Groundwater Flow Model of the Mission Creek Subbasin Desert Hot Springs, California

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April 2007

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ACRONYMS and ABBREVIATIONS

AF	Acre-Feet
AFY	Acre-Feet per Year
CRA	Colorado River Aqueduct
CVWD	Coachella Valley Water District
DWA	Desert Water Agency
DWR	Department of Water Resources
GHB	General Head Boundary
MCGS	Mission Creek Groundwater Subbasin
MODFLOW	Modular three-dimensional finite-difference ground-water model
MSL	Mean Sea Level
MSWD	Mission Springs Water District
MWD	Metropolitan Water District of Southern California
RWQCB	Regional Water Quality Control Board
PEST	Parameter Estimation Software
SWP	State Water Project
TDS	Total Dissolved Solids
UWMP	Urban Water Management Plan
WMP	Water Master Plan

1.0 Introduction

Mission Springs Water District (MSWD) was established in 1953 and was formerly called the Desert Hot Springs County Water District. The MSWD's service area covers 135 square miles and serves over 25,000 people in the City of Desert Hot Springs and ten (10) smaller communities in Riverside County, California.

The MSWD is located in the Coachella Valley, northwest of the Salton Sea, within the Colorado Desert region. The Coachella Valley can be characterized as desert; as it experiences low precipitation on the valley floor (averaging between five and six inches per year) and high precipitation in the local mountains (averaging between 30 and 40 inches per year). Seasonal temperature extremes can range from over 115° F in the summer to below 32° F in the winter. Major surface water features in the area are the Whitewater River, Mission Creek, San Gorgonio River, Little and Big Morongo Washes, Dry Morongo, and Long Canyon.

MSWD's water source is 100 percent groundwater drawn from multiple active production wells. Psomas was contracted by MSWD to develop a regional numerical groundwater flow model of the Mission Creek Groundwater Subbasin (MCGS or Subbasin) and compile a report that documents model development and results of requested simulations.

1.1 Purpose

Psomas understands that MSWD anticipates a need to increase groundwater pumping in order to meet projected water needs within its service area over the next 25 years. In order to offset drawdown of groundwater levels brought about by increased groundwater pumping, MSWD proposes to recharge groundwater through select placement of spreading water in percolation ponds within the Subbasin. This model was developed for the purpose of estimating what changes to groundwater elevations, if any, can be expected to occur within the Subbasin from increased groundwater pumping coupled with the proposed groundwater recharge efforts. Model-estimated groundwater elevations were developed for six separate simulations in five year increments beginning with 2006.

2.0 Conceptual Model Development

Three-dimensional views of the MCGS and approximate location of the crystalline bedrock are presented below in Figure 2-1, *Three Dimensional - Mission Creek Groundwater Subbasin*. The MSWD service area is shown overlain on the aerial image in yellow while Mission Creek and Banning Faults are shown at the surface as light-brown lineaments. Approximate location of crystalline bedrock is depicted by the blue/beige plane below and parallel to the surface map.

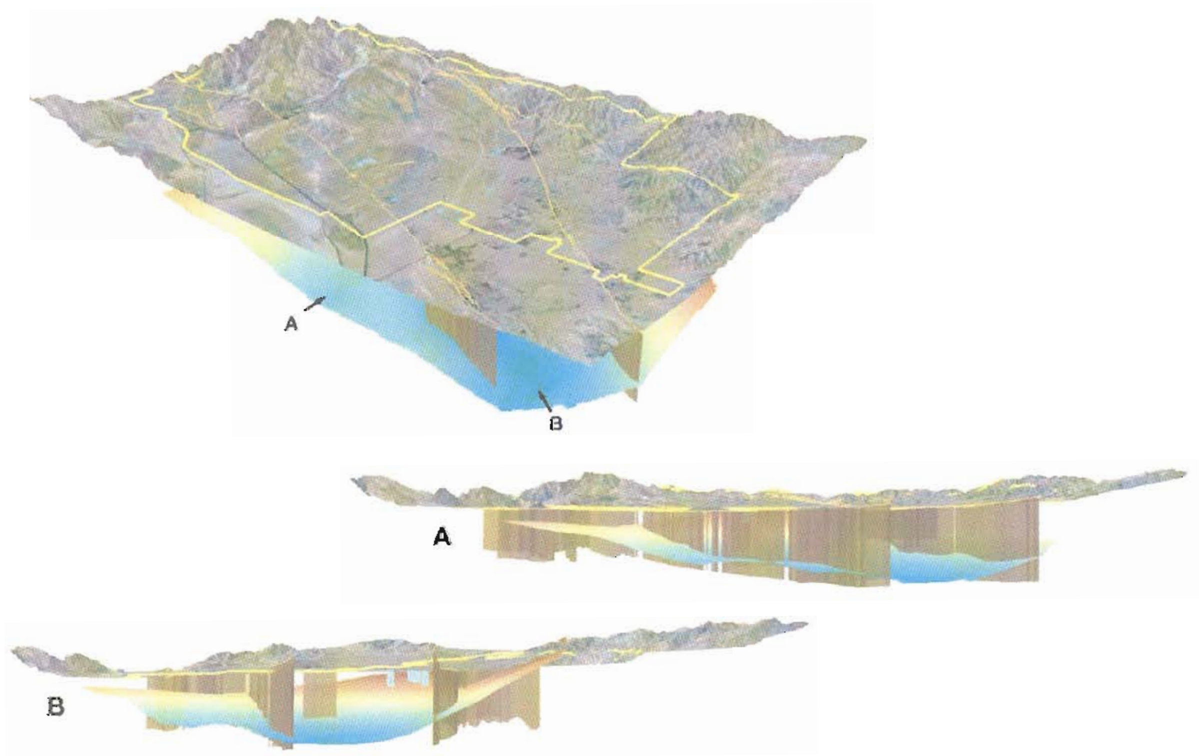


Figure 2-1
Three Dimensional - Mission Creek Groundwater Subbasin

These faults are also seen extending below the ground surface to the Subbasin crystalline bedrock in gravity survey data collected and interpreted by GSi/water. Crystalline bedrock elevations were also estimated by GSi/water personnel from the same gravity survey data. The middle and lower images in Figure 2-1 show three-dimensional profile (or sectional) views of the Subbasin as seen looking along directions of the arrows positioned at locations A and B, respectively. These views provide a visual description of the fault lines and the elevation of the bedrock within the Subbasin. View "A" looks north toward the Banning Fault, which serves as the Subbasin's southern boundary. View "B" looks northwest between the Banning and Mission Creek Faults into what comprises the Mission Creek aquifer.

2.1 Data and Interpretations from Previous Investigations

Psomas reviewed previously published literature and developed a three-dimensional conceptual understanding of the Subbasin prior to developing the numerical model.

Regional groundwater models have been developed for the Coachella Valley since the late 1970's. However, it was not until 1998 that Mayer and May (Michigan Technological University) developed a numerical flow model to evaluate alternative groundwater recharge strategies and approximate the area that would be influenced by proposed groundwater recharge efforts.

In 2004, Psomas (Psomas, 2004a) prepared a local groundwater model that covered a small portion of the Mission Creek Subbasin to estimate the potential groundwater changes from a proposed new municipal well.

In a separate study, Psomas also prepared a groundwater budget for the Mission Creek Subbasin as a management tool that included estimates of basin inflow, outflow, and storage change (Psomas, 2004b). Reports and field efforts for gravity survey, thermal, and estimates of groundwater input by GSi/water were essential in Psomas' development of the water budget.

The results of these previous analyses were useful in developing the conceptual model of groundwater flow in the Subbasin, providing various estimates of inflow and outflow components, and the completion of this study.

2.1.1 Summary of Subbasin Hydrogeology

The MCGS underlies the northwest portion of the Coachella Valley and is bounded by the crystalline rocks of the San Bernardino Mountains on the west and the Banning fault on the south. The Mission Creek fault bounds the northern, northeastern, and eastern edges and the Indio Hills bound the Subbasin on the southeast. Both the Mission Creek and Banning faults are right-lateral strike-slip faults of the San Andreas system and are considered subsurface barriers that limit groundwater flow in and out of the MCGS.

The primary water-bearing deposits in the Subbasin are relatively unconsolidated late Pleistocene, Holocene alluvial fan, and terrace deposits. Pleistocene deposits consist of formations such as: 1) the Ocotillo Conglomerate, which is a thick sequence of poorly bedded coarse sand and gravel; and 2) the Cabezon Fanglomerate, which is a boulder conglomerate with abundant sand, silt, along with some clay as described by Proctor (1968). More recent geophysical surveys have suggested that water bearing formations may extend a few thousand feet to crystalline in some parts of the basin. The volume of available water from such depths is still largely unknown.

2.1.2 Understanding Aquifer Parameters

A brief summary of primary aquifer parameters is presented below and is intended to provide the reader a brief summary of the variables affecting groundwater flow and the data used in this analysis.

Groundwater exists in the small openings between the particles of clay, silt, sand, and gravel that make up the alluvial deposits of the aquifer. The percent of total volume of the aquifer occupied by these openings, or pores, is called porosity.

The parameter relating movement of groundwater through the aquifer is known as hydraulic conductivity (K) and depends on the size and arrangement of the water transmitting pores (or rock fractures) within a geologic formation, and on dynamic characteristics of the fluid such as kinematic viscosity and specific weight. The hydraulic conductivity of different geologic materials varies and is greatest with materials with high effective porosity (e.g., sand and gravels) and lowest for materials with low porosity such as silts and clays.

Hydraulic conductivity can be expressed as:

$$K = \frac{k\gamma}{\upsilon}$$

where

K	= hydraulic conductivity
k	= intrinsic permeability
γ	= specific weight
ν	= kinematic viscosity

The ability of an aquifer to transmit water through pore spaces is referred to as transmissivity (T) and is defined as the rate of flow (e.g., gallons per day) moving through the entire saturated thickness of an aquifer and is equal to the hydraulic conductivity multiplied by the saturated thickness (b), or

$$T = Kb$$

Transmissivity of the Subbasin has been previously estimated by others (Tyley 1971, GTC 1979, Mayer & May 1996, Slade 2000). However, Slade (2000) developed a comprehensive regional evaluation of the special distribution of transmissivity within the Subbasin from specific capacity data of MSWD wells.

2.1.3 Mission Creek Groundwater Subbasin Contours

Contours of estimated groundwater elevations for 1991 are based on data published by Robert Fox (1992). These 1991 contours are shown below in Figure 2-2, *1991 Groundwater Elevation Contours - ft MSL,* and appear to indicate that groundwater flow is northeast toward the Mission Creek fault in the northwest portion of the Subbasin. However, due to gouge created by the strike slip nature of the Mission Creek fault, it is not believed that water flows north through the fault into the Desert Hot Springs Subbasin. The apparent flow direction may be a function of localized pumping cone depressions.

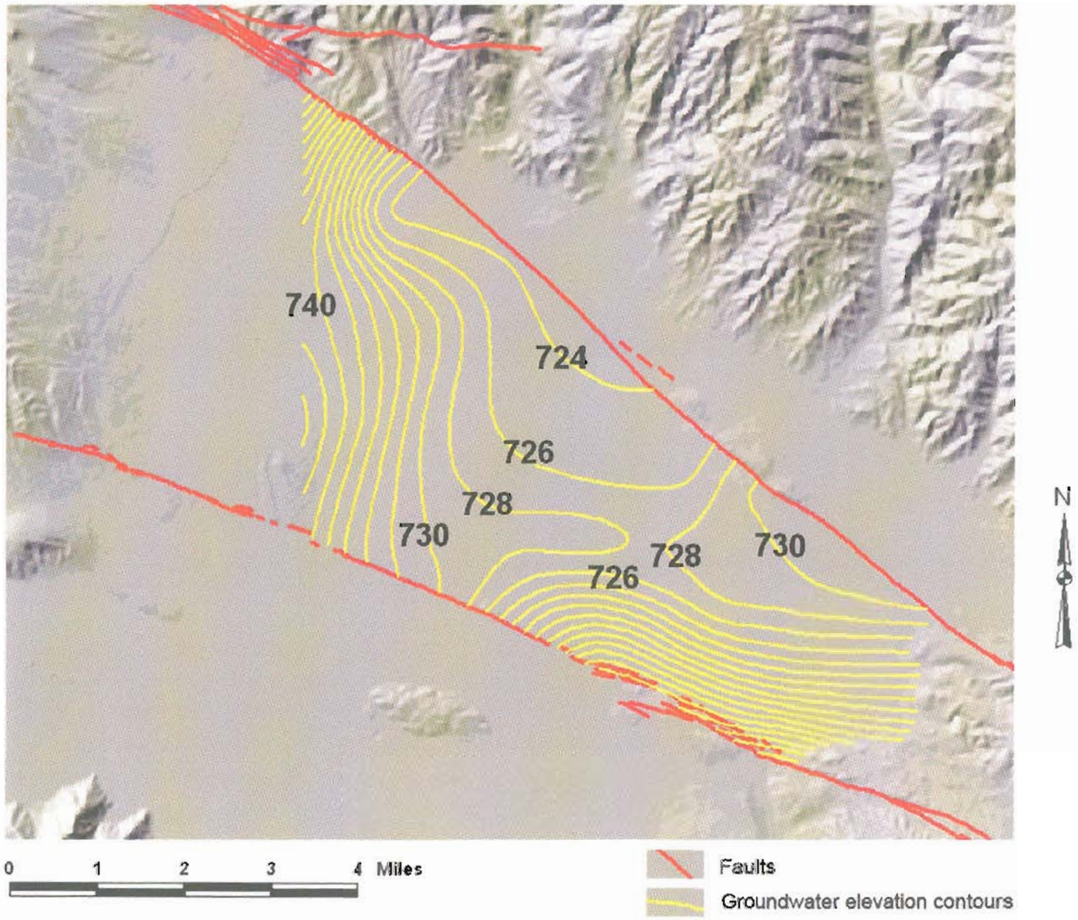


Figure 2-2
1991 Groundwater Elevation Contours - ft MSL (Fox 1992)

In the eastern portion of the Subbasin, groundwater flow generally trends toward the southwest. The perpendicular contours along the fault in multiple locations suggest the primary groundwater flow is parallel to the fault in these areas and the faults are acting as effective groundwater barriers. In addition, the contouring depicted in Figure 2-2 suggests that flux across the Banning fault is more pronounced in the area adjacent to the Indio Hills.

The 2004 approximated groundwater contours developed by Psomas are presented below in Figure 2-3, *2004 Groundwater Elevation Contours - ft MSL.* Although the groundwater levels are lower than those observed in 1991 the general areas of groundwater flow across the Mission Creek fault are similar to those observed in 1991. In addition, groundwater outflow across the Banning fault appears to occur over a wider area in 2004 than in 1991 based on the construction of the contours.

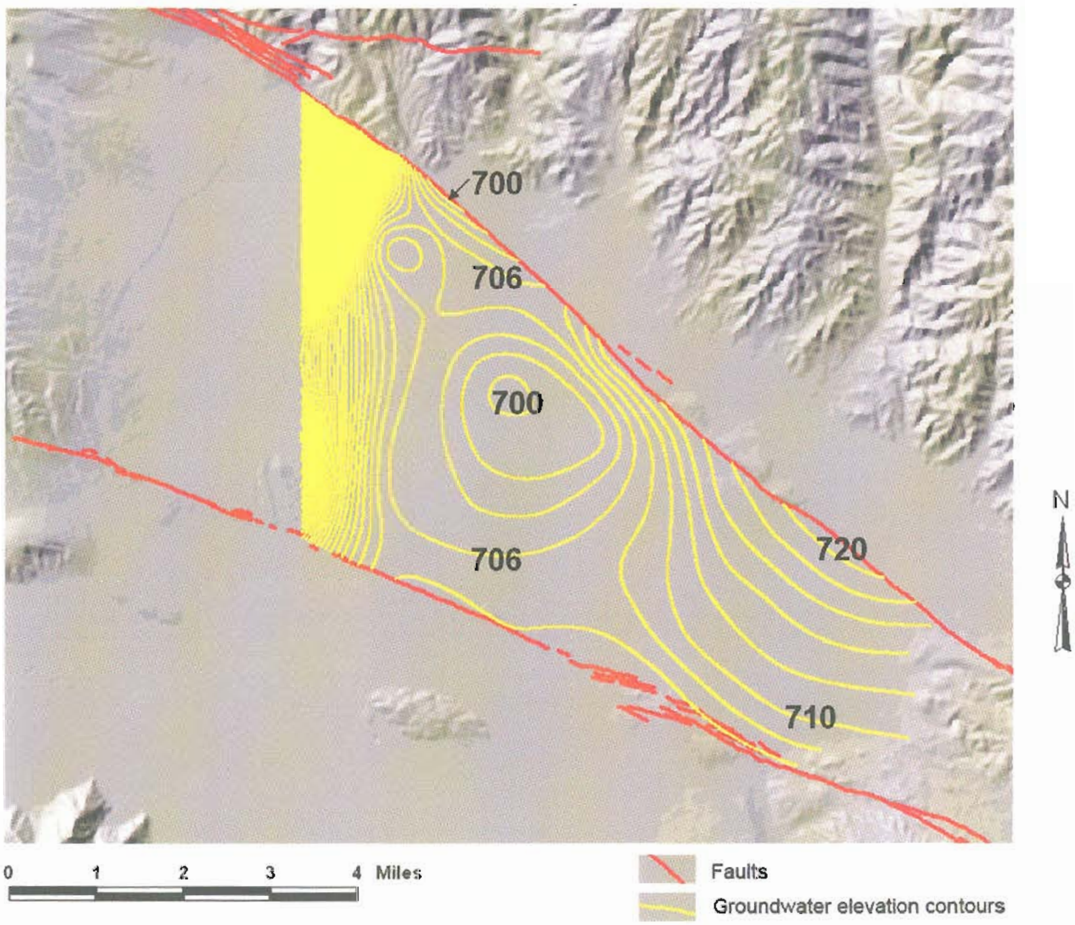


Figure 2-3
2004 Groundwater Elevation Contours - ft MSL (Psomas 2004b)

2.2 Model Domain and Boundary Conditions

The current model domain is bounded by the Mission Creek and Banning faults, the Indio Hills, and generally follows the Colorado River Aqueduct on the western boundary. The 500 ft by 500 ft model cells and locations of boundary flow are depicted in Figure 2-4, *Location of General Head Boundaries and Drain Boundaries*. The blue-colored cells represent General Head Boundaries and the yellow-colored cells represent Drain Boundaries. General Head Boundaries can be used to simulate flow into or out of the model domain but drain boundaries are used only to simulate outflow from the system.

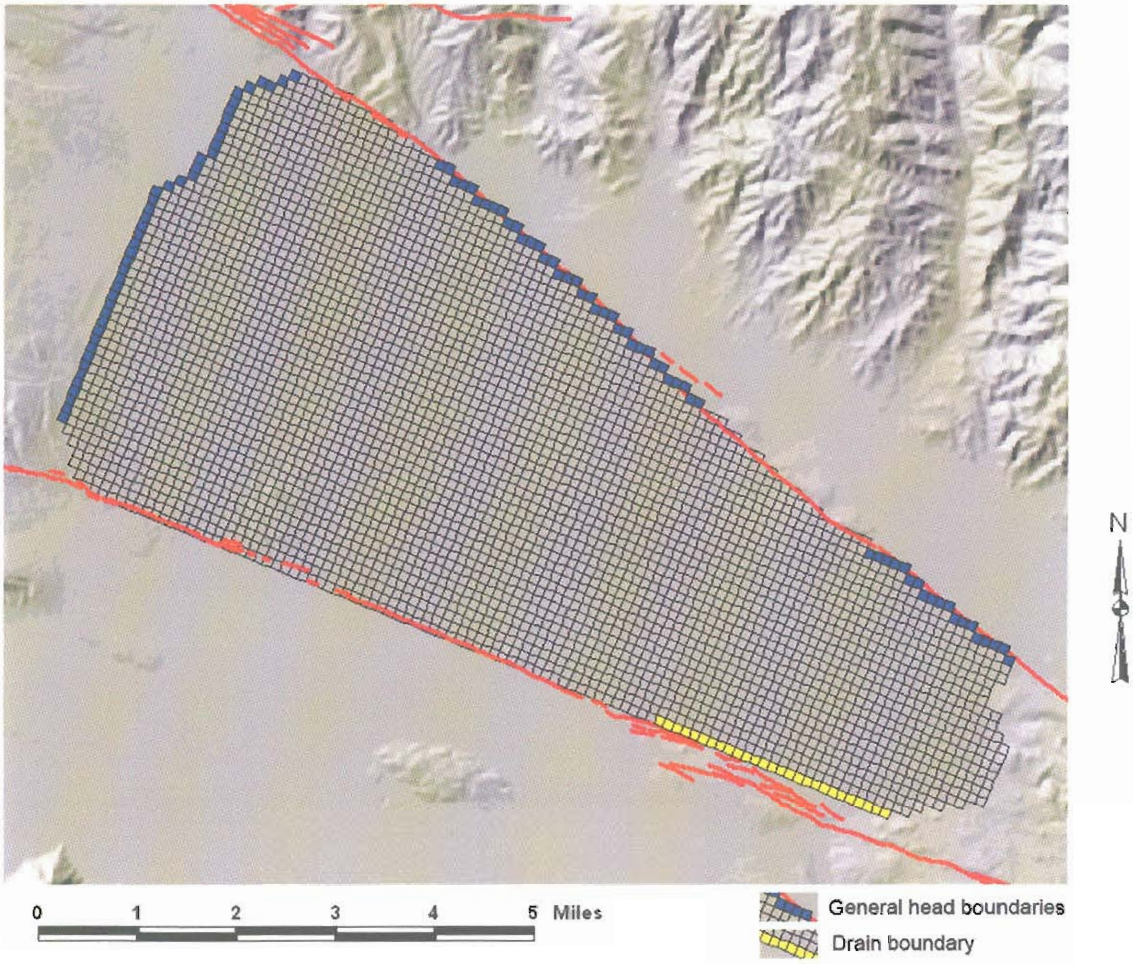


Figure 2-4
Location of General Head Boundaries and Drain Boundaries

The direction of conceptual flow across each of the boundaries is shown in Figure 2-5, *Inflow and Outflow Conceptualization Across Model Boundaries*.

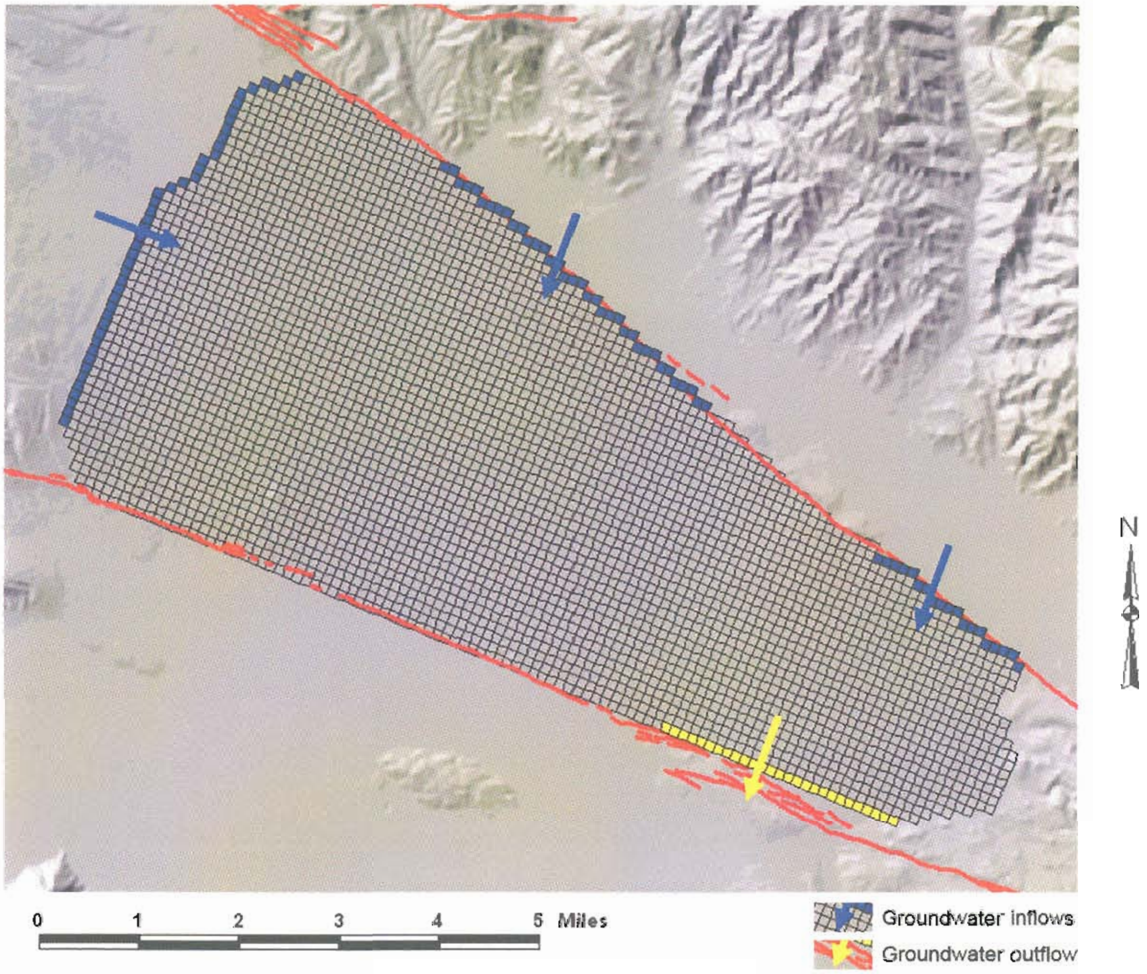


Figure 2-5
Inflow and Outflow Conceptualization Across Model Boundaries

Groundwater pumping from 16 municipal wells was incorporated in the model during development. The locations of the wells are presented in Figure 2-6, *Groundwater Pumping Wells*. Because of their proximity to one another, Mission Springs Water District wells 23 and 30 were placed within the same model cell during model development. Similarly, wells 22 and 24 were also placed in a single model cell.

The pumping history of the wells is presented in Table 2-1, *Approximate Groundwater Pumping Volume per Year / Well*.

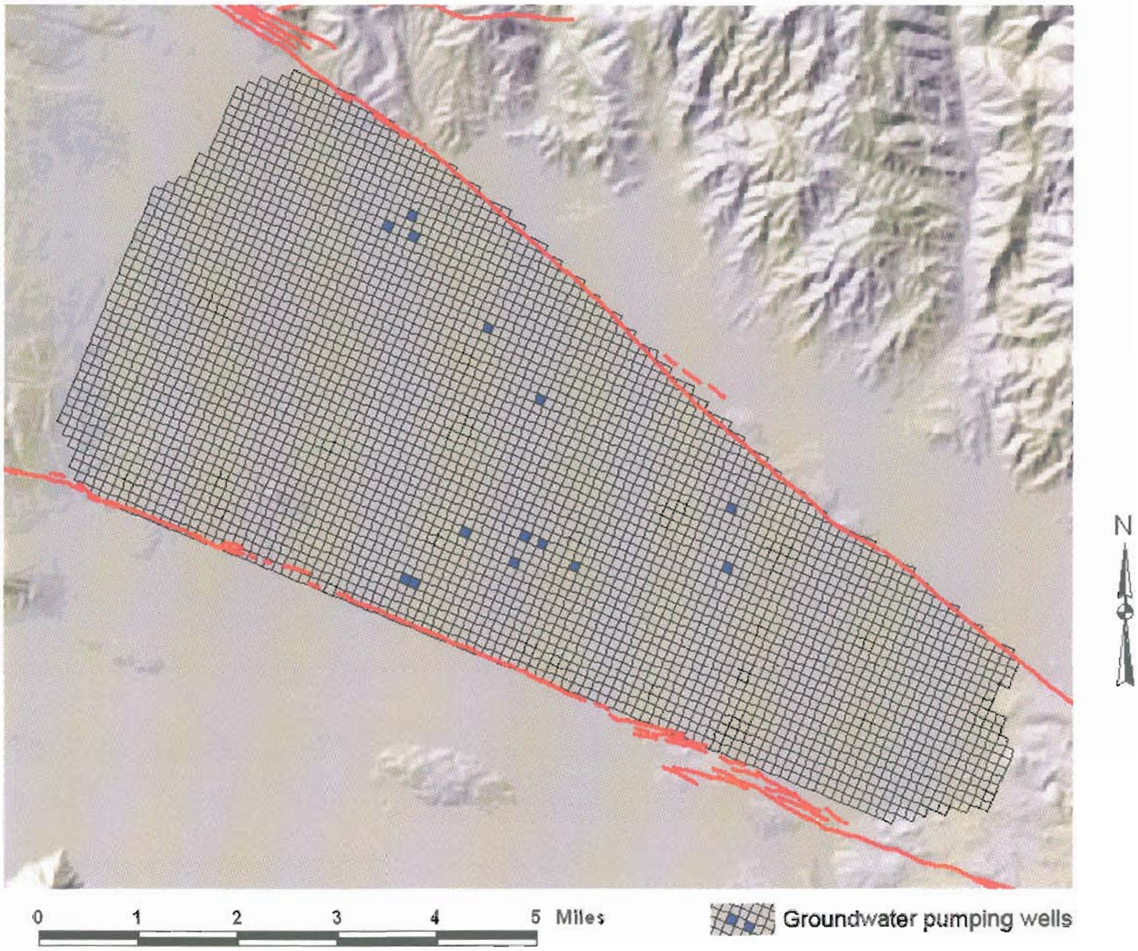


Figure 2-6
Groundwater Pumping Wells

Table 2-1
Approximate Groundwater Pumping Volume per Year / Well
(all values in AF/yr)

Year	MSWD Wells											
	22	23	24	27	28	29	30	31	32	New Well (Sec1)	New Well (Sec 1)	New Well (Sec 2)
2007	2,477	0	1,097	443	1,923	2,301	901	1,102	1,773	0	0	0
2008	2,400	0	1,100	419	1,800	2,000	800	1,000	1,600	0	0	0
2009	2,100	0	1,000	421	1,800	1,900	800	900	1,300	0	0	0
2010	2,200	0	1,150	453	1,850	2,100	850	1,000	1,300	0	0	0
2011	2,000	0	1,150	437	1,750	2,100	850	900	1,200	800	0	800
2012	2,000	0	1,250	431	1,850	2,100	900	1,000	1,200	950	0	950
2013	2,000	0	1,150	435	1,750	2,000	900	1,000	1,140	950	800	950
2014	2,050	0	1,200	429	1,800	2,100	900	1,100	1,140	1,000	1,000	1,000
2015	2,100	0	1,200	423	1,800	2,100	900	1,100	1,340	1,100	1,100	1,100
2016	2,200	0	1,200	457	1,800	2,100	900	1,100	1,450	1,200	1,200	1,200
2017	2,250	0	1,200	451	1,800	2,100	900	1,100	1,650	1,300	1,300	1,300
2018	2,250	0	1,200	450	1,800	2,150	900	1,295	1,650	1,400	1,400	1,400
2019	2,250	0	1,200	450	1,800	2,150	900	1,500	1,689	1,500	1,500	1,500
2020	1,300	0	1,200	400	1,300	1,300	900	1,100	1,200	1,080	1,000	1,000
2021	1,358	0	1,200	400	1,300	1,300	900	1,100	1,200	1,100	1,200	1,100
2022	1,356	0	1,200	400	1,300	1,300	900	1,100	1,200	1,200	1,300	1,200
2023	1,344	0	1,200	400	1,300	1,300	900	1,100	1,200	1,300	1,400	1,300
2024	1,332	0	1,200	400	1,300	1,300	900	1,100	1,200	1,400	1,450	1,400
2025	1,420	0	1,200	400	1,400	1,400	900	1,200	1,200	1,450	1,450	1,450
2026	1,420	0	1,200	400	1,400	1,400	900	1,200	1,200	1,450	1,450	1,450
2027	1,420	0	1,200	400	1,400	1,400	900	1,200	1,200	1,450	1,450	1,450
2028	1,420	0	1,200	400	1,400	1,400	900	1,200	1,200	1,450	1,450	1,450
2029	1,420	0	1,200	400	1,400	1,400	900	1,200	1,200	1,450	1,450	1,450
2030	1,420	0	1,200	400	1,400	1,400	900	1,200	1,200	1,450	1,450	1,450
Row	21	15	21	49	15	26	15	49	42	35	31	38
Column	39	25	39	42	28	47	25	41	45	54	47	44

In 1997 the Desert Water Agency (DWA) began construction on series of spreading ponds in the northwest portion of the Subbasin near the Colorado River Aqueduct. The location of the spreading area is shown in blue in Figure 2-7, *Location of Desert Water Agency Spreading Basin Facility*. Reported spreading volumes are presented in Table 2-2, *Reported Spreading Volume*.

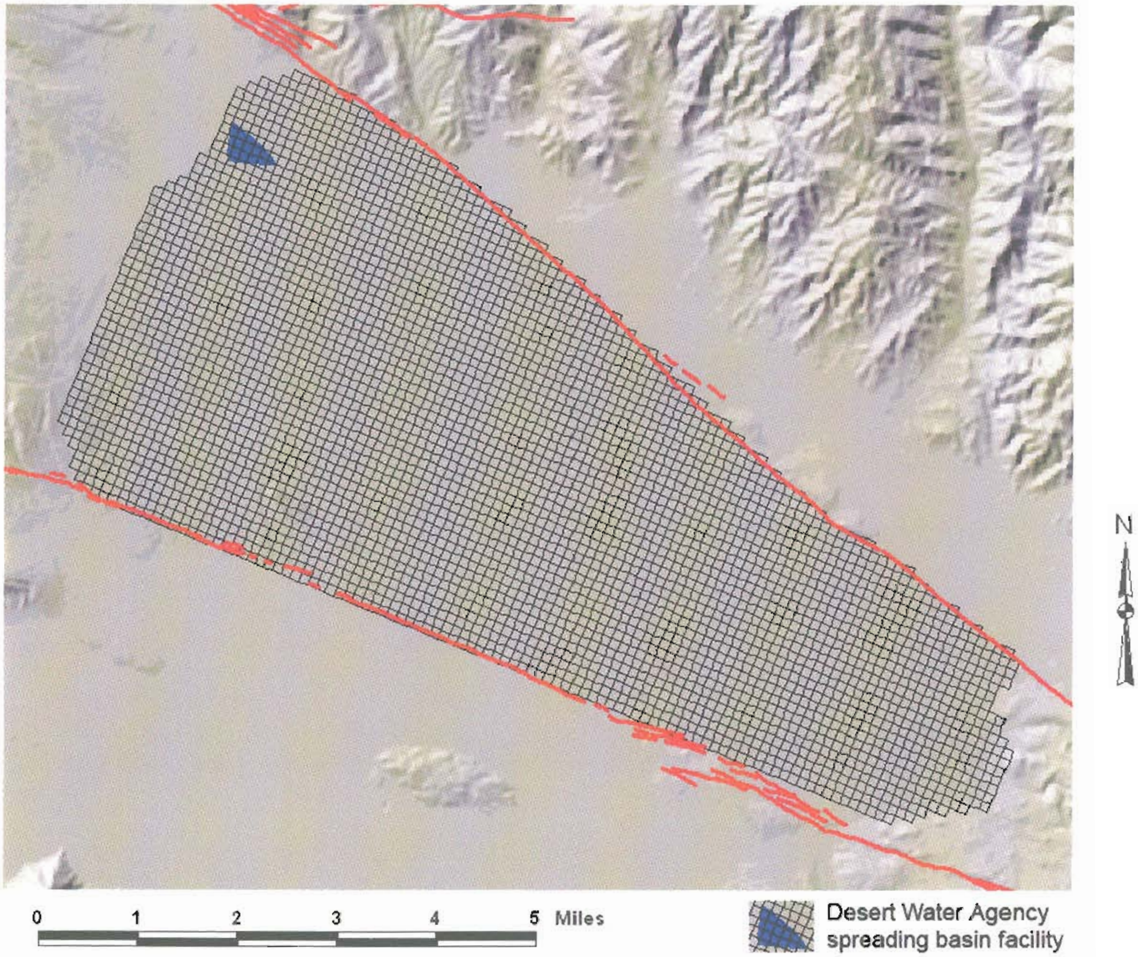


Figure 2-7
Location of Desert Water Agency Spreading Basin Facility

Table 2-2
Reported Spreading Volume

Year	Spreading Volume* (AF/yr)
2003	4,733
2004	0
2005	5.564
2006	24,700

*values do not account for evaporation or other losses.

2.3 Groundwater Elevation Data

A total of 96 groundwater elevation measurements from 27 wells were used in calibrating this model. The locations of these wells are shown in Figure 2-8, *Groundwater Elevation Data used in Model Calibration*. Groundwater elevations collected from two wells in the northwestern portion of the model domain (MSWD No. 34 and the DWA monitoring well) were approximately 300 ft above other measured water levels in the model domain. These unexpected groundwater elevations resulted in additional calibration efforts that are introduced in Section 2.4 and explained further in Section 3.0.

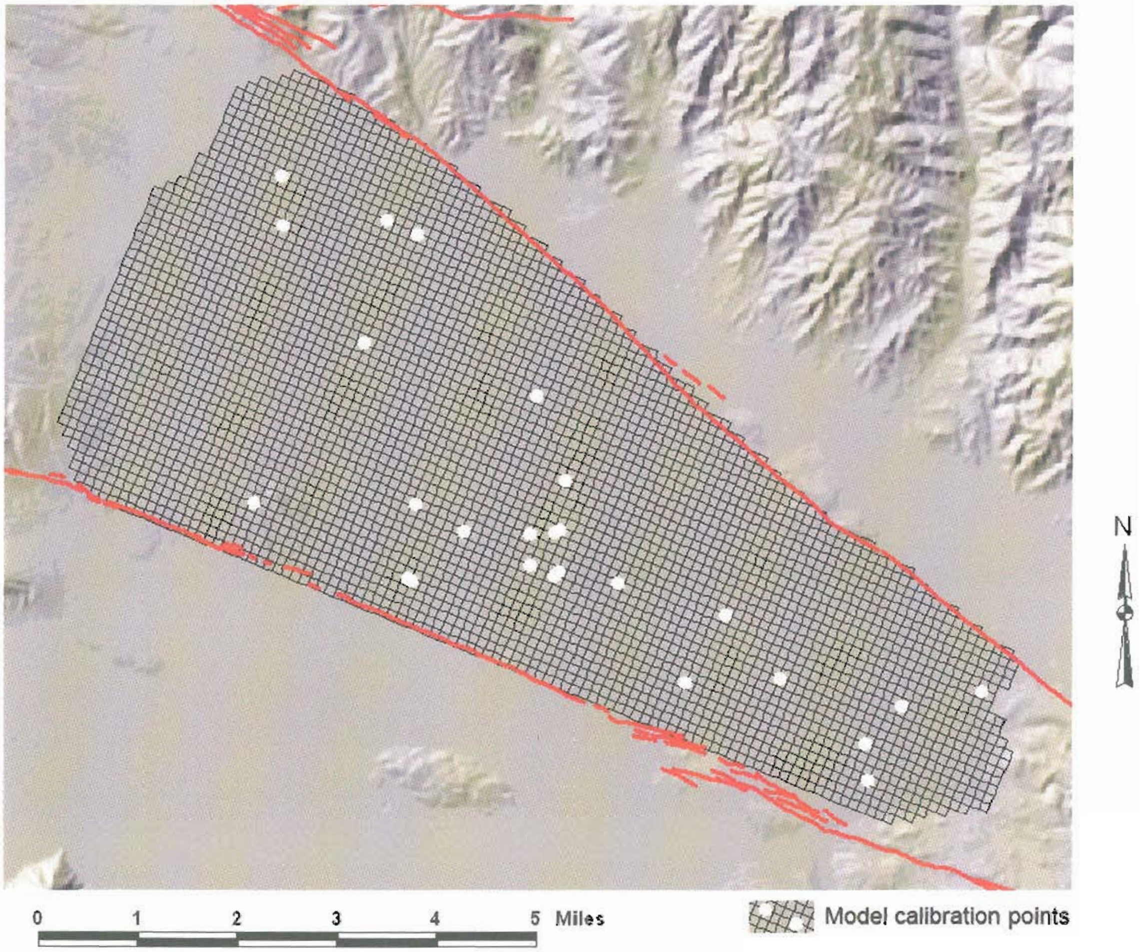


Figure 2-8
Groundwater Elevation Data used in Model Calibration

2.4 Summary of Conceptual Model(s)

Uncertainty in estimating aquifer parameters makes it important to consider alternative candidate conceptual models that characterize a groundwater system. Psomas evaluated four candidate conceptual models during calibration in order to approximate the spatial distribution of transmissivity and storativity within the MCGS.

The four alternative conceptual models evaluated were:

1. One Transmissivity and Storativity Zone, Isotropic
2. Two Transmissivity and Storativity Zones, Isotropic
3. One Transmissivity and Storativity Zone, Anisotropic
4. Two Transmissivity and Storativity Zones, Anisotropic

An aquifer is considered to be isotropic when the parameters that govern groundwater flow are essentially the same in all directions (e.g., homogeneous). An anisotropic aquifer is one where parameter values are a function of direction.

For the purpose of this report, a one zone conceptual model assumes that the transmissivity and storativity are the same for the entire Subbasin (i.e., the same in both areas shown below). A two zone conceptual model assumes that transmissivity and/or storativity in one zone will be different in one or more directions than the corresponding value in the other zone. Two distinct zones within the Subbasin were developed by Psomas and are presented below in Figure 2-9, *Location of Transmissivity and Storativity Zones, Groundwater Elevation, Wells and Spreading Basin*.

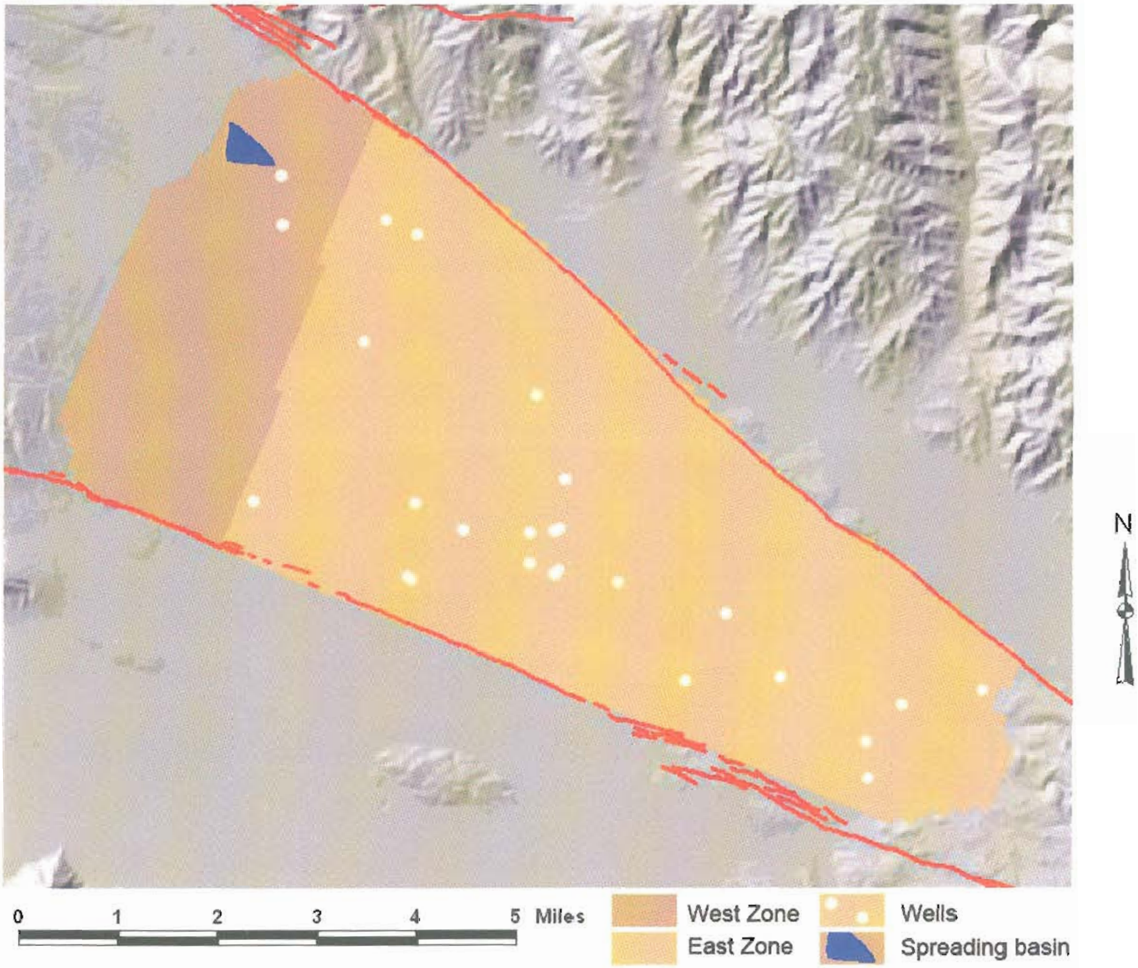


Figure 2-9
Location of Transmissivity and Storativity Zones

3.0 Conceptual Model Validation

The conceptual model validation phase focused on the spatial distribution of transmissivity and storativity within the MCGS. Variation in the distribution of these two aquifer parameters were originally suspected when field data revealed large differences in groundwater elevations collected in the northwest portion of the MCGS.

In a perfect model the measured and modeled groundwater elevation data will follow a single straight line when plotted on an x-y graph. The sum of the squares errors each data point is away from this ideal straight line is used to measure the accuracy of modeled results. In model development, the objective is to minimize uncertainty (i.e., have data points close to the line) so that more confidence can be placed in the results of simulations run after final development.

Four alternate conceptual models were previously summarized in the Section 2-4. The calibration graphs for each alternative (measured vs. model-estimated groundwater elevations) are presented in Figures 3-1, *Measured vs. Model Estimated Groundwater Elevation – One Transmissivity and Storativity Zone, Isotropic Conditions,* Figure 3-2, *Measured vs. Model Estimated Groundwater Elevation – One Transmissivity and Storativity Zone, Anisotropic Conditions*, Figure 3-3, *Measured vs. Model Estimated Groundwater Elevation – Two Transmissivity and Storativity Zones, Isotropic Conditions*, and Figure 3-4, *Measured vs. Model Estimated Groundwater Elevation – Two Transmissivity and Storativity Zones, Anisotropic Conditions.* In the first three graphs one data point toward the far right (DWA well) is obviously not close to the straight line. In the last graph (Figure 3-4) this data point has moved significantly toward the line indicating better parameter estimates in this conceptual model alternative.

A summary of parameters, including the sum of the squared errors between model-estimated and actual groundwater elevations, are presented in Table 3-1, *Summary of Parameter Estimates and Sum of Squared Errors.*

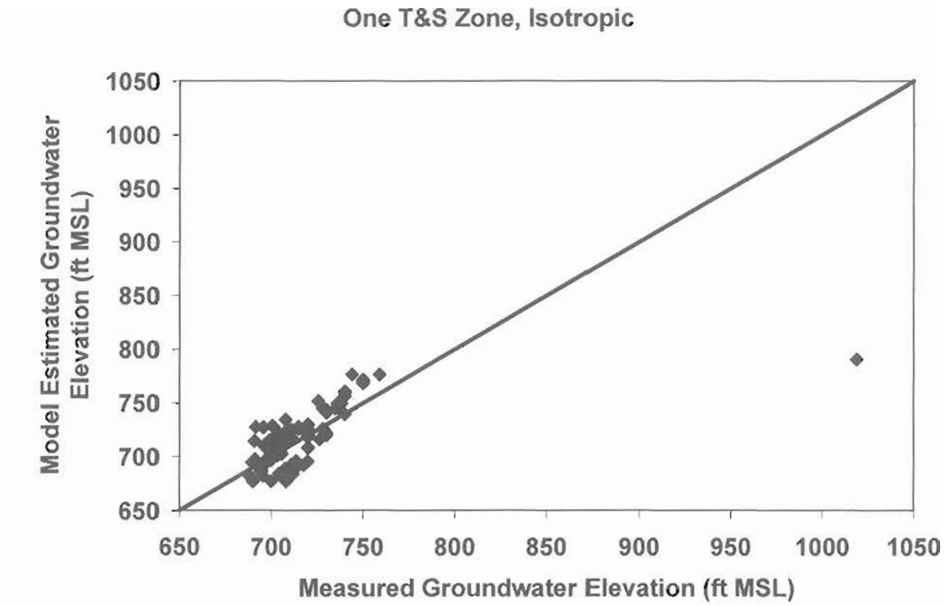


Figure 3-1
Measured vs. Model Estimated Groundwater Elevation – One Transmissivity and Storativity Zone, Isotropic Conditions

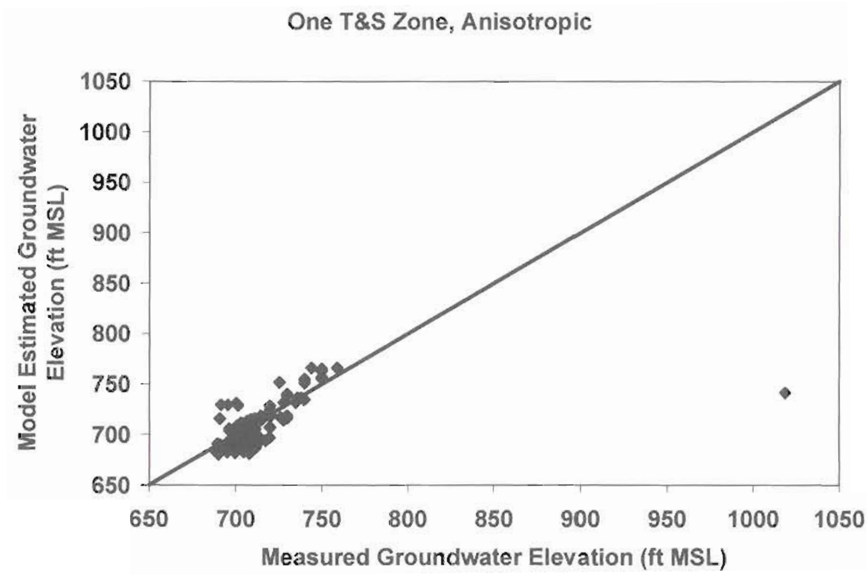


Figure 3-2
Measured vs. Model Estimated Groundwater Elevation – One Transmissivity and Storativity Zone, Anisotropic Conditions

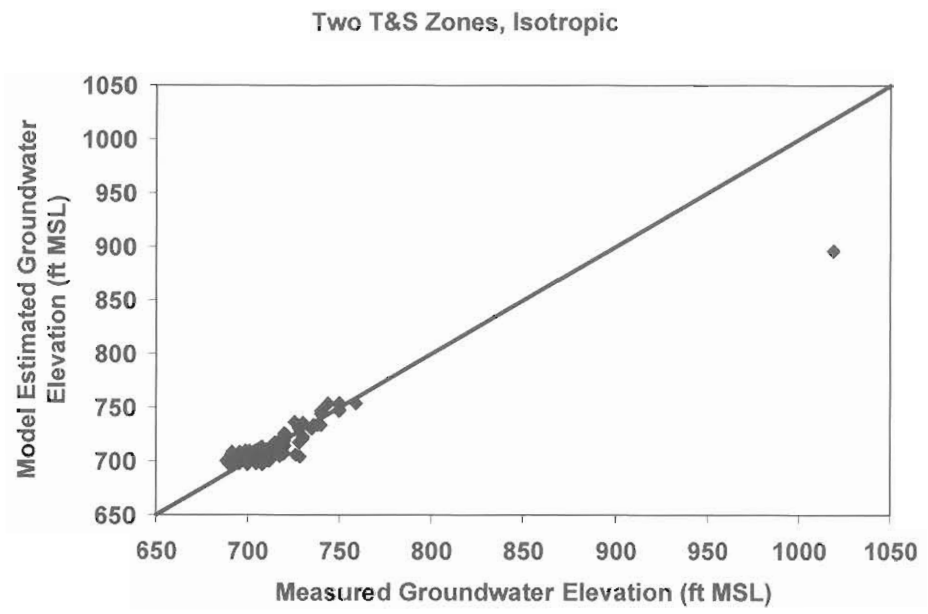


Figure 3-3
Measured vs. Model Estimated Groundwater Elevation – Two Transmissivity and Storativity Zones, Isotropic Conditions

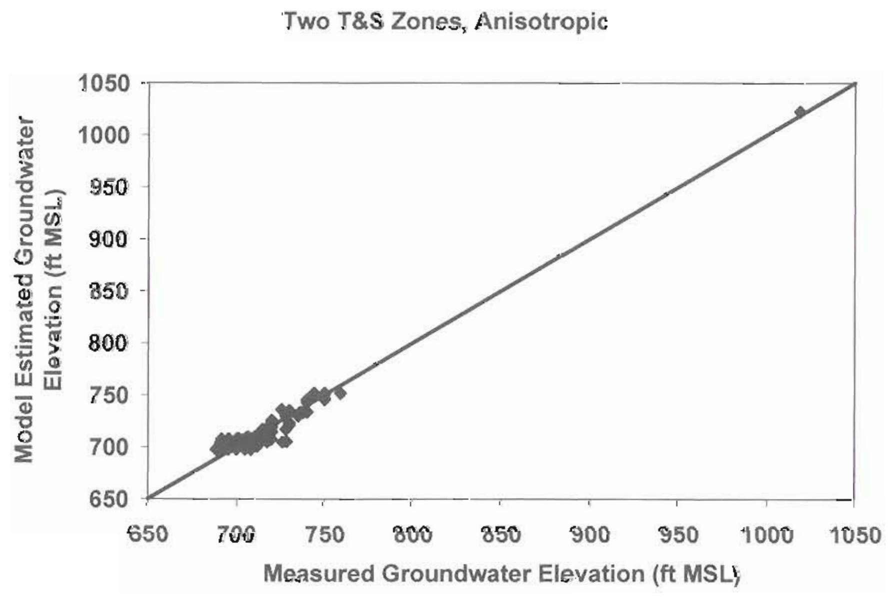


Figure 3-4
Measured vs. Model Estimated Groundwater Elevation – Two Transmissivity and Storativity Zones, Anisotropic Conditions

Table 3-1
Summary of Parameter Estimates and Sum of Squared Errors

Conceptual Model Description	Transmissivity (ft²/day)				Storativity		Sum of Squared Errors (ft²)
	West		East				
	x	y	x	Y	West	East	
One Zone – Isotropic	7,010	7,010	7,010	7,010	0.15	0.15	74,470
One Zone – Anisotropic	6,260	41,800	6,260	41,800	0.13	0.13	92,294
Two Zones – Isotropic	516	516	37,500	37,500	0.028	0.17	20,041
Two Zones – Anisotropic	212	4,047	44,100	48,400	0.0029	0.22	4,153

From Table 3-1 above, the Two-Zone Anisotropic alternative has the lowest sum of squared errors and therefore best characterizes the MCGS.

4.0 Numerical Flow Model Calibration

The model calibration process consists of adjusting values of initial model input parameters and model geometry in an attempt to reasonably match field conditions. Initial values for both transmissivity and storativity were developed during conceptual model validation efforts previously discussed in Section 3.

The numerical model calibration process involved calibrating to both steady-state and transient conditions. In steady-state simulations, there are no observed changes in hydraulic head with time while transient simulations involve a change in hydraulic head with time (e.g. an aquifer stressed by a well-field).

The steady state calibration was used to assess model geometry, confirm the conceptual model of ground-water flow, and test the appropriateness of simulated boundary conditions. The transient calibration was then used to fine-tune the model hydraulic properties through a period of prolonged aquifer stress.

Model calibration included comparisons between model-simulated values and field values for the following data:

- Hydraulic head data,
- Groundwater-flow direction,
- Hydraulic-head gradient,
- Water mass balance

4.1 Calibration – Parameter Estimates

Calibration of the model was completed with PEST (Parameter ESTimation), an industry standard software package that solves inverse problems and is considered a general-purpose, model-independent, parameter estimation and model predictive error analysis package.

The Subbasin's western boundary and the two boundaries of the Mission Springs Fault were simulated with MODFLOW's General Head Boundary package (GHB), and the flow across the Banning Fault was simulated with MODFLOW's Drain package (DRN).

The model accuracy was calculated using the root mean square (RMS) error between actual measurements of hydraulic head and model-generated hydraulic head simulations at the end of each model run. Model accuracy is increased by minimizing the RMS error. The RMS error measures the absolute value of the variation between measured and simulated hydraulic heads.

Table 4-1, *Summary of Calibrated Model Parameters*, summarizes the calibrated parameters for the model including the sum of squared errors. The location of the boundary parameters are shown in Figure 4-1, *Location of Boundaries Listed in Table 4-1.*

Table 4-1
Summary of Calibrated Model Parameters

Parameter	Model Value
Transmissivity (ft^2/day)	
West Zone (X-direction)	1,329
West Zone (Y-direction)	2,703
East Zone (X-direction)	46,123
East Zone (Y-direction)	61,000
Storativity (dimensionless)	
West Zone	0.024
East Zone	0.250
Boundary Conditions	
Western Boundary	
Initial Boundary Head (ft)	1,300
Annual Drop (ft)	0.69
Conductance (ft^2/day)	64.56
Mission Springs Fault – West	
Initial Boundary Head - MSF – West	747
Annual Drop (ft) - MSF – West	0.94
Conductance (ft^2/day) - MSF – West	47.07
Mission Springs Fault – East	
Initial Boundary Head - MSF – East	760
Annual Drop (ft) - MSF – East	0.90
Conductance (ft^2/day) - MSF – East	49.96
Banning Fault	
Initial Drain Head (ft)	695
Annual Drop - Drain (ft)	0.06
Conductance (ft^2/day) – Drain	645.37
North-South Fault Conductance (ft^2/day)	**2.63E-03**
Effective Annual Spreading (AF/yr)	
Spreading in 2003	91
Spreading in 2005	5,564
Spreading in 2006	18,778
Sum of Squared Errors (ft^2)	**3,629**

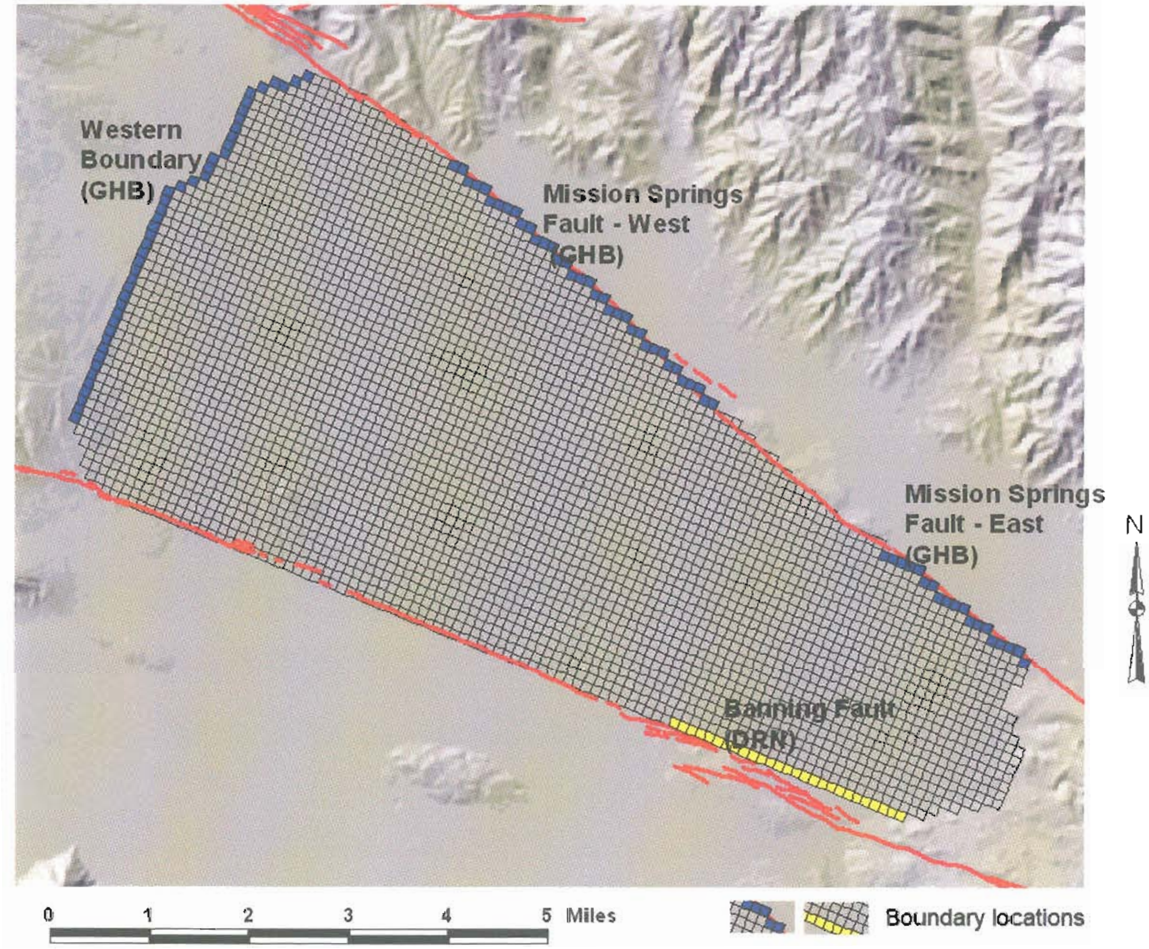


Figure 4-1
Location of Boundaries Listed in Table 4-1

The parameter estimates for the numerical model have transmissivity values that are consistent with previous models and published literature. The parameters exhibit an exceptional "fit" to actual groundwater elevations as evidenced by the low sum of squared errors. Furthermore, anisotropy in the western zone is more pronounced than in the eastern zone and estimates for boundary heads and conductance are consistent with published literature.

4.2 Calibration – Groundwater Elevation

Figure 4-2, *Measured vs. Model Estimated Groundwater Elevation*, presents the comparison of actual groundwater elevations with model-estimated groundwater elevations for two zone anisotropic conceptualization.

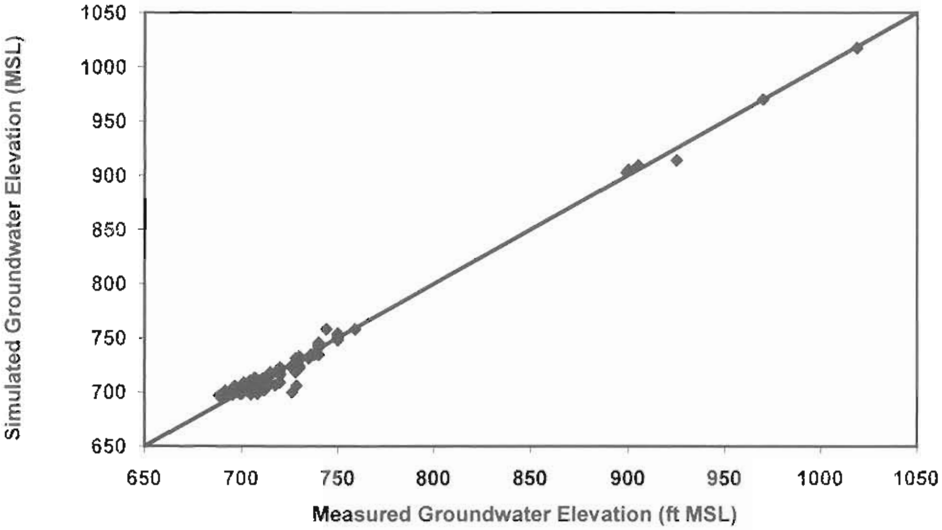


Figure 4-2
Measured vs. Model Estimated Groundwater Elevation

A summary of the calibration statistics for measured vs. model-estimated groundwater elevation is presented in Table 4-2, *Summary of Model Calibration Statistics*. An industry standard is that the standard deviation of model errors divided by the range of measured groundwater elevations should be less than 0.1 (or 10 percent).

Table 4-2
Summary of Model Calibration Statistics

Calibration Statistic	Model Values
Sum of Squared Errors (ft2)	3,627
Standard Deviation of Errors (ft)	6.21
Range (ft)	320.05
Standard Deviation Divided by Range	0.019 (1.9%)

4.3 Calibration - Hydrographs

Model efficacy is confirmed by duplicating a historical period of operation. This analysis uses the traditional "historical-matching method" in which a period of historical data is compared to model-predicted water levels.

Model calibration hydrographs are presented for several representative wells in Appendix A. The hydrographs show both the actual data used in the calibration simulations and the model-predicted groundwater elevations. In some cases, the water table elevation predicted by the model is slightly lower than the actual groundwater elevation measured in the wells (i.e., greater depth to groundwater values). However, all graphs are generally representative of the overall regional water table.

The comparison between modeled and actual groundwater elevations demonstrates that the model simulated past conditions well and may be used with confidence to estimate future conditions under various stress conditions.

4.4 Initial Groundwater Budget Summary

Groundwater budgets for each stress period are presented in Table 4-3, *Groundwater Budget Summary [in AF]*. Groundwater pumping is shown to have increased over the years, reaching a current level of about 16,000 AF/yr. This pumping has resulted in changes to the boundary flows and resulted in groundwater storage declines that were about 8,000 AF/yr during the late 1990s and early 2000s. The spreading of Colorado River water initially resulted in a reduction of the storage decline, and, in 2006, resulted in a recovery of groundwater storage, even under the estimated reduced amounts. In response to the release of spreading basin water into the MCGS in 2006, it acknowledged that the boundary inflow was reduced from previous years and reversed a trend of increases. This is likely a result of the spreading groundwater mound's hydrostatic pressure against the downgradient side of the Mission Creek Fault immediately adjacent to the recharge ponds.

Figure 4-3, *Boundary Inflow*, summarizes the boundary inflow for the simulation period. Figure 4-4, *Boundary Outflow*, summarizes the boundary outflow and Figure 4-5, *Groundwater Pumping*, summarizes groundwater pumping. Figure 4-6, *Groundwater Storage Change*, summarizes the groundwater storage change.

Table 4-3
Groundwater Budget Summary [in AF]

Year	Inflow			Outflow			Storage Change
	Boundary Inflow	Spreading Basins	Total	Boundary Outflow	Pumping	Total Outflow	
Steady State	6313	0	6313	6313	0	6313	0
1961	6294	0	6294	6333	0	6333	-39
1962	6276	0	6276	6352	0	6352	-76
1963	6260	0	6260	6370	0	6370	-110
1964	6244	0	6244	6387	0	6387	-143
1965	6229	0	6229	6403	0	6403	-174
1966	6214	0	6214	6419	0	6419	-205
1967	6199	0	6199	6433	0	6433	-234
1968	6185	0	6185	6446	0	6446	-261
1969	6171	0	6171	6459	0	6459	-288
1970	6158	0	6158	6449	985	7434	-1276
1971	6147	0	6147	6434	1060	7494	-1347
1972	6137	0	6137	6411	1633	8044	-1907
1973	6130	0	6130	6372	2692	9064	-2934
1974	6126	0	6126	6325	2768	9093	-2967
1975	6124	0	6124	6260	3890	10150	-4026
1976	6126	0	6126	6188	3965	10153	-4027
1977	6129	0	6129	6108	4042	10150	-4021
1978	6132	0	6132	6023	4119	10142	-4010
1979	6135	0	6135	5933	4194	10127	-3992
1980	6139	0	6139	5836	4672	10508	-4369
1981	6143	0	6143	5732	5040	10772	-4629
1982	6147	0	6147	5623	5264	10887	-4740
1983	6153	0	6153	5511	5306	10817	-4664
1984	6158	0	6158	5393	5796	11189	-5031
1985	6165	0	6165	5268	6257	11525	-5360
1986	6173	0	6173	5134	6765	11899	-5726
1987	6183	0	6183	4994	7214	12208	-6025
1988	6194	0	6194	4846	7608	12454	-6260
1989	6207	0	6207	4690	7980	12670	-6463
1990	6221	0	6221	4522	8972	13494	-7273
1991	6236	0	6236	4354	8514	12868	-6632
1992	6251	0	6251	4179	9017	13196	-6945
1993	6268	0	6268	3895	10284	14179	-7911
1994	6286	0	6286	3786	10599	14385	-8099

Year	Inflow			Outflow			Storage Change
	Boundary Inflow	Spreading Basins	Total	Boundary Outflow	Pumping	Total Outflow	
1995	6305	0	6305	3576	10762	14338	-8033
1996	6326	0	6326	3352	11694	15046	-8720
1997	6346	0	6346	3141	10673	13814	-7468
1998	6366	0	6366	2937	10944	13881	-7515
1999	6387	0	6387	2723	12084	14807	-8420
2000	6409	0	6409	2498	12427	14925	-8516
2001	6430	0	6430	2282	11756	14038	-7608
2002	6451	0	6451	2059	12938	14997	-8546
2003	6459	91	6550	1831	13316	15147	-8597
2004	6508	0	6508	1604	14624	16228	-9720
2005	5442	5564	11006	1378	15686	17064	-6058
2006	3125	18778	21903	1965	16547	18512	3391

DWA/CVWD began construction of the MCGS Spreading Ponds in 1997 and water was first released in 2003.

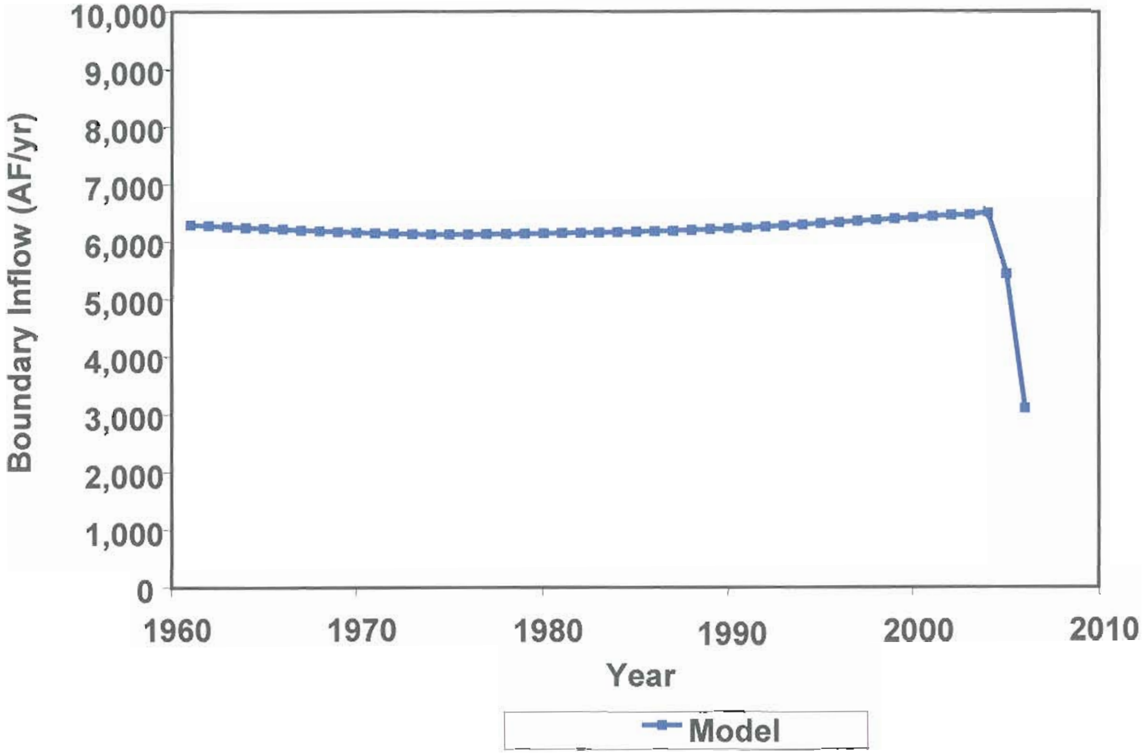


Figure 4-3
Boundary Inflow

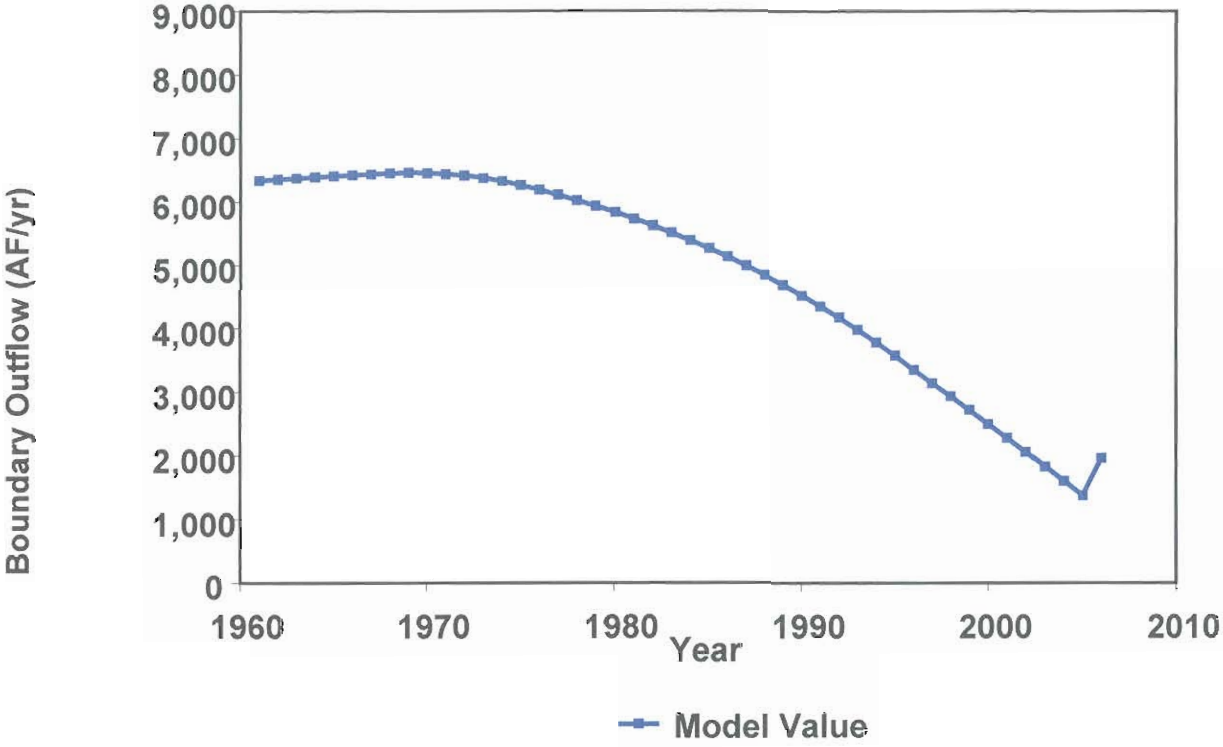


Figure 4-4
Boundary Outflow

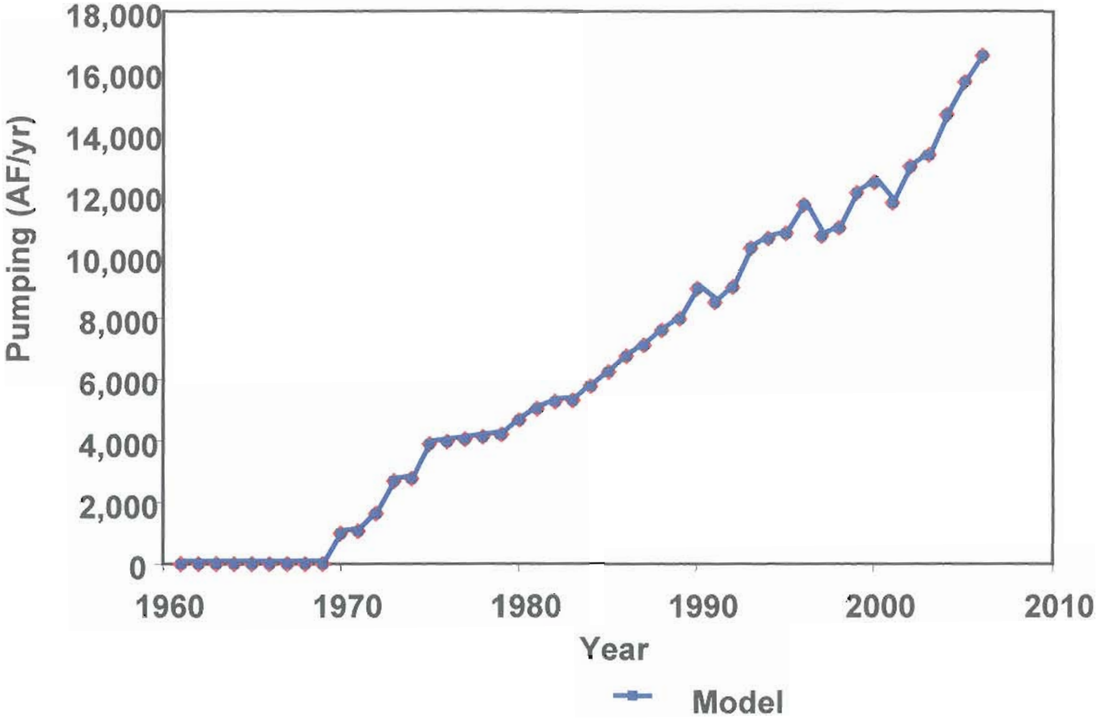


Figure 4-5
Groundwater Pumping

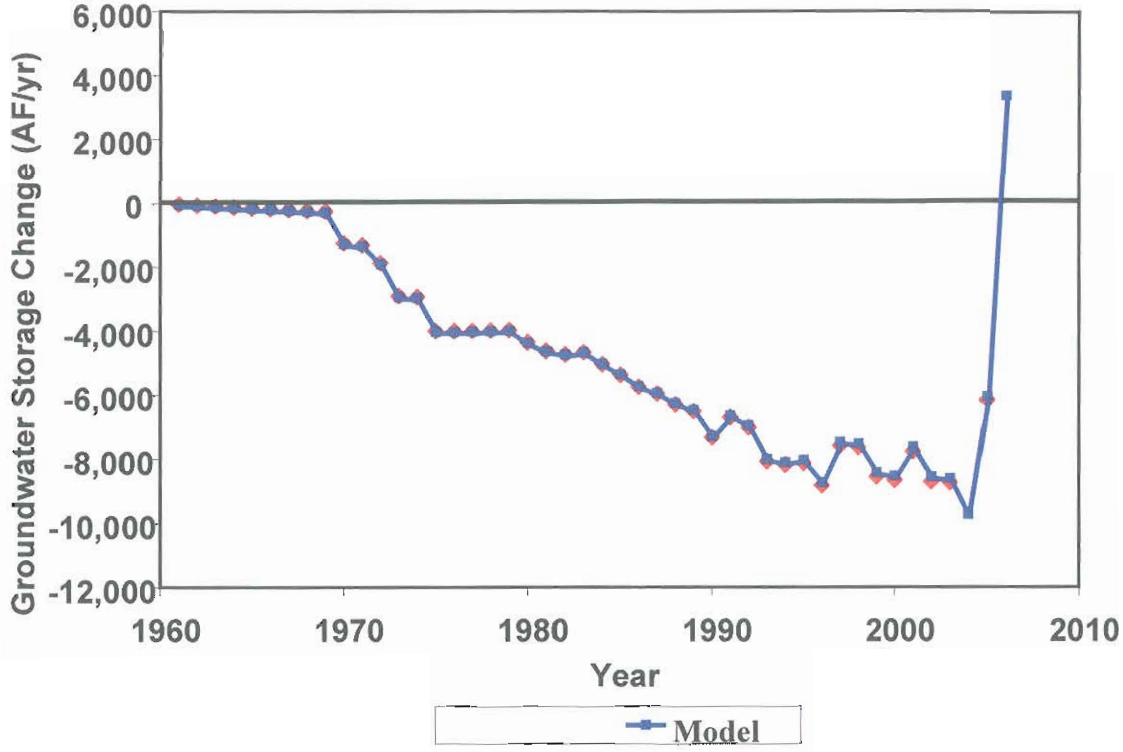


Figure 4-6
Groundwater Storage Change

5.0 Final Numerical Flow Model Development

The numerical groundwater flow model was developed using MODFLOW – 2000 (Harbaugh et al. 2000), an industry-standard finite-difference code developed by the United States Geological Survey. Aquifer properties and calibrated model parameters incorporated in the model were previously presented in Table 4-1. The model was divided into 47 stress periods and the first stress period was simulated as steady state. Each subsequent stress period (2 thru 47) were 365 days long and simulated the period between July 1961 and June 2006. The next step in model development was to incorporate the water budget components and prepare for future simulation runs.

Components of the water budget used in the model are described in the following sections.

5.1 Groundwater Extraction

Estimates of future pumping projections are summarized in Table 5-1, *Summary of Anticipated Future Groundwater Pumping*, and were derived from data provided by MSWD, CVWD, and DWA. Detailed annualized pumping for each well is presented in Table 5-2, *Assumed Future Groundwater Pumping*.

The general location of proposed future wells is presented in Figure 5-1, *Proposed MSWD Wells (Selected by GSi/water)*. It was assumed that new wells proposed in Section 26 and Section 35 would be online in 2008. Additional new wells in Section 26 and 35 would be online in 2009. Furthermore, a new well in Section 1 and a new well in Section 2 are assumed to come online in 2011. Finally, additional new wells in Section 1 and 2 are assumed to come online in 2013.

Table 5-1
Summary of Anticipated Groundwater Pumping (MCGS)

Year	MCGS Existing Wells	MCGS Future Wells	Recycled Water Production*	Total MCGS Well Production	CVWD Pumping	Private Pumping	Total Pumping
2007	12,017	0	0	12,017	3,400	1,566	16,983
2008	11,119	1,740	0	12,859	3,600	1,566	18,025
2009	10,221	3,480	0	13,701	3,800	1,566	19,067
2010	10,903	3,640	0	14,543	4,000	1,566	20,109
2011	10,387	5,200	0	15,587	4,200	1,566	21,353
2012	10,931	5,700	0	16,631	4,600	1,566	22,797
2013	10,375	7,300	0	17,675	4,900	1,566	24,141
2014	10,719	8,000	0	18,719	5,200	1,566	25,485
2015	10,963	8,800	2,000	19,763	5,500	1,566	26,829
2016	11,207	9,600	2,000	20,807	5,900	1,566	28,273
2017	11,451	10,400	2,000	21,851	6,300	1,566	29,717
2018	11,695	11,200	2,000	22,895	6,600	1,566	31,061
2019	11,939	12,000	2,000	23,939	6,900	1,566	32,405
2020	8,700	8,080	5,350	16,780	7,100	1,566	25,446
2021	8,758	8,800	5,350	17,558	7,600	1,566	26,724
2022	8,756	9,600	5,350	18,356	8,000	1,566	27,922
2023	8,744	10,400	5,350	19,144	8,200	1,566	28,910
2024	8,732	11,200	5,350	19,932	8,600	1,566	30,098
2025	9,120	11,600	6,070	20,720	8,900	1,566	31,186
2026	9,120	11,600	6,070	20,720	9,000	1,566	31,286
2027	9,120	11,600	6,070	20,720	9,400	1,566	31,686
2028	9,120	11,600	6,070	20,720	9,800	1,566	32,086
2029	9,120	11,600	6,070	20,720	10,200	1,566	32,486
2030	9,120	11,600	6,720	20,720	10,700	1,566	32,986

Table 5-2
Assumed Future Groundwater Pumping

Year	MSWD Wells											
	22	23	24	27	28	29	30	31	32	New Well (Sec1)	New Well (Sec 1)	New Well (Sec 2)
2007	2,477	0	1,097	443	1,923	2,301	901	1,102	1,773	0	0	0
2008	2,400	0	1,100	419	1,800	2,000	800	1,000	1,600	0	0	0
2009	2,100	0	1,000	421	1,800	1,900	800	900	1,300	0	0	0
2010	2,200	0	1,150	453	1,850	2,100	850	1,000	1,300	0	0	0
2011	2,000	0	1,150	437	1,750	2,100	850	900	1,200	800	0	800
2012	2,000	0	1,250	431	1,850	2,100	900	1,000	1,200	950	0	950
2013	2,000	0	1,150	435	1,750	2,000	900	1,000	1,140	950	800	950
2014	2,050	0	1,200	429	1,800	2,100	900	1,100	1,140	1,000	1,000	1,000
2015	2,100	0	1,200	423	1,800	2,100	900	1,100	1,340	1,100	1,100	1,100
2016	2,200	0	1,200	457	1,800	2,100	900	1,100	1,450	1,200	1,200	1,200
2017	2,250	0	1,200	451	1,800	2,100	900	1,100	1,650	1,300	1,300	1,300
2018	2,250	0	1,200	450	1,800	2,150	900	1,295	1,650	1,400	1,400	1,400
2019	2,250	0	1,200	450	1,800	2,150	900	1,500	1,689	1,500	1,500	1,500
2020	1,300	0	1,200	400	1,300	1,300	900	1,100	1,200	1,080	1,000	1,000
2021	1,358	0	1,200	400	1,300	1,300	900	1,100	1,200	1,100	1,200	1,100
2022	1,356	0	1,200	400	1,300	1,300	900	1,100	1,200	1,200	1,300	1,200
2023	1,344	0	1,200	400	1,300	1,300	900	1,100	1,200	1,300	1,400	1,300
2024	1,332	0	1,200	400	1,300	1,300	900	1,100	1,200	1,400	1,450	1,400
2025	1,420	0	1,200	400	1,400	1,400	900	1,200	1,200	1,450	1,450	1,450
2026	1,420	0	1,200	400	1,400	1,400	900	1,200	1,200	1,450	1,450	1,450
2027	1,420	0	1,200	400	1,400	1,400	900	1,200	1,200	1,450	1,450	1,450
2028	1,420	0	1,200	400	1,400	1,400	900	1,200	1,200	1,450	1,450	1,450
2029	1,420	0	1,200	400	1,400	1,400	900	1,200	1,200	1,450	1,450	1,450
2030	1,420	0	1,200	400	1,400	1,400	900	1,200	1,200	1,450	1,450	1,450

Year	New MSWD Wells					CVWD Wells				Private Wells		
	(Sec 2)	(Sec 35)	(Sec 35)	(Sec 26)	(Sec 26)	3405	3408	3409	3410	Hidden Springs CC	Mission Lakes CC	Sands RV
2007	0	0	0	0	0	536	817	1,126	1,327	234	1,045	287
2008	0	870	0	870	0	536	817	1,126	1,327	234	1,045	287
2009	0	870	870	870	870	536	817	1,126	1,327	234	1,045	287
2010	0	910	910	910	910	536	817	1,126	1,327	234	1,045	287
2011	0	900	900	900	900	536	817	1,126	1,327	234	1,045	287
2012	0	950	950	950	950	536	817	1,126	1,327	234	1,045	287
2013	800	950	950	950	950	536	817	1,126	1,327	234	1,045	287
2014	1,000	1,000	1,000	1,000	1,000	536	817	1,126	1,327	234	1,045	287
2015	1,100	1,100	1,100	1,100	1,100	536	817	1,126	1,327	234	1,045	287
2016	1,200	1,200	1,200	1,200	1,200	536	817	1,126	1,327	234	1,045	287
2017	1,300	1,300	1,300	1,300	1,300	536	817	1,126	1,327	234	1,045	287
2018	1,400	1,400	1,400	1,400	1,400	536	817	1,126	1,327	234	1,045	287
2019	1,500	1,500	1,500	1,500	1,500	536	817	1,126	1,327	234	1,045	287
2020	1,000	1,000	1,000	1,000	1,000	536	817	1,126	1,327	234	1,045	287
2021	1,100	1,100	1,100	1,100	1,100	536	817	1,126	1,327	234	1,045	287
2022	1,200	1,200	1,200	1,200	1,200	536	817	1,126	1,327	234	1,045	287
2023	1,300	1,300	1,300	1,300	1,300	536	817	1,126	1,327	234	1,045	287
2024	1,400	1,400	1,400	1,400	1,400	536	817	1,126	1,327	234	1,045	287
2025	1,450	1,450	1,450	1,450	1,450	536	817	1,126	1,327	234	1,045	287
2026	1,450	1,450	1,450	1,450	1,450	536	817	1,126	1,327	234	1,045	287
2027	1,450	1,450	1,450	1,450	1,450	536	817	1,126	1,327	234	1,045	287
2028	1,450	1,450	1,450	1,450	1,450	536	817	1,126	1,327	234	1,045	287
2029	1,450	1,450	1,450	1,450	1,450	536	817	1,126	1,327	234	1,045	287
2030	1,450	1,450	1,450	1,450	1,450	536	817	1,126	1,327	234	1,045	287

All Values in AF/yr
Mission Creek Subbasin

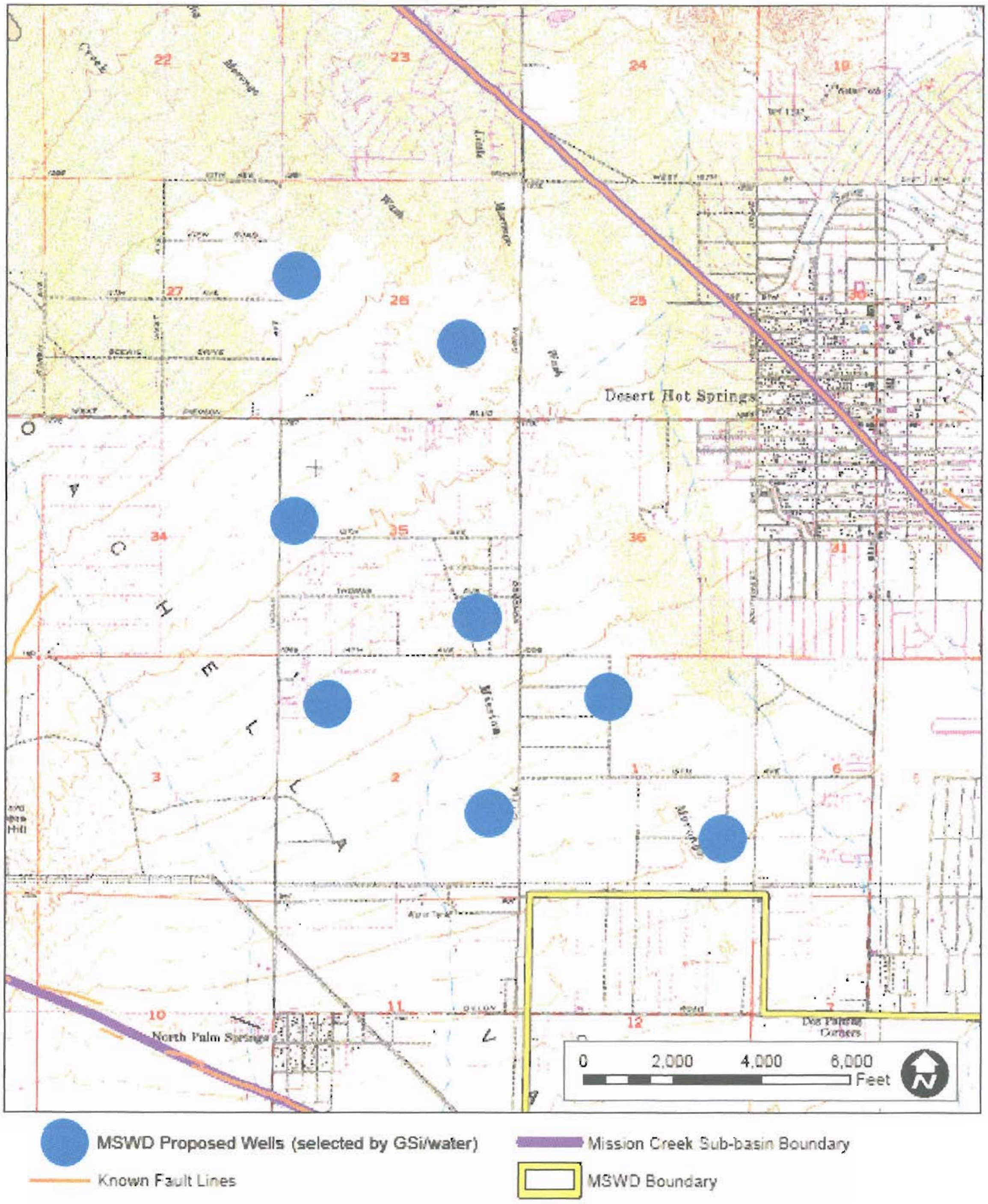


Figure 5-1
MSWD Proposed Wells (Selected by GSi/water)

5.2 Boundary Conditions

Initial boundary heads were estimated and validated during model calibration. It was assumed that boundary heads would continue to decline during the analysis period. Therefore, the decrease in head each year was estimated in order to simulate the general condition of lowering groundwater during simulation runs. Although it is recognized that recent spreading of Colorado River water in the western area of the model domain caused a recovery of groundwater levels in 2005 and 2006, the declining boundary head represents a worst-case scenario.

5.3 Groundwater Recharge

Average annual spreading basin water delivery volumes were derived from the 2005 Coachella Valley Water District and the 2005 Mission Springs Water District Urban Water Management Plans. It is anticipated that CVWD and DWA intend to recharge an annual average of almost 16,000 AF/yr during the years covered in this analysis.

It is recognized that some spreading water will not recharge the underlying groundwater basin but will be lost to evaporation and the initial wetting of the unsaturated zone. Although future losses to wetting the unsaturated zone are expected to be minimal after several years of operation, evaporative losses are probable but will depend seasonal conditions and daily temperatures at the time spreading water is released. For the purposes of this analysis, it was assumed that an average of 15,000 AF of spread water will reach the groundwater basin annually.

5.4 Water Budget Summary

Table 5-3, *Summary of Groundwater Budget,* summarizes the storage change anticipated in the declining boundary head scenario described in Section 5.2, above.

Table 5-3
Summary of Groundwater Budget

Scenario	Inflow			Outflow			Storage Change
	Spreading	Boundary Inflow	Total Inflow	Pumping	Boundary Outflow	Total Outflow	
Declining Boundary Head	15,000	5,978	20,978	26,961	3,218	30,179	-9,202

All values represent average of 2007-2030 Simulation and are in AF/yr.

5.5 Drawdown Results

Anticipated drawdown in the MCGS was estimated by subtracting the groundwater elevations estimated by the model in 2006 from the groundwater elevations estimated by the model at the end of each simulation period. Simulations were run in five (5) year increments from 2006 thru 2030 and the average model estimated drawdown is presented below in Table 5-4, *Model Estimated Drawdown*. Figure 5-2 shows the drawdown in each model cell after the end of the simulation period (i.e., 2030). In addition, five (5) year incremental groundwater elevation contours are presented graphically in Figures 5-3 thru 5-7.

Table 5-4
Model Estimated Drawdown

Year		Model Estimated Average Drawdown (ft)
Year 5	2011	14
Year 10	2016	32
Year 15	2021	50
Year 20	2026	67
Year 25*	2030	82

The final simulation is 24 years.

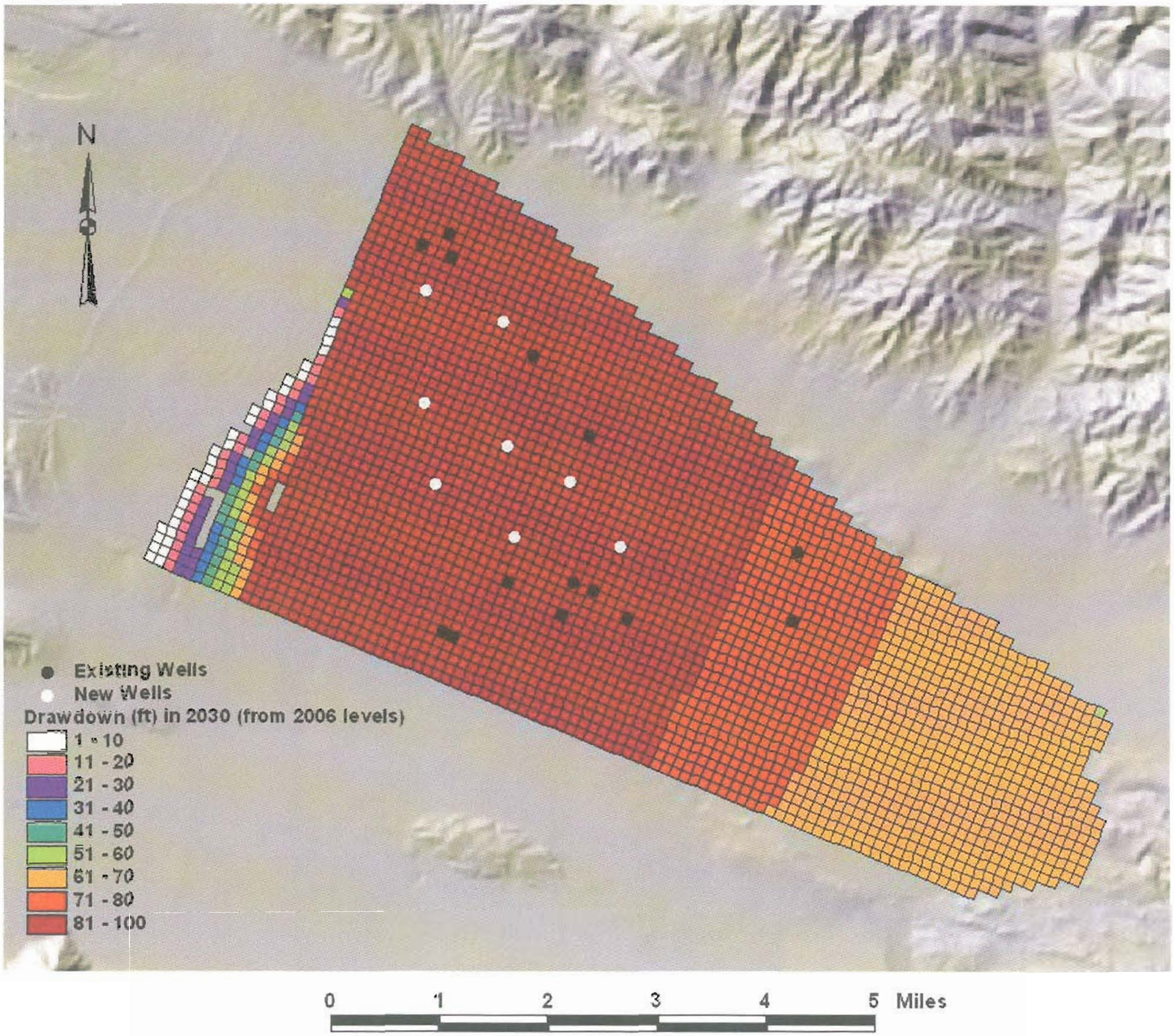
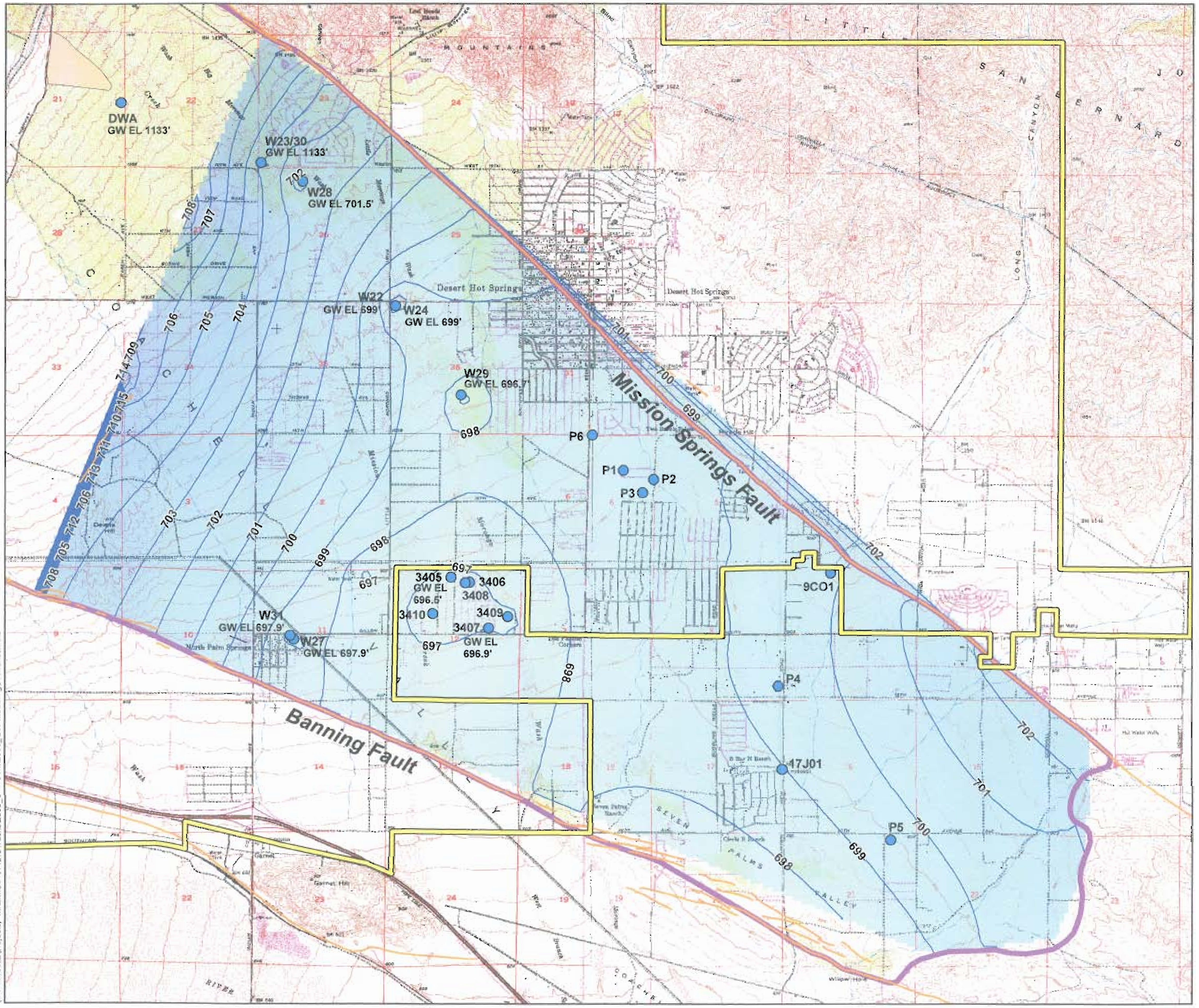


Figure 5-2
Model Estimated Drawdown

Mission Springs Water Budget Report



Legend

- MSWD Service Area Boundary
- Mission Creek Sub-basin Boundary
- Known Fault Lines
- Modeled Groundwater Elevation Contours (1-Foot Contour Interval)
- Production Wells (2006)

0 0.5 1 1.5 2 Miles

Scenario: Declining Boundary Heads & 15K Spreading Basin - Year 0

Modeled Groundwater Elevation - 2006

MSWD PSOMAS

Figure 5-3

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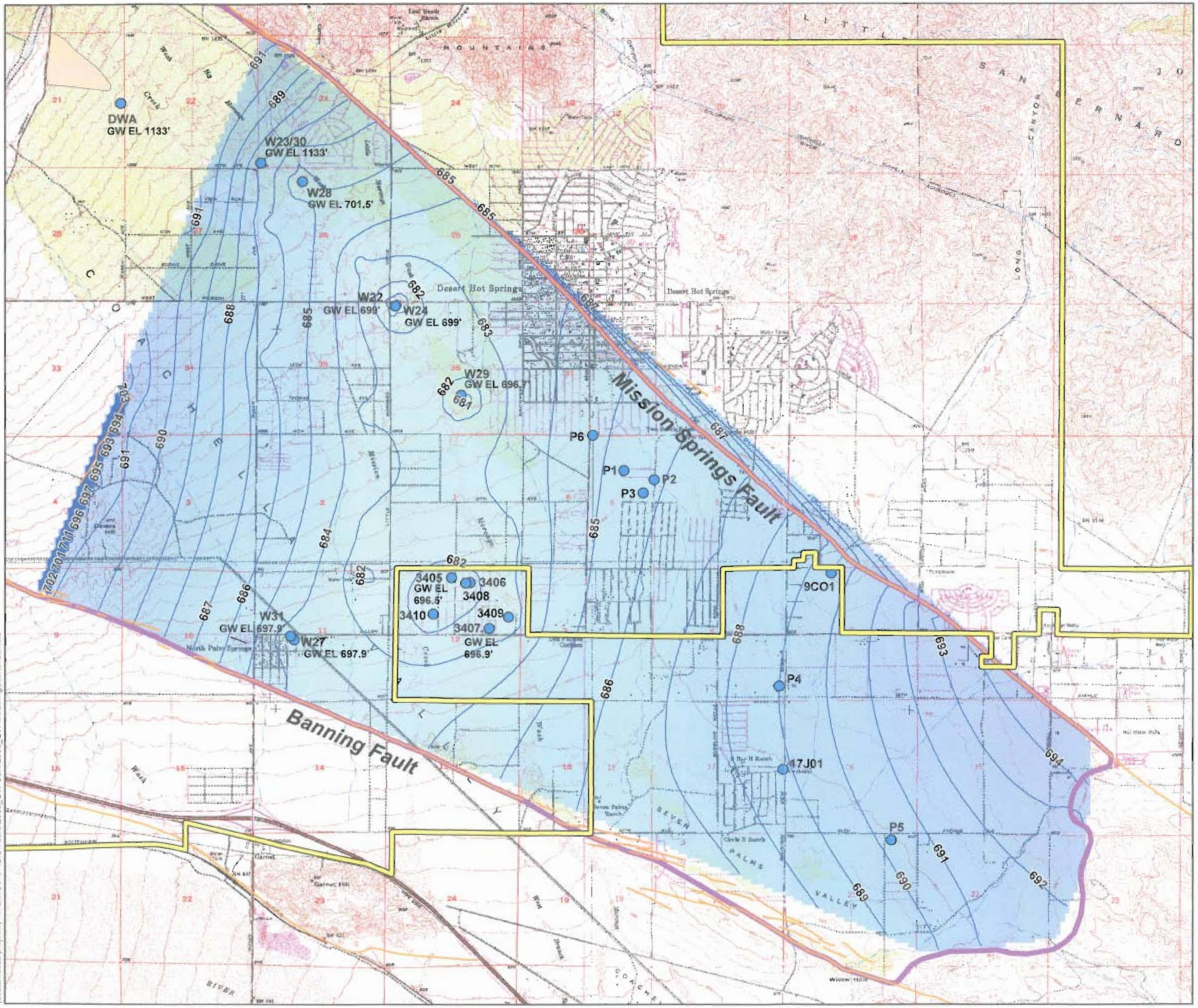
Mission Springs Water Budget Report



Legend

- MSWD Service Area Boundary
- Mission Creek Sub-basin Boundary
- Known Fault Lines
- Modeled Groundwater Elevation Contours (1-Foot Contour Interval)
- Production Wells (2006)

0 0.5 1 1.5 2 Miles

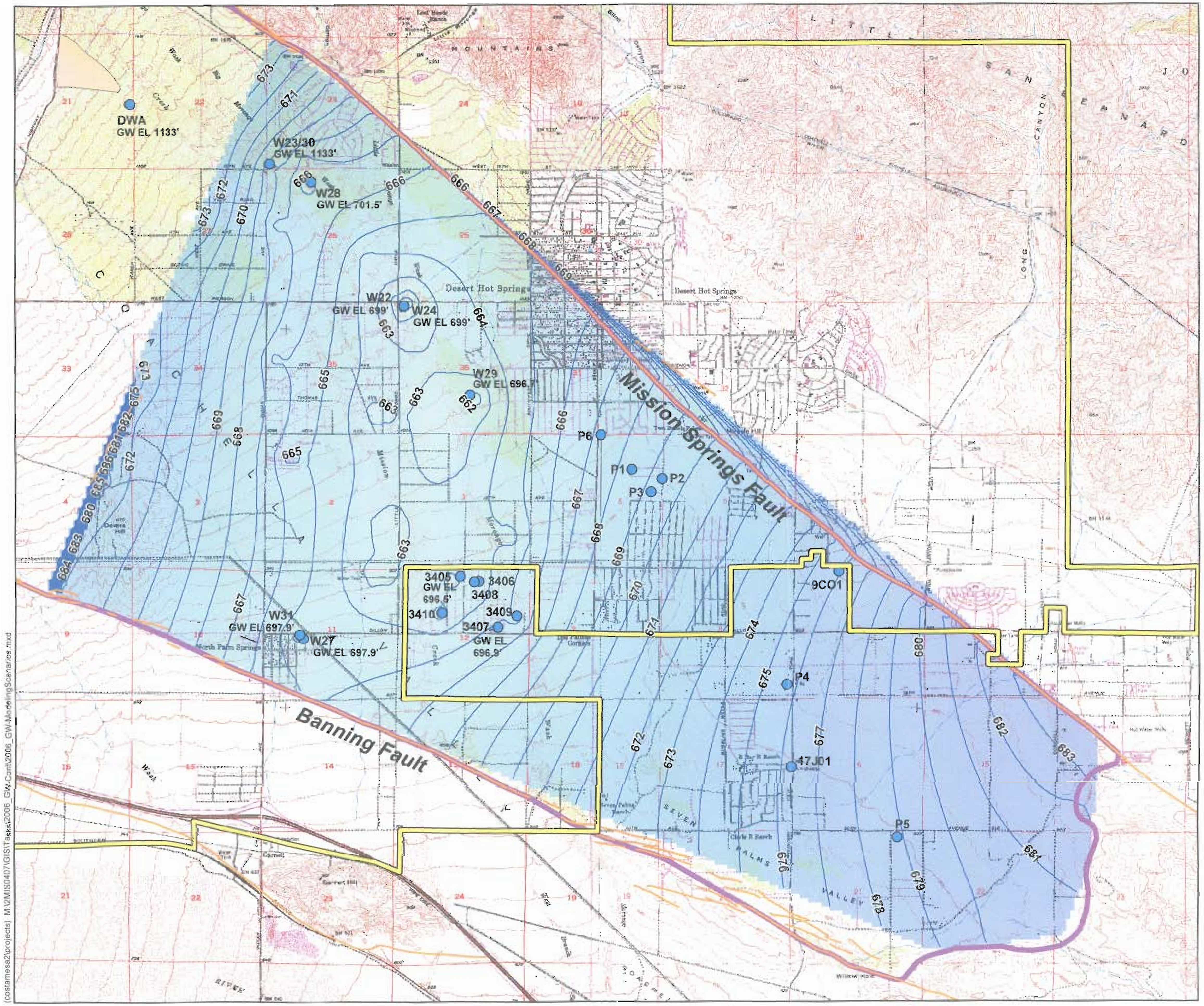
Scenario: Declining Boundary Heads & 15K Spreading Basin - Year 5

Modeled Groundwater Elevation - 2011

MSWD PSOMAS

Figure 5-4

Mission Springs Water Budget Report



Legend

- MSWD Service Area Boundary
- Mission Creek Sub-basin Boundary
- Known Fault Lines
- Modeled Groundwater Elevation Contours (1-Foot Contour Interval)
- Production Wells (2006)

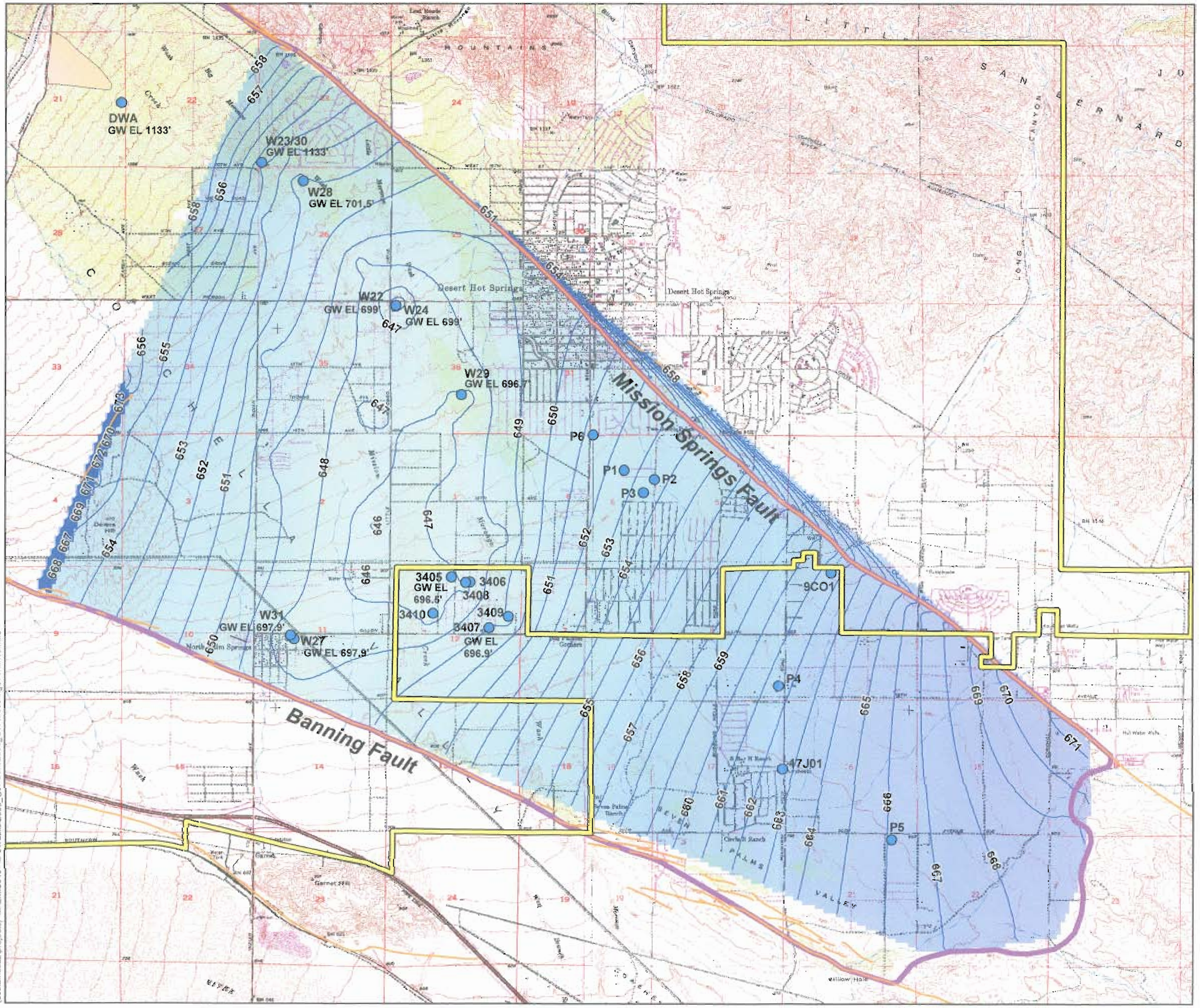
0 0.5 1 1.5 2 Miles

Scenario: Declining Boundary Heads & 15K Spreading Basin - Year 10

Modeled Groundwater Elevation - 2016

MSWD PSOMAS

Figure 5-5



Mission Springs Water Budget Report

Legend

- MSWD Service Area Boundary
- Mission Creek Sub-basin Boundary
- Known Fault Lines
- Modeled Groundwater Elevation Contours (1-Foot Contour Interval)
- Production Wells (2006)

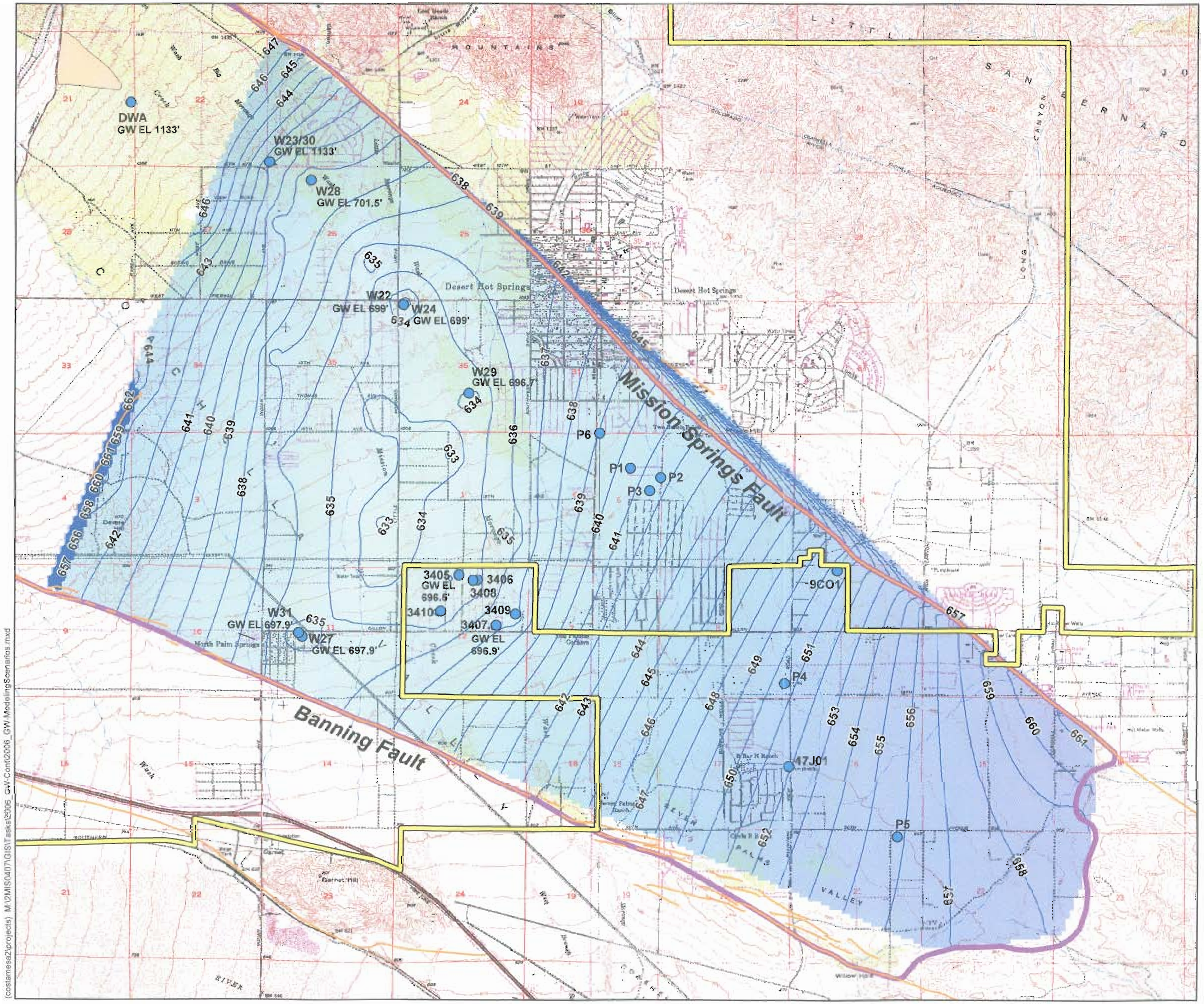
0 0.5 1 1.5 2 Miles

Scenario: Declining Boundary Heads & 15K Spreading Basin - Year 15

Modeled Groundwater Elevation - 2021

MSWD PSOMAS

Figure 5-6



Legend

- MSWD Service Area Boundary
- Mission Creek Sub-basin Boundary
- Known Fault Lines
- Modeled Groundwater Elevation Contours (1-Foot Contour Interval)
- Production Wells (2006)

0 0.5 1 1.5 2 Miles

Scenario: Declining Boundary Heads & 15K Spreading Basin - Year 20

Modeled Groundwater Elevation - 2026

MSWD PSOMAS

Figure 5-7

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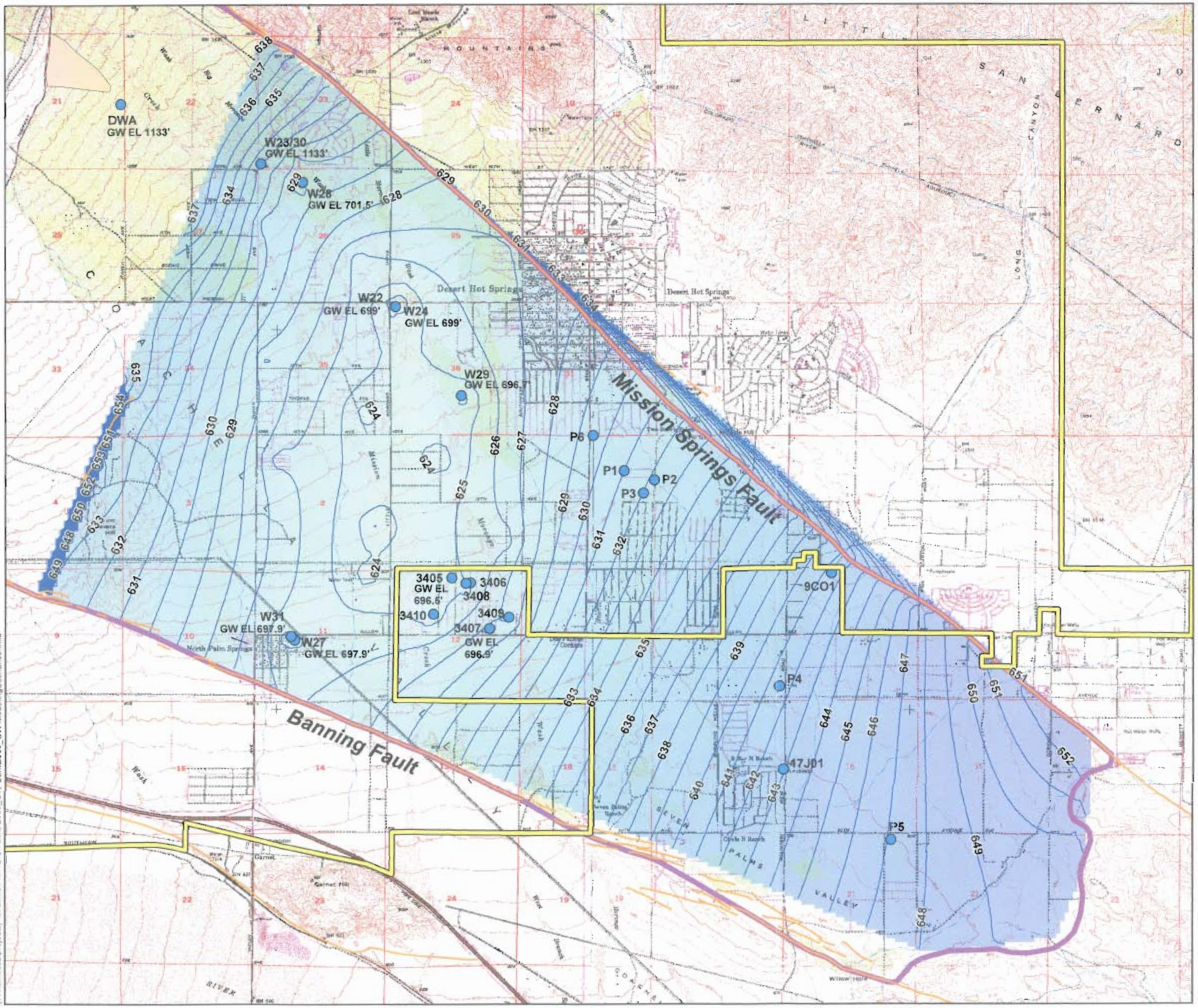
Mission Springs Water Budget Report



Legend

- MSWD Service Area Boundary
- Mission Creek Sub-basin Boundary
- Known Fault Lines
- Modeled Groundwater Elevation Contours (1-Foot Contour Interval)
- Production Wells (2006)

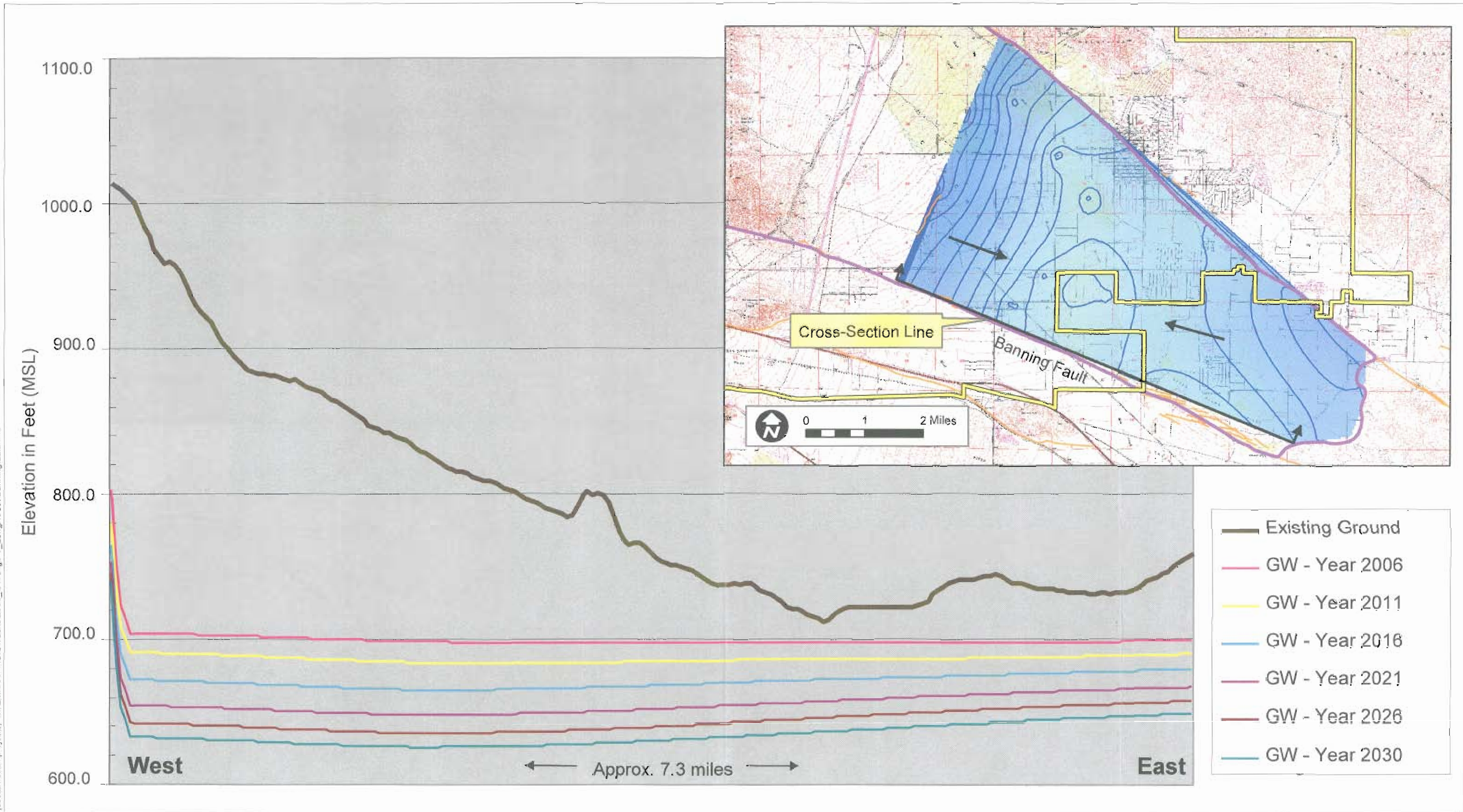
0 0.5 1 1.5 2 Miles

Scenario: Declining Boundary Heads & 15K Spreading Basin - Year 24

Modeled Groundwater Elevation - 2030

MSWD PSOMAS

Figure 5-8



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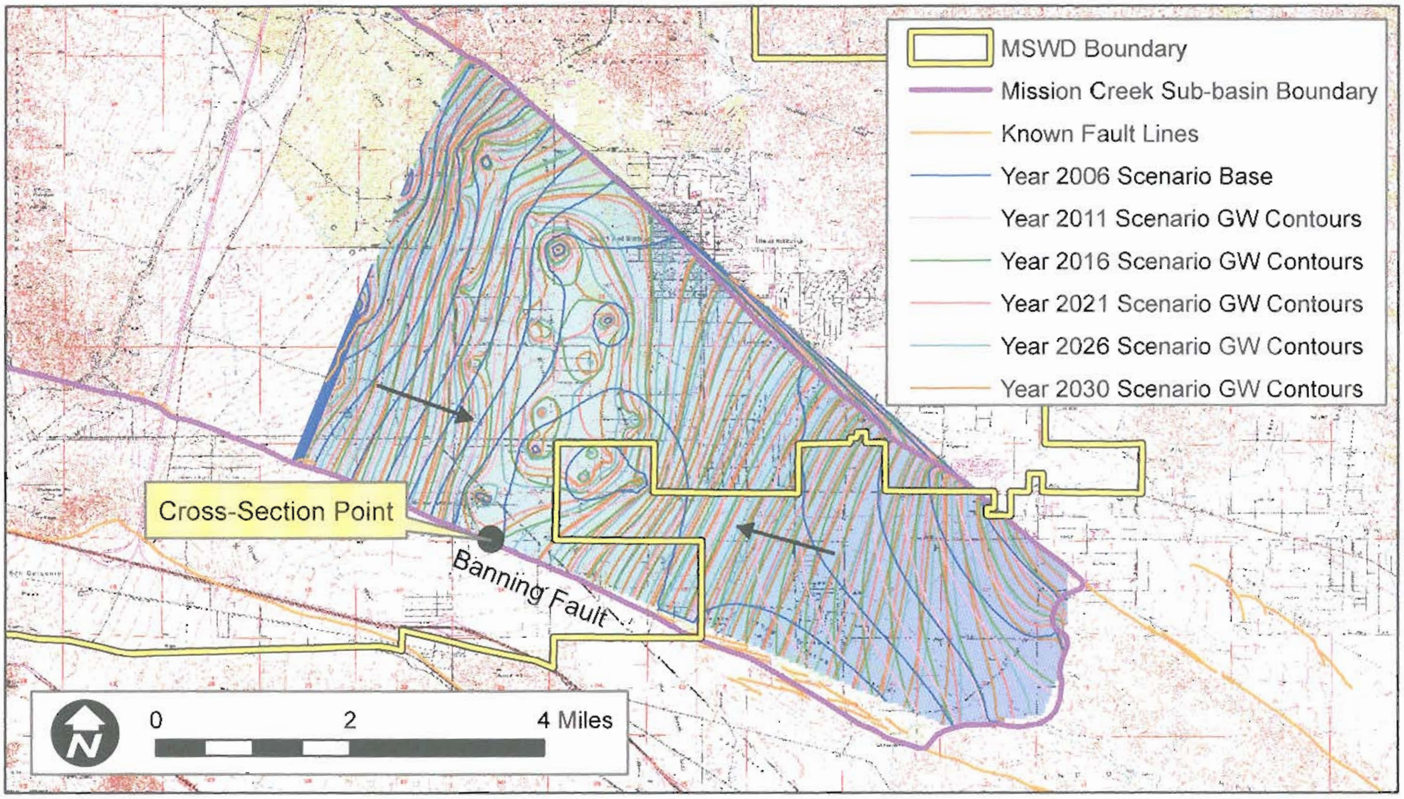
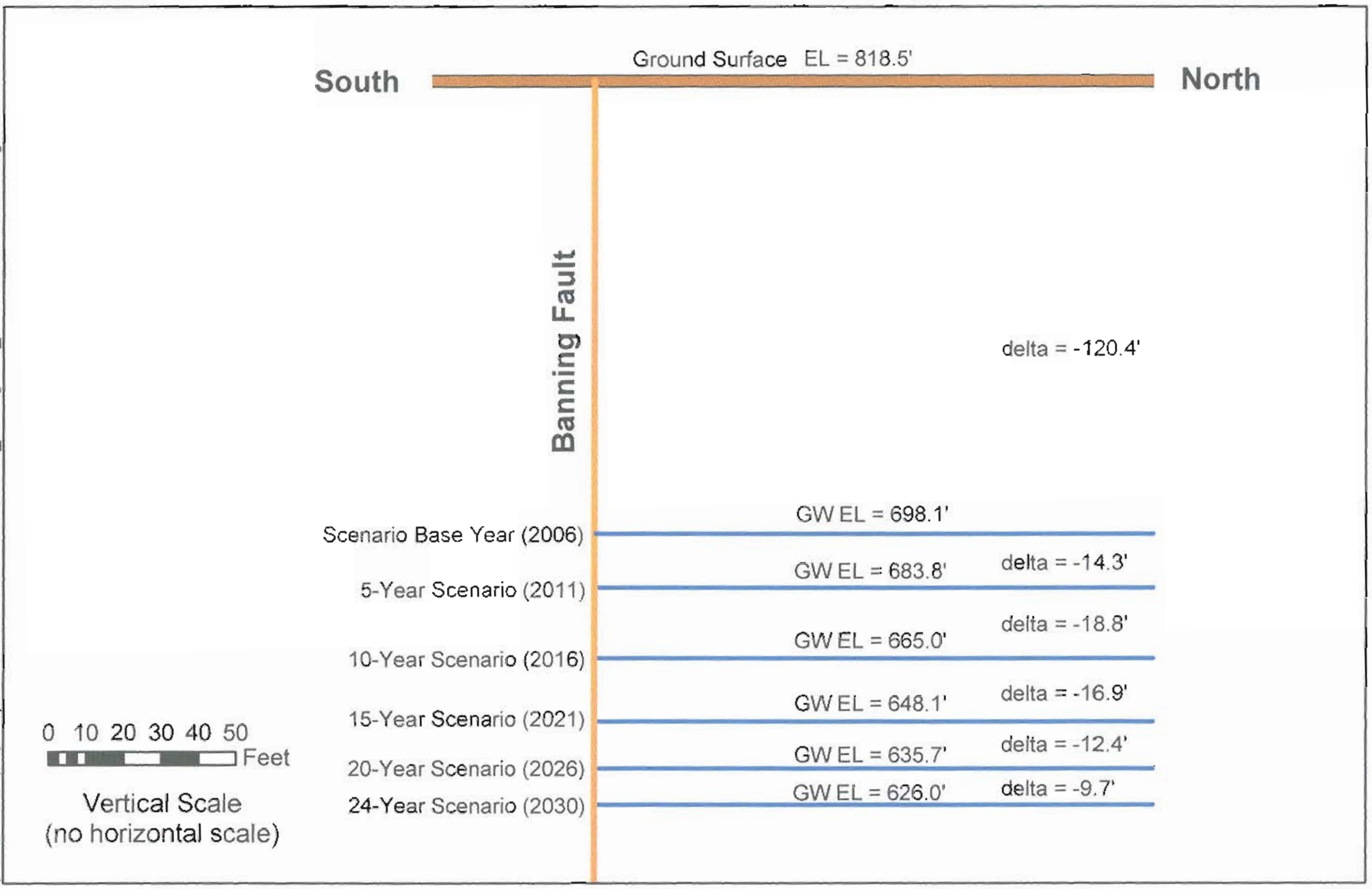
Groundwater Elevation Longitudinal Cross Section Along Banning Fault -- All Scenarios





(costamesa2\projects) M:\2MIS0407\GIS\Tasks\2006_GW\fig5-10_ScenarioXSect-Banningfault.mxd

Groundwater Elevation Cross Section Point at Banning Fault -- All Scenarios

6.0 Sensitivity

The sensitivity analysis was performed to assess the response of the model results to changes in various input parameter values. The model is sensitive to a parameter when a change of the parameter value changes the distribution of simulated hydraulic head. When the model is sensitive to an input parameter, the value and distribution of that parameter within the model are more accurately determined during model calibration because small changes to the parameter value cause large changes in hydraulic head. If a change of parameter value does not change the simulated hydraulic head distribution, the model is insensitive to that parameter. When the model is insensitive to an input parameter, the value and distribution of that parameter within the model are more difficult to accurately determine from model calibration because large changes to the parameter do not cause large changes in hydraulic head. These values of these parameters may not represent actual values

It is recognized that annual future spreading basin water will affect the groundwater level decline simulated in this analysis. Several simulations were run to test the sensitivity of spreading basin water to MCGS water level decline. The five scenarios used evaluated are presented below:

1. Spreading of 5,000 AF/yr
2. Spreading of 10,000 AF/yr
3. Spreading of 15,000 AF/yr
4. Spreading of 20,000 AF/yr
5. Spreading of 25,000 AF/yr

In order to simulate the full range of potential conditions, two sets of simulations were run for each spreading scenario: 1) the annual decline in boundary heads continued from 2007 to 2030 at the same rate as in the calibration period, and 2) there is no continued annual decline in boundary heads - assigned equivalent to 2006 heads.

Table 6-1, *Summary of Groundwater Budget for Ten Simulations*, summarizes the groundwater budget for each of the ten simulations. Note that the boundary inflow and outflow are relatively constant across spreading scenarios and between the two alternative boundary head assumptions. Boundary outflow increases as spreading increases and the change in total outflow is relatively small as compared to boundary inflow and to storage changes. This observation is significant to future groundwater management activities in that future investigations that resulted in refinement of boundary heads would be a lower priority than investigations related to the spreading operations or the geologic features between the spreading basins and the production wells.

Table 6-1
Summary of Groundwater Budget for Ten Simulations

Scenario	Inflow			Outflow			Storage Change
	Spreading	Boundary Inflow	Total Inflow	Pumping	Boundary Outflow	Total Outflow	
2006 Boundary Heads & 5K Spreading	5,000	6,936	11,936	26,961	1,335	28,296	-16,360
2006 Boundary Heads & 10K Spreading	10,000	6,458	16,458	26,961	2,117	29,078	-12,620
2006 Boundary Heads & 15K Spreading	15,000	6,198	21,198	26,961	3,117	30,078	-8,880
2006 Boundary Heads & 20K Spreading	20,000	5,995	25,996	26,961	4,175	31,136	-5,141
2006 Boundary Heads & 25K Spreading	25,000	5,834	30,835	26,961	5,276	32,237	-1,402
Declining Boundary Heads & 5K Spreading	5,000	6,676	11,676	26,961	1,394	28,356	-16,680
Declining Boundary Heads & 10K Spreading	10,000	6,230	16,231	26,961	2,210	29,171	-12,940
Declining Boundary Heads & 15K Spreading	15,000	5,978	20,978	26,961	3,218	30,179	-9,202
Declining Boundary Heads & 20K Spreading	20,000	5,785	25,785	26,961	4,288	31,249	-5,464
Declining Boundary Heads & 25K Spreading	25,000	5,631	30,631	26,961	5,396	32,357	-1,726

All values represent average of 2006-2030 Simulation and are in AF/yr.

7.0 Analysis Assumptions and Limitations

The modeling was completed in accordance with the following technical methodology and assumptions:

- Because of the volume of previously published data available for the MCGS, no subsurface soil or groundwater investigations were performed as part of this scope of services. Accordingly, Psomas' interpretations and recommendations are based solely on our analyses of available data from previous investigations and reports, extensive discussions with MSWD staff, and limited field investigations.

- It is further assumed that existing and proposed pumping occurs an average of 18 hours per day, 365 days a year and that the total volume for each well is as presented in Table 4-2. This is simulated as an equivalent constant pumping rate.

- This analysis assumes that the water produced from proposed wells will be in addition to the existing pumping from other production wells. This approach provides for a "worst-case" drawdown prediction from proposed pumping. Any gradual increase in pumping during initial startup of new wells and/or any reduction of other production wells during the twenty-five year evaluation period will result in a water level drawdown that is lower than estimated.

- The aquifer formation is composed of porous media, with groundwater flow obeying Darcy's law.

- All well diameters are sufficiently small that the volume of water removed from the well bore during pumping is negligible.

Model Limitations

- A groundwater model is an approximation of actual conditions. The accuracy of the model results depends on the accuracy of the input data. The groundwater water model for this study was constructed with available historical and site specific hydrological data to determine groundwater flow direction, contributing recharge areas to the MCGS, and spreading basin water deliveries. A correct interpretation of the model results should consider the following:

    - Model parameters such as hydraulic conductivity are applied uniformly to a model cell. The assumption of homogeneity may case inaccuracies because field conditions, geologic formations, and climatic conditions are typically heterogeneous.
    - The groundwater model was discretized using a grid with cells measuring 500 feet by 500 feet. Model results are evaluated on a regional basin scale and should not be used for detailed analyses such as simulating water level drawdown near a single well.

- Well pumping rates used in the groundwater model were average annual rates for municipal and private wells. Use of average annual pumping rates may introduce some error in the smaller time increments (e.g., monthly, weekly, or daily) water level drawdown results.

8.0 References

Anderson, Mary P., Woessner, William W., Applied Groundwater Modeling – Simulation of Flow and Advective Transport, Academic Press, Inc., 1992

Biehler, S., A Geophysical Investigation of the Desert Hot Springs Area, Upper Coachella Valley, California, 1979

California Department of Water Resources, Coachella Valley Investigation. Bulletin No. 108, 1964.

California Division of Mines and Geology (Proctor, Richard), Geology of the Desert Hot Springs – Upper Coachella Valley Area, California – Special Report 94, 1968

Coachella Valley Water District, Urban Water Management Plan - Final Report, December 2005

Drenth, Benjamin J., Moore, Douglas; Young, Charles T; Michigan Technological University, Geophysical Response Of The Mission Creek Fault Near Desert Hot Springs, California, 2003.

Fox, Robert C., and Groundwater Resources Investigation: Update, October 1992.

Geotechnical Consultants Inc. (GTC), Hydrogeologic Investigation, Mission Creek Subbasin within the Desert Hot Springs County Water District, 1979

GSi/water, Gravity Survey Data, Personal Communication, 2003.

GSi/water, Ground Water Input to the Alluvium Basin of the Mission Springs Water District, January 2005

Harbaugh, Arlen W., Banta, Edward R., Hill, Mary C., and McDonald, Michael G., 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.

Krieger & Stewart Inc., Groundwater Recharge Potential within Mission Creek Subbasin, November 1980

Krieger & Stewart Inc., Engineers Report – Basin Water Supply and Initial Ground Water Replenishment And Assessment Program For The Mission Creek Subbasin, April 2003.

Mayer, Alex S. and May, Wesley L. - Mathematical Modeling of Proposed Artificial Recharge for the Mission Creek Subbasin. Final Draft Report. Department of Geological Engineering and Sciences, Michigan Technological University, Houghton, Michigan.

Psomas, 2004a. Hydrogeological Evaluation and Drawdown Analysis for Little Morongo/900 Zone Well Project, Mission Creek Subbasin. Report prepared for Mission Springs Water District, Desert Hot Springs, California, June 2004

Psomas, 2004b. Preliminary Water Balance for the Mission Creek Groundwater Sub-Basin. Report prepared for Mission Springs Water District, Desert Hot Springs, California, January 2004

Michigan Technological University, Mathematical Modeling of Proposed Artificial Recharge of the Mission Creek Subbasin, January 1998.

Mission Springs Water District, Mission Springs Water District Urban Water Management Plan 2000, 2000.

Mission Springs Water District, Mission Springs Water District Urban Water Management Plan 2005, February 2006.

Slade & Associates LLC, Hydrogeological Evaluation, Well Siting, and Recharge Potential Feasibility Study – Mission Creek Groundwater Subbasin Riverside County, California, May 2000.

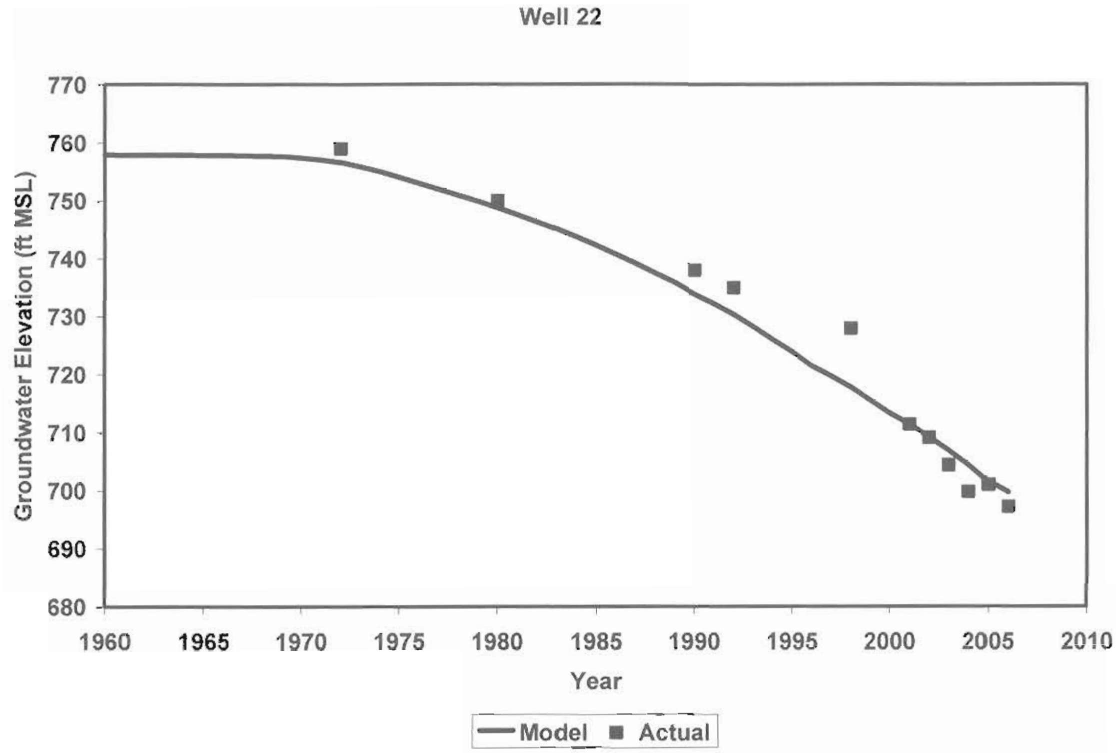
Tyley, S.J., Analog Model Study of the Ground-Water Basin of the Upper Coachella Valley, California, U.S. Geological Survey Water-Supply Paper 2027. 1974

Todd, D.K., Ground Water Hydrology, 1980.

United States Geological Survey, Evaluation of a Groundwater Flow and Transport Model of the Upper Coachella Valley, California, Water Resource Investigation Report 91-4142, 1992.

United States Geological Survey, Hydrology of the San Bernardino Mountains and Eastern San Gabriel Mountains California – Hydrologic Investigations Atlas HA1, 1954.

Appendix A
Hydrographs of Actual and Model Estimated Groundwater Elevations


Well 22
770
760
750
740
730
720
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Groundwater Elevation (ft MSL)
1960
1965
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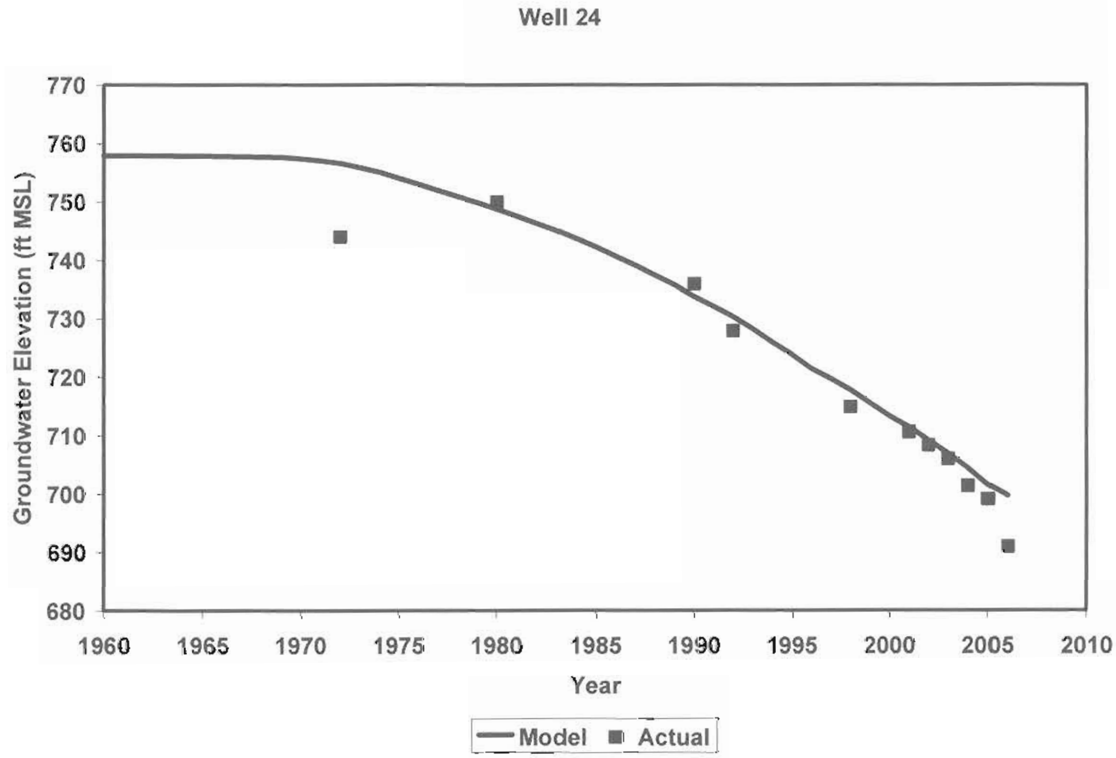
2000
2005
2010
Year
Model
Actual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Groundwater Elevation (ft MSL)
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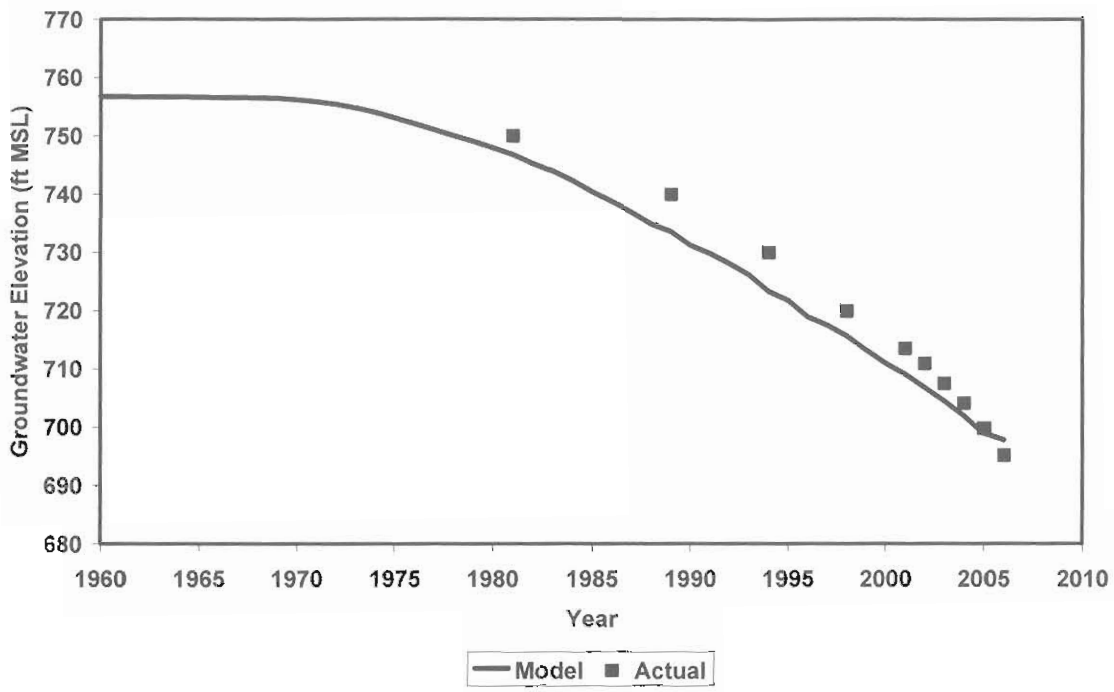
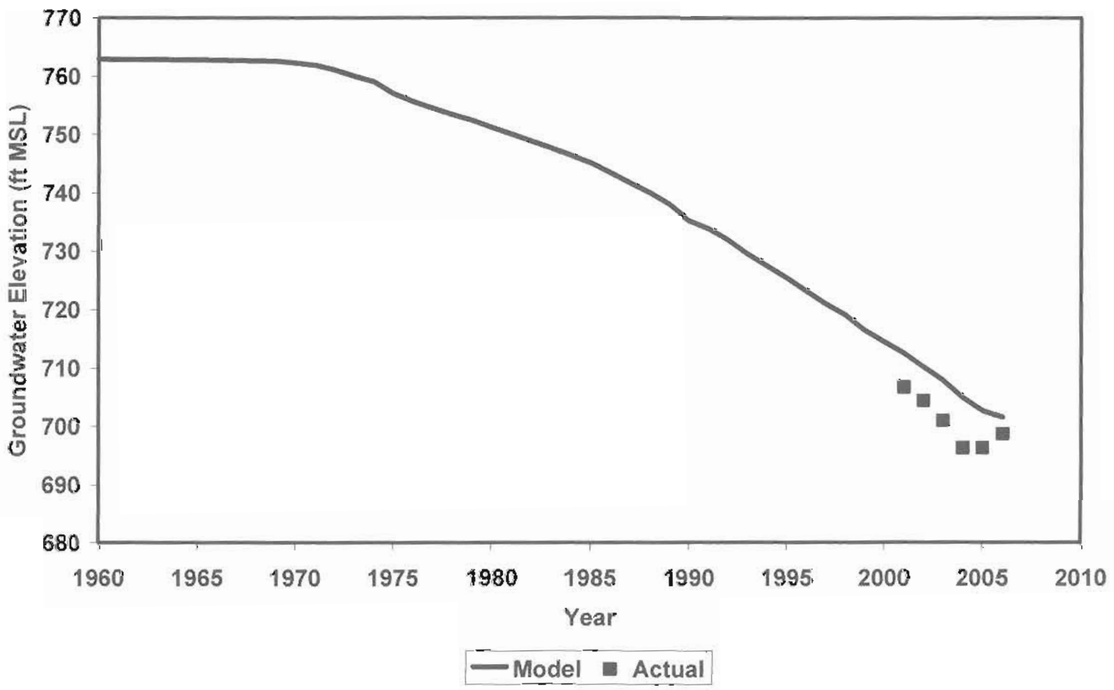
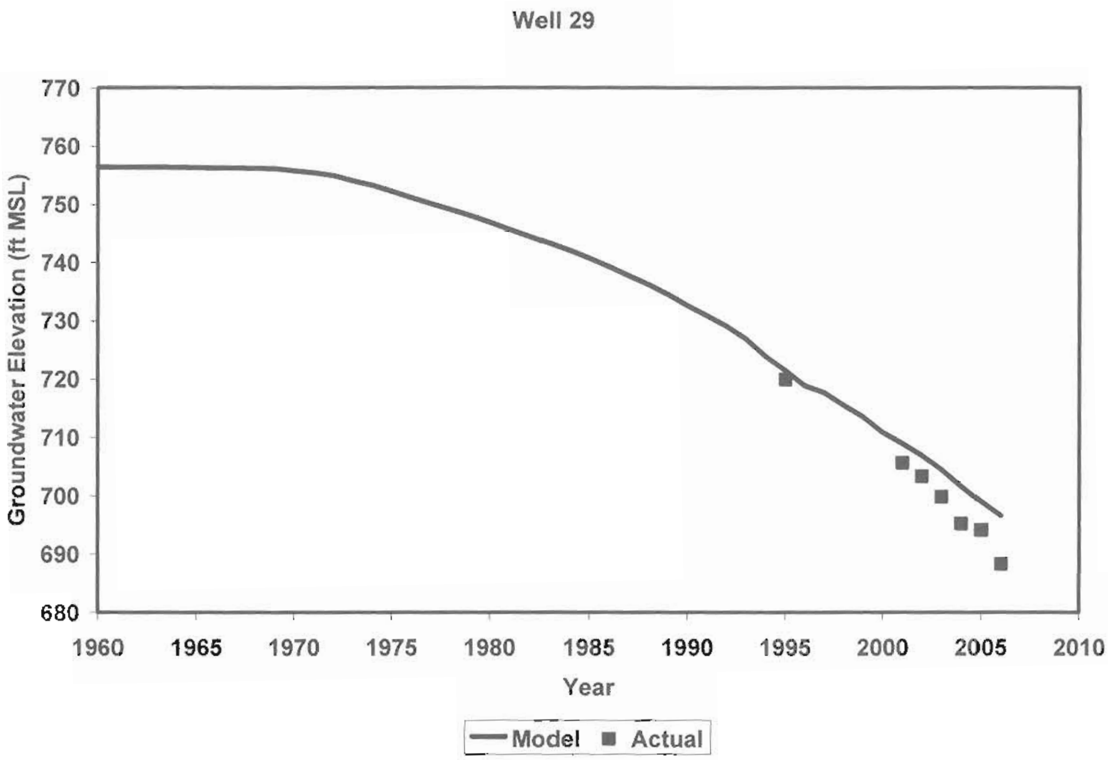
2005
2010
Year
Model
Actual

Well 27



Well 28




Well 29
Groundwater Elevation (ft MSL)
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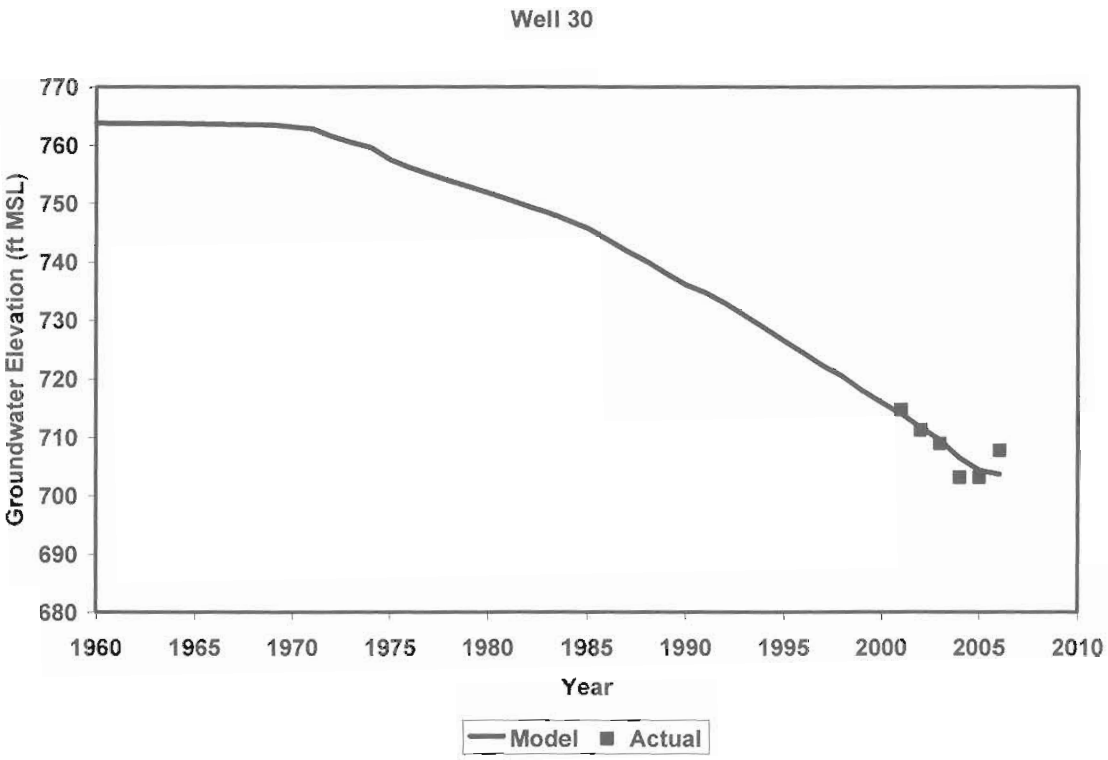
Actual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Groundwater Elevation (ft MSL)
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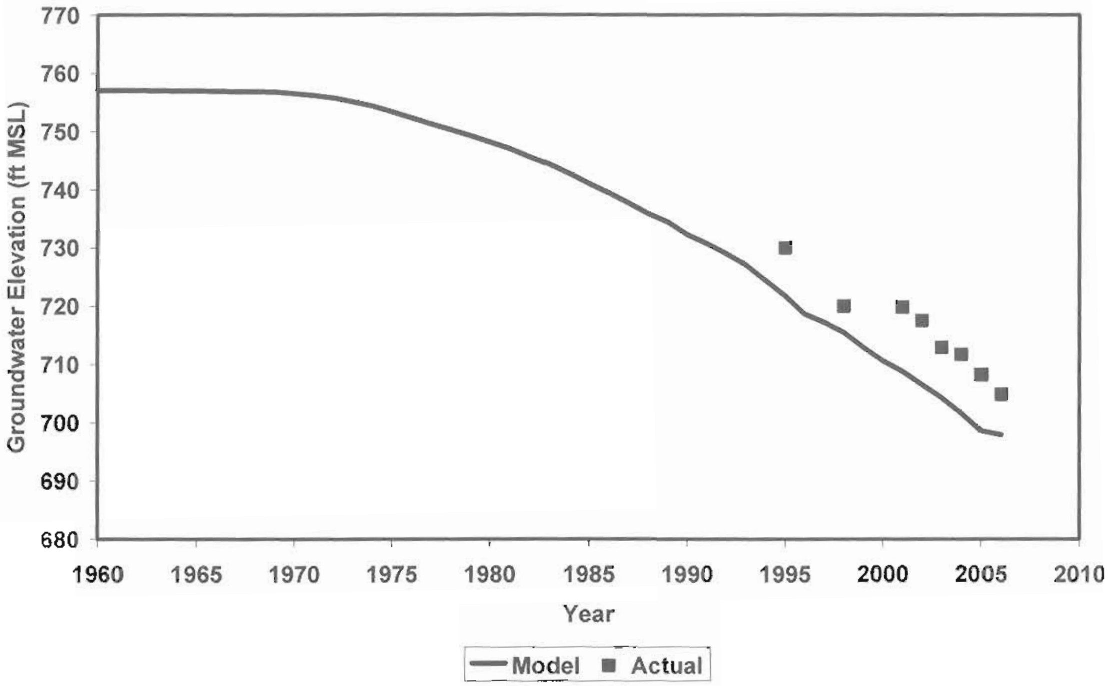
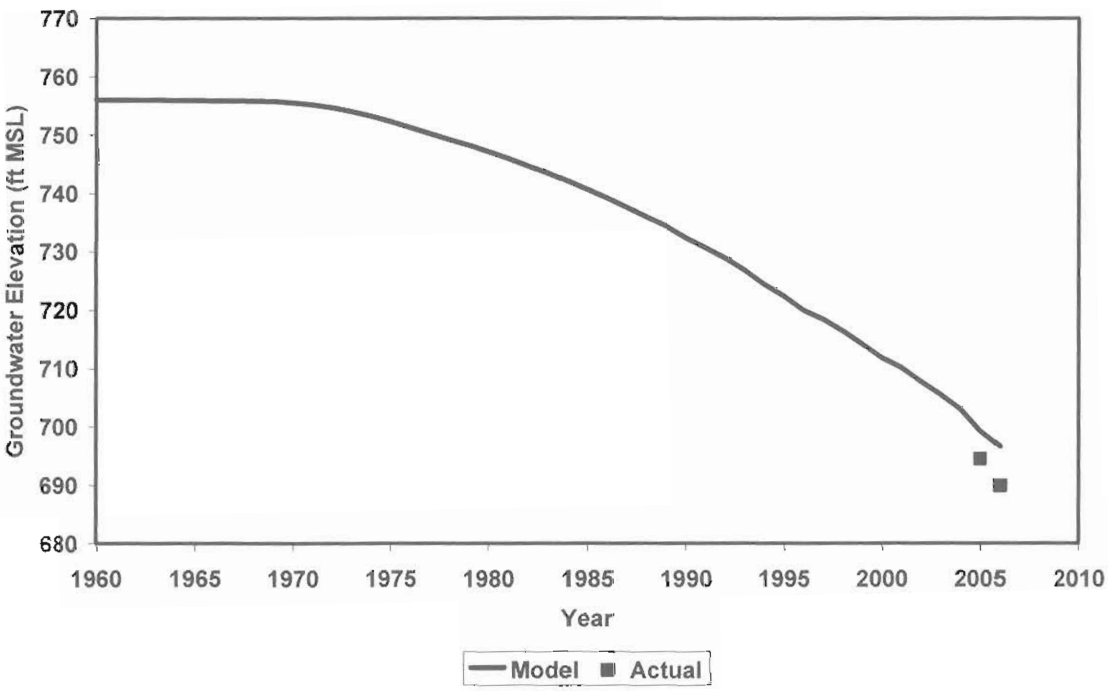
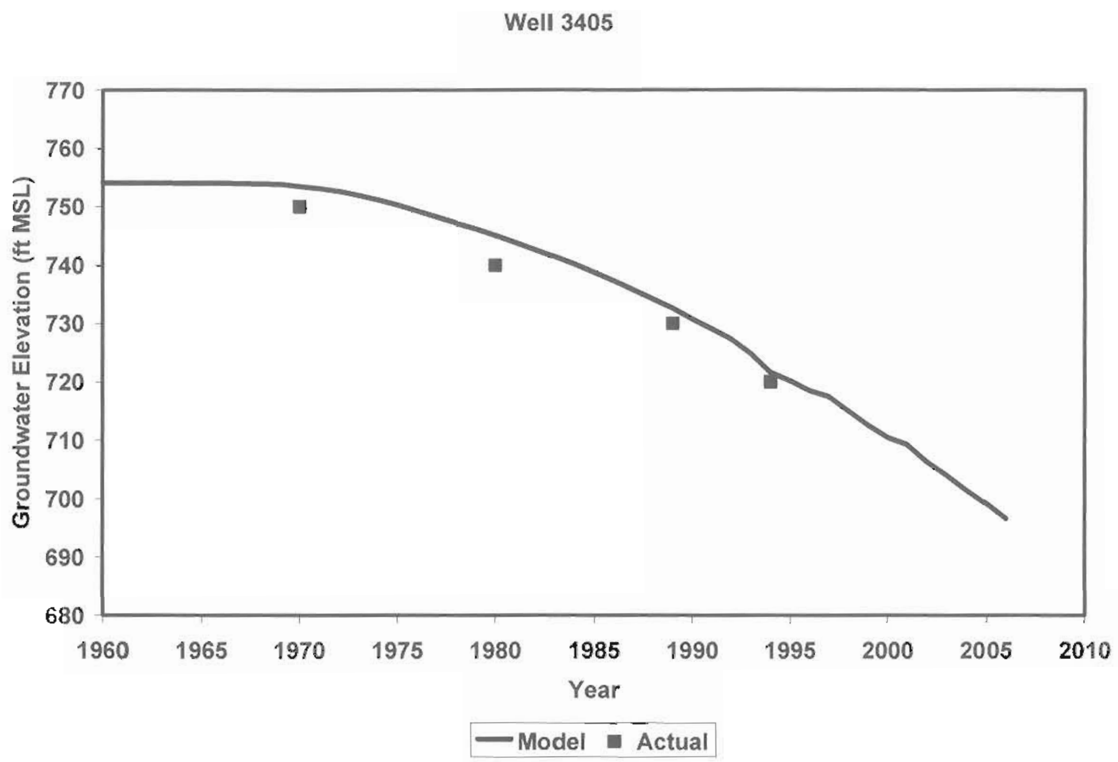
Year
Model
Actual

Well 31



Well 32

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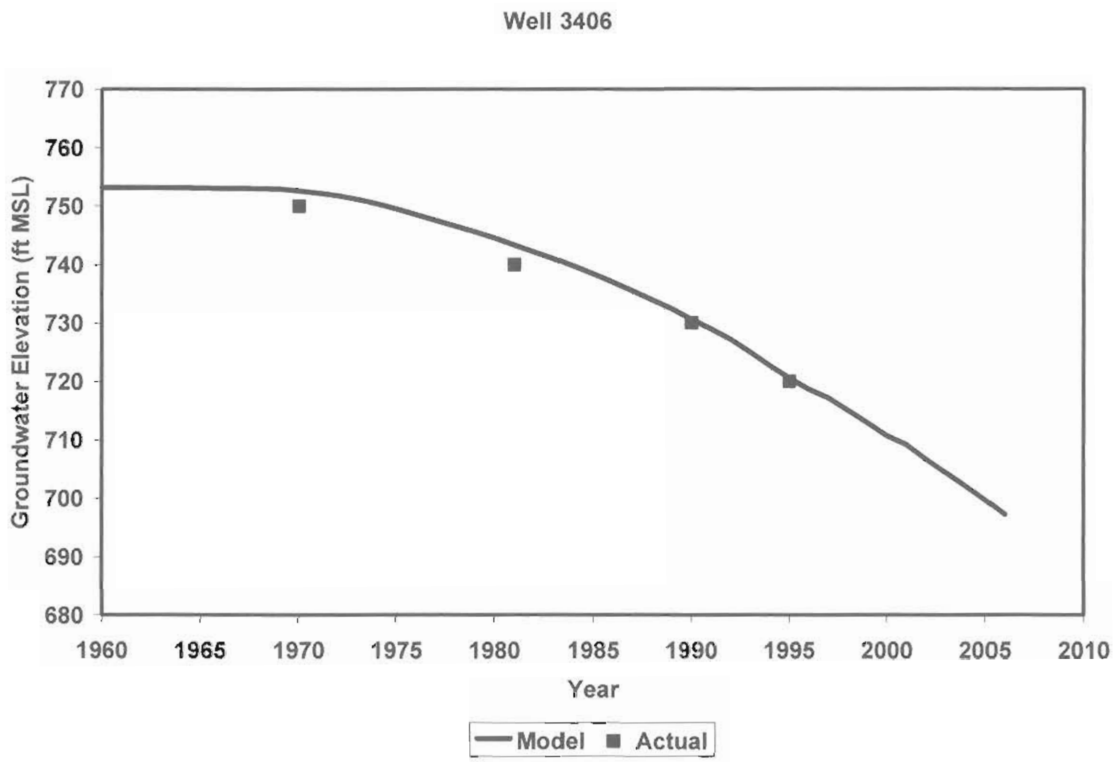
Groundwater Elevation (ft MSL)
1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010
Year
Model
Actual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Model
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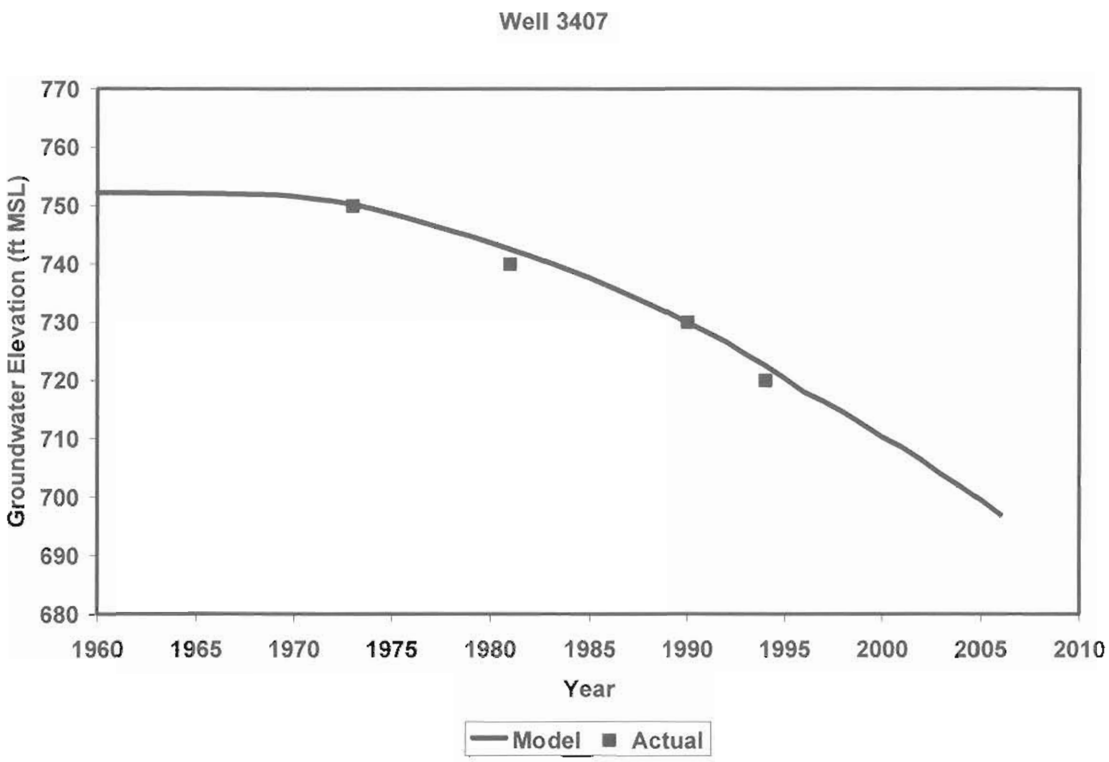
Well 3407
Groundwater Elevation (ft MSL)
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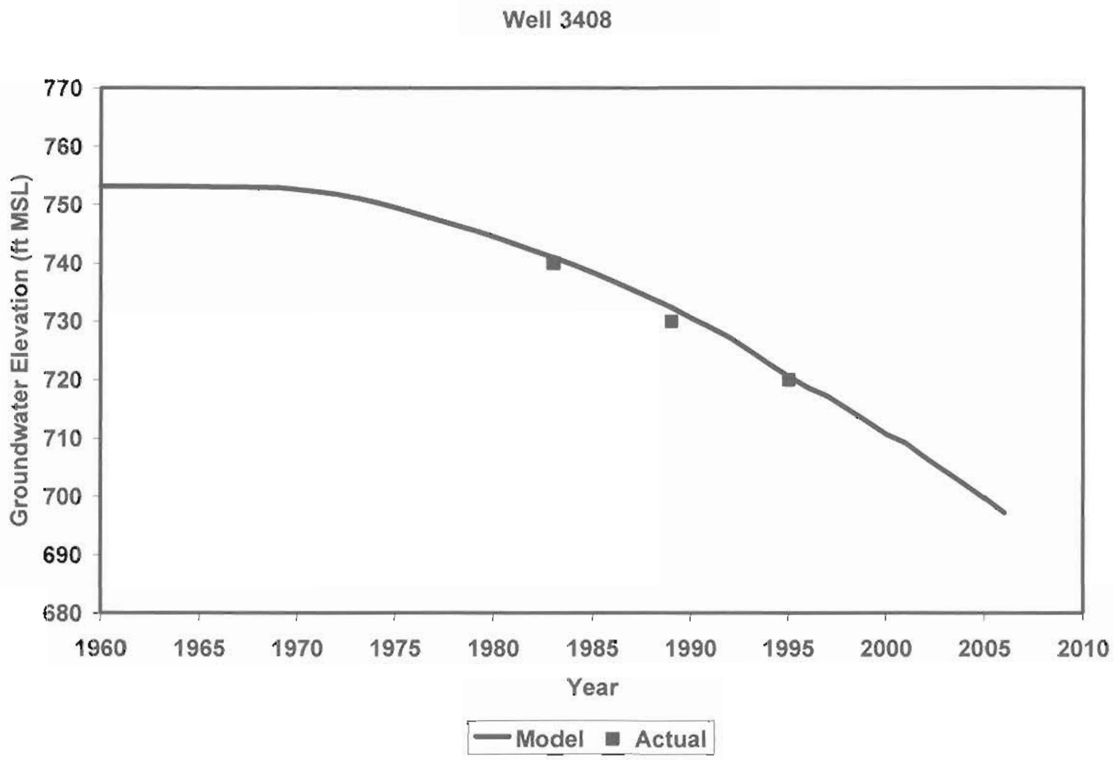
Well 3408
Groundwater Elevation (ft MSL)
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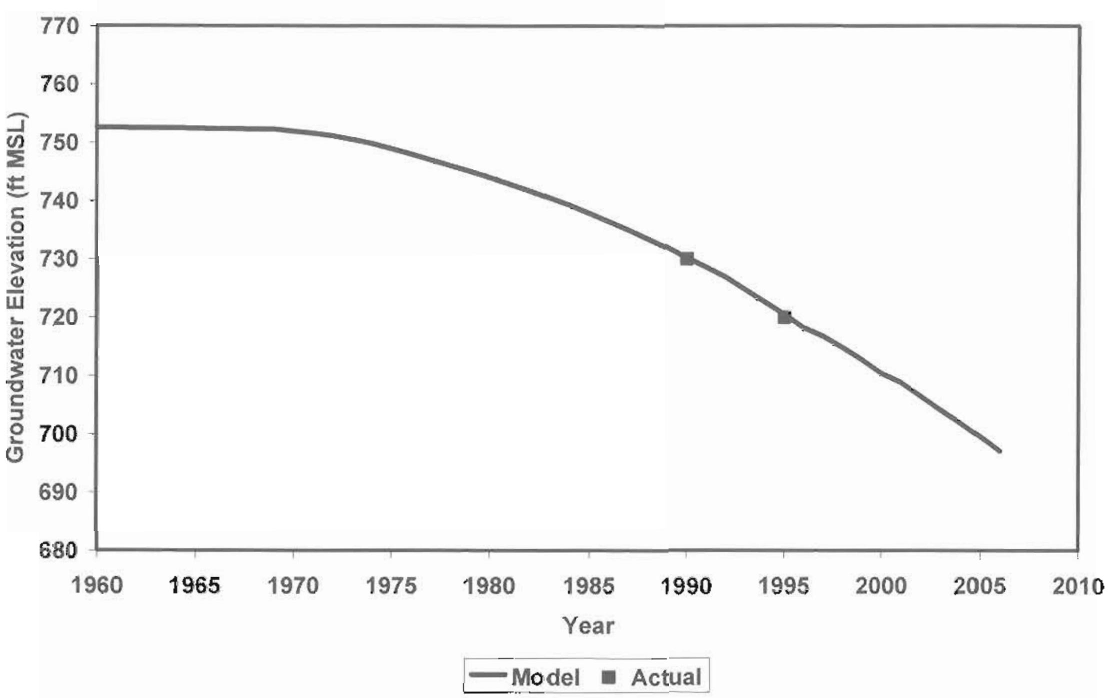
Year
Model
Actual

Well 3409



Well DWA