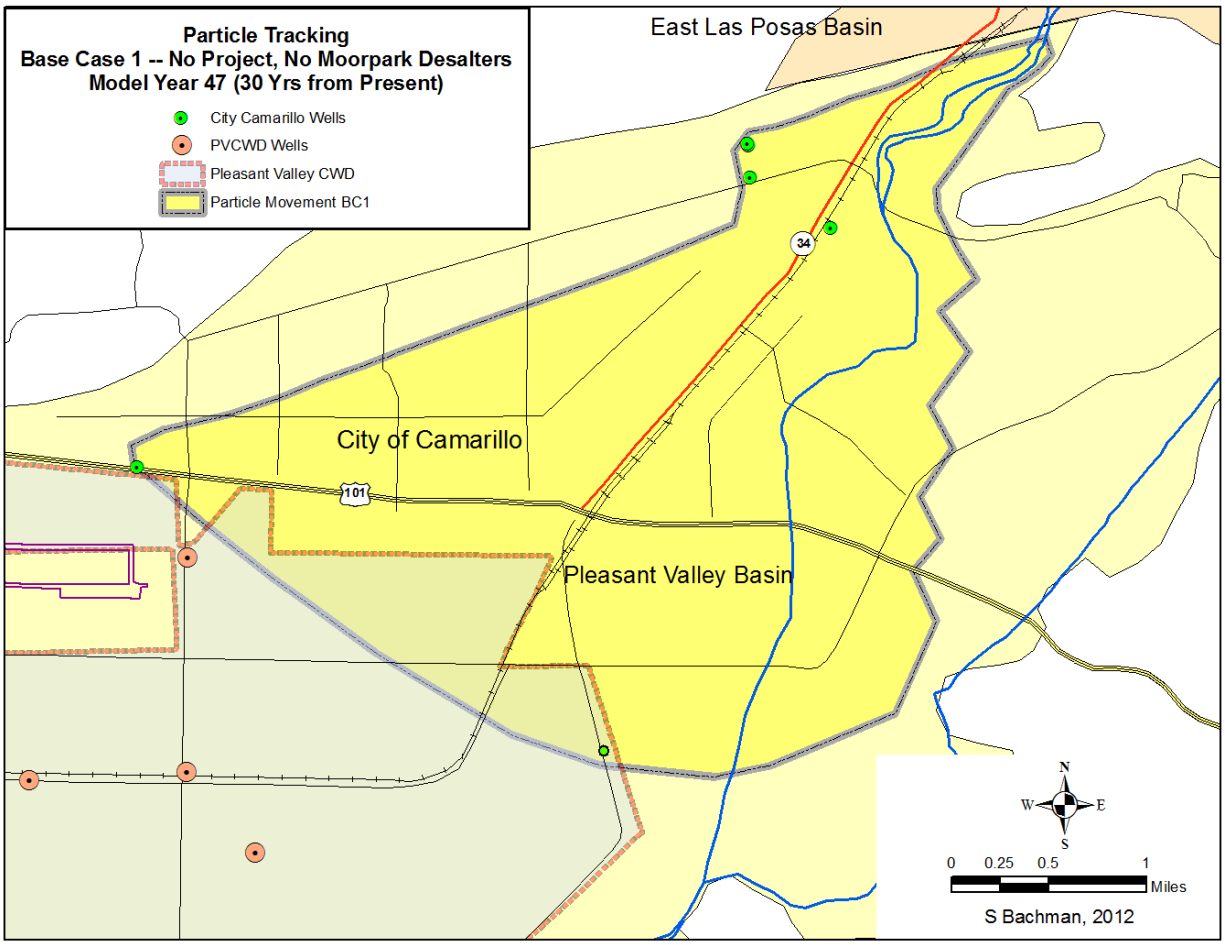
Northern Pleasant Valley Desalter Groundwater Analysis and Modeling

Report to Desalter Working Group



November, 2014

Prepared by Steven Bachman, PhD

Table of Contents

1 INTRODUCTION 1

2 HYDROGEOLOGY OF NORTHERN PLEASANT VALLEY BASIN 1

2.1 GENERAL GEOLOGY 2
2.2 HYDROGEOLOGY 5
Trends in Groundwater Elevations 5
Groundwater Quality 10
Subsidence 17
Aquifer Properties 17

3 ANALYSIS OF FLOW – ARROYO LAS POSAS 17

4 MODEL SETUP 24

4.1 MODEL HYDROGEOLOGY 24
4.2 MODELING CONDITIONS 25
4.3 STEADY-STATE MODEL 28
4.4 TRANSIENT CALIBRATION OF MODEL 28
PROJECT MODELING 33
Model Base Period 33
Modeling Inputs 35
Base Cases 35
Project Scenarios 36
Model Results in Groundwater Mound 37
Model Results within City of Camarillo 37
Model Results at Southern Edge of City of Camarillo 37
Further Optimizing of Desalter Wells Locations 38
25-Year Project 38

5 PARTICLE TRACKING 49

5.1 VERIFICATION OF PARTICLE TRACKING 49
5.2 PARTICLE TRACKING RESULTS 49

6 USING MODEL RESULTS 58

7 ANALYSIS OF RESULTS 62

7.1 PROJECT EFFECTS RELATIVE TO CURRENT CONDITIONS 62
7.2 EFFECT ON EXISTING WELLS 63
7.3 REMOVAL OF BRACKISH WATER 63
7.4 EFFECT ON WATER QUALITY AND SEAWATER INTRUSION 64

8 MARGIN OF ERROR 71

9 POTENTIAL FOR LAND SUBSIDENCE DURING PROJECT 72

10 MONITORING AND CONTINGENCY PLAN 74

10.1 MONITORING PLAN 74
Wells as Monitoring Points 74
Surface Water Monitoring 75
Monitoring Data Analysis 76
Reporting 76
10.2 CONTINGENCY PLAN 78
Contingency Plan for Groundwater Elevations 78
Contingency Triggers for Groundwater Elevations 78

Contingency Actions for Groundwater Elevations 79
Contingency Plan for Groundwater Quality *81*

11 RECOMMENDATIONS 84

12 CONCLUSIONS 85

13 LIMITATIONS 86

14 APPENDIX 87

14.1 WATER QUALITY GRAPHS 87
14.2 AQUIFER TESTING 88
14.3 ADDITIONAL CALIBRATION WELLS 115
14.4 ADDITIONAL PROJECT RESULTS 117

1 Introduction

Poor-quality brackish water from upstream discharges has infiltrated into the northern Pleasant Valley basin (NPV) since 1994. This infiltration has caused a large mound of poor-quality groundwater in NPV that has both raised groundwater elevations almost 200 ft within the mound and deteriorated groundwater quality for both agricultural and municipal pumpers. The proposed NPV Desalter project aims to reverse the water quality degradation by pumping poor-quality groundwater from the mound and treating it to drinking water standards. The timing of the proposed project is dependent upon the arrival of the Salinity Management Pipeline (SMP) into the Camarillo area near the location of the proposed project because brine from the reverse osmosis treatment process must be discharged to the SMP.

This study included constructing a groundwater flow model to simulate a range of scenarios to help answer several questions:

- Groundwater elevations – would the NPV Desalter pumping effectively reduce the mound of poor quality groundwater and prevent its migration into the main portion of the Pleasant Valley basin? Could the pumping occur without adversely affecting the basin and other pumpers?
- Water quality – how far has the poor-quality water spread into the basin[1]? Could the project pull this water back effectively? What duration of desalting project would the re-captured water sustain? Would all the poor-quality water be extracted?
- Project Capacity – how many wells would be required, what capacity could be pumped and treated, what would pumping rates be, and where would the desalter wells be located?

The study consisted of collecting and analyzing surface water and groundwater data, constructing and calibrating a groundwater flow model, simulating salt migration through particle tracking modeling, and analyzing a number of model scenarios to test capacity and location of desalter wells, and the groundwater response to this pumping.

2 Hydrogeology of Northern Pleasant Valley Basin

NPV is the northern extension of the main Pleasant Valley basin, an important source of groundwater for both urban use and the irrigation of the extensive crops of the Oxnard Plain. The discussion of the hydrogeology of the NPV is organized from the general to the specific, with general geology followed by aquifer testing and aquifer properties.

[1] Poor quality water defined as exceeding Los Angeles Regional Water Quality Control Board, Basin Plan Objectives, TDS 700 mg/L, sulfate 300 mg/L, chloride 150 mg/L (*http://www.waterboards.ca.gov/losangeles/water_issues/programs/basin_plan/electronics_documents/bp3_water_quality_objectives.pdf*)

2.1 General Geology

Historical interest in NPV has largely focused on structural geology, with a number of faults identified over the years. Because some of these faults are considered active, evaluating these faults in terms of geologic hazards has been a priority. Some of these faults have surface expression, whereas others are buried in the alluvium (Figure 1 indicates faults as they are depicted by the U.S. Geological Survey in their latest GIS coverage[2]). Whether any of these faults impede groundwater movement is discussed in the next section.

Faulting and accompanying folding in NPV is largely controlled by regional stresses associated with the rotation and movement of the Transverse Ranges. Compressional forces dominate, with the major faults in the area having a significant component of north-south thrusting. The Simi-Santa Rosa Fault Zone (Figure 1) is associated with anticlinal folding, both along the Camarillo Hills and as shown crossing Section A-A' just south of the Reunion Beryl #2 well. NPV is located in a syncline that trends south-southwest through the approximate location of the Pitts #1 well.

Two cross sections were constructed approximately orthogonally through the center of NPV (Figure 1). Stratigraphic correlations along the section lines were made primarily using oil well geophysical logs, supplemented by water well drillers logs. Section A-A' was tied on both ends to Turner and Mukae's (1975) regional cross sections B-B' and D-D'. The sections were also tied to cross sections being constructed by United Water Conservation District as part of the effort to revise the Ventura Regional Groundwater Model. The interpreted geophysical log for the Pitts #1 well is shown in Figure 2.

The water-bearing units of the Lower (LAS) and Upper (UAS) Aquifer Systems rest on both older sedimentary units and Conejo Volcanics. The UAS and LAS together reach a thickness of as much as 1,500 ft in NPV (Figure 3, Figure 4). The basal LAS consist of the Grimes Canyon Aquifer overlain by the Fox Canyon Aquifer. The Fox Canyon is now the primary water-producing unit in NPV. The LAS is folded and partially truncated at the north end of NPV (Figure 3). This truncation is evident where the LAS is exposed in the hills on the west and east sides of northernmost NPV (Figure 1). Along Arroyo Las Posas, this truncation surface is unconformably overlain by the sediments deposited by the arroyo (description in following paragraph). The UAS is present in NPV but is not a major water-producing unit. It is entirely truncated in the northern portion of NPV (Figure 3).

Unconformably overlying the UAS and LAS is an alluvial unit deposited along the Arroyo Las Posas. Drillers' logs indicate that this alluvial unit, herein designated as the Shallow Aquifer, consists of sand and gravel, with finer-grained units in overbank locations (e.g., Figure 4). The maximum thickness of the unit in NPV is about 200 ft. Where the sand and gravel facies of the Shallow Aquifer overlies the Fox Canyon Aquifer, there is a ready conduit for recharge from the arroyo to the Fox Canyon (e.g., Figure 3). This occurs in a limited area within NPV, but apparently is the main recharge area for NPV. The limits of this recharge area are discussed in the next chapter.

[2] USGS, 2003, *Simulation of Groundwater/Surface Water Flow in the Santa Clara-Calleguas Basin, Ventura County, California*, WRIR 02-4136, 157 p.

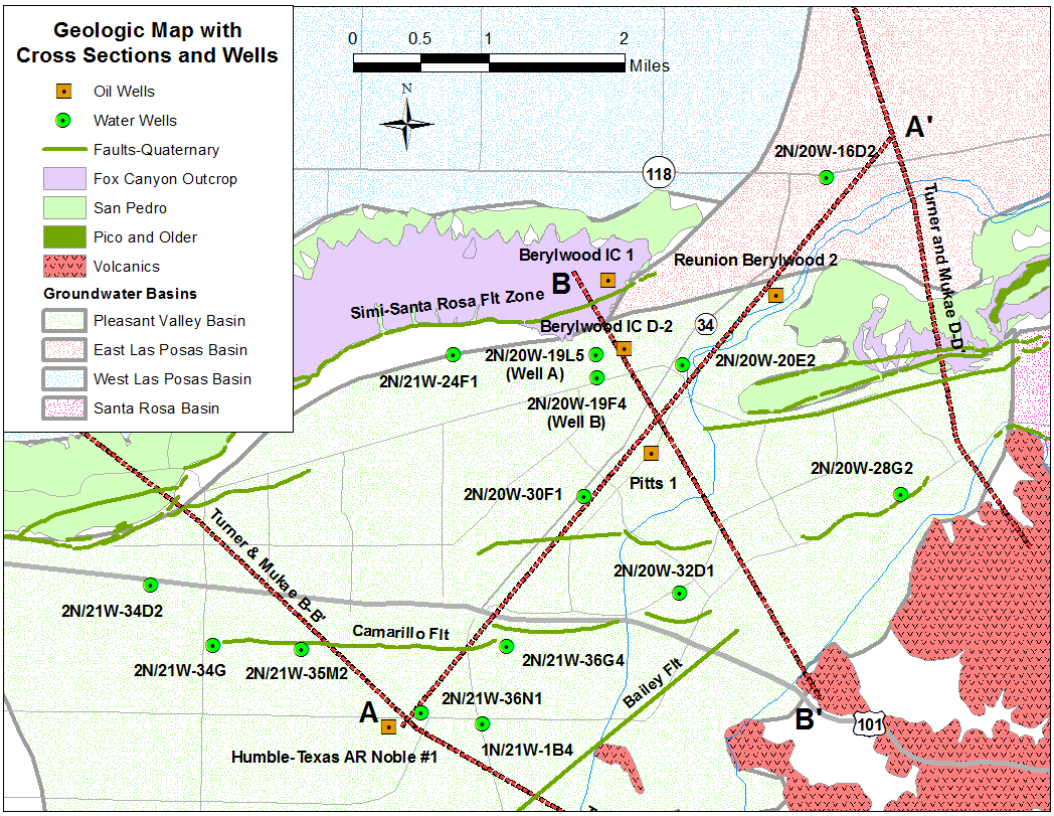


Figure 1. Geologic map of NPV indicating location of cross sections in following figures. Wells used in hydrographs are also shown.

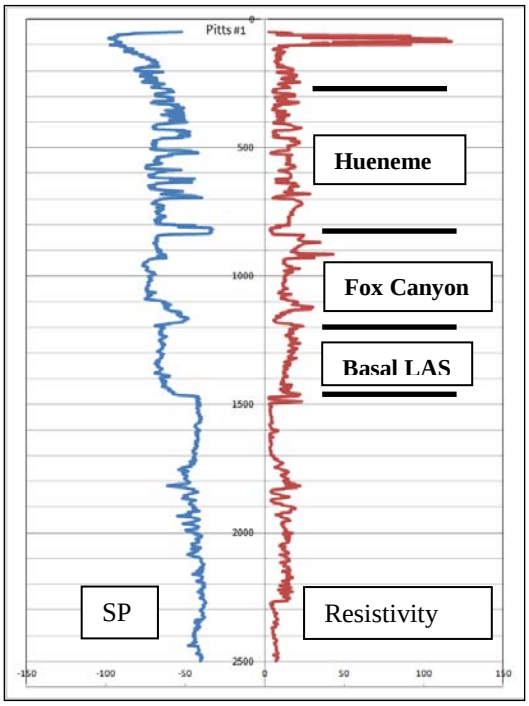


Figure 2. Geophysical log from Pitts #1 oil well (see location map). SP (spontaneous potential) is measured in millivolts; resistivity is measured in ohms m^2/m.

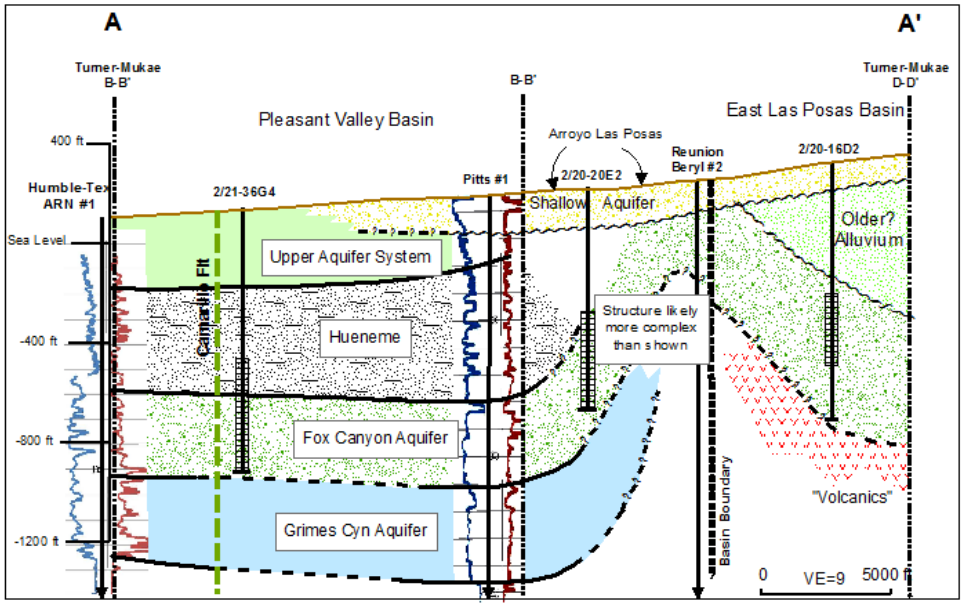


Figure 3. Section A-A' that crosses the project area from southwest (A) to northeast (A') (see location map). The southern end of the section ties to Turner-Mukae's section B-B' and United Water's regional cross sections and the northern end of the section ties to Turner-Mukae's section D-D'. The northern end of the project area is located at the basin boundary, where an anticline (and likely at least one fault structure) forms the boundary between NPV and the East Las Posas basin. Note that the Fox Canyon Aquifer is truncated by the Shallow Aquifer near the basin boundary; where this relationship occurs, water from the arroyo can percolate through the Shallow Aquifer into the Fox Canyon Aquifer, providing a conduit for movement of brackish water from the arroyo into the Fox Canyon. Perforations in water wells are indicated by hachured areas.

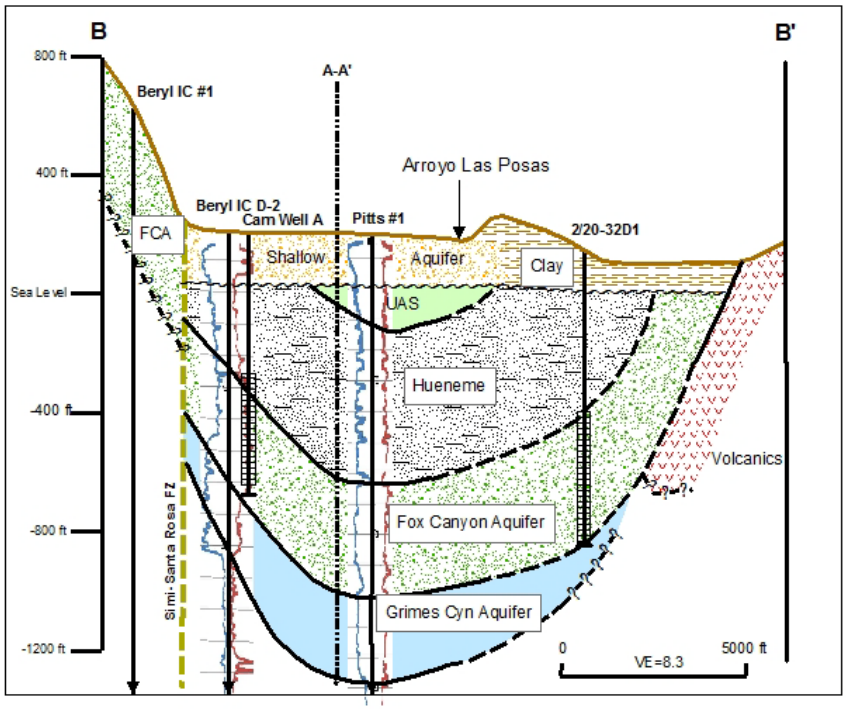


Figure 4. Section B-B' that crosses the project area from northwest (B) to southeast (B') (see location map). Although this section indicates the same relationships between geologic units as Section A-A', the Fox Canyon Aquifer in Section B-B' is overlain by clay-rich alluvium and does not present a ready path for movement of surface water into the Fox Canyon Aquifer.

2.2 Hydrogeology

NPV has seen rapid changes in both water levels and water quality over a two-decade period. The trigger for these changes appears to be the advent of overflow of dry-weather flow from the Las Posas basin, with the dual effect of rapidly raising groundwater elevations from this new source of recharge and deterioration of water quality from the poorer-quality baseflow in the arroyo.

Trends in Groundwater Elevations

Hydrographs constructed in the northern portion of NPV (Figure 1) exhibit the rapid rise (over 200 ft) in groundwater elevations that began in the early 1990s (Figure 5). In the portions of NPV closest to the Santa Rosa basin (and away from the recharge area in NPV), groundwater elevations had risen by about 50 ft by 2005 (Figure 6); there are no data available for later time periods in that area. South across Highway 101, there was a less substantial rise in groundwater elevations (Figure 7, Figure 8, Figure 9), with water level trends complicated by recovery from drought pumping in the late 1980s and early 1990s, increased in-lieu surface water deliveries by United Water Conservation District, and the beginning of the Conejo Creek Project.

Groundwater elevation maps were constructed for Spring of 1994 (Figure 10) and 2011 (Figure 11). There was a significant pumping depression in NPV (groundwater elevations as low as 120 feet below sea level) in 1994 (Figure 10). The additional percolation from the dry-weather flow (base flow) of Arroyo Las Posas had sufficiently recharged the Lower Aquifer System of NPV that by 2011 the pumping depression was eradicated and a recharge mound

created (Figure 11). At its northern edge, this recharge mound creates heads that are near ground surface. Figure 12 indicates that groundwater elevations increased by as much as 225 ft from 1980 to 2011. As discussed previously, some of this rise in groundwater elevations south of Highway 101 is likely caused by increased in-lieu surface water deliveries by United Water Conservation District and the Conejo Creek Project to the area.

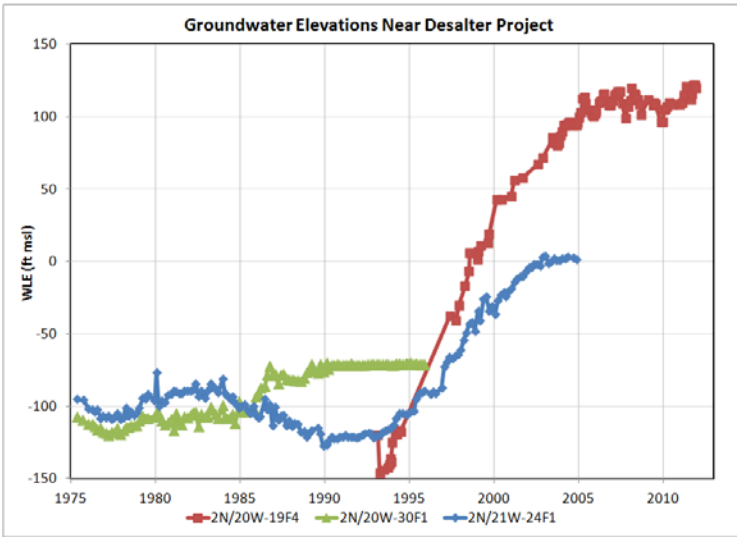


Figure 5. Hydrographs for wells near Desalter Project. See map for well locations.

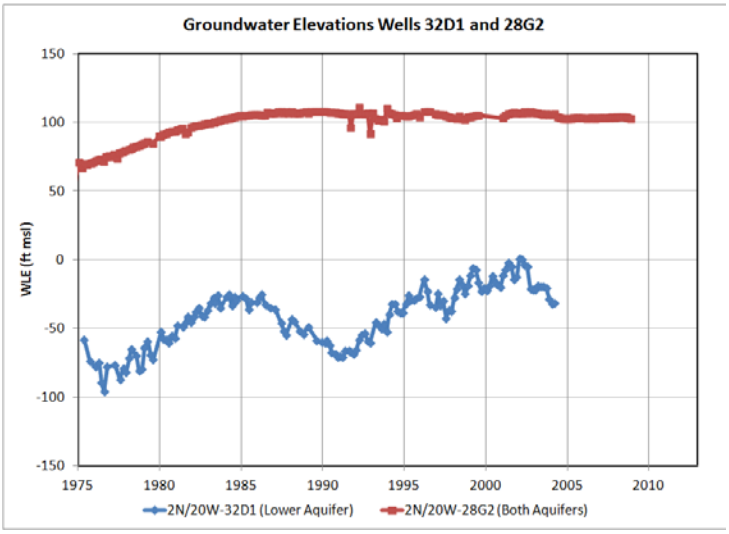


Figure 6. Hydrographs for wells 32D1 and 28G2. See map for well locations.

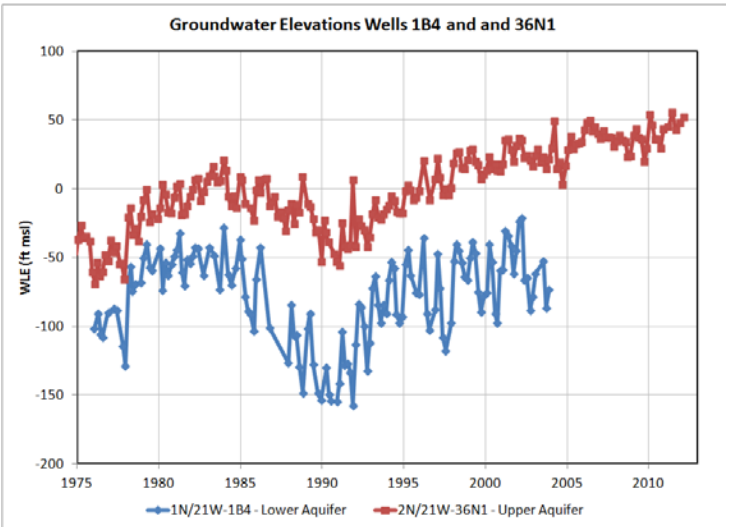


Figure 7. Hydrographs for wells 1B4 and 36N1. See map for well locations.

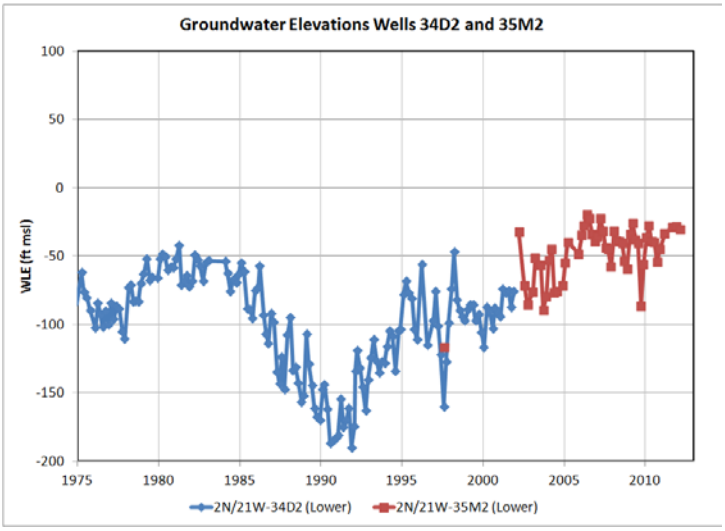


Figure 8. Hydrographs for wells 34D2 and 35M2. See map for well locations.

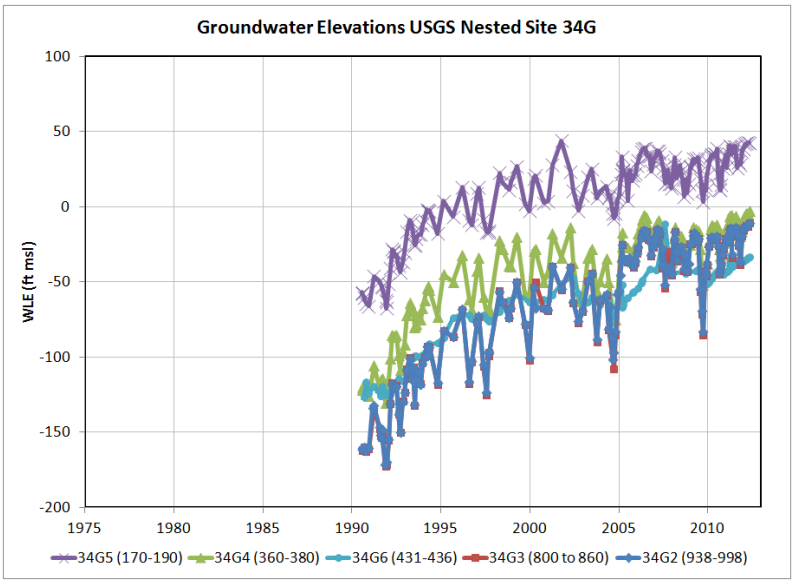


Figure 9. Hydrographs for USGS nested site 34G. See map for well locations.

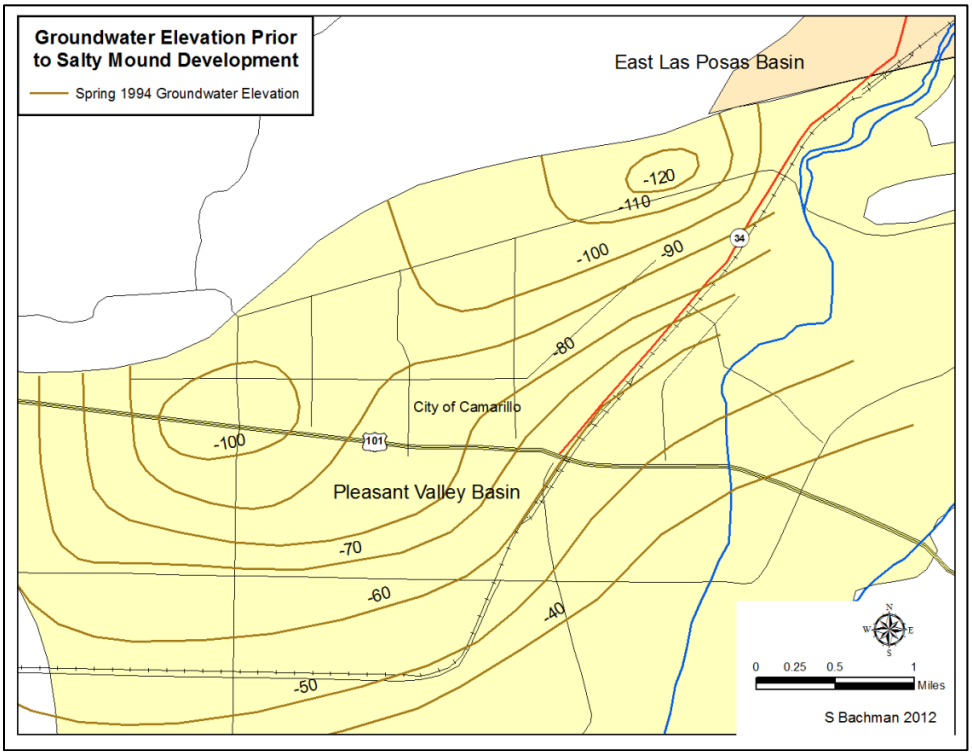


Figure 10. Groundwater elevation map for Spring 1994.

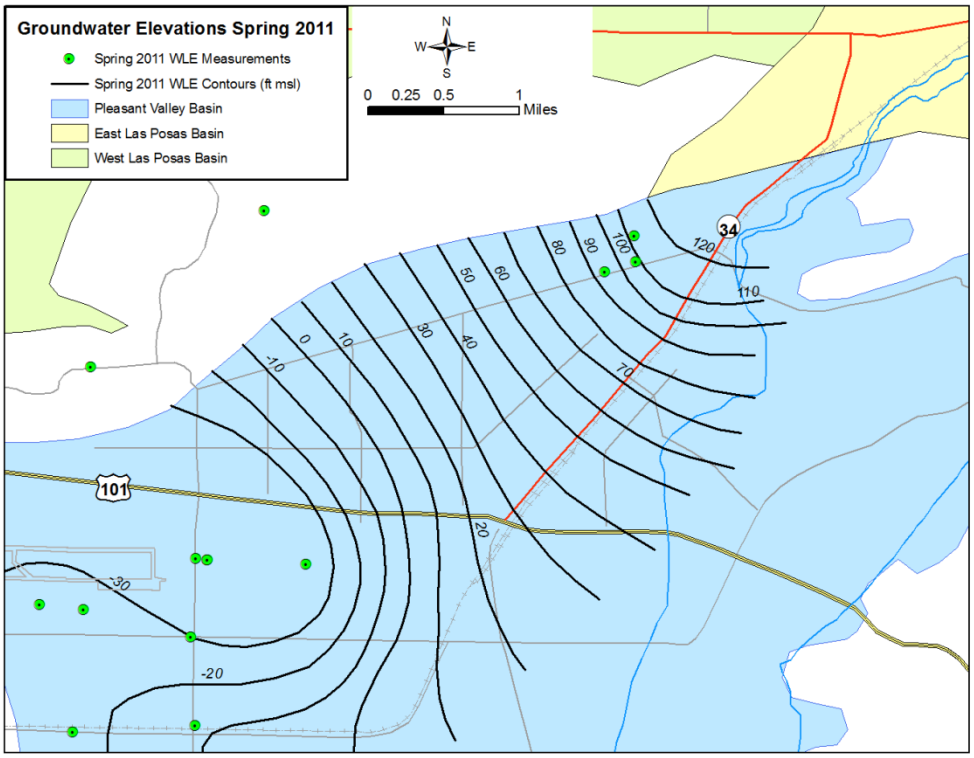


Figure 11. Groundwater elevation map for Spring 2011.

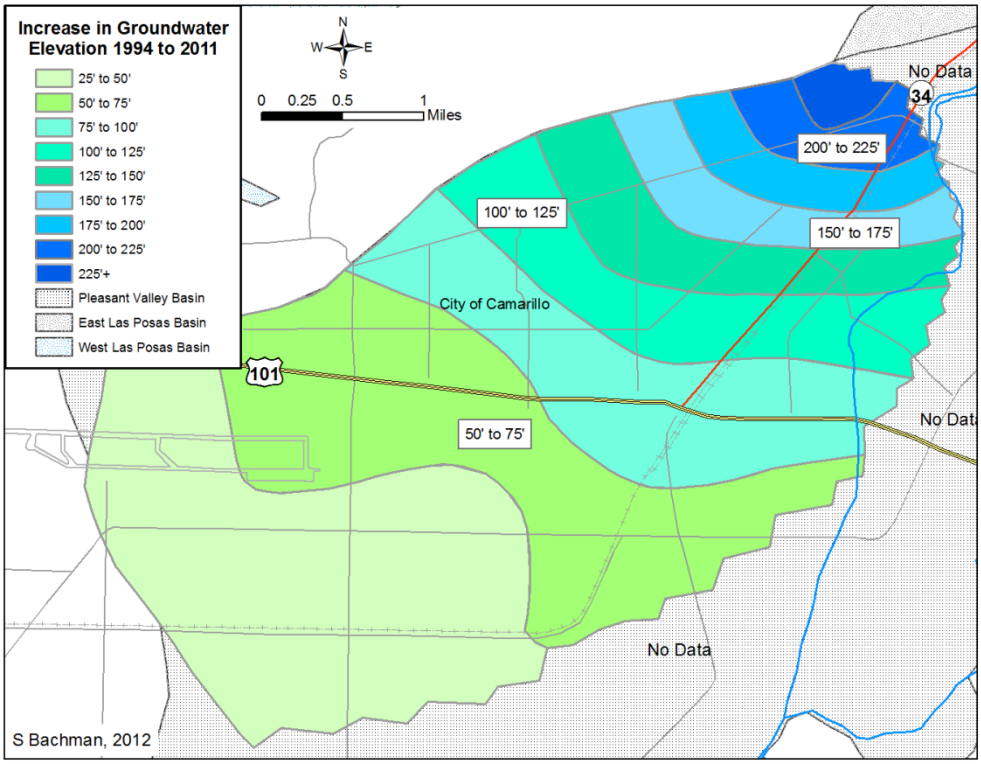


Figure 12. Increase in groundwater elevation from 1994 to 2011.

Groundwater Quality

The effect of the recharge of the poorer-quality base flow of Arroyo Las Posas is evident in the wells closest to the area of recharge in the northernmost wells in NPV. Figure 14 and Figure 15 show increases in sulfate, chloride, and TDS starting in the 1990s; Figure 14 shows the most distinct change in water quality sometime after year 1995. For context, groundwater elevations started to rise in about 1992 in these wells – a lag time between a rise in groundwater elevation and actual movement of the poor-quality out into the aquifer would be expected. The observed lag time was used to help calibrate the groundwater model.

PV wells located towards the center of the basin have not yet detected the water quality changes seen in the wells located in northern PV (Figure 16 to Figure 21). There is a data gap in recent sampling in much of NPV because the wells that provided earlier data have been destroyed as urban growth occurred. Thus, it is not known how much further the poor quality water has migrated southward in PV. The particle tracking analysis discussed in a later chapter models the possibilities for this migration.

Two additional water quality analyses were performed in NPV. Stiff diagrams (charting milliequivalents of major cations and anions) for the 1980s and in 2010-11 were constructed to examine differences in water quality with time and space (Figure 22 and Figure 23). There is a variety of water quality types shown in Figure 22, indicating different sources of water and/or different histories of migration of the waters. From the 1980s to 2010-11, the only evident change in water quality occurs in the northernmost wells, where sulfate and chloride now dominate the major ions. This is consistent with the determination of water quality documented in preceding paragraphs in this northern portion of NPV. The gap in recent data in NPV is also documented in Figure 23.

A series of graduated-dot maps were constructed for groundwater quality in NPV in 2010-11. Although chloride concentrations have increased in NPV, levels are below drinking water standards. In the main Pleasant Valley basin, chloride concentrations above 200 mg/L are problematic for irrigation of many crops (Figure 24) and are not related to the baseflow recharge in NPV. Increased TDS and sulfate concentrations in NPV are higher than drinking water standards (Figure 25 and Figure 26), one of the main reasons the NPV Desalter Project was conceived to remove the excess salts that have infiltrated into NPV.

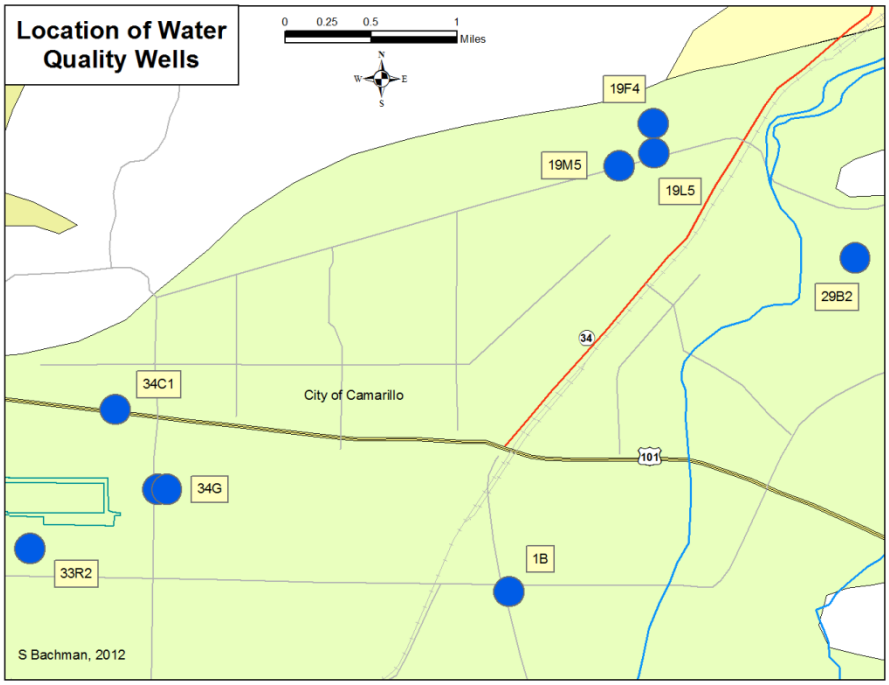


Figure 13. Location of wells with water quality graphs. Some of the graphs are in the Appendix.

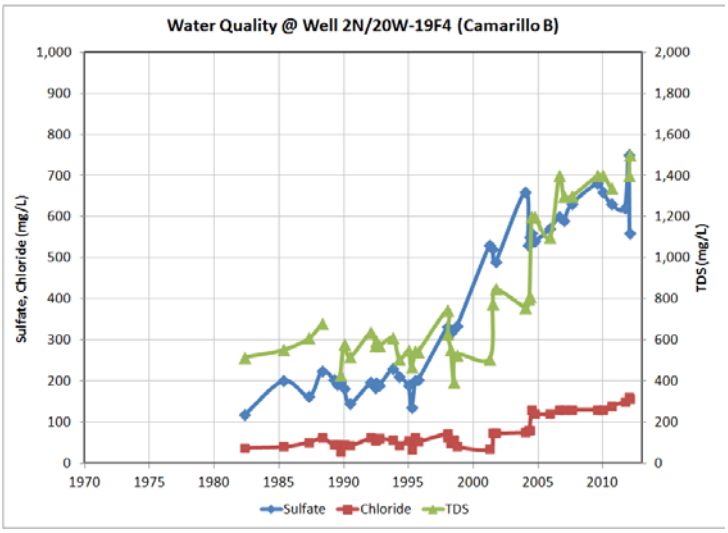


Figure 14. Water quality in well 19F4. See map for location.

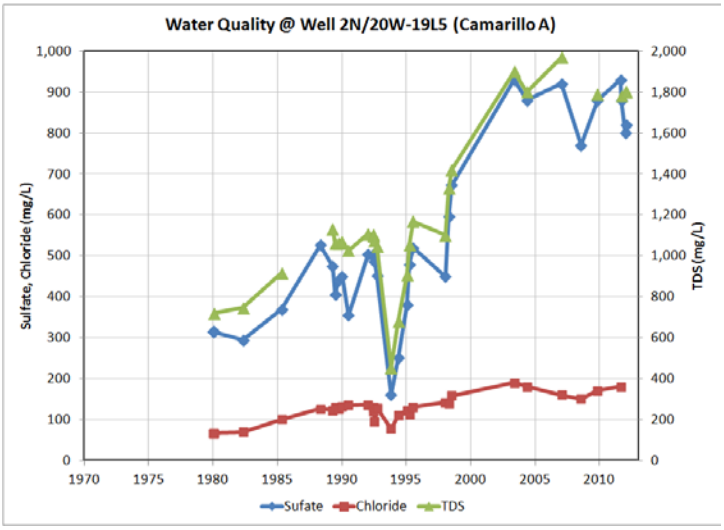


Figure 15. Water quality in well 19L5. See map for location.

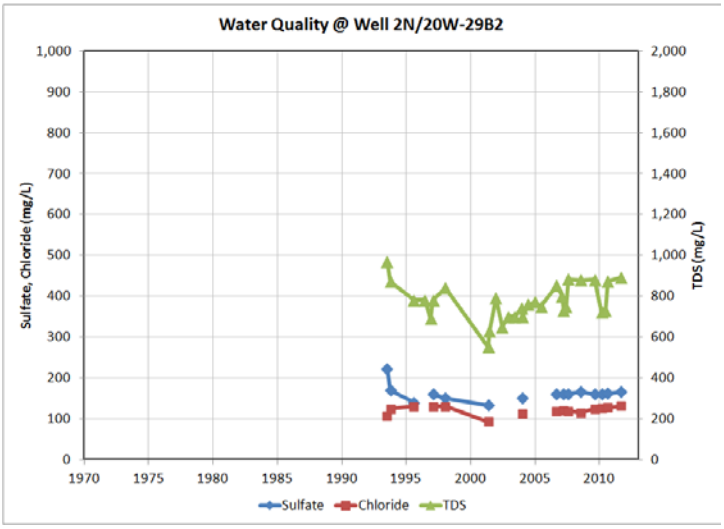


Figure 16. Water quality in well 29B2 (Camrosa WD Woodcreek well). See map for location.

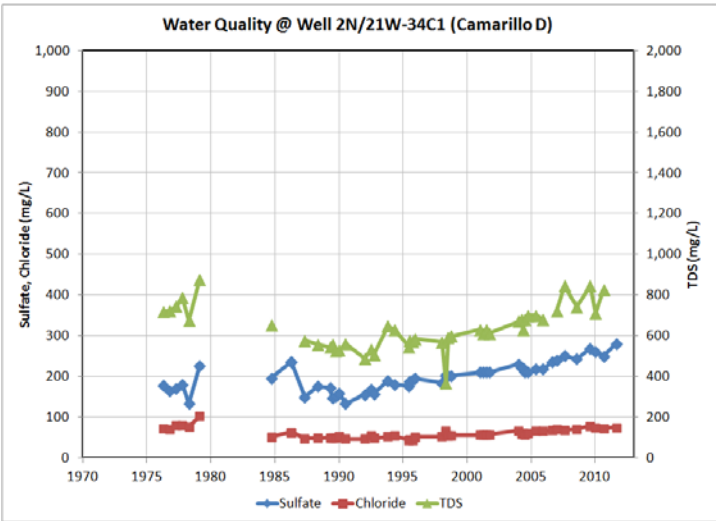


Figure 17. Water quality in well 34C1. See map for location.

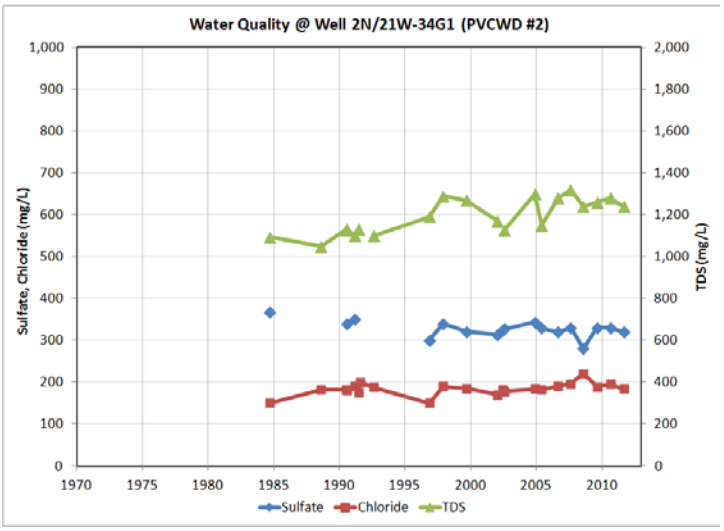


Figure 18. Water quality in well 34G1. See map for location.

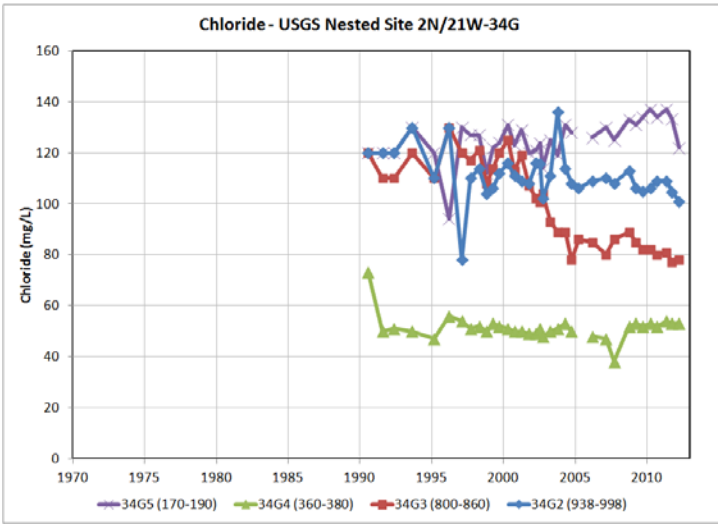


Figure 19. Chloride in wells 34G. See map for location.

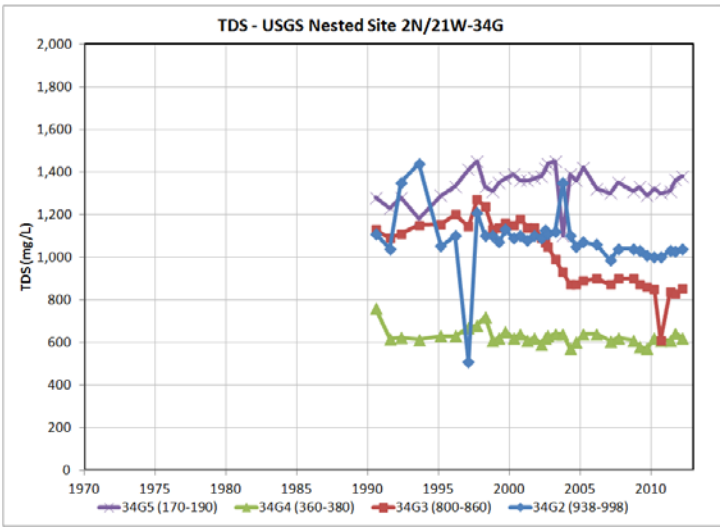


Figure 20. TDS in wells 34G. See map for location.

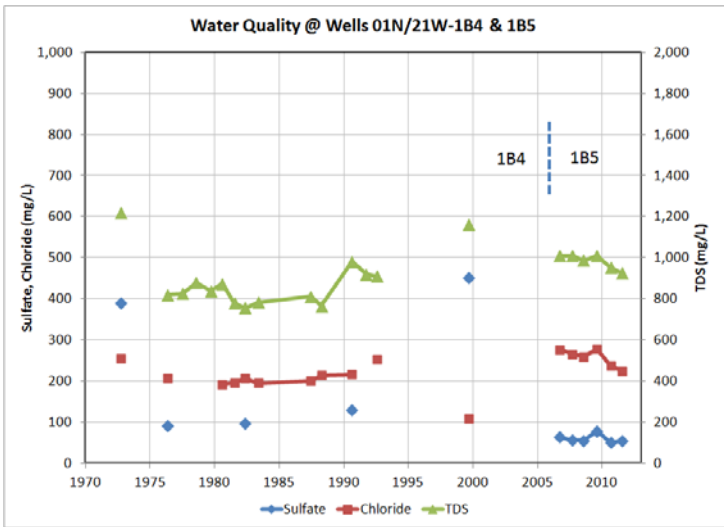


Figure 21. Water quality in wells 1B. See map for location.

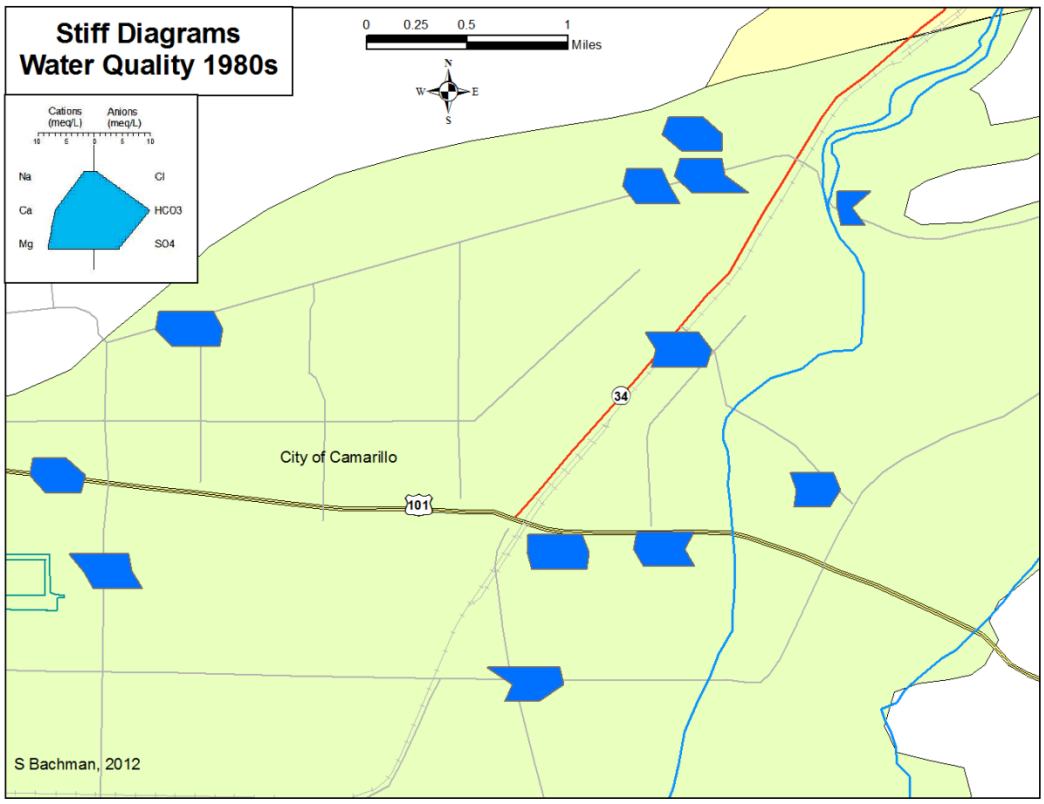


Figure 22. Stiff water quality diagrams for NPV groundwater in the 1980s.

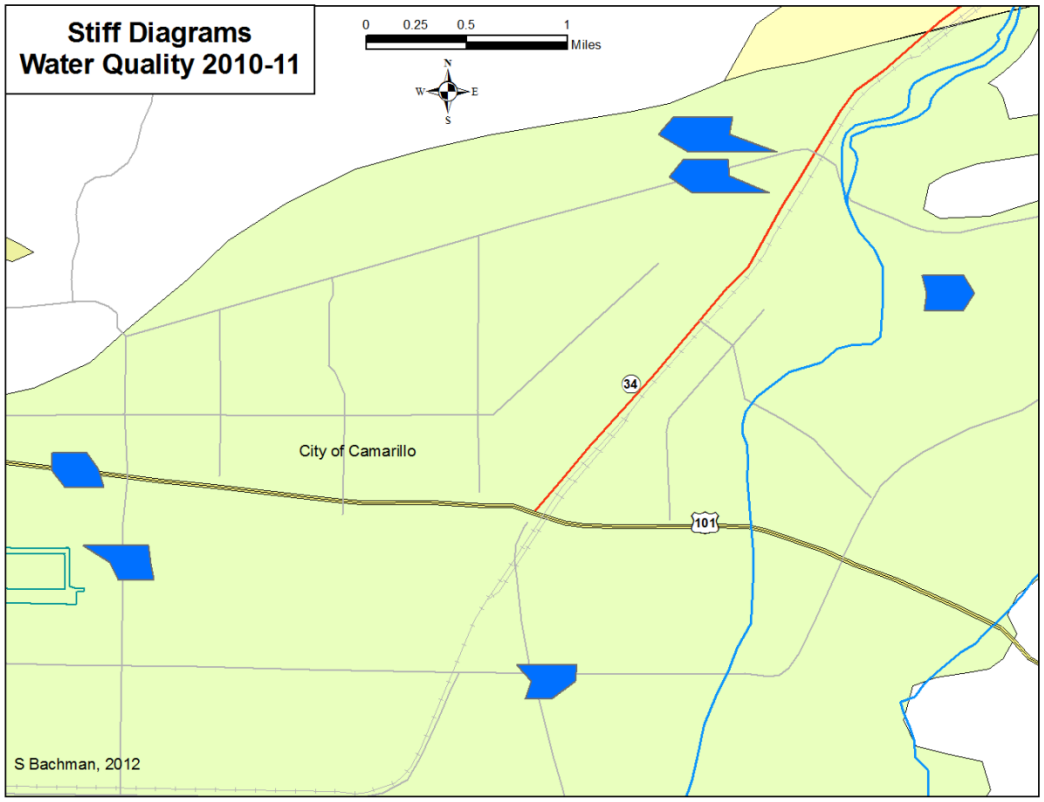


Figure 23. Stiff water quality diagrams for NPV groundwater 2010-11. See previous figure for Stiff legend.

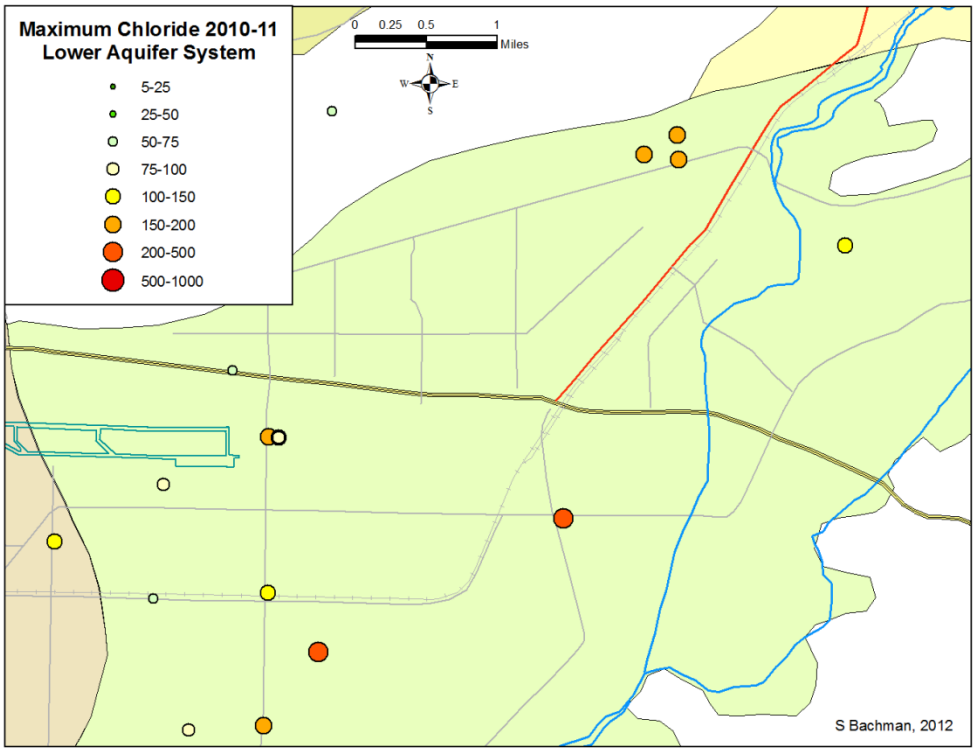


Figure 24. Maximum chloride concentrations (mg/L) measured in Lower Aquifer System wells during 2010 and 2011.

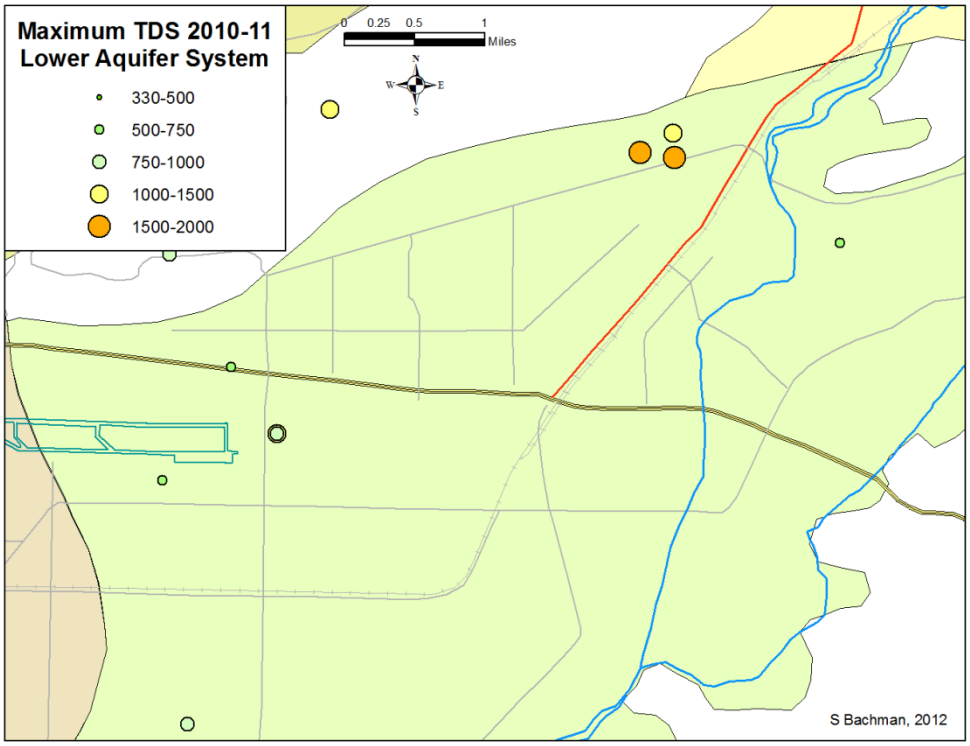


Figure 25. Maximum TDS concentrations (mg/L) measured in Lower Aquifer System wells during 2010 and 2011.

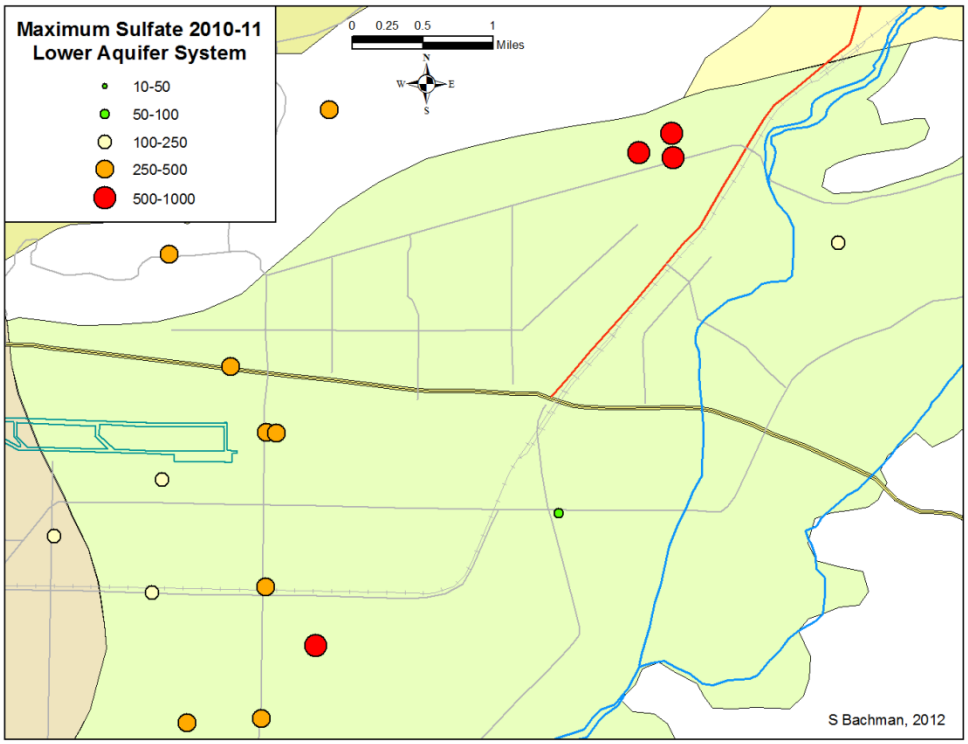


Figure 26. Maximum sulfate concentrations (mg/L) measured in Lower Aquifer System wells during 2010 and 2011.

Subsidence

Potential subsidence caused by historical lowering of groundwater elevations has not been measured in the NPV area, although there are no reported surface indications of subsidence (e.g., offset roads or parking lots, foundation cracking, etc.). The USGS documented a couple of feet of subsidence on the Oxnard Plain that they related to overdraft of the Oxnard Plain basin. There is a baseline of information from a LIDAR fly-over a decade ago; portions of this survey have been processed, largely at well heads and in Arroyo Las Posas. There is also additional information from traditional surveys within NPV.

When subsidence occurs because of lowered groundwater elevations in a basin, there is dewatering of the finer-grained sediments within and between the aquifers, but the pore space in sand and gravel aquifers is largely unaffected by lowered groundwater elevations. Because groundwater elevations dropped significantly by the early 1990s (see Figure 7 and Figure 8), any subsidence related to those lowered water levels has likely already occurred – future subsidence, if any, related to drops in groundwater elevations to similar depths in the future may be largely mitigated by the earlier event.

Aquifer Properties

A series of aquifer tests, dynamic spinner logs, and vertical chemical profiles were conducted in 2011 for the City of Camarillo (contracted by TMR Geological Consulting Services). Two of Camarillo's production wells (A and B) and two other nearby wells were used as pumping and observation wells for the aquifer tests. All of the testing was conducted in the Fox Canyon Aquifer. The details of the results are included in the Appendix and on the attached CD. Ranges of results included:

Transmissivity: 4,000 to 10,300 ft^2/day

Storativity: 3.1E-06 to 4.5 E-04

Horizontal Hydraulic Conductivity: 11 to 30 ft/day

3 Analysis of Flow – Arroyo Las Posas

The flow of Arroyo Las Posas as it crosses the boundary between the Las Posas basin (LPB) and NPV is one of the most important components of the water balance for the NPV Desalter. There is no permanent gage at the basin boundary, so gages upstream and downstream of the project area must be used in flow analysis. Additional information was provided by a two-month long dry-weather flow study conducted in late 2011 in the LPB[3].

The two permanent gage sites of interest (Figure 27) are upstream in the LPB at Hitch Blvd (Gages #841, 841a) and downstream near Highway 101 (Gages #806, 806a). The gages have overlapping but not completely coincident periods of record (Table 1). A number of analyses were conducted to understand baseflow and stormflow relationships between the gage sites. An

[3] Larry Walker and Assoc., 2012, *Phase I Study: Surface Flow and Groundwater Recharge in Arroyo Las Posas*, report to Calleguas Municipal Water District.

examination of historical aerial photos also provided insight into the downstream progression of baseflow percolation as the Shallow Aquifer in the LPB filled.

Baseflow in Arroyo Las Posas is a mixture of natural dry-weather flows, discharges from wastewater treatment plants, discharge from dewatering wells in Simi Valley, and agricultural tail waters. The terminus of the baseflow has moved downstream over the past decades as basins adjacent to the arroyo have filled, with spillage across the LPB-NPV boundary occurring in the early 1990s. Since that time, baseflow has entirely percolated into groundwater in the upstream quarter-mile or so of the arroyo as it flows into NPV (Figure 28).

In contrast, stormflows percolate into a longer reach of the arroyo than baseflow (Figure 28). The extent of stormflow percolation in NPV is not known with certainty. Aquifer testing in City of Camarillo wells A and B indicate that confined aquifer conditions exist at those locations, somewhat limiting the potential extent of percolation of stormflow into the Fox Canyon Aquifer. The possible downstream limit of significant percolation may occur where the arroyo changes from a wider braided stream to a narrow channel (Figure 28).

There are a number of inputs and outputs to streamflow between the Hitch and 101 gage sites. These include:

a) Tributaries within LPB (flow gain);
b) Percolation into groundwater as the arroyo flows over the LPB (flow lost);
c) Rising groundwater as the arroyo flows over the LPB (flow gain),
d) Percolation into groundwater as the arroyo flows over the NPV (flow lost); and
e) Tributaries and stormwater channels within NPV (flow gain).

There is only a loose correlation between daily flows gaged at the Hitch and 101 sites (Figure 29). The main reason for this poor correlation of daily flows is that baseflow is included in the comparison, and baseflow at Hitch never reaches the 101 gage site (it completely percolates along the route). However, if stormflow totals (the total flows from individual storm events) are compared, there is a good correlation between the two gage sites (Figure 30). Stormflow totals are somewhat higher at the 101 gage site, indicating that storm runoff between the two gages is higher than percolation from the arroyo.

It is important to separate infiltration of baseflow from infiltration of stormflow because baseflow is the source of poor-quality water in the aquifers. To estimate the amount of baseflow infiltration into NPV, the fate of baseflow between the Hitch gage site and the NPV basin boundary must be determined. The two-month long dry-weather study of the arroyo in LPB by Larry Walker Associates characterized flow at a number of sites in the reach between the Hitch gage and the LPB/NPV boundary. Net dry-weather loss along this reach averaged 10.6 acre-feet per day (Table 2). This net loss includes all additions and subtractions of water along the reach from the Hitch gage to the NPV boundary – water flowing in from upstream of the gage, water from tributaries and treatment plants along the reach, infiltration into the groundwater basin, and evapotranspiration losses. There were some uncertainties that will be addressed in a follow-up study during the 2012 dry season.

By subtracting the daily losses from the daily baseflow at Hitch, the baseflow reaching NPV can be estimated for the period 1994-2010 (baseflow first reached NPV about 1994). Within rounding errors, the baseflow reaching NPV is 3,851 acre-feet per year (10.55 acre-feet per day loss multiplied by 365 days) less than the baseflow at the Hitch gage. The summation of these daily estimates is shown in Table 4. Note that all baseflow entering NPV is percolated, which has been established by visual and aerial photography evidence. In addition, there is little or no recorded baseflow at the 101 gage site.

Stormflow percolation in NPV must be calculated using a different technique. Because there is currently little infiltration of stormflow in the Las Posas basin (infiltration of baseflow keeps groundwater elevations at stream level), it was assumed that stormflow gaged at the Hitch site reached the Las Posas basin/NPV boundary (plus additional tributary flows that are ungaged). The stormflow likely bypassed the first quarter-mile of the NPV reach because this reach has perennial flow and percolation of baseflow. Thus, infiltration of stormflow likely occurs downstream of the first quarter-mile of the arroyo, with the downstream limit of percolation indicated in Figure 28 and discussed earlier.

There is no direct measurement of percolation rates in the area of stormflow percolation. However, percolation rates can be estimated from baseflow percolation (Table 3). Baseflow percolates about 23 acre-feet per day (8,300 acre-feet per year divided by 365 days/year) over the measured length of the streambed where percolation occurs (1,400 ft). This equates to an infiltration rate of about 0.02 acre-feet per day per foot of arroyo length. If the same infiltration rate (0.02 acre-feet per day per foot) is used over the 5,500 ft reach where storm flow can infiltrate, a maximum of 89 acre-feet per day of storm water can be infiltrated.

The average number of days of stormflow at the Hitch gage was calculated using the daily measured flow at that gage for the period of record 1990-2011. Stormflow was considered to be the portion of the flow in a day that was in excess of the 5-day average from the previous baseflow-only period. This increase in flow occurred on average over the period of record about 54 days/year (ranges from 18 to 103 days/year). When the infiltration rate from the previous paragraph is applied during the stormflow days of the year, percolated stormflow can be estimated (Table 4). It should be noted that ungaged tributary flows between the Hitch gage and NPV are not included in this estimate. Infiltration of baseflow into NPV averages about 8,300 acre-feet per year and infiltration of stormflow averages at least 2,200 acre-feet per year (Table 4).

These estimated recharge rates are based on current data and studies, and likely have an error range of tens of percent. Potential errors in percolation amounts are integrated into the groundwater modeling for this study; amounts of percolation are varied to determine the sensitivity of percolation amounts to project modeling results.

Gage	Period of Record	Missing Yrs since 1990
Gage #841,a (Hitch)	1990 to present	WY 1996
Gage #806,a (101)	1968 to present	WY 2008

Table 1. Period of record of gages used in this study.

Reach between Gage Sites	Reach Gain (Loss) (CFD)	Reach Gain (Loss) (AFD)
Portion of 5 to 6 below Hitch	78,577	1.80
6 to 7	(5,967)	(0.14)
7 to 8	193,226	4.43
8 to 9	(480,211)	(11.0)
9 to 10	Unknown	
10 to 11 at NPV Boundary	(245,806)	(5.64)
Total Gain (Loss)	**(460,181)**	**(10.6)**

Table 2. Calculations of dry-weather stream gains and losses in Las Posas basin between the Hitch gage and the NPV border, based on Table 3 of the Larry Walker Assoc. study.

Recharge Area	Reach Length (ft)	Annual Recharge (AFY)	Daily Recharge (AFD)	Unit Recharge Rate (AFD/ft)
Baseflow	1,400	8,307	23	0.02
Stormflow	5,500		89	0.02

Table 3. Calculation of recharge rate for stormflows in NPV. The average annual recharge for baseflow was based on daily and annual calculations (see Table 4). The average recharge of 8,307 AFY equates to a daily recharge rate of 23 AFD, or 0.02 AFD for each foot of reach length. Using this unit recharge rate over the 5,500 feet of stormflow reach yields a potential of 89 AFD of stormflow recharge. 89 AFD was then applied in the daily stormflow calculations as the upper limit on daily infiltration.

	Hitch Gage		NPV Infiltration	
Calendar Year	**Storm Flow (AF)**	**Base Flow (AF)**	**Storm Flow (AF)**	**Base Flow (AF)**
1994	3,229	9,663	1,528	5,812
1995	27,621	10,980	4,229	7,129
1996	8,628	11,139	1,475	7,278
1997	7,206	10,313	1,308	6,462
1998	39,138	10,252	5,258	6,402
1999	1,783	14,879	739	11,028
2000	5,794	13,516	1,216	9,654
2001	17,206	12,465	1,891	8,614
2002	5,458	11,686	1,450	7,835
2003	10,763	12,110	1,296	8,260
2004	14,552	14,532	2,425	10,670
2005	50,615	11,639	4,166	7,788
2006	5,974	13,104	1,581	9,253
2007	3,092	13,404	1,844	9,554
2008	13,131	11,536	3,891	7,675
2009	6,098	12,514	2,103	8,663
2010	12,140	12,776	1,884	9,147
Avg	**13,672**	**12,147**	**2,252**	**8,307**

Table 4. Estimated baseflow and stormflow percolating into NPV. All of the Arroyo Las Posas baseflow crossing into NPV percolates into NPV. A portion of the stormflow crossing into NPV percolates into NPV. Totals are summations of daily flows. Significant figures are to nearest thousand at best. The sensitivity of modeling results to streamflow was tested and is described in the section "Using Model Results".

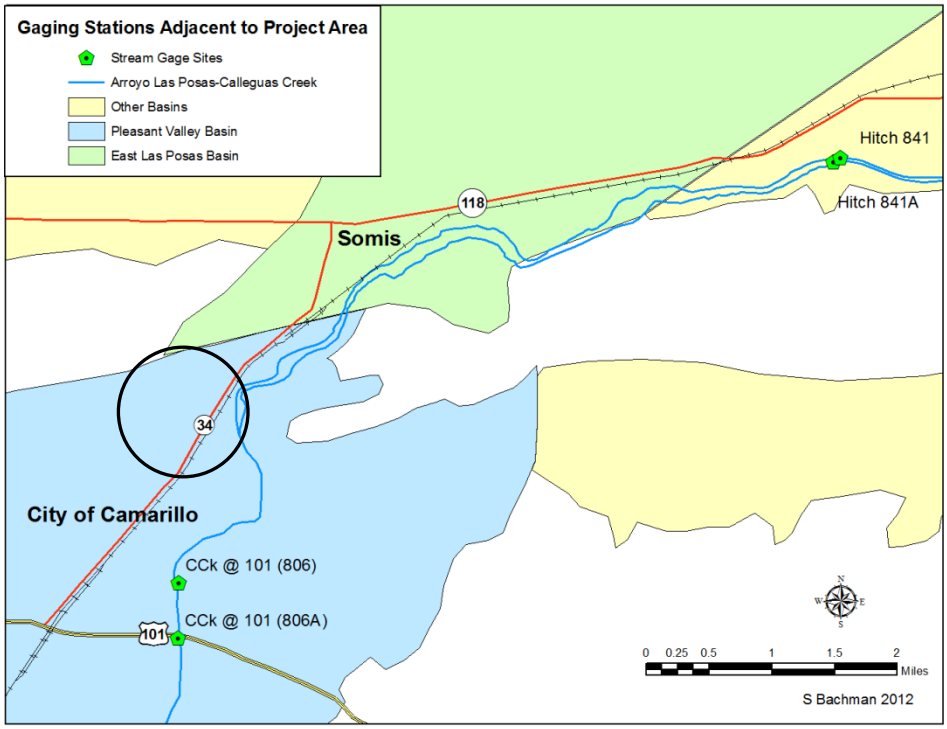


Figure 27. Gages on Arroyo Las Posas/Calleguas Creek used in this study. Circle is location of project.

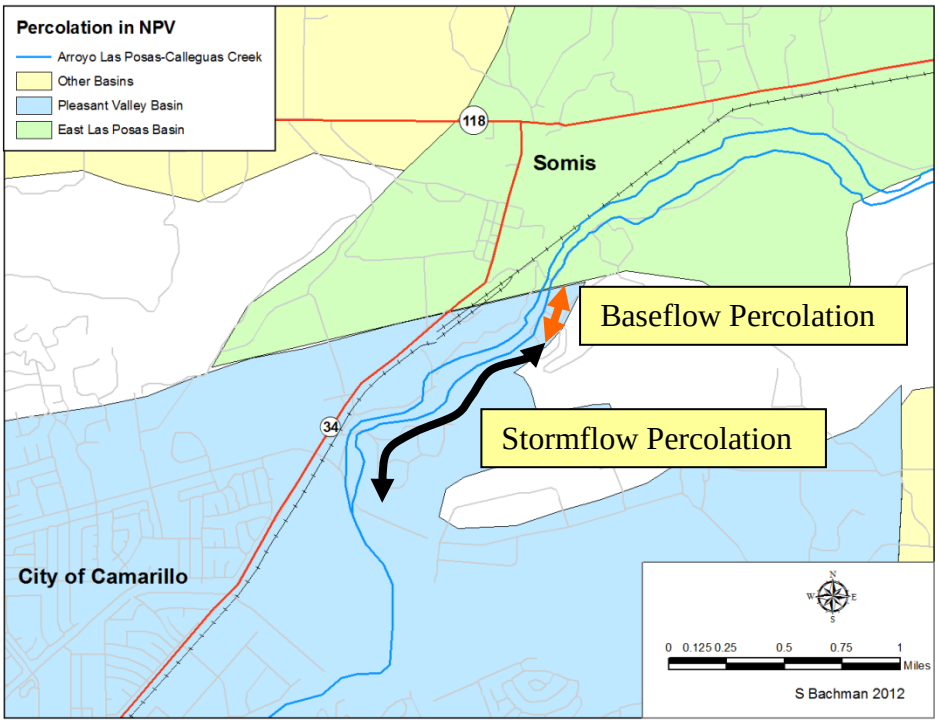


Figure 28. Location of percolation of baseflow and stormflow of Arroyo Las Posas into groundwater.

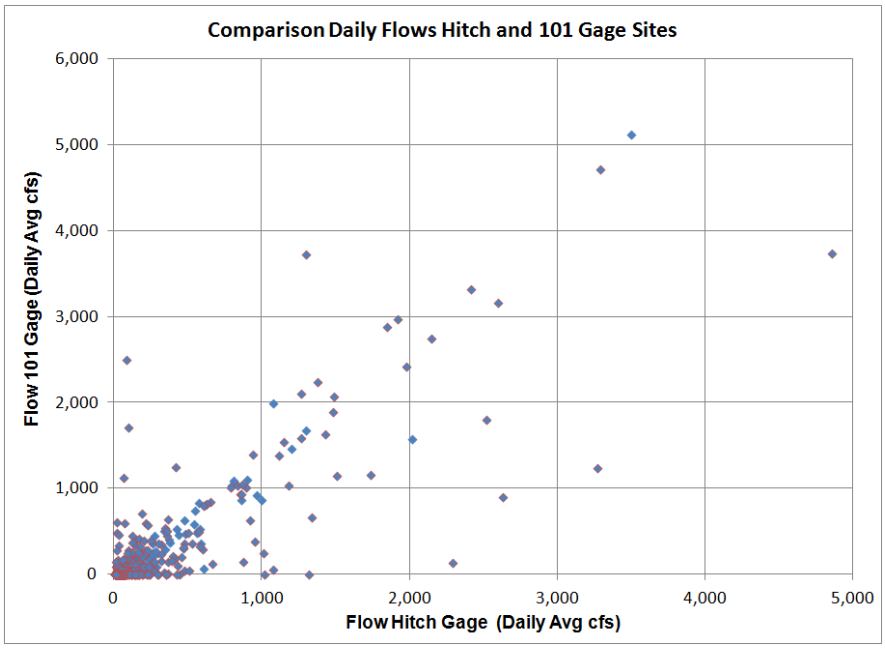


Figure 29. Comparison of daily flows at Hitch and 101 gage sites.

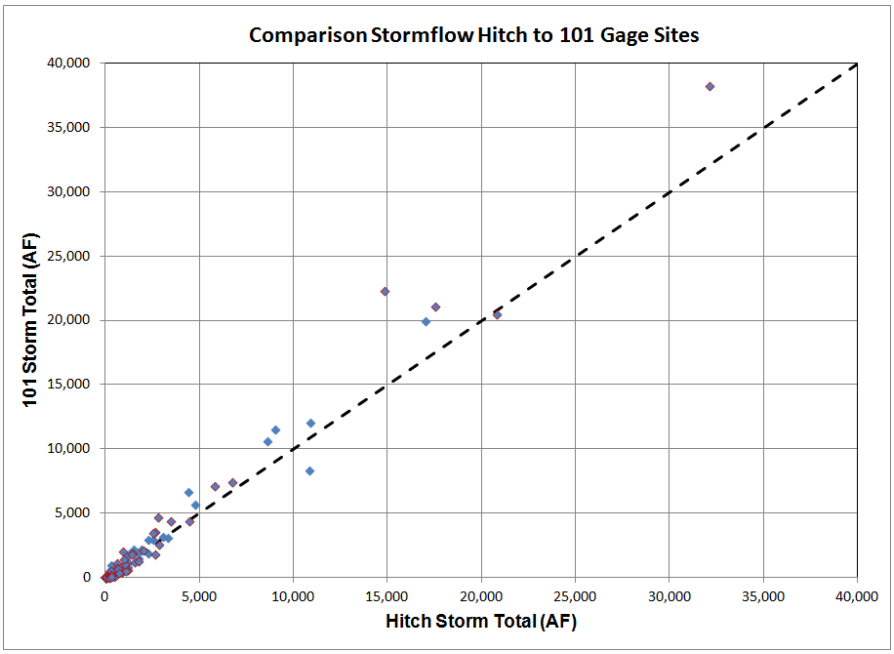


Figure 30. Comparison of storm total flows at Hitch and 101 gage sites.

4 Model Setup

The MODFLOW 2000 interface Groundwater Vistas version 6 was used for the modeling. Grid spacing is variable, with the smallest cells (200 ft by 200 ft) located in the project area to accommodate particle tracking.

4.1 Model Hydrogeology

Although the geology of the project area appears highly folded and faulted in the cross sections shown in this report (Figure 3 and Figure 4), it must be noted that the vertical exaggeration in the cross sections is 8.3:1 to 9:1, meaning that the folds are shown with much more amplitude than actual (this is done to better show the stratigraphy in the cross section). The beds are actually relatively flat-lying and can be readily modeled (the model uses the actual dips of the beds). Faulting which causes documented offsets in groundwater elevations and thus represent hydrogeologic boundaries can be accommodated by either low-flow or no-flow boundaries.

The model has two layers, Shallow Aquifer/Upper Aquifer/Hueneme (Layer 1) and Fox Canyon Aquifer (Layer 2), with both layers extending to the coast (Figure 31). In practice, the active portion of Layer 1 largely represents the Shallow Aquifer because the layer is considered no-flow outside of the area where the Shallow Aquifer overlies the Fox Canyon Aquifer (Figure 32). The active potion of Layer 1 is considered to be unconfined. The outer limit where the Shallow Aquifer lies directly on the Fox Canyon Aquifer is somewhat uncertain. Its location is estimated based on historical aerial photos showing the location of stream percolation, aquifer testing (City of Camarillo wells are in the confined portion of aquifer and therefore outside of the area where the unconfined Shallow Aquifer rests directly in the Fox Canyon), the cross sections discussed earlier, and stream morphology.

The active area of Layer 1 accommodates all the percolation from Arroyo Las Posas. Layer 1 aquifer properties were initially estimated and then refined during the model calibration process (Table 5).

The thickness of Layer 2 (Fox Canyon Aquifer) within the project area varies laterally somewhat, based on perforated intervals and well logs. South of US 101, the aquifer thickness used was that defined by the US Geological Survey in their groundwater model. In all cases within the project area and within a mile or so south of Highway 101, the thickness of Layer 2 was between 300 ft and 340 ft. Layer 2 aquifer properties in the project area were based on the recent aquifer testing of City of Camarillo's and nearby wells (discussed in an earlier section), where the effects of constant rate pumping on nearby wells were measured (Table 5) and on USGS model-calibrated values.

The thickness of the Fox Canyon in the model is the overall thickness based on drilling results. Within this overall aquifer thickness there are more- and less-transmissive beds. The extent of these beds both vertically and across the modeled area is very likely to be highly variable, and cannot be determined from a few wells penetrating the aquifer. Any attempt to separate the Fox Canyon Aquifer into more- and less-transmissive zones would not only be difficult, it would be highly misleading as to the knowledge of aquifer details. Increased uncertainty in model results occurs when model complexity increases without more data

control[4]. The calibrated property values in the model thus represent an average across the aquifer – the horizontal conductivity represents the average for lateral flow through all beds and the vertical conductivity is the average for vertical flow through very-transmissive beds as well as less-transmissive beds. This averaging of layer properties is inherent in essentially every groundwater model. It should also be noted that aquifer properties outside of the project area were based on the calibrated USGS regional groundwater model[5].

The model boundaries were defined by basin edges (no-flow) and a set of constant-head cells located near the coastline and at a distance sufficient from the project area not to cause unwanted boundary effects. The values of the constant-head cells were based on sets of historical groundwater elevations measured during the calibration period. The model edge at the Pleasant Valley/Santa Rosa basin boundary was considered a no-flow boundary for model simplification. Because there is likely some movement of groundwater across this basin boundary, groundwater elevations in NPV may be higher than modeled and the effects of pumping may be overstated. There is also a no-flow boundary between the Pleasant Valley and East Las Posas basins. This is based upon observed groundwater elevations that indicate large differences in head (100+ ft) across the boundary.

4.2 Modeling Conditions

The model has annual stress periods, with 25 time steps each. Pumping for the appropriate model period was assigned to each well location based on historical pumping reported semi-annually to the FCGMA. Streamflow percolation was simulated by a set of cells with a specified flux located along the arroyo between the northern edge of the Pleasant Valley basin and the southern edge of Layer 1. Water was added to Layer 1 based on the estimated streamflow percolation of Table 4.

There were three types of modeling runs performed:

1. Steady State – Model was run in steady-state mode (inputs and outputs are constant) during an historical period when there was little change in groundwater elevations. Used to test the overall water balance, conceptual geometry, and aquifer properties for stability.
2. Transient Calibration – Model was run in transient mode (input and outputs change with time) using historical data. Groundwater elevations predicted by the model should match measured historical water levels during the calibration period. Selected parameters (hydraulic properties of layers) were varied until there was a reasonable match.
3. Project Modeling – Project scenarios were simulated for a future period given specific inputs and outputs to the calibrated transient model.

[4] US Environmental Protection Agency, Office of Science Advisor, 2009, *Guidance on the Development, Evaluation, and Application of Environmental Models*, EPA/100/K-09/003.
[5] USGS, 2003, *Simulation of Groundwater/Surface Water Flow in the Santa Clara-Calleguas Basin, Ventura County, California*, WRIR 02-4136, 157 p.

	Kx (ft/day)	Kz (ft/day)	S
Model – Layer 1	40	20	0.15
Model – Layer 2	18	10	2E-04
Aquifer Tests Fox Canyon (Layer 2)	11-30	2-4	3E-06 to 5E-04

Table 5. Aquifer properties from aquifer tests on Camarillo wells A & B and adjacent wells compared to calibrated aquifer properties in model. Kx = horizontal conductivity, Kz = vertical conductivity, S = storativity. The modeled value for Kz in layer 2 is a calibrated value, which can vary from aquifer tests at a specific well because it applies to a large area of the model.

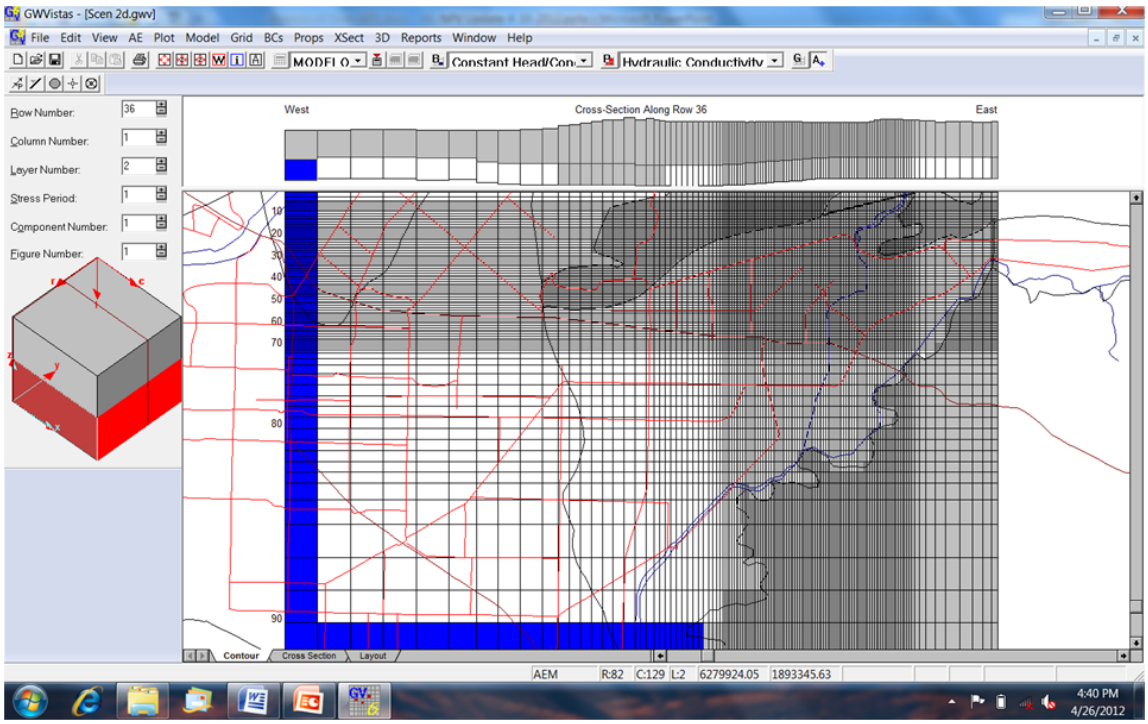


Figure 31. Model grid for layer 2. Model cell size was significantly decreased in the project area to accommodate particle tracking. Shaded areas are no-flow boundaries coinciding with the edges of the groundwater basins; blue model cells are constant head boundaries near the coastline.

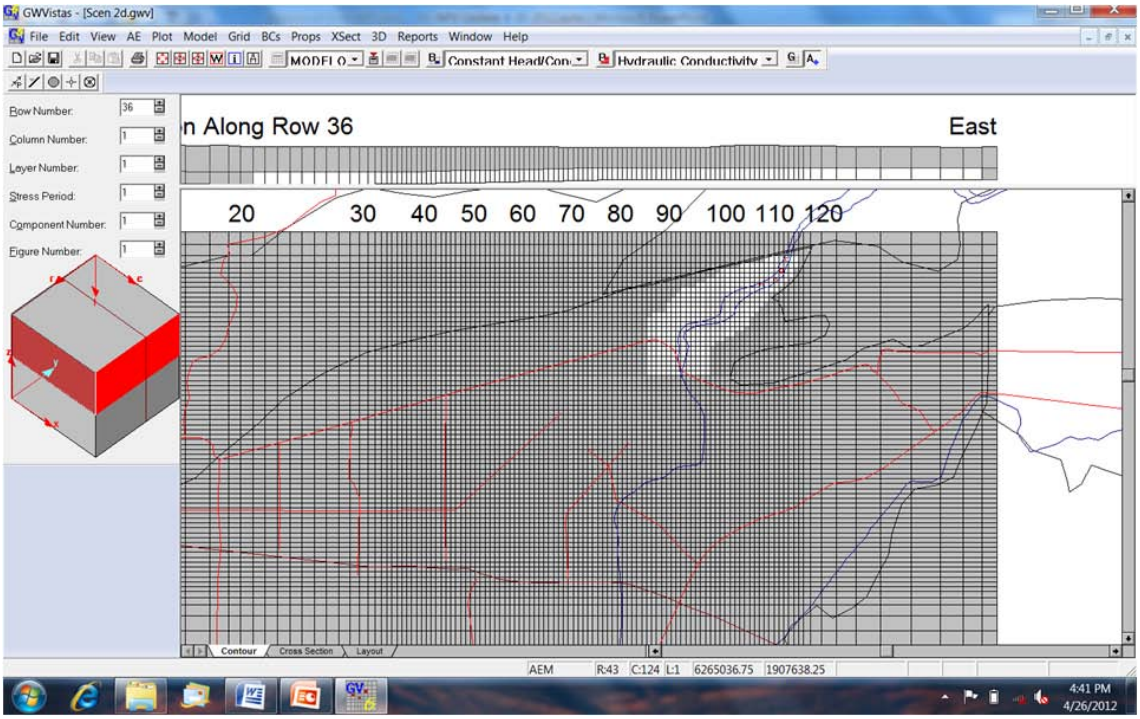


Figure 32. Model grid for layer 1. Model cell size was significantly decreased in the project area to accommodate particle tracking. Shaded areas are no-flow boundaries coinciding with the modeled extent of the Shallow Aquifer.

4.3 Steady-State Model

The model was run in steady-state mode for the period 1983 through 1986 to test the stability of the model. This period was chosen because there was little change in groundwater elevations and there was little baseflow yet reaching NPV from the Las Posas basin. Average stormflow and reported pumping for the period were used as inputs and outputs. Results simulated by the model indicated that water levels did not change during the period, verifying that the model was stable and ready for transient calibration (Figure 33).

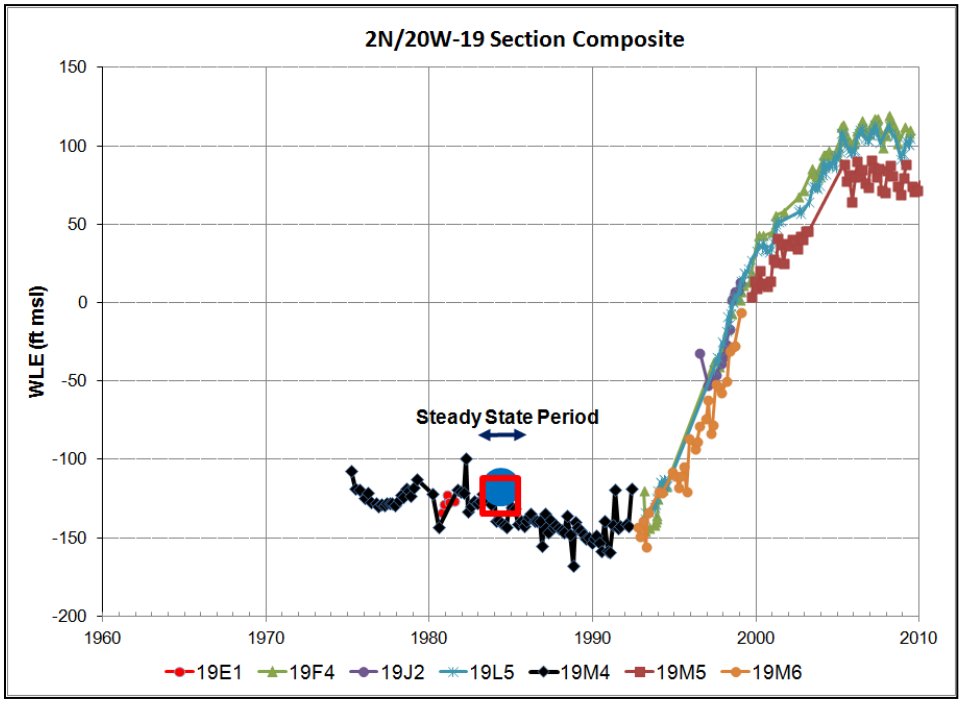


Figure 33. Composite groundwater elevations in area of Camarillo's wells A and B (2N/20W-19 location shown on Figure 34). Symbols are initial heads (blue circle) and final heads (red box) in the steady-state model.

4.4 Transient Calibration of Model

The model was then run in transient mode. Annual stress periods with 25 time steps each were prepared for the time interval 1994 through 2010. This period coincided with the beginning of spillage of brackish arroyo baseflow into NPV and the rapid rise in groundwater elevations caused by percolation of this brackish water. Streamflow percolation was simulated by introducing water into Layer 1 in the annual quantities indicated in Table 4. Baseflow was added in the first quarter-mile of the arroyo south of the boundary with the Las Posas basin and stormflow was added in the remainder of the arroyo within the extent of Layer 1. Production wells were pumped with the annual volume reported by well operators to the FCGMA (varied by year).

A set of wells with measured historical groundwater elevations was selected as "target" wells for the calibration period (Figure 34). The measured groundwater elevations for the target wells were input into the model for comparison with modeled values. The model then compared target

to simulated groundwater elevations in these wells. The calibration process is iterative, with changes made to the model following one calibration run and then the model is run again. There were approximately 25 calibration runs for this study. The RMS error for each calibration well is indicated in Figure 35. Contours of measured groundwater elevations at the beginning and the end of the calibration period are indicated in Figure 36 and Figure 37.

Although Groundwater Vistas has various methods of auto-calibration, the only automated tool used in this calibration was doing a sensitivity analysis of single model parameters. Because there were measured constraints on many of the model parameters, the only parameters that were allowed to be varied in the calibration process were Layer 1 hydraulic conductivity (horizontal and vertical), Layer 1 storage coefficient, and Layer 2 vertical conductivity.

The results of the calibration process are indicated in Figure 38 and Figure 39, with additional targets in the Appendix. The most important parameters in model verification are the timing and magnitude of change of groundwater elevations. In addition, calibration error is calculated by Groundwater Vistas – the scaled root mean squared (RMS) error of this model is 4.5%, well within the recommended error range of 10%[6]. An expanded list of calibration statistics is shown in Table 6.

The rise in groundwater elevations during the calibration period was significant, so the model is calibrated over a range of groundwater elevations; this is important in simulating project effects because pumping down the mound of brackish water would also occur over this same range of groundwater elevations.

Statistic	Value
Residual Standard Dev	16.48
Absolute Residual Mean	11.51
RMS Error	16.48
Scaled Residual Standard Dev	0.045
Scaled Absolute Mean	0.031
Scaled RMS	0.045

Table 6. Statistics at completion of model calibration.

[6] Zheng, C., and C. Neville, 1994, Practical Modeling of Pump-and-Treat Systems Using MODFLOW, PATH3d and MT3D, Short Course Notes.

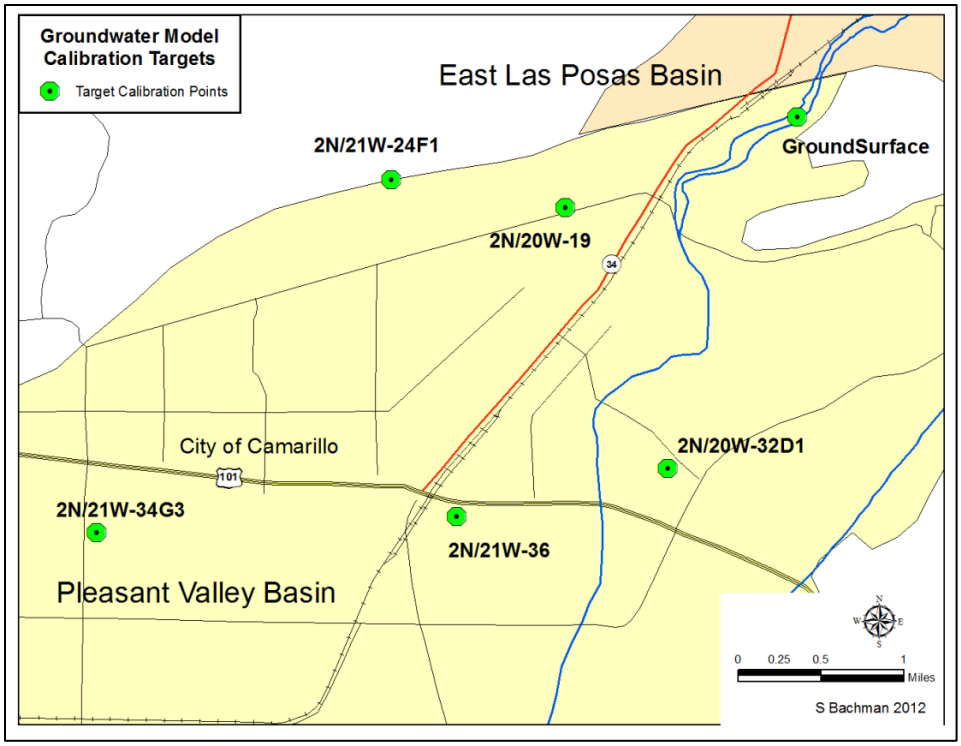


Figure 34. Calibration targets. Charts for two of these targets are shown in following pages; the remainder are included as Appendix 14.3. In addition to wells with measured groundwater elevations, a calibration target was chosen in the area of the groundwater mounding to ensure that groundwater elevations did not exceed ground surface (MODFLOW allows this to occur in unconfined aquifers).

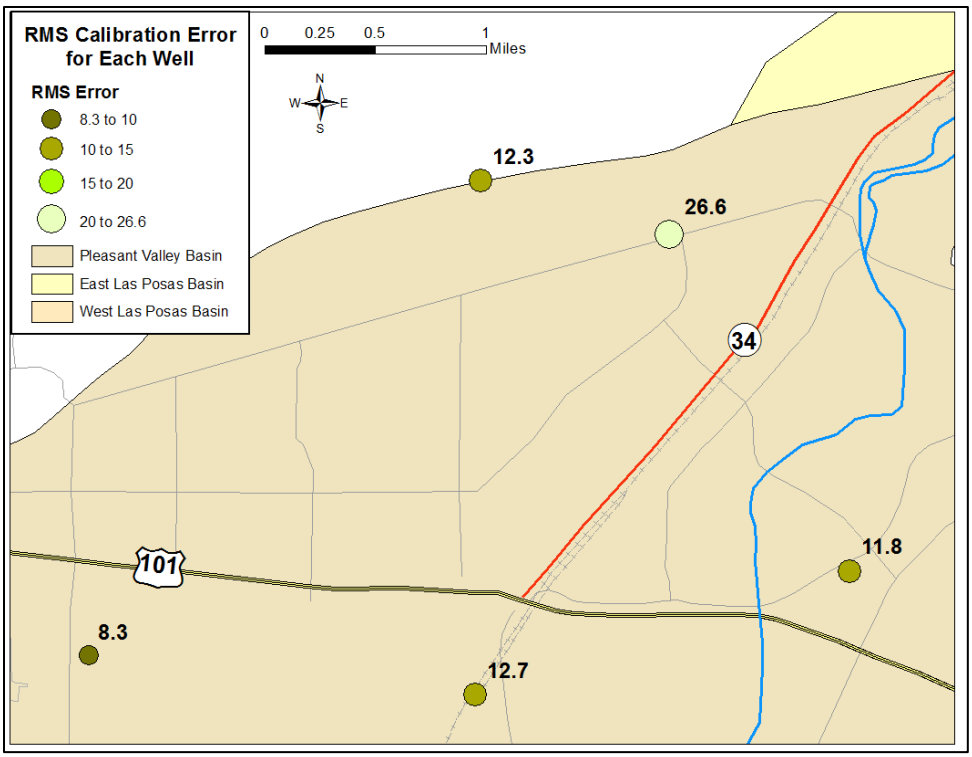


Figure 35. Model RMS error for each calibration well.

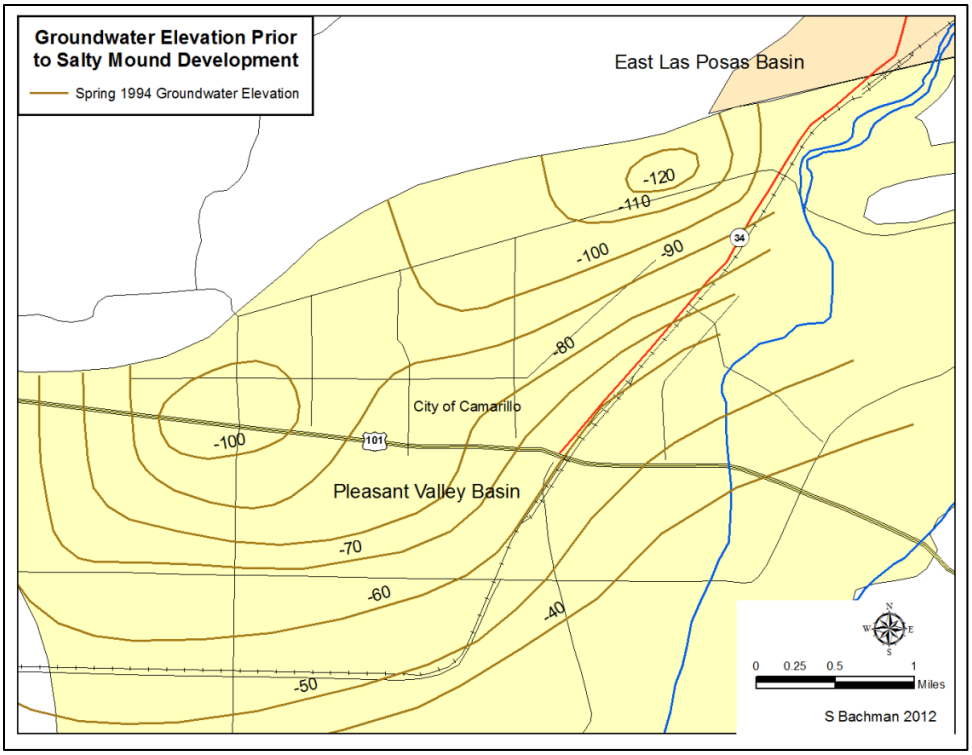


Figure 36. Groundwater elevations in spring 1994, just prior to the beginning of growth of the brackish mound beneath NPV.

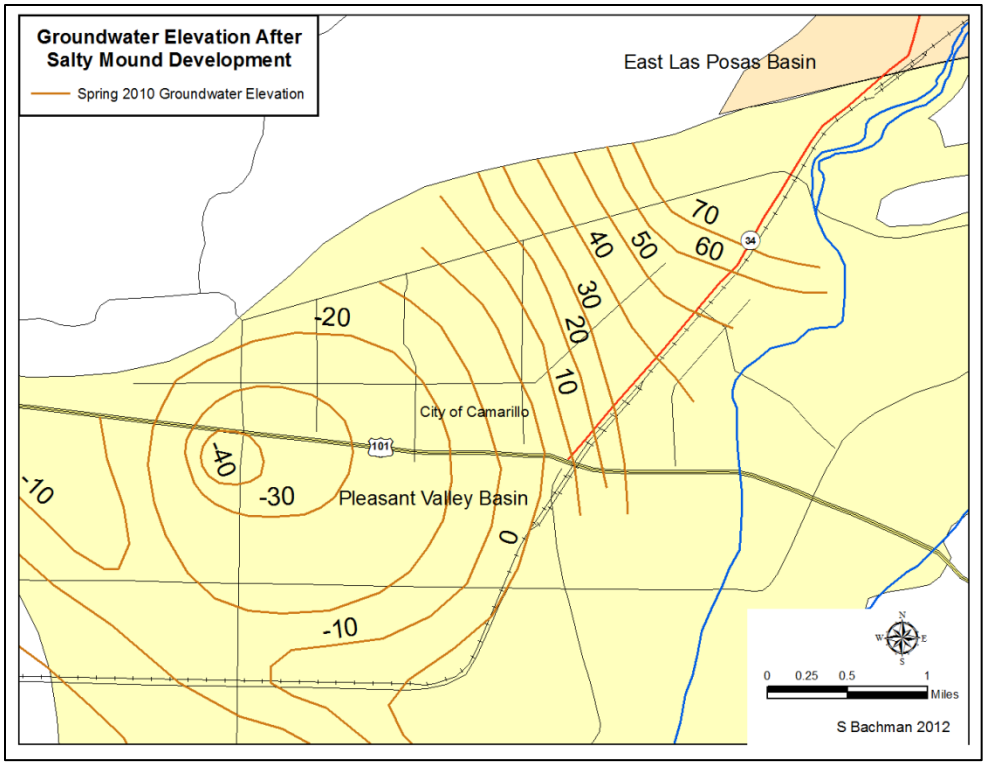


Figure 37. Groundwater elevations in spring 2010, after development of the brackish mound beneath NPV.

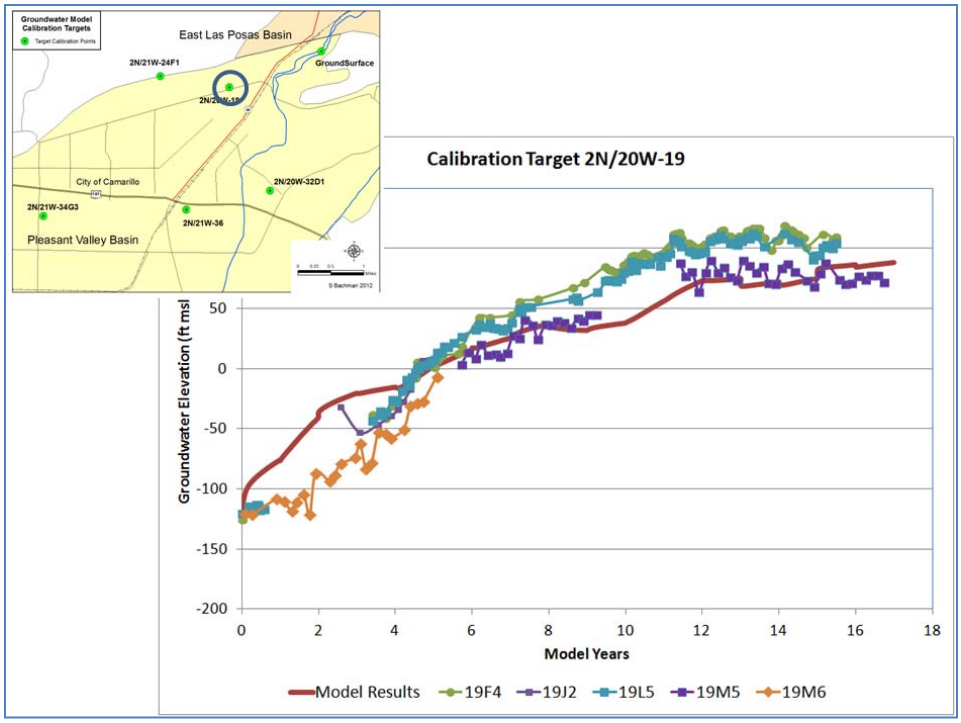


Figure 38. Calibration targets in section 2N/20W-19. Multiple wells are used because a single well does not have adequate data across the calibration period.

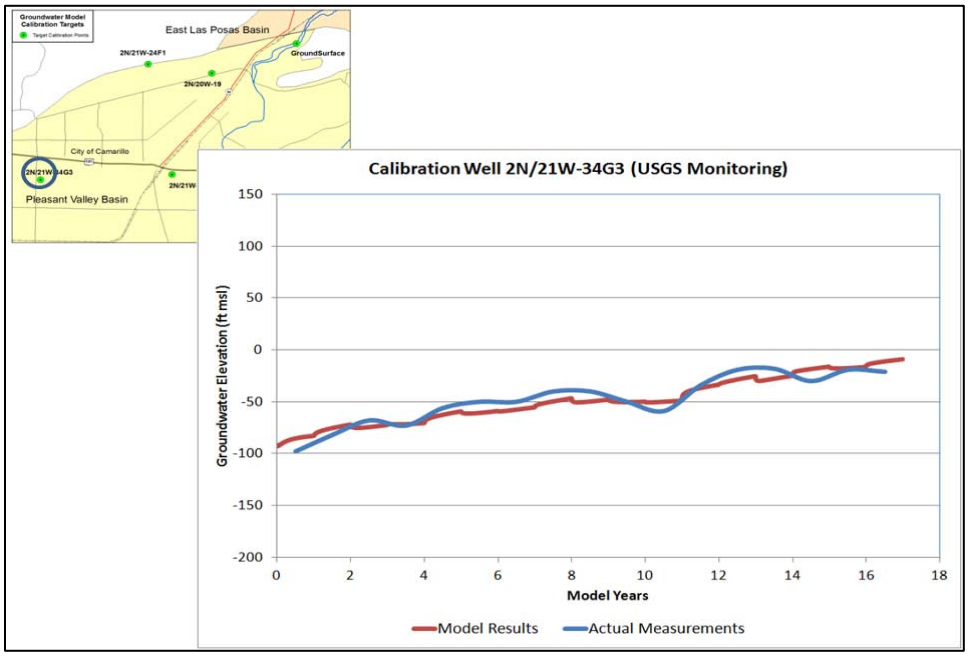


Figure 39. Calibration target 2N/21W-34G3.

Project Modeling

To model the effects of the project, both background hydrology (streamflow) and project yield/locations were varied. A representative base period was chosen to evaluate the project.

Model Base Period

A base period used for project modeling should reflect conditions that might be expected during the project. These conditions could include rainfall (e.g., wet and dry cycles), streamflow (base flow and storm flow), groundwater pumping, and discharges to the arroyo. In many basins, choosing a representative rainfall pattern would ensure that streamflow and pumping are also representative because they are inter-related.

In the NPV area, however, the largest changes in hydrology are not related to climate cycles – the basin filled because of increased upstream discharges from wastewater treatment plants and dewatering wells. Likewise, pumping has only partially been controlled by climate, with the majority controlled by urbanization and in-lieu projects such as the Pleasant Valley pipeline and the Conejo Creek project. Thus, the base period used in the modeling must reflect conditions expected during the project, rather than historical climate conditions that are of lesser effect in NPV.

Figure 40 is an illustration of historical streamflow in the Arroyo Simi-Arroyo Las Posas stream system. Discharges from wastewater treatment plants and dewatering wells have significantly increased streamflow over time. Any choice of a base period prior to the most recent two decades would not accurately portray future streamflow conditions that include these higher flows.

Choosing a base period that includes representative future pumping is also limited by local factors. The most serious concern is that prior to the 1980s, pumping was not reported in the NPV area. Although pumping prior to the 1980s could be estimated using historical aerial photographs and crop factors, it is the policy of the FCGMA that reported pumping is a more accurate method of determining pumping. In addition, pumping patterns within the NPV area have changed over the last several decades, as urbanization replaced some agricultural pumping. Figure 41 illustrates the change in pumping from the beginning of the reporting period. There was significantly higher pumping in the early years in the NPV area – even though the 1987-90 period was dry, the overall pumping in subsequent average and dry years never reached the 1984 to 1990 levels. Thus, to reflect current pumping trends, the model base period should be limited to within the period following 1990.

The period used for the project modeling started with the 17 years of the calibration period (1994-2010) and added 30 project years for a total model period of 47 years. The 1994-2010 period satisfies the constraints discussed above related to streamflow and pumping trends, plus it coincides with the advent of filling of the basin with brackish water, which will be tracked as part of the modeling.

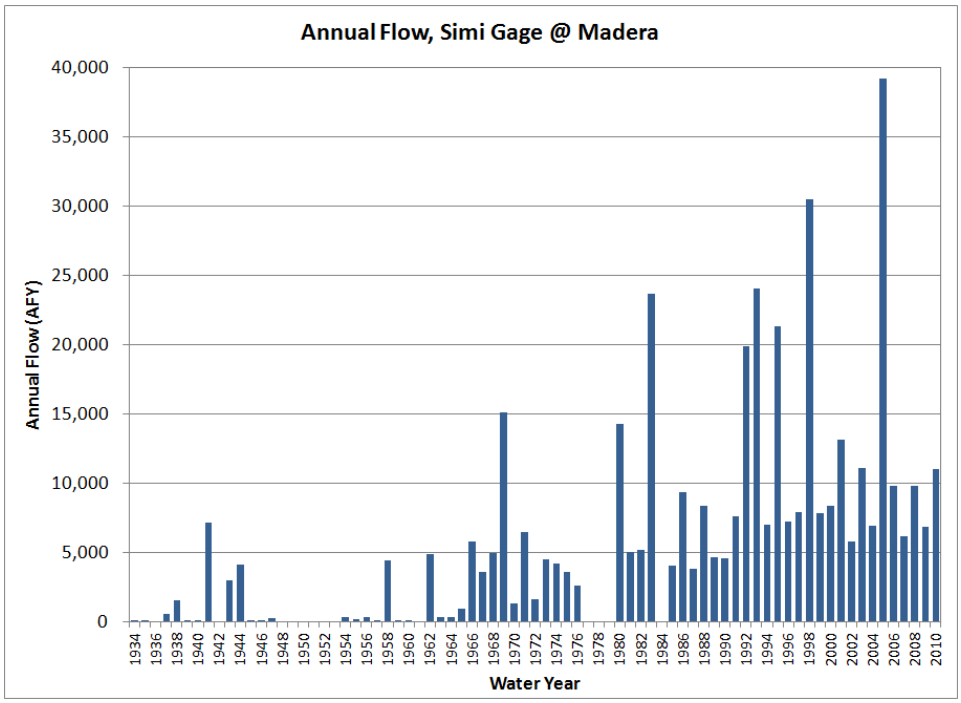


Figure 40. Annual streamflow in Arroyo Simi measured at the downstream (western) end of Simi Valley. This gage has the longest period of record in the Arroyo Simi-Arroyo Las Posas stream system. Note the significant increase in streamflow as upstream discharges increased with time. Representative streamflow for project modeling must be biased towards the last two decades to reflect the increase in arroyo flows during that time.

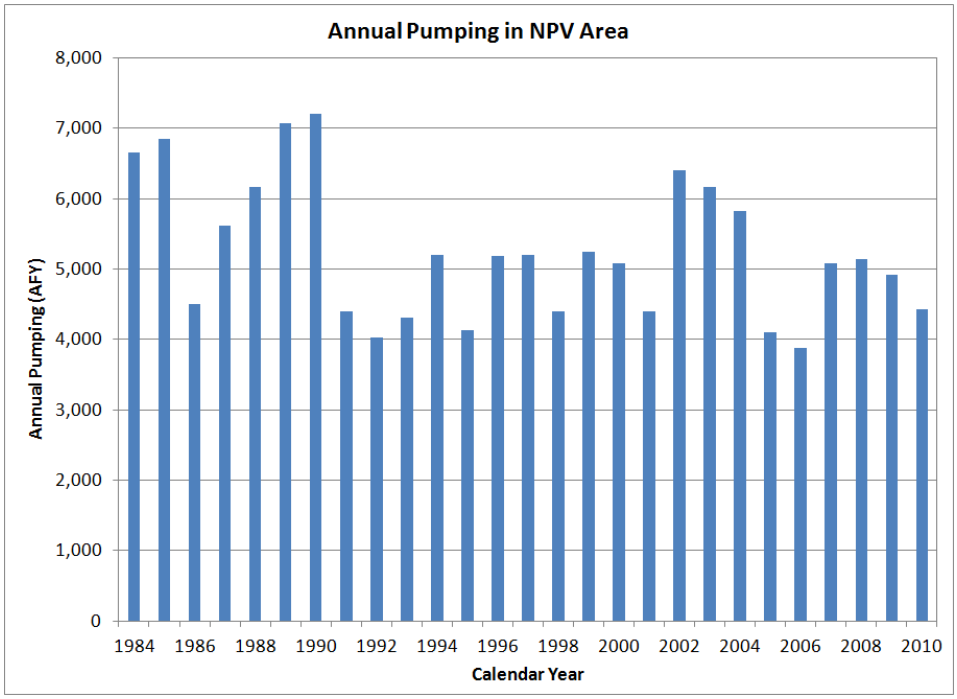


Figure 41. Groundwater pumping reported to the FCGMA in the NPV modeled area.

Modeling Inputs

Streamflow for model years 1 to 17 were the same as for model calibration. For the next 30 years, streamflow varied in two overall scenarios:

Scenario #1 – Annual streamflow (including baseflow and stormflow) was the average of the calibration period 1994-2010 (see average in Table 4). This captures the period of increased streamflow caused by wastewater and dewatering discharges. This scenario assumes that no desalters (with their accompanying shallow groundwater pumping) were built and operated in Las Posas basin. This is a best-case scenario for source water for the NPV Desalter project.

Scenario #2 – Baseflow percolating into NPV is identical to Scenario #1 until the beginning of model year 23, when 5,000 AFY of baseflow is removed from NPV as a Las Posas desalter comes on line[7]. At the beginning of model year 28, the rest of the baseflow is removed by Las Posas desalting, leaving only stormflow entering NPV (as was the case prior to 1994). The amount of stormflow entering NPV would vary depending upon the effect of future upstream pumping for desalters in the Las Posas basin. Historically, when baseflow was lower prior to discharges of wastewater and dewatering into the arroyo, stormflow commonly flowed across NPV and was measured at a gage near US 101. Therefore, it is likely that stormflow would reach NPV in quantity after the man-made baseflow was removed. Recharge of stormflow in NPV could actually increase with the removal of baseflow – stormflow would then have a longer length of streambed available for percolation. Scenario #2 is a worse-case scenario for source water for the NPV Desalter and the best-case for removal of brackish water.

Groundwater pumping at individual wells for model years 1 to 17 was from FCGMA reported pumping. For model years 18 to 47 under all scenarios, groundwater pumping at each well was the average of the past five years of pumping reported to the FCGMA. The five-year period was chosen to reflect current pumping patterns, unbiased by historical changes in pumping caused by past urbanization. The only exception to the five-year average was for City of Camarillo wells (existing and new desalter wells) that varied with each scenario as to location and amounts of pumping.

Base Cases

The base case for the modeling analysis is that no desalting project would be built. All other inputs and outputs remain the same except that there is no project pumping. There is one change, however – City of Camarillo moves pumping of its 4,500 AFY FCGMA allocation to Well D and the Airport Well because the brackish water at its wells A and B make those wells unusable for potable supply.

In Base Case #1, the mound of poor-quality water continued to grow, extending into the main portion of the Pleasant Valley basin (Figure 42). Particle tracking for this scenario indicates that salts would affect a wide area of the basin, causing a potential new threat to aquifers within the FCGMA (see section Particle Tracking).

[7] This desalter is likely to be the Moorpark Desalter, but any desalter project along the arroyo in Las Posas will yield the same effect in NPV.

In Base Case #2 where desalters in the Las Posas basin eventually remove brackish baseflow from the arroyo, the recharge mound at the northern edge of NPV remained, but was less pronounced (Figure 43). The main reason for any mound remaining in Base Case #2 is that the City of Camarillo has moved its pumping away from NPV towards the Highway 101/Camarillo Airport area, reducing pumping of the mound.

Project Scenarios

A number of project scenarios were run with the model against the backdrop of Scenarios #1 and #2 changes in baseflow in the arroyo. In some of the project scenarios, the City of Camarillo's pumping is moved entirely to the desalter wells, eliminating pumping of Well D and the Airport Well (all scenarios except those with "-AP" at the end of scenario number). In other scenarios, there continues to be some pumping near the airport (scenarios with "-AP" at end of scenario number). As modeling results were discussed periodically among the desalter participants, the focus of later model runs was on using Scenario #2 arroyo flows because they represented a worse-case track for project longevity and effects, as well as a best-case for removing salts from the aquifer. Two scenarios also tested the sensitivity of varying the amount of baseflow in the arroyo that percolates into NPV (increase/decrease by 20%). Well locations used in the modeling are indicated on Figure 44. The project scenarios are summarized below:

Scenarios #1a and #2a – 4,500 AFY of desalter pumping (equivalent to Camarillo's FCGMA allocation) from two wells (existing wells A and B).

Scenarios #1b and #2b – 9,000 AFY of desalter pumping from four wells (wells A and B plus two nearby new wells).

Scenarios #1c and #2c – 9,000 AFY of desalter pumping from four wells (wells A and B plus two new wells extending northeast in a line from the existing wells). The only different between #b and #c is the location of the two new wells.

Scenario #2c-25yr – Same as Scenario #2c except project pumps water for 25 years instead of 30 yrs.

Scenario #2c-AP – Same as Scenario #2c except 2,000 AFY are pumped from Well D and the Airport Well during the project.

Scenarios #1d and #2d – 11,800 AFY of desalter pumping (the highest customer demand from desalter group) from five wells (wells A and B plus three new wells extending northeast in a line from the existing wells).

Scenario #2e – Scenario #2c (9,000 AFY of desalter pumping from four wells) with baseflow infiltration increased to 120% of calculated 8,300 AFY.

Scenario #2e-AP – Same as Scenario #2e except 2,000 AFY are pumped from Well D and the Airport Well during the project.

Scenario #2f – Scenario #2c (9,000 AFY of desalter pumping from four wells) with baseflow infiltration decreased to 80% of calculated 8,300 AFY.

Scenario #2f-AP – Same as Scenario #2f except 2,000 AFY are pumped from Well D and the Airport Well during the project.

Scenario #2g – 7,500 AFY of desalter pumping from four wells (wells A and B plus two new wells, one to the northeast of the existing wells and one to the south of the existing wells that would target "stranded brackish water" indentified during particle tracking).

Scenario #2h – 9,000 AFY of desalter pumping from four wells (same as Scenario #2c with further optimization of well locations).

Scenario #2h-AP – Same as Scenario #2h except 2,000 AFY are pumped from Well D and the Airport Well during the project.

Scenario #2h – 9,000 AFY of desalter pumping from four wells (same as Scenario #2c with further optimization of well locations).

Scenario #2i – 11,800 AFY of desalter pumping from five wells over 25 years (rather than 30 yrs).

Modeling results were analyzed several ways. The modeled change in groundwater elevations at several monitoring points within and adjacent to NPV were plotted and scenarios were compared. Groundwater elevation contour maps were also compared among scenarios. Particle tracking provided a technique to evaluate the potential movement of salts from their site of infiltration, their potential path of migration into NPV, and their movement after desalter pumping began.

The monitoring points that were used for evaluating model results included a combination of calibration wells, wells at the northern edge of agricultural production in the Pleasant Valley basin, and monitoring points located within the model at strategic positions within NPV. The locations of these monitoring points are shown in Figure 45.

The groundwater model operates on one-year time steps. Thus, the groundwater elevations indicated at specific monitoring points are an annual average – actual groundwater elevations would be higher during the wet portion of the year and lower during the dry portion of the year. The range of measured annual fluctuations in groundwater elevations is indicated for each hydrograph.

Model Results in Groundwater Mound

The mound of poor-quality water is only pumped down at higher desalter pumping rates in Scenario #1 options (Figure 46), whereas the mound is dissipated to a larger degree at lower pumping rates in Scenario #2 options (Figure 47). Without desalter pumping in Base Cases #1 and #2, the mound of poor-quality water would remain as a prominent feature.

Model Results within City of Camarillo

None of the pumping options in Scenario #1 would reduce the mound of poor-quality water to below historical-low groundwater elevations (Figure 48, Figure 50). In contrast, the higher pumping-rate options of Scenario #2 eliminate the mound completely, in some cases lowering water levels below historical-low groundwater elevations (Figure 49, Figure 51).

Model Results at Southern Edge of City of Camarillo

Model results at three locations south of the City of Camarillo were analyzed: the USGS monitoring well at the PVCWD office and the two active agricultural wells closest to the

southern boundary of the City of Camarillo (Figure 45). All Scenario #1 pumping options failed to reduce the effect of the mounding of the poor-quality groundwater at the USGS monitoring well site (Figure 52). In contrast, the higher pumping-rate options of Scenario #2 essentially eliminated the post-1994 groundwater mounding (Figure 53, Figure 54, Figure 55).

Further Optimizing of Desalter Wells Locations

To further optimize the location of the desalter wells, two additional scenarios (Scenarios #2h and #2h-AP) were added that mimicked Scenarios #2c and #2c-AP (9.000 AFY, 4 wells) except that the well farthest to the northeast was moved within the area of the other three desalter wells (location shown in Particle Tracking section, Figure 73). There were some decided advantages to this move, which are discussed in the Particle Tracking section. The potential disadvantage was that drawdown could be increased at the southern edge of Camarillo; however, as indicated in Figure 56, there is no discernible extra drawdown along the southern edge of the City.

25-Year Project

Following discussions with the NPV Desalter group, the option of a 25-year project (instead of 30 years) was modeled at project pumping rates of 9,000 AFY (Scenario #2c-25yr) and 11,800 AFY (Scenario #2i). Several iterations with differing well locations were simulated to determine least impact on surrounding pumpers and maximum potential recovery of brackish water. The iterations were combined with particle tracking described in the next section to determine when project wells would no longer pump brackish water and would therefore be turned off. Five wells were used in the 11,800 AFY simulation (Figure 57) and an additional monitoring point was added (Pleasant Valley Mutual Water Company well 19E1; Figure 58).

Simulated hydrographs at monitoring points indicate that when the project pumps for 25 years, drawdown effects are muted compared to a 30-year project (Figure 58 to Figure 60).

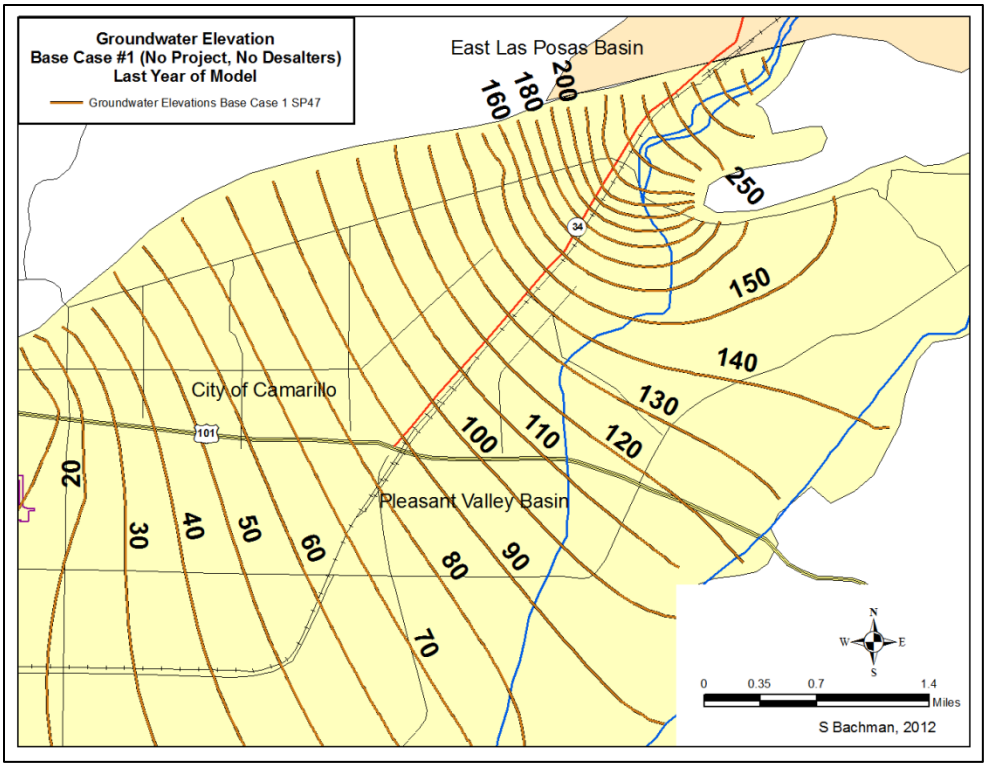


Figure 42. Scenario #1 Base Case groundwater elevations at end of 47-year modeling period. No project, no Las Posas basin desalters upstream (i.e., no pumping of shallow, brackish groundwater anywhere along Arroyo Las Posas and Calleguas Creek).

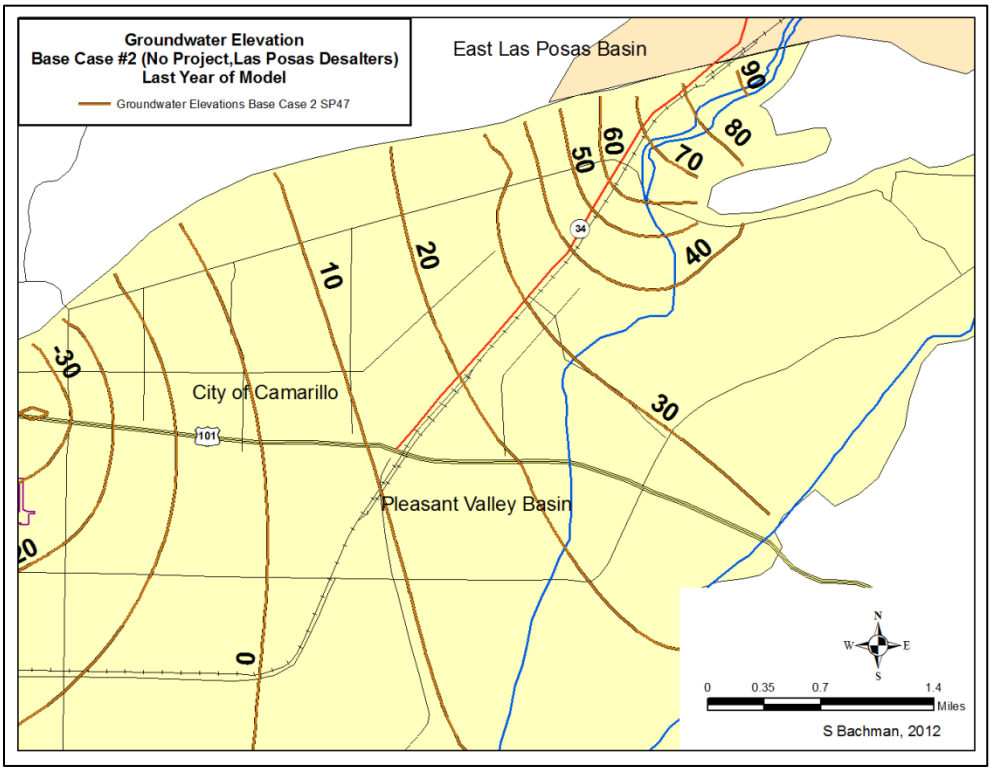


Figure 43. Scenario #2 Base Case groundwater elevations at end of 47-year modeling period. No project, but progressive reduction in brackish baseflow as Las Posas desalters comes on line.

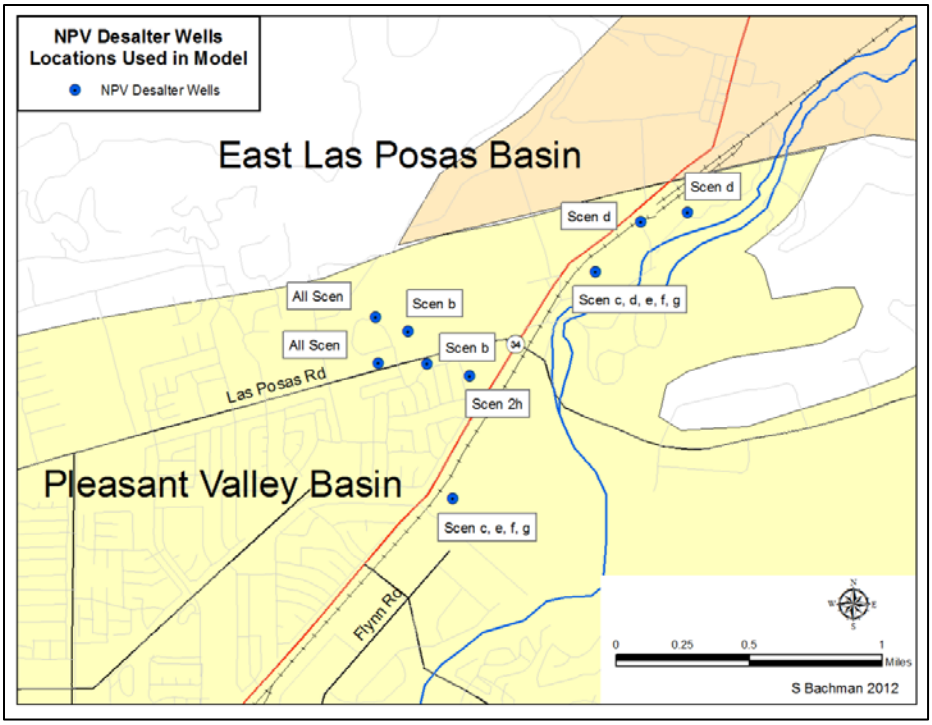


Figure 44. Location of wells used in desalter model runs. Label next to well indicates which scenario(s) the well was used for.

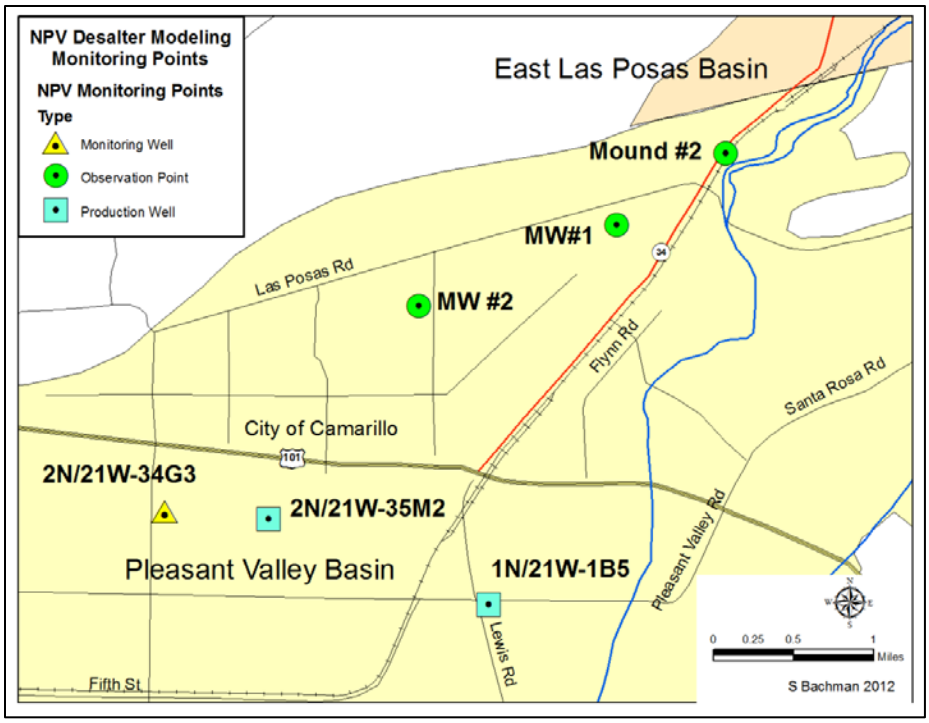


Figure 45. Location of monitoring points in model used for evaluation of the varying project scenarios. Monitoring wells and production wells are actual wells; observation points are selected in the model to simulate what a monitoring well would observe at that location. Mound #2 is a Shallow Aquifer (model Layer 1) monitoring point whereas the other monitoring points are in the Fox Canyon Aquifer (model Layer 2).

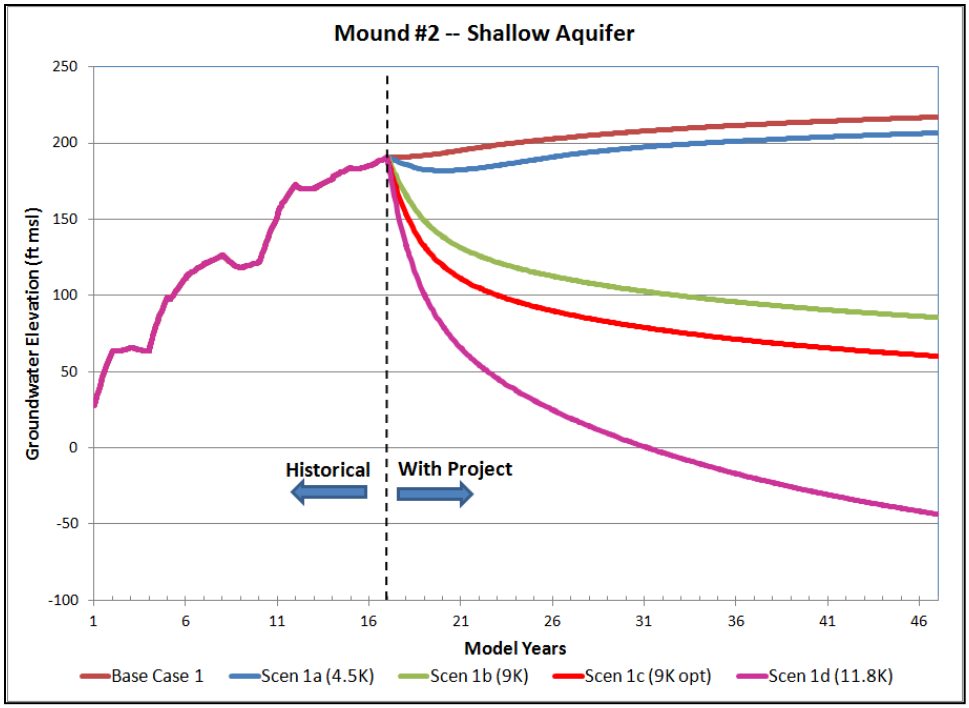


Figure 46. Hydrograph of Scenario #1 options at Mound #2 observation point. See previous map for location.

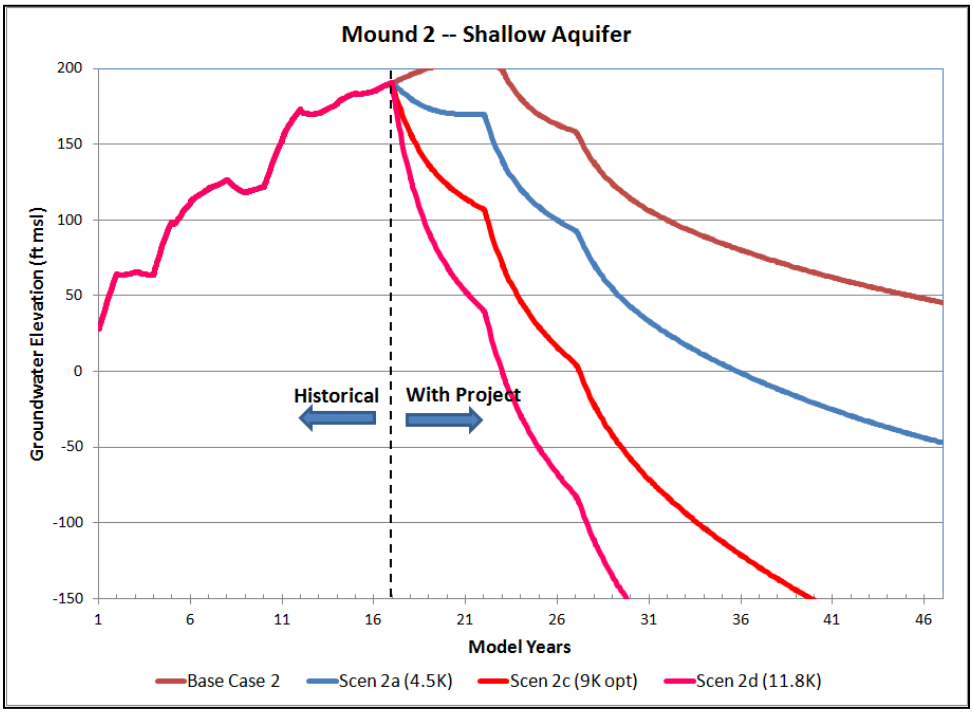


Figure 47. Hydrograph of Scenario #2 options at Mound #2 observation point. See previous map for location.

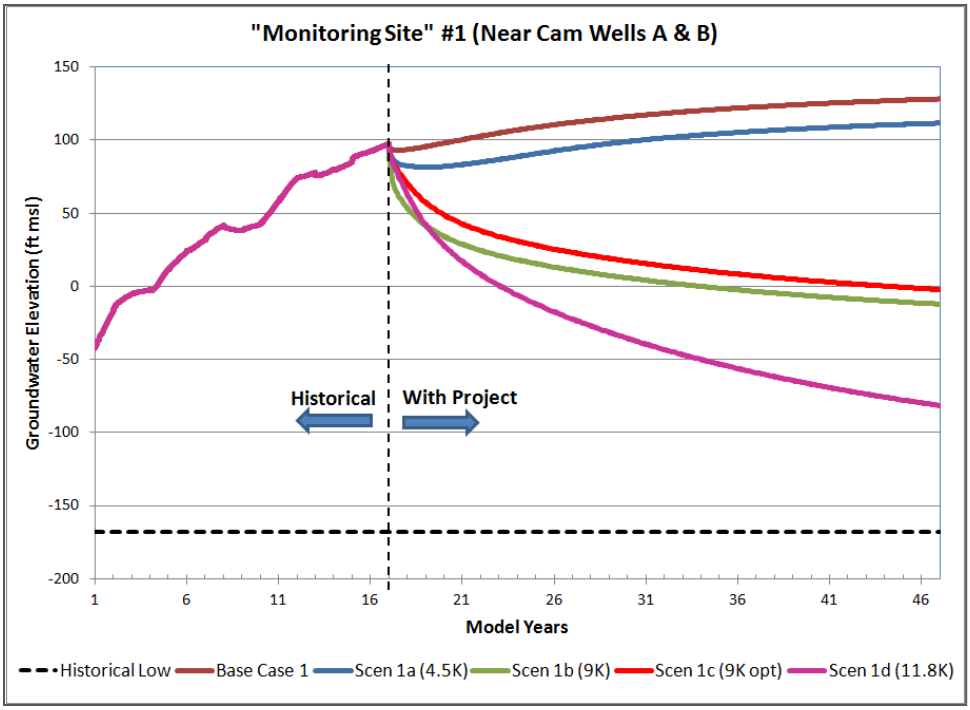


Figure 48. Hydrograph of Scenario #1 options near City of Camarillo's well #A and #B. Historical low is for well 2N/20W-19M4. Seasonal variations of about ±8 ft from yearly average are observed in measured groundwater elevations. See previous map for location.

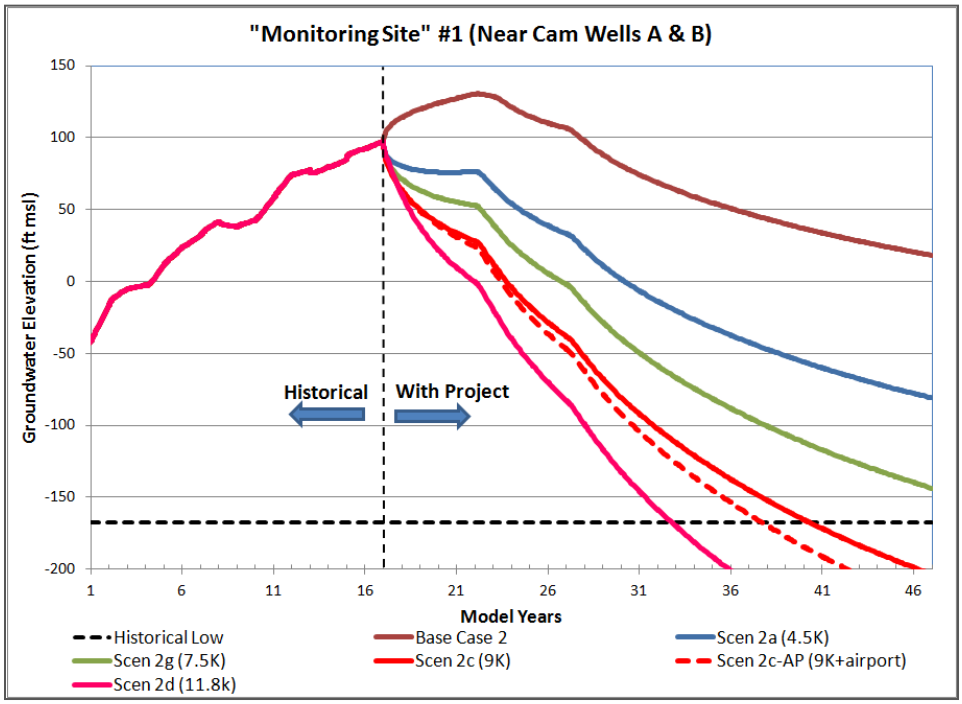


Figure 49. Hydrograph of Scenario #2 options near City of Camarillo's well #A and #B. Historical low is for well 2N/20W-19M4. Seasonal variations of about ±8 ft from yearly average are observed in measured groundwater elevations. See previous map for location.

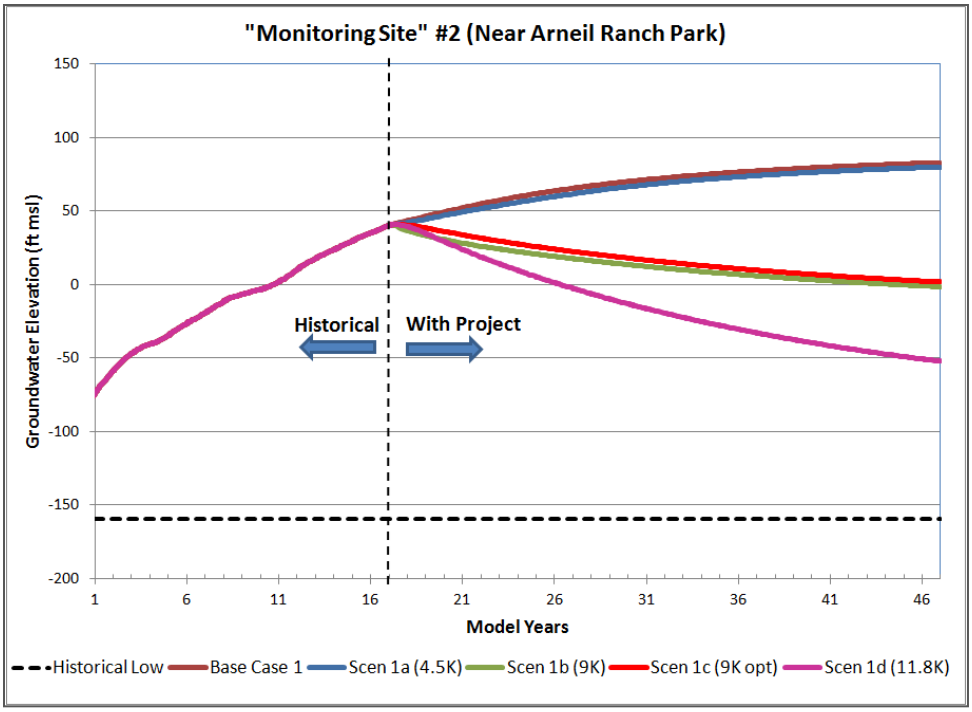


Figure 50. Hydrograph of Scenario #1 options near middle of City of Camarillo. Historical low is for well 2N/21W-25B1. Seasonal variations of ±5 ft from yearly average were observed in measured groundwater elevations. See previous map for location.

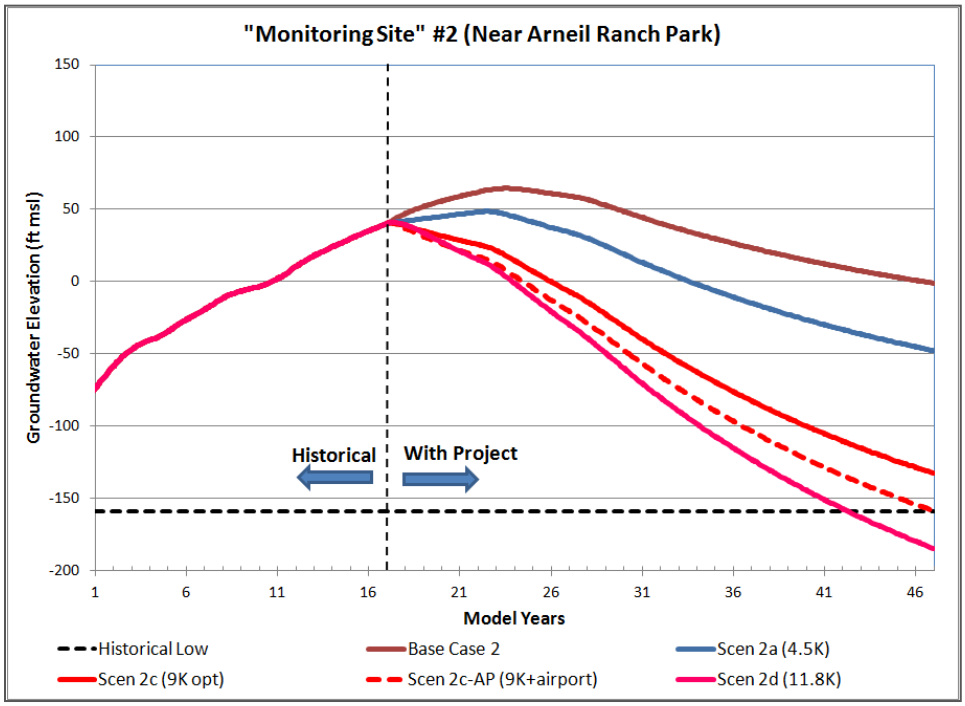


Figure 51. Hydrograph of Scenario #2 options near middle of City of Camarillo. Historical low is for well 2N/21W-25B1. Seasonal variations of ±5 ft from yearly average were observed in measured groundwater elevations. See previous map for location.

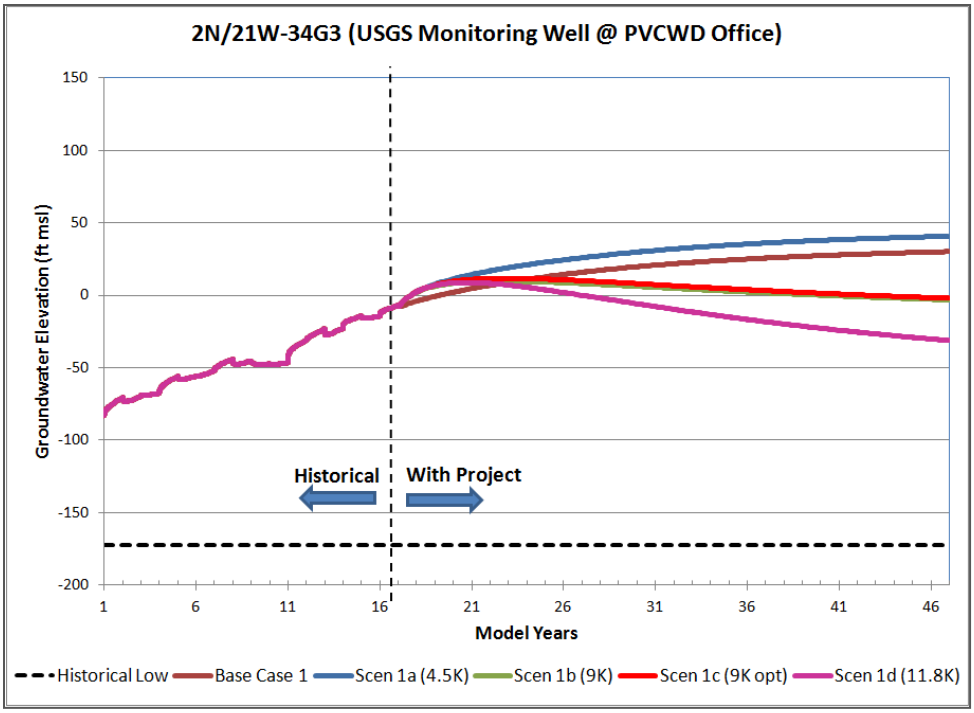


Figure 52. Hydrograph of Scenario #1 options at USGS monitoring site at PVCWD office. Historical low is for well 2N/21W-34G3. Seasonal variations up to ±25 ft from yearly average were observed in measured groundwater elevations. See previous map for location.

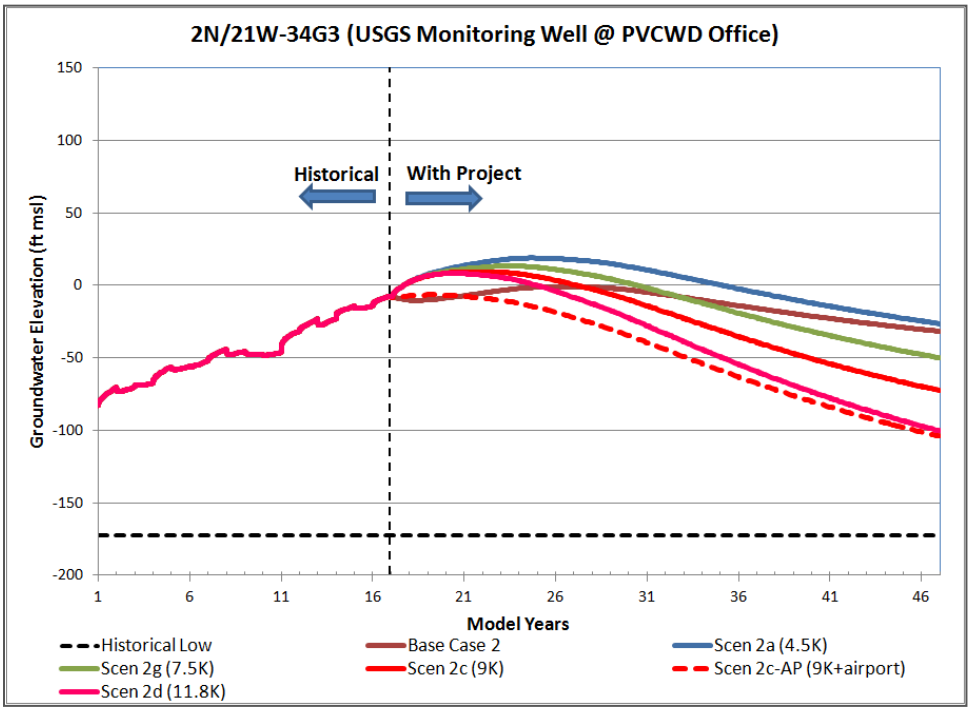


Figure 53. Hydrograph of Scenario #2 options at USGS monitoring site at PVCWD office. Historical low is for well 2N/21W-34G3. Seasonal variations up to ±25 ft from yearly average were observed in measured groundwater elevations. See previous map for location.

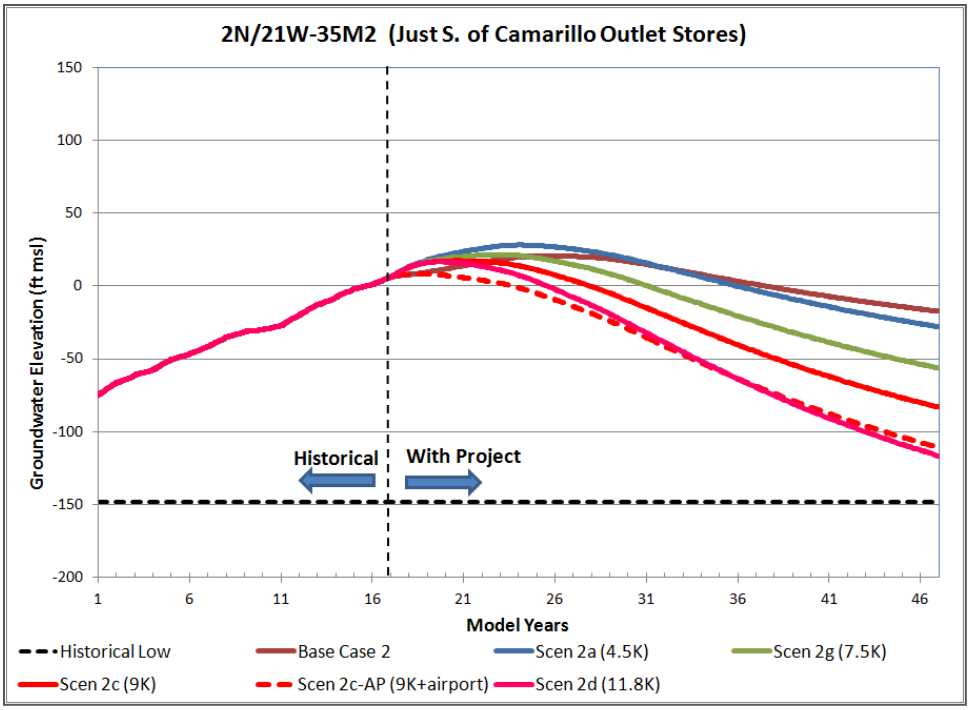


Figure 54. Hydrograph of Scenario #2 options at well 35M2, south of Camarillo Outlet stores (farthest north pumping in that area). Historical low is for nearby well 2N/21W-35K1. Seasonal variations up to ±25 ft from yearly average were observed in measured groundwater elevations. See previous map for location.

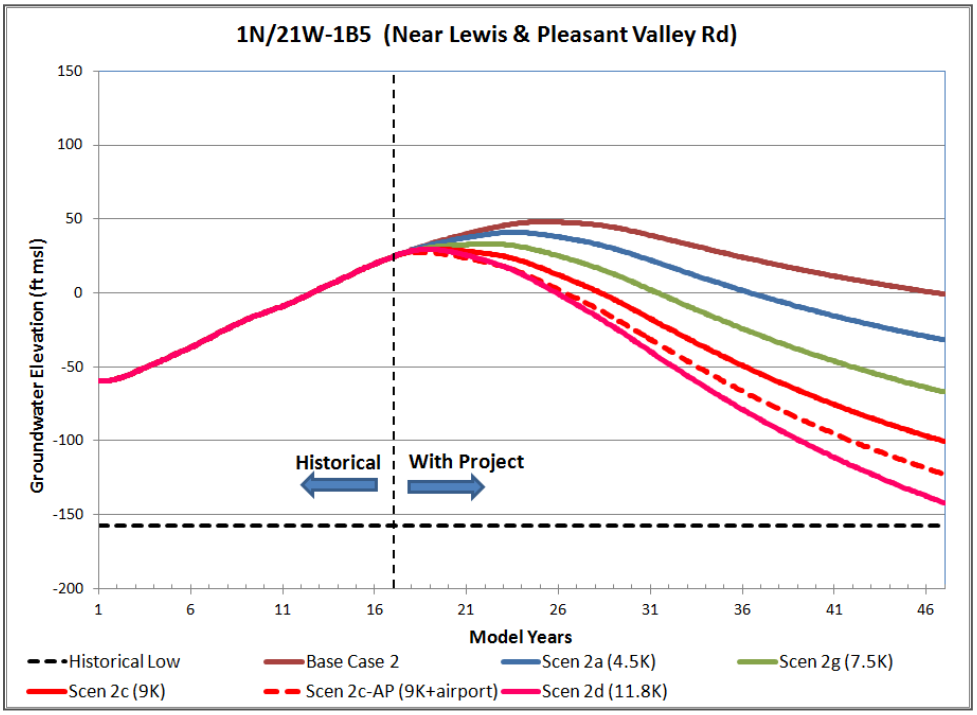


Figure 55. Hydrograph of Scenario #2 options at well 1B5, near the intersection of Lewis and Pleasant Valley roads. This well represents the farthest north pumping in that area. Historical low is for well 1N/21W-1B4. Seasonal variations up to ±25 ft from yearly average were observed in measured groundwater elevations. See previous map for location.

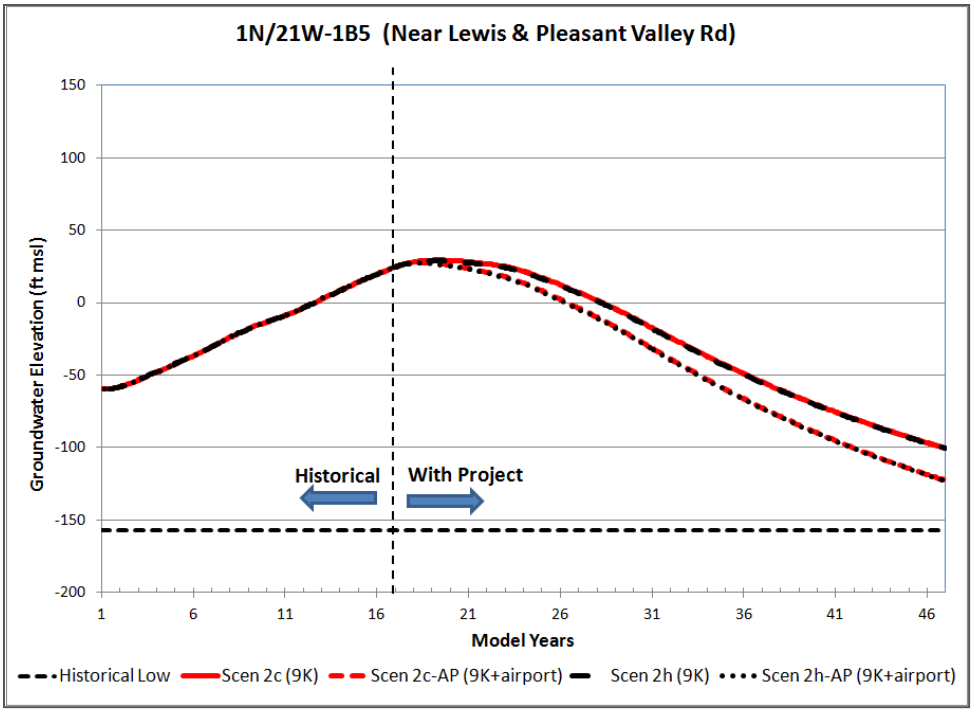


Figure 56. There is no discernible effect at well 1B5 near the City of Camarillo's southern border from moving the farthest-northeast well in Scenario #2c (9,000 AFY, 4 wells) back into the area of the other three desalter wells (Scenario #2h, 9,000 AFY, 4 wells). Seasonal variations up to ±25 ft from yearly average were observed in measured groundwater elevations. Location of moved well indicated in Figure 73.

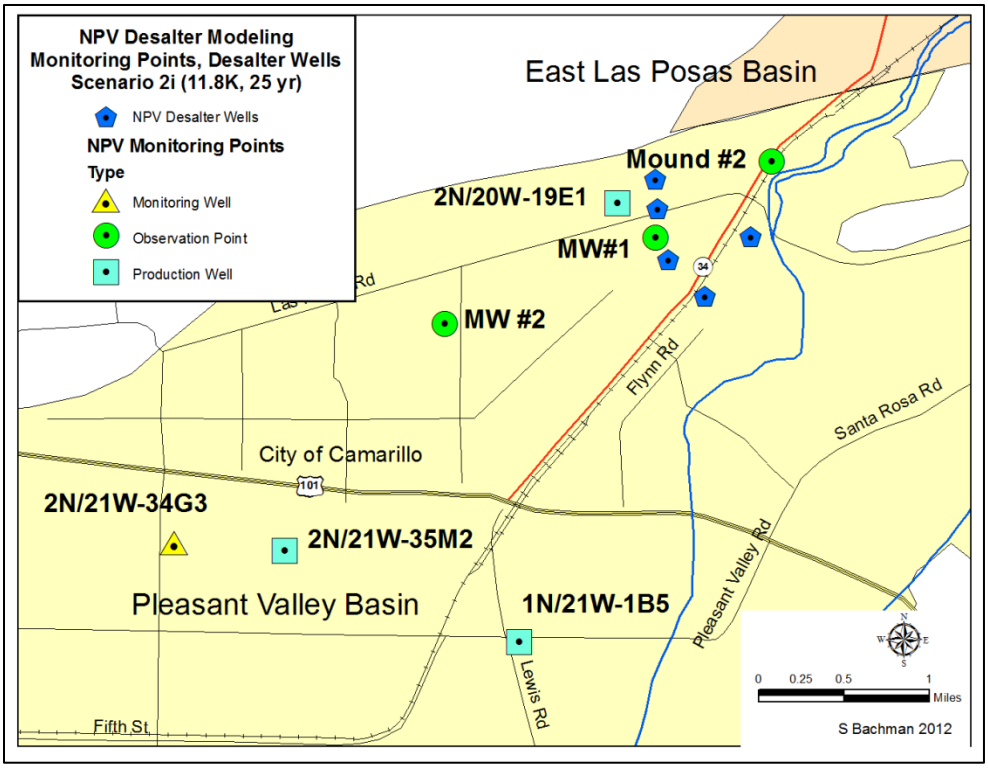


Figure 57. Location of desalter and monitoring wells for Scenario #2i (11,800 AFY, 5 wells, 25 years).

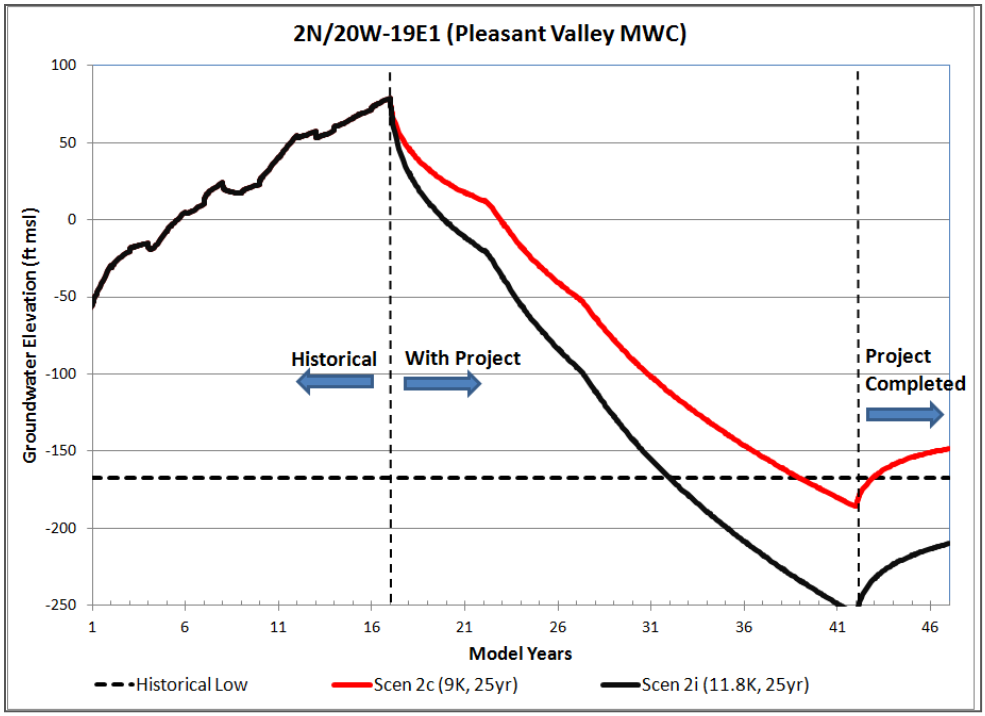


Figure 58. Simulated hydrograph at 19E1 well for 25-year project for pumping rates of 9,000 and 11,800 AFY, including 5 years of recovery following the completion of project pumping. Historical low is for nearby well 2N/20W-19M4. Seasonal variations up to ±10 ft from yearly average were observed in measured groundwater elevations. Well location in previous figure.

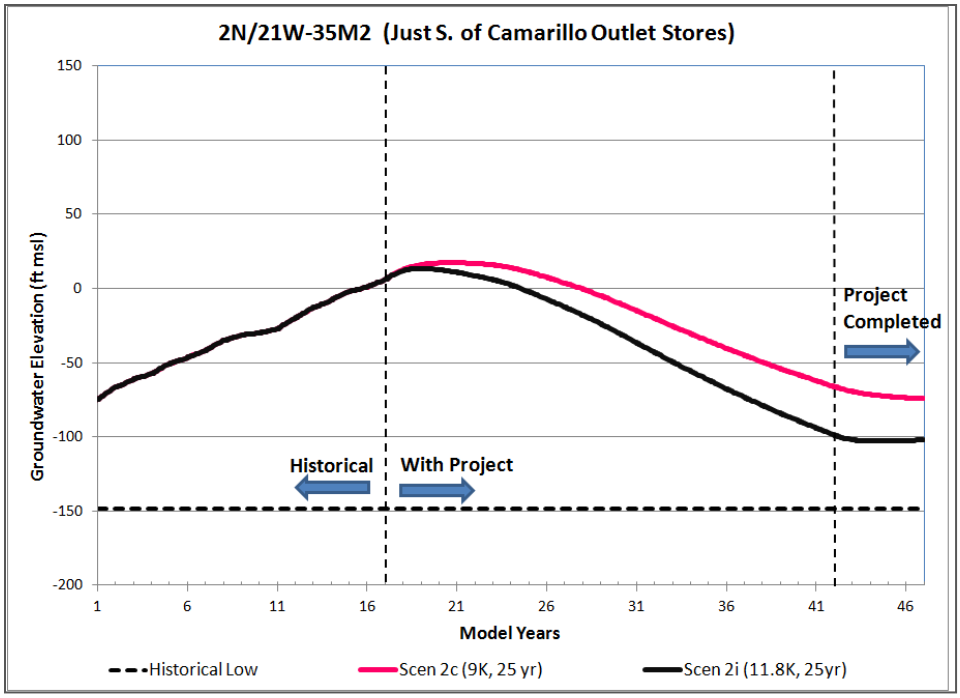


Figure 59. Simulated hydrograph at well 35M2 (southwestern edge of City of Camarillo) for 25-year project for pumping rates of 9,000 and 11,800 AFY, including 5 years of recovery following the completion of project pumping. Historical low is for nearby well 2N/21W-35K1. Seasonal variations up to ±25 ft from yearly average were observed in measured groundwater elevations.

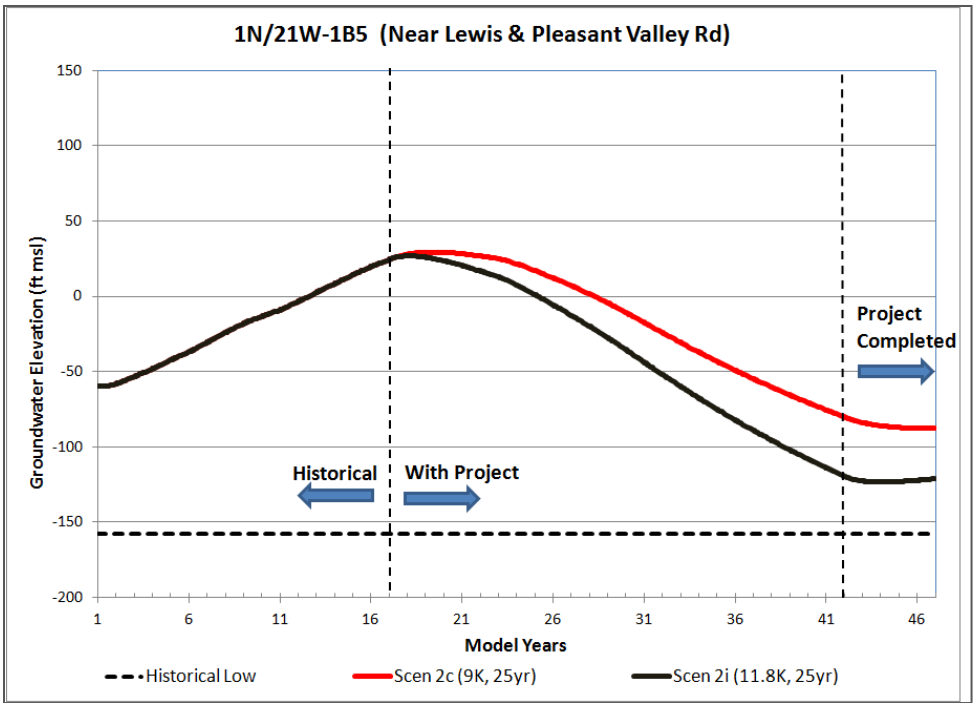


Figure 60. Simulated hydrograph at well 1B5 at southern boundary of City of Camarillo for 25-year project for pumping rates of 9,000 and 11,800 AFY, including 5 years of recovery following the completion of project pumping. Seasonal variations up to ±25 ft from yearly average were observed in measured groundwater elevations.

5 Particle Tracking

Particle tracking is an especially useful tool for analyzing projects such as the NPV Desalter. The particle tracking component of MODFLOW, called MODPATH, uses the MODFLOW grid and cell-by-cell model results to simulate the movement of a particle within the groundwater flow path. A starting time and location of a particle is designated, and the path of the particle is then traced during any portion of the model period. The particle moves both horizontally and vertically (potentially from one model layer to another) depending upon the groundwater gradient in each cell of the model for each time step of the model. Because this model used 25 time steps in each of 47 annual stress periods, a particle could be tracked over as many as 1,175 time steps.

In this study, particles were used to simulate plug-flow in the aquifer. In other words, the brackish water moves as a mass through the aquifer, pushing fresh water in front of it. There is no assumed dilution or dispersion at the front of the water mass. At monitoring wells along the coastline, there appears to be a relatively sharp contrast between seawater and fresh water, so this assumption does not likely lead to large error.

The results of one set of particle tracks are indicated in Figure 61. A set of these particle tracking results was generated for each scenario, with the set containing tracks of particles at different starting times. In all Scenario #2 options, one set of particle tracks was timed to coincide with the end of baseflow percolation into NPV (when upstream desalters had removed all baseflow from the arroyo). This set of particles represented the beginning of movement of better-quality stormflow, so the location of the tail-end of the brackish water could be tracked.

By combining the results of the set of particle tracks for each scenario, an approximation of the location of the brackish water at any time could be determined. For the Base Case scenarios, the furthest travel of the particles at the end of the 47 years of the model is indicated. For all other scenarios, the progressive movement of the particles is indicated.

5.1 Verification of Particle Tracking

An additional verification of the groundwater model is available as the result of the particle tracking simulations. The arrival time of the first particles released in the model (coinciding with base flow first reaching NPV) can be compared against the time when measured water quality changed in production wells (Figure 62 and Figure 63). As shown in the two charts, water levels rose several years prior to the arrival of brackish water. The delay time for these brackish water molecules to actually reach the wells coincides with the arrival time predicted by particle tracking, providing model verification. This verification can be accomplished for wells within about the first 10 years of travel time from the arroyo; beyond that, the recommended monitoring wells can be used for verification in the future.

5.2 Particle Tracking Results

Results for Base Cases – For Base Case #1 (no desalters in either Las Posas basin or NPV), particles track across Highway 101 and beneath the agricultural fields of Pleasant Valley (Figure 64). The potential of salts reaching that far south is a new threat to the water resources of the Pleasant Valley basin. If desalters are built in Las Posas and baseflow into NPV is eliminated

(Base Case #2), brackish water that entered the aquifer prior to reduction of baseflow would continue to move southward towards the main Pleasant Valley basin, but at a slower rate (Figure 65).

Results with NPV Desalter Pumping – Particle movement with NPV desalters operating (starting in model year 18) is largely dependent upon the location of the desalter wells and the rate of pumping. The locations of desalter wells were optimized iteratively by examining both water level drawdown and particle tracking. Thus, the scenarios in this evaluation are largely dependent upon pumping rate. As pumping rates were increased (4,500-7,500-9,000 AFY), the period and extent of migration was shortened.

In Scenario #2a (4,500 AFY, 2 wells, Figure 66, Figure 67) particles just cross beneath Highway 101 before they are reversed. Most importantly, there is a relatively large area of potential brackish water that remains stranded at model year 47. When pumping rates are increased to 7,500 AFY (Scenario #2g, 4 wells – Figure 68, Figure 69) and 9,000 AFY (Scenario #2c, 4 wells – Figure 70, Figure 71) the southward extent and the area of potential stranded salts are decreased. When the airport wells are pumped during the model simulation (Figure 72), brackish water migrates farther to the southwest, but is effectively recovered before model year 47. The effectiveness of the recovery may be caused by better alignment of the brackish water with the recovery wells.

Scenario #2h (9,000 AFY, 4 wells) was constructed to extend the period during which the desalter wells were potentially pumping brackish water. As indicated in Figure 73, moving the northeastern well resulted in desalter wells pumping potentially brackish water over a longer period of time.

Simulation of the 25-year, 11,800 AFY project (Scenario #2i) indicates that there is complete recapture of particles prior to the end of model year 47 (Figure 74). In the scenario, two wells were shut off near the end of the model period as particles were recaptured (i.e., “brackish water” was completely recaptured at that site). For a 25-year project pumping 9,000 AFY, not all the brackish water is removed (42-yr interpolation between arcs for 40 and 47 years in Figure 71).

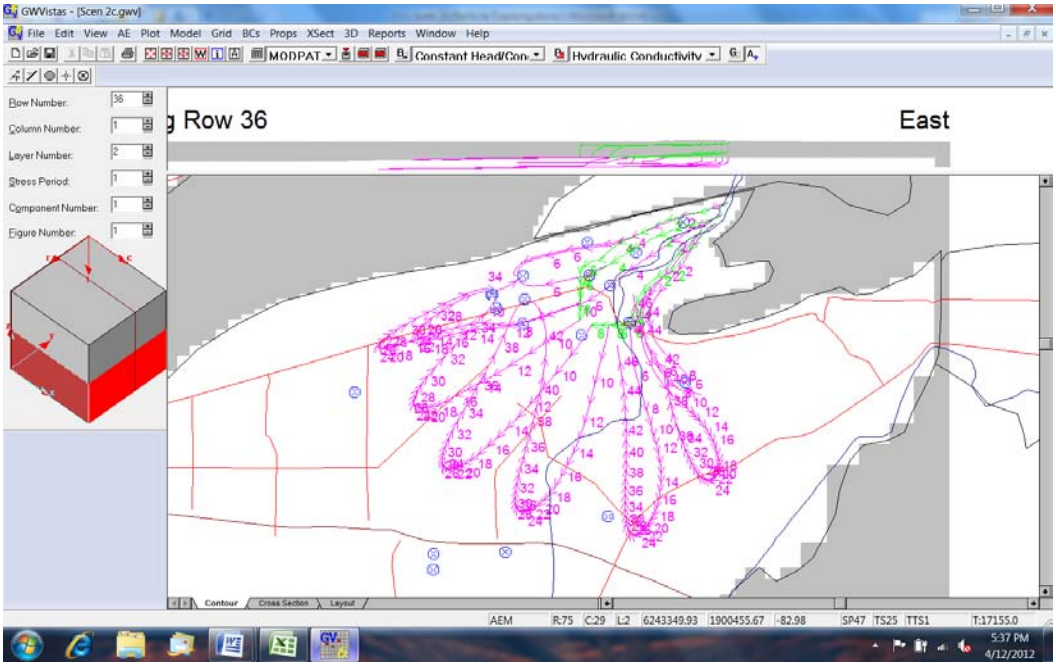


Figure 61. Particle tracking results for Scenario #2c (9,000 AFY, 4 wells) with a set of particles released at the baseflow recharge area at the beginning of year 1 of the model. Years are shown for each particle track; the light green tracks are when the particle is in Layer 1, whereas the purple tracks are when the particle is in Layer 2. Particles reverse direction following the beginning of desalter pumping in year 18.

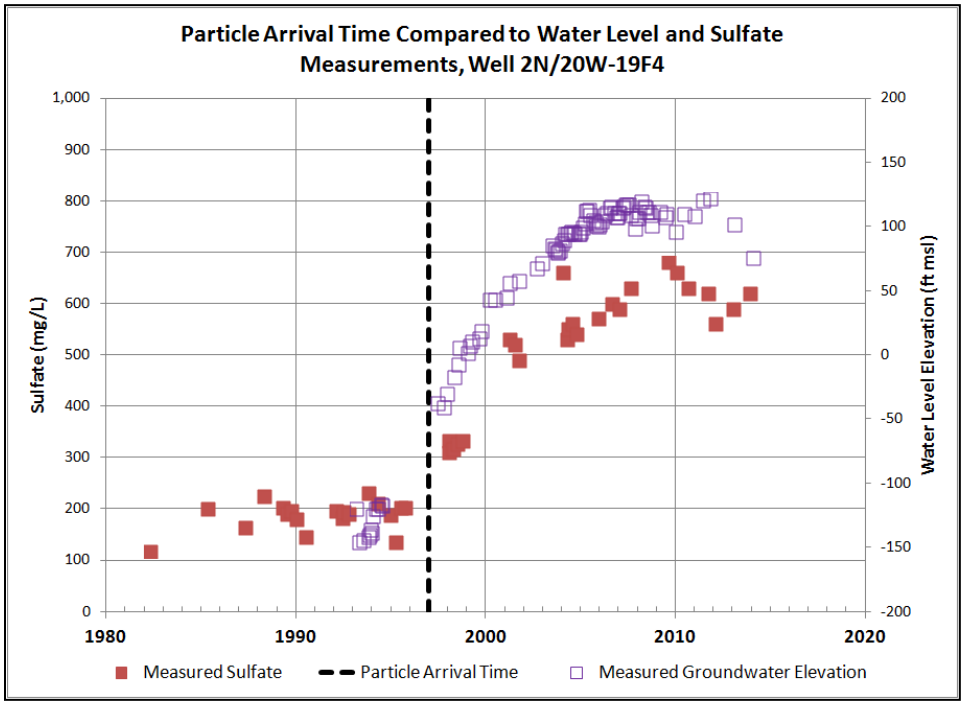


Figure 62. Measurements of sulfate concentrations and groundwater elevations compared to timing of arrival of first particles at well 19F4. Note that measured groundwater elevations rise several years prior to the first brackish water arriving, with the predicted brackish water arrival coinciding with its actual arrival.

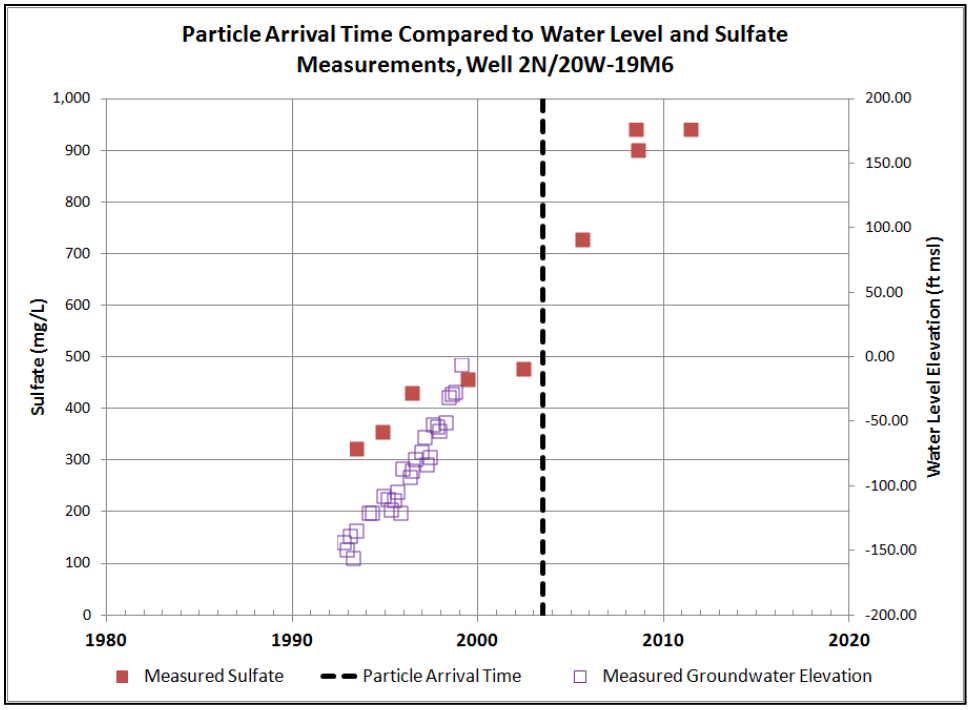


Figure 63. Measurements of sulfate concentrations and groundwater elevations compared to timing of arrival of first particles at well 19M6. Note that measured groundwater elevations rise several years prior to the first brackish water arriving, with the predicted brackish water arrival coinciding with its actual arrival.

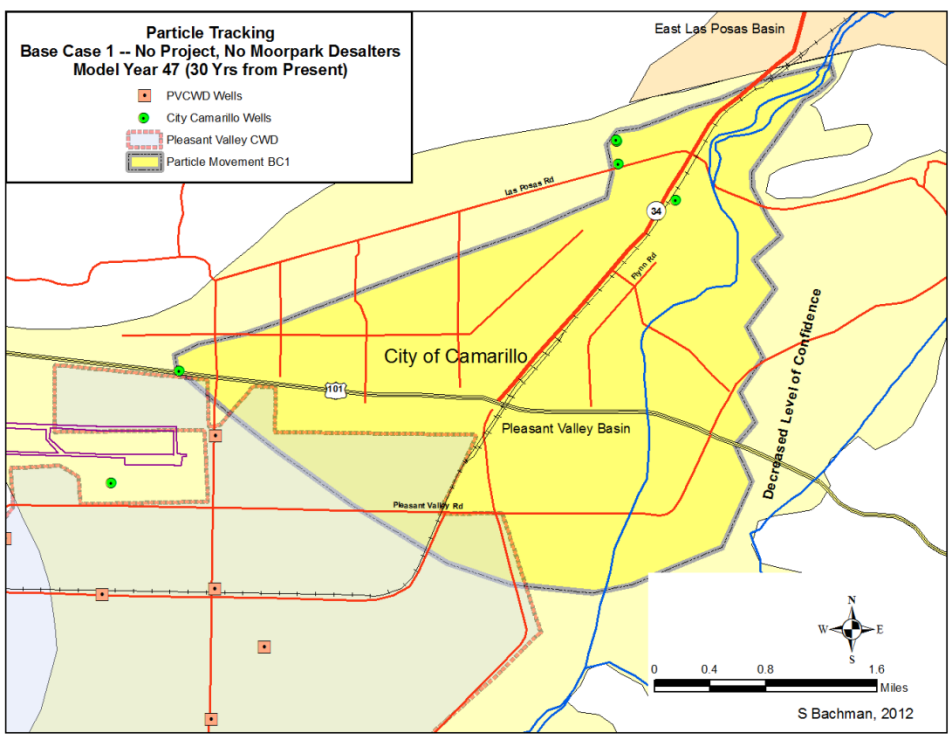


Figure 64. Particle tracking results for Base Case #1, indicating that by the end of model year 47 (30 years from now), the poor-quality water could migrate beneath the agricultural fields of the Pleasant Valley County Water District.

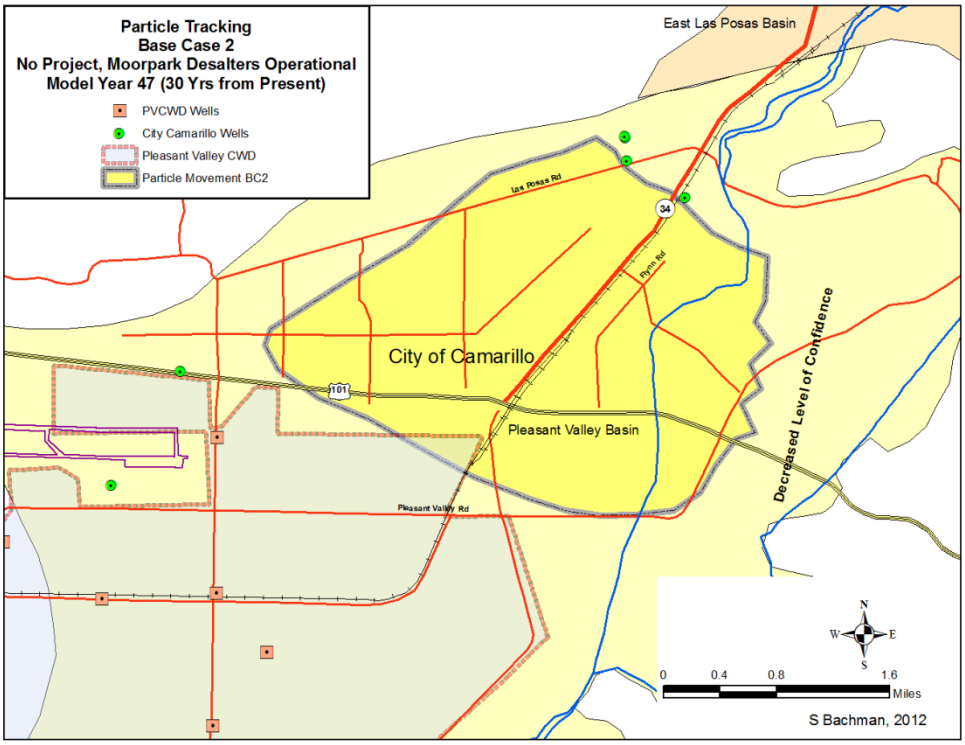


Figure 65. Particle tracking results for Base Case #2, indicating that by the end of model year 47 (30 years from now), the poor-quality water could migrate south of Highway 101 even with Las Posas desalters operating.

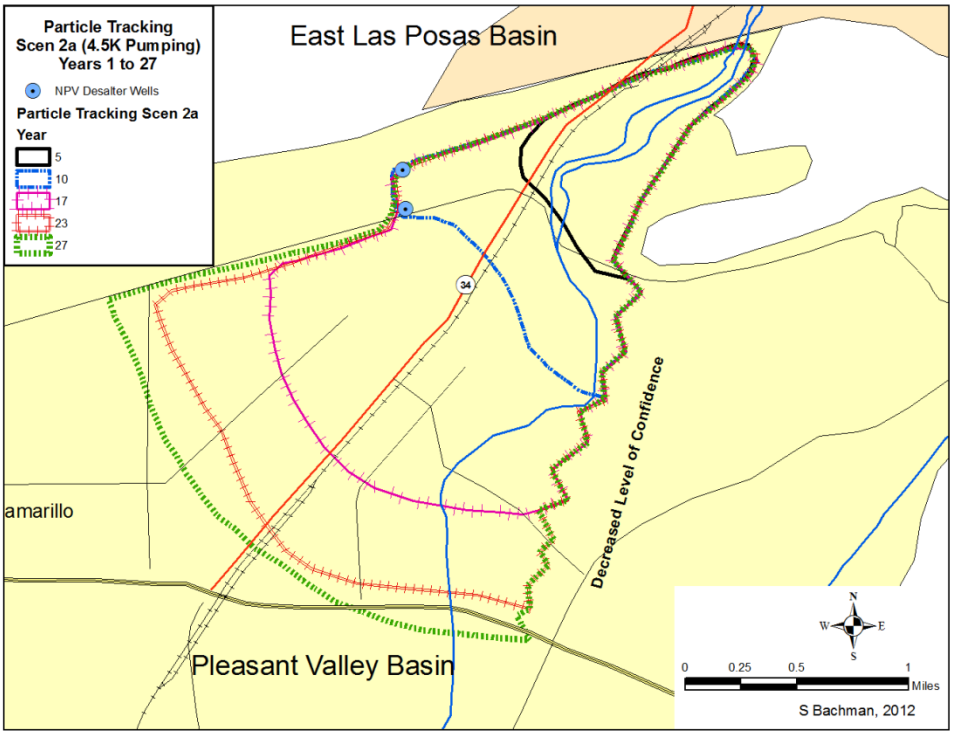


Figure 66. Particle tracking for Scenario #2a (4,500 AFY, 2 wells), model years 1 to 27. Particle movement slowed down somewhat after the beginning of desalter pumping in year 18.

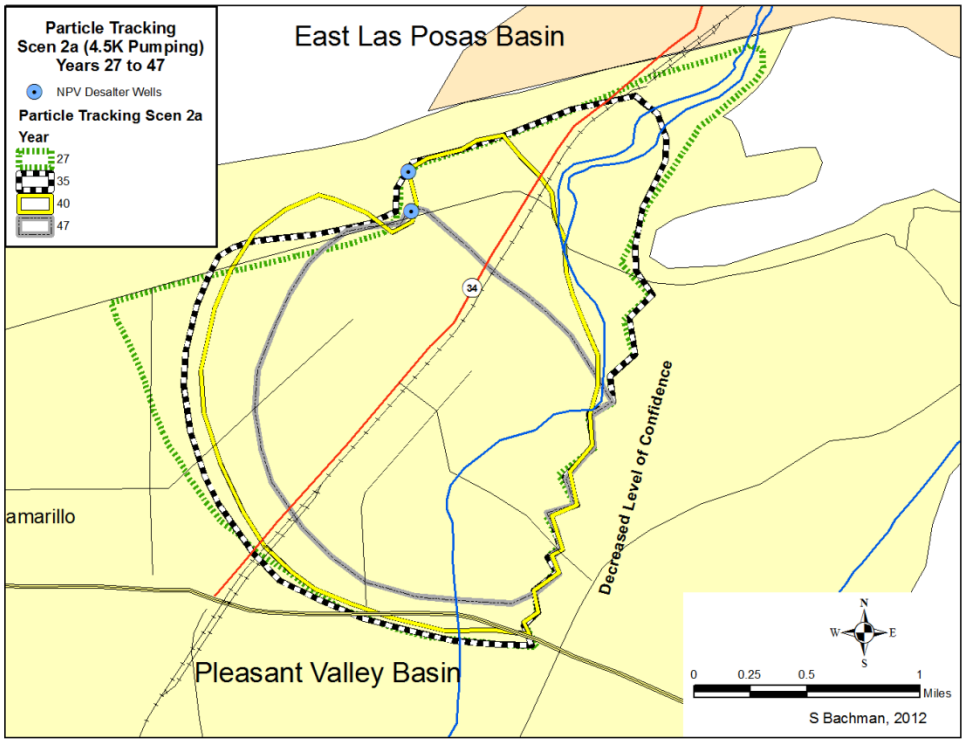


Figure 67. Particle tracking for Scenario #2a (4,500 AFY, 2 wells), model years 27 to 47. After model year 27, particles reverse direction and the area of potential brackish water decreases somewhat. There is a significant area of potentially stranded salts (inside year 47 boundary).

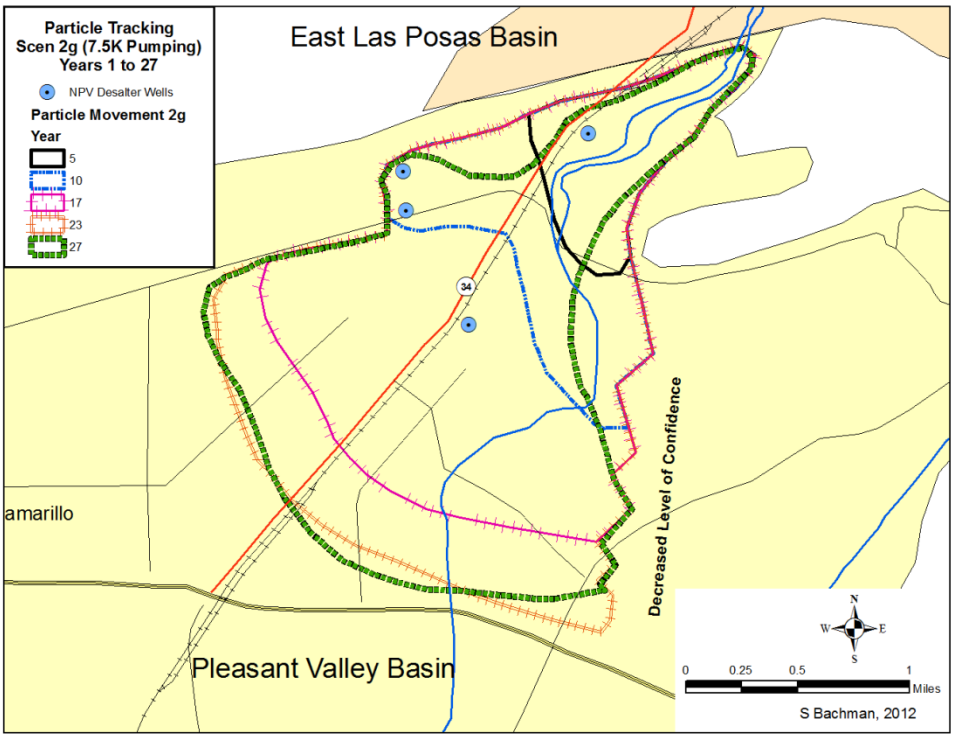


Figure 68. Particle tracking for Scenario #2g (7,500 AFY, 4 wells), model years 1 to 27. Particles stop migrating to southwest by model year 23.

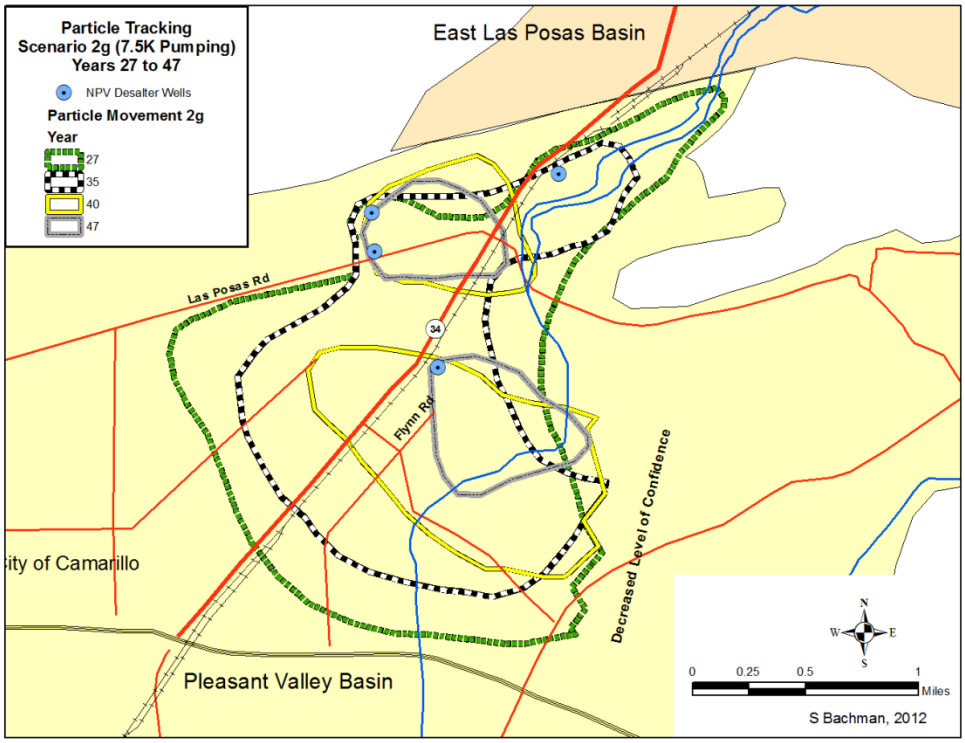


Figure 69. Particle tracking for Scenario# 2g (7,500 AFY, 4 wells), model years 27 to 47. Potential areas with brackish water in model year 47 are significantly reduced from Scenario #2a (4,500 AFY, 2 wells).

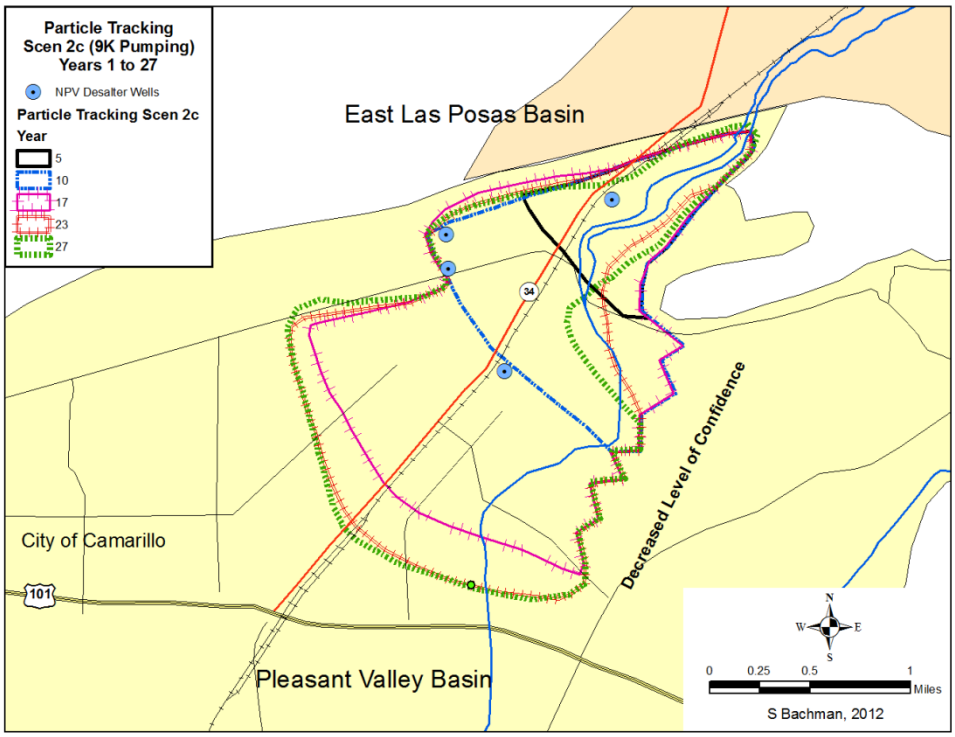


Figure 70. Particle tracking for Scenario #2c (9,000 AFY, 4 wells), model years 1 to 27. Particles stop migrating to southwest by model year 23.

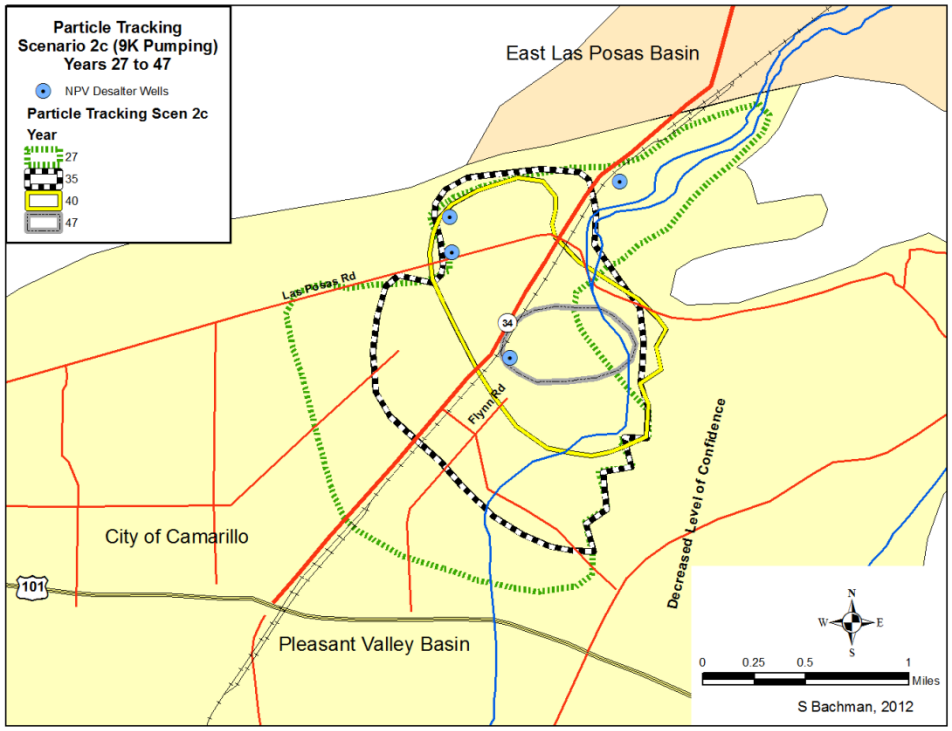


Figure 71. Particle tracking for Scenario #2c (9,000 AFY, 4 wells), model years 27 to 47. Potential areas of brackish water are almost eliminated by model year 47. For a 25-year project (ending in model year 42), an interpolation can be made between arcs for 40 and 47 years.

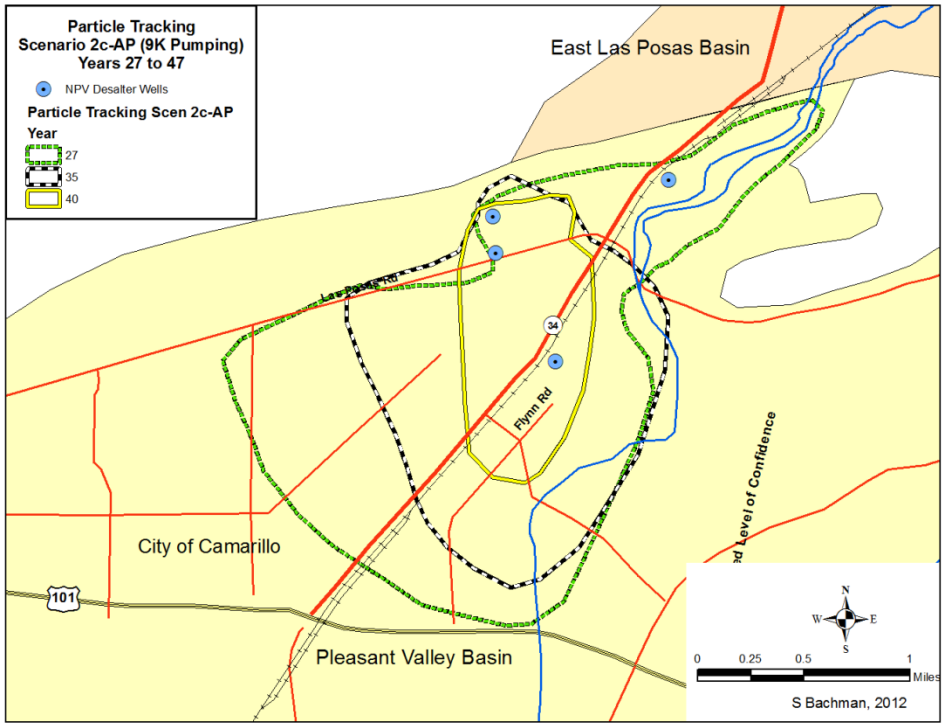


Figure 72. Particle tracking for Scenario #2c-AP (9,000 AFY, 4 wells, pumping of Airport wells), model years 27 to 47. Comparison to the previous figure indicates that the pumping at the airport wells tends to migrate the brackish water farther southwest by year 27, but results in elimination of the brackish water before model year 47.

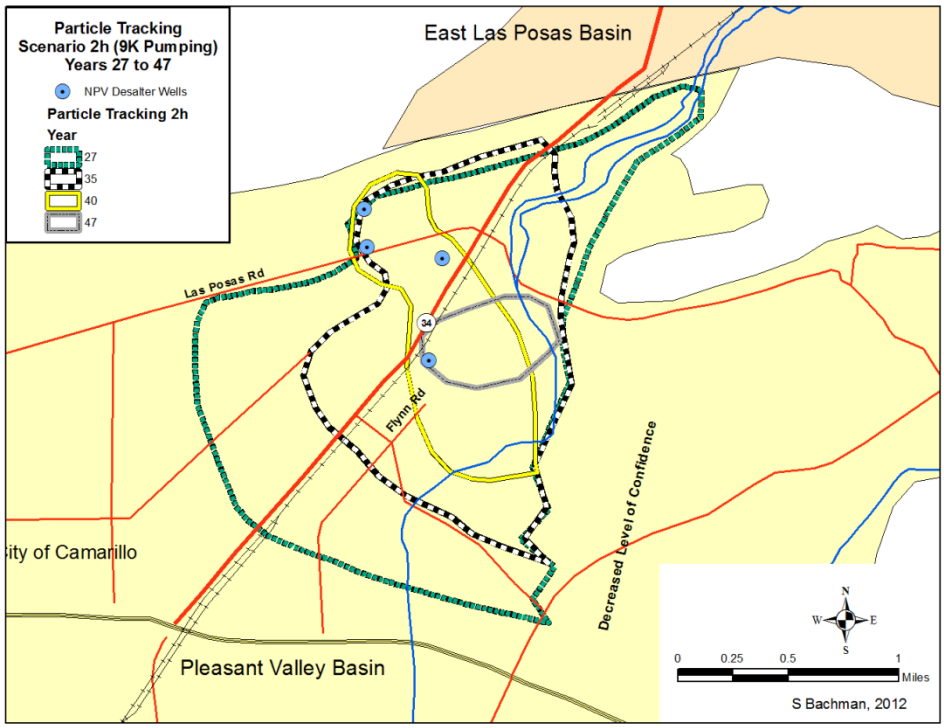


Figure 73. Particle tracking for Scenario #2h (9,000 AFY, 4 wells), which mimics Scenario #2c except that farthest northeast desalter well was moved closer to the other desalter wells.

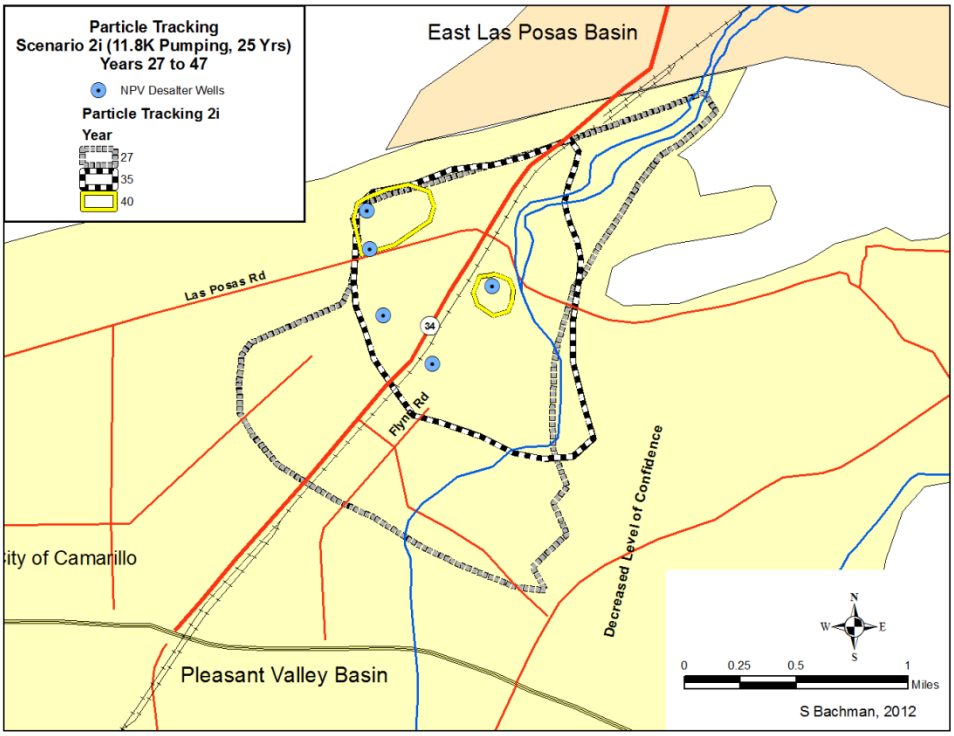


Figure 74. Particle tracking results for Scenario #2i, the 11,800 AFY project that was shortened to 25 years. All particles are recovered by model year 47, suggesting a successful recapture of brackish water.

6 Using Model Results

Modeling is used to simulate actual behavior in the aquifer. When interpreting model results, it is important to determine how well the model does represent aquifer responses. Three methods were used to determine the accuracy of the modeling and how sensitive model results are to inputs such as streamflow.

Water Level Comparisons – this was the model calibration process discussed earlier in the report. Because calibration took place during the building of the mound, the model is well suited for simulating depletion of the mound over the same water level range (i.e., the model is operated within its calibrated range).

Water Quality Comparisons – water quality measured in wells can be compared to the results of the particle tracking analysis. In theory, you could compare water quality changes throughout the historical period. In practice, there were few wells within the city limits of Camarillo during the 17-year period when model results could be compared to measured results. There is the opportunity to do this with Camarillo's wells A and B – they are within the mound of poor-quality water and there are abundant water level and water quality data during this period. In these wells, there is a lag time of 5 to 10 years between when water levels started to rise and when increased salts reached the wells. MODFLOW and MODPATH model results predict that particles released in the area of baseflow infiltration along the arroyo would reach wells A and B in a similar time frame. Thus, there is agreement between observed and modeled results.

Sensitivity Analysis – the sensitivity of model parameters such as aquifer properties was part of the model calibration – the model parameters were optimized for calibration to measured groundwater elevations. The sensitivity of the model to major input and outputs such as pumping and recharge need to be addressed separately for this model. Groundwater pumping in the model is from data reported by pumpers to the FCGMA. Although there has been long discussion on the accuracy of this self-reporting, the amount of pumping in the model does not vary between scenarios except for City of Camarillo and desalter pumping. Thus, the changes in aquifer response between the various scenarios, where only desalter pumping is varied, are likely to be fairly representative of actual changes.

The significant input to the model is percolation from streamflow. In particular, the amount of baseflow (brackish water) is important in determining both groundwater elevations and particle tracking. To test the sensitivity of the model to variations in the amount of baseflow, baseflow was varied by ± 20% for Scenario #2c (9,000 AFY, 4 wells). The largest effect in groundwater elevations in the sensitivity analysis is in the area where baseflow percolation occurs (Figure 75). Farther from the area of percolation, the effects of changing baseflow become more muted (Figure 76 and Figure 77). At reduced baseflow, particles do not extend as far southwest as in Scenario #2c and the area of "stranded brackish water" at model year 47 is eliminated (Figure 78). With increased baseflow, particles extend farther southwest and the area of "stranded brackish water" at model year 47 is larger (Figure 79). This information is integrated into the analysis of the project in the following chapter.

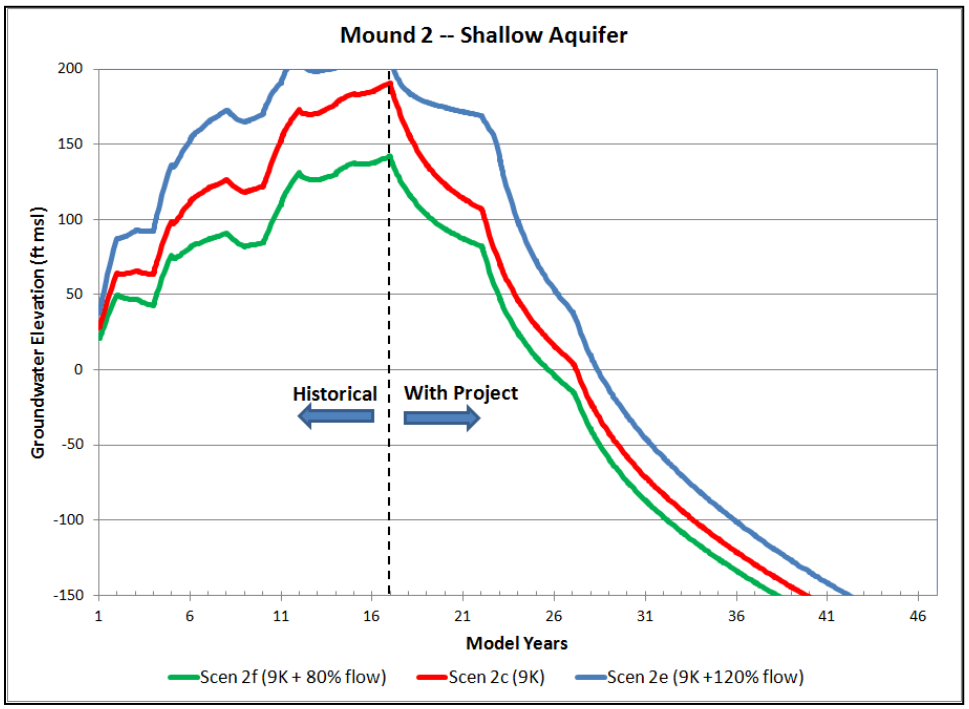


Figure 75. Sensitivity analysis at observation point Mound #2 (Figure 45) by changing baseflow by ± 20% for Scenario #2c (9,000 AFY, 4 wells).

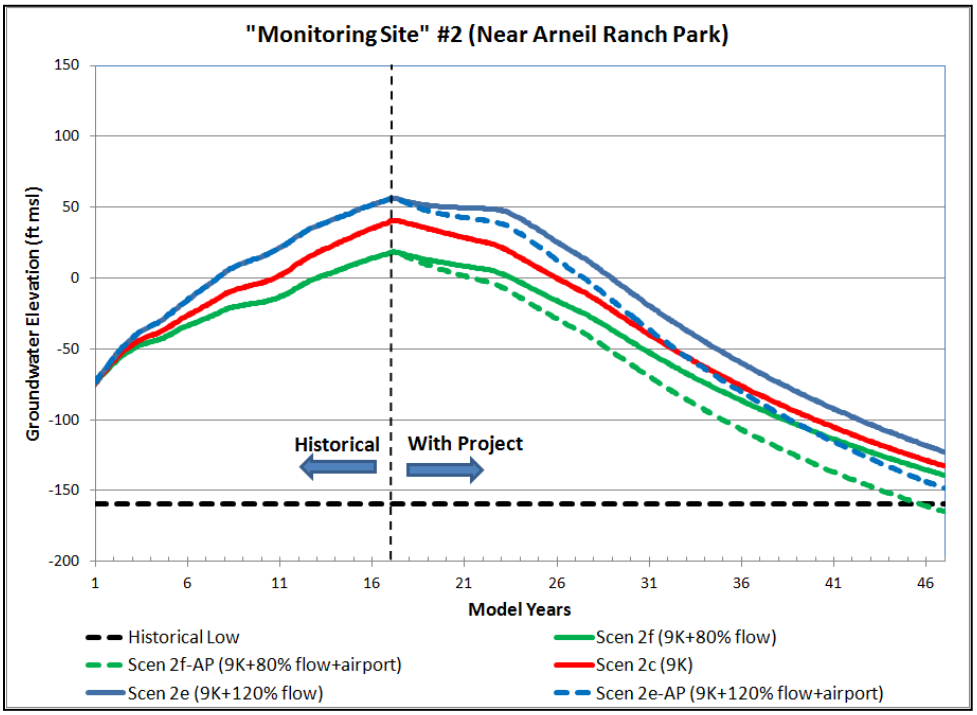


Figure 76. Sensitivity analysis at observation point MW #2 (Figure 45) by changing baseflow by ± 20% for Scenario #2c (9,000 AFY, 4 wells).

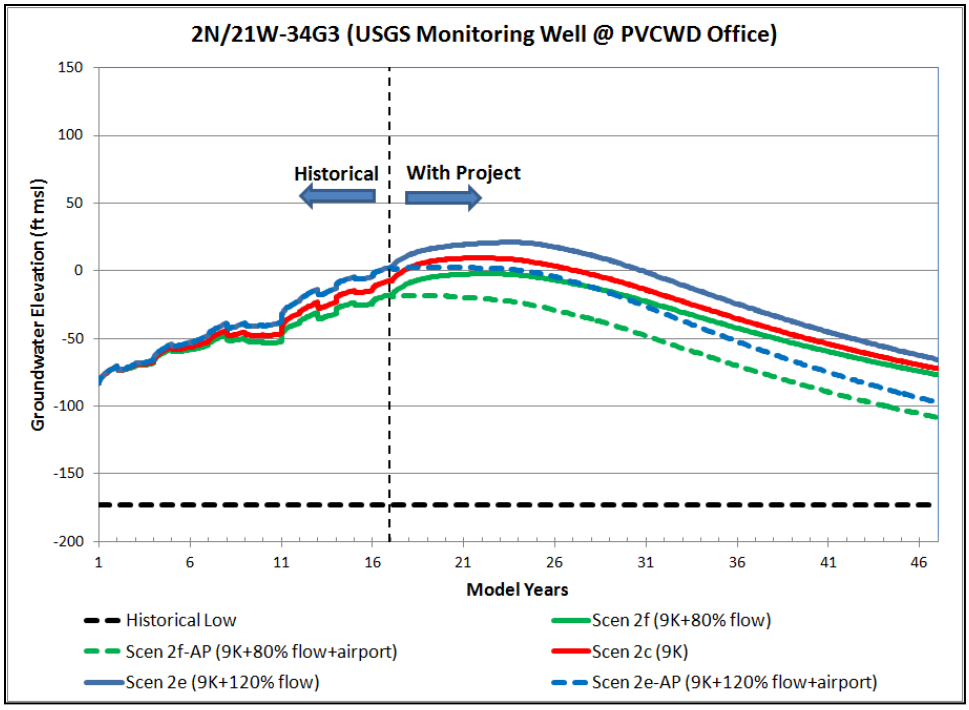


Figure 77. Sensitivity analysis at monitoring well 34G3 by changing baseflow by ± 20% for Scenario #2c (9,000 AFY, 4 wells).

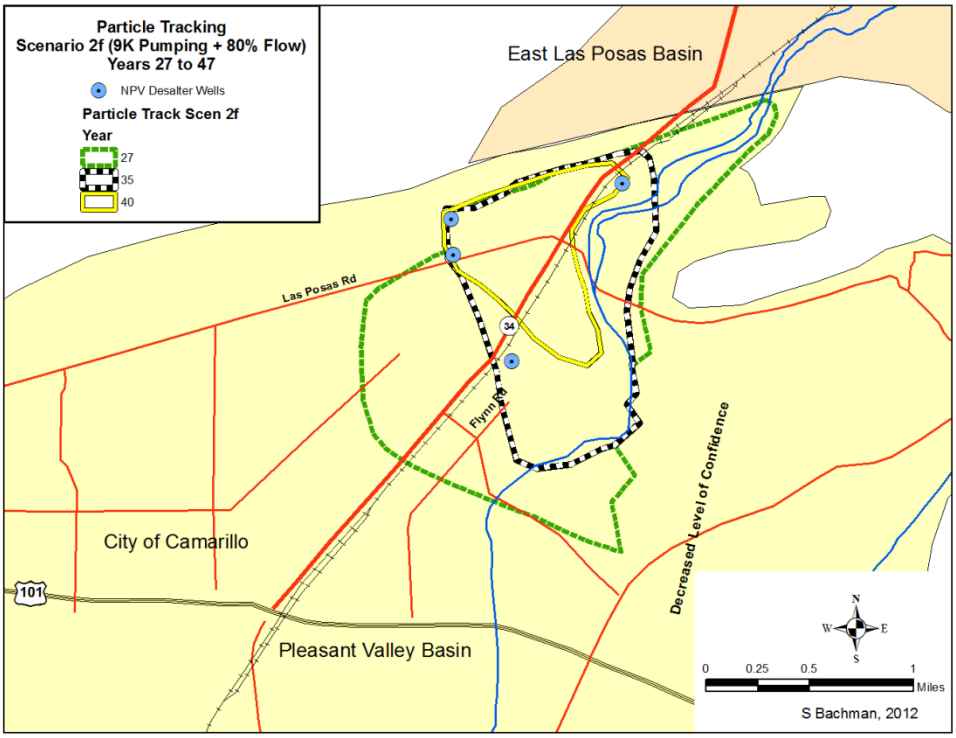


Figure 78. Sensitivity analysis for particle tracking for Scenario #2f (Scenario #2c with 80% baseflow infiltration). Compare results to those shown on Figure 71 for Scenario #2c (9,000 AFY, 4 wells).

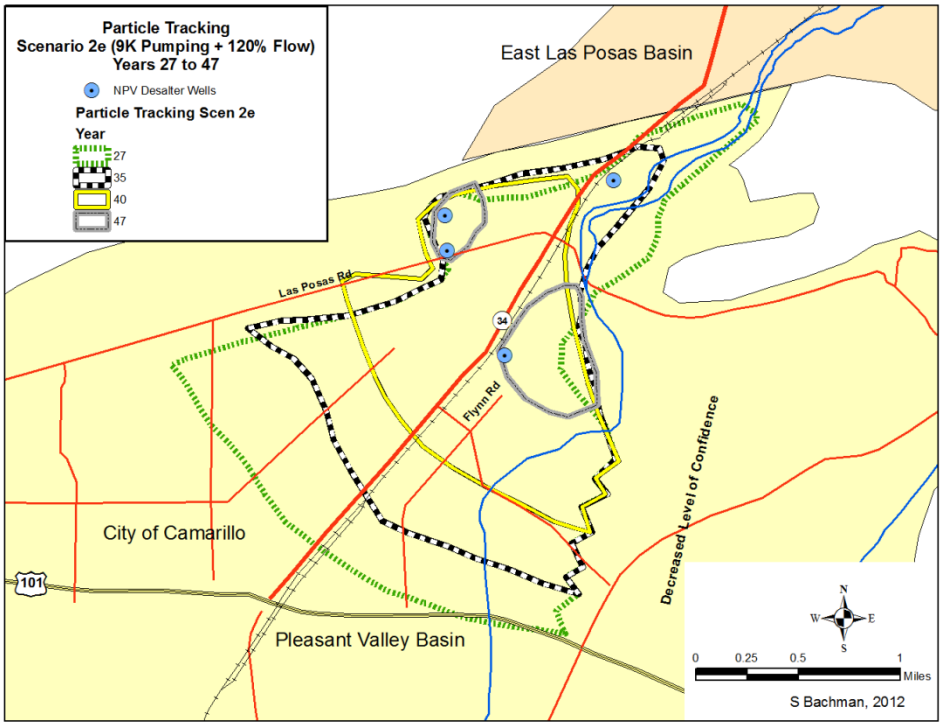


Figure 79. Sensitivity analysis for particle tracking for Scenario# 2e (9,000 AFY, 4 wells, baseflow 120%). Compare results to those shown on Figure 71 for Scenario #2c (9,000 AFY, 4 wells, 100% baseflow.

7 Analysis of Results

Modeling results indicate that with no desalter pumping in NPV and/or the Las Posas basin, poor-quality water could continue its migration towards and into the agricultural areas of the main Pleasant Valley basin. NPV desalter pumping largely eliminates that threat to the aquifers. Both Scenario #1 options (no desalter pumping in the Las Posas basin) and Scenario #2 (reduced flow in arroyo caused by upstream desalter projects) were evaluated in this study. Base Case #1 and Scenario #1 project scenarios were was used to determine project effects compared to current conditions. Base Case #2 project scenarios were used to assess worst-case effects for the NPV desalter project.

At lowered rates of desalter pumping (e.g., 4,500 AFY), the mound of brackish water in NPV would be reduced but not eliminated. Likewise, there would likely be "stranded brackish water" under the City of Camarillo at these lower pumping rates that would continue moving southward into the basin. At higher rates of desalter pumping, there becomes a trade-off between salt removal and lowered groundwater elevations. The effect of project pumping on the Pleasant Valley basin is summarized in this section.

7.1 Project Effects Relative to Current Conditions

To evaluate the project relative to current (no project) conditions, groundwater model Base Case #1 model runs were used to project effects over the 25-year life of the project. Base Case #1 continues the current flows in Arroyo Las Posas during this 25-year project period because there are currently no approved projects in the Las Posas basin that would decrease that flow. Project Scenario #1c (same base flow, 9,000 AFY desalter pumping) was then compared to Base Case #1 results at four different sites in the northern Pleasant Valley basin – two very near project pumping (Figure 80, Figure 81) and two in the closest down-gradient areas of private pumping (Figure 82, Figure 83).

Near project pumping wells, modeled groundwater elevations at the end of the 25-year project dropped 100 to 120 ft from their historical highs – highs created by the growth of the mound of brackish water over the last decades. During the life of the project, as modeled no-project groundwater elevations rise as the mound of brackish water continues to degrade the aquifer, project groundwater elevations are as much as 150 ft lower than no-project elevations. However, project groundwater elevations remain above pre-mounding elevations and well above measured historical low elevations in these wells (Figure 80, Figure 81). Thus, the effect on these nearby wells is an increased pumping lift, but there would be no negative effect on the wells themselves – groundwater elevations would remain within historical fluctuations. Nearby well owners would also benefit over time from improved water quality, potentially more than offsetting any increased pumping lift.

In the nearest down-gradient wells, the model predicts that project groundwater elevations would drop no more than 30 ft below historical high levels caused by the mounding of brackish groundwater (Figure 82, Figure 83). The potential overall decrease in groundwater elevations is in the range of the semi-annual fluctuations in groundwater elevations from wet to dry portions of the year. Groundwater elevations would remain above pre-mounding elevations, and greater than 150 ft above historical low groundwater elevations. Well owners in these areas would also

likely avoid the arrival of the mound of brackish water that is predicted to degrade their water quality in the future if the project is not implemented (Figure 86).

7.2 Effect on Existing Wells

To determine the potential worst-case effect on existing wells, pumping for Scenario #2c-25yr was used (this scenario has reduced base flow in the arroyo) in the analysis. Active wells in the vicinity of the NPV Desalter project are shown on Figure 84. The closest well is operated by the Pleasant Valley Mutual Water Company (19E1). Model results for 25-year projects indicate that water levels in this well would drop slightly below historical low levels near the end of the project, but then recover to above historical lows after project completion (Figure 85). Other nearby wells would likely see a similar pattern in groundwater elevations, but with levels not dropping below historical levels. The Bell Ranch well is shown on Figure 84. It is not clear at this time which basin that well is in – if it in the Pleasant Valley basin, the well would also likely see drawdown from the NPV Desalter project.

Another potential effect of NPV desalter pumping would be on the largely agricultural pumpers south of the Camarillo city limits. Wells along this southern boundary were used to estimate project effects. Modeled groundwater elevations at the USGS monitoring well at PVCWD's office (Figure 53) and other locations away from the project (Figure 54, Figure 55) indicate that groundwater elevations would remain above historical low groundwater elevations.

7.3 Removal of Brackish Water

Particle tracking results suggest that much of the poor-quality water that has infiltrated into NPV can be recaptured by NPV Desalter pumping. By careful examination of the set of particle traces that were initiated at different times during the model period, the period during which brackish water could potentially be pumped by the desalter wells can be estimated (Table 6). Three aspects are evident in the table:

- Moving the northeastern desalter well of Scenario #2c (9,000 AFY, 4 wells) increased substantially the period during which all four project wells could potentially operate as desalter wells (Scenario #2h, 9,000 AFY, 4 wells);
- The amount of brackish baseflow infiltrating into NPV is an important factor in project longevity; and
- A 25-year project could potentially recapture most of the "brackish" water.

It is important to note that particle tracking has its limitations and that conclusions based on the particle tracking should be tempered by these limitations. The limitations are that particle tracking inherits any errors from the main MODFLOW results, particle movement is plug flow and has no components of mixing processes (dispersion, diffusion), the brackish baseflow could be stratified in the aquifer and groundwater pumped could be a mix of brackish water and ambient better-quality groundwater, and individual wells could be pulling in brackish water from one direction and better-quality well from another direction. Thus, the actual water quality pumped by any desalter well may vary in salt concentration. This variation in concentration may be more pronounced in later stages of the project, when the brackish water may have taken complex travel paths from infiltration to extraction.

Scenario	5 wells	4 wells	3 wells	2 wells	1 well
2a (4.5K Pumping)				23 to 29	30+
2g (7.5K Pumping)		19 to 22	19 to 30+	30+	30+
2c (9K Pumping)		11 to 17	24 to 29	24 to 29	30+
2c-AP (9K Pumping)		11 to 17	24 to 29	24 to 29	24 to 29
2c-25yr (9K, 25-yr)		11 to 17	24 to 25		
2f (9K w/80% flow)		19 to 22	24 to 29	24 to 29	24 to 29
2f-AP (9K w/80% flow)		24 to 29	24 to 29	24 to 29	24 to 29
2e (9K w/120% flow)		19 to 22	30+	30+	30+
2e-AP (9K w/120% flow		19 to 22	30+	30+	30+
2h (9K optimized)		24 to 29	24 to 29	24 to 29	30+
2h-AP (9K optimized)		19 to 22	24 to 29	24 to 29	24 to 29
2i (11.8K, 25-yr)	19 to 22	19 to 22	24+		

Table 7. Results of particle tracking, indicating the number of years wells would pump "brackish" water for each Scenario #2 pumping option. For example, under Scenario #2g four wells would be within the area of "brackish" particles for at least 19 years but perhaps for as long as 22 years; three wells would be within the area of "brackish" particles for at least 19 years, but perhaps as long as 30+ years. In Scenario #2i, there is nearly complete recapture of "brackish" water by the end of the project.

7.4 Effect on Water Quality and Seawater Intrusion

The most noticeable water quality problems in the Oxnard Plain and Pleasant Valley basins are seawater intrusion near the coastline and the mound of brackish groundwater that is migrating southwestward from the opposite side of the basin. Removal of this later mound is the purpose of the proposed project – its effectiveness was discussed in the previous section. The effect of not doing the project is serious for the basin – the mound of brackish water will migrate into the main agricultural portion of the Pleasant Valley basin (Figure 86). Therefore, a no-project scenario has a serious negative water quality effect on the basin.

The second water quality problem is the long-recognized seawater intrusion at the coastline. The Lower Aquifer System of the Oxnard Plain and Pleasant Valley basins has been characterized over the past decades as being below sea level in coastal areas, with a significant pumping depression along the boundary between the two basins (Figure 87). This has caused intrusion of seawater in local areas along the coast near offshore submarine canyons. To predict the effects of the project on seawater intrusion, two set of model results were combined:

1) In the northeastern half of the area of contours in where the project and modeled pumping wells were located, contours of groundwater elevations were derived directly from model results for Scenario 1c-25 yrs for the last year of the project.

2) Southwest of the above area, the large number of pumping wells were not modeled (outside the scope of the modeling effort), but the residual effect of the project can be determined as the difference between Base Case 1 (no project) and Scenario 1c-25 yrs (with project). This difference (which varied from a few 10s of feet to less than a foot) was then subtracted from the Fall 2013 groundwater elevations to approximate the effect of the project on the pumping depression.

With no project, the groundwater gradient in NPV steepens somewhat during the 25 years (Figure 88). The greatest effect, however, is that the pumping depression deepens and it widens to north of its present location. This widening and deepening is largely caused by the shift in pumping from Camarillo's NPV wells to its airport wells as the brackish water mound continues to degrade water quality in NPV – a shift in pumping necessary to meet DPH drinking water standards.

With the project operating for 25 years, the groundwater gradient in the project area is towards the southwest and west, towards the coastline (Figure 89). The pumping depression is widened slightly towards the east and the eastern gradient of the pumping depression is steepened somewhat. There would be no adverse effect on seawater intrusion – the pumping depression remains at the same elevation and location and there would be no change to the groundwater gradient seaward of the pumping depression. Thus, the modeling indicates that there would be no adverse effect from the project on seawater intrusion.

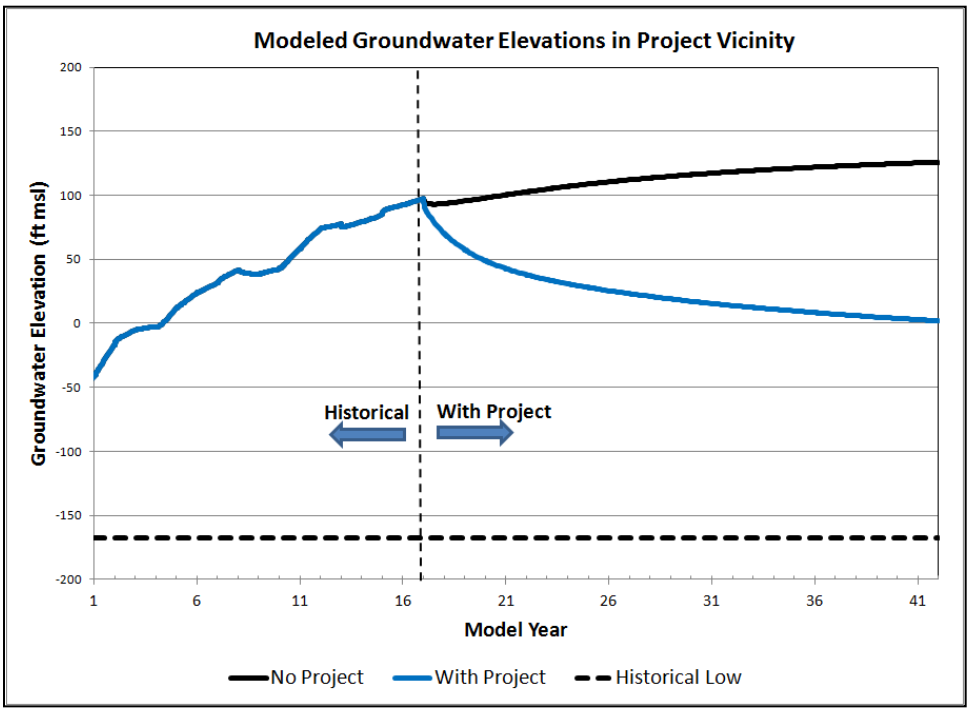


Figure 80. Modeled groundwater elevations near project pumping wells for no project (Base Case #1, current conditions with no change in arroyo base flow) and project (Scenario #1c-9,000 AFY-25 yr). Historical low is for well 2N/20W-19M4.

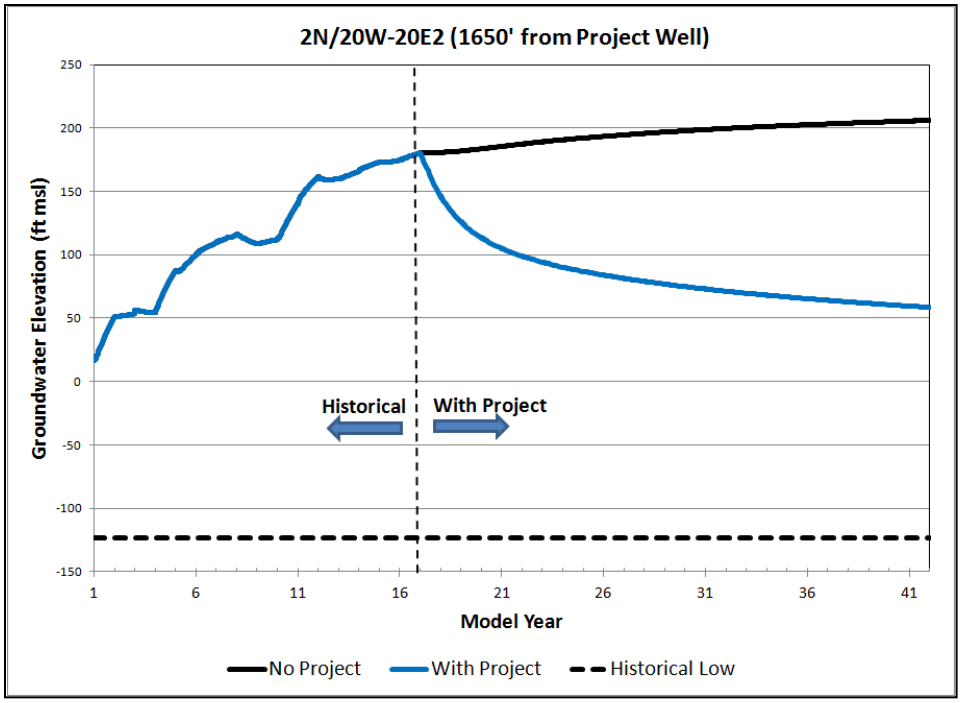


Figure 81. Modeled groundwater elevations 1650 feet from project pumping wells for no project (Base Case #1, current conditions with no change in arroyo base flow) and project (Scenario #1c-9,000 AFY-25 yr).

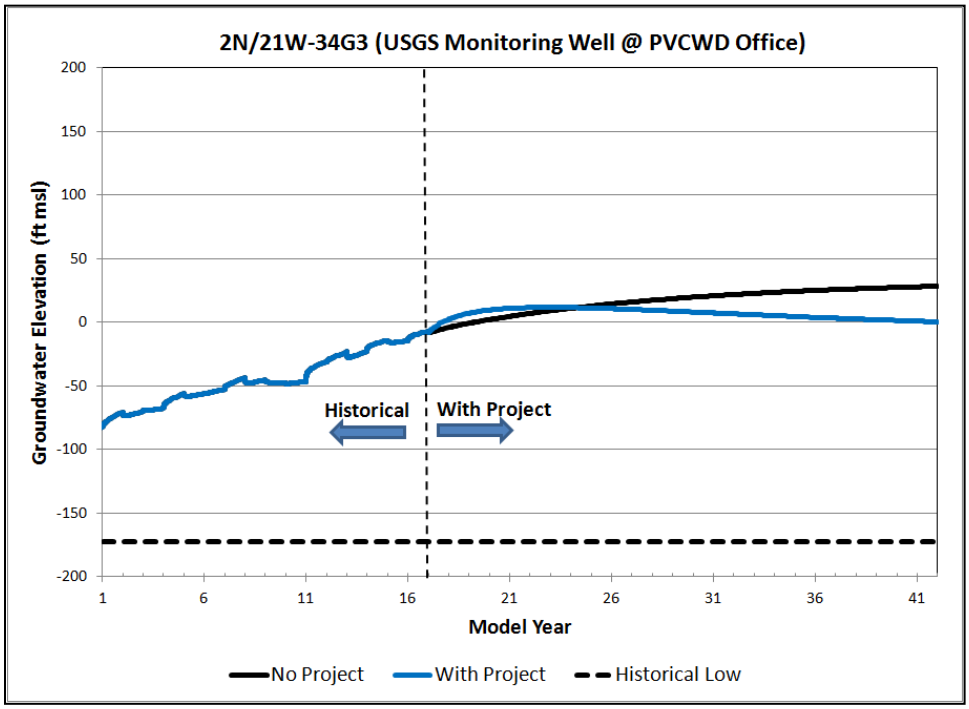


Figure 82. Modeled groundwater elevations south of Highway 101 for no project (Base Case #1, current conditions with no change in arroyo base flow) and project (Scenario #1c-9,000 AFY-25 yr). The slight rise in elevation when the project commences is caused by reduced pumping of Camarillo's nearby airport wells.

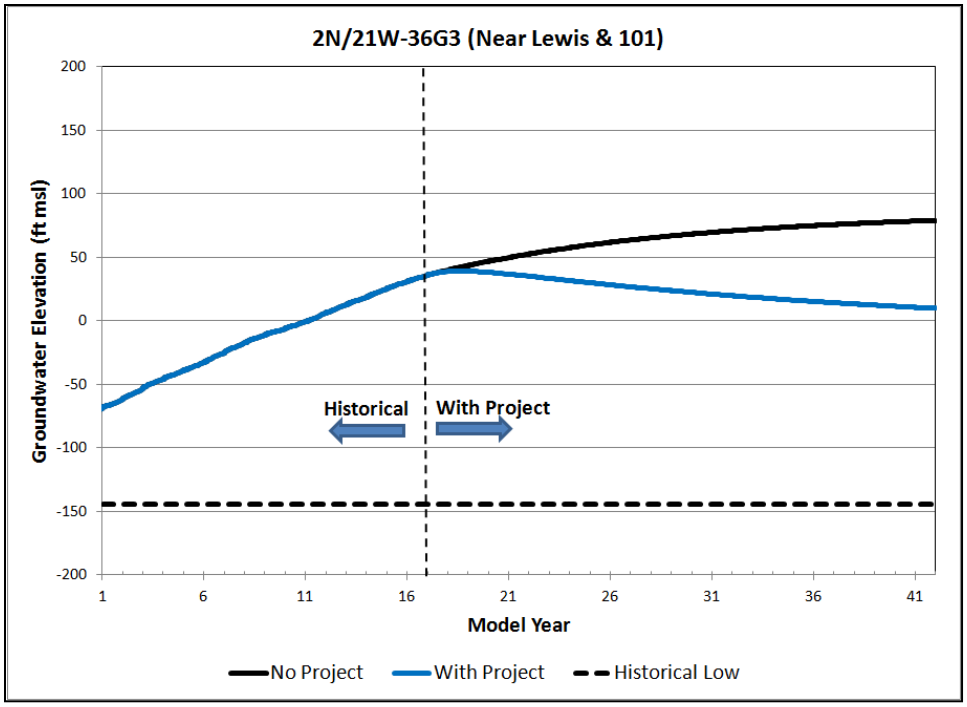


Figure 83. Modeled groundwater elevations south of Highway 101 for no project (Base Case #1, current conditions with no change in arroyo base flow) and project (Scenario #1c-9,000 AFY-25 yr). Historical low is for nearby well 2N/21W-36L2.

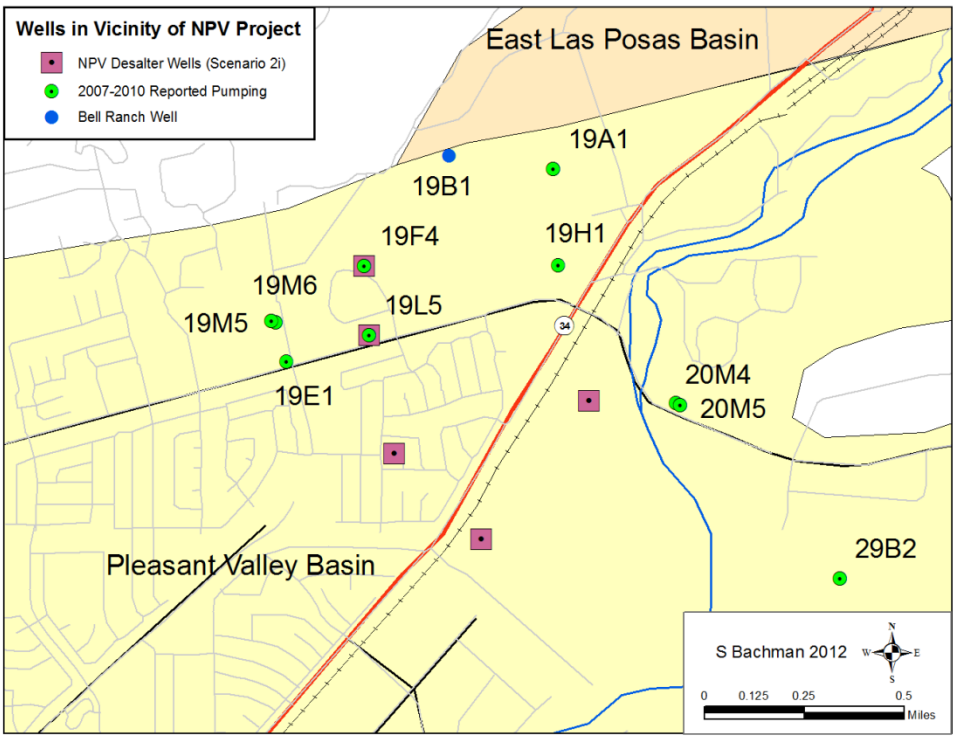


Figure 84. Map of wells in vicinity of desalter project.

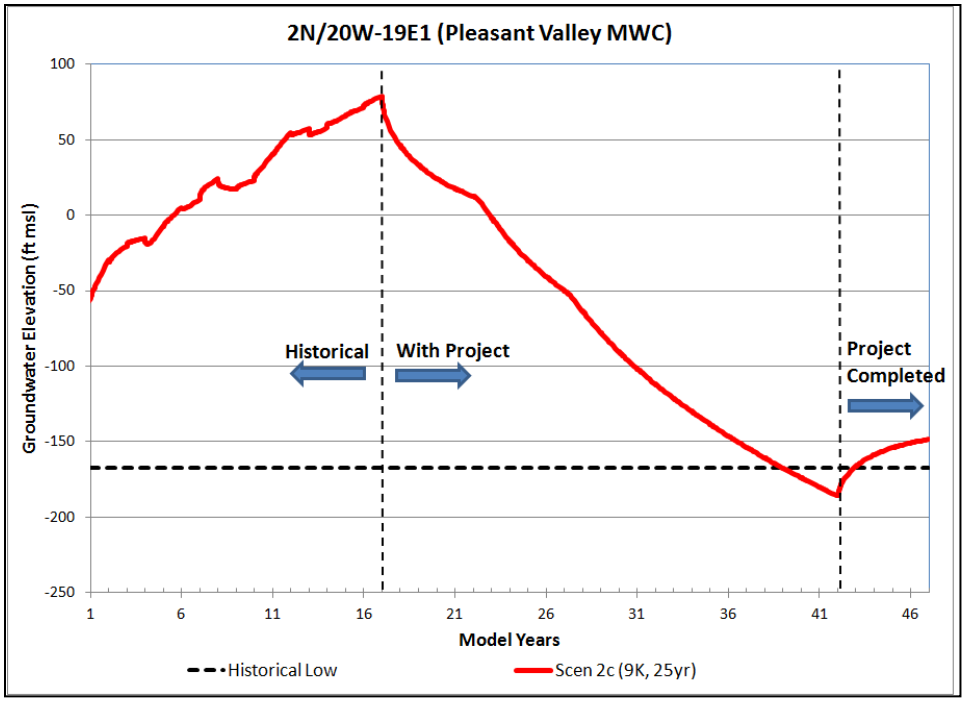


Figure 85. Effect of 25-year project on closest well. Groundwater elevations partially recover following completion of the project. Historical low is from nearby well 2N/20W-19M4, which has a longer historical record (well 19M4 adjacent to wells 19M5 and 19M6). See previous map for locations.

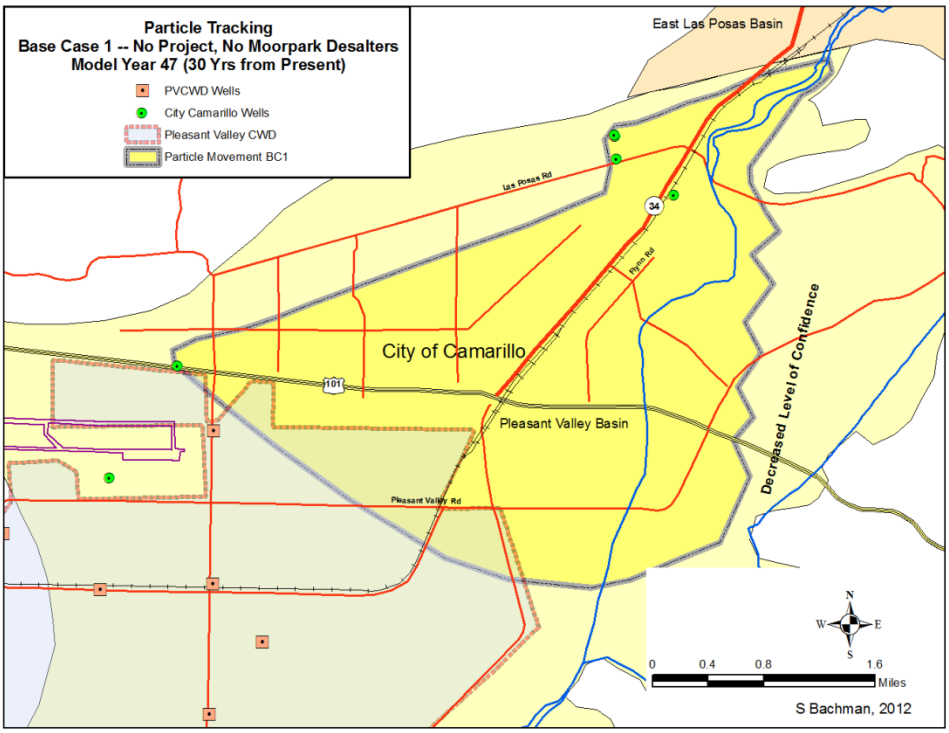


Figure 86. Base Case #1 particle tracking results indicating the potential movement of the plume of brackish water into the main agricultural portion of the Pleasant Valley basin if a desalting project is not completed.

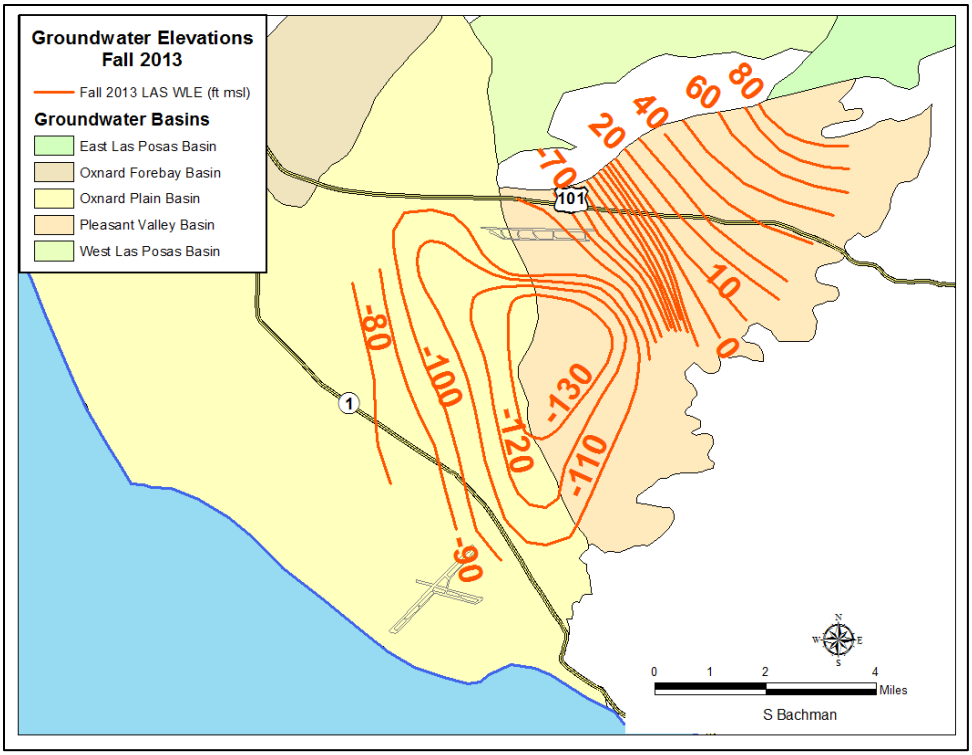


Figure 87. Contours of measured groundwater elevations in wells in Fall 2013. Note the pumping depression that has formed along the boundary between the Pleasant Valley and Oxnard Plain basins. This pumping depression forms a landward groundwater gradient from the coastline to the basin boundary.

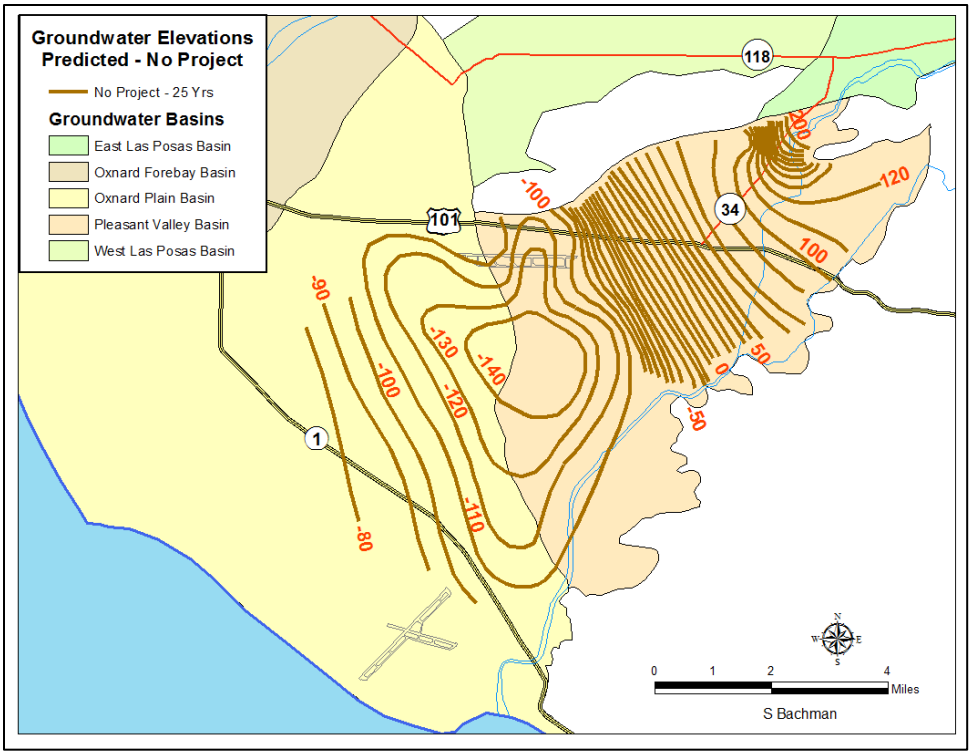


Figure 88. Groundwater elevations predicted 25 years in the future, based on the groundwater modeling, under current conditions (no change in base flow in the arroyo) and with no desalting project. The groundwater gradient from NPV to the southwest increases in steepness from Fall 2013, but the pumping depression deepens and widens to the north as Camarillo replaces NPV pumping with pumping near the Camarillo airport. This change in pumping pattern is necessitated by the migration of the mound of brackish water into Camarillo's NPV wells.

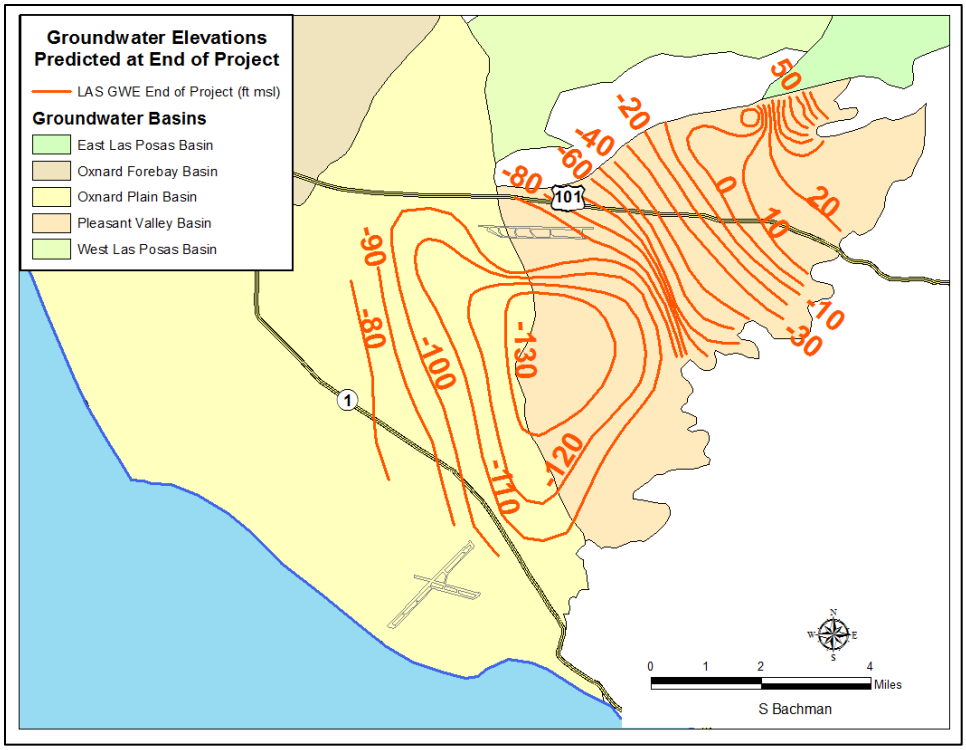


Figure 89. Groundwater elevations predicted 25 years in the future, based on the groundwater modeling, with the NPV desalting project in operation. Groundwater gradients in NPV have flattened somewhat from Fall 2013, but the pumping depression remains largely unchanged.

8 Margin of Error

The margin of error in the analysis is made up of uncertainty in the model inputs and the accuracy of the measured data used for model calibration. The accuracy of model results is meant in this context as how accurately groundwater elevations are predicted in the model.

Measured data are used as inputs into the model (e.g., pumping, streamflow) and for calibration of the model (groundwater elevations). The accuracy of these data can vary upon how (and how often) they are measured. DWR has estimated the accuracy of these data in general; pumping is better measured within the FCGMA and is reflected in Table 8.

Besides pumping and streamflow, model inputs include aquifer geometry, hydraulic conductivity, streamflow percolation, and storativity (amount of aquifer volume filled with extractable water). These inputs were estimated based on a limited number of available measurements within study area. The measurement uncertainty for these inputs is also affected by the fact that the variability in these inputs throughout the model domain cannot be characterized by a limited number of point measurements.

The uncertainty associated with the model inputs is reduced through the process of model calibration. However, because different combinations of inputs can result in similar levels of calibration, all models are non-unique and uncertainty (potential error) in the model results

remains, even with the very best calibrated models. The best method to evaluate potential error in the model results is through sensitivity analyses[8] – that is, change input values in the calibrated model and see what the effect is on modeled groundwater elevations. The results of this analysis are shown in Table 9.

The sensitivity analyses indicate that the input values most likely to affect model results are pumping, streamflow, and layer 2 horizontal hydraulic conductivity and storativity. However, the actual margin of error in the model is reduced by the calibration process, as discussed earlier. The root mean square error of the calibrated model – that is, the difference between model results and measured groundwater elevations in the calibration period – is 16.5 ft.

Data Type	DWR[9]	Within Project Area
Pumping	± 20-100%	± 15%
Streamflow-gaged	± 5-10%	± 10%
Streamflow-ungaged	± 10-200%	± 20%
Groundwater Elevation	± 5%	± 5%

Table 8. Potential accuracy of measured data.

Input Type	Sensitivity Analysis	Change in Modeled Groundwater Elevation (ft)
Pumping	± 25%	± 27 ft
Streamflow	± 20%	± 20 ft
Horizontal Conductivity (Lyr 1)	500%	1.6 ft
Horizontal Conductivity (Lyr 2)	500%	14.8 ft
Vertical Conductivity (Lyr 1)	500%	<<1 ft
Vertical Conductivity (Lyr 2)	500%	<<1 ft
Storativity (Lyr 1)	500%	1.25 ft
Storativity (Lyr 2)	200%	18 ft

Table 9. Sensitivity of model to changes in input values.

9 Potential for Land Subsidence During Project

Land subsidence can occur when pumping causes groundwater elevations to drop sufficiently to dewater sediments in the basin or to create pressure gradients where water flows out of the sediments. It is the fine-grained sediments (e.g., mudstone) which may be present both within the aquifers and as low-permeability layers between the aquifers that cause land subsidence – water lost from these sediments is permanent and causes compaction of the material. In contrast,

[8] US Environmental Protection Agency, Office of Science Advisor, 2009, *Guidance on the Development, Evaluation, and Application of Environmental Models*, EPA/100/K-09/003. "Sensitivity analysis is recommended as the principal evaluation tool for characterizing the most and least important sources of uncertainty in environmental models."

[9] California Department of Water Resources, 1981, Table 28 from Peters, short course notes on water budgets.

water lost from coarser-grained sediments (e.g., sand and gravel) causes minimal compaction and water can re-enter the pore spaces when water levels rise.

Repeated cycling of groundwater elevations caused by drought/wet periods or pumping/recharge periods is less likely to cause further subsidence as long as groundwater elevations remain above historical lows. In NPV, groundwater elevations reached their lowest level prior to 1994, and then rose substantially after that time (e.g., Figure 90). Thus, the potential for land subsidence is significantly reduced if project groundwater elevations remain above historical low elevations. If groundwater elevations drop below historical lows, then the land surface elevation in the area of the low groundwater elevations should be monitored regularly to detect any subsidence.

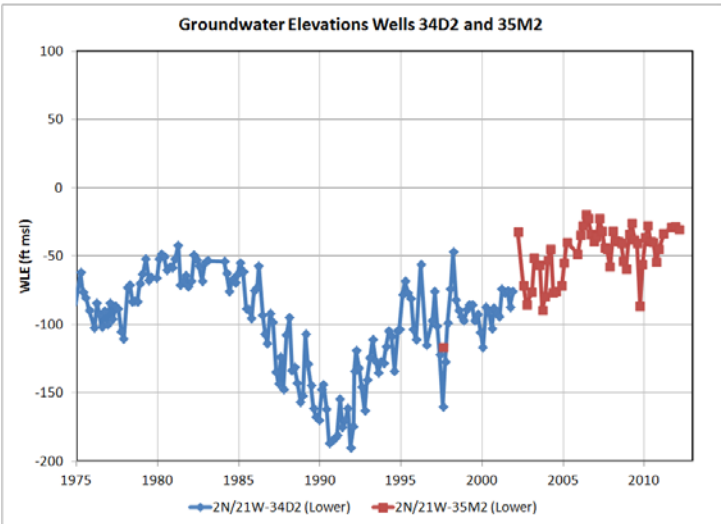


Figure 90. Example of historical low groundwater elevation prior to 1994.

10 Monitoring and Contingency Plan

A Monitoring and Contingency Plan serves the multiple purposes of assisting Project operators in fine-tuning operation of the Project, providing a basis for compliance with FCGMA requirements, and providing a level of comfort for other pumpers in the NPV. The Plan is discussed in two parts in the following sections.

10.1 Monitoring Plan

The recommended monitoring plan for the desalter project includes drilling new monitoring wells, monitoring water levels and water quality in existing wells, monitoring water quality and flow at one stream location, and analyzing/reporting results annually.

Wells as Monitoring Points

Dedicated Monitoring Wells – It is recommended that three new monitoring wells be installed in NPV. The purpose of the monitoring wells is two-fold: establishing baseline information and tracking the progress of the desalter project as it pulls salts from the basin. The recommended approximate locations of the new monitoring wells are indicated in Figure 91. They are spaced on either side of the calculated particle track boundary for 17 years of groundwater movement since brackish water first reached NPV (approximates today's conditions).

It is recommended that the monitoring wells be completed at multiple depths (e.g., typical U.S. Geological Survey monitoring well), with each sampled zone sealed from the rest of the well (e.g., Figure 92). The approximate depth and screened intervals at each well location as indicated in Table 10; the actual screened intervals will have to be determined after a geophysical log is run between the time the well is drilled and it is cased. Each screened interval is continuously gravel-packed from 10 to 20 feet below the screen to 10 to 20 feet above the screen. A bentonite seal is placed at the bottom of the hole and between each screened interval (Figure 92).

The screen length in a monitoring well can vary from tens of feet (targeting a specific zone within an aquifer) up to hundreds of feet (targeting most or all of an aquifer's thickness). Each end member has its own advantages and disadvantages. The purpose of the recommended monitoring wells is to determine the salt content in each of the major units and how they change with time. Thus, a relatively thick interval is sampled in each recommended screen interval (particularly in the Fox Canyon Aquifer, which is the primary water-producing zone in NPV and is the target of the desalter project). Thus, sampling results should be similar to what would be detected in a typical Fox Canyon production well and in desalter project extraction wells.

The monitoring wells should be designed such that a transducer can be installed and a submersible pump temporarily lowered in each well for sampling. A 2-inch PVC casing and screen are generally used for each screened interval. This allows multiple screened intervals to be completed in each well bore. However, if depth to groundwater is expected to exceed 200 ft, the casing size should be increased to 4-inch to accommodate a larger sampling pump that can adequately lift water to the surface. If 4-inch wells are required, it may be more practical to drill each well separately rather than nesting the wells.

A transducer/data logger should be installed in each screened casing, with data downloaded periodically. It might be advantageous for the transducers to measure both water levels and electrical conductivity – the movement of brackish groundwater may be more complex than periodic water quality sampling can detect. Recommended sampling intervals are shown in Table 11.

There is an existing USGS monitoring well cluster located near Highway 101 and Las Posas Rd (2N/21W-34G). The cluster has screened intervals appropriate to this project and is already being monitored by United Water Conservation District for both water levels and water quality. These data should be included and analyzed in the Annual Monitoring Report.

The new monitoring wells should be surveyed for location and elevation. The existing USGS well already has an accurate elevation from processed LIDAR data. The monitoring wells are recommended to be surveyed (traditional survey or LIDAR) every ten years to detect any changes in elevation related to subsidence. Both the wellhead and surrounding land surface should be surveyed to ensure adequate detection of subsidence.

Monitoring in Project Area – In the project area (Figure 84), it is recommended that three existing production wells be monitored. One of Pleasant Valley Mutual Water Company's wells (19M5 or 19E1) and the Bell Ranch well (19B1) are the closest to the likely desalter wells, and will indicate localized effects of pumping for the desalter. An additional well is recommended to be chosen among the wells farther to the east. If allowed by the well owner, a transducer/data logger should be installed in each production well. Recommended sampling intervals are shown in Table 11.

Desalter Extraction Wells – Extraction wells used in the desalter project should be equipped with transducers/data loggers unless SCADA hardware already measure water levels. Electrical conductivity should be automatically measured on an interval recommended in Table 11.

Monitoring for Regional Groundwater Trend Evaluation – Baseline regional monitoring is important so that regional trends (e.g., drought conditions, regional water quality changes) can be identified and accounted for in project monitoring. To factor these regional effects, monitoring points that are far enough away to be unaffected by the project should be utilized. Both the County of Ventura and United Water Conservation District regularly monitor a set of wells in the Pleasant Valley basin; results of this monitoring should be obtained and used annually for identifying both regional water level and water quality trends.

Surface Water Monitoring

Dry-weather base flow into NPV along Arroyo Las Posas should be sampled regularly to determine the quality of this source of recharge to NPV. An appropriate site should be determined that is very close to the NPV-East Las Posas basin boundary and is currently perennially wet. Dry-weather sampling will detect the quality of the brackish recharge water that is currently recharging NPV. As desalters are built in the Las Posas basin, base flow should diminish with time.

It is recommended that base flow water quality be sampled monthly during the months of May through October. If rainfall occurs that brings storm water into NPV during the sampling season, it is still appropriate to collect a sample from the arroyo for comparison to the quality of

base flow. Such storm events prior to sampling should be noted in the Annual Report. Recommended sampling is shown in Table 11. Calleguas Municipal Water District currently contracts for regular monitoring of Arroyo Las Posas in the Las Posas basin – perhaps the NPV monitoring can be coordinated with that effort.

Monitoring Data Analysis

Transducer data should be downloaded quarterly and examined for overall trends and potential trigger values. When water quality analyses are received, a similar examination is warranted. Water level, streamflow, and quality data should be maintained in digital form for annual analyses and determination of trends and trigger values.

Reporting

An Annual Report is recommended to be prepared by July following the end of the calendar year. The Annual Report should show a summary of desalter operations, data analyses and graphs, conclusions formed from the analyses, and recommendations for future operations and monitoring. The Report should also include regional maps of groundwater elevation contours to document any effects of the project on the wider Pleasant Valley basin. These maps can be constructed by either United Water Conservation District or specifically for the Annual Report using the regional groundwater elevation measurements made by United Water and the County of Ventura. The Annual Report may be submitted to regulatory agencies as required.

In addition to the annual reporting, the FCGMA will be notified within one month of any unexpected or critical results from project monitoring. Examples of such results include rapidly dropping water levels, approach of target groundwater elevations, and unexpected water quality analyses.

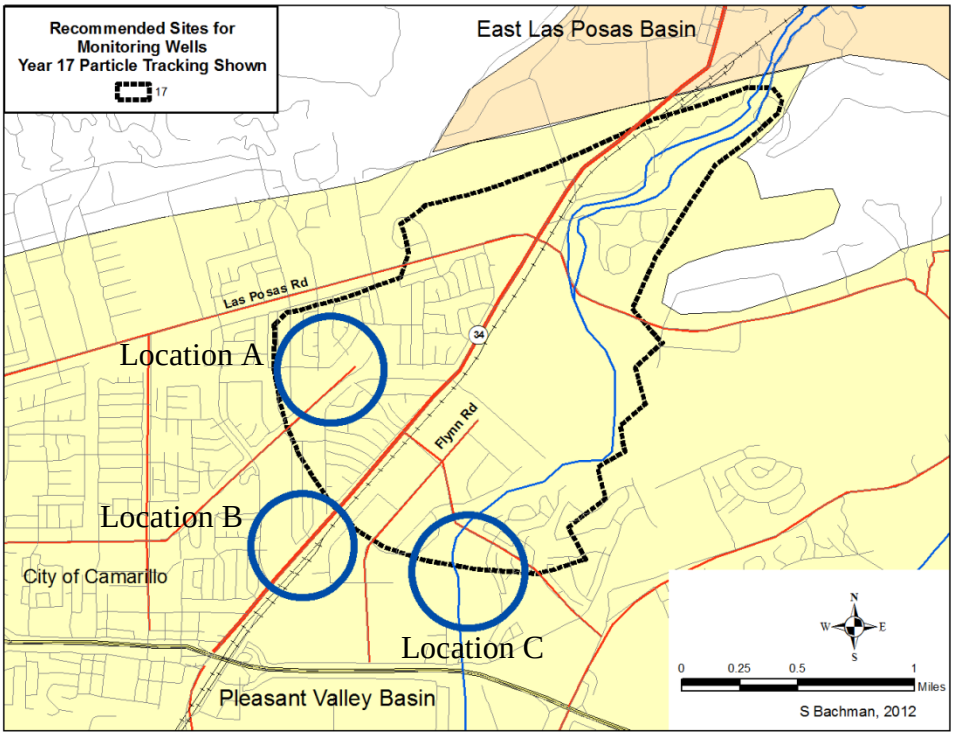


Figure 91. Recommended sites (circles) for installation of new monitoring wells. It is recommended that wells be installed with at least one well one either side of the particle tracking boundary of 17 years (approximates today's condition).

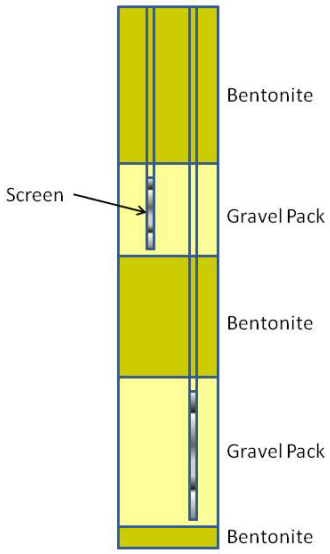


Figure 92. Monitoring well completion schematic. Each screened interval is isolated above and below by a bentonite seal. Gravel pack extends 10 to 20 feet above and below screen.

Well Location	Total Depth	Shallow Aquifer Screen	Hueneme Screen	Fox Canyon Screen
A	1050’	60-170’	430-640’	680-1030’
B	1100’	60-110’	620-740’	830-1080’
C*	1100’	60-140’	none	660-1080’

Table 10. Approximate depth and screened intervals for recommended monitoring wells. Actual screened intervals would be based on electric logs run prior to casing the holes. *May be less expensive to drill two separate smaller-diameter wells.

	Dedicated Monitoring Wells	Monitored Production Wells	Desalter Extraction Wells	Surface Water
Groundwater Elevation	Transdcr-3 hr	Transdcr-3 hr	Transdcr-3 hr	
Electrical Conductivity	Transdcr-3 hr	Transdcr-3 hr	Transdcr-3 hr	
General Minerals	Quarterly	Quarterly	Monthly	Monthly dry season

Table 11. Recommended sampling for desalter project.

10.2 Contingency Plan

A Contingency Plan deals with issues that may arise during operation of the project, including unexpected water level declines or unexpected changes in water quality.

Contingency Plan for Groundwater Elevations

Contingency Triggers for Groundwater Elevations

Contingency triggers are numerical values for groundwater elevations /water quality concentrations beyond which a contingency plan is implemented. There are several factors that must be considered in devising triggers for the desalter project that would result in implementing project contingencies.

- Groundwater elevations rose for decades in the project area as the aquifers were filled with a large mound of non-native brackish water (discharge from wastewater treatment plants, dewatering of shallow aquifers) that spilled over from the Las Posas basin. Without this recharge, groundwater elevations in the project areas would currently be much lower. Recovery of this brackish water would be expected to lower groundwater elevations.
- There is a water quality benefit to all pumpers who would potentially be affected by future movement of the brackish water if the desalter project is not built. This benefit must be balanced against lower groundwater elevations that the pumpers may experience. The benefit applies to both municipal pumpers (sulfates exceeding drinking water standards) and agricultural pumpers (chlorides exceeding tolerance levels in salt-sensitive crops).

- Groundwater elevations in the project area may be lower in the future from causes unrelated to desalter pumping – such as current overdraft of the basin and/or increased pumping related to crop changes.

It is reasonable that contingency planning be based upon historical groundwater elevations. Figure 93 indicates historical groundwater elevations in the project area.

Table 12 indicates the low historic groundwater elevation. If groundwater elevations were to approach and/or drop below the historical low groundwater elevation, a set of Contingency Actions would take place.

To ensure that pumping activities by others in the project area do not draw down groundwater elevations excessively, project operators will ask the Fox Canyon Groundwater Management Agency to limit new pumping in the project area so that overall pumping does not exceed an annual use of 4 AF/acre.

Contingency Actions for Groundwater Elevations

Contingency actions are taken when groundwater elevations measured in the Monitoring Plan approach or are deeper than a groundwater elevation trigger. The actions are progressive, from informational/planning to modifying project operations.

Groundwater Elevation within 16 ft of Trigger – Given the margin of error in model calibration is a maximum of 16 ft, the first contingency is set at 16 ft above the trigger elevation of 168 ft below mean sea level (historical low). When any measured groundwater elevation within the project area drops to 152 ft below mean sea level, the project operator should review the monitoring data to determine the reason(s) for the drop. The project operator should also commence monthly downloads of the transducers installed in that project area to determine if groundwater elevations are expected to drop below the trigger level. The owner/operator of the monitored well and the FCGMA will be informed of the findings. A survey of the elevation of monitoring well(s) in the area where water levels are within 16 ft of their trigger will be conducted to determine if any subsidence has occurred and to use as a benchmark if further decreases in groundwater elevations occur.

Potential mitigation of the effects of water levels dropping below the trigger values in the future will be discussed with the well owner/operator if project pumping is determined to be the primary cause of the drop. Mitigation measures to be discussed could include reimbursement for increased pumping lifts, reimbursement for required well modifications, and/or modifying project pumping patterns. For production wells drilled prior to the rise in groundwater elevations in 1994, mitigation could include lowering bowls and/or deepening the well. For wells drilled after 1994 within the project area, mitigation discussed will include paying for increased pumping costs caused by project pumping. It is not possible to specify in advance how the project pumping patterns would change without knowing the configuration of the groundwater elevations in the affected area. However, the primary response would likely be reduced pumping in the area where water levels were approaching the trigger.

Groundwater Elevation Deeper than Trigger – If measured groundwater elevations in the Monitoring Area are deeper than the trigger value consecutively for more than six months

of measurements, and project pumping is determined to be the primary cause of the drop, the mitigation discussed in the previous paragraph will be implemented in a step-wide procedure. The owner/operator of the monitored well and the FCGMA will be informed of the trigger exceedance.

Two types of actions would occur as mitigation measures. A plan would be formulated with the affected well owner(s), as discussed in the section above, to mitigate effects on the well owner(s) well. Project operators will lower bowls and/or deepen any wells in the project area adversely affected by project pumping if those wells were drilled prior to the rise in groundwater elevations in 1994. For wells drilled after 1994 within the project area, project operators will pay for increasing pumping costs caused by project pumping. In addition, project pumping would be re-adjusted so that the project well closest to the affected area would reduce pumping by 10% for a period of six months. If these actions do not mitigate the problem within a six-month period (i.e., prevent further drops in groundwater elevations or mitigate the effects on the well owner(s) of the drop in groundwater elevation), then pumping from this project well would be reduced an additional 10% (for a total reduction of 20%) for a period of six months and further evaluated. This step-wise reduction every six months would continue until the problem is mitigated.

This mitigation plan will be discussed with the well owner/operator(s) and reported to the FCGMA.

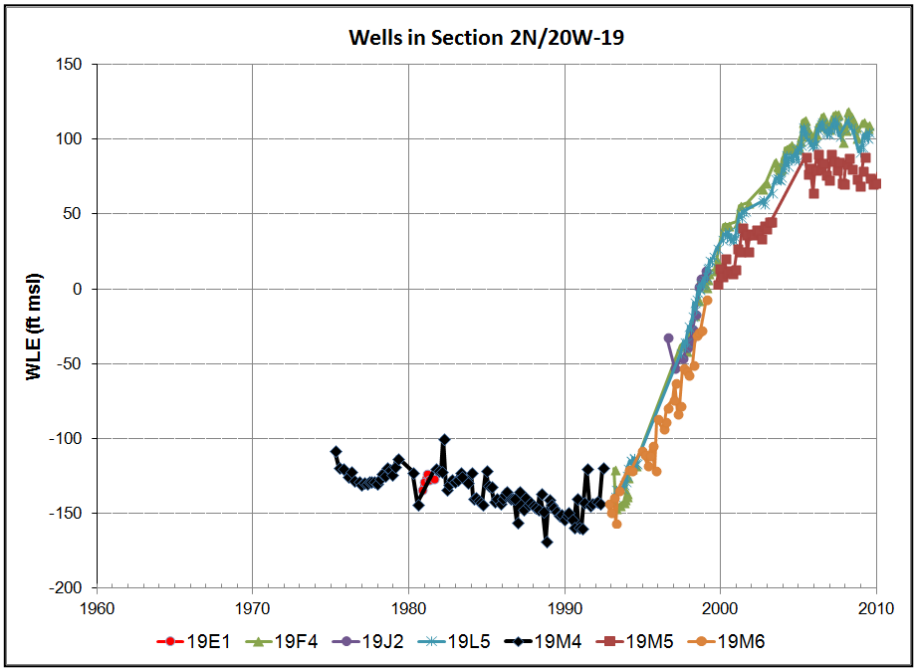


Figure 93. Groundwater elevations for wells in project area.

Well	Historical Low GWE (ft msl)
2N/20W-19M4	-168

Table 12. Trigger groundwater elevation for Contingency Plan.

Contingency Plan for Groundwater Quality

The purpose of the Desalter Project is to pump brackish water, treat it to remove salts, and discharge the salts from the watershed. It is an expectation of the Project that the FCGMA will extend its policy from the Las Posas basin that allows pumping and treating of this brackish without the use of FCGMA allocations or credits. The movement of salts can be more complex than modeled for this Project – particle tracking assumes plug flow (no dispersion or dilution) – and the aquifer is very likely to be more complex in its geometry and internal bedding than can be modeled. In reality, the water extracted for desalting may vary in salt content from day-to-day and month-to-month. Such variation is expected, cannot be avoided, and does not detract from the goals of the Project or the benefits of the Project to the aquifer.

As the Project matures and the travel paths of brackish water become more complex as the salts are recovered from aquifer areas further away from Project pumping, there are likely to be episodic periods when individual wells pump fresh water. Although this cannot be avoided when attempting to clean up the entire area of brackish groundwater, a contingency plan for FCGMA allocations and credits is prudent. The purpose of the contingency plan is to differentiate between extended pumping of fresh groundwater (which would require the use of FCGMA allocations and/or credits) and pumping of primarily brackish groundwater (which would fit under the FCGMA policy related to pumping and treating brackish groundwater).

Analytical test results can be variable, and single water quality test results cannot characterize the duration, magnitude, or frequency of the measured quality. Therefore, it is recommended that single water quality test results should be used as triggers to initiate a response, rather than only as a means to determine whether brackish water is being pumped.

Pumping of Primarily Brackish Groundwater – As discussed previously, the salt content of brackish groundwater pumped by the Project is likely to vary episodically with time. Thus, the determination of primarily brackish groundwater must take this into account. For purposes of defining primarily brackish groundwater, three components were examined – chloride, sulfate, and Total Dissolved Solids (TDS). In all cases, concentrations were lower prior to the influence of the brackish water and considerably higher after the introduction of brackish water (Figures 94 to 96). Water Quality Objectives[10] are currently being exceeded for all three constituents.

High sulfate concentrations are problematic for municipal drinking water, whereas high chloride concentrations are problematic for agricultural irrigation. To reflect both concerns, TDS is used here as the benchmark for project water quality. It is recommended that the criteria for brackish water be a threshold of 700 mg/L of TDS to reflect both historical concentrations and the Basin Plan Objective. Using this threshold,

[10] *Water Quality Control Plan Los Angeles Region*, 1995, Los Angeles Regional Water Quality Control Board, p. 3-19.

pumped groundwater with TDS concentrations above 700 mg/L would be considered brackish water and its removal beneficial to the aquifers.

Extended Pumping of Fresh Groundwater – At some time in the future, Project wells will likely start pumping a mixture of brackish and ambient groundwater as the brackish water is removed. It is unlikely that the transition from brackish to ambient groundwater will be a sharp break – it is most likely to be transitional, with periods of pumping brackish and fresher water. Given this scenario, there must be criteria for determining how this transition is considered. It is recommended that when TDS concentrations drop below 700 mg/L in any Project well, a verification period would begin to ensure that brackish water has indeed been removed from the portion of the aquifer supplying water to the well. This verification period would be one year in duration, with water quality testing increased to monthly during the period. If, after one year, TDS concentrations remained below 700 mg/L, then subsequent pumping would be considered as pumping fresh groundwater subject to the FCGMA allocation system. This contingency is illustrated in Table 13.

If future pumping of water from a Project well that has transitioned from brackish to fresh water returns to a brackish water condition, then the verification period would be reversed – it would require one year of verified pumping of groundwater above 700 mg/L TDS to return the well to a brackish water status. These criteria are summarized in the table below. This information would be provided to the FCGMA in the Annual Report.

Contingency	Project well pumping brackish water has TDS drop below 700 mg/L	Project well pumping fresh water has TDS increase to above 700 mg/L
Action	Begin one year verification period	Begin one year verification period
Considered Fresh Water	Monthly testing remains below 700 mg/L for verification period	Any monthly test is below 700 mg/L
Addt'l Evaluation	Evaluate whether regional conditions contributed to drop	Evaluate whether regional conditions contributed to increase
Considered Brackish Water	Any monthly test exceeds 700 mg/L	Monthly tests remain above 700 mg/L for verification period
Termination of Action	One year of pumping below 700 mg/l (reverts to fresh water) or any monthly test greater than 700 mg/L (remains brackish water)	One year of pumping above 700 mg/L (reverts to brackish water) or any test less than 700 mg/L (remains fresh water)
FCGMA Allocation	No allocation required	Prorated use of allocation*
Sunset Provision	If well pumps fresh water for 24 consecutive months, well permanently reverts to fresh water status	

Table 13. Contingency actions for water quality. * If any monthly measurement is greater than 700 mg/L TDS, then allocation is prorated across reporting year (e.g., if TDS is greater than 700 mg/L for two of the twelve months, then pumping for those two months does not require an allocation).

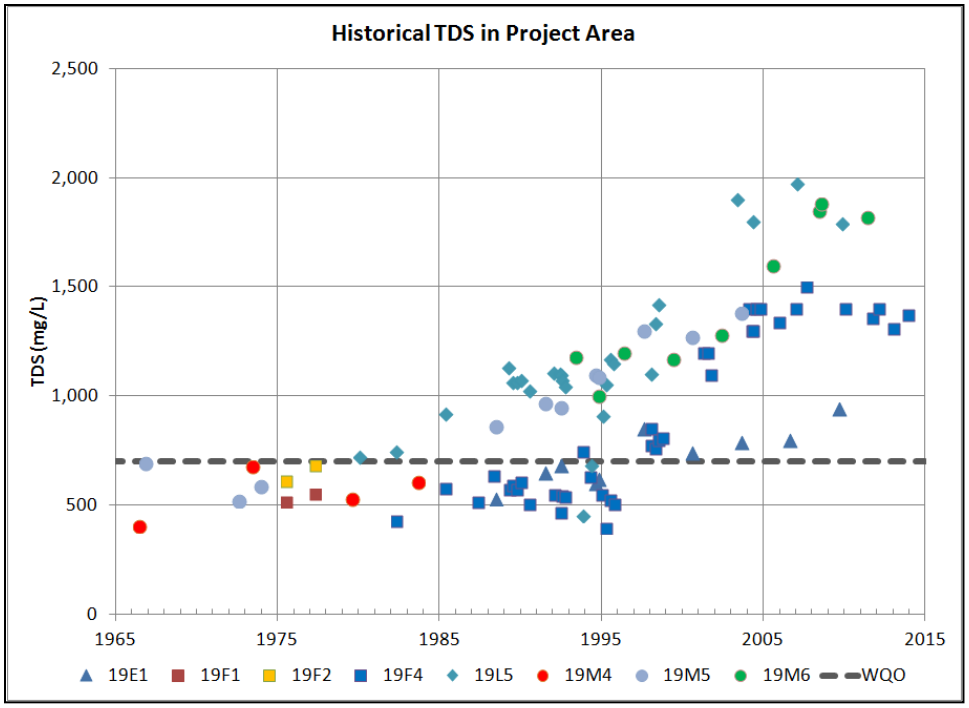


Figure 94. Historical TDS concentrations in project area. WQO is Regional Board's water quality objective for groundwater in the Pleasant Valley basin.

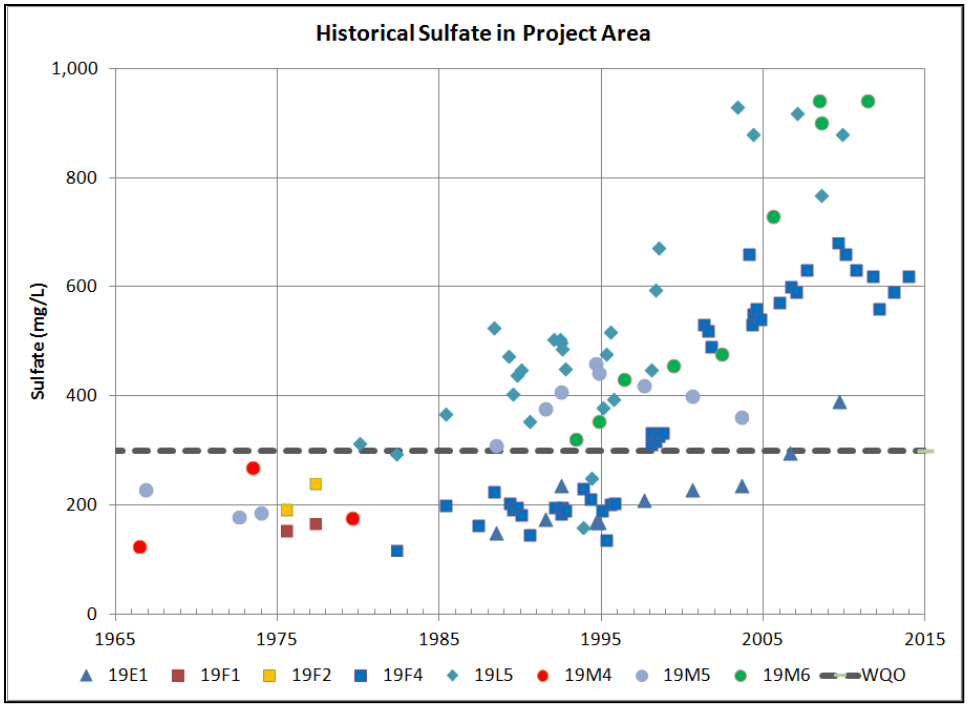


Figure 95. Historical sulfate concentrations in project area. WQO is Regional Board's water quality objective for groundwater in the Pleasant Valley basin.

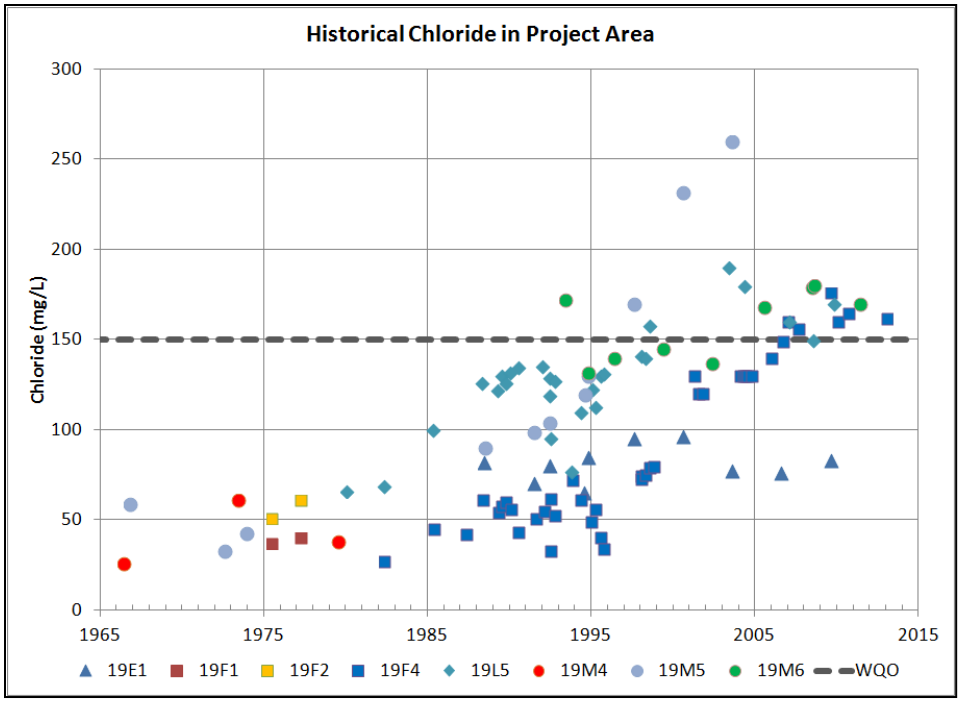


Figure 96. Historical chloride concentrations in project area. WQO is Regional Board's water quality objective for groundwater in the Pleasant Valley basin.

11 Recommendations

Analyses and modeling using current data have largely reached the limit of our understanding of the brackish water problem. Recommendations are therefore centered on obtaining additional information for design and subsequent monitoring of the Project. There is sparse measured information outside of the location of Camarillo's production wells on the current location and concentration of the poor-quality baseflow that has infiltrated into NPV. It is recommended that three monitoring wells with pressure and electrical conductivity sensors be installed downstream of the NPV area within the City of Camarillo to measure both groundwater elevations and salt content. Installing these wells prior to design of the desalting project would help verify the accuracy of the modeling and particle tracking and allow any necessary adjustments to be made in modeling conclusions. The general locations of recommended monitoring wells are indicated in Figure 91 with wells located on either side of the 17-year particle boundary that approximates today's condition. These wells would help verify both current water quality and water level predictions from the model and would be used to track these parameters as the project progresses.

A comprehensive Monitoring Plan should be implemented, as discussed in section 10.1. Besides monitoring the three new monitoring wells, a surface water monitoring point is recommended to be installed along Arroyo Las Posas where it crosses the basin boundary into NPV. The data collected for the Monitoring Plan should be analyzed regularly and presented in an Annual Report.

It is also recommended that a Contingency Plan be implemented as discussed in the previous section. The Contingency Plan identifies groundwater elevations in several areas that would trigger a Project response. It also recommends water quality criteria to determine when Project wells are pumping brackish or fresh water.

An additional recommendation relates to pumpers near the NPV Desalter pumping area. Predicted changes in groundwater elevations caused by pumping for the desalter can be addressed prior to commencement of the Project by agreements with affected parties. It is recommended that such an understanding be arranged with Pleasant Valley Mutual Water Company, which may be affected by increased pumping if new desalter wells are constructed. Likewise, discussions may be prudent with other pumpers within the area of pumping for the desalter.

12 Conclusions

The MODFLOW model successfully simulated the historical buildup of the mound of poor quality beneath NPV, so it appears to be an appropriate tool to test various configurations of the NPV Desalter pumping. An unexpected result of the modeling of base case conditions (without project) was the potential threat of migration of poor-quality water into the agricultural areas of the Pleasant Valley basin. This result reinforces the need for desalter projects to prevent further groundwater contamination.

All modeled pumping scenarios indicate that there will be reduction of the mound of poor-quality groundwater, with a resulting decrease in groundwater elevations in NPV. This decrease in groundwater elevations is necessary – there can't be cleanup without it. The extent of the drawdown varies by pumping scenario, but modeling of the 25-year project scenario suggests that only in the area of desalter pumping will groundwater elevations temporarily drop below historical low levels near the end of project pumping. The Contingency Plan discusses actions to be taken when groundwater elevations reach this depth.

Both changes in groundwater elevations and particle tracking simulated by the model suggest that the NPV Desalter project would work as planned – the mound of poor-quality water would be pumped down, there would be a significant amount of water available for desalting, and much of the brackish water that has infiltrated into the aquifer would be recovered. Modeling of the 9,000 AFY, 25-year project suggests that such a project is feasible and would recover most of the "brackish water."

Groundwater modeling and particle tracking are robust tools to predict the effects of desalter pumping, but their limitations and the limitations of the streamflow data indicate that the results should be used cautiously. Monitoring of groundwater elevations and quality is the best method of verifying the results of this model. Monitoring and Contingency Plans recommended here should be implemented. Dedicated monitoring wells recommended as part of the Monitoring Plan should be installed prior to desalter design to verify model results and to analyze the progress of the project.

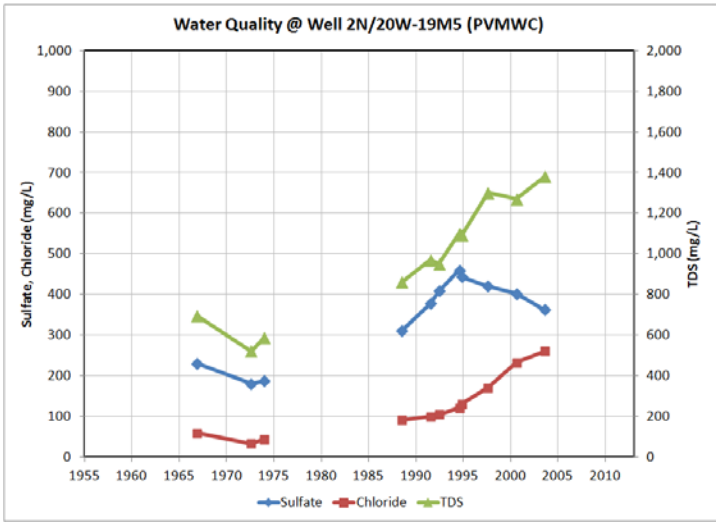
13 Limitations

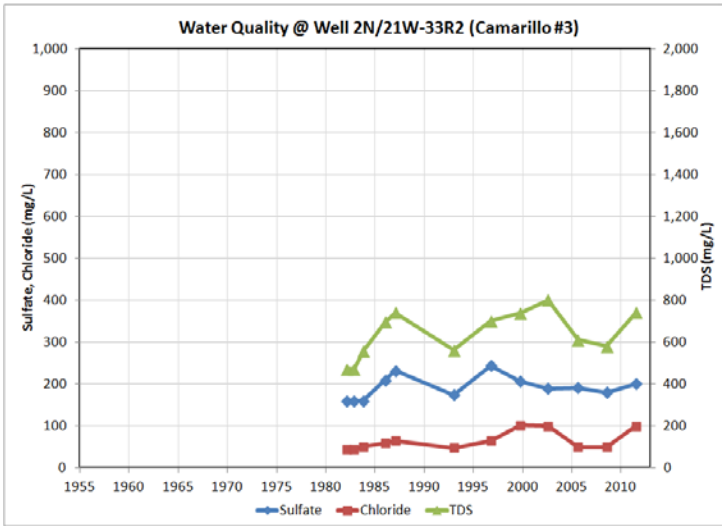
Many of the conclusions in this report are based on groundwater modeling results. It is important to note that modeling of complex hydrogeologic conditions requires simplification of these complex conditions and, thus, modeling results are a simplified approximation of future groundwater conditions. Measurement of actual future conditions utilizing the recommended Monitoring Plan should be the primary guide to the efficacy of the project, and adaptive management based on these monitoring results will be required to ensure that the project meets its objectives.

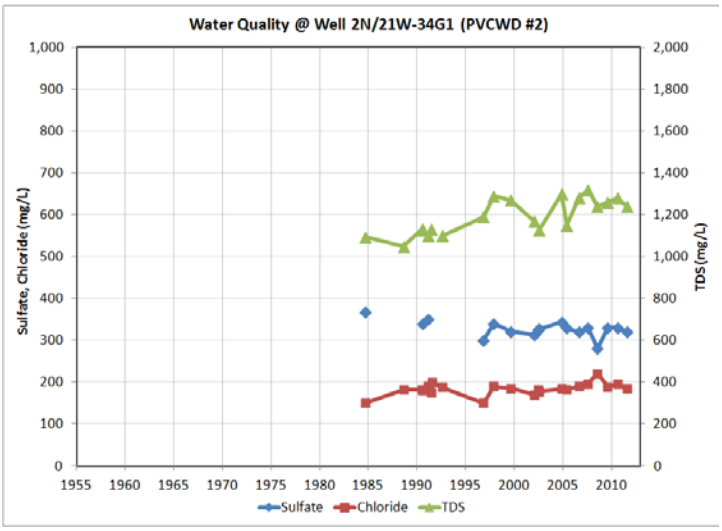
14 Appendix

14.1 Water Quality Graphs

Additional graphs are shown here. See location map Figure 13.







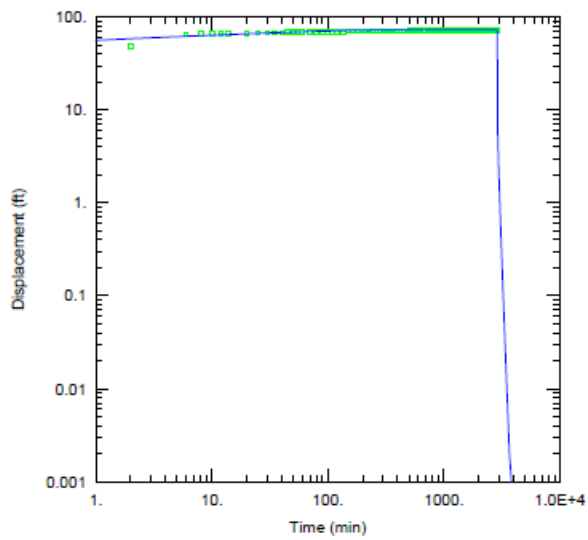
14.2 Aquifer Testing

Aquifer testing results contracted by TMR Geological Consulting Services for City of Camarillo. A summary of those results are shown below, with more-detailed results shown in this section and on the attached CD. Reference points, not included in TMR tables, include Camarillo Well A - 206 ft, Camarillo Well B - 210 ft, PVMWC Well #10 - 203 ft, PVMWC Well #11 - 200 ft.

Date	Length of Test	Pumping Well	Pumping Rate gpm	Observation Wells	Distance to Pumping Well (feet)
6/1/2011	48 hr	Camarillo Well A	1840	Camarillo Well A	0
				Camarillo Well B	909
				PVMWC Well 10	1265
				PVMWC Well 11	1162
6/6/2011	48 hr	Camarillo Well B	1534	Camarillo Well B	0
				Camarillo Well A	909
				PVMWC Well 10	1299
				PVMWC Well 11	1429

Well ID	Total Depth (ft)	Depth To Top of Screen (ft)	Aquitard Thickness
Well A	875	467	307
Well B	779	459	315
Well 10	920	564	404
Well 11	816	540	293
Average	847.5	507.5	
	Aquifer Thickness	**340**	**329.75**

		Aquifer Properties			Aquitard Properties	
Pumping Well	Observation Wells	Transmissivity	Storativity	Horizontal Hydraulic Conductivity	Vertical Hydraulic Conductivity	Leakage Coefficient
		ft^2/day		ft/day	ft/day	min^{-1}
Camarillo Well A	Camarillo Well A	4700	-	-	-	--
	Camarillo Well B	5772	1.1E-04	17.0	3.3	6.9E-06
	PVMWC Well 10	10340	5.0E-05	30.4	3.9	8.3E-06
	PVMWC Well 11	6864	4.5E-04	20.2	4.1	8.6E-06
Camarillo Well B	Camarillo Well B	7052	-	-	-	--
	Camarillo Well A	3929	3.1E-06	11.6	1.7	3.6E-06
	PVMWC Well 10	5821	8.8E-06	17.1	2.5	5.2E-06
	PVMWC Well 11	5424	5.0E-06	16.0	2.1	4.4E-06



WELL TEST ANALYSIS

PROJECT INFORMATION

Client: City of Camarillo
Location: Camarillo
Test Well: Camarillo Well A
Test Date: 6/1/11

AQUIFER DATA

Saturated Thickness: 340 ft
Aquitard Thickness (b'): 330 ft
Anisotropy Ratio (Kz/Kr): 1
Aquitard Thickness (b''): 1 ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Camarillo Well A	6253685	1911929

Observation Wells

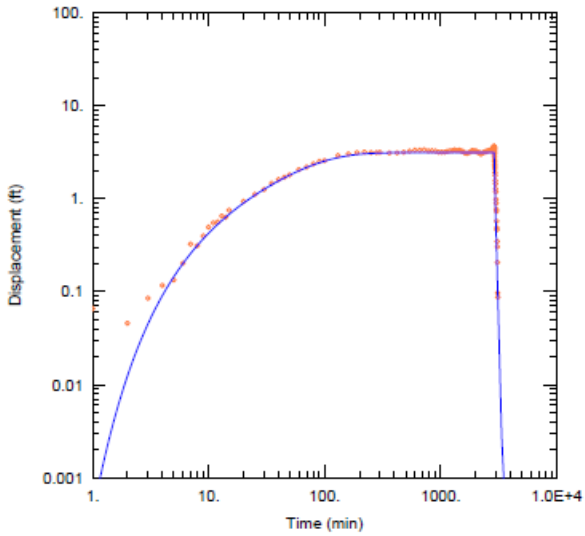
Well Name	X (ft)	Y (ft)
Camarillo Well A	6253685	1911929

SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush

T = 4700.4 ft^2/day
1/B' = 0.0[illegible]242 ft^{-1}
1/B'' = 0. ft^{-1}

S = 9.791E-5
ß'/r = 0.0[illegible]998 ft^{-1}
ß''/r = 0. ft^{-1}



WELL TEST ANALYSIS

PROJECT INFORMATION

Client: City of Camarillo
Location: Camarillo
Test Well: Camarillo Well A
Test Date: 6/1/11

AQUIFER DATA

Saturated Thickness: 340. ft
Aquitard Thickness (b'): 330. ft

Anisotropy Ratio (Kz/Kr): 1.
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Camarillo Well A	6253685	1911929

Observation Wells

Well Name	X (ft)	Y (ft)
Camarillo Well B	6253624	1912836

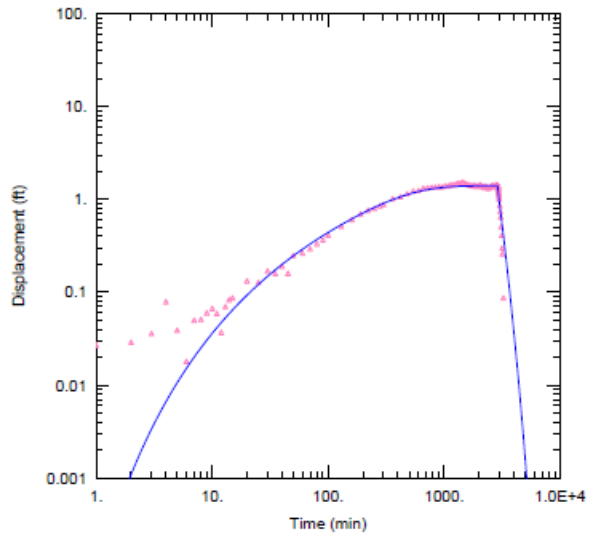
SOLUTION

Aquifer Model: Leaky

T = 5771.8 ft^2/day
1/B' = 0.001312 ft^{-1}
1/B" = 0. ft^{-1}

Solution Method: Hantush

S = 0.0001085
B'/r = 0.001102 ft^{-1}
B"/r = 0. ft^{-1}



WELL TEST ANALYSIS

PROJECT INFORMATION

Client: City of Camarillo
Location: Camarillo
Test Well: Camarillo Well A
Test Date: 6/1/11

AQUIFER DATA

Saturated Thickness: 340. ft
Aquitard Thickness (b'): 330. ft

Anisotropy Ratio (Kz/Kr): 1.
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Camarillo Well A	6253685	1911929

Observation Wells

Well Name	X (ft)	Y (ft)
PVMWC Well 10	6252463	1912256

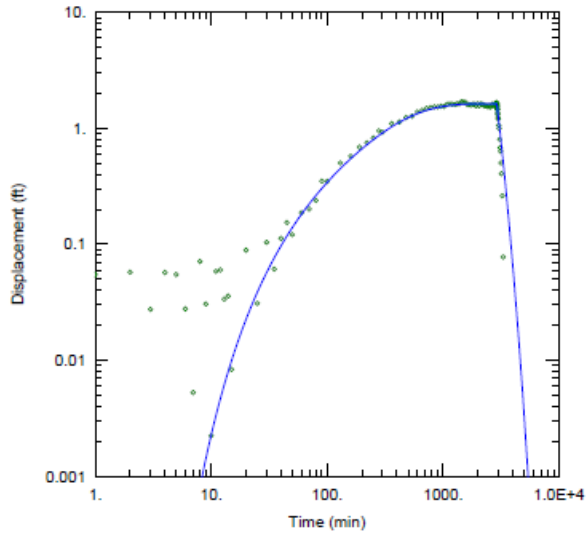
SOLUTION

Aquifer Model: Leaky

T = 1.034E+4 ft^2/day
1/B' = 0.0[11]1073 ft^{-1}
1/B" = 0. ft^{-1}

Solution Method: Hantush

S = 5.0E-5
ß'/r = 0.0[3]375 ft^{-1}
ß"/r = 0. ft^{-1}



WELL TEST ANALYSIS

Data Set: C:\...\PVMWC Pumping Well A Obs Well Drawdown Data.aqt
Date: 12/03/11 Time: 10:14:23

PROJECT INFORMATION

Client: City of Camarillo
Location: Camarillo
Test Well: Camarillo Well A
Test Date: 6/1/11

AQUIFER DATA

Saturated Thickness: 340. ft
Aquitard Thickness (b'): 330. ft
Anisotropy Ratio (Kz/Kr): 1.
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Camarillo Well A	6253685	1911929

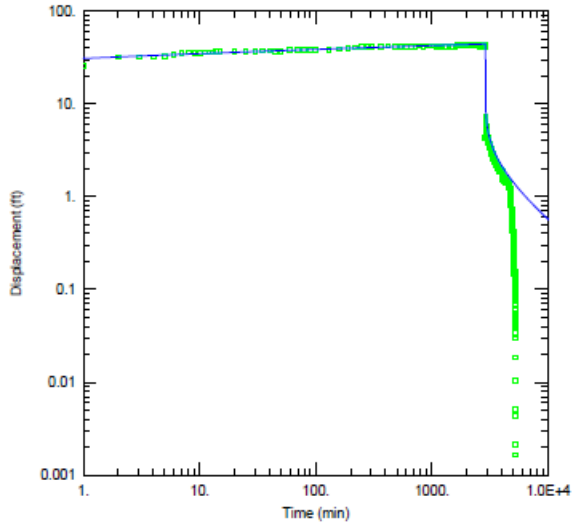
Observation Wells

Well Name	X (ft)	Y (ft)
PVMWC Well 11	6252523	1911925

SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush

T = 6864.2 ft^2/day
1/B' = 0.00134 ft^{-1}
1/B" = 0. ft^{-1}
S = 0.0004509
δ'/r = 0.00398 ft^{-1}
δ"/r = 0. ft^{-1}



WELL TEST ANALYSIS

PROJECT INFORMATION

Client: City of Camarillo
Location: Camarillo
Test Well: Camarillo Well B
Test Date: 6/6/11

AQUIFER DATA

Saturated Thickness: 340. ft
Aquitard Thickness (b'): 330. ft

Anisotropy Ratio (Kz/Kr): 1.
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Camarillo Well B	6253624	1912836

Observation Wells

Well Name	X (ft)	Y (ft)
Camarillo Well B	6253624	1912836

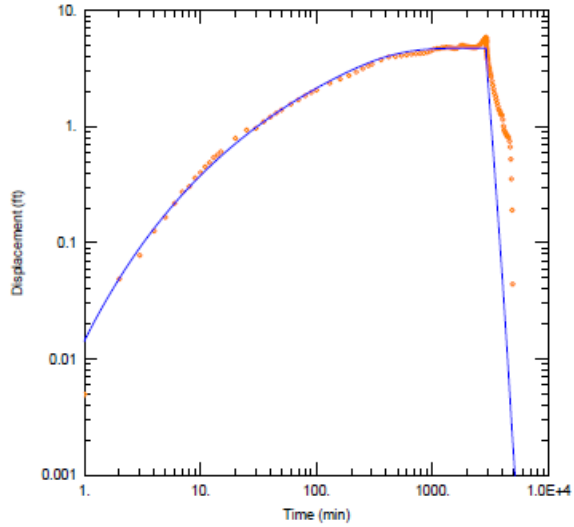
SOLUTION

Aquifer Model: Leaky

T = 7051.7 ft^2/day
1/B' = 8.547E-6 ft^{-1}
1/B" = 0. ft^{-1}

Solution Method: Hantush

S = 2.308E-5
ß'/r = 0.01213 ft^{-1}
ß"/r = 0. ft^{-1}



WELL TEST ANALYSIS

Data Set: C:\...\PVMWC Pumping Well B_Observation Wells.agt
Date: 12/02/11 Time: 22:22:25

PROJECT INFORMATION

Client: City of Camarillo
Location: Camarillo
Test Well: Camarillo Well B
Test Date: 6/6/11

AQUIFER DATA

Saturated Thickness: 340. ft
Aquitard Thickness (b'): 330. ft
Anisotropy Ratio (Kz/Kr): 1.
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Camarillo Well B	6253624	1912836

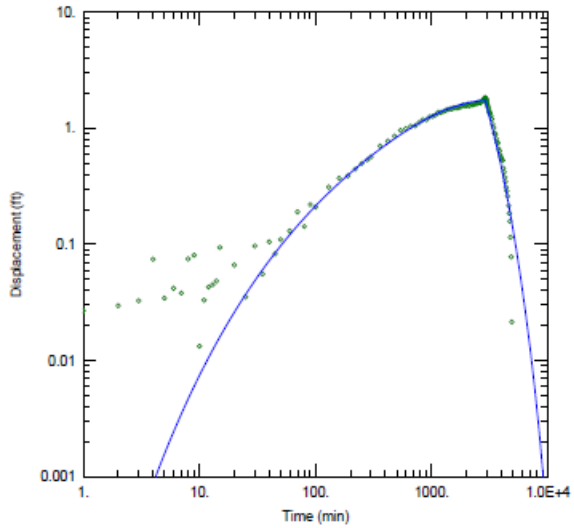
Observation Wells

Well Name	X (ft)	Y (ft)
Camarillo Well A	6253685	1911929

SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush

T = 3928.6 ft^2/day
1/B' = 0.001146 ft^{-1}
1/B" = 0. ft^{-1}
S = 3.137E-6
ß'/r = 0.008851 ft^{-1}
ß"/r = 0. ft^{-1}



WELL TEST ANALYSIS

Data Set: C:\...\PVMWC Pumping Well B_Observation Wells.agt
Date: 12/02/11 Time: 18:09:26

PROJECT INFORMATION

Client: City of Camarillo
Location: Camarillo
Test Well: Camarillo Well B
Test Date: 6/6/11

AQUIFER DATA

Saturated Thickness: 340. ft
Aquitard Thickness (b'): 330. ft
Anisotropy Ratio (Kz/Kr): 1.
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Camarillo Well B	6253624	1912836

Observation Wells

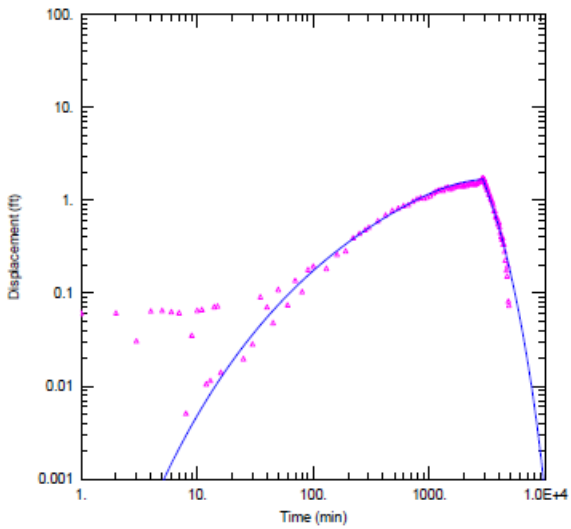
Well Name	X (ft)	Y (ft)
PVMWC Well 10	6252463	1912256

SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush

T = 5821.4 ft^2/day
1/B' = 0.00113 ft^{-1}
1/B" = 0. ft^{-1}

S = 8.761E-8
ß'/r = 0.011 ft^{-1}
ß"/r = 0. ft^{-1}



WELL TEST ANALYSIS

PROJECT INFORMATION

Client: City of Camarillo
Location: Camarillo
Test Well: Camarillo Well B
Test Date: 6/6/11

AQUIFER DATA

Saturated Thickness: 340. ft
Aquitard Thickness (b'): 330. ft

Anisotropy Ratio (Kz/Kr): 1.
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Camarillo Well B	6253624	1912836

Observation Wells

Well Name	X (ft)	Y (ft)
PVMWC Well 11	6252523	1911925

SOLUTION

Aquifer Model: Leaky

T = 5423.6 ft^2/day
1/B' = 0.0[11]076 ft^{-1}
1/B" = 0. ft^{-1}

Solution Method: Hantush

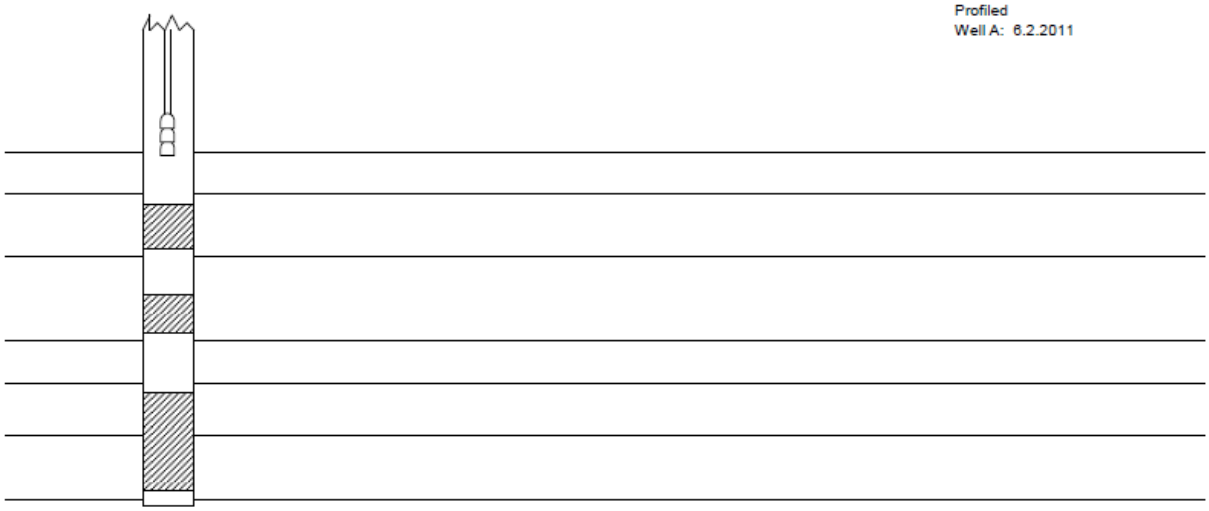
S = 5.034E-6
ß'/r = 0.0[13]13 ft^{-1}
ß"/r = 0. ft^{-1}

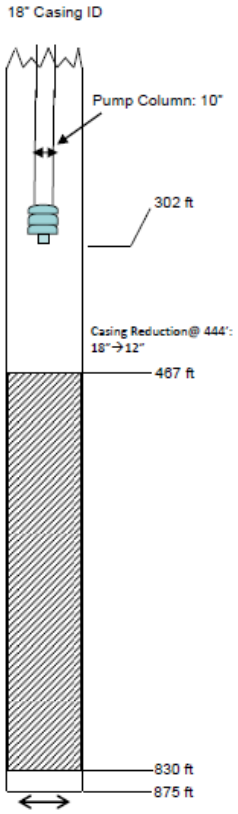
BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES

50 Tiburon Street Suite 7
San Rafael , CA 94901
Toll Free.866.298.8701
Phone.415.453.2501
Fax.415.453.2509

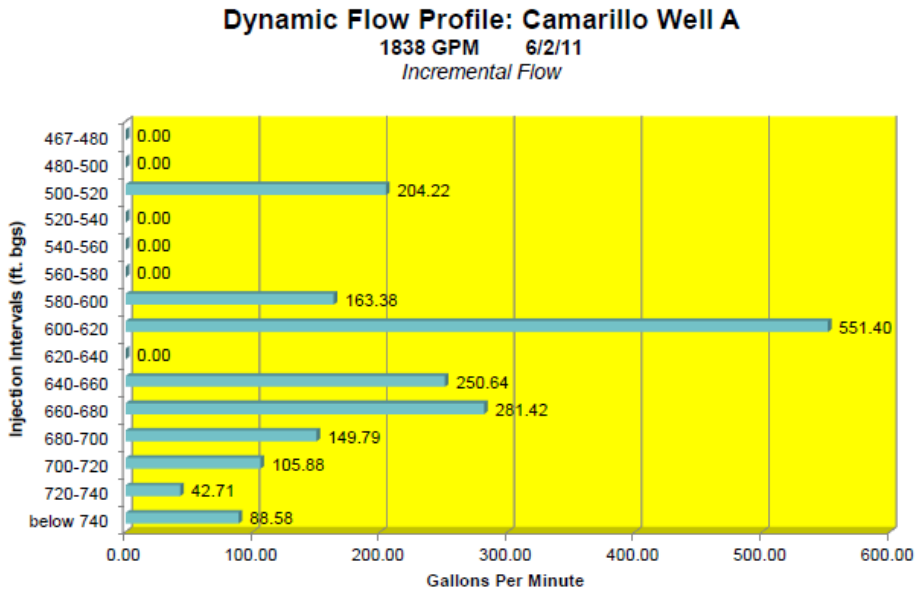
Final Report: Dynamic Flow and Chemistry Profile
City of Camarillo Well A

Profiled
Well A: 6.2.2011





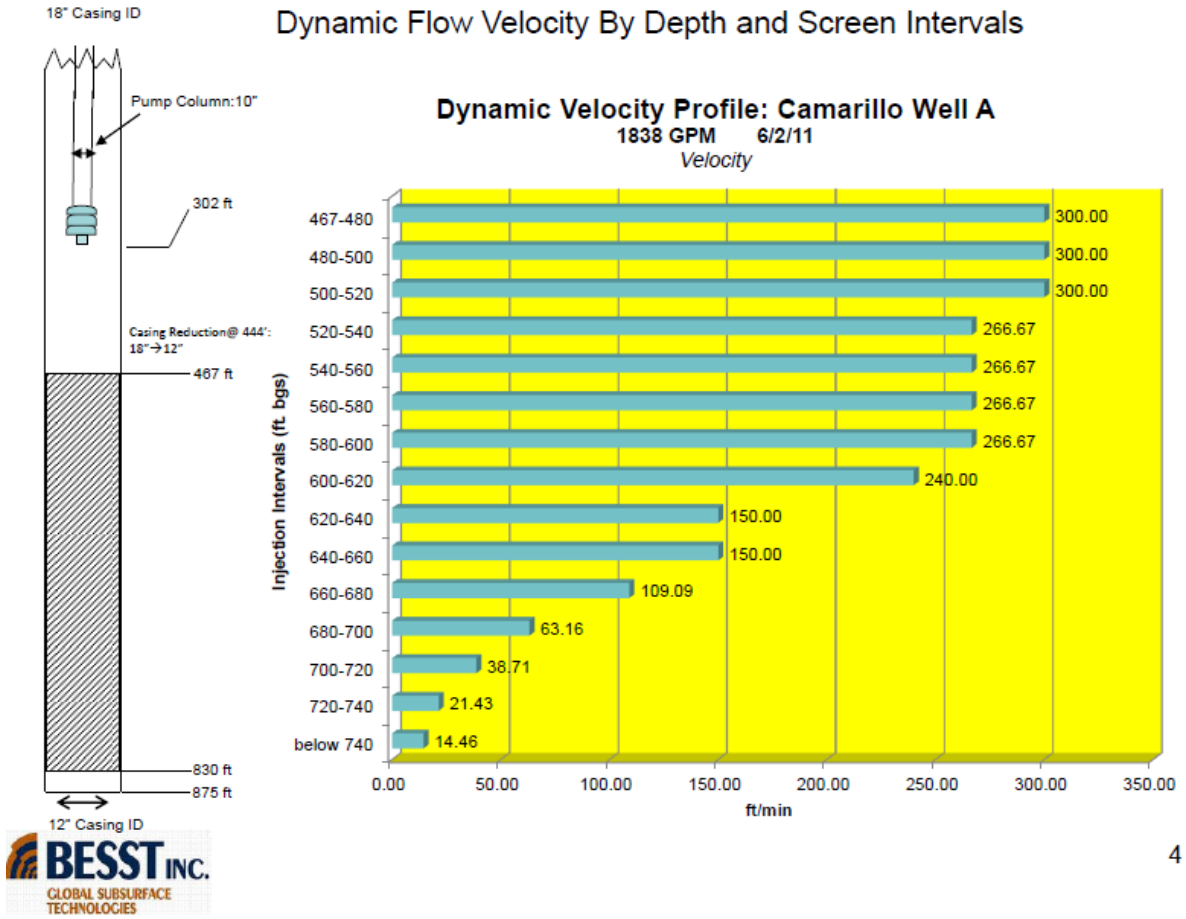
Dynamic Flow Contribution (GPM) By Depth and Screen Intervals

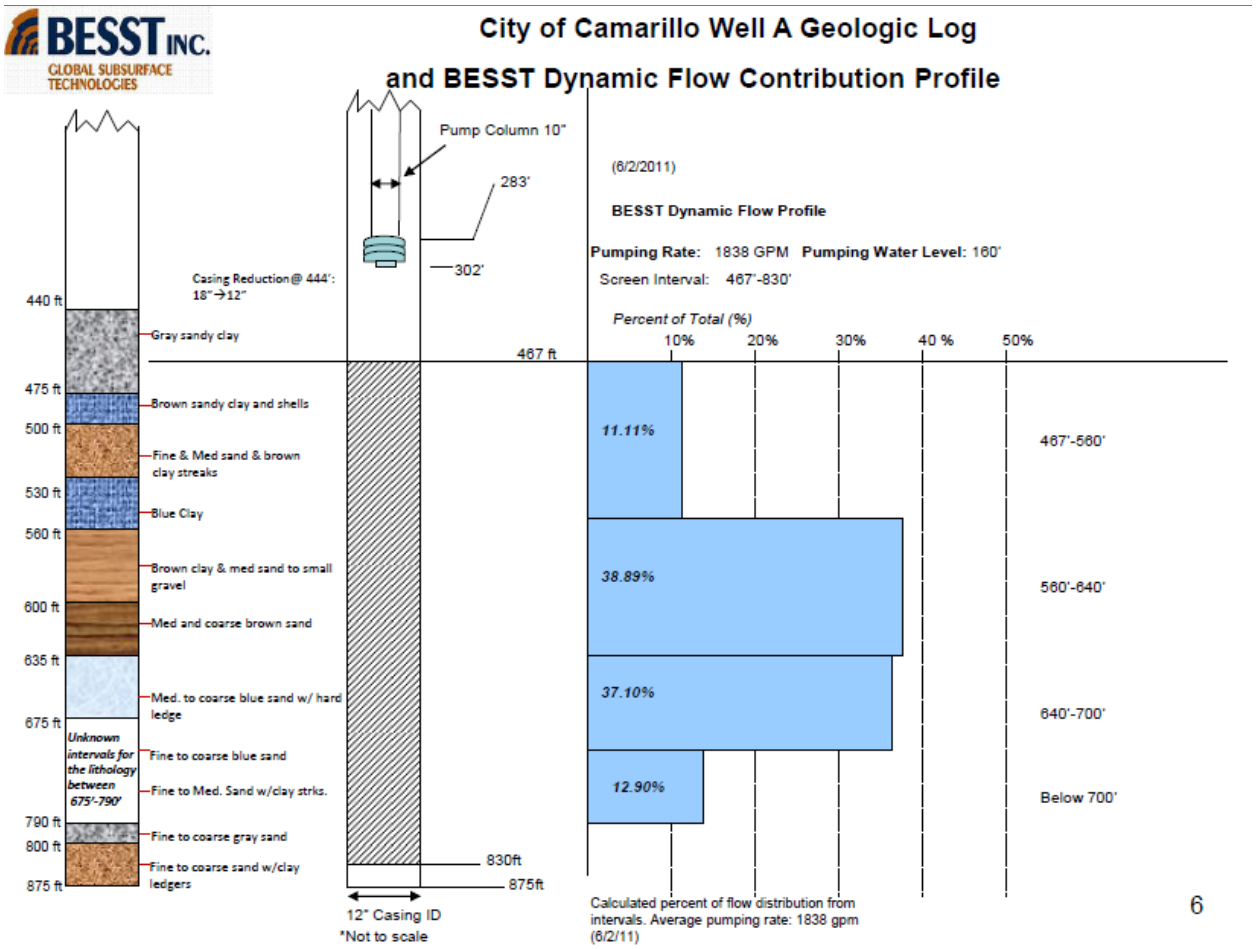


The graph shows dynamic flow contribution vs. the injection depth intervals (ft. bgs). There is one screen interval in Well A. The screened interval is between 467'-830' and produces a cumulative flow of 1838 GPM. This test was conducted under steady state conditions and pumping water level was 160 ft below ground surface. During the descent down the well, our tubing became blocked between 760'-770' bgs. The dye tracer tubing would not continue any deeper inside the well and we assumed the bottom of the well within this interval. Our last viable dye injection was conducted at 760' bgs. This information may be verified by conducting a video survey of the well casing. The graph above shows a breakdown of Incremental Flow in relation to the Dye Injection Intervals.

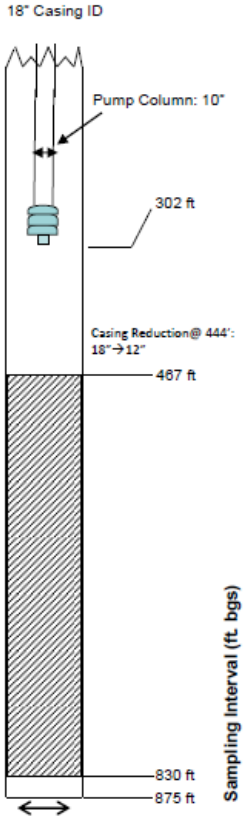
3

BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES

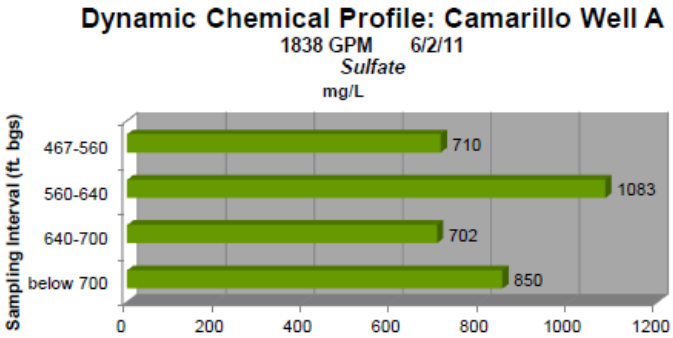

Dynamic Flow Velocity By Depth and Screen Intervals
18" Casing ID
Pump Column:10"
302 ft
Casing Reduction@ 444':
18"→12"
467 ft
830 ft
875 ft
12" Casing ID
Dynamic Velocity Profile: Camarillo Well A
1838 GPM 6/2/11
Velocity
Injection Intervals (ft. bgs)
467-480
480-500
500-520
520-540
540-560
560-580
580-600
600-620
620-640
640-660
660-680
680-700
700-720
720-740
below 740
300.00
300.00
300.00
266.67
266.67
266.67
266.67
240.00
150.00
150.00
109.09
63.16
38.71
21.43
14.46
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
ft/min
BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES
4


BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES
City of Camarillo Well A Geologic Log
and BESST Dynamic Flow Contribution Profile
Pump Column 10"
283'
302'
(6/2/2011)
BESST Dynamic Flow Profile
Pumping Rate: 1838 GPM Pumping Water Level: 160'
Screen Interval: 467'-830'
Casing Reduction@ 444': 18"→12"
Percent of Total (%)
10%
20%
30%
40 %
50%
440 ft
475 ft
500 ft
530 ft
560 ft
600 ft
635 ft
675 ft
790 ft
800 ft
875 ft
467 ft
Gray sandy clay
Brown sandy clay and shells
Fine & Med sand & brown clay streaks
Blue Clay
Brown clay & med sand to small gravel
Med and coarse brown sand
Med. to coarse blue sand w/ hard ledge
Unknown intervals for the lithology between 675'-790'
Fine to coarse blue sand
Fine to Med. Sand w/clay strks.
Fine to coarse gray sand
Fine to coarse sand w/clay ledgers
11.11%
38.89%
37.10%
12.90%
467'-560'
560'-640'
640'-700'
Below 700'
830ft
875ft
12" Casing ID
*Not to scale
Calculated percent of flow distribution from intervals. Average pumping rate: 1838 gpm (6/2/11)
6

Chemical Mass Balance Analysis: Sulfate



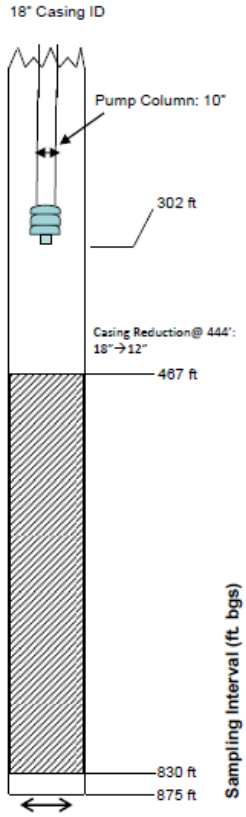
Sulfate	ft. bgs	ft. bgs	GPM	mg/L	GPM	mg/L	
	Depth	Interval	Cumulative Flow	Measured Concentration	Incremental Flow	Incremental Concentration	Mass Balance Check
	Tap	467-560	1838.00	870	204.22	710	144998
	560	560-640	1633.78	890	714.78	1083	774002
	640	640-700	919.00	740	681.84	702	478473
	700	below 700	237.16	850	237.16	850	201587
							1599060	870



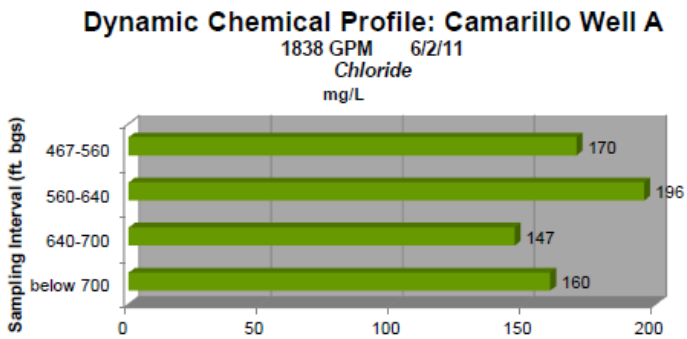
BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES

7

Chemical Mass Balance Analysis: Chloride



Chloride	ft. bgs	ft. bgs	GPM	mg/L	GPM	mg/L	
	Depth	Interval	Cumulative Flow	Measured Concentration	Incremental Flow	Incremental Concentration	Mass Balance Check
	Tap	467-560	1838.00	170	204.22	170	34718
	560	560-640	1633.78	170	714.78	196	139892
	640	640-700	919.00	150	681.84	147	99904
	700	below 700	237.16	160	237.16	160	37946
							312460	170

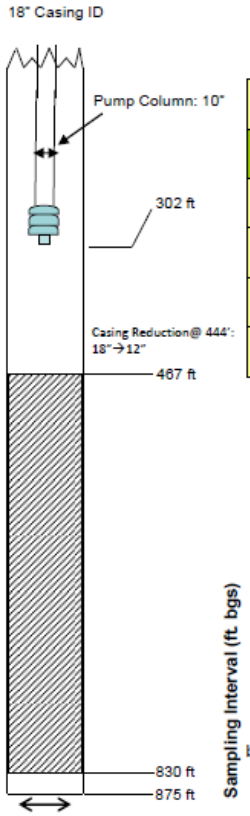


The laboratory has reported a chloride concentration of 540 mg/L for the water sample taken at 560' which appears to be aberrant, evidenced by the cation:anion imbalance reported at this depth. With Tom Regan's consent, we've adjusted the measured concentrations to 170 mg/L to match what we agree is likely the case down hole. Confirmation is found in the agreement with the zonal concentrations seen in the Specific Conductance analysis on the next page.

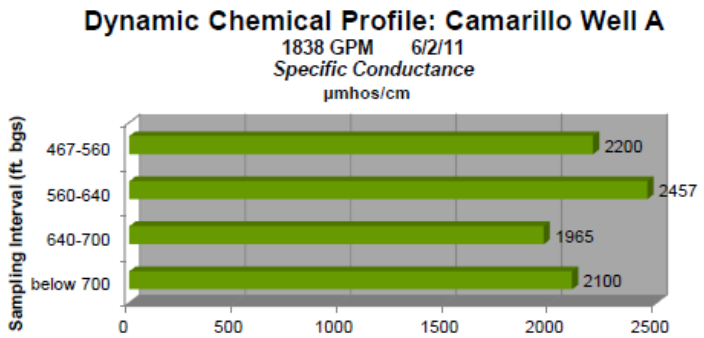
BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES

8

Chemical Mass Balance Analysis: Specific Conductance

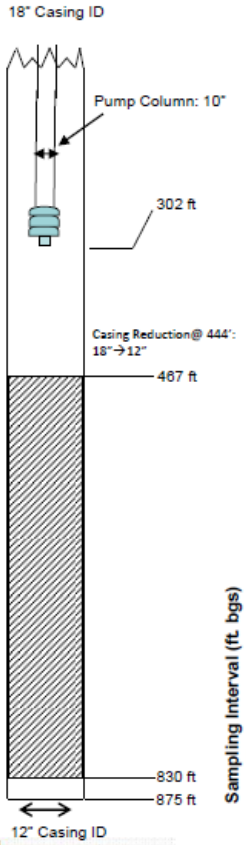


Specific Conductance	ft. bgs	ft. bgs	GPM	µmhos/cm	GPM	µmhos/cm	
	Depth	Interval	Cumulative Flow	Measured Concentration	Incremental Flow	Incremental Concentration	Mass Balance Check
	Tap	467-560	1838.00	2,200	204.22	2200	449289
	560	560-640	1633.78	2,200	714.78	2457	1756311
	640	640-700	919.00	2,000	681.84	1965	1339961
	700	below 700	237.16	2,100	237.16	2100	498039
							4043600	2200



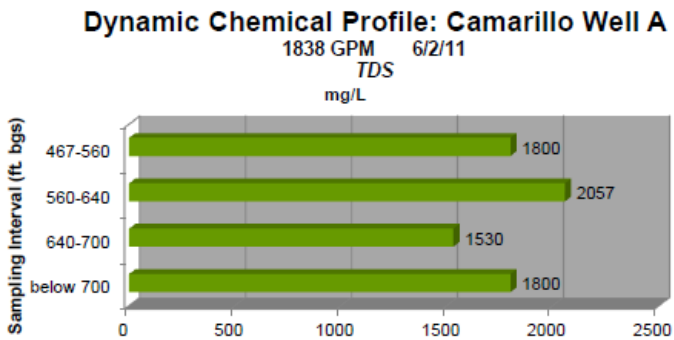
BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES

9



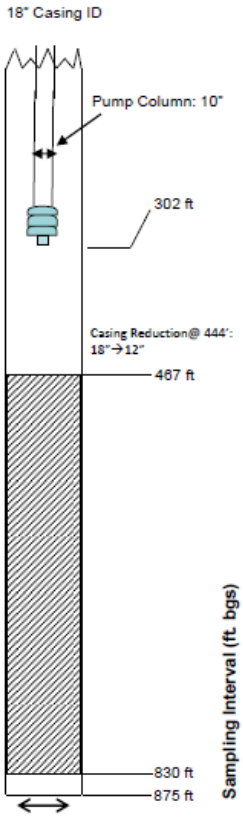
Chemical Mass Balance Analysis: Total Dissolved Solids

TDS	ft. bgs	ft. bgs	GPM	mg/L	GPM	mg/L	
	Depth	Interval	Cumulative Flow	Measured Concentration	Incremental Flow	Incremental Concentration	Mass Balance Check
	Tap	467-560	1838.00	1,800	204.22	1800	367600
	560	560-640	1633.78	1,800	714.78	2057	1470400
	640	640-700	919.00	1,600	681.84	1530	1043510
	700	below 700	237.16	1,800	237.16	1800	426890
							3308400
							1800



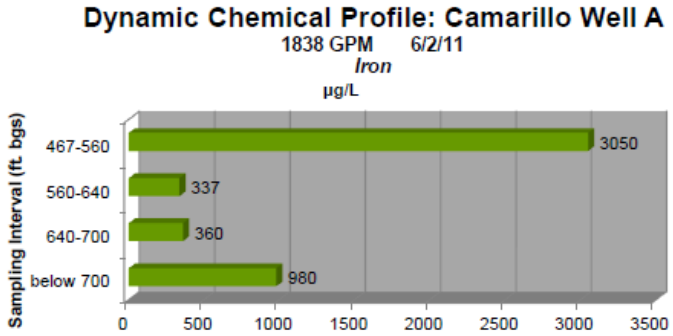
BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES

10



Chemical Mass Balance Analysis: Iron

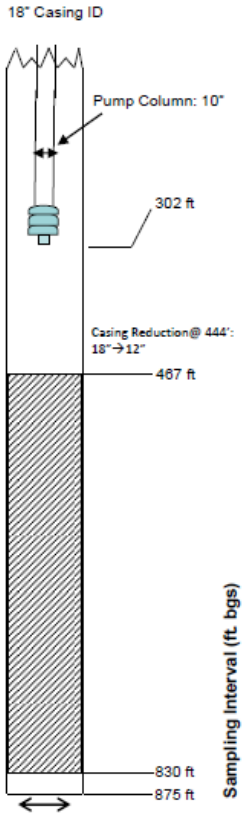
Iron	ft. bgs	ft. bgs	GPM	µg/L	GPM	µg/L	
	Depth	Interval	Cumulative Flow	Measured Concentration	Incremental Flow	Incremental Concentration	Mass Balance Check
	Tap	467-560	1838.00	730	204.22	3050	622878
	560	560-640	1633.78	440	714.78	337	240982
	640	640-700	919.00	520	681.84	360	245462
	700	below 700	237.16	980	237.16	980	232418
							1341740	730



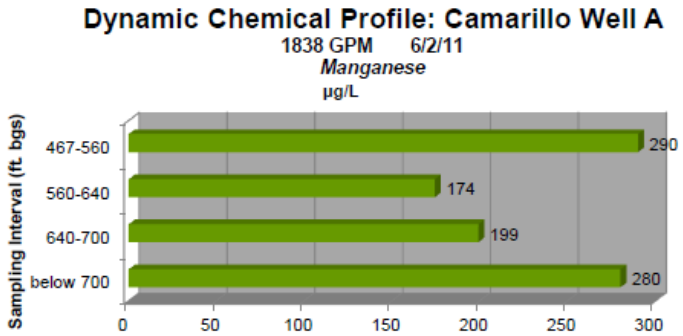
BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES

15

Chemical Mass Balance Analysis: Manganese



Manganese	ft. bgs	ft. bgs	GPM	µg/L	GPM	µg/L	
	Depth	Interval	Cumulative Flow	Measured Concentration	Incremental Flow	Incremental Concentration	Mass Balance Check
	Tap	467-560	1838.00	210	204.22	290	59224
	560	560-640	1633.78	200	714.78	174	124576
	640	640-700	919.00	220	681.84	199	135775
	700	below 700	237.16	280	237.16	280	66405
							385980
							210



BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES

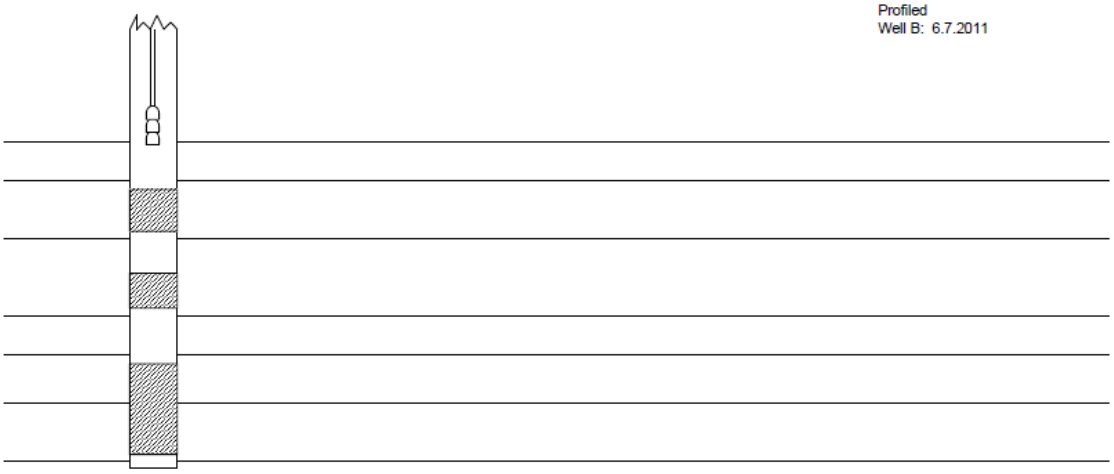
16

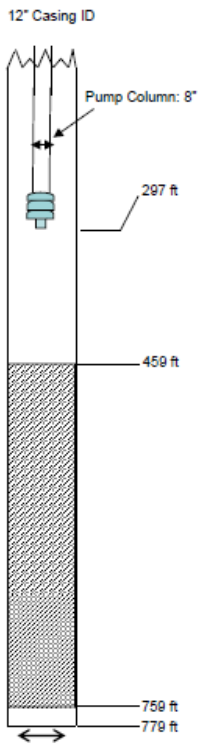
BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES

50 Tiburon Street Suite 7
San Rafael , CA 94901
Toll Free.866.298.8701
Phone.415.453.2501
Fax.415.453.2509

Final Report: Dynamic Flow and Chemistry Profile
City of Camarillo Well B

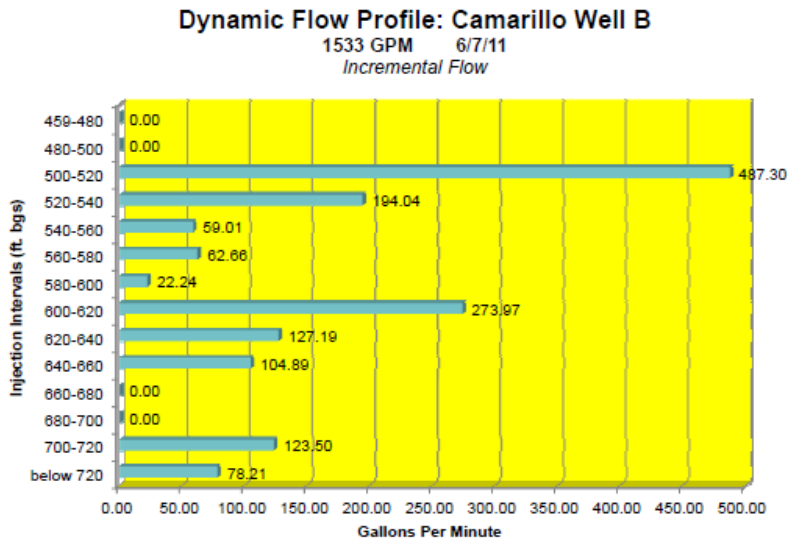
Profiled
Well B: 6.7.2011





BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES

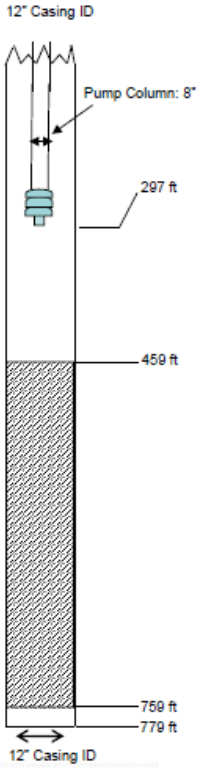
Dynamic Flow Contribution (GPM) By Depth and Screen Intervals



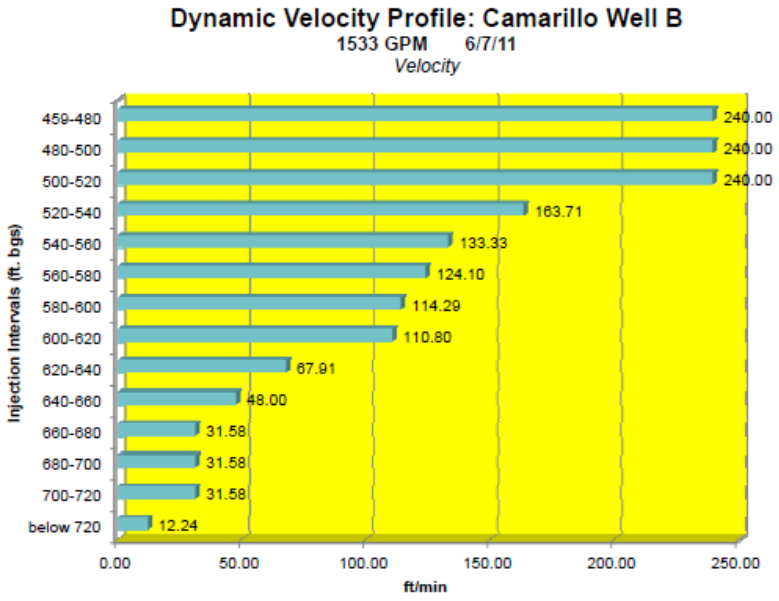
The graph shows dynamic flow contribution vs. the injection depth intervals (ft. bgs). There is one screen interval in Well B. The screened interval is between 459'-759' and produces a cumulative flow of 1533 GPM. This test was conducted under steady state conditions and pumping water level was between 63.1 and 63.6 ft below the top of the access pipe. The graph above shows a breakdown of Incremental Flow in relation to the Dye Injection Intervals.

Note: There was no dye return at the surface when it was injected at or below 480 ft. bgs. This indicates that the vertical flow boundary layer is between 470 and 480 ft. bgs . There is no vertical/upward flow below 480 ft. bgs.

3

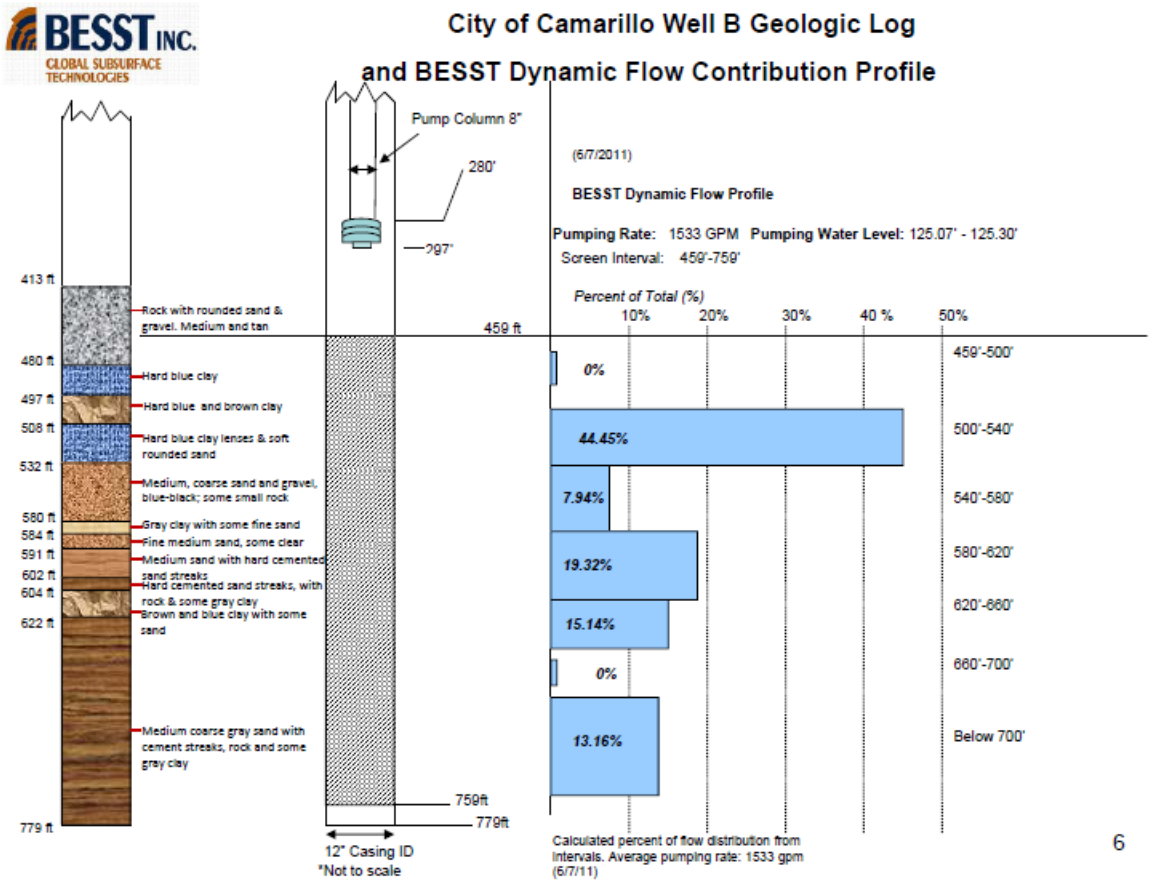


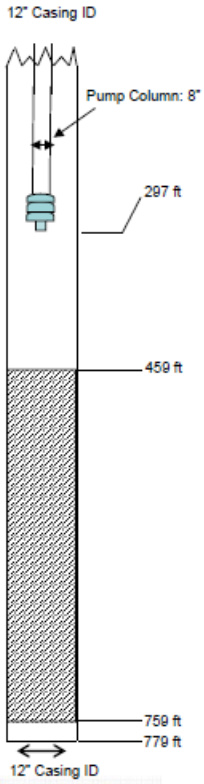
Dynamic Flow Velocity By Depth and Screen Intervals



BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES

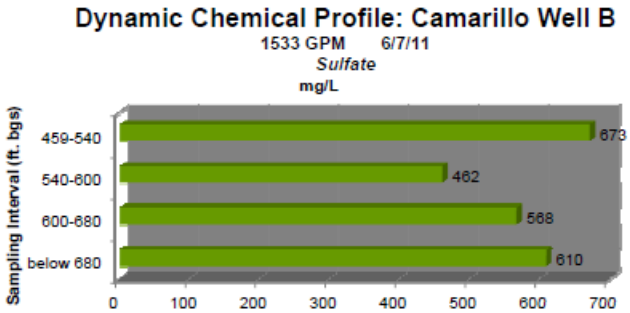
4


BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES
City of Camarillo Well B Geologic Log
and BESST Dynamic Flow Contribution Profile
Pump Column 8"
280'
297'
(6/7/2011)
BESST Dynamic Flow Profile
Pumping Rate: 1533 GPM Pumping Water Level: 125.07' - 125.30'
Screen Interval: 459'-759'
Percent of Total (%)
10%
20%
30%
40 %
50%
413 ft
Rock with rounded sand & gravel. Medium and tan
459 ft
480 ft
Hard blue clay
497 ft
Hard blue and brown clay
508 ft
Hard blue clay lenses & soft rounded sand
532 ft
Medium, coarse sand and gravel, blue-black; some small rock
580 ft
584 ft
Gray clay with some fine sand
591 ft
Fine medium sand, some clear
602 ft
Medium sand with hard cemented sand streaks
604 ft
Hard cemented sand streaks, with rock & some gray clay
622 ft
Brown and blue clay with some sand
Medium coarse gray sand with cement streaks, rock and some gray clay
759ft
779ft
779 ft
12" Casing ID
*Not to scale
0%
44.45%
7.94%
19.32%
15.14%
0%
13.16%
459'-500'
500'-540'
540'-580'
580'-620'
620'-660'
660'-700'
Below 700'
Calculated percent of flow distribution from intervals. Average pumping rate: 1533 gpm (6/7/11)
6

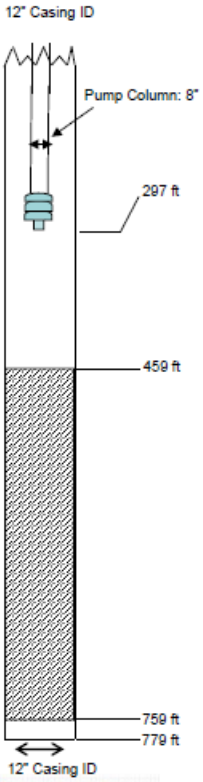


Chemical Mass Balance Analysis: Sulfate

Sulfate	ft. bgs	ft. bgs	GPM	mg/L	GPM	mg/L	
	Depth	Interval	Cumulative Flow	Measured Concentration	Incremental Flow	Incremental Concentration	Mass Balance Check
	Tap	459-540	1533.00	610	681.33	673	458197
	540	540-600	851.67	560	143.91	462	66435
	600	600-680	707.76	580	506.05	568	287455
	680	below 680	201.71	610	201.71	610	123043
							935130	610

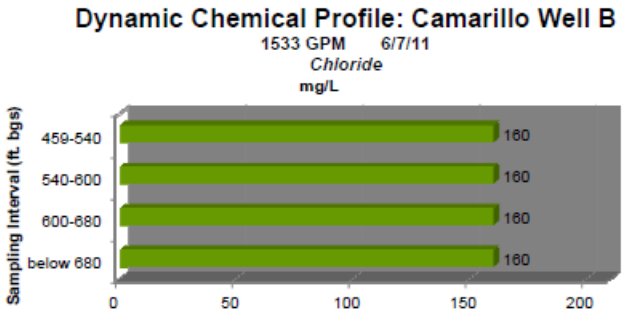


7



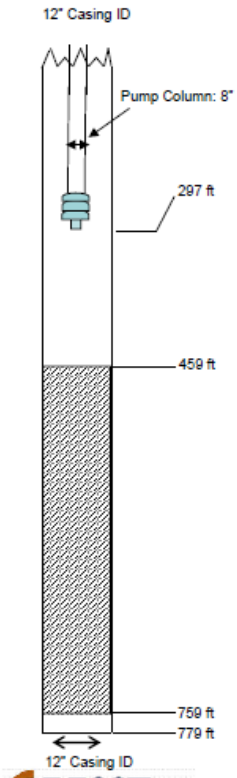
Chemical Mass Balance Analysis: Chloride

Chloride	ft. bgs	ft. bgs	GPM	mg/L	GPM	mg/L	
	Depth	Interval	Cumulative Flow	Measured Concentration	Incremental Flow	Incremental Concentration	Mass Balance Check
	Tap	459-540	1533.00	160	681.33	160	109013
	540	540-600	851.67	160	143.91	160	23026
	600	600-680	707.76	160	506.05	160	80967
	680	below 680	201.71	160	201.71	160	32274
							245280	160



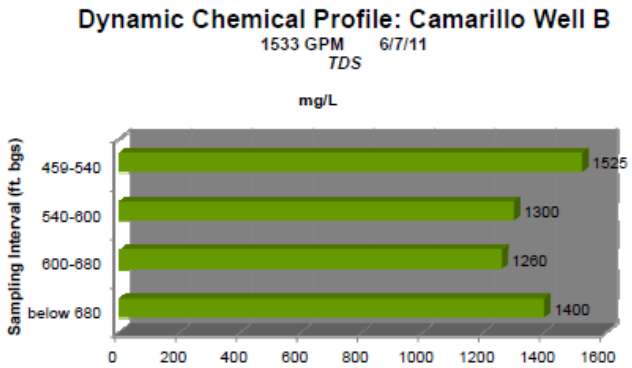
BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES

8



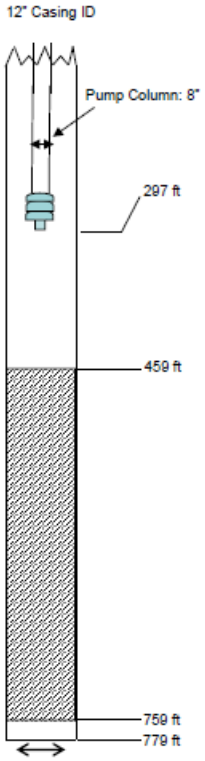
Chemical Mass Balance Analysis: Total Dissolved Solids

TDS	ft. bgs	ft. bgs	GPM	mg/L	GPM	mg/L	
	Depth	Interval	Cumulative Flow	Measured Concentration	Incremental Flow	Incremental Concentration	Mass Balance Check
	Tap	459-540	1533.00	1,400	681.33	1525	1039033
	540	540-600	851.67	1,300	143.91	1300	187084
	600	600-680	707.76	1,300	506.05	1260	637688
	680	below 680	201.71	1,400	201.71	1400	282395
							2146200	1400



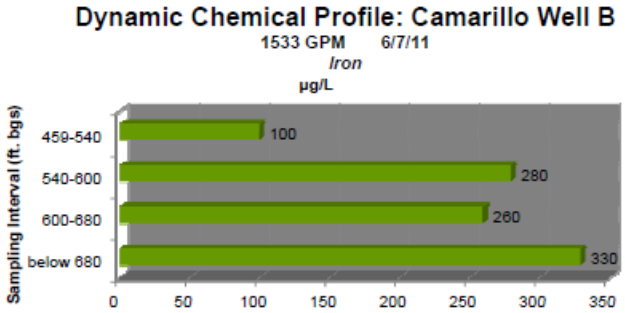
10

BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES



Chemical Mass Balance Analysis: Iron

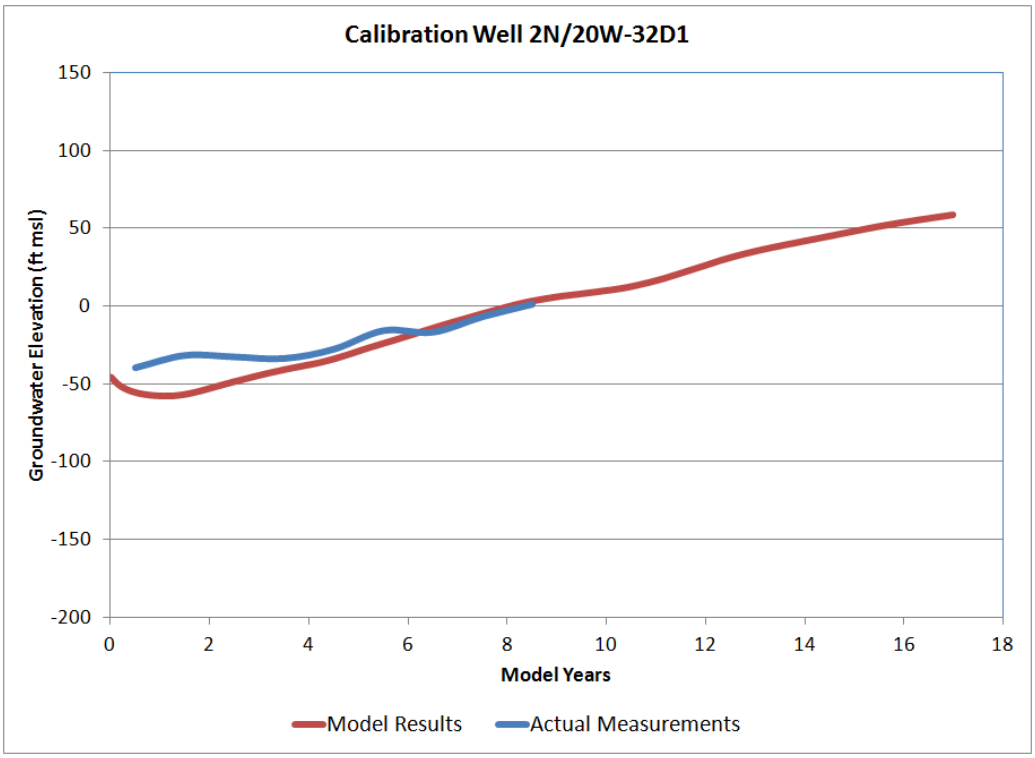
Iron	ft. bgs	ft. bgs	GPM	µg/L	GPM	µg/L	
	Depth	Interval	Cumulative Flow	Measured Concentration	Incremental Flow	Incremental Concentration	Mass Balance Check
	Tap	459-540	1533.00	200	681.33	100	68133
	540	540-600	851.67	280	143.91	280	40295
	600	600-680	707.76	280	506.05	260	131607
	680	below 680	201.71	330	201.71	330	66564
							306600	200

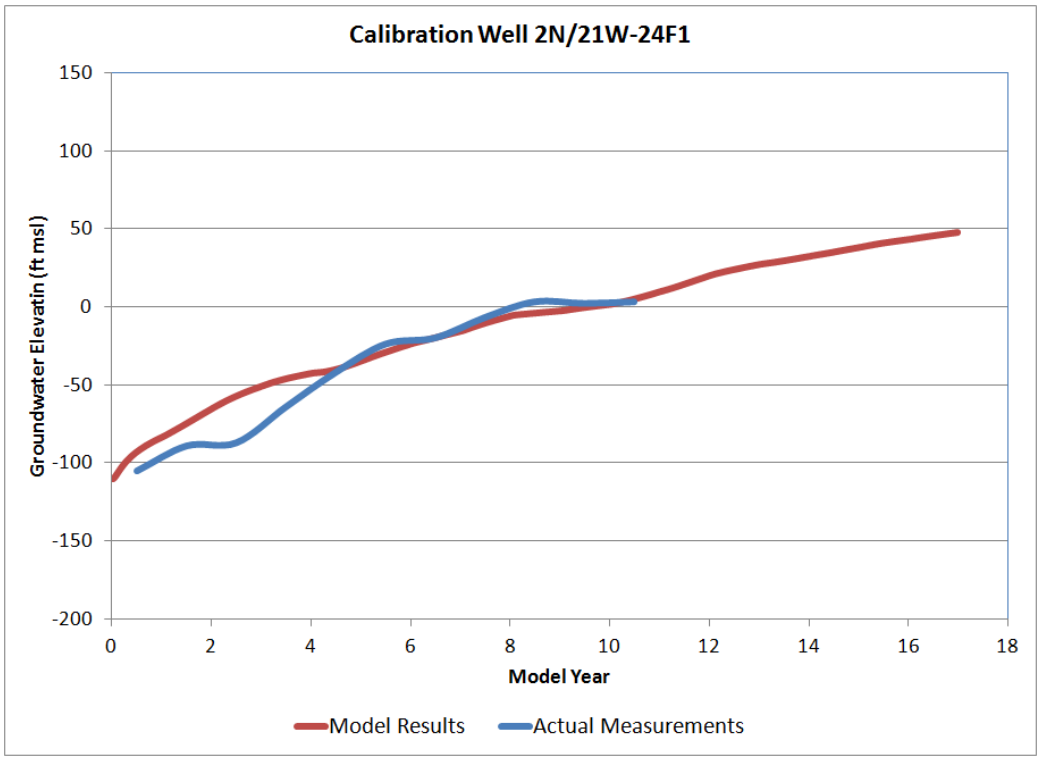


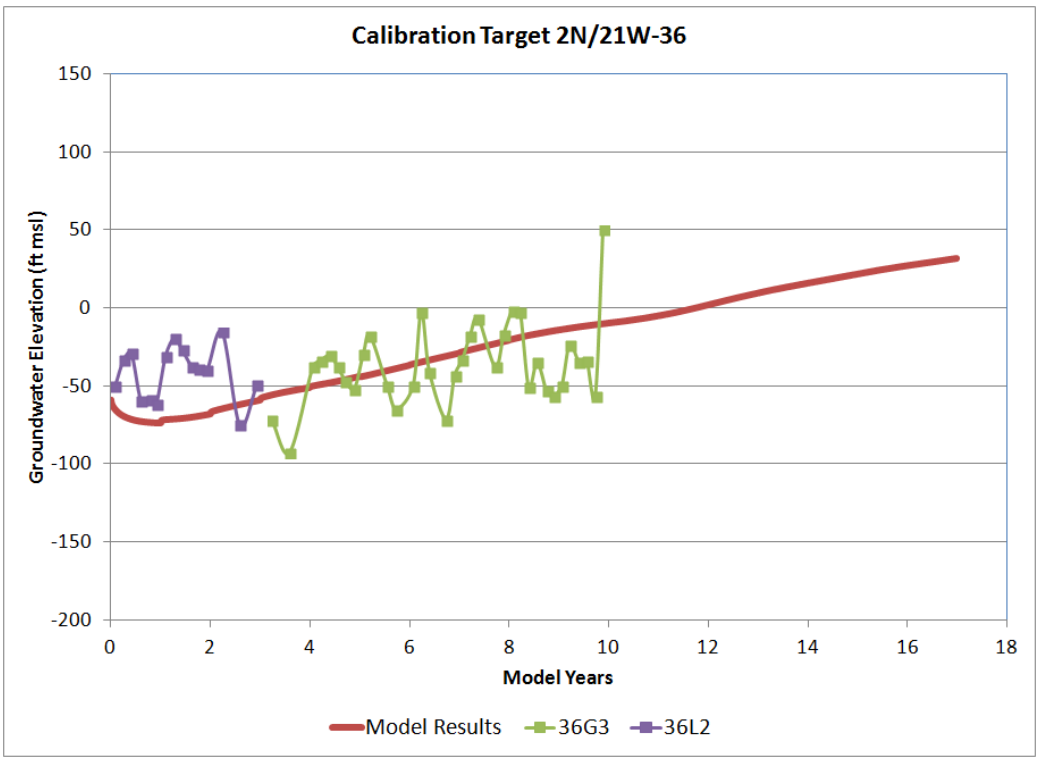
BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES

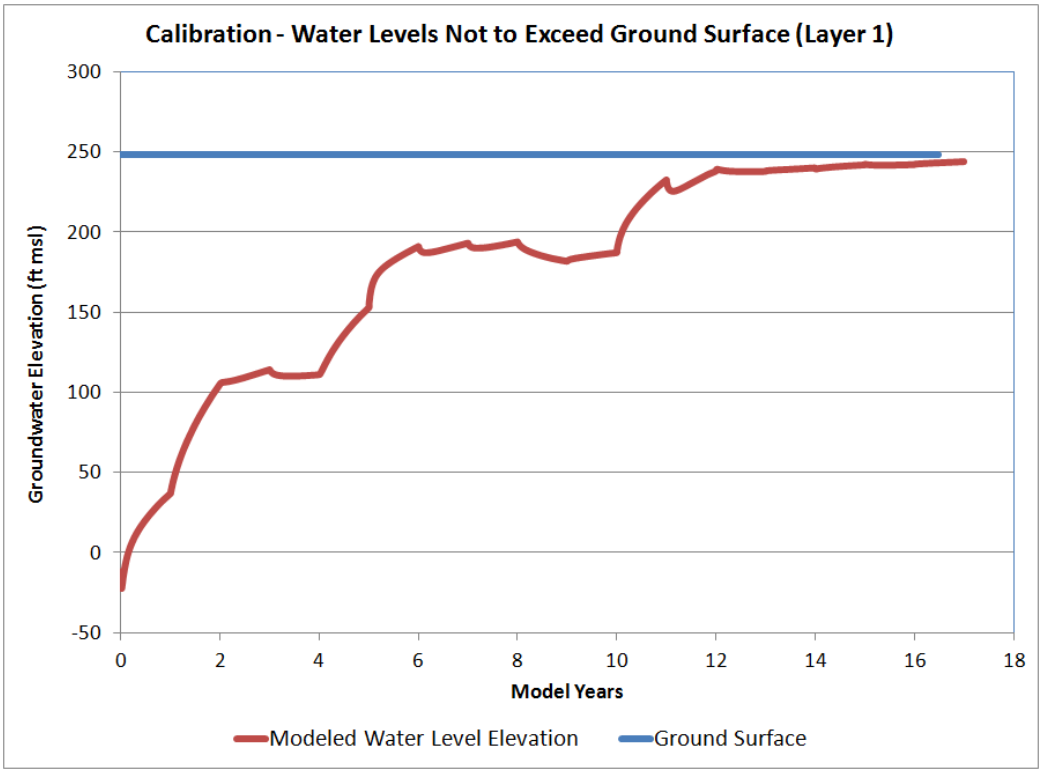
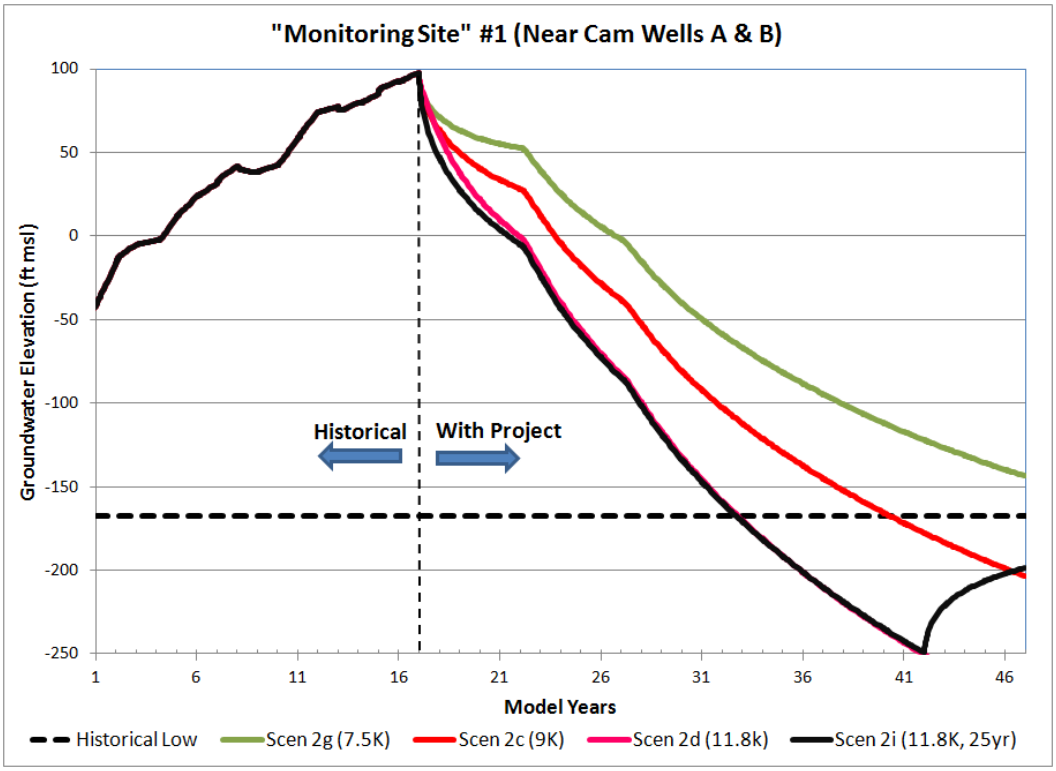
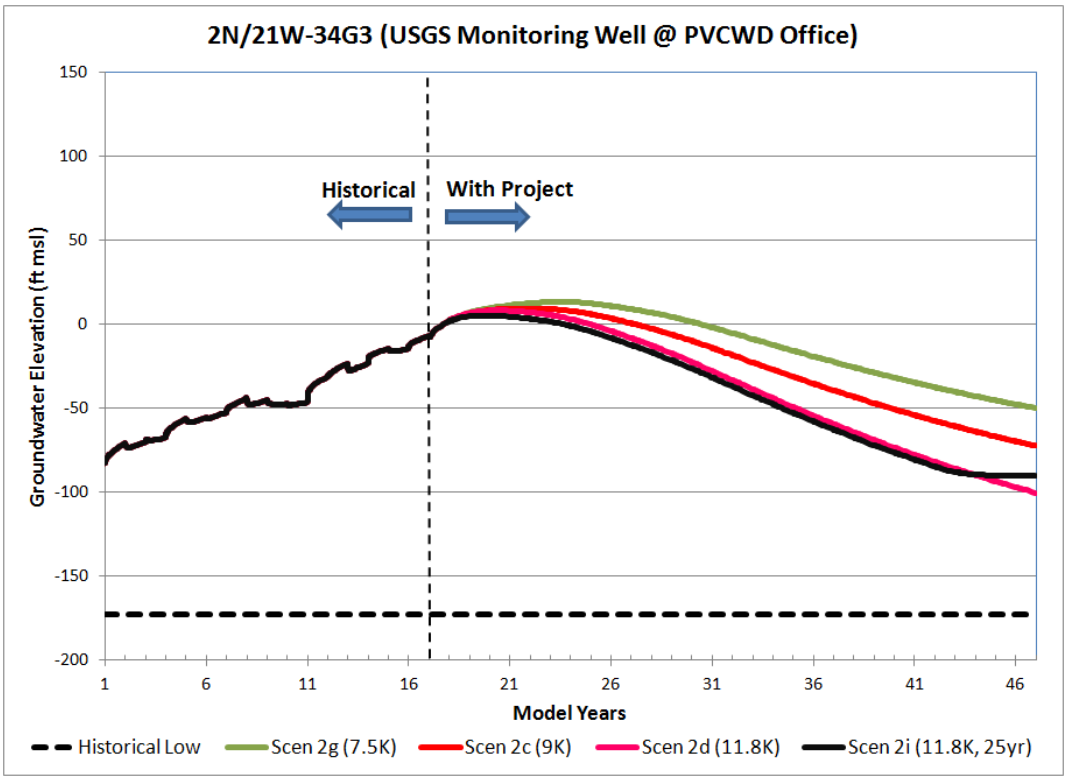
15

14.3 Additional Calibration Wells






Calibration Target 2N/21W-36
Groundwater Elevation (ft msl)
150
100
50
0
-50
-100
-150
-200
0
2
4
6
8
10
12
14
16
18
Model Years
Model Results
36G3
36L2


Calibration - Water Levels Not to Exceed Ground Surface (Layer 1)
Groundwater Elevation (ft msl)
300
250
200
150
100
50
0
-50
0
2
4
6
8
10
12
14
16
18
Model Years
Modeled Water Level Elevation
Ground Surface

14.4 Additional Project Results