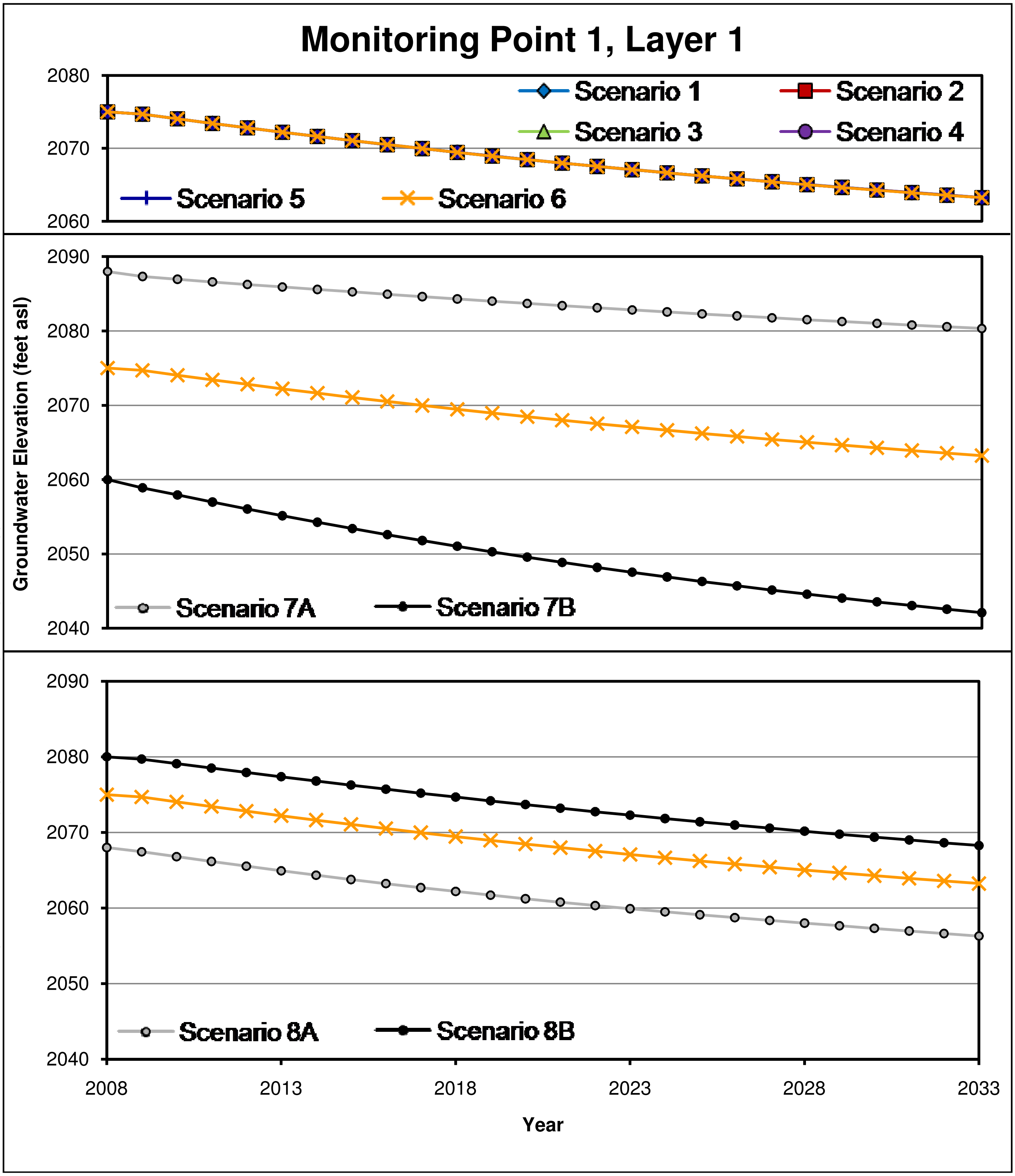
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for TPWD-18 in the Mesquite Subbasin

K/J 0964003*00
March 2010

Figure H-17



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureH-18.pptx

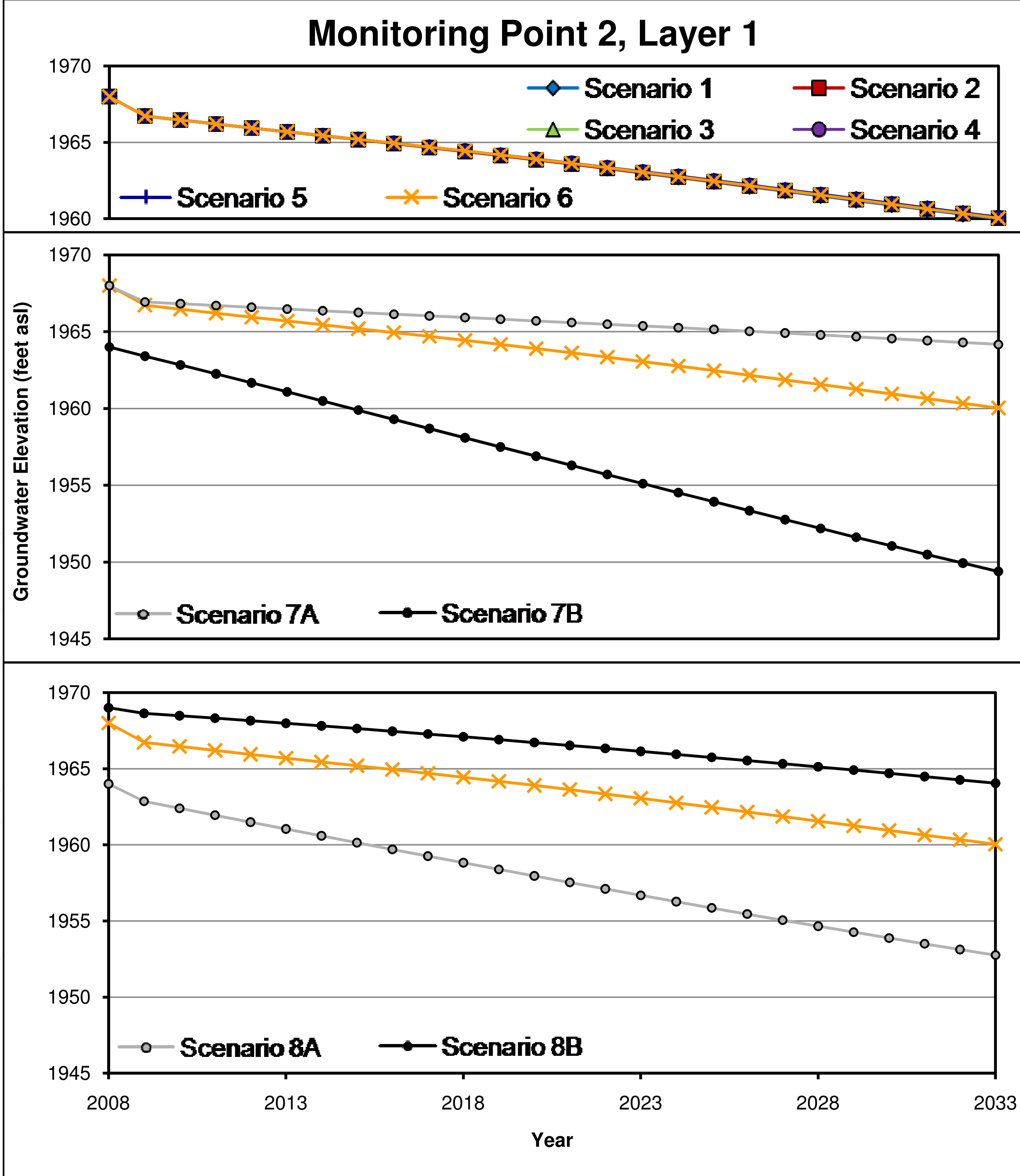
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for Monitoring Point 1 in the Mesquite Subbasin

K/J 0964003*00
March 2010

Figure H-18



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureH-19.pptx

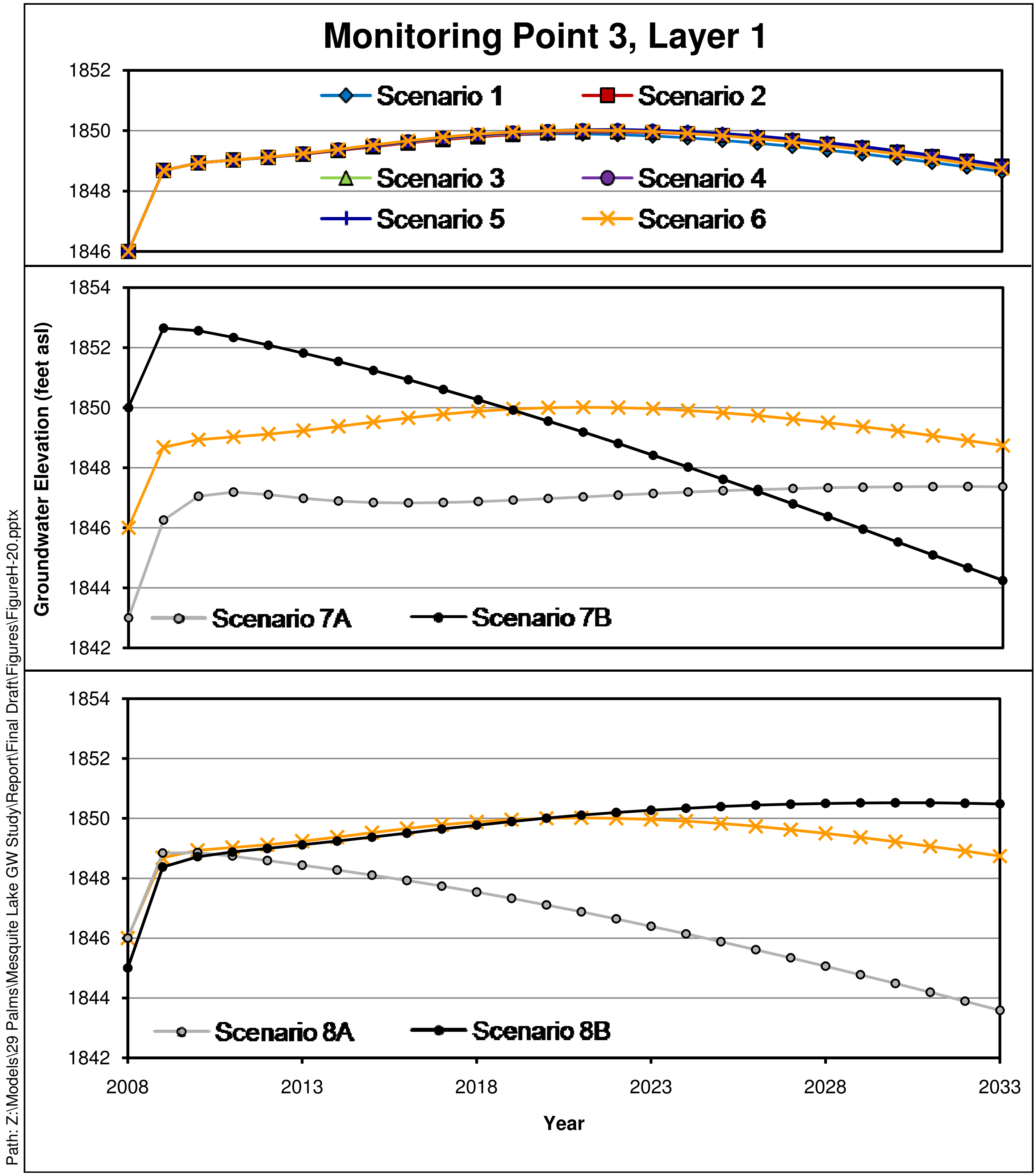
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for Monitoring Point 2 in the Mesquite Subbasin

K/J 0964003*00
March 2010

Figure H-19



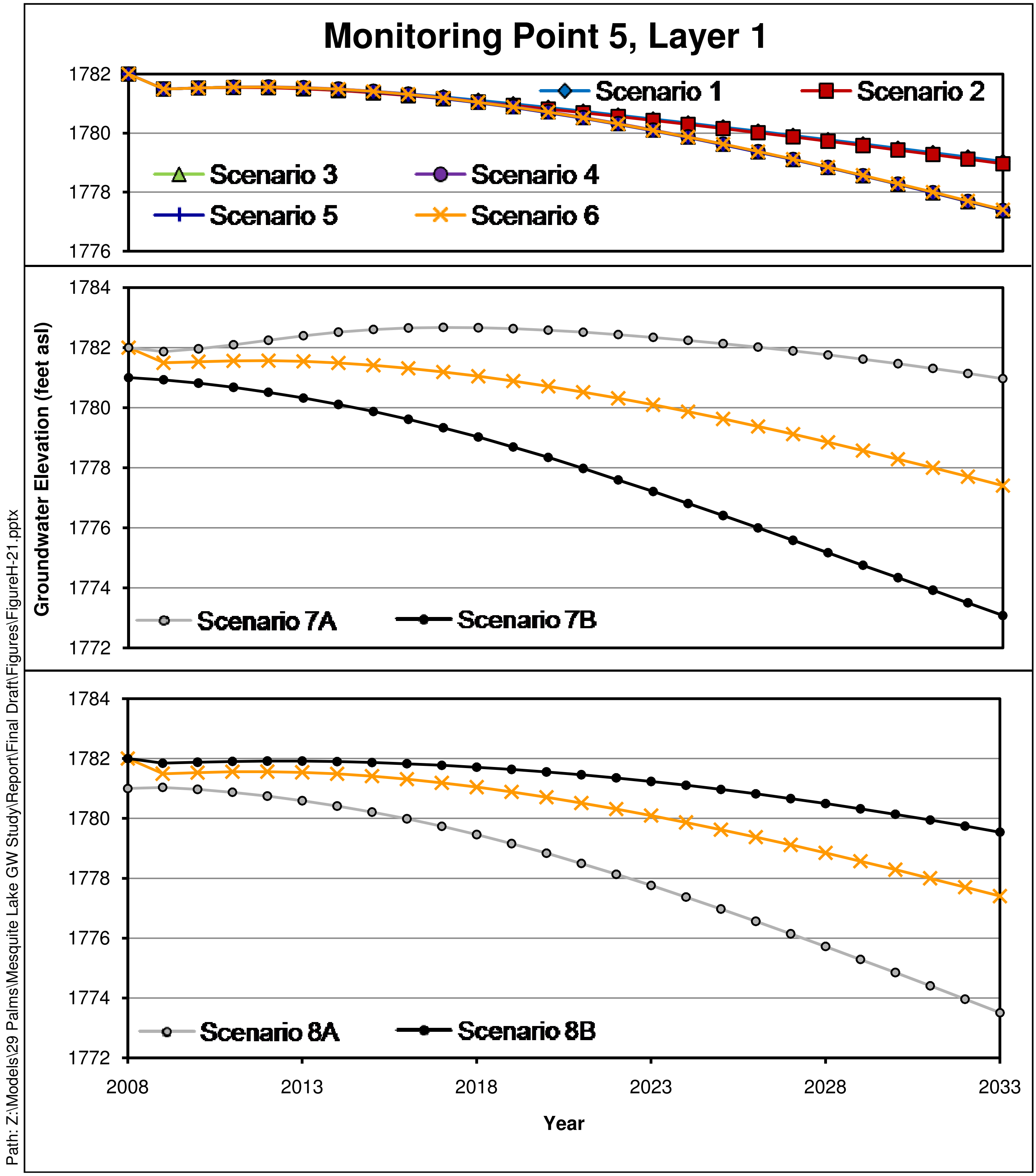
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for Monitoring Point 3 in the Mesquite Subbasin

K/J 0964003*00
March 2010

Figure H-20



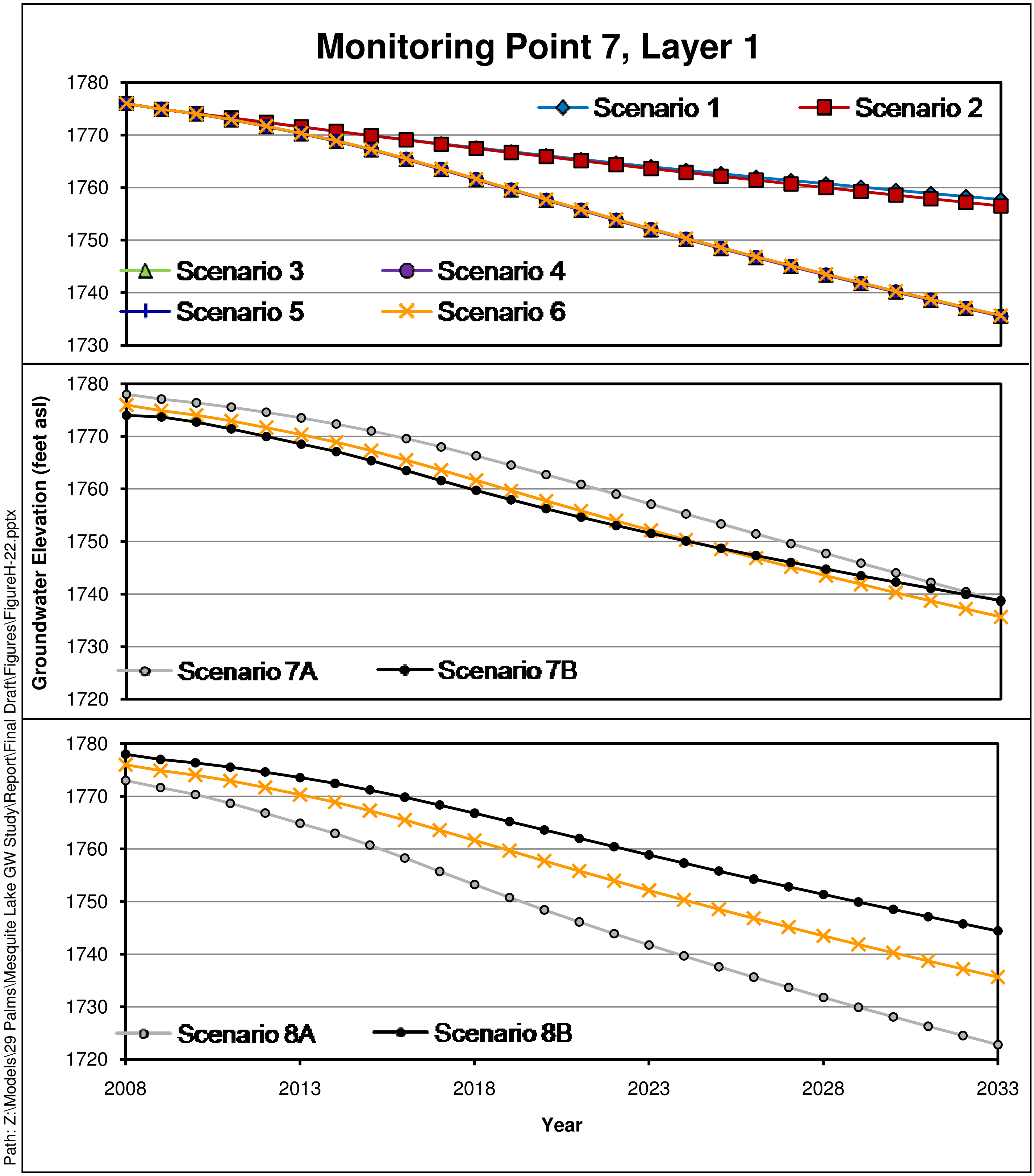
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for Monitoring Point 5 in the Mesquite Subbasin

K/J 0964003*00
March 2010

Figure H-21



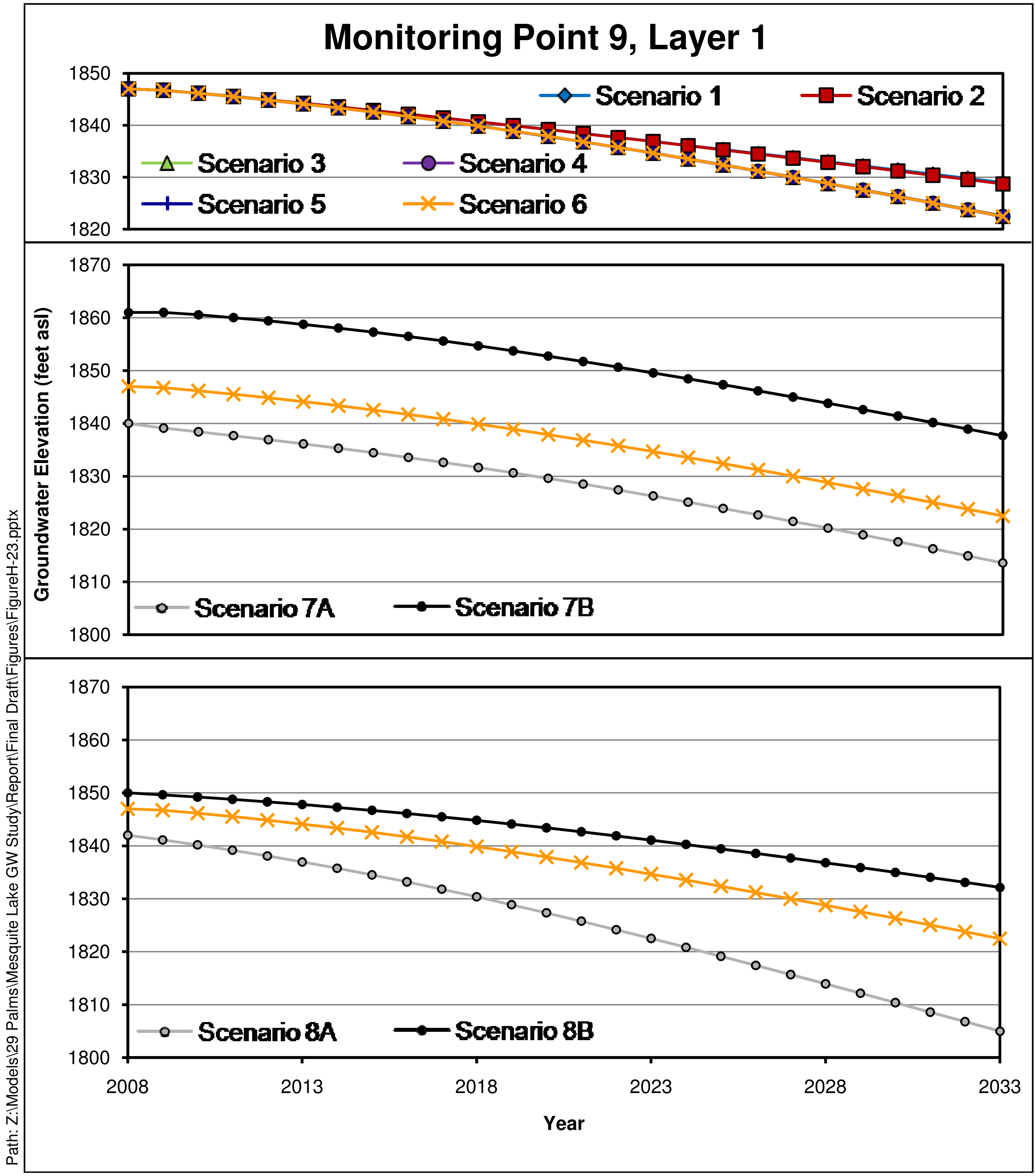
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for Monitoring Point 7 in the Mesquite Subbasin

K/J 0964003*00
March 2010

Figure H-22



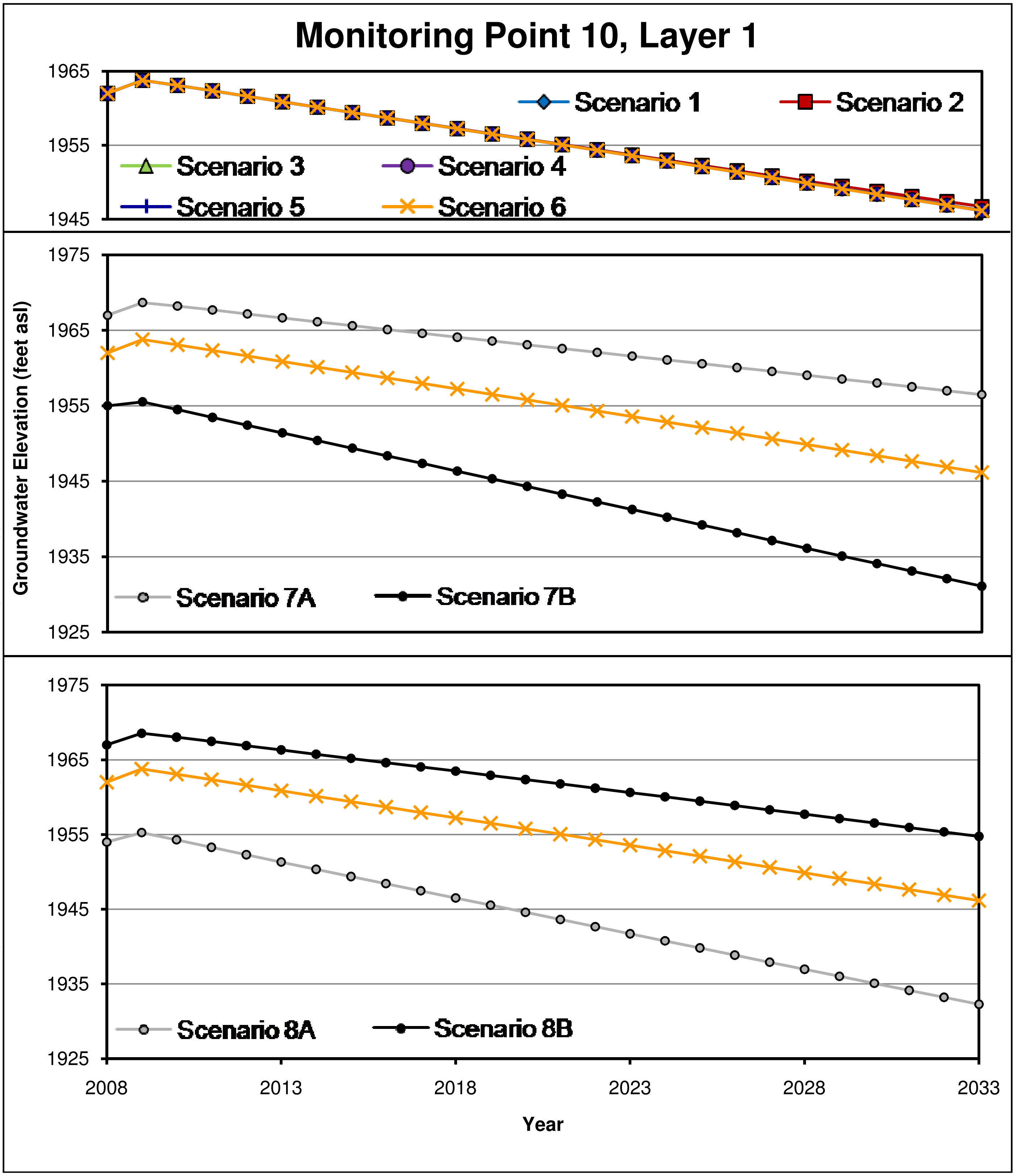
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for Monitoring Point 9 in the Mesquite Subbasin

K/J 0964003*00
March 2010

Figure H-23



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureH-24.pptx

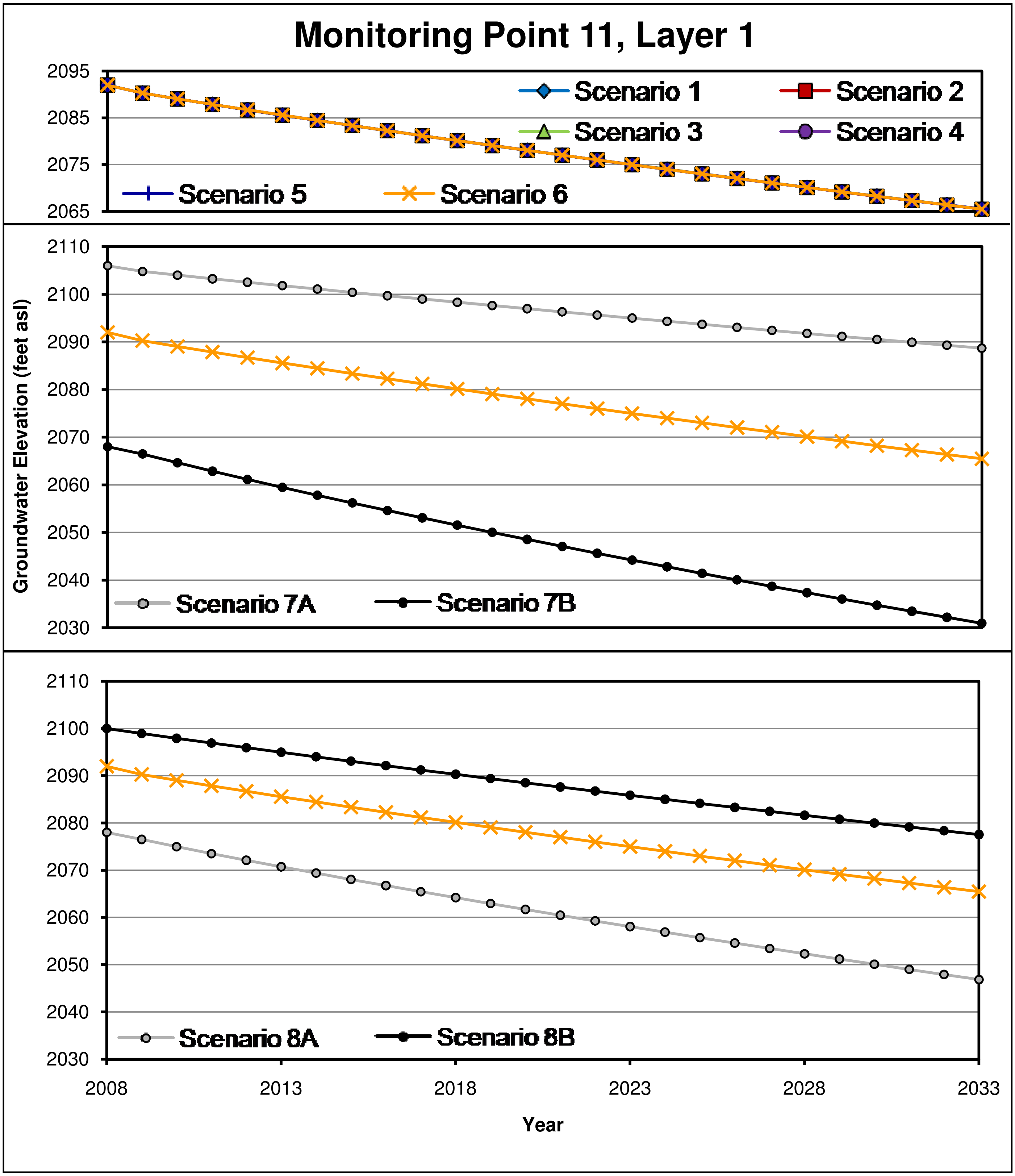
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for Monitoring Point 10 in the Mesquite Subbasin

K/J 0964003*00
March 2010

Figure H-24



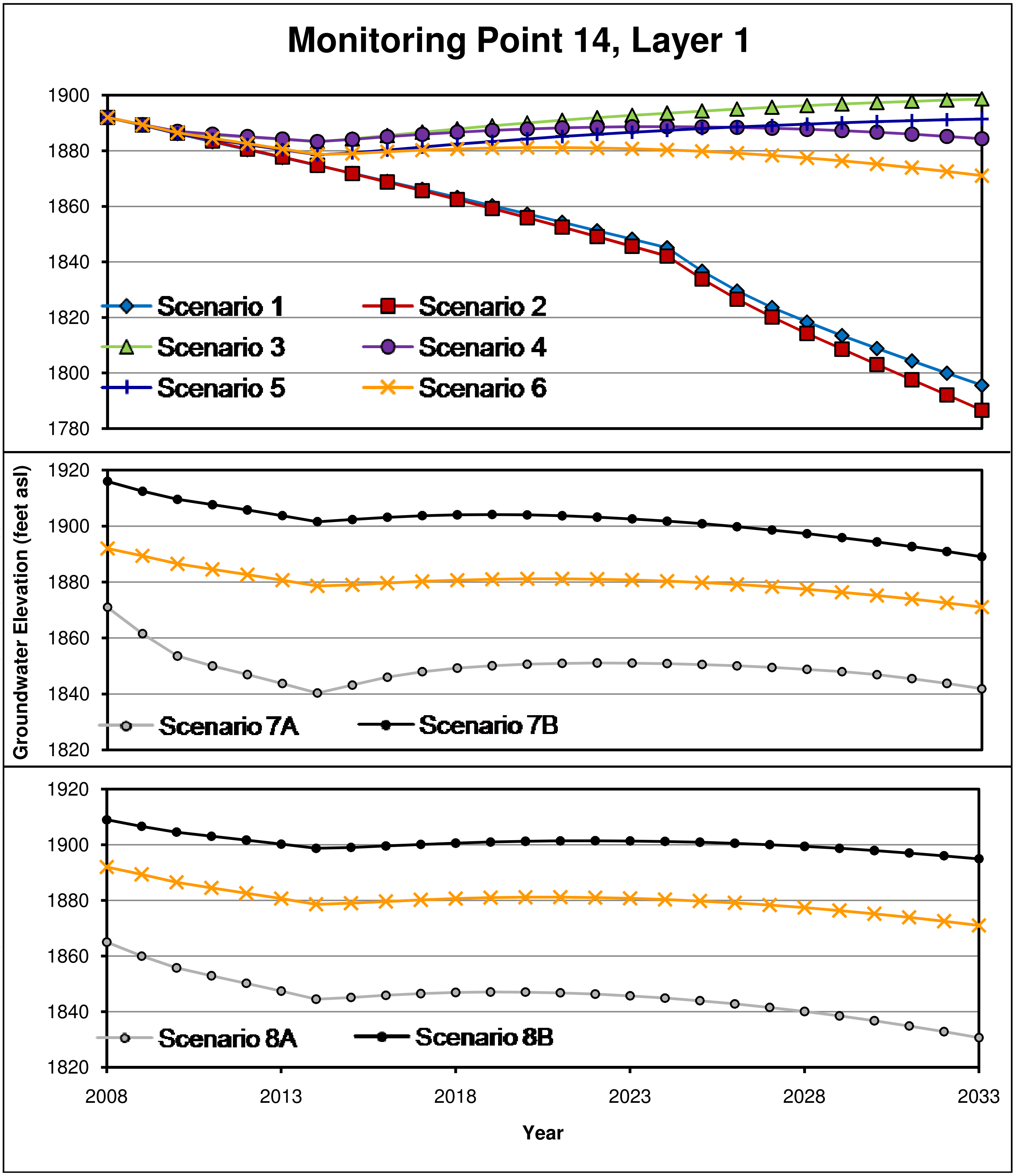
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for Monitoring Point 11 in the Mesquite Subbasin

K/J 0964003*00
March 2010

Figure H-25



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureH-26.pptx

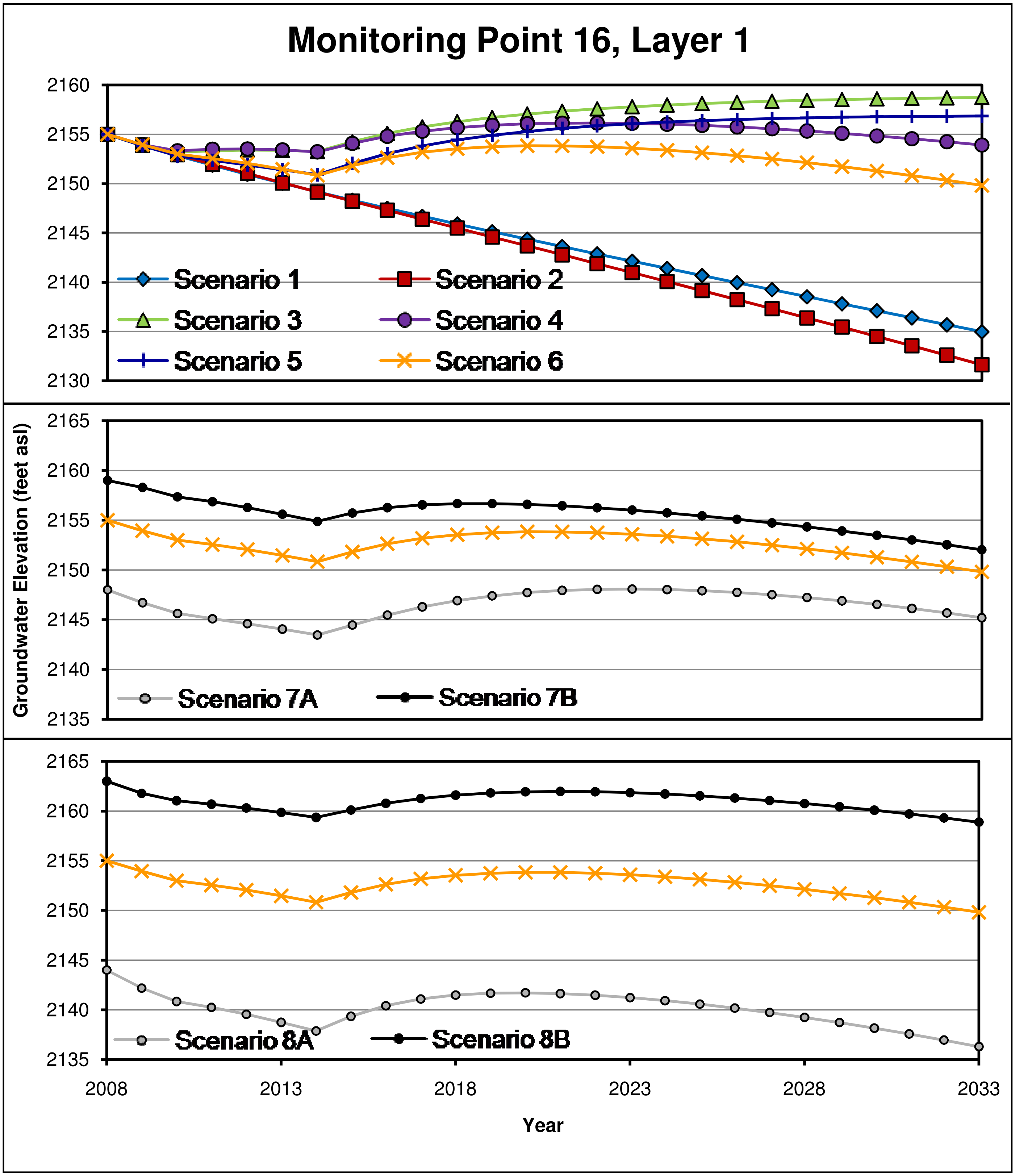
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for Monitoring Point 14 in the Fortynine Palms Subbasin

K/J 0964003*00
March 2010

Figure H-26



Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureH-27.pptx

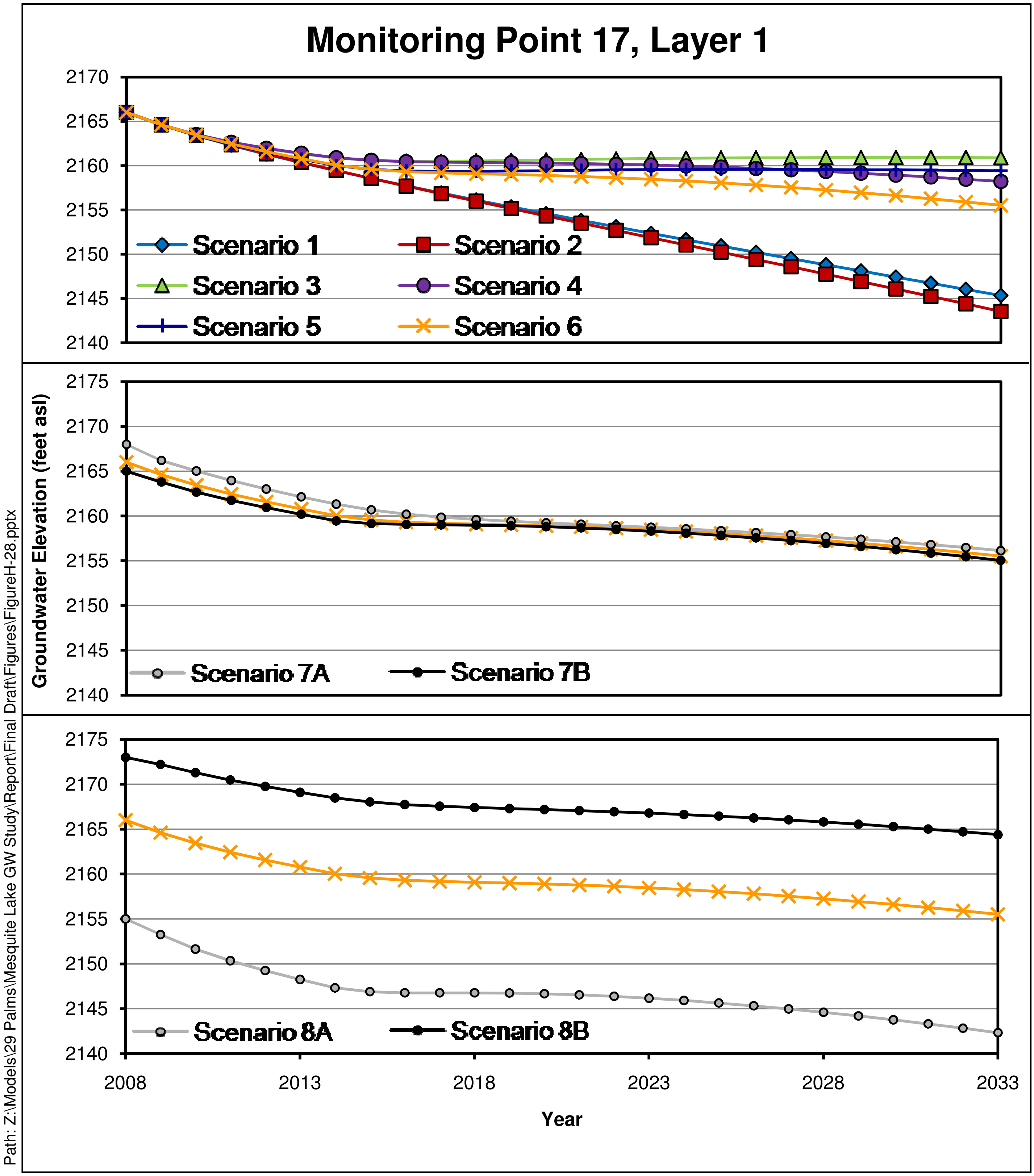
Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for Monitoring Point 16 in the Indian Cove Subbasin

K/J 0964003*00
March 2010

Figure H-27



Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Hydrographs for Monitoring Point 17 in the Indian Cove Subbasin

K/J 0964003*00
March 2010

Figure H-28

Appendix I: MODFLOW Model Sensitivity Analysis Results

Appendix I: MODFLOW Model Sensitivity Analysis Results

Appendix H contains additional tables and graphs to support the sensitivity analysis of the MODFLOW model.

List of Tables

I-1 Annual Boundary Fluxes, Sensitivity Scenario 7

I-2 Annual Boundary Fluxes, Sensitivity Scenario 8

List of Figures

I-1 Hydraulic Conductivity Sensitivity Scenario Results for Wells in the Indian Cove Subbasin

I-2 Hydraulic Conductivity Sensitivity Scenario Results for Wells in the Fortynine Palms Subbasin

I-3 Hydraulic Conductivity Sensitivity Scenario Results for Wells in the Eastern Subbasin

I-4 Hydraulic Conductivity Sensitivity Scenario Results for Wells in the Mesquite Subbasin

I-5 Specific Yield Sensitivity Scenario Results for Wells in the Indian Cove Subbasin

I-6 Specific Yield Sensitivity Scenario Results for Wells in the Fortynine Palms Subbasin

I-7 Specific Yield Sensitivity Scenario Results for Wells in the Eastern Subbasin

I-8 Specific Yield Sensitivity Scenario Results for Wells in the Mesquite Subbasin

Table I-1a: Annual (calendar year) boundary fluxes (Q, in acre-feet) from the model domain for Model Scenario 7A, along with percent differences from Scenario 6 results. Note that the annual fluxes are rounded to the nearest acre-foot, but the averages are based on unrounded amounts. Negative numbers indicate fluxes out of the model domain. 2008 fluxes are the results of the calibrated transient model, and are not included in the averages at the bottom of this table.

			Evapotranspiration				General Head Boundary Flux							
Year	Well Discharge	Recharge	Mesquite Dry Lake		Oasis of Mara		Across Transverse Arch		From Copper Mountain Subbasin		From Joshua Tree Subbasin		To Dale Basin	
			Q	+/-	Q	+/-	Q	+/-	Q	+/-	Q	+/-	Q	+/-
2008	-4,246	8	-1,658	--	0	--	806	--	136	--	20	--	-512	--
2009	-4,467	8	-1,169	-28.4%	0	0.0%	774	-4.8%	130	-2.0%	26	0.0%	-509	-0.2%
2010	-4,543	8	-1,033	-36.4%	0	0.0%	756	-7.3%	129	-3.3%	27	-0.1%	-507	-0.3%
2011	-4,675	8	-986	-39.2%	0	0.0%	745	-9.0%	130	-4.1%	28	-0.1%	-504	-0.5%
2012	-4,709	8	-965	-40.3%	0	0.0%	737	-10.4%	130	-4.6%	28	-0.2%	-501	-0.6%
2013	-4,744	8	-953	-40.8%	0	0.0%	731	-11.5%	130	-4.7%	28	-0.2%	-499	-0.7%
2014	-4,778	8	-944	-41.1%	0	0.0%	726	-12.6%	131	-5.1%	28	-0.3%	-497	-0.8%
2015	-4,952	8	-937	-41.1%	0	0.0%	722	-13.4%	131	-5.2%	28	-0.4%	-493	-1.0%
2016	-4,986	8	-931	-41.1%	0	0.0%	719	-14.3%	131	-5.5%	28	-0.5%	-490	-1.1%
2017	-5,021	8	-925	-41.0%	0	0.0%	717	-15.0%	132	-5.7%	28	-0.6%	-487	-1.3%
2018	-5,055	8	-918	-40.9%	0	0.0%	715	-15.7%	132	-6.0%	28	-0.6%	-484	-1.4%
2019	-5,089	8	-912	-40.7%	0	0.0%	713	-16.3%	132	-6.2%	28	-0.7%	-481	-1.5%
2020	-5,123	8	-906	-40.5%	0	0.0%	711	-16.9%	133	-6.5%	28	-0.8%	-478	-1.6%
2021	-5,157	8	-899	-40.2%	0	0.0%	709	-17.5%	133	-6.7%	28	-0.9%	-475	-1.7%
2022	-5,192	8	-892	-39.9%	0	0.0%	708	-18.0%	133	-6.4%	28	-1.0%	-473	-1.8%
2023	-5,226	8	-885	-39.7%	0	0.0%	707	-18.5%	133	-6.2%	28	-1.0%	-470	-1.9%
2024	-5,260	8	-877	-39.4%	0	0.0%	706	-19.0%	134	-6.4%	28	-1.1%	-467	-2.0%
2025	-5,294	8	-869	-39.2%	0	0.0%	705	-19.4%	134	-6.5%	28	-1.2%	-464	-2.1%
2026	-5,329	8	-861	-38.9%	0	0.0%	704	-19.9%	134	-6.7%	27	-1.2%	-462	-2.1%
2027	-5,363	8	-853	-38.6%	0	0.0%	703	-20.3%	134	-6.8%	27	-1.3%	-459	-2.2%
2028	-5,397	8	-845	-38.4%	0	0.0%	702	-20.7%	134	-7.0%	27	-1.3%	-457	-2.3%
2029	-5,431	8	-836	-38.1%	0	0.0%	701	-21.1%	134	-7.2%	27	-1.4%	-454	-2.4%
2030	-5,465	8	-828	-37.8%	0	0.0%	701	-21.4%	134	-7.3%	27	-1.4%	-452	-2.5%
2031	-5,500	8	-819	-37.5%	0	0.0%	700	-21.8%	135	-7.5%	26	-1.5%	-449	-2.5%
2032	-5,534	8	-810	-37.3%	0	0.0%	699	-22.1%	135	-7.6%	26	-1.5%	-446	-2.6%
2033	-5,568	8	-801	-37.0%	0	0.0%	699	-22.5%	135	-7.7%	26	-1.6%	-444	-2.7%
Avg.	-5,114	8	-906	-39.0%	0	0.0%	716	-16.5%	133	-6.0%	28	-0.8%	-476	-1.6%

Table I-1b: Annual (calendar year) boundary fluxes (Q, in acre-feet) from the model domain for Model Scenario 7B, along with percent differences from Scenario 6 results. Note that the annual fluxes are rounded to the nearest acre-foot, but the averages are based on unrounded amounts. Negative numbers indicate fluxes out of the model domain. 2008 fluxes are the results of the calibrated transient model, and are not included in the averages at the bottom of this table.

			Evapotranspiration				**General Head Boundary Flux**							
Year	**Well Discharge**	**Recharge**	**Mesquite Dry Lake**		**Oasis of Mara**		**Across Transverse Arch**		**From Copper Mountain Subbasin**		**From Joshua Tree Subbasin**		**To Dale Basin**	
			Q	**+/-**	**Q**	**+/-**	**Q**	**+/-**	**Q**	**+/-**	**Q**	**+/-**	**Q**	**+/-**
2008	-4,246	8	-1,658	--	0	--	806	--	136	--	20	--	-512	--
2009	-4,467	8	-2,719	66.6%	0	0.0%	1,101	35.4%	106	-20.1%	27	2.1%	-512	0.4%
2010	-4,543	8	-2,701	66.2%	0	0.0%	1,105	35.6%	99	-25.7%	28	2.2%	-511	0.5%
2011	-4,675	8	-2,680	65.4%	0	0.0%	1,111	35.8%	100	-25.9%	28	2.2%	-509	0.5%
2012	-4,709	8	-2,656	64.4%	0	0.0%	1,118	36.0%	100	-26.7%	29	2.2%	-507	0.6%
2013	-4,744	8	-2,628	63.3%	0	0.0%	1,125	36.2%	99	-27.7%	29	2.2%	-506	0.7%
2014	-4,778	8	-2,599	62.3%	0	0.0%	1,132	36.4%	98	-28.4%	29	2.2%	-504	0.7%
2015	-4,952	8	-2,566	61.2%	0	0.0%	1,140	36.5%	93	-33.0%	29	2.2%	-502	0.8%
2016	-4,986	8	-2,532	60.1%	0	0.0%	1,147	36.7%	92	-33.9%	29	2.2%	-500	0.9%
2017	-5,021	8	-2,495	59.1%	0	0.0%	1,154	36.8%	89	-36.3%	29	2.2%	-498	1.0%
2018	-5,055	8	-2,456	58.1%	0	0.0%	1,161	37.0%	83	-41.2%	29	2.2%	-496	1.1%
2019	-5,089	8	-2,418	57.3%	0	0.0%	1,168	37.1%	83	-41.2%	29	2.2%	-494	1.2%
2020	-5,123	8	-2,376	56.2%	0	0.0%	1,174	37.2%	81	-42.6%	29	2.1%	-492	1.2%
2021	-5,157	8	-2,338	55.5%	0	0.0%	1,181	37.4%	82	-42.6%	29	2.1%	-490	1.3%
2022	-5,192	8	-2,299	54.8%	0	0.0%	1,188	37.6%	82	-42.3%	29	2.1%	-488	1.4%
2023	-5,226	8	-2,255	53.7%	0	0.0%	1,194	37.7%	81	-43.2%	29	2.1%	-486	1.5%
2024	-5,260	8	-2,216	53.0%	0	0.0%	1,201	37.9%	81	-43.3%	29	2.1%	-484	1.6%
2025	-5,294	8	-2,170	51.8%	0	0.0%	1,207	38.0%	81	-43.3%	28	2.0%	-482	1.6%
2026	-5,329	8	-2,130	51.0%	0	0.0%	1,213	38.2%	81	-43.3%	28	2.0%	-480	1.7%
2027	-5,363	8	-2,090	50.4%	0	0.0%	1,220	38.4%	82	-43.4%	28	2.0%	-478	1.8%
2028	-5,397	8	-2,051	49.6%	0	0.0%	1,226	38.5%	82	-43.4%	28	2.0%	-476	1.9%
2029	-5,431	8	-2,006	48.5%	0	0.0%	1,232	38.7%	82	-43.5%	28	2.0%	-474	2.0%
2030	-5,465	8	-1,964	47.6%	0	0.0%	1,238	38.9%	71	-51.3%	28	1.9%	-472	2.0%
2031	-5,500	8	-1,922	46.7%	0	0.0%	1,245	39.1%	71	-51.3%	27	1.9%	-471	2.1%
2032	-5,534	8	-1,883	45.9%	0	0.0%	1,251	39.3%	69	-52.8%	27	1.9%	-469	2.2%
2033	-5,568	8	-1,845	45.1%	0	0.0%	1,257	39.5%	69	-52.9%	27	1.9%	-467	2.3%
Average	-5,114	8	-2,320	56.3%	0	0.0%	1,180	37.5%	85	-39.4%	28	2.1%	-490	1.3%

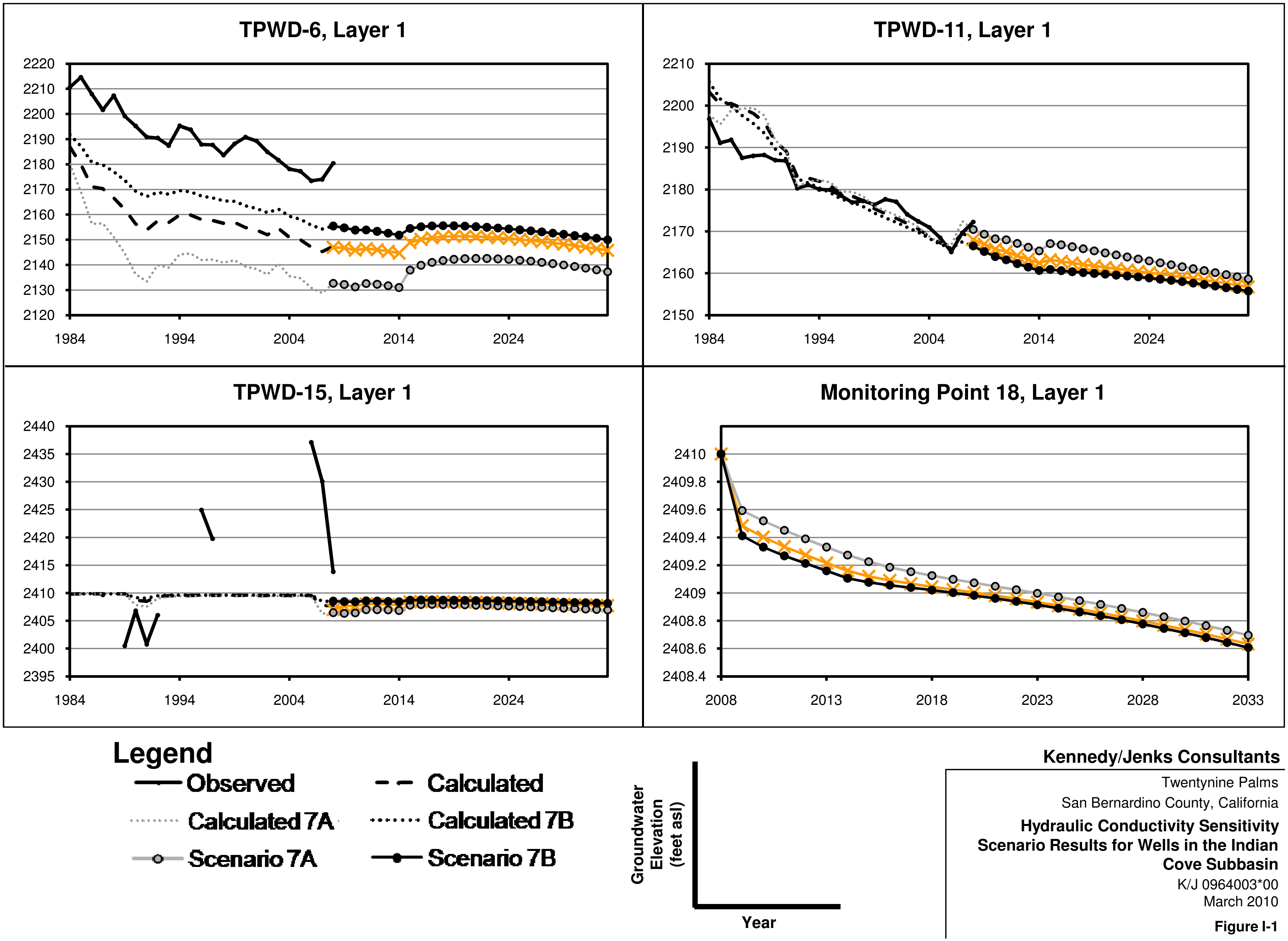
Table I-2a: Annual (calendar year) boundary fluxes (Q, in acre-feet) from the model domain for Model Scenario 8A, along with percent differences from Scenario 6 results. Note that the annual fluxes are rounded to the nearest acre-foot, but the averages are based on unrounded amounts. Negative numbers indicate fluxes out of the model domain. 2008 fluxes are the results of the calibrated transient model, and are not included in the averages at the bottom of this table.

			Evapotranspiration				General Head Boundary Flux									
Year	Well Discharge	Recharge	Mesquite Dry Lake		Oasis of Mara		Across Transverse Arch		From Copper Mountain Subbasin		From Joshua Tree Subbasin		To Dale Basin			
			Q	+/-	Q	+/-	Q	+/-	Q	+/-	Q	+/-	Q	+/-		
2008	-4,246	8	-1,658	--	0	--	806	--	136	--	20	--	-512	--		
2009	-4,467	8	-1,583	-3.0%	0	0.0%	871	7.1%	140	5.3%	29	8.7%	-506	-0.9%		
2010	-4,543	8	-1,572	-3.3%	0	0.0%	872	7.0%	137	2.4%	30	8.8%	-504	-0.9%		
2011	-4,675	8	-1,562	-3.6%	0	0.0%	875	6.9%	137	1.1%	30	9.0%	-501	-1.0%		
2012	-4,709	8	-1,551	-4.0%	0	0.0%	878	6.9%	137	0.9%	31	9.2%	-499	-1.0%		
2013	-4,744	8	-1,537	-4.5%	0	0.0%	883	6.8%	135	-1.4%	31	9.5%	-497	-1.1%		
2014	-4,778	8	-1,521	-5.0%	0	0.0%	887	6.8%	135	-1.5%	31	9.7%	-495	-1.1%		
2015	-4,952	8	-1,503	-5.6%	0	0.0%	891	6.8%	136	-1.6%	31	9.8%	-492	-1.2%		
2016	-4,986	8	-1,484	-6.1%	0	0.0%	896	6.7%	137	-1.8%	31	10.0%	-489	-1.3%		
2017	-5,021	8	-1,464	-6.6%	0	0.0%	900	6.7%	136	-2.8%	31	10.1%	-486	-1.4%		
2018	-5,055	8	-1,442	-7.2%	0	0.0%	904	6.7%	135	-3.9%	31	10.3%	-483	-1.5%		
2019	-5,089	8	-1,418	-7.7%	0	0.0%	909	6.7%	134	-4.9%	31	10.4%	-480	-1.6%		
2020	-5,123	8	-1,394	-8.4%	0	0.0%	913	6.7%	135	-5.0%	31	10.6%	-477	-1.8%		
2021	-5,157	8	-1,371	-8.9%	0	0.0%	917	6.7%	135	-5.5%	31	10.7%	-475	-1.9%		
2022	-5,192	8	-1,346	-9.4%	0	0.0%	921	6.7%	135	-5.0%	31	10.9%	-472	-2.0%		
2023	-5,226	8	-1,320	-10.0%	0	0.0%	925	6.7%	135	-4.7%	31	11.0%	-469	-2.1%		
2024	-5,260	8	-1,295	-10.5%	0	0.0%	929	6.7%	134	-5.8%	31	11.1%	-466	-2.2%		
2025	-5,294	8	-1,269	-11.2%	0	0.0%	933	6.7%	135	-5.8%	31	11.3%	-463	-2.3%		
2026	-5,329	8	-1,245	-11.7%	0	0.0%	937	6.8%	132	-8.0%	31	11.4%	-461	-2.4%		
2027	-5,363	8	-1,220	-12.2%	0	0.0%	941	6.8%	126	-12.5%	31	11.5%	-458	-2.5%		
2028	-5,397	8	-1,195	-12.8%	0	0.0%	945	6.8%	125	-13.3%	31	11.6%	-455	-2.6%		
2029	-5,431	8	-1,169	-13.5%	0	0.0%	949	6.9%	124	-14.0%	30	11.8%	-452	-2.8%		
2030	-5,465	8	-1,143	-14.1%	0	0.0%	953	6.9%	123	-15.3%	30	11.9%	-450	-2.9%		
2031	-5,500	8	-1,118	-14.7%	0	0.0%	957	7.0%	120	-17.3%	30	12.0%	-447	-3.0%		
2032	-5,534	8	-1,092	-15.4%	0	0.0%	961	7.0%	118	-19.2%	30	12.2%	-444	-3.1%		
2033	-5,568	8	-1,068	-16.0%	0	0.0%	966	7.1%	118	-19.2%	30	12.3%	-442	-3.2%		
Average	-5,114	8	-1,355	-8.7%	0	0.0%	917	6.8%	132	-6.5%	31	10.6%	-475	-1.9%		

Table I-2b: Annual (calendar year) boundary fluxes (Q, in acre-feet) from the model domain for Model Scenario 8B, along with percent differences from Scenario 6 results. Note that the annual fluxes are rounded to the nearest acre-foot, but the averages are based on unrounded amounts. Negative numbers indicate fluxes out of the model domain. 2008 fluxes are the results of the calibrated transient model, and are not included in the averages at the bottom of this table.

			Evapotranspiration				General Head Boundary Flux							
			Mesquite Dry Lake		Oasis of Mara		Across Transverse Arch		From Copper Mountain Subbasin		From Joshua Tree Subbasin		To Dale Basin	
Year	Well Discharge	Recharge	Q	+/-	Q	+/-	Q	+/-	Q	+/-	Q	+/-	Q	+/-
2008	-4,246	8	-1,658	--	0	--	806	--	136	--	20	--	-512	--
2009	-4,467	8	-1,665	2.0%	0	0.0%	771	-5.2%	127	-4.0%	25	-5.8%	-513	0.6%
2010	-4,543	8	-1,659	2.1%	0	0.0%	773	-5.1%	128	-4.1%	26	-5.9%	-511	0.6%
2011	-4,675	8	-1,657	2.2%	0	0.0%	777	-5.1%	129	-4.2%	26	-6.0%	-509	0.6%
2012	-4,709	8	-1,654	2.4%	0	0.0%	781	-5.0%	130	-4.3%	26	-6.1%	-508	0.7%
2013	-4,744	8	-1,651	2.6%	0	0.0%	785	-5.0%	131	-4.1%	26	-6.2%	-506	0.7%
2014	-4,778	8	-1,646	2.8%	0	0.0%	789	-5.0%	132	-4.1%	26	-6.4%	-505	0.7%
2015	-4,952	8	-1,640	3.0%	0	0.0%	793	-4.9%	133	-4.0%	26	-6.5%	-502	0.8%
2016	-4,986	8	-1,632	3.3%	0	0.0%	798	-4.9%	133	-4.1%	26	-6.6%	-500	0.9%
2017	-5,021	8	-1,624	3.6%	0	0.0%	802	-4.9%	134	-4.2%	26	-6.8%	-498	0.9%
2018	-5,055	8	-1,614	3.9%	0	0.0%	806	-4.9%	135	-4.2%	26	-6.8%	-496	1.0%
2019	-5,089	8	-1,603	4.3%	0	0.0%	810	-4.8%	135	-4.2%	26	-6.9%	-493	1.0%
2020	-5,123	8	-1,592	4.6%	0	0.0%	814	-4.8%	136	-4.2%	26	-7.0%	-491	1.1%
2021	-5,157	8	-1,579	5.0%	0	0.0%	818	-4.8%	137	-4.1%	26	-7.2%	-489	1.2%
2022	-5,192	8	-1,566	5.4%	0	0.0%	822	-4.8%	137	-3.5%	26	-7.3%	-487	1.2%
2023	-5,226	8	-1,552	5.8%	0	0.0%	826	-4.8%	138	-2.9%	26	-7.4%	-485	1.3%
2024	-5,260	8	-1,538	6.3%	0	0.0%	830	-4.7%	139	-2.8%	26	-7.5%	-483	1.4%
2025	-5,294	8	-1,524	6.6%	0	0.0%	833	-4.7%	139	-2.8%	26	-7.6%	-481	1.5%
2026	-5,329	8	-1,508	6.9%	0	0.0%	837	-4.7%	140	-2.7%	26	-7.7%	-479	1.5%
2027	-5,363	8	-1,493	7.4%	0	0.0%	840	-4.7%	140	-2.6%	25	-7.8%	-477	1.6%
2028	-5,397	8	-1,477	7.7%	0	0.0%	844	-4.7%	141	-2.4%	25	-7.9%	-475	1.7%
2029	-5,431	8	-1,462	8.2%	0	0.0%	847	-4.7%	141	-2.3%	25	-8.0%	-473	1.7%
2030	-5,465	8	-1,446	8.7%	0	0.0%	850	-4.7%	142	-2.2%	25	-8.1%	-471	1.8%
2031	-5,500	8	-1,431	9.2%	0	0.0%	853	-4.6%	142	-2.2%	25	-8.2%	-469	1.9%
2032	-5,534	8	-1,415	9.6%	0	0.0%	857	-4.6%	143	-2.0%	24	-8.3%	-468	2.0%
2033	-5,568	8	-1,398	10.0%	0	0.0%	860	-4.6%	143	-2.0%	24	-8.4%	-466	2.0%
Average	-5,114	8	-1,561	5.2%	0	0.0%	817	-4.8%	136	-3.3%	26	-7.1%	-489	1.2%

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureI-1.pptx



Kennedy/Jenks Consultants

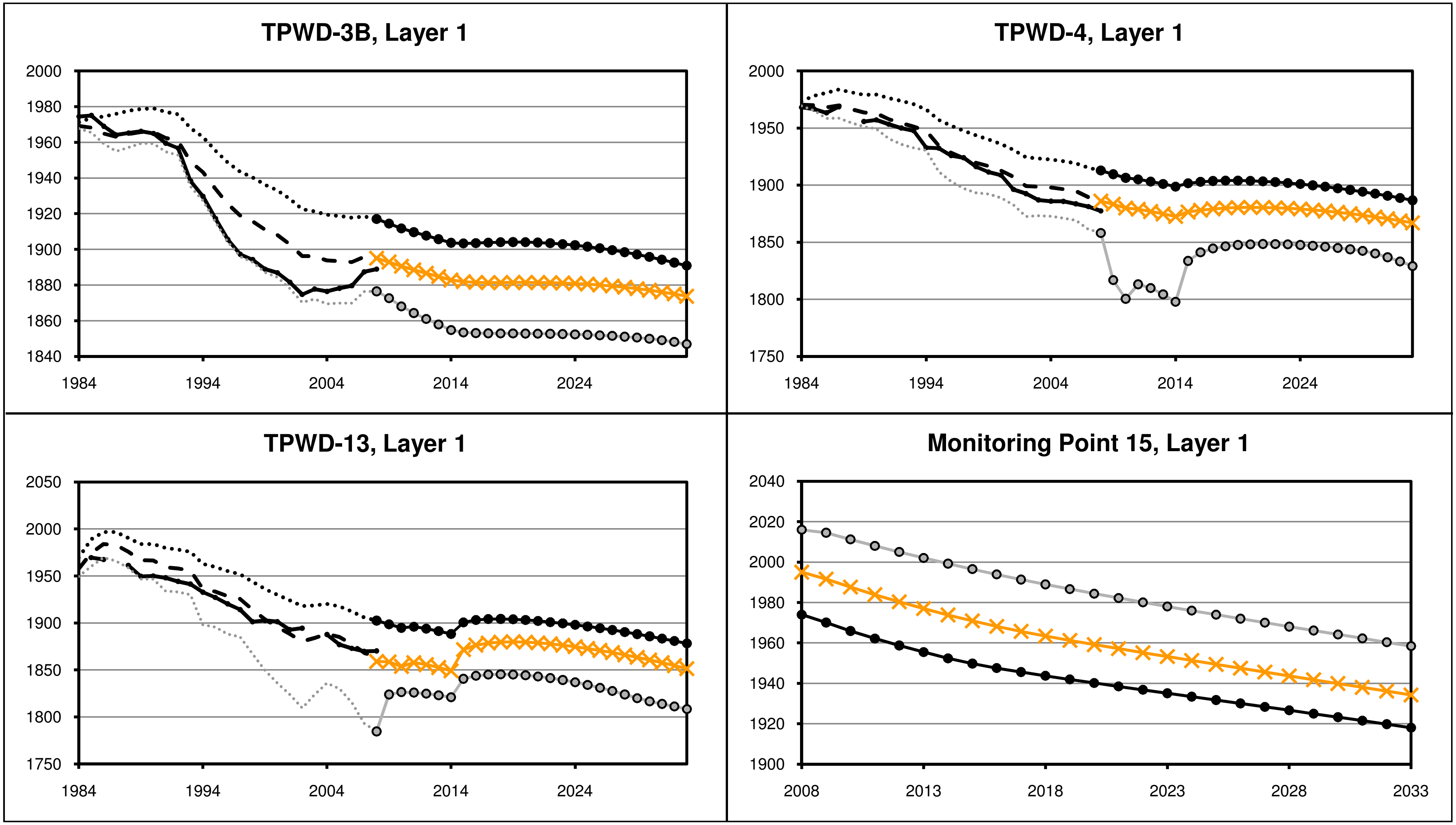
Twentynine Palms
San Bernardino County, California

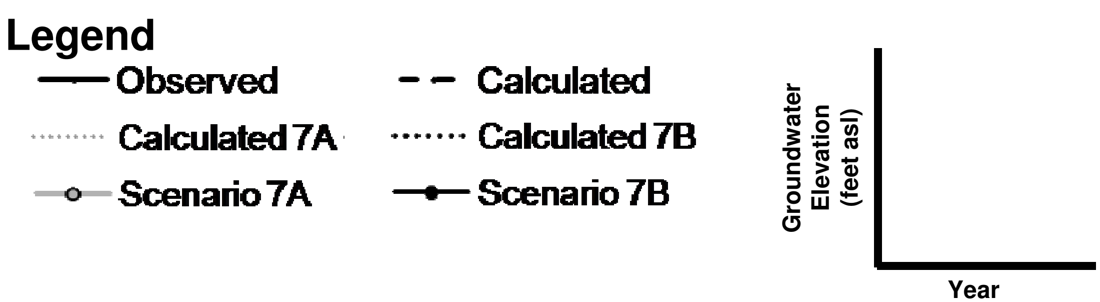
Hydraulic Conductivity Sensitivity Scenario Results for Wells in the Indian Cove Subbasin

K/J 0964003*00
March 2010

Figure I-1

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureI-2.pptx





Kennedy/Jenks Consultants

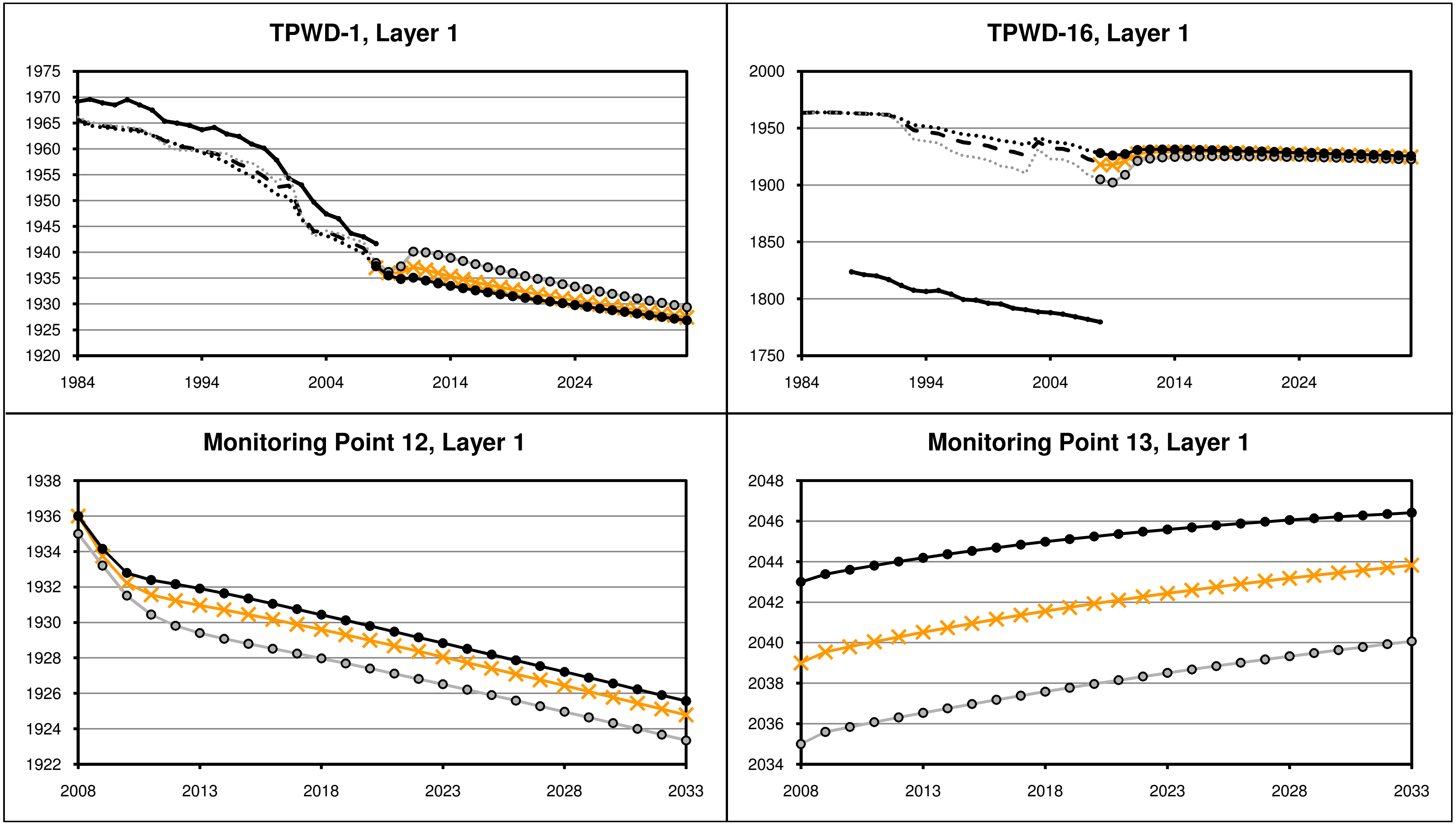
Twentynine Palms
San Bernardino County, California

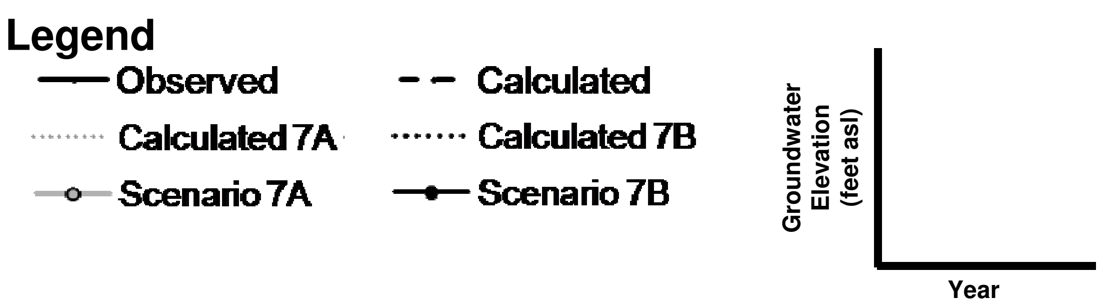
Hydraulic Conductivity Sensitivity Scenario Results for Wells in the Fortynine Palms Subbasin

K/J 0964003*00
March 2010

Figure I-2

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureI-3.pptx





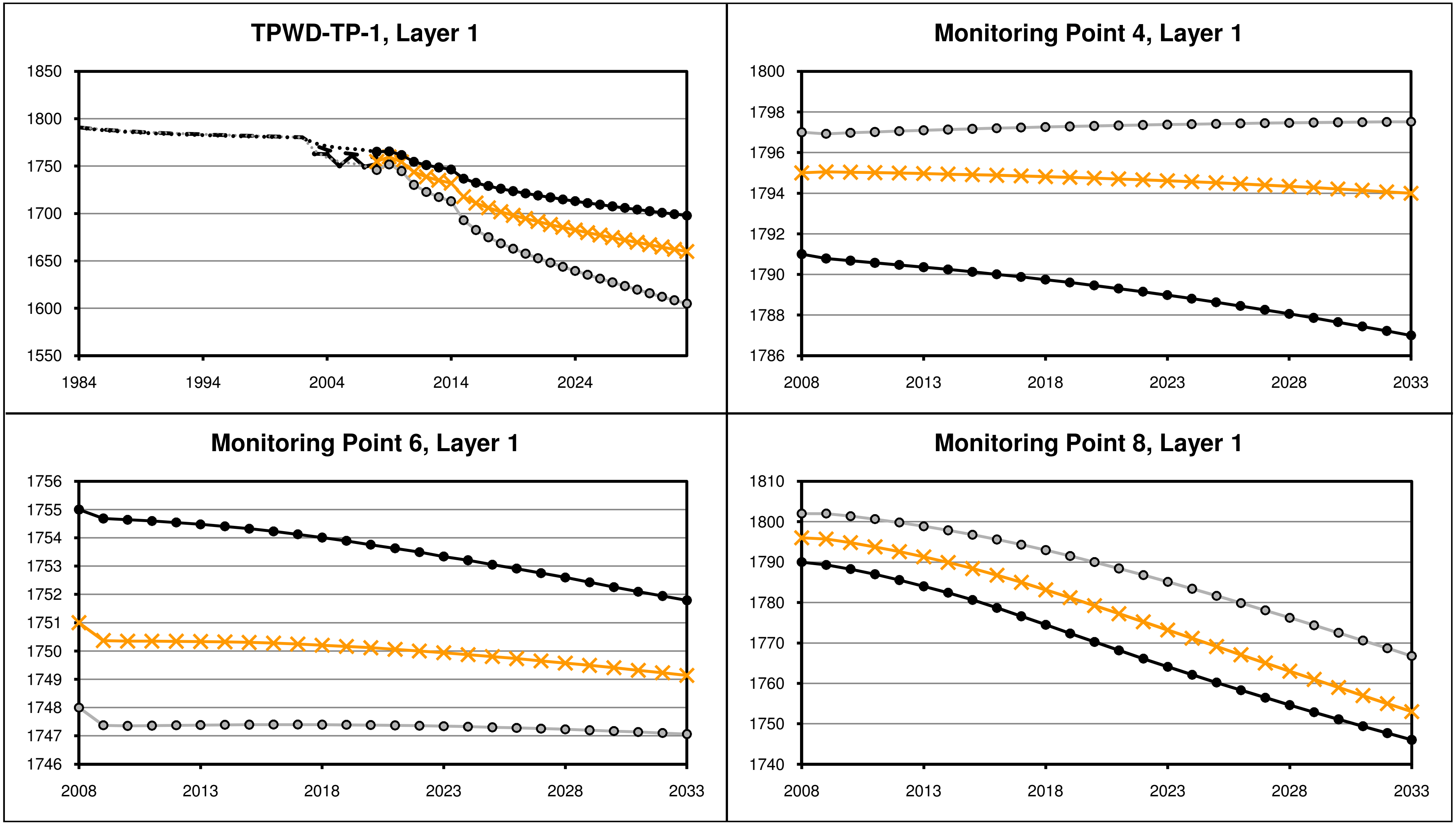
Kennedy/Jenks Consultants

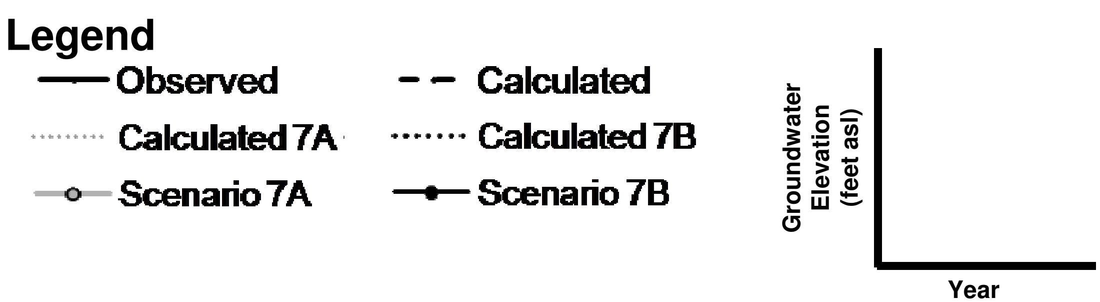
Twentynine Palms
San Bernardino County, California

Hydraulic Conductivity Sensitivity Scenario Results for Wells in the Eastern Subbasin

K/J 0964003*00
March 2010

Figure I-3





Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureI-4.pptx

Kennedy/Jenks Consultants

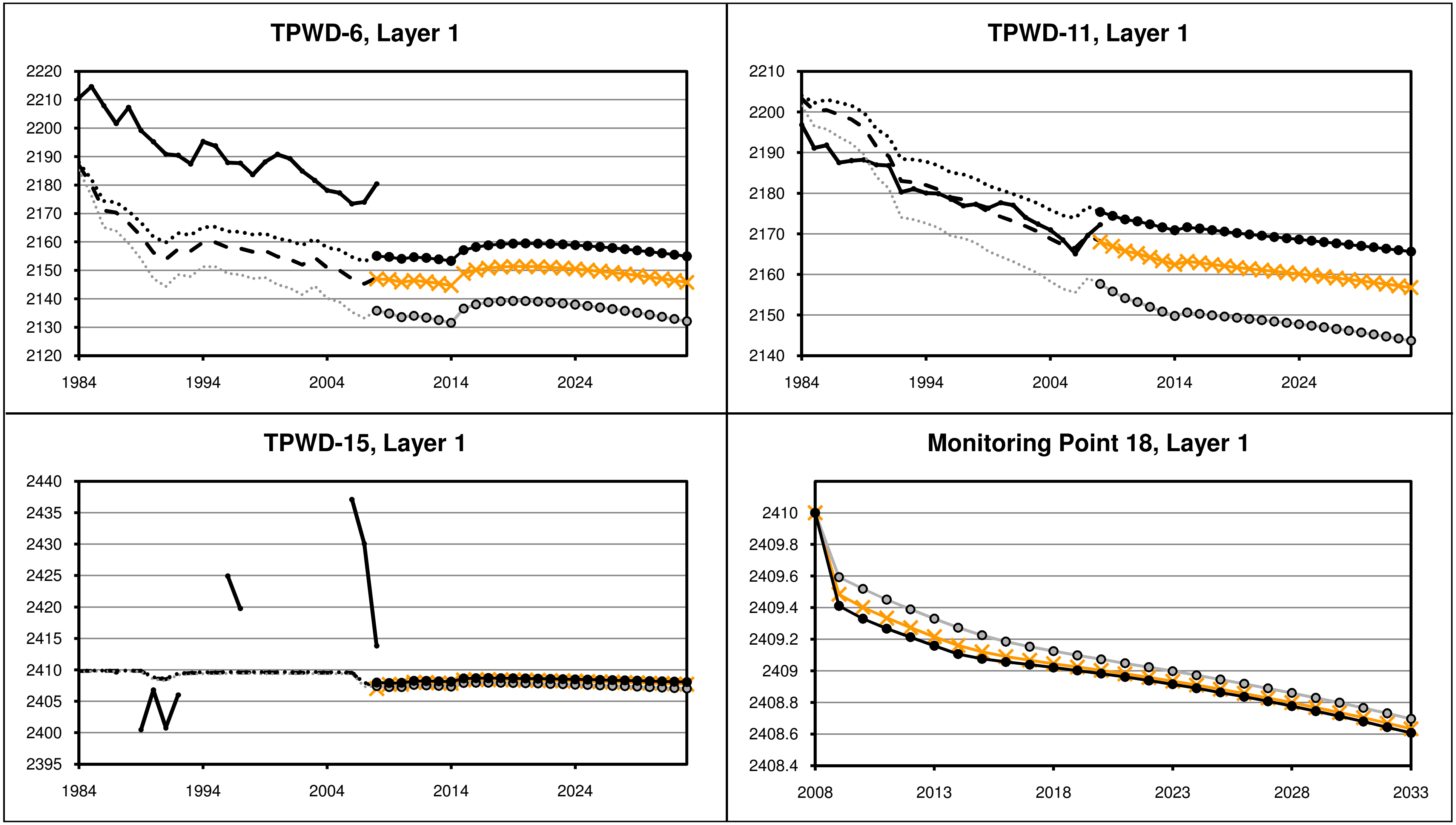
Twentynine Palms
San Bernardino County, California

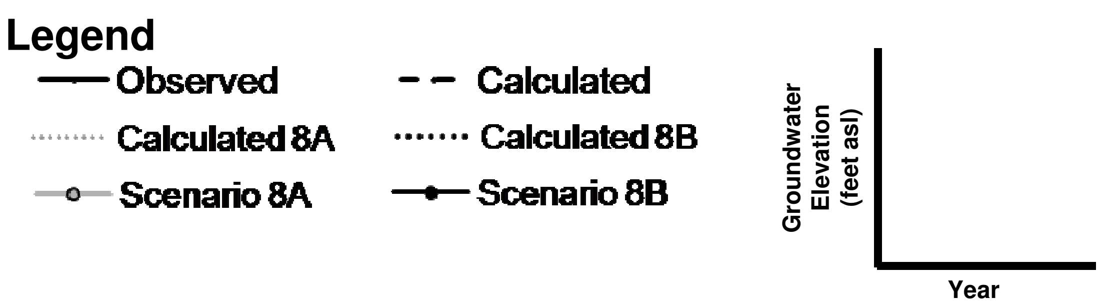
Hydraulic Conductivity Sensitivity Scenario Results for Wells in the Mesquite Subbasin

K/J 0964003*00
March 2010

Figure I-4

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureI-5.pptx





Kennedy/Jenks Consultants

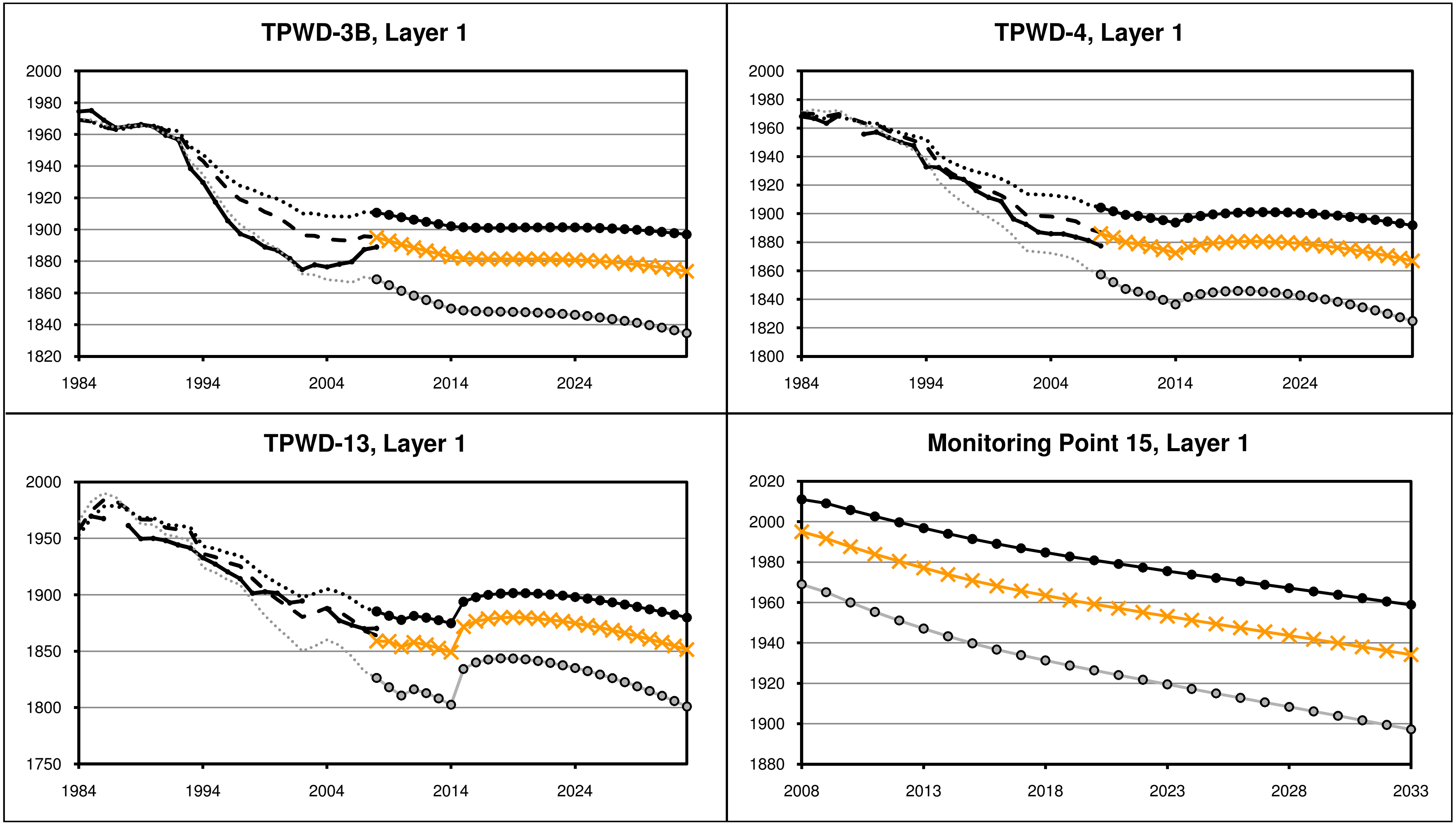
Twentynine Palms
San Bernardino County, California

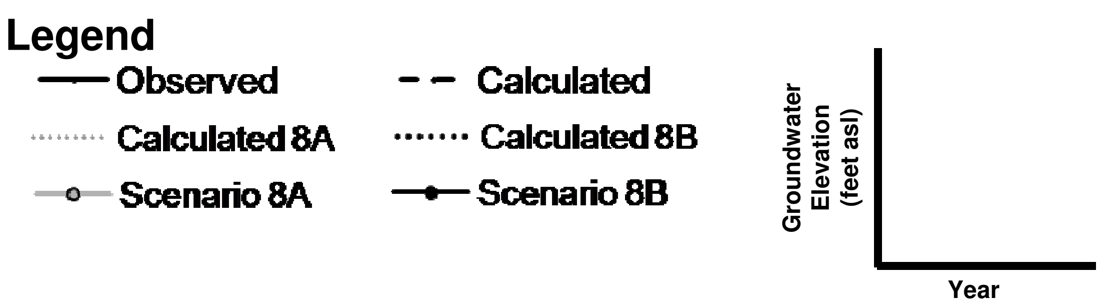
Specific Yield Sensitivity Scenario Results for Wells in the Indian Cove Subbasin

K/J 0964003*00
March 2010

Figure I-5

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureI-6.pptx





Kennedy/Jenks Consultants

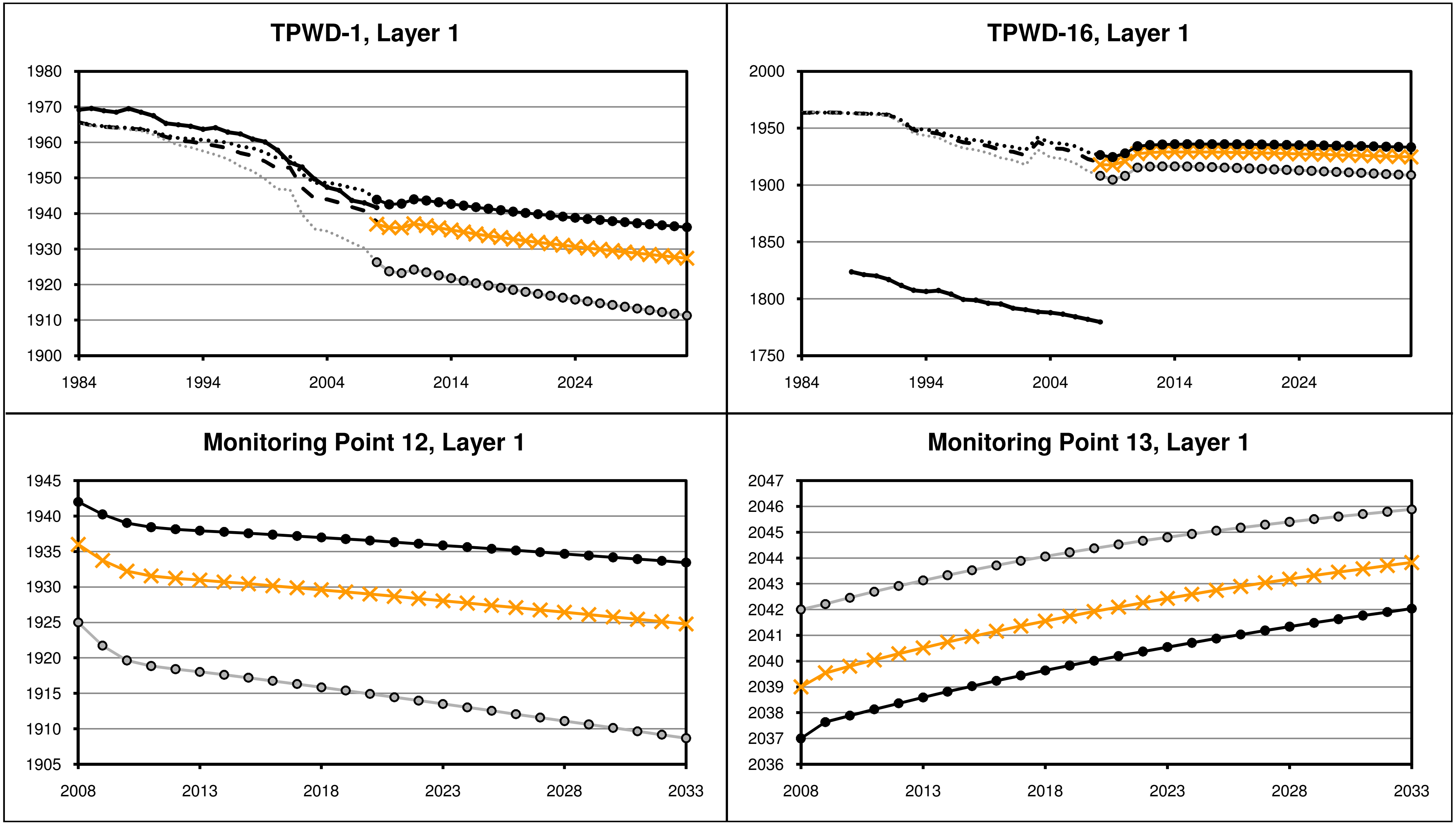
Twentynine Palms
San Bernardino County, California

Specific Yield Sensitivity Scenario Results for Wells in the Fortynine Palms Subbasin

K/J 0964003*00
March 2010

Figure I-6

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureI-7.pptx



Legend

- Observed
- Calculated
- Calculated 8A
- Calculated 8B
- Scenario 8A
- Scenario 8B

Groundwater Elevation (feet asl)

Year

Kennedy/Jenks Consultants

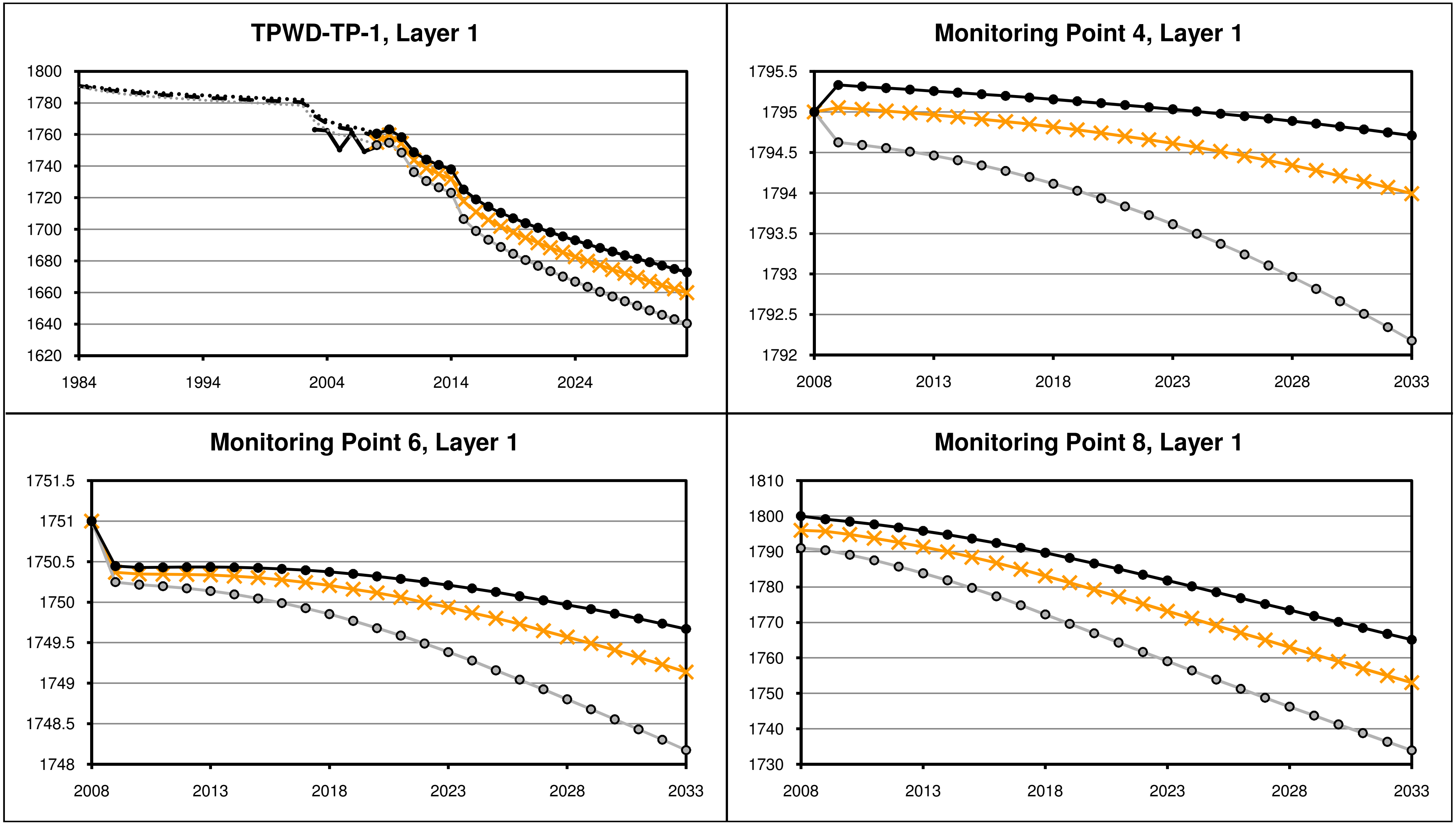
Twentynine Palms
San Bernardino County, California

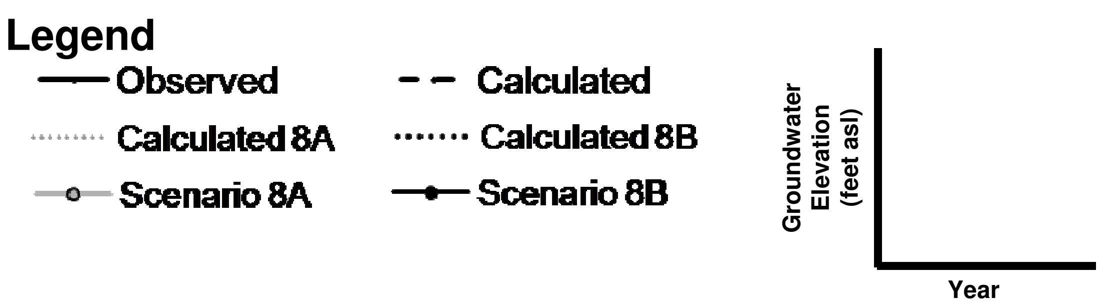
Specific Yield Sensitivity Scenario Results for Wells in the Eastern Subbasin

K/J 0964003*00
March 2010

Figure I-7

Path: Z:\Models\29 Palms\Mesquite Lake GW Study\Report\Final Draft\Figures\FigureI-8.pptx





Kennedy/Jenks Consultants

Twentynine Palms
San Bernardino County, California

Specific Yield Sensitivity Scenario Results for Wells in the Mesquite Subbasin

K/J 0964003*00
March 2010

Figure I-8