City of Pismo Beach and South San Luis Obispo County Sanitation District Central Coast Blue Phase 1B Hydrogeologic Evaluation

Executive Summary

Prepared for:
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GEOSCIENCE

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EXECUTIVE SUMMARY

1.0 INTRODUCTION

Central Coast Blue (CCB) is a regional recycled water project that will reduce the risk of seawater intrusion and improve water supply sustainability in northwestern Santa Maria River Valley Groundwater Basin (Basin; see Figure ES-1). The project will use advanced-treated recycled water from the City of Pismo Beach and the South San Luis Obispo County Sanitation District (SSLOCSD) Wastewater Treatment Plants (WWTPs) as an injection water source. This water will then be injected in the Arroyo Grande-Tri-Cities Mesa portion of the Basin to establish a seawater intrusion barrier and improve the reliability of groundwater supplies in the region. As part of the Phase 1B Hydrogeologic Evaluation, GEOSCIENCE Support Services, Inc. (GEOSCIENCE) was tasked with expanding the previous Regional Groundwater Sustainability Project (RGSP) Phase 1A Model to include an evaluation of injection and extraction scenarios with flows from the SSLOCSD and City of Pismo Beach WWTPs.

1.1 Background of Existing Groundwater Models

Four main groundwater models were developed in the Project area over the last few years. Cleath and Associates developed a model in 1996 covering most of Nipomo Mesa Management Area (NMMA) comprising two layers and a grid size of 1,000 ft by 1,000 ft. It was calibrated from 1977 to 1994. The Santa Maria Valley Groundwater Basin Model developed by Luhdorff & Scalmanini, Consulting Engineers (LSCE, 2000) covers the entire Santa Maria Valley Management Area (SMVMA) and part of the NMMA. It was calibrated from Fall 1944 to Spring 1997 with 6-month stress periods and consisted of six model layers with a uniform cell size of 2,000 ft by 2,000 ft.

The remaining models are centered around the Northern Cities Management Area (NCMA): the NCMA Groundwater Model (Wallace, 2016) and the RGSP Phase 1A Model (CHG, 2017). The NCMA Groundwater Model has three model layers and a cell size of 127 ft by 127 ft. It included both a steady state and a transient calibration period and was calibrated from 1986 to 2004 with a monthly stress period. The Phase 1A Model is the most recent model and also the most discretized, with a cell size of 200 ft by 200 ft and 13 model layers. The model extent is shown on Figure ES-1. It was calibrated from Spring 2005 to Fall 2015 with 6-month stress periods. All of these models were purely groundwater flow models and did not contain a solute transport model component.

1.2 Scope of Work

The following tasks were included in the development of the CCB Phase 1B groundwater flow and solute transport model (Phase 1B Model):

- Task 0 – Project Management
- Task 1 – Data Assessment
- Task 2 – Conceptual Model
- Task 3 – Model Construction
- Task 4 – Model Calibration and Sensitivity Analysis
- Task 5 – Scenario Evaluation
- Task 6 – Model Report

The Phase 1B Model development represents a collaborative process by which the model development and calibration was modified based on feedback from the Technical Advisory Committee (TAC). Members of the TAC included representatives of the Nipomo Mesa Management Area Technical Group (NMMA TG), GSI (representing the Northern Cities Management Area (NCMA)), and Water Systems Consulting, Inc. (WSC). Comments during the process were provided during routine progress meetings as well as in response to a series of technical memorandums (TMs) that were issued throughout the process of developing the model and running project scenarios to document the work. These include:

- Groundwater Model Boundaries, dated June 15, 2018 (GEOSCIENCE, 2018a)
- Agricultural Pumping Estimates, dated January 16, 2018 (GEOSCIENCE, 2018b)
- TM No. 1 – Conceptual Model, dated June 15, 2018 (GEOSCIENCE, 2018c)
- TM No. 2 – Calibration Plan, dated June 15, 2018 (GEOSCIENCE, 2018d)
- TM No. 3 – Model Calibration, dated May 14, 2019 (GEOSCIENCE, 2019a)
- TM No. 4 – Model Scenario Evaluation, dated May 14, 2019 (GEOSCIENCE, 2019b)

This executive summary presents an overview of all of the modeling work. Additional information is available in the individual TMs listed above.

2.0 CCB PHASE 1B GROUNDWATER FLOW AND SOLUTE TRANSPORT MODEL

2.1 Conceptual Model, Model Grid, and Boundary Conditions

The CCB Phase 1B Model represents an expansion of the Phase 1A Model, and covers the entire NCMA and NMMA, and part of SMVMA (Figure ES-1). By incorporating the entire NMMA and part of SMVMA, the expanded model extent allowed scenarios in the NCMA to be run with a reduced risk of boundary effects. The larger extent also allowed for the incorporation of more data. This in turn helps ensure that the behavior of the natural system is more accurately captured. The conceptual understanding of the geohydrology, groundwater flow directions, inflows (recharge), and outflows (discharge) for the CCB Phase 1B Groundwater Model area was developed from available datasets and existing studies, as detailed in TM No. 1: Conceptual Model (GEOSCIENCE, 2018c).

The Phase 1B Model was developed for the unconsolidated to semi-consolidated water-bearing sediments within the model area. SEAWAT, a block-centered, finite-difference groundwater flow code developed by the United States Geologic Survey (USGS; Guo and Langevin, 2002), represents the model code used for model development. The main water-bearing formations are the Paso Robles Formation and the Careaga Sand, which constitute the deeper aquifer, and the dune sand, terrace deposits, and quaternary alluvium, which constitute the shallow aquifer (LSCE, 2017). The low-yield formations which underlie and also generally flank the main groundwater basin are considered impermeable and are not part of the modeled groundwater flow system. The conceptual groundwater model consists of ten model layers:

- Layer 1 – Ocean floor (allows for vertical leakage from the ocean to the underlying aquifer (i.e., model layer 2) and inflow and outflow from the surficial aquifer (recent alluvium/young and old dune sand)
- Layer 2 – Recent alluvium/young and old dune sand
- Layers 3 through 7 – Paso Robles Formation
- Layer 8 through 10 – Careaga Sand

2.1.1 Model Layer Development using Three-Dimensional Lithologic Model

Developing a robust, geologically accurate conceptual model for the Phase 1B Model area was a critical first step for model construction. Therefore, as part of the development of the Phase 1B Model, a 3-D lithologic model was constructed to better identify the physical extents, thickness, continuity, and lithology of the geologic units within the NCMA, NMMA, and portion of the SMVMA (Figure ES-2). The construction of the 3-D lithologic model, which is detailed in TM No. 1: Conceptual Model (GEOSCIENCE, 2018c), was based on 23 previously-published cross-sections (DWR, 2002; FUGRO, 2015; LSCE, 2000; and

NMMA Technical Group, 2017) and more than 400 lithologic logs from the SMBC Study (FUGRO, 2015) and Division of Oil, Gas, and Geothermal Resources (DOGGR) wells.

Lithology was estimated using a geostatistical sequential indicator simulation technique coupled with ordinary kriging and observed lithology. Results from the 3-D lithologic model were used to define model layers and estimate initial aquifer parameters (i.e., hydraulic conductivity and storativity values; refer to GEOSCIENCE, 2018d). Figures ES-3 through ES-5 provide cross-sectional views of the model-generated lithology in the Phase 1B Model area. Boundaries between layers were delineated from the final 3-D Lithologic Model. Groundwater flow is assumed to occur primarily horizontally within each of the model layers while the layers maintain hydraulic connection to each other through vertical leakance. Layers 3, 5, 7, and 9 were considered to be primarily aquitards, although these layers can have relatively high hydraulic conductivity in various locations due to the lateral discontinuities of low permeability beds.

2.2 Model Grid

The Phase 1B Model domain covers an area of approximately 197 square miles (125,857 acres) in the northwest portion of the Santa Maria Groundwater Basin. The finite-difference grid consists of 600 rows in the northeast-to-southwest direction and 932 columns in the northwest-to-southeast direction along the model domain and has ten model layers. The grid is rotated at 40° clockwise to be consistent with Phase 1A modeling and to minimize the number of model cells. Each model cell of the Phase 1B Model represents an area of 100 ft x 100 ft (Figure ES-1), which represents a finer resolution than the Phase 1A model. This finer grid improves the resolution of physical features, such as local faults and basin boundaries, as well as the location of wells – including injection well siting. The stress period (i.e., time period) used to vary model fluxes, such as pumping and recharge, occurred monthly.

2.3 Boundary Conditions

A boundary condition is any external influence or effect that acts either as a source or sink, adding or removing water from the groundwater flow system. The boundary conditions used in the Phase 1B Model are no-flow (inactive), wells, general head boundaries (GHB), and stream (Figure ES-6). The active area of the model coincides with the boundaries of the groundwater basin in the north and northeast. These boundaries are based on local geology and DWR groundwater basin boundaries. Additional information on model boundaries is provided in the model boundaries TM (GEOSCIENCE, 2018a) and in TM-3: Model Calibration (GEOSCIENCE, 2019a).

Well boundary conditions, or specified flux, are used to simulate mountain front recharge, pumping, stormwater infiltration, and WWTP infiltration. Since the model area does not continue to the natural southern edge of the basin, a GHB was used along the southern boundary of the active model area to simulate the observed long-term trends in groundwater levels over time. Groundwater elevation trends from wells near the GHB were used to simulate groundwater elevations at the model boundary. A GHB was also used to simulate the Pacific Ocean (model layer 1) and the model connection to the Arroyo Grande Creek alluvial valley.

The Santa Maria River Fault was simulated in the Phase 1B Model as a partial barrier to groundwater flow based on observed offsets in groundwater levels in wells on either side of the fault (GEOSCIENCE, 2018c) and previous hydrogeological investigations (DWR, 2002; Worts, 1951). A horizontal flow barrier was used to simulate the Santa Maria River Fault, the conductance of which was varied along its length and refined during model calibration.

2.1 Groundwater Inflow and Outflow

The primary sources of groundwater recharge and discharge in the model area are summarized in the following table and discussed briefly below. Additional information on recharge and discharge terms are provided in TM-1: Conceptual Model and TM-3: Model Calibration (GEOSCIENCE, 2018c and 2019a).

Table 2-1. Model Recharge and Discharge Terms

Model Term	
Recharge	Areal Recharge from Precipitation
	Mountain Front Recharge
	Streambed Percolation
	Return Flow from Municipal Use
	Return Flow from Agricultural Use
	Return Flow from Golf Course Irrigation
	Artificial Recharge
	Underflow Inflow
Discharge	Municipal Pumping
	Small Purveyor Pumping
	Agricultural Pumping
	Golf Course Pumping
	Underflow Outflow to the Ocean and Offshore Aquifers

2.1.1 Groundwater Inflow Terms

Areal Recharge from Precipitation

Areal recharge is the deep percolation of direct precipitation on the ground surface which eventually recharges the aquifers within the groundwater basin. Estimates of deep percolation of areal recharge were made using the U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS) Curve Number technique (USDA, 1986).

Mountain Front Recharge

The term "mountain front recharge" is frequently used to describe the contribution of water from surrounding mountains to groundwater recharge in adjacent basins, which occurs along the mountain front. It was assumed that areal recharge that occurs in the mountainous portion of the subbasins eventually becomes mountain front recharge. Therefore, the SCS curve method was used initially to estimate areal recharge in these mountains and applied as mountain front recharge. This estimated value was then adjusted per the recommendation of the TAC.

Streambed Percolation

The Arroyo Grande and Los Berros Creeks are located within the active model domain of the Phase 1B Model[1]. Streambed percolation from these creeks was simulated using the Streamflow Routing Package. The Streamflow Routing Package applies recharge to stream cells that are sequentially numbered in the downstream direction. Model input for the routing package includes stream inflow, stream channel geometry, and streambed conductance.

Return Flow from Municipal Use

Return flow refers to the amount of water that returns to the aquifer after application of water to the land surface in the form of irrigation, or from leaks in water and sewer lines. This includes the use of both groundwater and imported water. Annual return flows from municipal water use was estimated by local agencies and modified per TAC recommendations. Recharge from septic system returns was assumed to be negligible.

Return Flow from Agricultural Use

Agricultural return flow from the irrigation of crops is dependent on irrigation efficiencies and soil type, which vary spatially, by crop type, and through time. Applied water in excess of crop demand as a result of inefficiencies in the irrigation system was assumed to return to the aquifer.

1 Oso Flaco Creek located in the NMMA is mainly fed from agricultural runoff and affects local, alluvial and perched aquifers that were not modeled by the regional Phase 1B Model. Therefore, this creek was not simulated.

Return Flow from Golf Course Irrigation

Return flow in the Phase 1B Model area is also generated from irrigation of the Pismo Beach Golf Course, Monarch Dunes, Cypress Ridge, and Black Lake golf courses. All golf courses return flows were lumped with the municipal return flows except for the Pismo Beach Golf Course. Pumping for the Pismo Beach Golf Course was not available and was estimated by using standard crop evapotranspiration rates for a grassy area.

Artificial Recharge

Artificial groundwater recharge in the Phase 1B model area is achieved through the spreading of stormwater and treated wastewater from the City of Pismo Beach and SSLOCSD WWTPs. Discharge requirements for the Nipomo Community Services District Southland Wastewater Treatment Facility (Order No. R3-2012-0003; Regional Board, 2012) found that spreading in the WWTP infiltration ponds, located in the northern portion of the NMMA, did not reach the water table due to the presence of very low permeability materials in the subsurface. As such, flows from Southland were not modeled.

Underflow Inflow

The southern boundary of the active model area intersects the Santa Maria River Valley Groundwater Basin along the Santa Maria River. This boundary is represented by a GHB to simulate groundwater underflow across the boundary and percolation from the Santa Maria River. Subsurface inflow is also accounted for in the Arroyo Grande Creek using a GHB.

2.1.2 Groundwater Outflow Terms

Municipal and Small Purveyor Pumping

Municipal pumping records were obtained from public and private water agencies operating within the model area. Pumping for each well was assigned to model layers based on screen interval information. For wells screened in multiple aquifers, a portion of the well's total production was apportioned to each aquifer according to the screened interval of the well and the transmissivity.

Agricultural Pumping

Unlike municipal pumping which is directly measured from metered water wells, agricultural pumping is largely unmetered and was therefore estimated indirectly. Various studies in the area have estimated agricultural pumping in the past using assorted techniques. Type curves for different crop types were established for each management zone. These curves illustrate the relationship between agricultural water demand (or the evapotranspiration of applied water) and annual precipitation, and were used along with assumed irrigation efficiencies to develop estimates of agricultural pumping (refer to GEOSCIENCE 2018b for additional information). Based on recommendations from the TAC and available screened intervals for a handful of agricultural wells, the agricultural pumping was distributed between layers according to an area-specific scheme.

Golf Course Pumping

Pumping for the Pismo Beach Golf Course was not available and was estimated by using standard crop evapotranspiration rates for a grassy area.

Underflow Outflow to the Ocean and Offshore Aquifers

While water level contours indicate that the primary groundwater flow direction is towards the ocean, a localized reversal of groundwater gradients from groundwater pumping can cause seawater intrusion. Underflow outflow to the ocean proper is anticipated to occur only through the interface of model layer 2 with the coast. Underflow across the coastal line in the other model layers is assumed to continue through the aquifer offshore. As documented in the Santa Maria Valley Characterization Study (FUGRO, 2015) and by DWR (1979), this offshore aquifer extends upwards of 10 miles from the shoreline. Underflow inflow and outflow to the ocean and offshore aquifer represent model-calculated values.

2.2 Model Calibration

The method of calibration used for the Phase 1B Model was the industry standard “history matching” technique, which involves adjusting model parameters to produce the best-fit between simulated and observed groundwater system responses. During the process of calibration, model parameters are adjusted using reasonable anticipated values until model-generated water levels and concentrations match historical observations. Parameters that were adjusted during model calibration include:

- Horizontal and vertical hydraulic conductivity,
- Storativity,
- Streambed conductance,
- Mountain front recharge,
- HFB conductance,
- Dispersivity, and
- Effective porosity.

The CCB Phase 1B Model calibration consisted of:

- Steady-state flow calibration (1977), and
- Transient flow and solute transport calibration from 1977 through 2016 using monthly stress periods.

In addition, the model was calibrated in a multi-step process involving external review of initial calibration results by the TAC and implementation of revisions to the model as part of subsequent calibration efforts. From a calibration quality perspective, it was decided to prioritize a reflection of local understanding of the regional area over matching localized observations.

2.2.1 Flow Model Calibration

Steady-state and transient flow calibration statistics are summarized in the following table.

Table 2-2. CCB Phase 1B Groundwater Flow Model Calibration Statistics

Statistic	Steady-State Calibration (1977)	Transient Calibration (1977-2016)	
		All Target Wells	Key Wells*
Mean Residual[1]	5.7 ft	2.2 ft	-1.1 ft
Absolute Mean Residual	19.8 ft	16.4 ft	9.6 ft
Minimum Residual	-29.3 ft	-22.5 ft	-35.7 ft
Maximum Residual	76.9 ft	97.2 ft	61.8 ft
Standard Deviation of Residual	19.1 ft	16.4 ft	9.6 ft
Relative Error[2]	6.4 %	8.6%	8.5 %

* Given the uncertainty in many measured water levels, transient model calibration focused on a second set of target wells composed of key wells that were considered more reliable by both the NCMA and NMMA.

[1] Residual = measured head less predicted head

[2] Relative Error = standard deviation of the residuals divided by the observed head range

As shown in Figures ES-7 and ES-8, the water level residuals for the transient calibration are mainly clustered around a straight line. The calibration is further supported by a relative error 8.6% for all target wells and 8.5% for key wells, which is below the recommended error of 10% (Environmental Simulations, Inc., 1999). While the relative error is similar using all target wells and just the key wells, the standard deviation of the residual is significantly lower when only considering key wells. Some of the higher residuals are located at target wells located north of the Santa Maria River Fault. At the recommendation of the TAC, less emphasis was placed on calibrating the Phase 1B Model in this area because there is still quite a bit of uncertainty associated with the hydrogeology in this area. It is not clear if these aquifers are continuous with regional aquifers. This should be addressed through future generations of the model.

Figure ES-9 shows a histogram of transient calibration water level residuals of 7,280 water level measurements from the 136 wells, and Figure ES-10 shows the spatial distribution of residuals (for all target wells) for the last 10 years of the model calibration period (average of 2007 through 2016). In addition, the distribution of water level residuals for all target wells through time was plotted on Figure ES-11. Figure ES-11 shows that the average water level residual is randomly distributed over the calibration period and is not particularly correlated with wet or dry periods.

Representative hydrographs for the Recent Alluvium/Young and Old Dune Sand, Paso Robles Formation, and Careaga Sand aquifers are shown on Figures ES-12 through ES-14, respectively, for the transient calibration run. In general, the patterns of the model-simulated and measured water levels are similar in that the model appears to capture the long- and short-term temporal trends in groundwater levels in most parts of the model area.

Summaries of the average annual water budgets for the NCMA, NMMA, and SMVMA from 1977 through 2016 are provided as Figures ES-15 through ES-17. An annual groundwater balance for the NCMA is also provided as attached Table ES-1. As shown in the figures, the calibration period shows a higher annual total outflow than total inflow in each management area, resulting in an annual average change in groundwater storage of approximately -36 acre-ft/yr in the NCMA, -566 acre-ft/yr in the NMMA, and -511 acre-ft/yr in the SMVMA. This is generally evidenced by slightly declining water levels in much of the model area.

2.2.2 Variable Density Flow Calibration

The solute transport model relies on data from the groundwater flow model (e.g., seepage velocities and flow directions). The flow in and out of each model cell is read by SEAWAT and used to track concentrations of TDS. The solute transport model calibration process used available data to match model-simulated TDS concentrations against measured values. Wells screened in more than one layer were not used for calibration as their concentration would be a mix of various layers. Model parameters (i.e., effective porosity and dispersivity) were adjusted until a good match between measured and model-generated TDS concentrations were achieved. The 1977 initial conditions for TDS were based on measured concentrations or estimated from historical concentration trends.

A few assumptions were made to estimate TDS loads from the water budget components and boundaries. Because these loads are not known, they contribute to uncertainty in the TDS solute transport model. The initial concentration was estimated using very sparse data that were averaged both temporally and spatially, because most TDS concentration data did not go back as far as 1977. In addition, all the available data were aggregated by aquifer, yielding three basic distributions for the Alluvium/Dune Sand, the Paso Robles Formation, and the Careaga Sands.

Measured versus model-generated TDS concentrations through time for target wells along the coast and inland are shown on Figures ES-18 and ES-19, respectively. Calibration statistics used for water levels are not well suited for solute transport modeling. Therefore, the assessment of goodness of fit was done visually. The model did not capture the TDS spike observed in Fall 2009 due to the fact that the location of the saltwater-freshwater interface was unknown. An iterative procedure which tests various locations of the interface until a good match can be achieved could be implemented. However, the TAC agreed that such an approach would be time consuming and still have some associated uncertainty. A second phase will include a geophysical survey which will help identify the actual location of the saltwater-freshwater interface. This information will then be used to update and refine the model. In addition, even though the model did not predict the elevated TDS in Fall 2009, it predicted an increase of inflow from offshore aquifers during the period from 2004 through 2010 (Table ES-1). It is possible that the TDS spike is due to this inflow from offshore aquifers, assuming that the offshore portions of the aquifers have higher TDS concentrations but that inflow is not necessarily directly from the ocean. This shows that the model can be used to predict saltwater intrusion by quantifying the change in inflow from the ocean and the offshore portions of the aquifers.

2.3 Sensitivity Analysis

A sensitivity analysis was performed on the calibrated Phase 1B Model. The purpose of the sensitivity analysis is to assess the model input parameters which have the greatest effects on the model's simulation results. For this analysis, the model's sensitivity was evaluated after first increasing the value of model input parameters by 50 percent (relative to the calibrated input value) and then decreasing the value of model input parameters by 50 percent. The following input parameters were varied for this analysis using a systematic approach:

- Areal Recharge
- Specific Yield
- Specific Storage
- Horizontal Hydraulic Conductivity, and
- Vertical Hydraulic Conductivity.

A sensitivity run was also made simulating the Santa Maria River Fault as a non-impediment to flow in order to assess the effect this fault has on simulated water levels. In addition, an assessment was made of the accuracy of estimated agricultural pumping volumes throughout the model domain and calibration period. To do so, estimated agricultural pumping was varied by 20%. This percentage was chosen as it approximately represents the amount of uncertainty that might be expected from estimating unmetered agricultural pumping on a regional scale (Faunt, 2009).

The sensitivity analysis indicates that the model is most sensitive to the presence of the Santa Maria River Fault as a groundwater flow barrier, increases in areal recharge, and decreases in specific storage. The model is also relatively sensitive to increases in agricultural pumping, which is one of the flux terms with the greatest amount of uncertainty.

3.0 MODEL SCENARIO EVALUATION

Seven (7) predictive scenario runs were made using the calibrated Phase 1B Model to evaluate and predict how future pumping and recycled water injection activities will affect potential seawater intrusion and the reliability of groundwater supplies in the region. The main assumptions for these scenario runs are summarized in the table below and the following section. Each model scenario was run for a period of 40 years. It is important to note that these scenarios focused on injection and extraction activities in the NCMA, so this is the location where the greatest variation in flux terms occurred; fluxes in the NMMA and SMVMA remained fairly constant.

Table 3-1. Model Scenario Assumptions

Model Scenario	Hydrology	Groundwater Pumping			CCB Implementation
		Agricultural	NMMA	NCMA	
Baseline	Historical (1977-2016)	Based on 2016 Crop Distribution and Historical Rainfall	Average of Last 5 Years (2012-2016) (5,663 AFY)	Average of Last 5 Years for Municipal (1,080 AFY) and Small Purveyors	None
1	Historical (1977-2016)	Based on 2016 Crop Distribution and Historical Rainfall	Average of Last 5 Years (5,663 AFY)	Municipal Extraction of 2,500 AFY	None
2	Historical (1977-2016)	Based on 2016 Crop Distribution and Historical Rainfall	Average of Last 5 Years (5,663 AFY)	Municipal Extraction of 2,500 AFY	Phase 1 (900 AFY)
3	Historical (1977-2016)	Based on 2016 Crop Distribution and Historical Rainfall	Average of Last 5 Years (5,663 AFY)	Maximum NCMA Allocation (4,330 AFY)	None
4	Historical (1977-2016)	Based on 2016 Crop Distribution and Historical Rainfall	Average of Last 5 Years (5,663 AFY)	Maximum NCMA Allocation (4,330 AFY)	Phase 2 (3,500 AFY)
5	Climate Change (2030 and 2070 Projections)	Based on Climate Change Predictions of Rainfall	Average of Last 5 Years (5,663 AFY)	Average of Last 5 Years for Municipal (1,080 AFY) and Small Purveyors	None
6	Historical Hydrology with Predicted Sea Level Rise	Based on 2016 Crop Distribution and Historical Rainfall	Average of Last 5 Years (5,663 AFY)	Average of Last 5 Years for Municipal (1,080 AFY) and Small Purveyors	None

The scenarios summarized above in Table 3-1 were developed with specific purposes in mind. The Baseline scenario was used as a point of reference for comparing other scenario runs with altered fluxes to the status quo. Scenarios 1 and 2 represent predicted effects without and with implementation of Phase 1 of the CCB, while Scenarios 3 and 4 represent predicted effects under maximum allocation pumping without and with Phase 2 of the CCB. The purpose of Scenario 5 is to identify potential impacts of climate change (compared to Baseline) and Scenario 6 helps identify potential impacts of sea level rise. Specific details associated with these scenario runs are discussed in the following sections.

3.1 Scenario Assumptions

Most scenarios are based on the baseline scenario, hence the assumptions used for the baseline are common to most of the subsequent scenarios. Specific deviations from the assumptions used for the baseline scenario run are specified for each scenario. Additional detail on modeling assumptions is provided in TM-4: Model Scenario Evaluation (GEOSCIENCE, 2019b). The baseline scenario is meant to represent a stable state of the NCMA where the groundwater resources can be utilized at a rate that would minimize the risk of seawater intrusion and excessive depletion of the groundwater resource.

The period from 1977 through 2016, which also represents the calibration period, was selected as the hydrologic base period for the scenario runs. As shown on Figure ES-20, this period includes wet, dry, and average hydrological conditions. For the purpose of the predictive runs, it is assumed that future land use will remain similar to current land use. Therefore, recharge terms dependent on the hydrologic base period, such as areal recharge from precipitation, mountain front recharge, and the stormwater infiltration component of artificial recharge, are the same as that used for model calibration. Other recharge and discharge assumptions for the baseline scenario are as follows:

- Wastewater infiltration: assumed to be the average of the last five years (i.e., 2012 through 2016).
- Return flows: based on assumed pumping, according to methodology used for calibration.
- Municipal and small purveyor pumping: assumed to be the average of the last five years (i.e., 2012 through 2016). The monthly municipal pumping distribution is shown in Table ES-2.
- Agricultural pumping: estimated using calibration methodology and 2016 crop distributions.

Initial water levels for the predictive model scenarios represent the water levels at the end of the calibration period (December 2016). For the GHBs in the model, the general water level trends exhibited during model calibration were maintained in the predictive scenarios but the heads at the end of the calibration period were used as the beginning head for the scenario GHBs.

3.1.1 CCB Phase 1 – Scenarios 1 & 2

Scenarios 1 and 2 represent predicted effects without and with implementation of Phase 1 of the CCB, respectively. The implementation of Phase 1 of the CCB in Scenario 2 consisted of five coastal wells (IW-1, IW-2A, IW-3, IW-4, and IW-5A) injecting a total of 900 AFY evenly distributed across all five wells. The location of these wells is shown on Figure ES-21. All five wells are screened in model layers 6, 7, and 8, which represent the Lower Paso Robles and the Upper Careaga Sand.

Municipal pumping in the NCMA under Scenario 1 and 2 conditions increased from 1,080 AFY under Baseline conditions to 2,500 AFY. This pumping was distributed based on well capacity and prior pumping record ratios.

3.1.2 CCB Phase 2 – Scenarios 3 & 4

Scenarios 3 and 4 represent predicted effects without and with implementation of Phase 2 of the CCB, respectively. The implementation of Phase 2 of the CCB in Scenario 4 consisted of seven coastal wells injecting a total of 3,500 AFY evenly distributed across all seven wells. The location of these wells is also shown on Figure ES-21. The five wells used for Phase 1 are screened in model layers 6, 8, and 8 (Lower Paso Robles and the Upper Careaga Sand) while two wells (IW-2B and IW-5B) are screened in model layer 10 (Lower Careaga Sand).

Municipal pumping in the NCMA under Scenario 3 and 4 conditions increased from 1,080 AFY under Baseline conditions to maximum allotted pumping for the municipal agencies – totaling 4,330 AFY. Pumping was distributed based on well capacity and prior pumping record ratios. Average demand for the last five years (2012 through 2016) was assumed to represent future demand. The portion of the demand not met by the maximum allocated pumping was assumed to come from imported water.

3.1.3 Climate Change – Scenario 5

Scenario 5 identifies potential impacts of climate change, compared to baseline conditions, to evaluate whether climate change would yield significant differences compared to approaches using historical hydrology. Climate change assumptions were based on the approach presented in the California Department of Water Resources (DWR) Guidance Document for Climate Change Data Use During Groundwater Sustainability Plan Development (2018).

Using this approach, annual and monthly DWR change factors for rainfall, potential evapotranspiration, and stream flow were applied to historical hydrology. Recharge and discharge terms, including areal recharge from precipitation, artificial recharge from stormwater infiltration, and agricultural pumping and return flows, were recomputed and updated based on the revised hydrology under climate change conditions. The remaining flux terms were kept the same as those used for the Baseline scenario.

3.1.4 Sea Level Rise – Scenario 6

Impacts from the potential rise in future sea level were specifically evaluated with Scenario 6. Projections of sea level rise presented in the DWR climate change document (2018) were also used for this analysis. According to sea level rise estimates by the National Research Council (NRC), DWR used sea level rise projections of 15 and 45 centimeters for the 2030 and 2070 climate change datasets. The flux terms used for Scenario 6 are identical to those used for the Baseline scenario, with the exception of the GHB at the ocean. This GHB was modified to match the projected 2030 and 2070 sea levels. Results from scenario runs under 2030 and 2070 sea level conditions were then aggregated and compared to the Baseline scenario.

3.2 Predictive Model Scenario Results

After the predictive scenario runs were performed using the calibrated Phase 1B Model, comparisons were made between the results from the Baseline scenario run and Scenarios 1 through 6 in order to evaluate the impacts from pumping, CCB injection, climate change, sea level rise, or combinations thereof. One of the main objectives of future pumping and injection operations in the NCMA is to minimize seawater intrusion, or the net flow from the ocean and offshore aquifers. In order to evaluate the scenario results in light of this objective, a multicriteria evaluation approach was used. This approach includes evaluating changes in groundwater levels, net inflow across the shoreline from offshore, groundwater budgets, and Deep Well Indexes.

The NCMA Deep Well Index, which takes into account three deep wells in the NCMA (see Figure ES-22), can be used as a general indicator for when the possibility of seawater intrusion increases. Based on historical observed instances of seawater intrusion (in 2009), a Deep Well Index threshold of 7.5 ft was developed. If the Deep Well Index is above this threshold, a generally seaward flux at the coast is maintained for most layers (especially layers 6 and 8) – therefore limiting or preventing seawater intrusion.

A summary of the water budgets for the NCMA was compiled in order to assess the potential impacts that each predictive scenario may have on underflow inflow from the ocean and offshore aquifers as well as changes in groundwater storage. The difference between the total inflow and total outflow equals the change in groundwater storage. Additional analysis, including the net inflow across the shoreline (both north of Arroyo Grande Creek and south of Arroyo Grande Creek), is presented in TM-4: Model Scenario Evaluation (GEOSCIENCE, 2019b).

Scenario results are summarized in the following table.

Table 3-2. Summary of Scenario Effects in the NCMA

Scenario	Description	Effect
Baseline	NCMA municipal pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016)	• Minimal seawater intrusion potential. • Deep Well Index fluctuates above and below threshold of 7.5 ft (Figure ES-23). • Groundwater flow is generally seaward. • Groundwater storage decreases by an average of 53 AFY (Figure ES-24, Table ES-3).
1	NCMA municipal pumping of 2,500 AFY with historical hydrology (1977-2016)	• Significant seawater intrusion potential. • Deep Well Index falls below threshold for majority of simulation period (Figure ES-25). • Inland flow across the shoreline is seen in model layers 6, 8, and 10. • Groundwater storage decreases by an average of 98 AFY (Figure ES-26, Table ES-4).
2	NCMA municipal pumping of 2,500 AFY with historical hydrology (1977-2016) and CCB Phase 1 injection of 900 AFY in 5 injection wells	• Seawater intrusion potential minimized with CCB operations. • Deep Well Index remains above threshold for the duration of the simulation period (Figure ES-27). • Very little inflow across the shoreline north and south of Arroyo Grande Creek. • Groundwater storage decreases by an average of 58 AFY (Figure ES-26, Table ES-5).
3	NCMA municipal pumping maximum allocation (4,330 AFY) with historical hydrology (1977-2016)	• High potential for seawater intrusion. • Deep Well Index remains well below the threshold for the duration of the simulation period (Figure ES-28). • Net underflow to offshore aquifers is reversed. • Groundwater storage decreases by an average of 195 AFY (Figure ES-29, Table ES-6).
4	NCMA municipal pumping maximum allocation (4,330 AFY) with historical hydrology (1977-2016) and CCB Phase 2 injection of 3,500 AFY in 7 injection wells	• Seawater intrusion potential minimized with CCB operations. • Deep Well Index remains above threshold for the duration of the simulation period (Figure ES-30). • Inland flow mitigated north of Arroyo Grande Creek. • Groundwater storage decreases by an average of 39 AFY (Figure ES-29, Table ES-7).

Scenario	Description	Effect
5	NCMA municipal pumping average of last 5 years (1,080 AFY) with climate change hydrologic conditions (applied to hydrologic years 1977-2016)	• Little difference from baseline conditions. • Deep Well Index fluctuates above and below threshold of 7.5 ft (Figure ES-31). • Net underflow across the shoreline shows slightly elevated inland flow in model layer 6 south of Arroyo Grande Creek during dry periods. • Groundwater storage decreases by an average of 71 AFY (Figure ES-32).
6	NCMA municipal pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016) and predicted sea level rise	• Little difference from baseline conditions. • Slight increase in Deep Well Index (Figure ES-33). • Net underflow across the shoreline shows slightly elevated inland flow in model layer 6 south of Arroyo Grande Creek during dry periods. • Groundwater storage decreases by an average of 40 AFY (Figure ES-34).

3.2.1 Particle Tracking for CCB Operations

Based on the predictive scenario results, Scenarios 2 and 4 were selected as possible candidates for CCB implementation. To help support the design and impact analysis, a particle tracking model was run to estimate the travel time from the injection sites to the nearest water supply wells. These results are shown on Figure ES-35 for Scenario 2 (representing NCMA municipal pumping of 2,500 AFY and CCB Phase 1 injection of 900 AFY), model layer 6, and on Figure ES-36 for Scenario 4 (representing NCMA municipal pumping at maximum allocation of 4,330 AFY and CCB Phase 2 injection of 3,500 AFY), model layer 6. All municipal wells are located at least one year of travel time away from the injected recycled water in Scenario 2. For Scenario 4, Pismo Well 23 is within 6-months travel time from the injected recycled water. However, it was communicated to GEOSCIENCE that Well 23 is having performance issues and likely will need to be replaced/relocated.

4.0 MODEL LIMITATIONS, UNCERTAINTY, AND FUTURE WORK

The CCB Phase 1B Groundwater Flow and Solute Transport Model is a useful tool for evaluating water levels and water quality of the aquifer systems. However, it is a simplified approximation of a complex geohydrologic system. The accuracy of a model prediction is dependent upon the assumptions used. A reliable groundwater model depends upon accurate and abundant sources of measured data and a satisfactory calibration and/or validation period. Often, in absence of complete or accurate records, model input represents estimated and/or averaged values (e.g., private pumping, agricultural pumping, mountain front recharge, etc.).

From a regional groundwater modeling perspective, it is expected that the model will not be able to match all wells in all parts of the model area due to local variability and uncertainty in observations. The goal of the model calibration was to match key wells with regional trends and improve the model over time through subsequent phases as more details are obtained and data becomes available. Therefore, specific uncertainties discussed in the model calibration TM (GEOSCIENCE, 2019a) should be investigated further in future versions of the regional model. Future use of an extended data set and calibration period should continue to improve the accuracy and reliability of the model.

In addition, estimates of recharge terms such as mountain front recharge and recharge from areal precipitation could be improved by integrating a precipitation runoff or surface water model component to the groundwater flow model. This would include subsurface flows in the unsaturated zone and more accurately reflect recharge both temporally and spatially, rather than using a lumped approach such as the SCS curve method utilized for this Phase 1B Model. However, given the lack of quality data for Arroyo Grande Creek discharge within the model domain, the calibration of an integrated surface water/ groundwater model would be difficult and carry a lot of uncertainty. Collection of good quality discharge data should therefore be conducted before such an effort is undertaken. Furthermore, additional review of geology and the creation of additional cross-sections, particularly in the northern NMMA where perched aquifer units and springs are present, could also help refine shallow layers and capture the complex hydrogeology in this area.

5.0 REFERENCES

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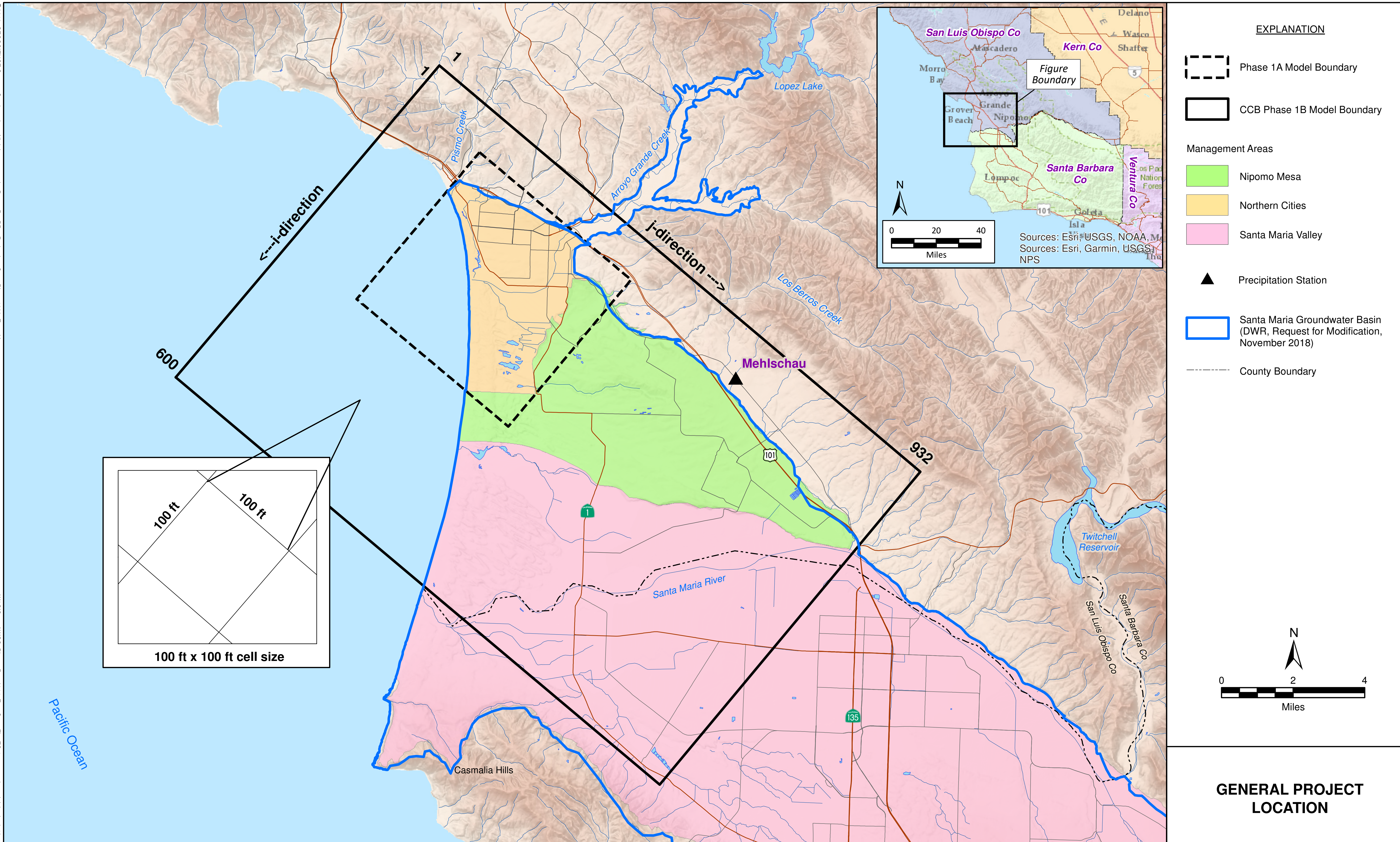
FIGURES



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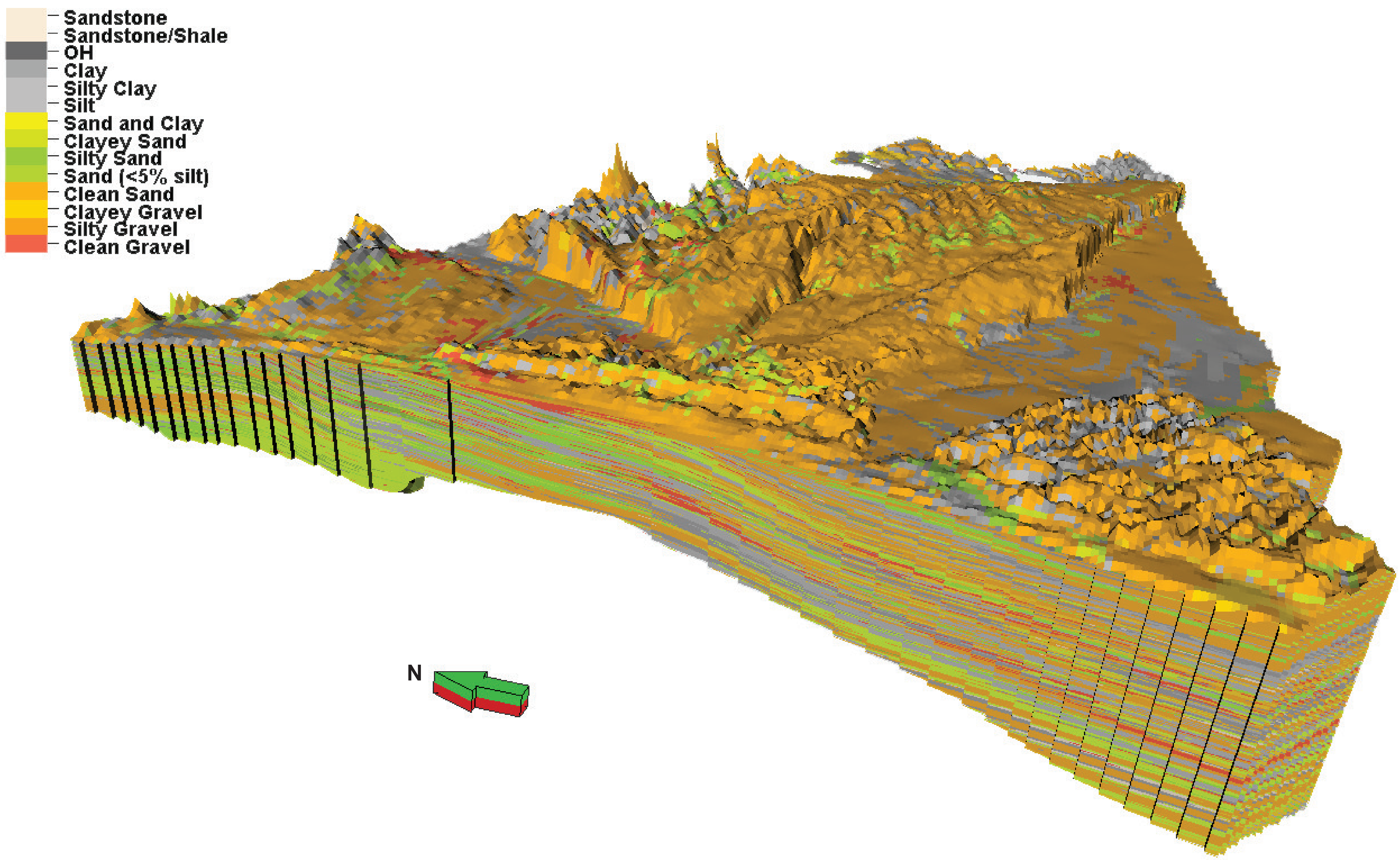
GENERAL PROJECT LOCATION

FIGURE ES-1

EXPLANATION



3-D VIEW OF THE
LITHOLOGIC MODEL

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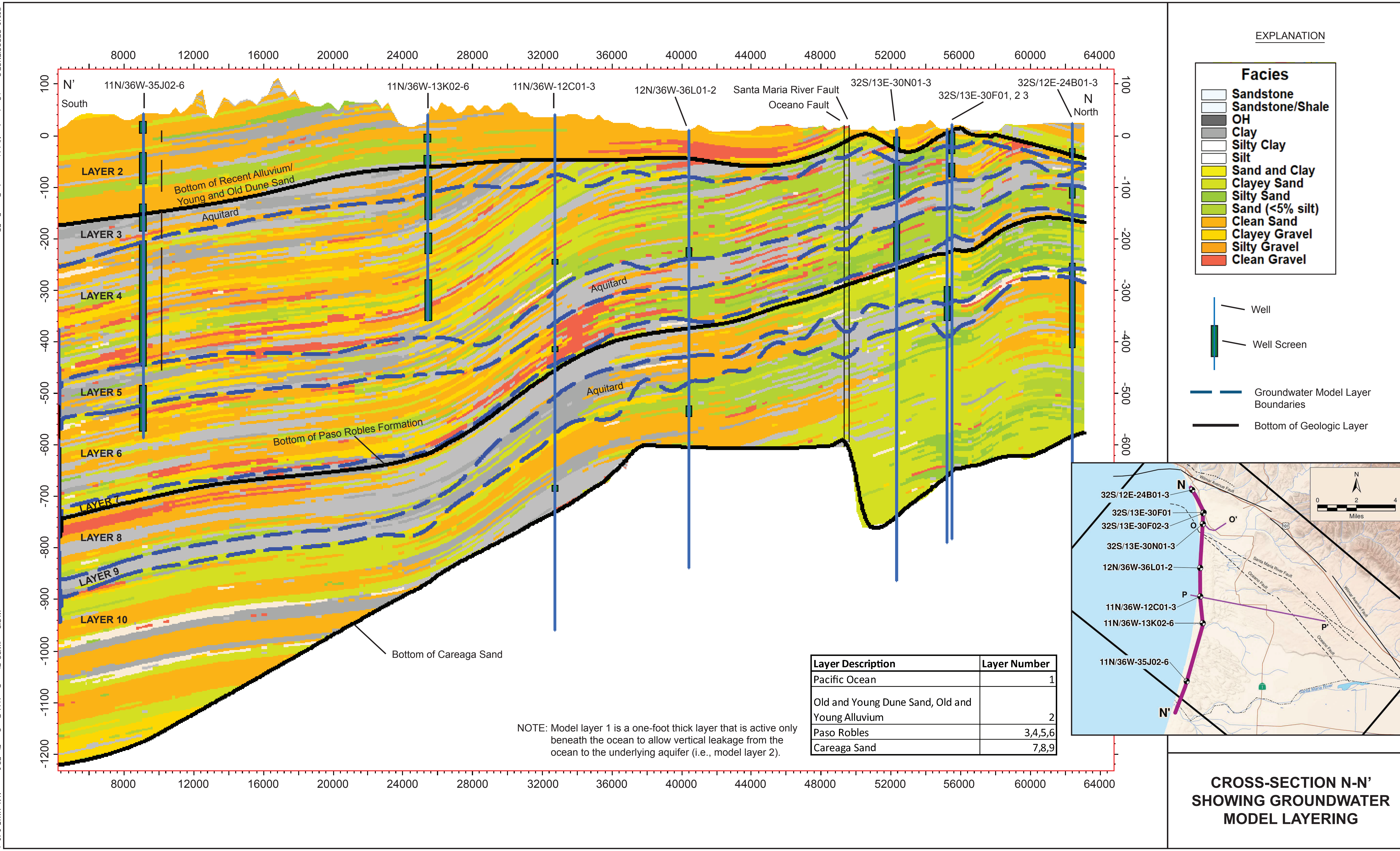
CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - EXECUTIVE SUMMARY

FIGURE ES-2

GEOSCIENCE



Layer Description	Layer Number
Pacific Ocean	1
Old and Young Dune Sand, Old and Young Alluvium	2
Paso Robles	3,4,5,6
Careaga Sand	7,8,9

NOTE: Model layer 1 is a one-foot thick layer that is active only beneath the ocean to allow vertical leakage from the ocean to the underlying aquifer (i.e., model layer 2).

CROSS-SECTION N-N' SHOWING GROUNDWATER MODEL LAYERING

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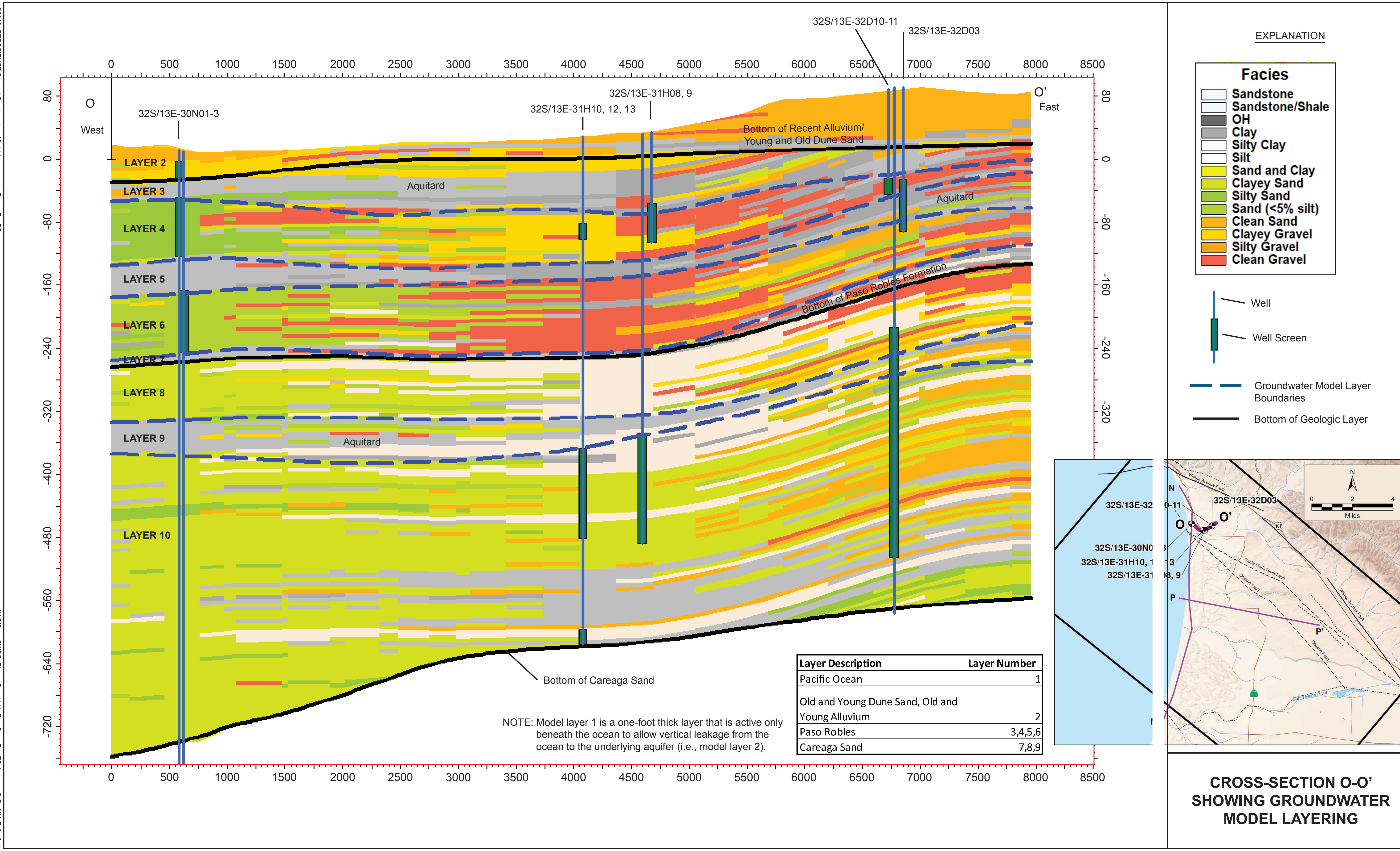
CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - EXECUTIVE SUMMARY

FIGURE ES-3

GEOSCIENCE



Layer Description	Layer Number
Pacific Ocean	1
Old and Young Dune Sand, Old and Young Alluvium	2
Paso Robles	3,4,5,6
Careaga Sand	7,8,9

CROSS-SECTION O-O' SHOWING GROUNDWATER MODEL LAYERING

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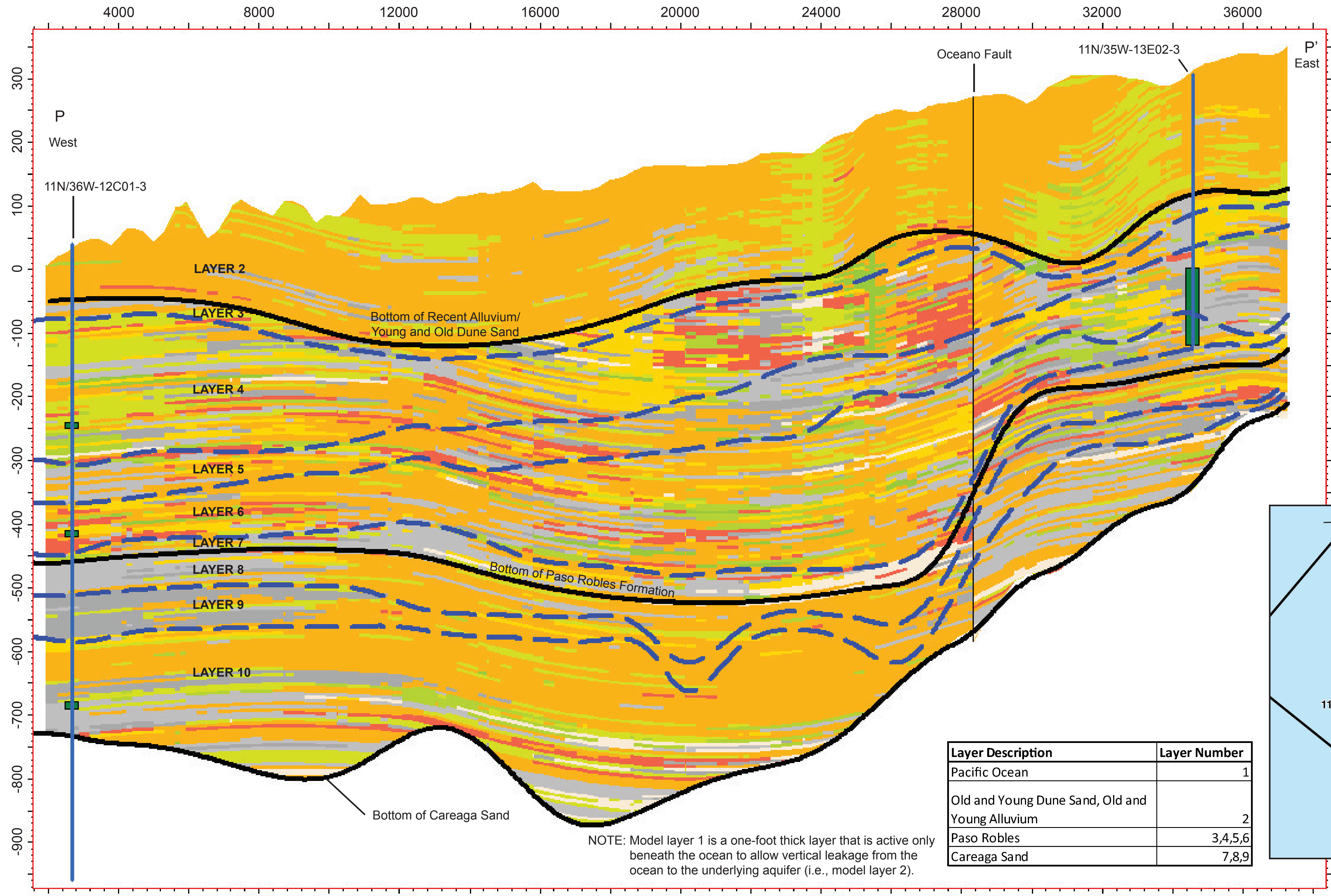
25-Nov-19

FIGURE ES-4

GEOSCIENCE



NOTE: Model layer 1 is a one-foot thick layer that is active only beneath the ocean to allow vertical leakage from the ocean to the underlying aquifer (i.e., model layer 2).

Layer Description	Layer Number
Pacific Ocean	1
Old and Young Dune Sand, Old and Young Alluvium	2
Paso Robles	3,4,5,6
Careaga Sand	7,8,9

EXPLANATION

Facies

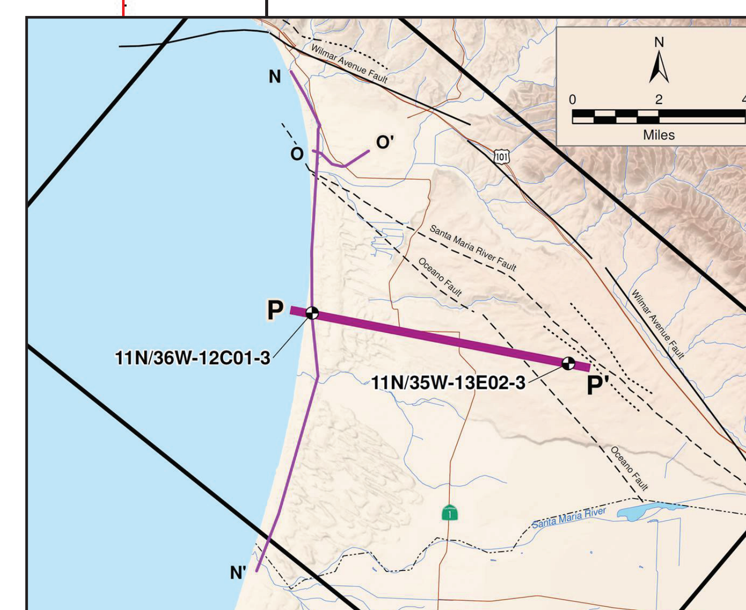
- Sandstone
- Sandstone/Shale
- OH
- Clay
- Silty Clay
- Silt
- Sand and Clay
- Clayey Sand
- Silty Sand
- Sand (<5% silt)
- Clean Sand
- Clayey Gravel
- Silty Gravel
- Clean Gravel

Well

Well Screen

Groundwater Model Layer Boundaries

Bottom of Geologic Layer



CROSS-SECTION P-P' SHOWING GROUNDWATER MODEL LAYERING

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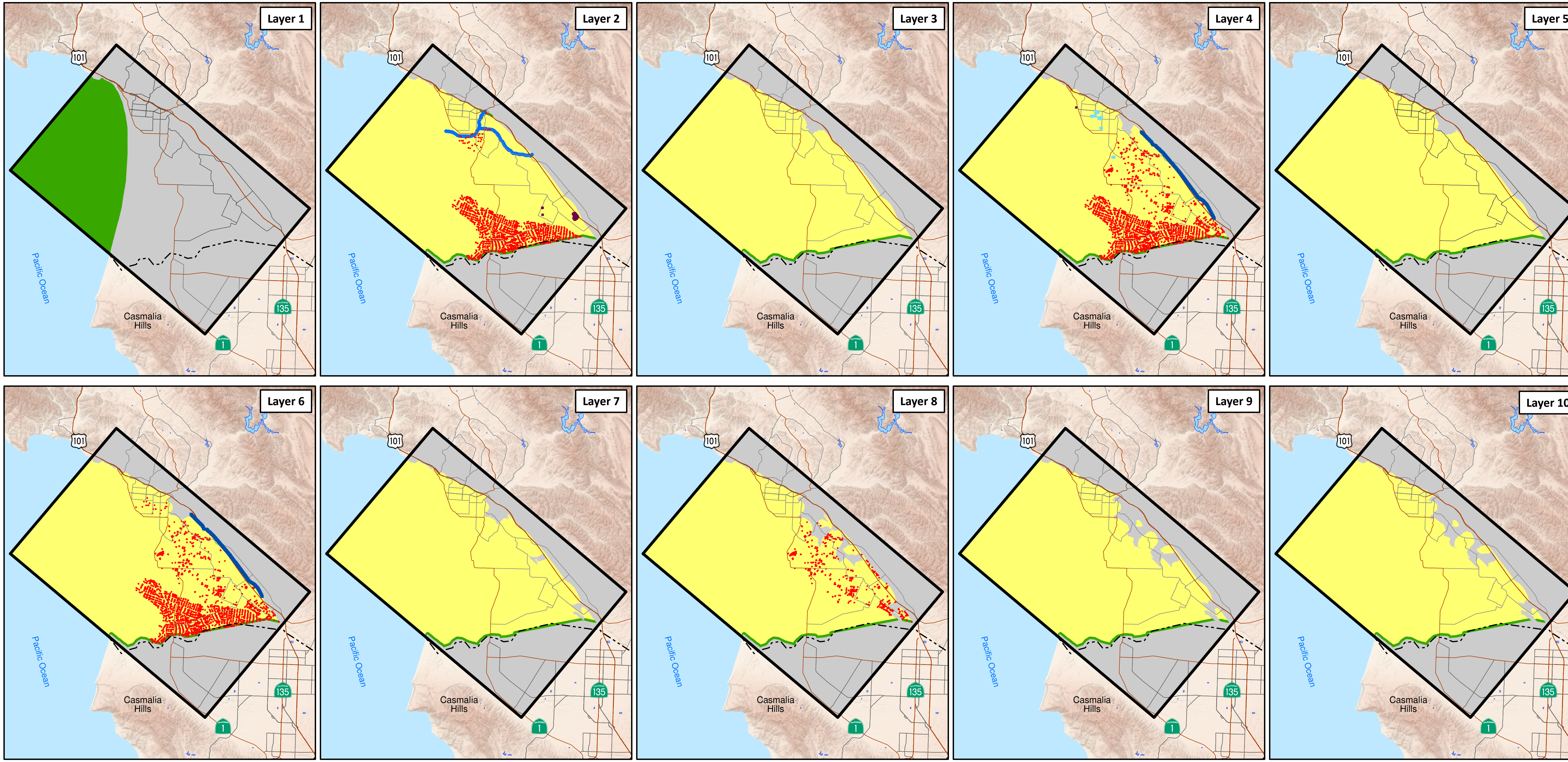

EXPLANATION

CCB Phase 1B Model Boundary

Active Model Cells

General-Head Boundary

No-Flow Cells

Stream

Well (Specified Flux)

Well Simulating Mountain Front Recharge

Agricultural Pumping Well

Well Simulating Stormwater Infiltration Pond

Well Simulating WWTP Infiltration Pond

N

0 5 10

Miles

BOUNDARY CONDITIONS

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FIGURE ES-6

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - EXECUTIVE SUMMARY

GEOSCIENCE

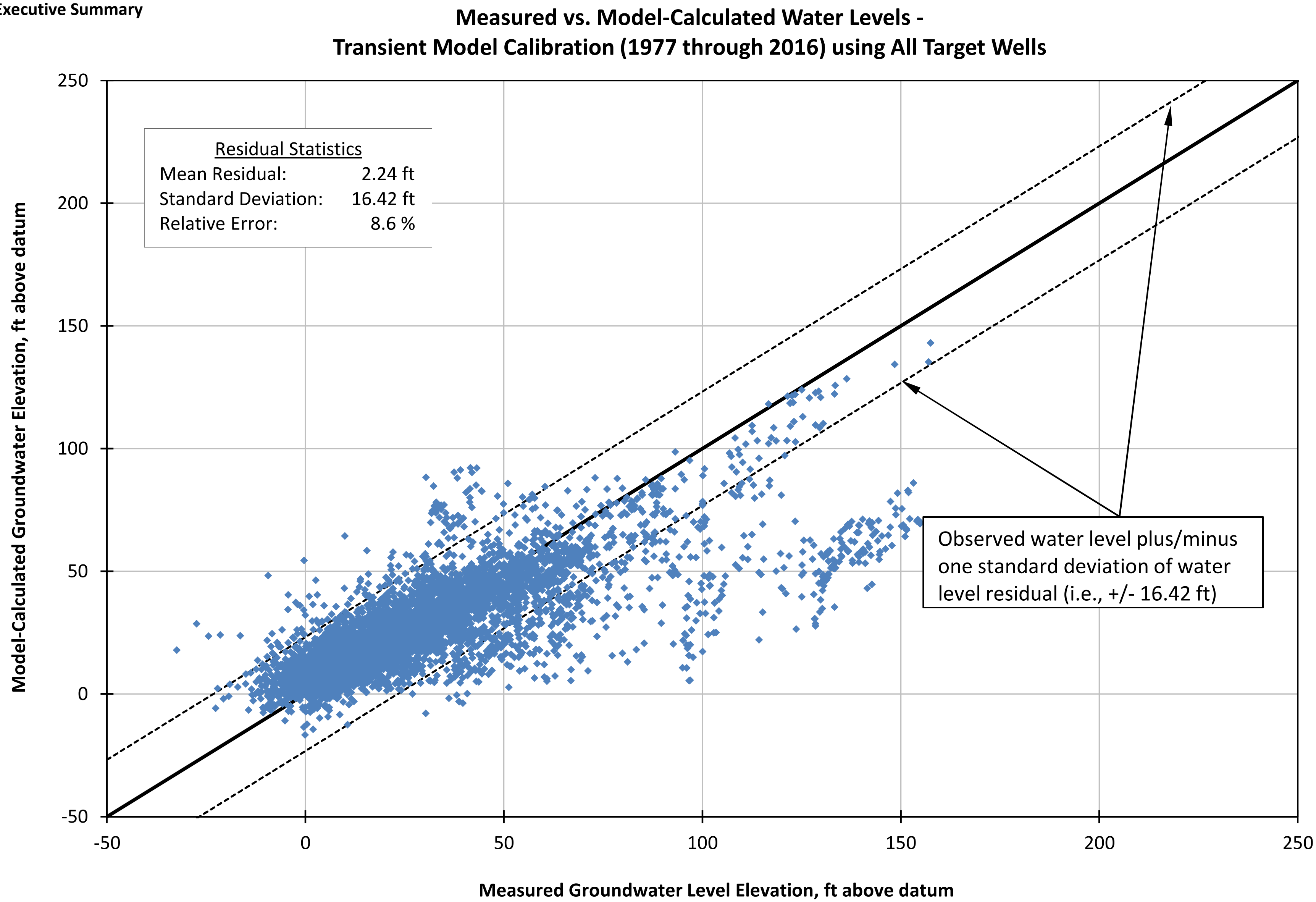

Measured vs. Model-Calculated Water Levels -
Transient Model Calibration (1977 through 2016) using All Target Wells
Residual Statistics
Mean Residual: 2.24 ft
Standard Deviation: 16.42 ft
Relative Error: 8.6 %
Observed water level plus/minus one standard deviation of water level residual (i.e., +/- 16.42 ft)
Model-Calculated Groundwater Elevation, ft above datum
Measured Groundwater Level Elevation, ft above datum
250
200
150
100
50
0
-50
-50
0
50
100
150
200
250

Figure ES-7

Measured vs. Model-Calculated Water Levels - Transient Model Calibration (1977 through 2016) using Key Wells

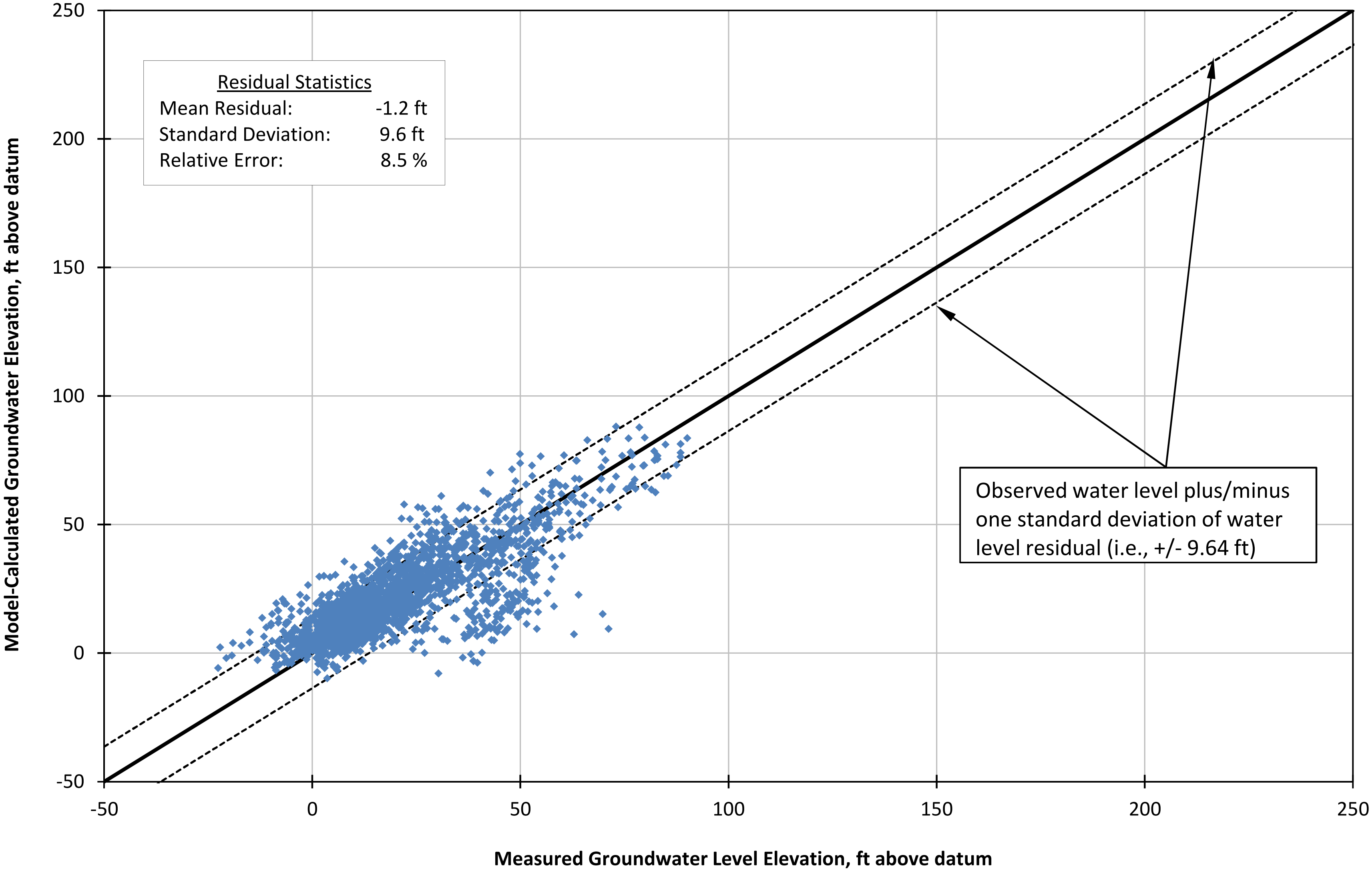


Figure ES-8

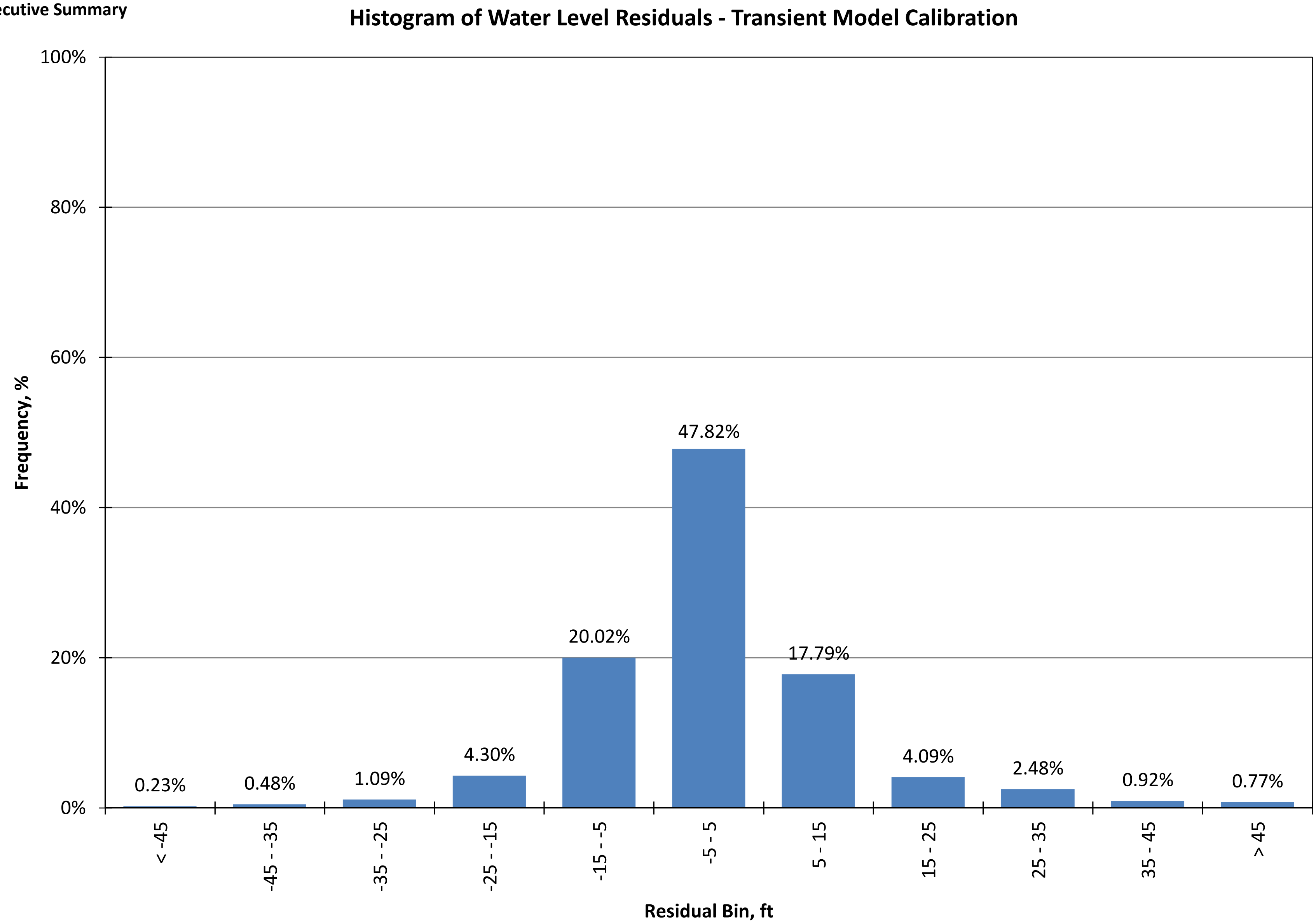
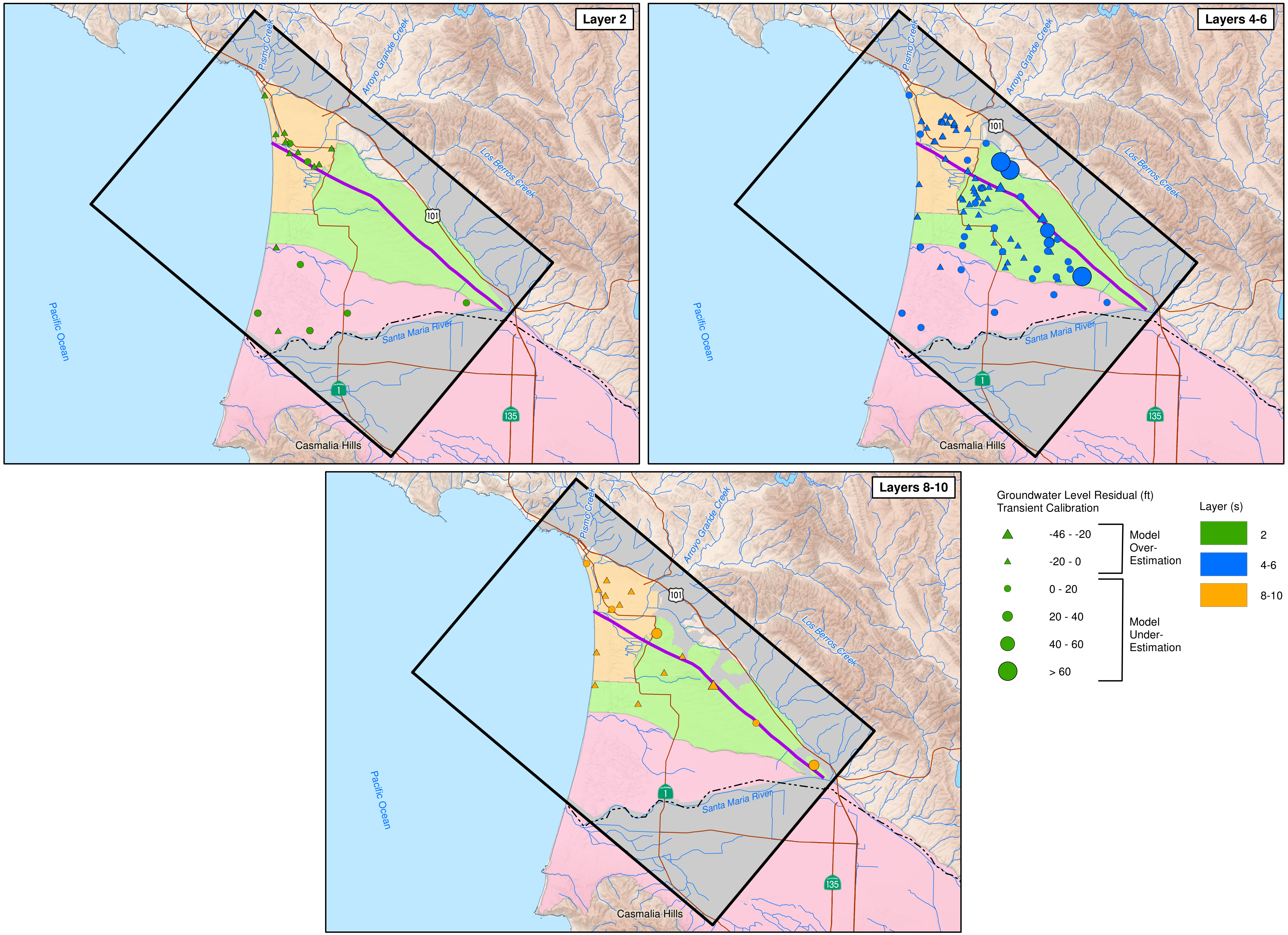

Histogram of Water Level Residuals - Transient Model Calibration
Frequency, %
100%
80%
60%
40%
20%
0%
0.23%
0.48%
1.09%
4.30%
20.02%
47.82%
17.79%
4.09%
2.48%
0.92%
0.77%
< -45
-45 - -35
-35 - -25
-25 - -15
-15 - -5
-5 - 5
5 - 15
15 - 25
25 - 35
35 - 45
> 45
Residual Bin, ft

Figure ES-9



SPATIAL DISTRIBUTION OF TRANSIENT CALIBRATION RESIDUALS (AVERAGE OF 2007 THROUGH 2016)

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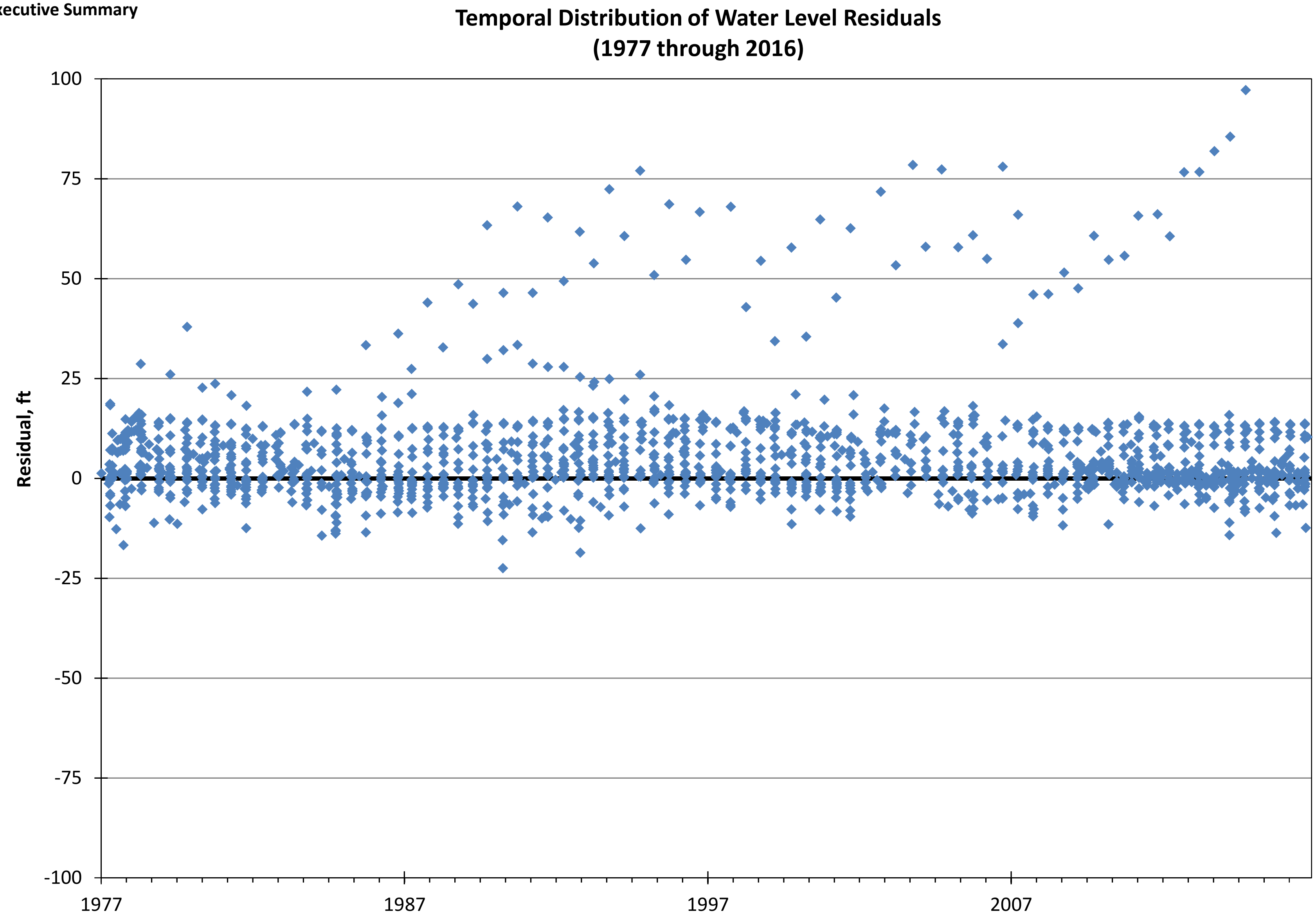
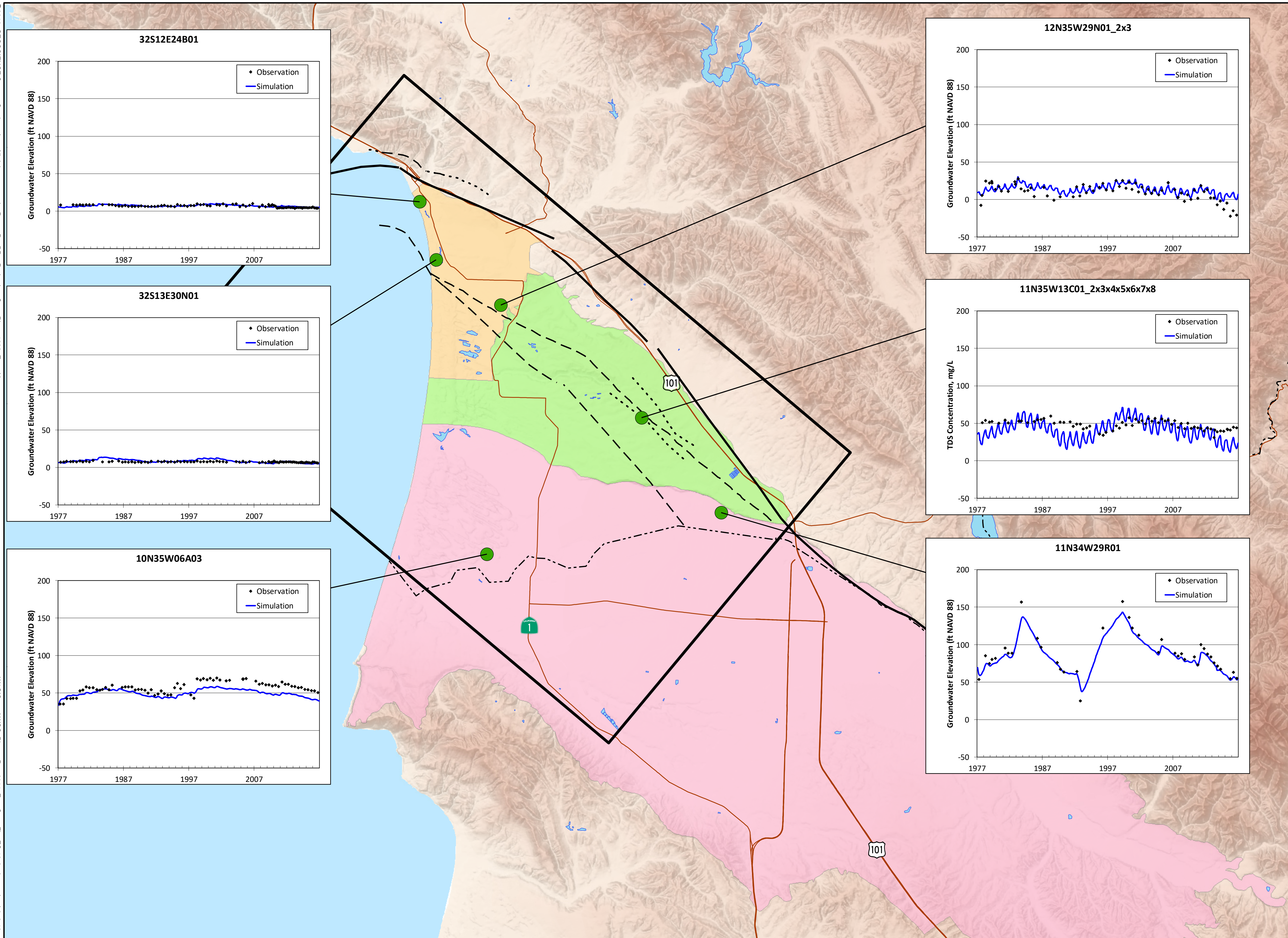

Temporal Distribution of Water Level Residuals
(1977 through 2016)
Residual, ft
100
75
50
25
0
-25
-50
-75
-100
1977
1987
1997
2007

Figure ES-11



EXPLANATION

CCB Phase 1B Model Boundary

Well Used for Hydrograph

Observed

Simulated

Management Areas

Nipomo Mesa

Northern Cities

Santa Maria Valley

County Boundary

N

0 3 6

Miles

SELECTED HYDROGRAPHS RECENT ALLUVIUM / YOUNG AND OLD DUNE SAND (MODEL LAYER 2)

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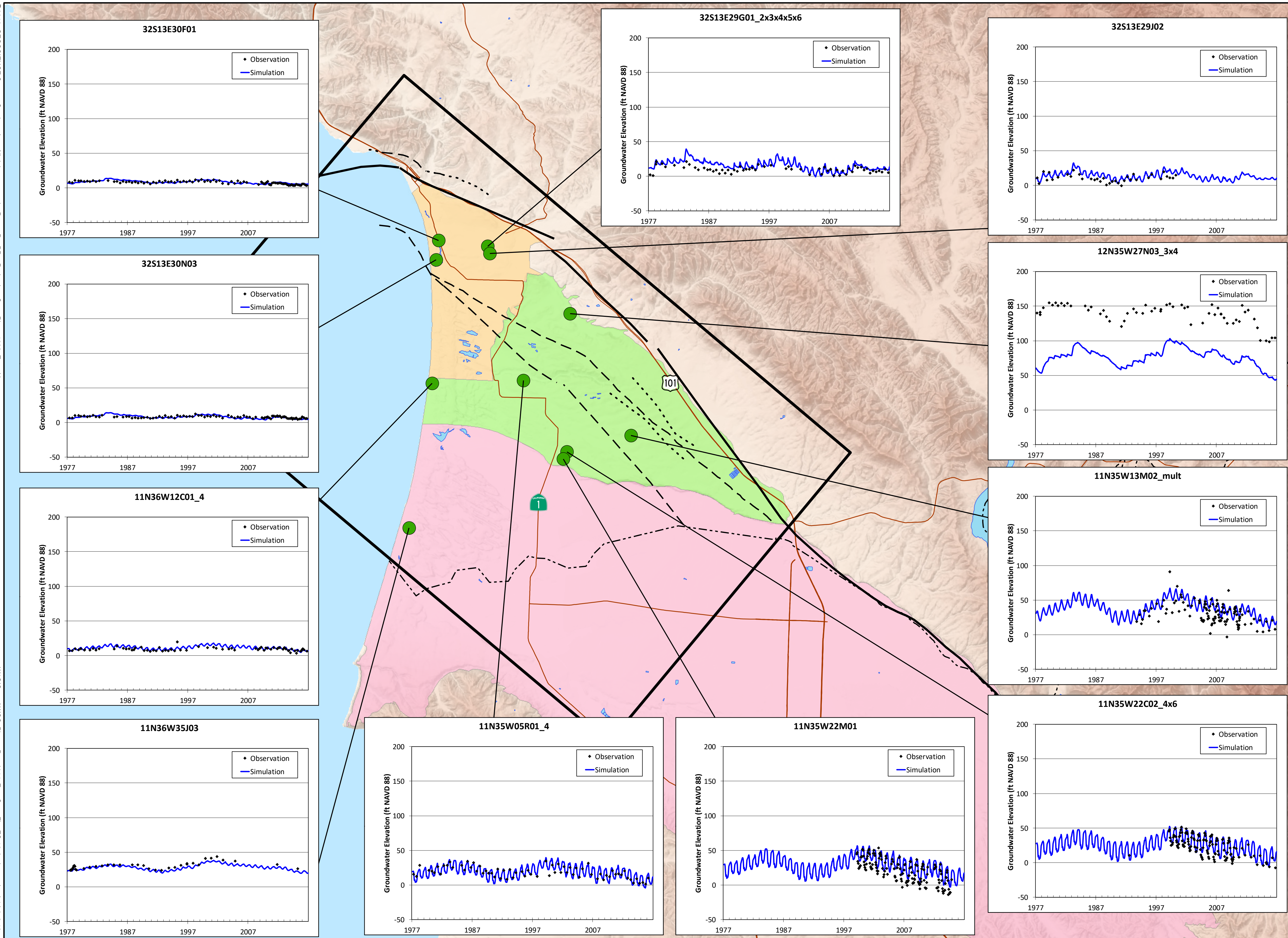
FIGURE ES-12

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - EXECUTIVE SUMMARY

GEOSCIENCE



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SELECTED HYDROGRAPHS PASO ROBLES FORMATION (MODEL LAYERS 4 THROUGH 6)

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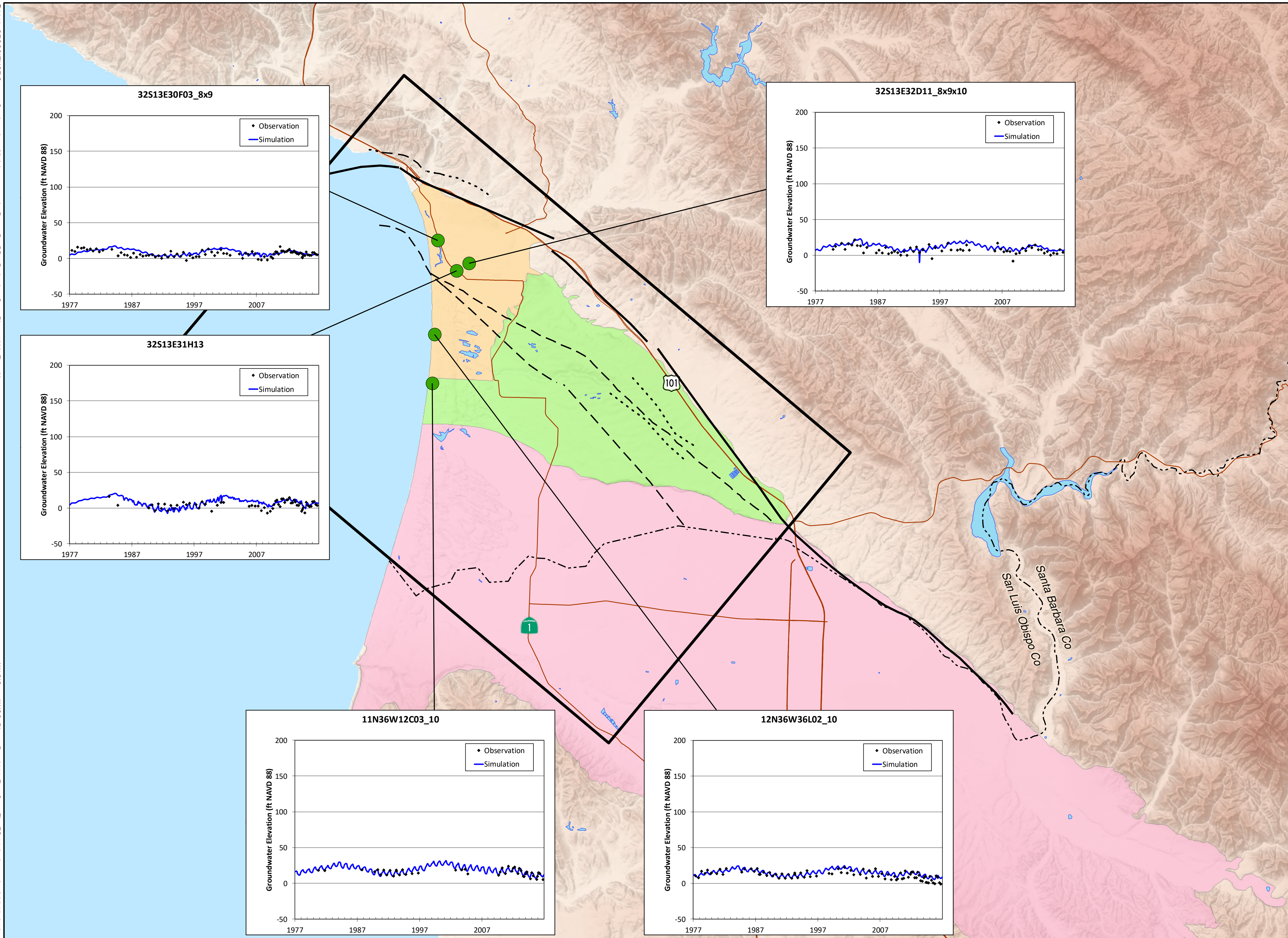
CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - EXECUTIVE SUMMARY

FIGURE ES-13

GEOSCIENCE



EXPLANATION

CCB Phase 1B Model Boundary

Well Used for Hydrograph

Observed

Simulated

Management Areas

Nipomo Mesa

Northern Cities

Santa Maria Valley

County Boundary

N

0 3 6

Miles

SELECTED HYDROGRAPHS CAREAGA SAND (MODEL LAYERS 8 THROUGH 10)

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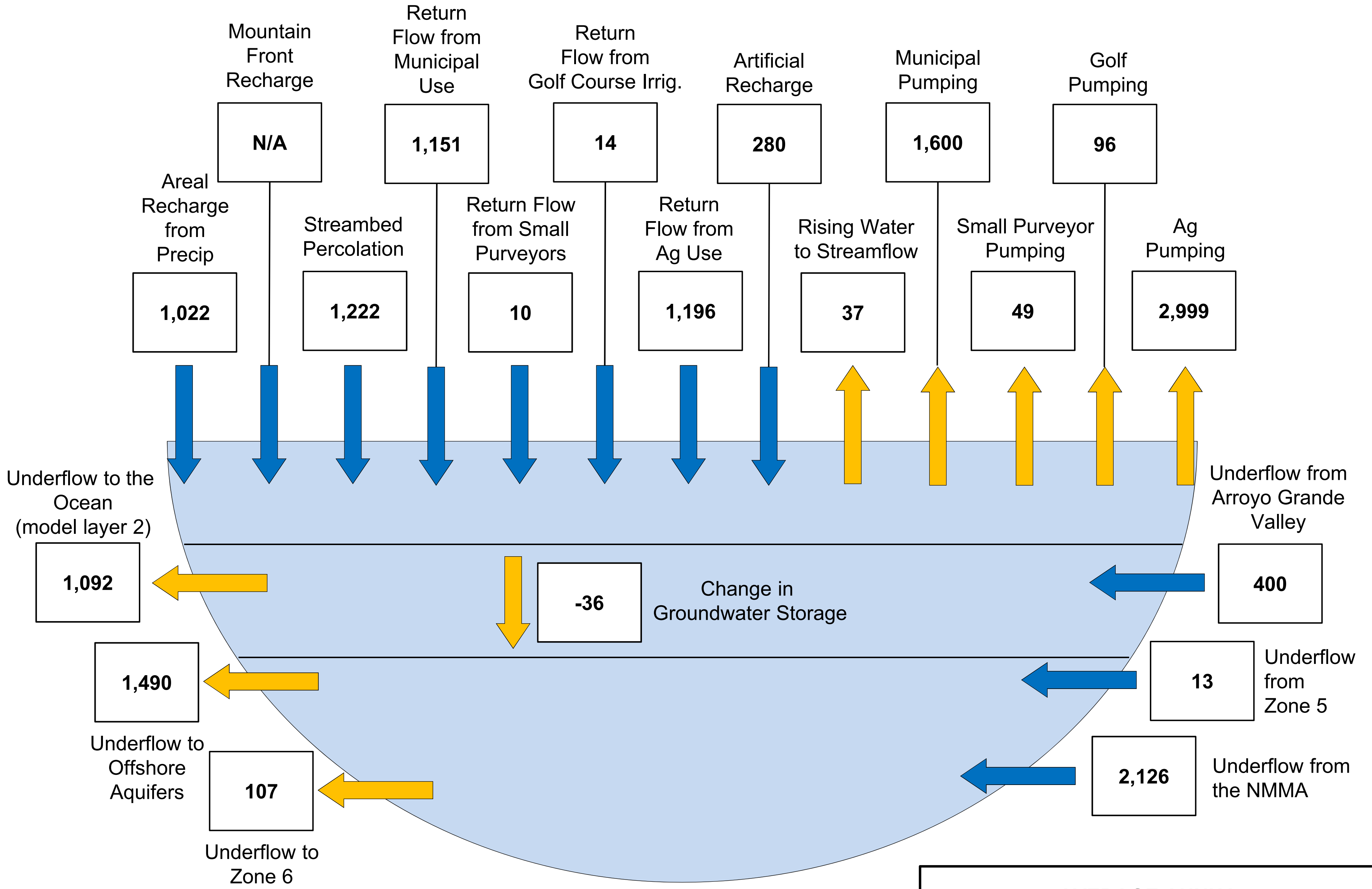
25-Nov-19

WATER SYSTEMS CONSULTING, INC.

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - EXECUTIVE SUMMARY

FIGURE ES-14

GEOSCIENCE



All values in acre-ft/yr

AVERAGE ANNUAL WATER BUDGETS (1977 THROUGH 2016) NCMA

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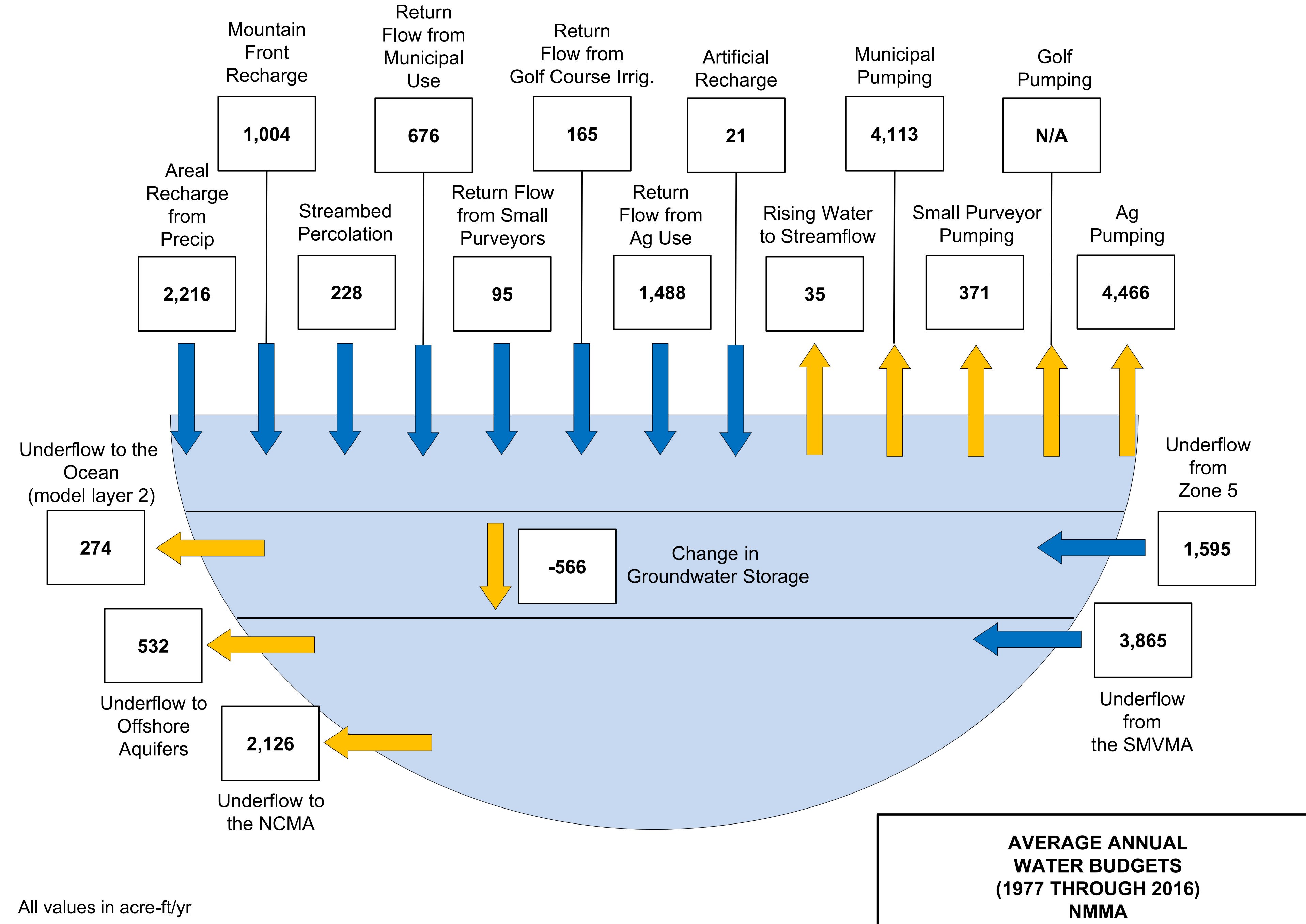

AVERAGE ANNUAL WATER BUDGETS (1977 THROUGH 2016) NMMA

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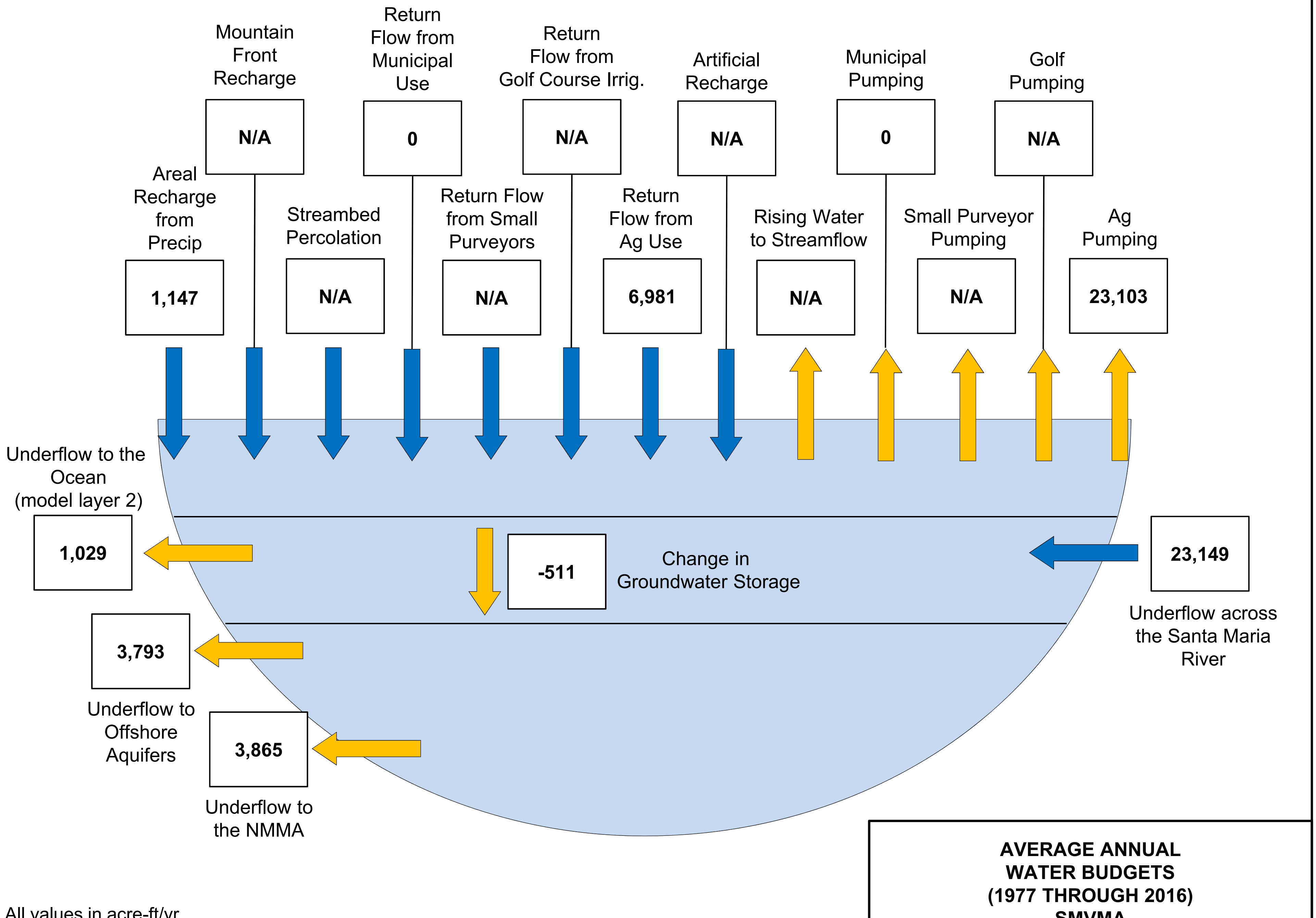
25-Nov-19



AVERAGE ANNUAL WATER BUDGETS (1977 THROUGH 2016) SMVMA

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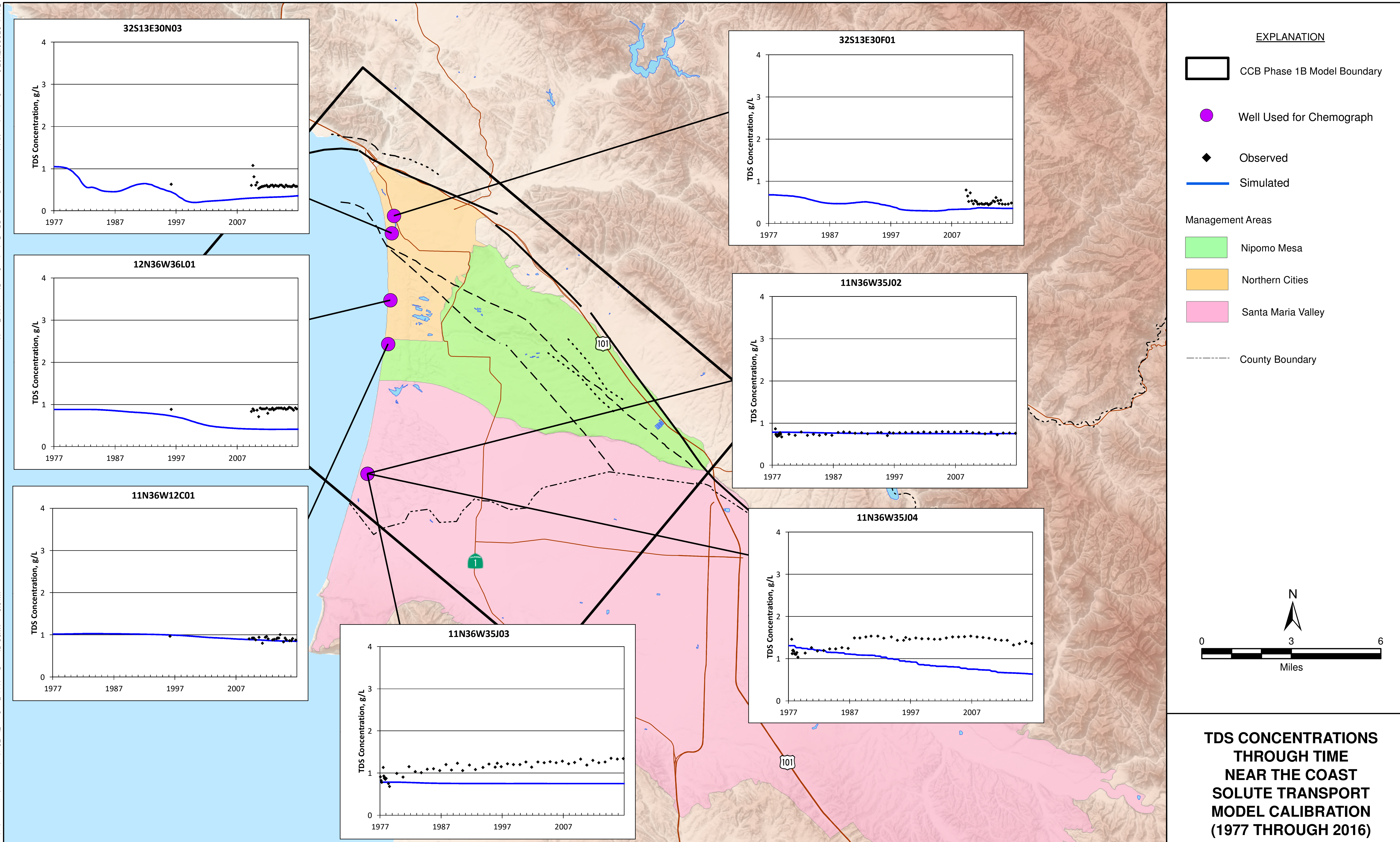
25-Nov-19



TDS CONCENTRATIONS THROUGH TIME NEAR THE COAST SOLUTE TRANSPORT MODEL CALIBRATION (1977 THROUGH 2016)

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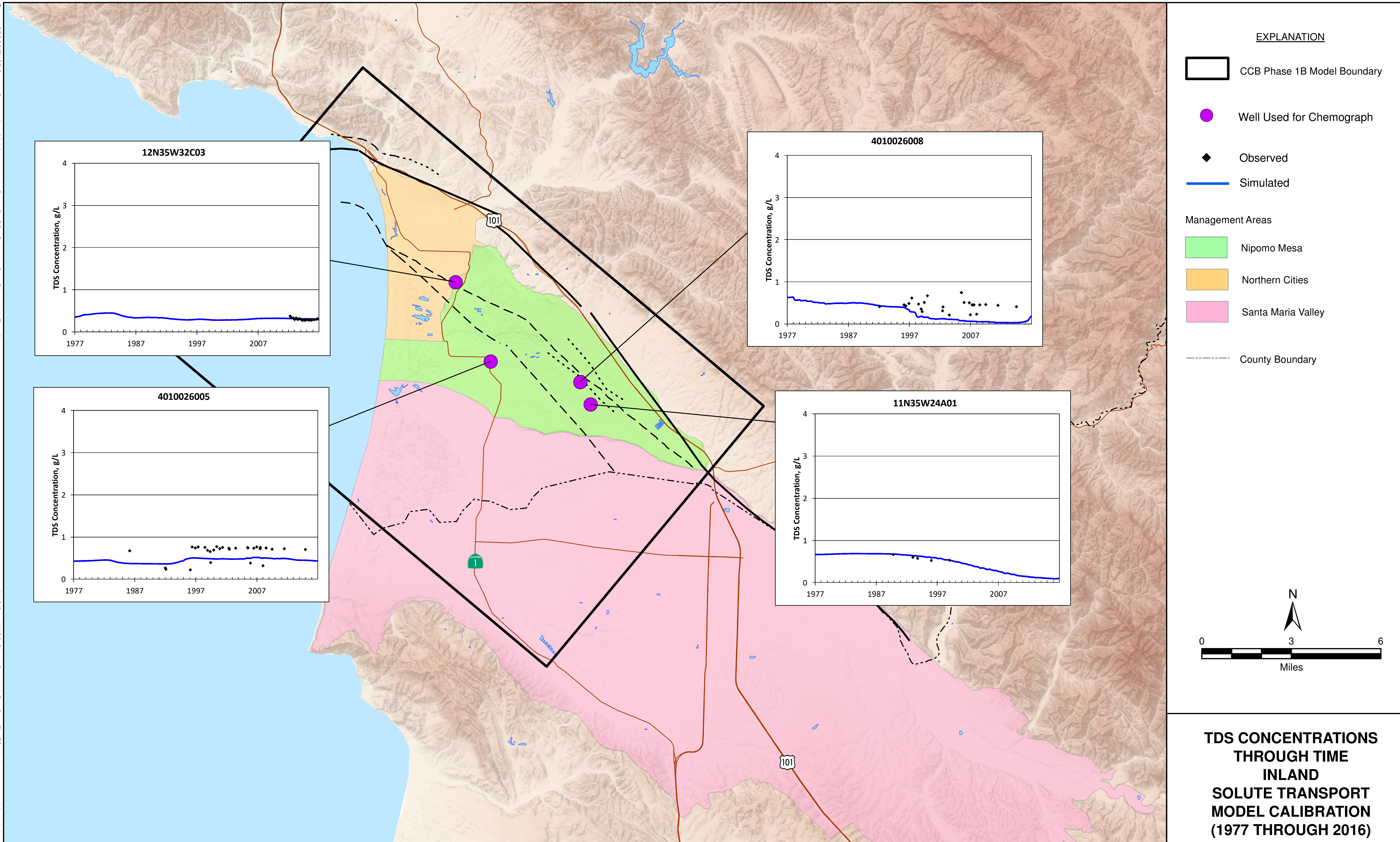
FIGURE ES-18

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - EXECUTIVE SUMMARY

GEOSCIENCE



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25-Nov-19

TDS CONCENTRATIONS THROUGH TIME INLAND SOLUTE TRANSPORT MODEL CALIBRATION (1977 THROUGH 2016)

WATER SYSTEMS CONSULTING, INC.

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - EXECUTIVE SUMMARY

FIGURE ES-19

GEOSCIENCE

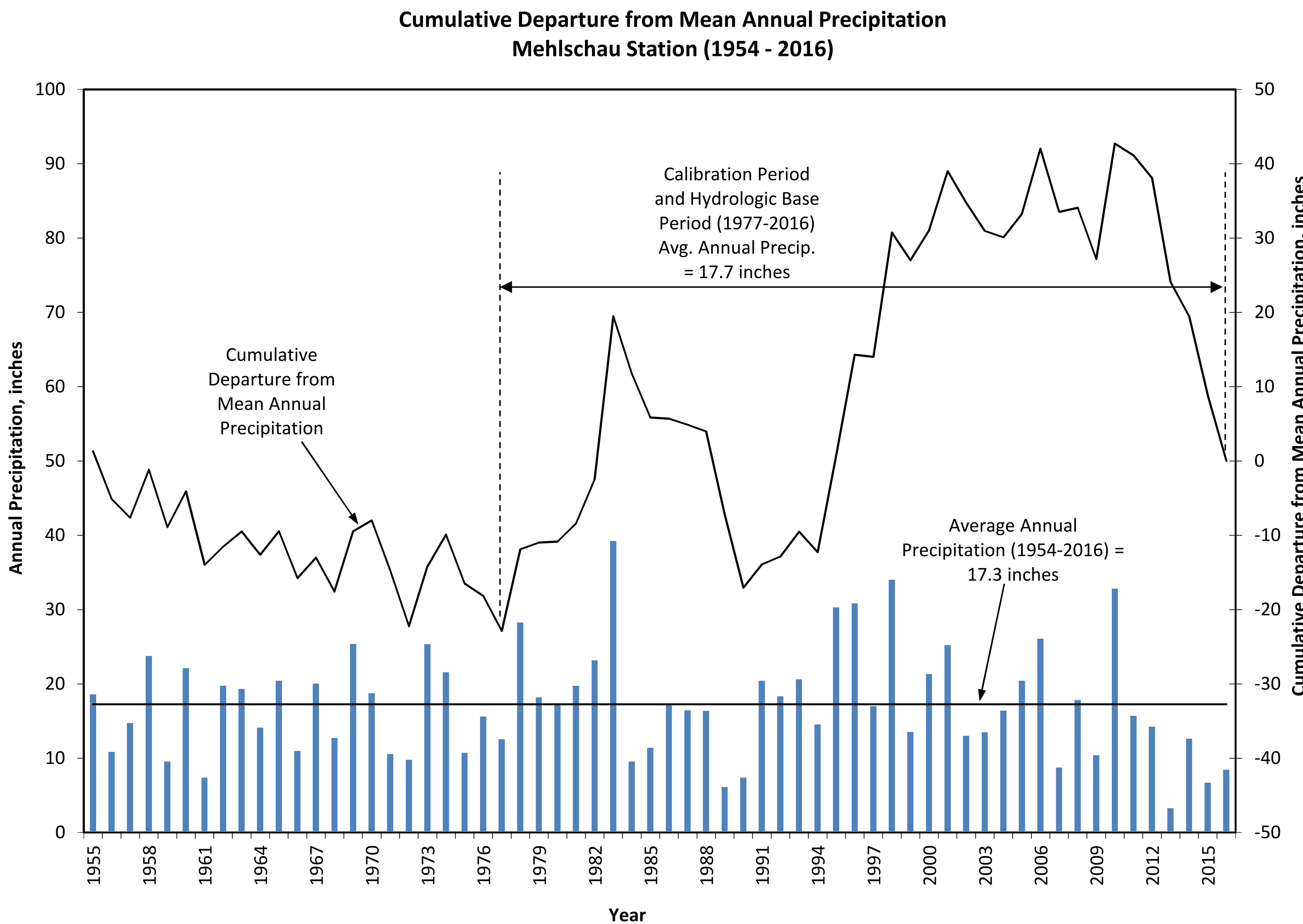
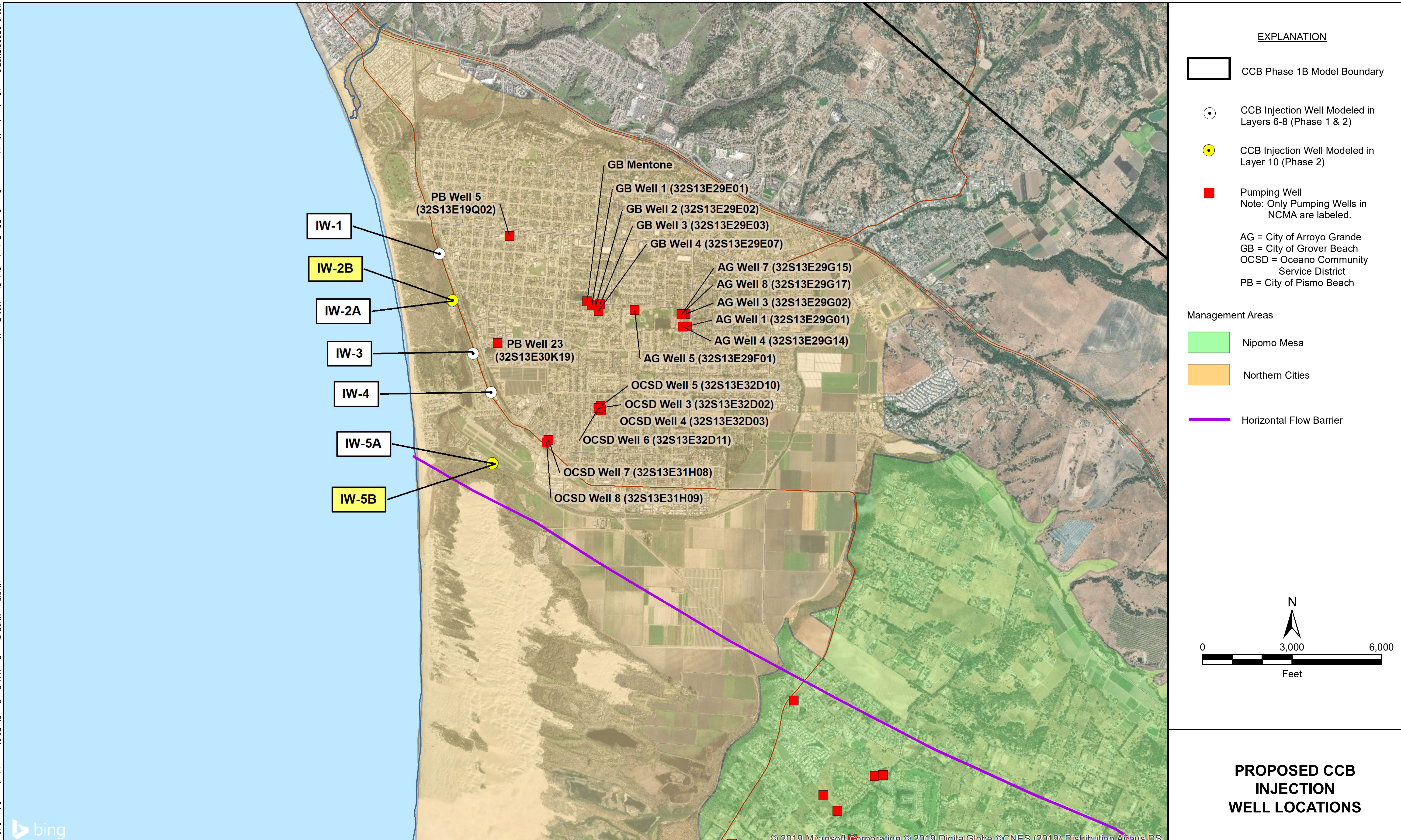

Cumulative Departure from Mean Annual Precipitation
Mehlschau Station (1954 - 2016)
Calibration Period and Hydrologic Base Period (1977-2016) Avg. Annual Precip. = 17.7 inches
Cumulative Departure from Mean Annual Precipitation
Average Annual Precipitation (1954-2016) = 17.3 inches
Annual Precipitation, inches
Cumulative Departure from Mean Annual Precipitation, inches
Year
100
90
80
70
60
50
40
30
20
10
0
50
40
30
20
10
0
-10
-20
-30
-40
-50
1955
1958
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
2015

Figure ES-20



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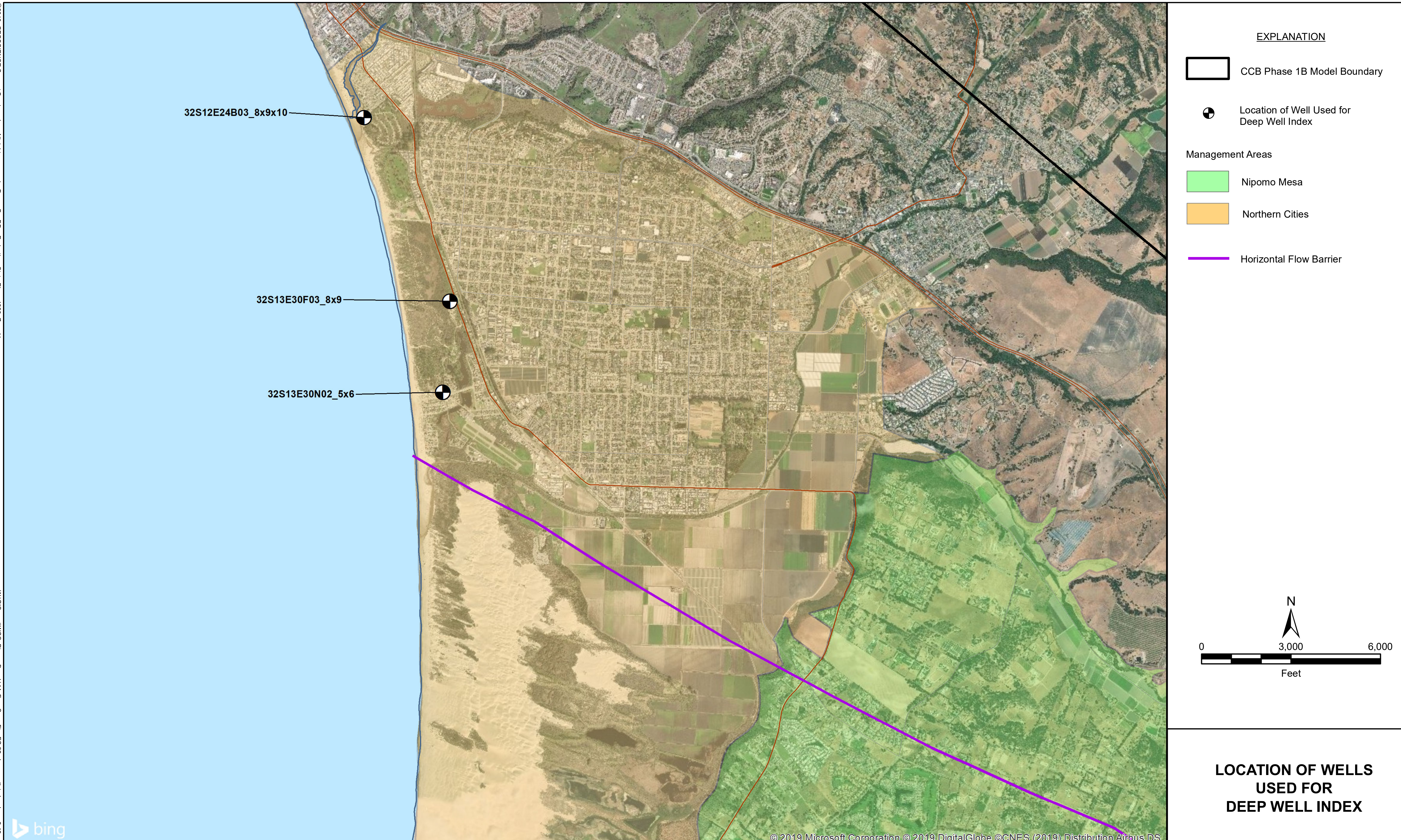
PROPOSED CCB INJECTION WELL LOCATIONS



W:\GIS_proj\WSC_Pismo_Beach\44_ExecSum_Fig_ES-22_deep_well_index_locs_8-19.mxd

LOCATION OF WELLS USED FOR DEEP WELL INDEX

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CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - EXECUTIVE SUMMARY

FIGURE ES-22

GEOSCIENCE

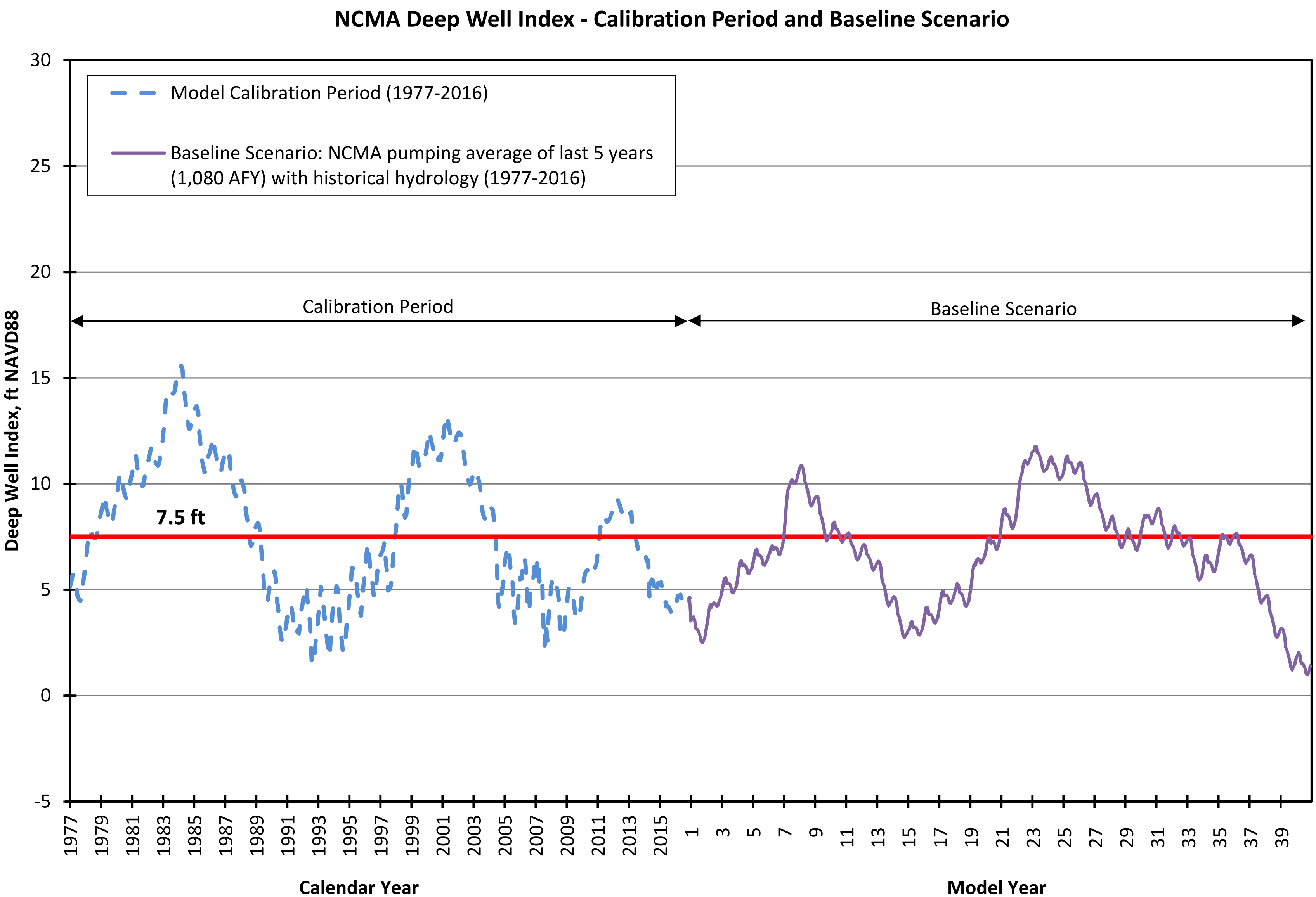
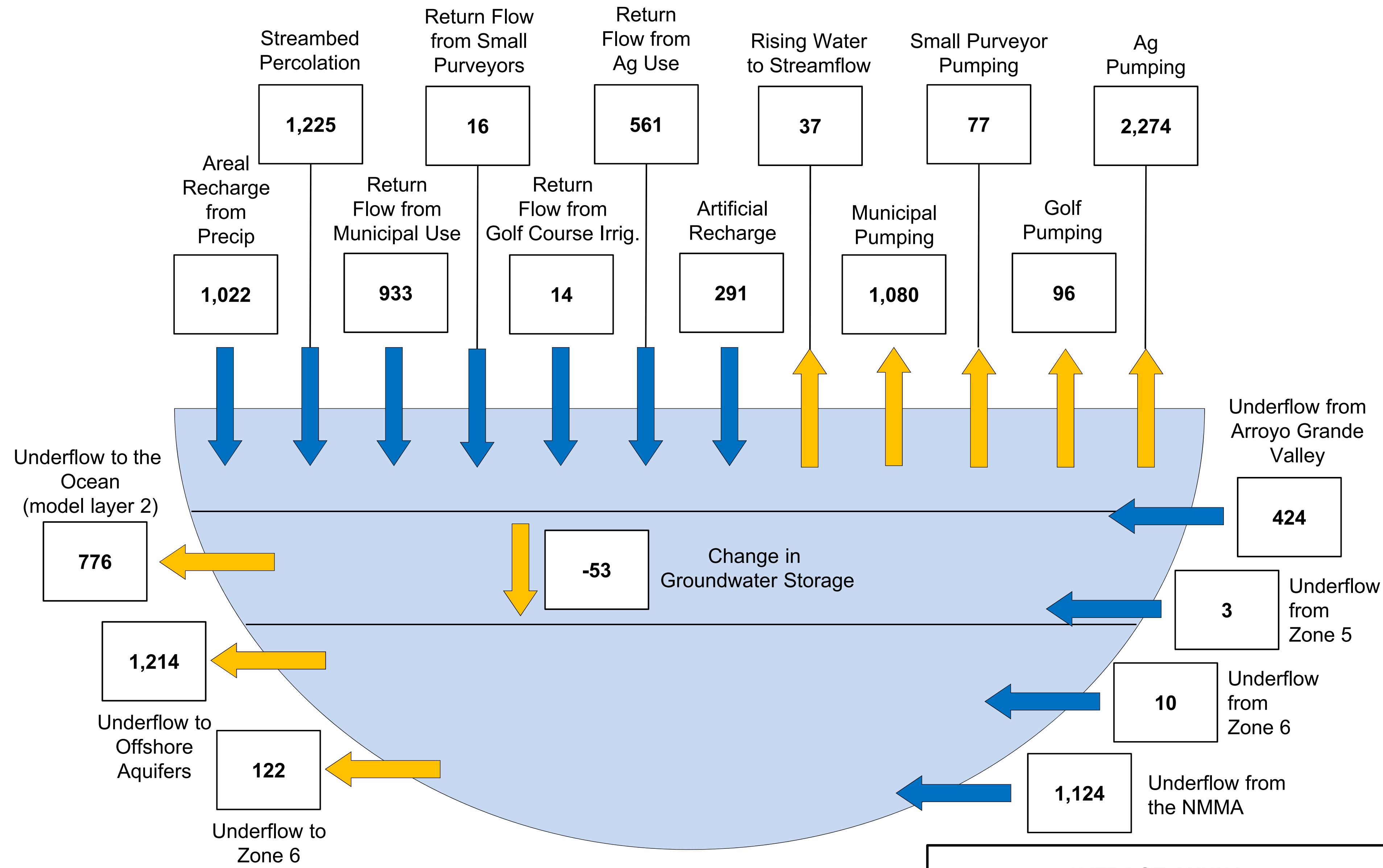

NCMA Deep Well Index - Calibration Period and Baseline Scenario
Model Calibration Period (1977-2016)
Baseline Scenario: NCMA pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016)
Calibration Period
Baseline Scenario
7.5 ft
Deep Well Index, ft NAVD88
30
25
20
15
10
5
0
-5
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
Calendar Year
Model Year

Figure ES-23



All values in acre-ft/yr
Baseline Scenario: NCMA municipal pumping average of last 5 years with historical hydrology (1977-2016)

AVERAGE ANNUAL WATER BUDGETS FOR THE NCMA BASELINE SCENARIO

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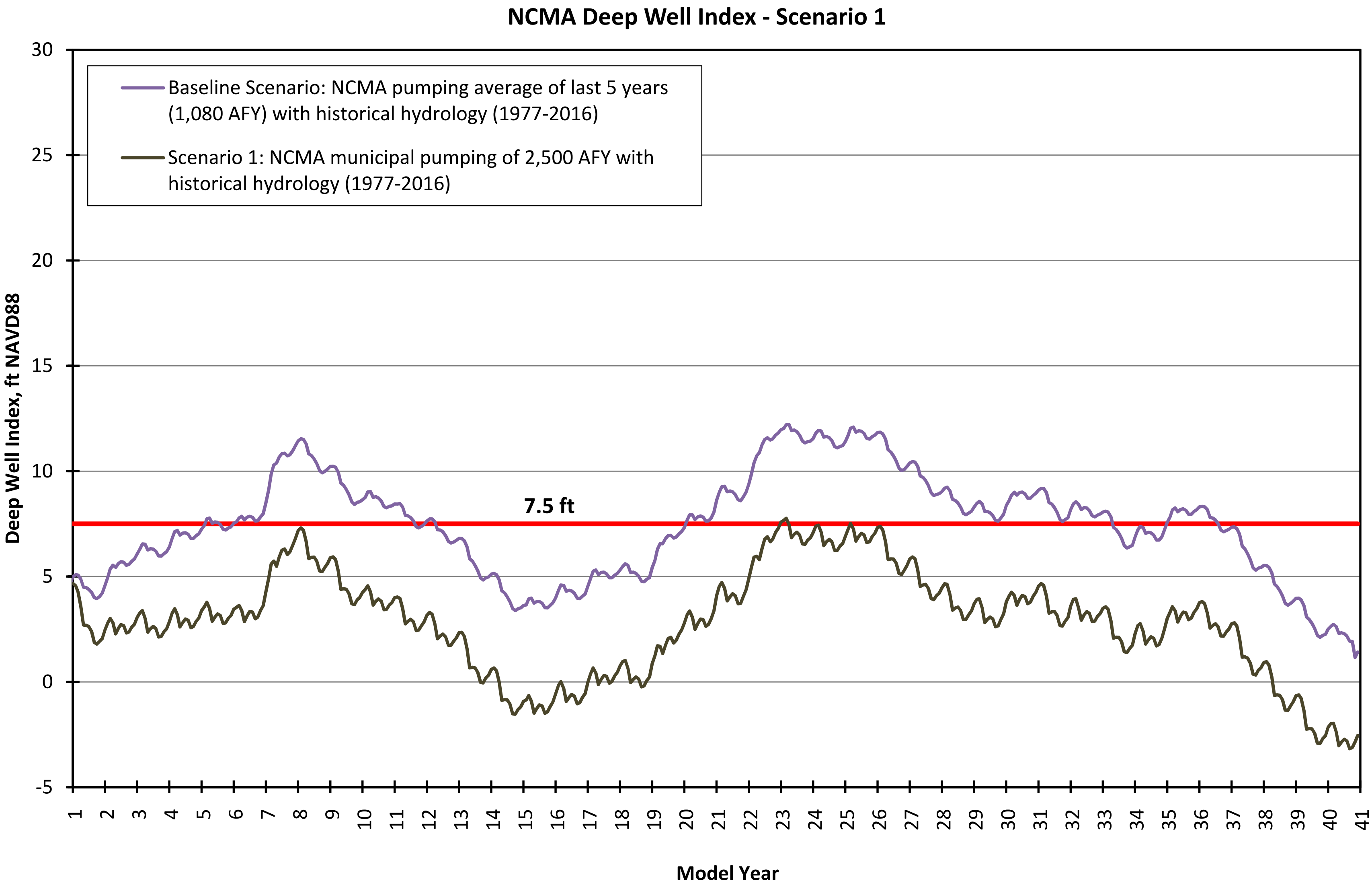
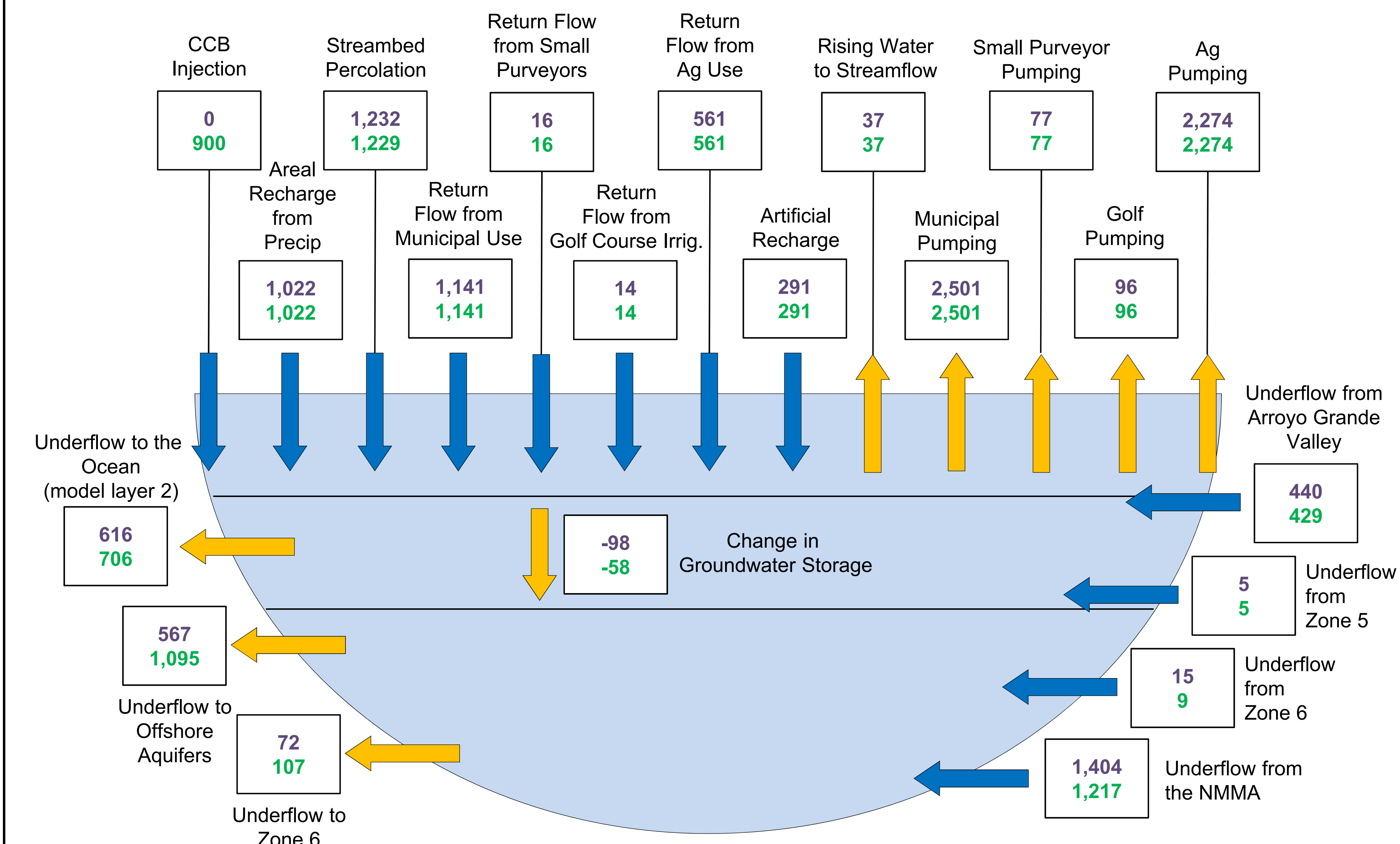

NCMA Deep Well Index - Scenario 1
Baseline Scenario: NCMA pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016)
Scenario 1: NCMA municipal pumping of 2,500 AFY with historical hydrology (1977-2016)
7.5 ft
Deep Well Index, ft NAVD88
Model Year
30
25
20
15
10
5
0
-5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41

Figure ES-25



All values in acre-ft/yr
Scenario 1: NCMA municipal pumping of 2,500 AFY with historical hydrology (1977-2016)
Scenario 2: NCMA municipal pumping of 2,500 AFY with historical hydrology and CCB Phase 1 injection of 900 AFY

0	Scenario 1
900	Scenario 2

AVERAGE ANNUAL WATER BUDGETS FOR THE NCMA SCENARIOS 1 & 2

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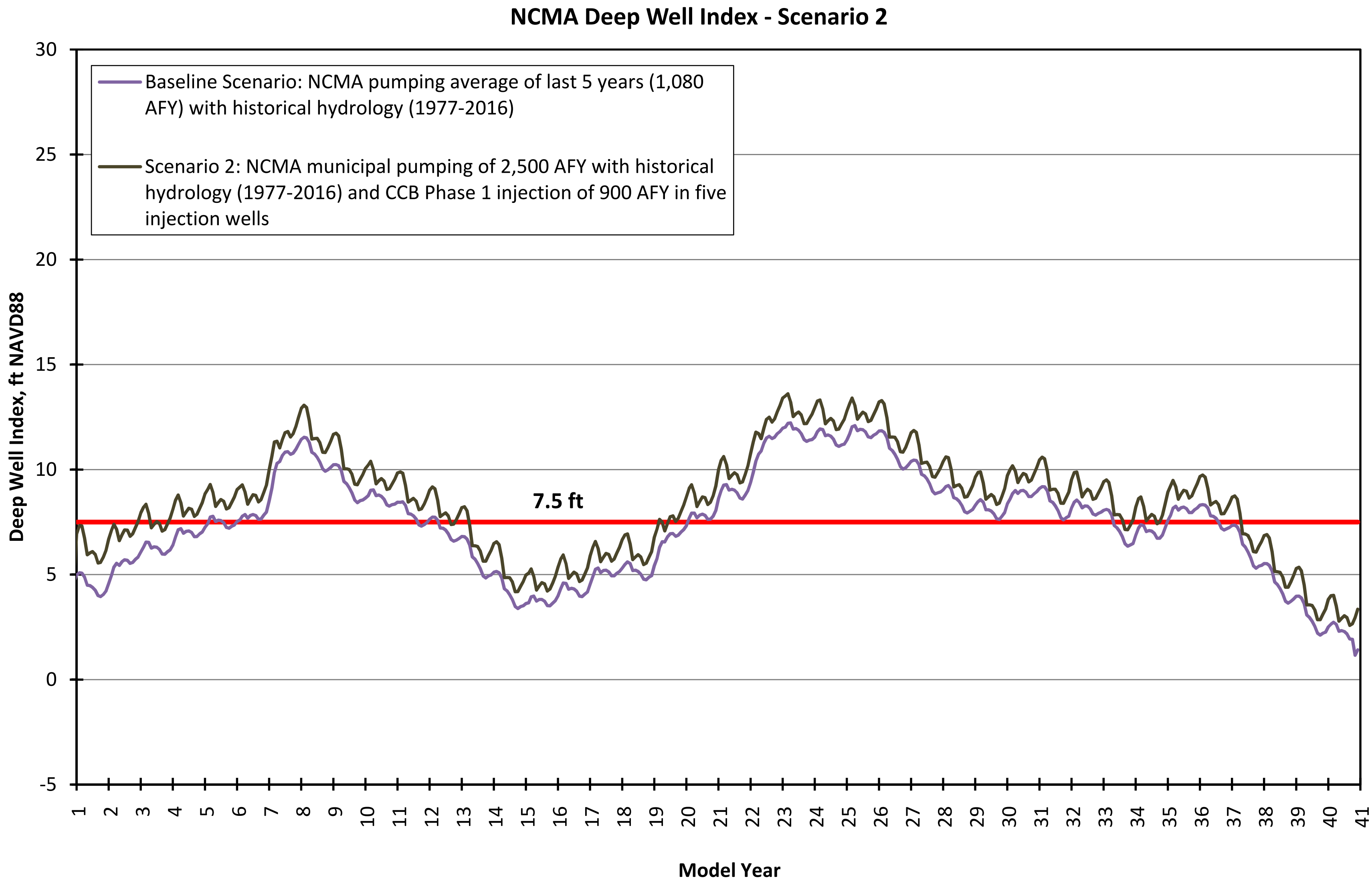
NCMA Deep Well Index - Scenario 2
Baseline Scenario: NCMA pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016)
Scenario 2: NCMA municipal pumping of 2,500 AFY with historical hydrology (1977-2016) and CCB Phase 1 injection of 900 AFY in five injection wells
7.5 ft
Deep Well Index, ft NAVD88
Model Year
30
25
20
15
10
5
0
-5
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
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26
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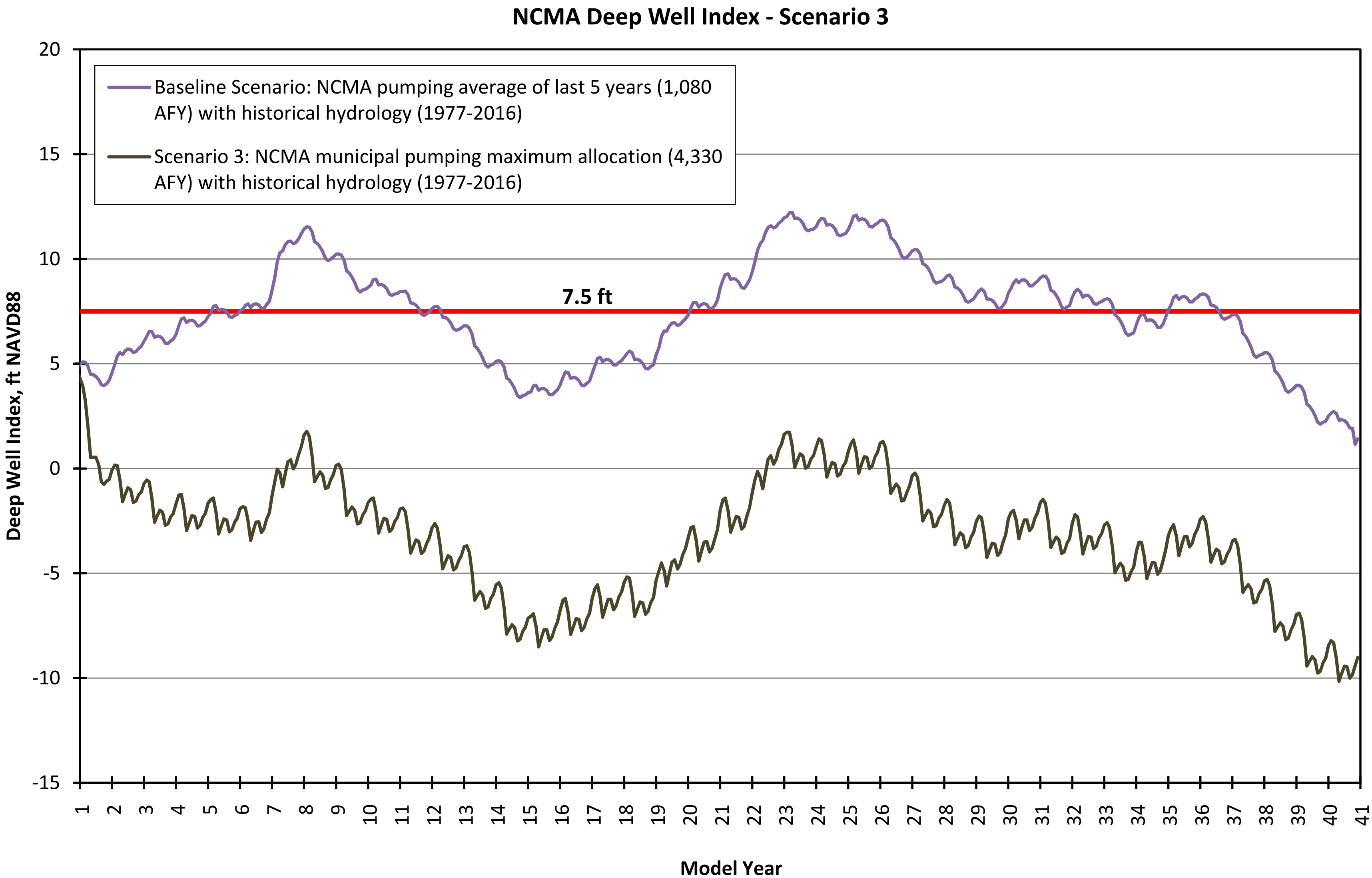
28
29
30
31
32
33
34
35
36
37
38
39
40
41

Figure ES-27


NCMA Deep Well Index - Scenario 3
Baseline Scenario: NCMA pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016)
Scenario 3: NCMA municipal pumping maximum allocation (4,330 AFY) with historical hydrology (1977-2016)
7.5 ft
Deep Well Index, ft NAVD88
Model Year
20
15
10
5
0
-5
-10
-15
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
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29
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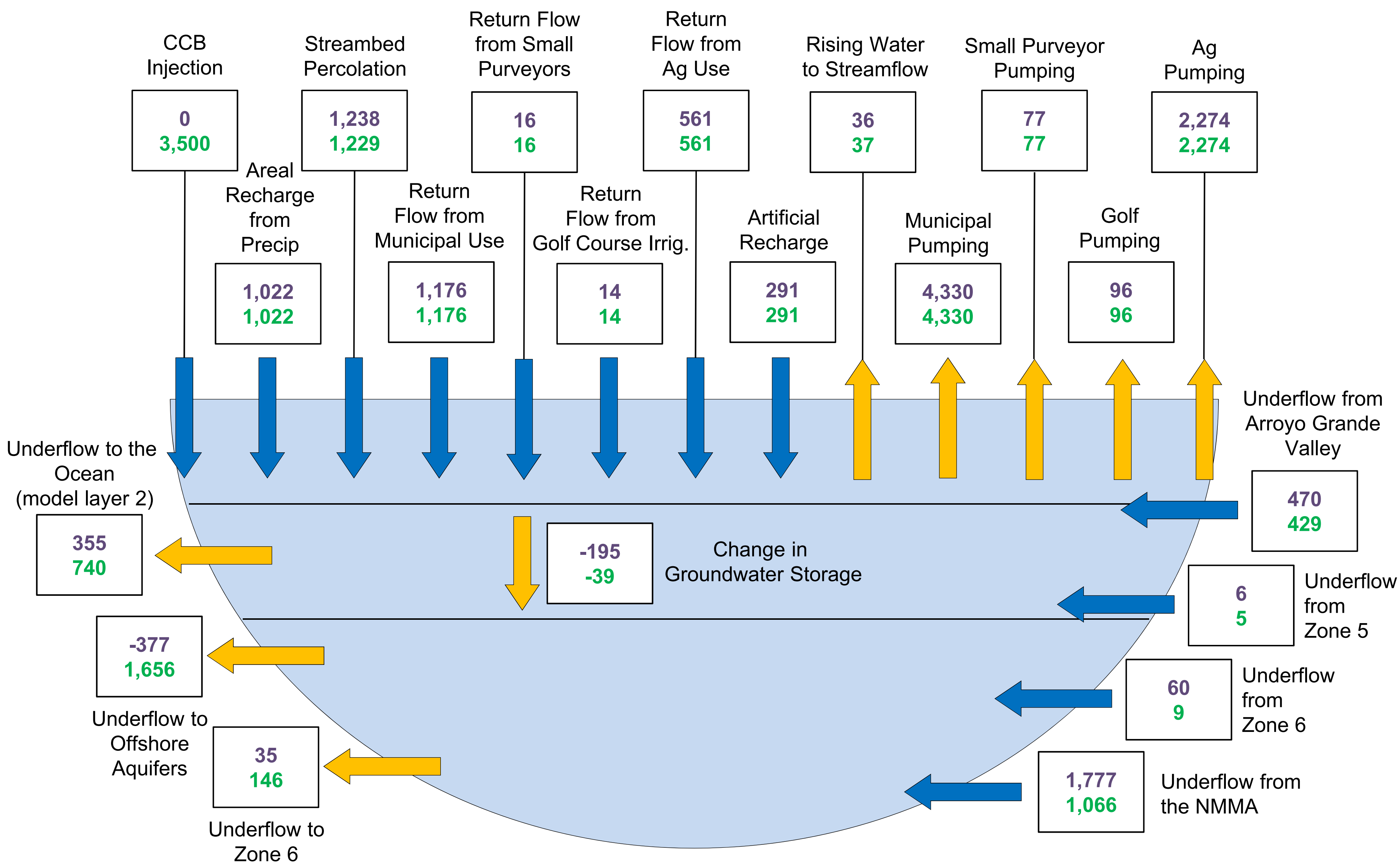
34
35
36
37
38
39
40
41

Figure ES-28



All values in acre-ft/yr
Scenario 3: NCMA municipal pumping maximum allocation with historical hydrology (1977-2016)
Scenario 4: NCMA municipal pumping of maximum allocation with historical hydrology and CCB Phase 2 injection of 3,500 AFY

0	Scenario 3
3,500	Scenario 4

AVERAGE ANNUAL WATER BUDGETS FOR THE NCMA SCENARIOS 3 & 4

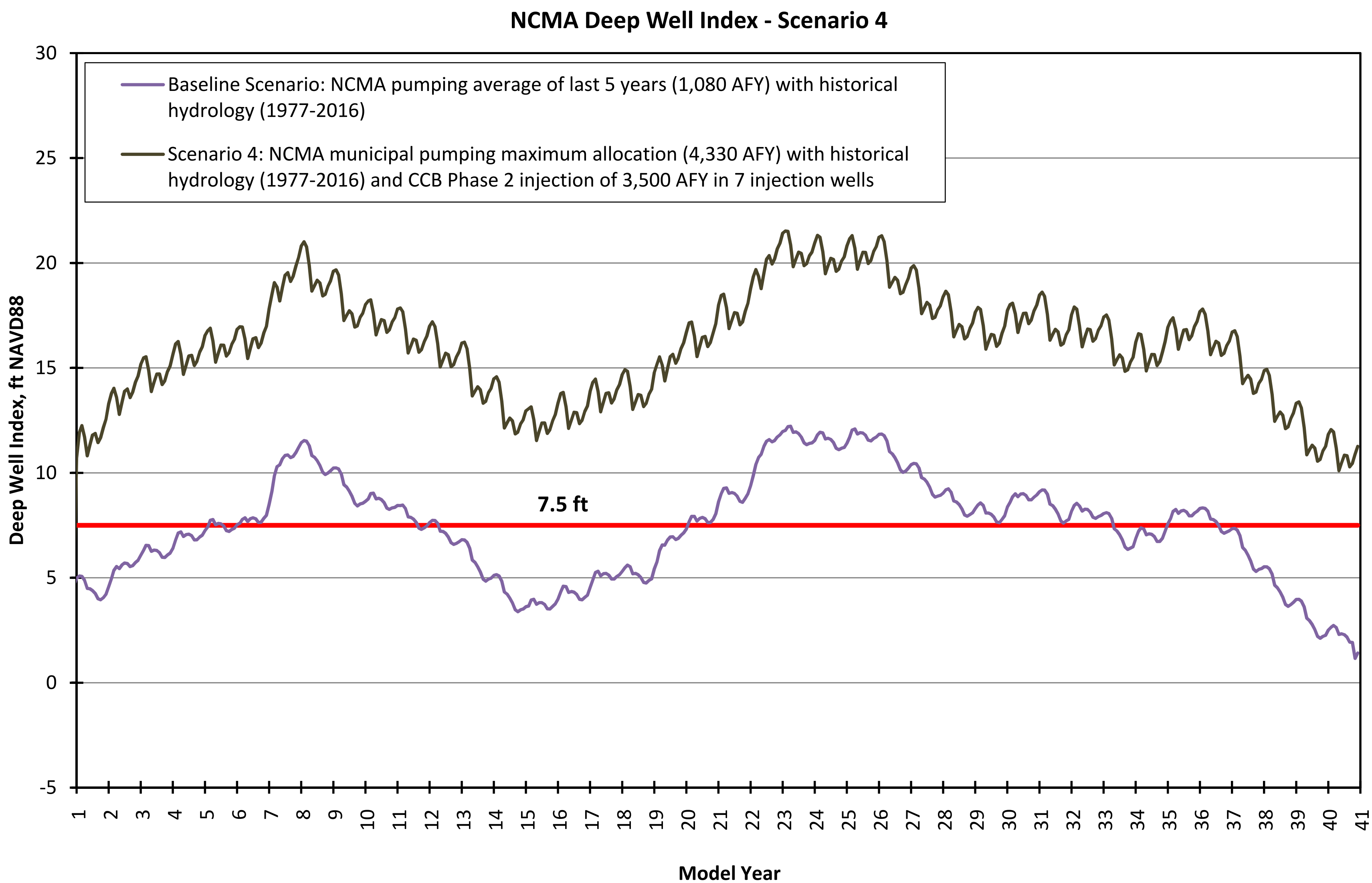
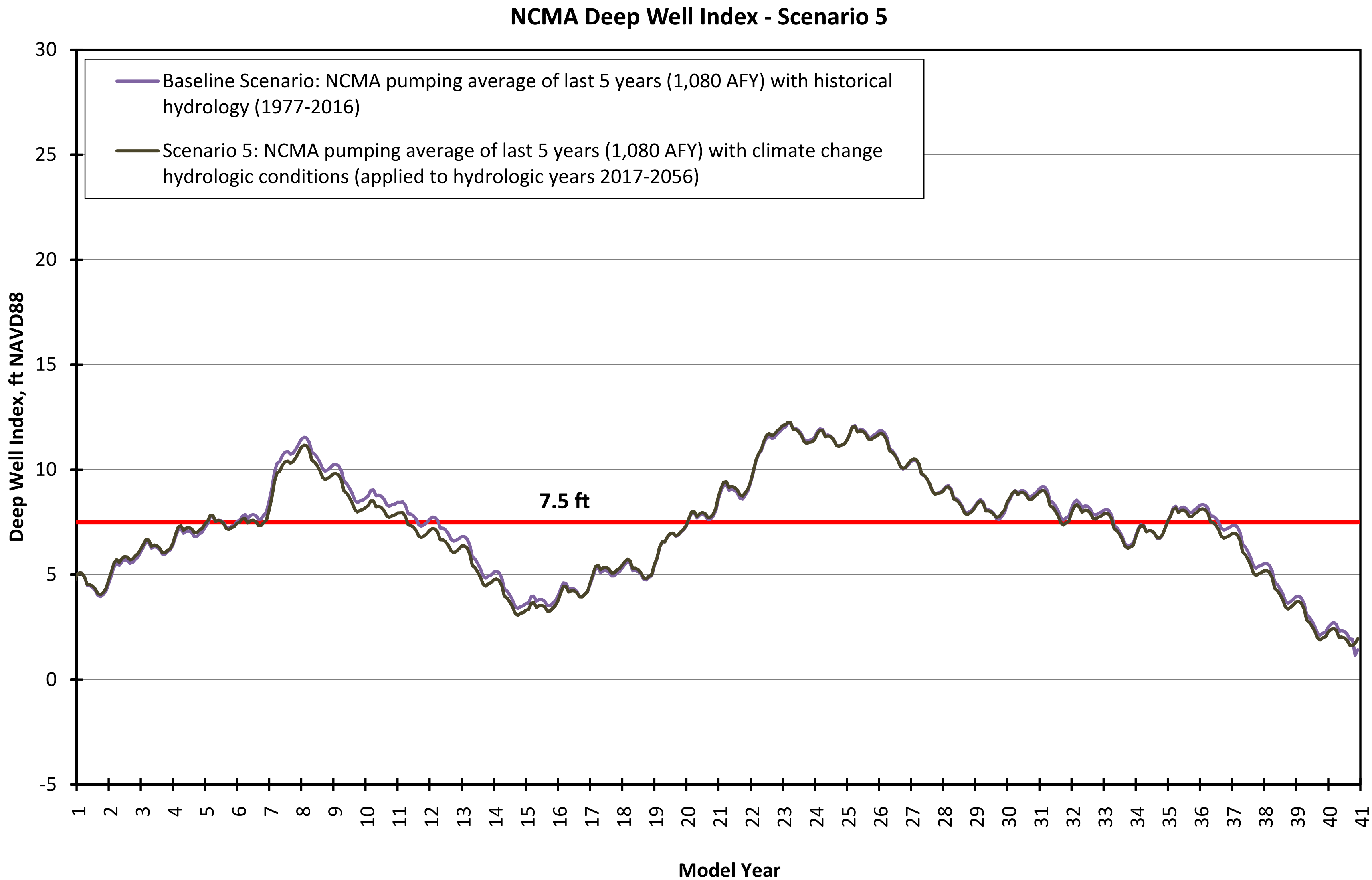

NCMA Deep Well Index - Scenario 4
Baseline Scenario: NCMA pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016)
Scenario 4: NCMA municipal pumping maximum allocation (4,330 AFY) with historical hydrology (1977-2016) and CCB Phase 2 injection of 3,500 AFY in 7 injection wells
7.5 ft
Deep Well Index, ft NAVD88
30
25
20
15
10
5
0
-5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41
Model Year

Figure ES-30


NCMA Deep Well Index - Scenario 5
Baseline Scenario: NCMA pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016)
Scenario 5: NCMA pumping average of last 5 years (1,080 AFY) with climate change hydrologic conditions (applied to hydrologic years 2017-2056)
7.5 ft
Deep Well Index, ft NAVD88
Model Year
30
25
20
15
10
5
0
-5
1
2
3
4
5
6
7
8
9
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11
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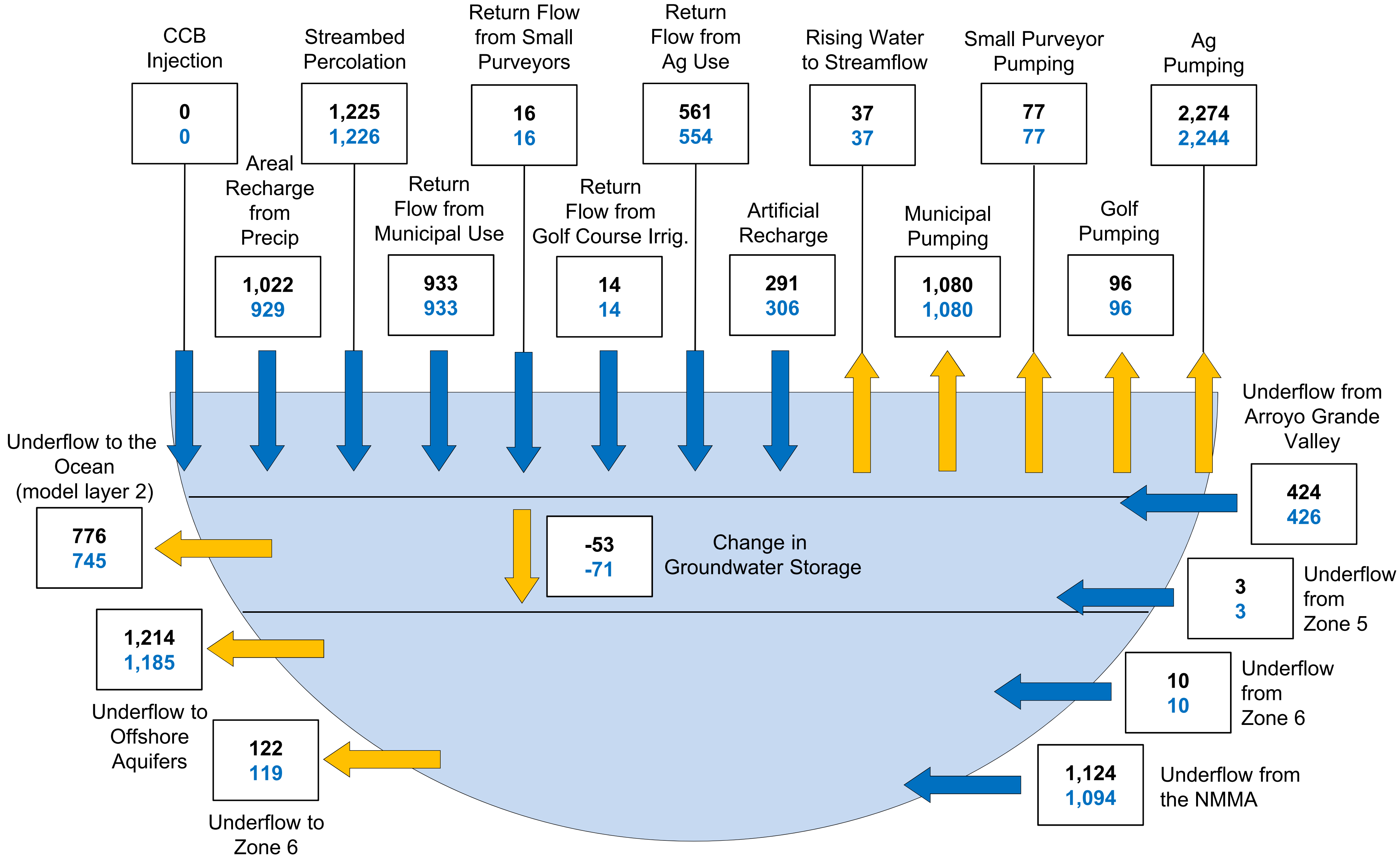
Figure ES-31



All values in acre-ft/yr
Baseline Scenario: NCMA municipal pumping average of last 5 years with historical hydrology (1977-2016)
Scenario 5: NCMA municipal pumping average of last 5 years with climate change (applied to hydrologic years 1977-2016)

1,022 929	**Baseline** **Scenario 5**

AVERAGE ANNUAL WATER BUDGETS FOR THE NCMA SCENARIO 5

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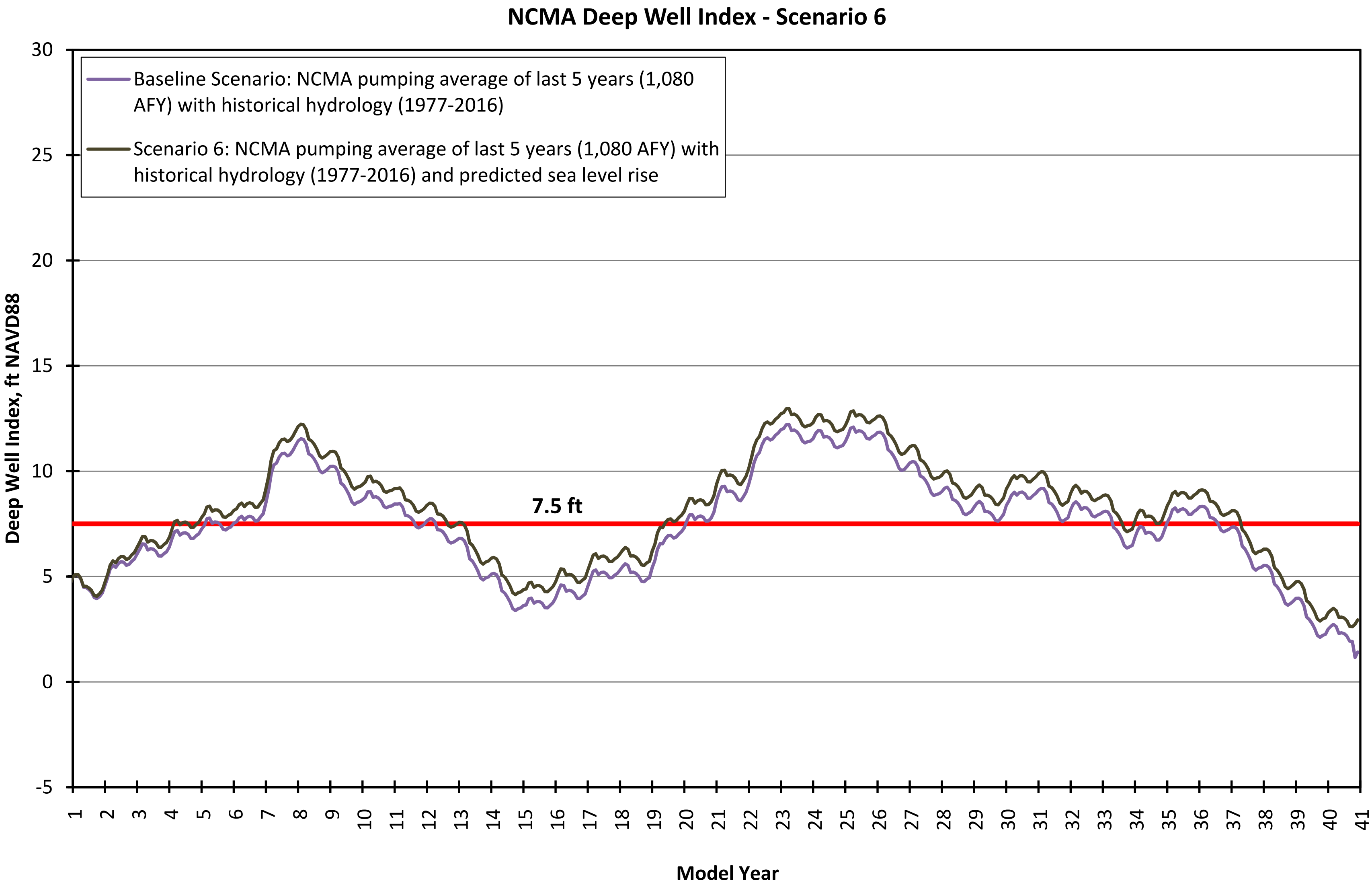
NCMA Deep Well Index - Scenario 6
Baseline Scenario: NCMA pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016)
Scenario 6: NCMA pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016) and predicted sea level rise
7.5 ft
Deep Well Index, ft NAVD88
Model Year
30
25
20
15
10
5
0
-5
1
2
3
4
5
6
7
8
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Figure 37

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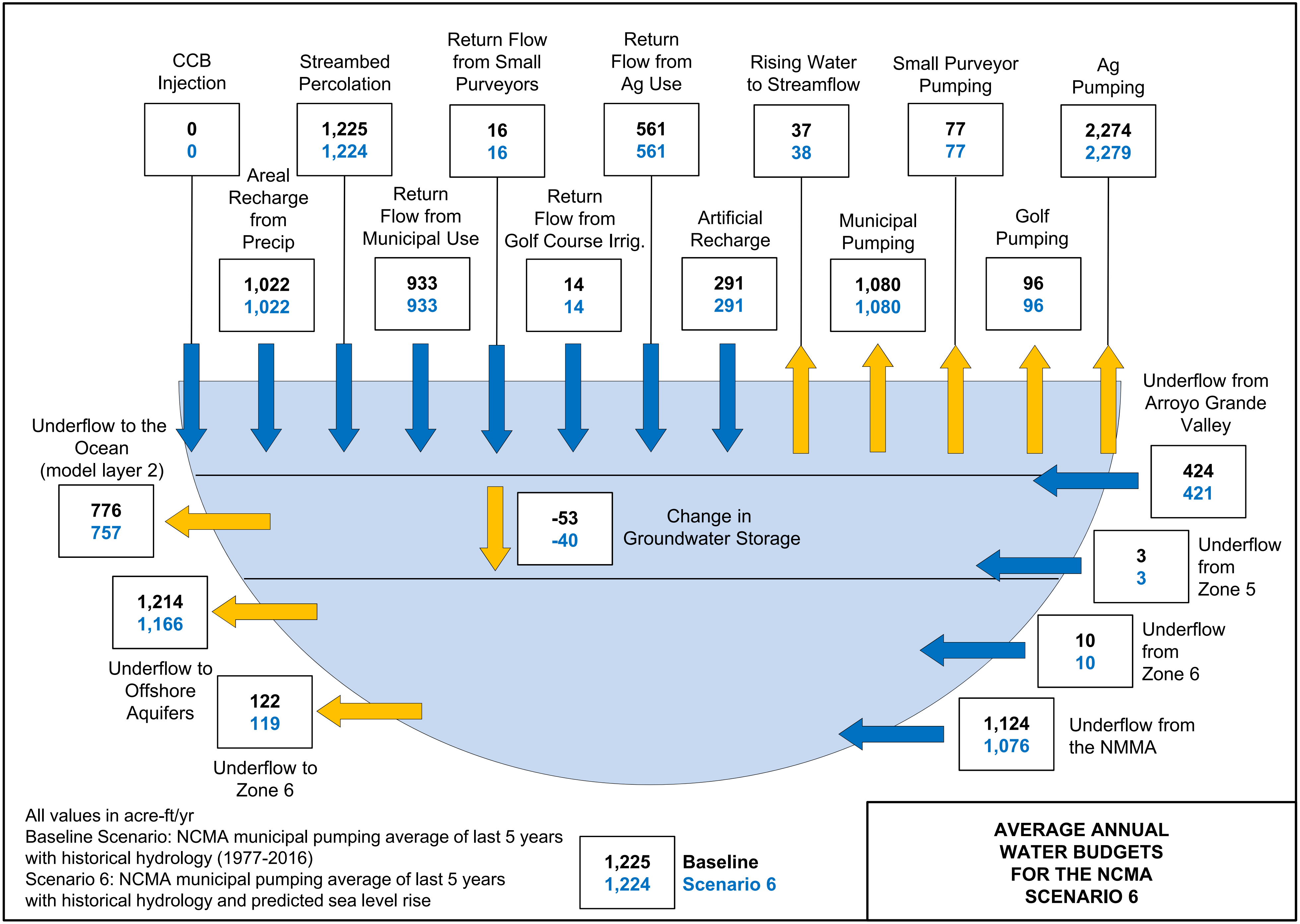
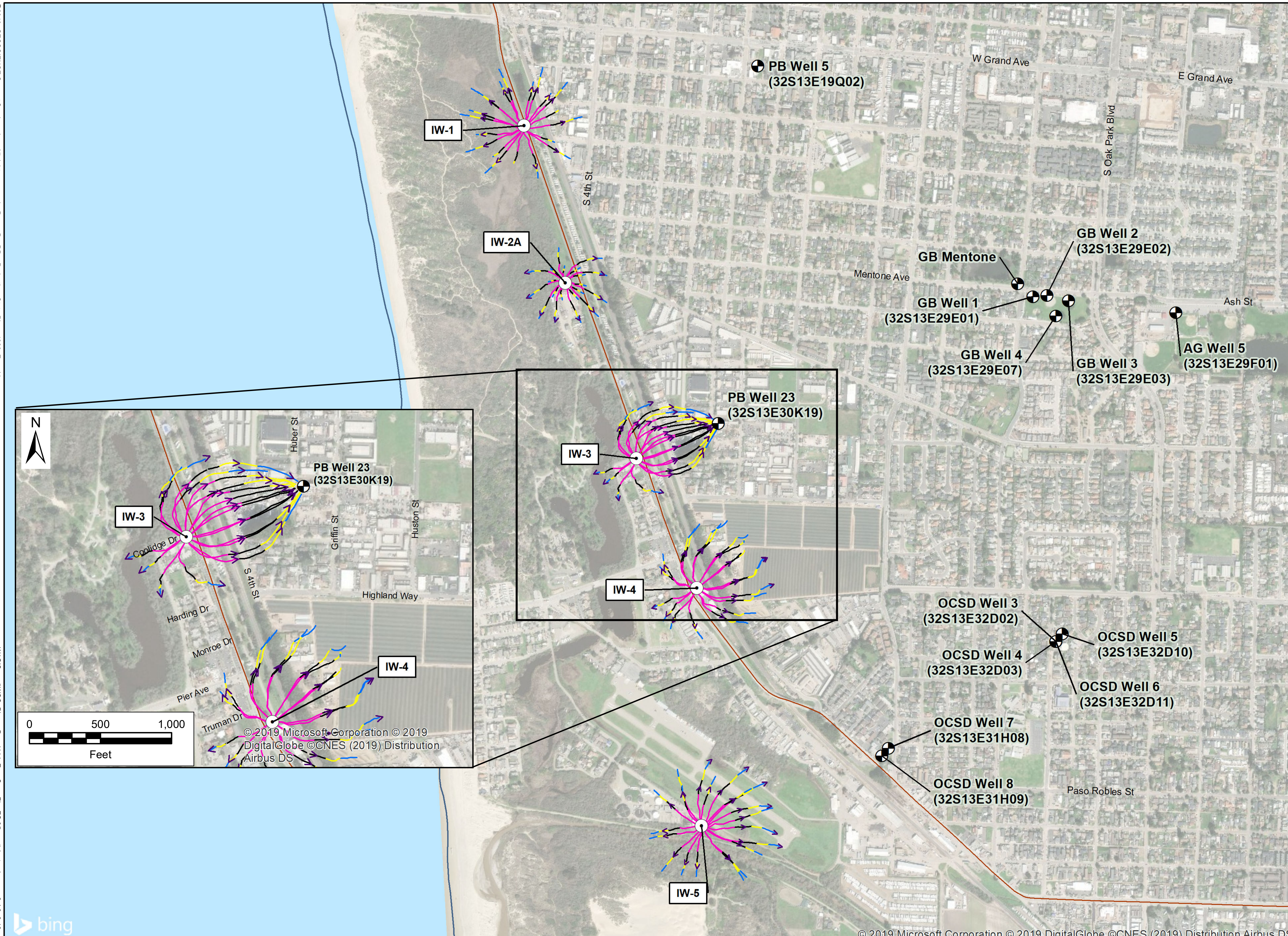


25-Nov-19



EXPLANATION

CCB Injection Well Modeled in Layer 6 (Phase 1)

Municipal Well Location

AG = City of Arroyo Grande
GB = City of Grover Beach
OCSD = Oceano Community Service District
PB = City of Pismo Beach

Recycled Water Particle Tracks
(Every 6 Months)
Note: Arrows show Groundwater Flow Direction

0 to 6 Months
6 to 12 Months
12 to 18 Months
18 to 24 Months

Scenario 2:
NCMA municipal pumping of 2,500 AFY with historical hydrology (1977-2016) and CCB Phase 1 injection of 900 AFY in 5 injection wells

N

0 1,000 2,000
Feet

RECYCLED WATER PARTICLE TRACKS UNDER CCB PHASE 1 (SCENARIO 2) CONDITIONS LAYER 6

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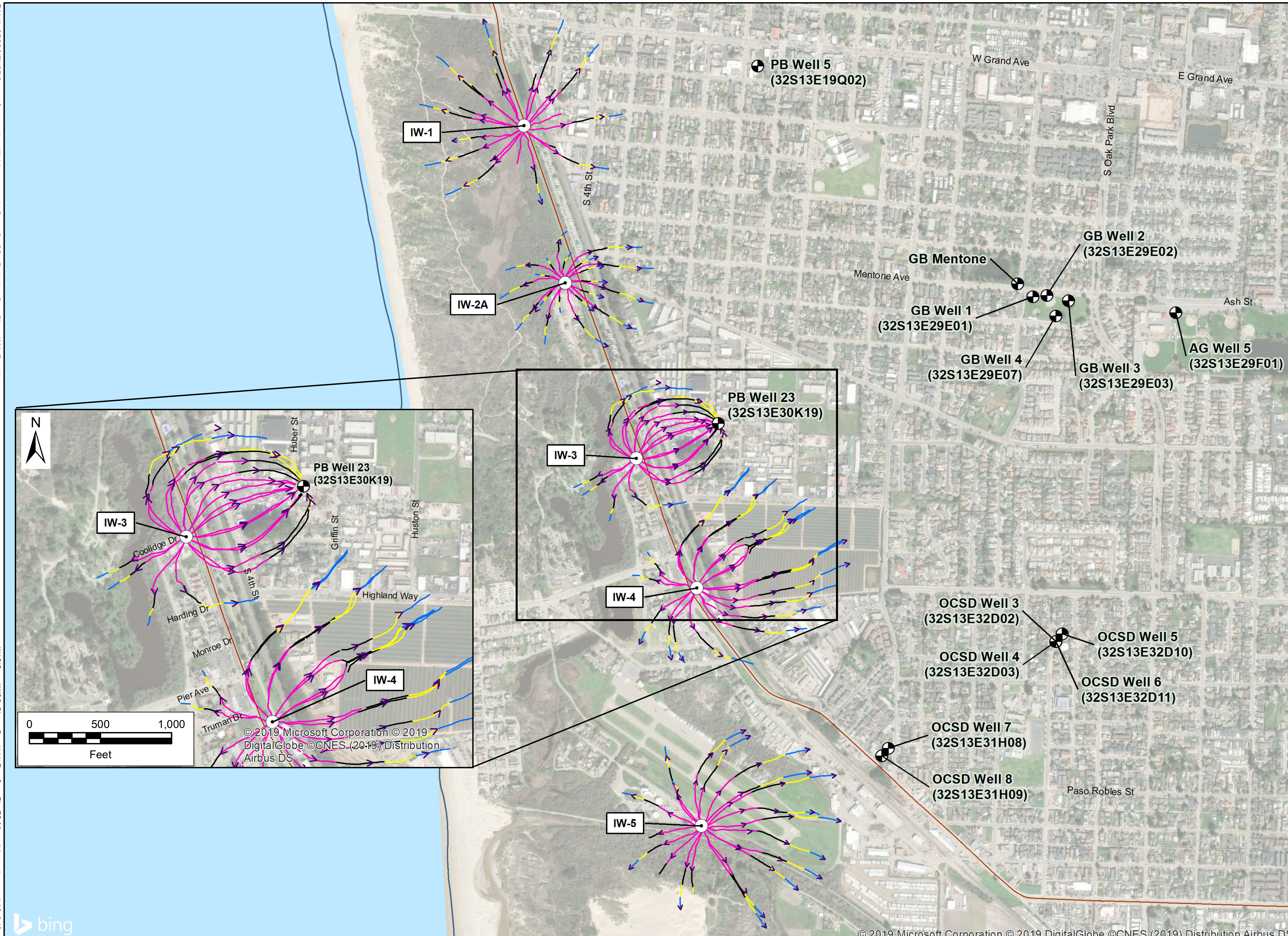
FIGURE ES-35

GEOSCIENCE



EXPLANATION

CCB Injection Well Modeled in Layer 6 (Phase 2)

Municipal Well Location

Recycled Water Particle Tracks
(Every 6 Months)
Note: Arrows show Groundwater Flow Direction

- 0 to 6 Months
- 6 to 12 Months
- 12 to 18 Months
- 18 to 24 Months

NOTE: Five Injection Wells in Layers 6-8 and Two Injection Wells in Layer 10

Scenario 4:
NCMA municipal pumping maximum allocation (4,330 AFY) with historical hydrology (1977-2016) and CCB Phase 2 injection of 3,500 AFY in 7 injection wells

N

0 1,000 2,000
Feet

RECYCLED WATER PARTICLE TRACKS UNDER CCB PHASE 2 (SCENARIO 4) CONDITIONS LAYER 6

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GEOSCIENCE

TABLES

Table ES-1

CCB Phase 1B Groundwater Model Calibration – NCMA Groundwater Balance (1977 - 2016)

Year	INFLOWS [acre-ft]													OUTFLOWS [acre-ft]											
	Areal Recharge from Precip (rch pkg)	Streambed Percolation (model)	Return Flow from Muni Use (rch pkg)	Return Flow from Small Purveyors (rch pkg)	Return Flow from Golf Course Irrig. (rch pkg)	Return Flow from Ag (rch pkg)	Artificial Recharge (wel pkg)	Underflow from NMMA (model)	Underflow from Arroyo Grande Valley (model)	Underflow from Zone 5 (model)	Underflow from Ocean (layer 2) (model)	Underflow from Offshore Aquifers (model)	TOTAL INFLOW	Rising Water Discharge to Streamflow (model)	Muni Pumping (wel pkg)	Small Purveyor Pumping (wel pkg)	Golf Pumping (wel pkg)	Ag Pumping (wel pkg)	Underflow to NMMA (model)	Underflow to Zone 5 (model)	Underflow to Zone 6 (model)	Underflow to Ocean (layer 2) (model)	Underflow to Offshore Aquifers (model)	TOTAL OUTFLOW	CHANGE IN STORAGE
1977	202	843	815	6	15	1,920	233	2,320	307	109	0	167	6,937	0	292	24	102	3,999	408	111	66	762	1,211	6,974	-37
1978	1,265	1,872	821	6	13	1,353	591	2,183	713	213	0	85	9,114	121	373	24	88	2,765	393	259	108	931	1,699	6,761	2,354
1979	1,364	975	796	6	14	1,929	276	2,297	526	239	0	55	8,476	69	270	24	95	3,945	451	210	130	1,097	1,794	8,087	390
1980	1,222	1,549	804	6	15	1,744	331	2,502	585	224	0	61	9,044	84	293	24	102	3,567	451	220	140	1,153	2,034	8,067	978
1981	1,370	999	782	6	14	1,860	304	2,622	523	239	0	56	8,774	77	216	24	92	3,804	454	212	148	1,225	2,145	8,396	378
1982	1,295	1,228	777	6	11	1,420	308	2,705	487	206	0	56	8,498	42	149	24	72	2,902	448	196	153	1,255	2,284	7,525	973
1983	3,116	2,942	752	6	12	1,208	655	2,893	648	227	0	45	12,504	197	67	24	82	2,468	646	234	205	1,728	3,043	8,693	3,811
1984	284	915	929	7	16	2,189	137	2,970	297	199	0	43	7,986	9	465	27	107	4,473	556	142	194	1,567	2,701	10,242	-2,257
1985	252	771	971	7	16	2,565	142	3,027	244	154	0	83	8,232	0	561	29	110	5,242	492	114	156	1,365	2,240	10,308	-2,075
1986	1,411	1,098	960	7	14	1,712	247	3,040	332	153	0	82	9,055	0	661	29	93	3,699	462	148	146	1,367	2,209	8,814	241
1987	588	815	910	7	13	1,643	203	2,769	379	185	0	94	7,606	0	846	29	88	3,549	403	170	130	1,256	1,960	8,433	-827
1988	785	819	1,138	7	15	1,718	221	2,559	203	166	0	148	7,778	0	1,188	29	98	3,714	408	121	104	1,258	1,713	8,635	-856
1989	2	686	1,175	7	17	2,331	89	2,378	304	142	0	229	7,359	0	1,272	29	116	5,034	513	120	77	1,080	1,301	9,541	-2,181
1990	68	699	1,077	7	16	2,280	130	2,319	136	112	0	352	7,195	0	1,261	29	108	4,924	512	68	47	871	1,068	8,887	-1,693
1991	946	1,073	1,020	7	14	1,155	367	2,130	369	135	0	332	7,549	0	1,221	29	94	2,644	367	151	46	882	1,188	6,622	927
1992	1,442	990	1,313	7	14	1,310	303	2,023	385	175	0	337	8,299	6	2,326	29	95	3,002	447	166	63	1,056	1,191	8,381	-82
1993	1,883	1,179	1,292	7	14	1,269	406	2,157	384	170	0	318	9,080	0	2,212	29	94	2,908	411	163	73	1,169	1,316	8,376	704
1994	917	791	1,251	7	13	1,480	167	2,264	399	202	0	309	7,800	6	2,003	34	90	3,388	410	178	68	1,044	1,220	8,440	-640
1995	2,221	2,379	1,219	8	13	1,165	503	2,449	427	174	0	255	10,813	21	2,178	44	91	2,670	454	182	96	1,229	1,684	8,650	2,163
1996	1,301	1,831	1,295	8	13	925	348	2,690	376	207	0	262	9,257	45	2,203	44	86	2,334	427	176	100	1,215	1,801	8,431	826
1997	1,082	2,612	1,350	8	16	1,229	302	2,612	226	132	0	249	9,818	0	2,600	44	104	3,098	440	111	103	1,240	1,862	9,602	215
1998	2,503	3,168	1,257	8	12	868	553	3,143	387	173	0	197	12,270	82	1,984	44	79	2,431	571	169	154	1,546	2,573	9,634	2,636
1999	1,065	1,047	1,423	8	14	489	268	3,252	334	160	0	153	8,212	2	2,224	44	95	1,357	511	140	169	1,541	2,572	8,655	-442
2000	1,160	1,125	1,466	13	14	519	301	3,191	546	216	0	150	8,702	77	2,358	63	96	1,317	461	215	162	1,543	2,483	8,775	-73
2001	1,542	1,407	1,427	13	13	776	465	3,308	661	253	0	134	10,000	154	2,284	65	89	2,354	445	245	168	1,499	2,547	9,850	150
2002	465	854	1,486	13	16	1,018	164	3,106	506	249	0	126	8,001	71	2,799	65	105	3,078	468	211	139	1,208	1,978	10,121	-2,120
2003	297	835	1,493	15	15	837	124	2,986	304	195	0	154	7,254	0	2,709	73	100	2,844	510	154	113	1,038	1,626	9,167	-1,913
2004	654	953	1,565	16	14	739	193	3,017	277	156	0	327	7,911	0	3,517	77	93	2,524	456	128	81	915	1,405	9,195	-1,285
2005	1,398	879	1,450	16	13	733	189	3,161	681	234	0	368	9,121	91	3,147	77	89	2,478	481	255	56	936	1,383	8,994	127
2006	2,149	932	1,424	16	12	671	446	2,972	681	272	0	313	9,889	132	3,011	77	81	2,307	485	270	80	1,095	1,505	9,043	845
2007	235	889	1,537	16	16	1,022	131	2,919	563	261	0	361	7,950	76	3,397	77	108	3,527	608	237	64	865	1,117	10,075	-2,126
2008	985	1,704	1,500	16	16	659	285	2,796	254	186	0	350	8,751	2	3,196	77	107	2,457	451	155	61	810	1,202	8,518	232
2009	176	901	1,434	16	16	757	161	2,656	296	153	0	271	6,836	0	2,466	77	105	2,729	515	137	56	703	933	7,721	-885
2010	2,184	1,424	1,329	16	12	429	609	2,427	448	181	0	173	9,232	16	1,678	77	82	1,547	428	204	86	911	1,285	6,314	2,918
2011	1,258	1,753	971	16	14	502	223	2,363	575	219	0	109	8,002	92	1,169	77	92	2,004	444	232	118	1,071	1,699	6,998	1,004
2012	477	668	919	16	14	554	169	2,401	291	177	0	81	5,767	0	1,138	77	93	2,292	423	146	121	958	1,586	6,834	-1,067
2013	32	834	953	16	18	818	88	2,223	231	137	0	120	5,470	0	1,414	77	118	3,277	614	115	95	746	1,108	7,562	-2,092
2014	151	863	1,105	16	15	745	124	2,036	176	116	0	174	5,521	0	1,039	77	98	3,047	571	100	70	539	816	6,357	-836
2015	0	684	952	16	16	773	115	1,596	227	98	0	159	4,636	0	933	77	111	1,825	649	104	62	499	703	4,962	-326
2016	1,145	887	887	16	13	548	309	1,662	293	121	0	126	6,007	0	880	77	87	2,425	426	132	72	524	880	5,503	505
Average	**1,022**	**1,222**	**1,151**	**10**	**14**	**1,196**	**280**	**2,603**	**400**	**183**	**0**	**187**	**8,268**	**37**	**1,600**	**49**	**96**	**2,999**	**477**	**170**	**107**	**1,092**	**1,677**	**8,304**	**-36**

Monthly Municipal Groundwater Pumping Assumptions for Model Scenarios

Month	Monthly Municipal Pumping, AFY						
	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
January	63	123	123	213	213	63	63
February	55	111	111	191	191	55	55
March	78	163	163	282	282	78	78
April	126	323	323	559	559	126	126
May	127	309	309	535	535	127	127
June	112	274	274	475	475	112	112
July	111	267	267	462	462	111	111
August	98	244	244	422	422	98	98
September	96	228	228	395	395	96	96
October	83	194	194	335	335	83	83
November	74	172	172	297	297	74	74
December	57	95	95	164	164	57	57

Table ES-2

NCMA Annual Groundwater Balance - Baseline Scenario

		INFLOWS [acre-ft]														OUTFLOWS [acre-ft]										
Model Year	Hydrologic Year	Areal Recharge from Precip (rch pkg)	Streambed Percolation (model)	Return Flow from Muni Use (rch pkg)	Return Flow from Small Purveyors (rch pkg)	Return Flow from Golf Course Irrig. (rch pkg)	Return Flow from Ag (rch pkg)	Artificial Recharge (wel pkg)	Underflow from NMMA (model)	Underflow from Arroyo Grande Valley (model)	Underflow from Zone 5 (model)	Underflow from Zone 6 (model)	Underflow from Ocean (layer 2) (model)	Underflow from Offshore Aquifers (model)	CCB Injection (wel pkg)	TOTAL INFLOW	Rising Water Discharge to Streamflow (model)	Muni Pumping (wel pkg)	Small Purveyor Pumping (wel pkg)	Golf Pumping (wel pkg)	Ag Pumping (wel pkg)	Underflow to NMMA (model)	Underflow to Zone 5 (model)	Underflow to Zone 6 (model)	Underflow to Ocean (layer 2) (model)	Underflow to Offshore Aquifers (model)	TOTAL OUTFLOW	CHANGE IN STORAGE
1	**1977**	202	844	933	16	15	552	247	1,408	315	122	7	0	136	0	4,796	0	1,080	77	102	2,232	696	125	79	487	674	5,552	-756
2	**1978**	1,265	1,871	933	16	13	392	626	1,245	721	230	9	0	83	0	7,403	117	1,080	77	88	1,585	569	280	100	633	1,034	5,563	1,839
3	**1979**	1,364	975	933	16	14	556	293	1,365	557	254	9	0	66	0	6,402	73	1,080	77	95	2,248	564	238	116	754	1,113	6,358	44
4	**1980**	1,222	1,549	933	16	15	502	350	1,513	614	240	10	0	73	0	7,038	87	1,082	77	102	2,031	500	247	123	766	1,306	6,321	716
5	**1981**	1,370	998	933	16	14	535	322	1,607	558	252	10	0	67	0	6,681	79	1,080	77	92	2,165	445	238	128	804	1,386	6,494	187
6	**1982**	1,295	1,227	933	16	11	411	326	1,650	528	219	11	0	73	0	6,700	48	1,080	77	72	1,662	388	220	129	813	1,464	5,953	747
7	**1983**	3,116	3,123	933	16	12	351	695	1,759	669	238	13	0	58	0	10,981	184	1,080	77	82	1,420	508	256	180	1,252	2,203	7,241	3,740
8	**1984**	284	912	933	16	16	631	145	1,978	349	211	11	0	49	0	5,536	13	1,082	77	107	2,556	517	170	170	1,072	1,924	7,689	-2,153
9	**1985**	252	769	933	16	16	751	150	2,040	284	163	10	0	65	0	5,451	0	1,080	77	110	3,049	465	139	138	838	1,533	7,428	-1,978
10	**1986**	1,411	1,096	933	16	14	544	262	1,900	367	161	11	0	68	0	6,782	0	1,080	77	93	2,198	391	171	132	840	1,516	6,497	285
11	**1987**	588	810	933	16	13	524	216	1,696	420	193	10	0	65	0	5,485	0	1,080	77	88	2,118	437	194	118	747	1,266	6,125	-640
12	**1988**	785	816	933	16	15	548	234	1,542	246	172	10	0	68	0	5,385	1	1,082	77	98	2,216	512	144	111	733	1,109	6,083	-698
13	**1989**	2	685	933	16	17	778	94	1,575	336	147	8	3	138	0	4,733	0	1,080	77	116	3,172	722	143	88	542	767	6,707	-1,973
14	**1990**	68	697	933	16	16	756	137	1,551	167	113	7	29	211	0	4,702	0	1,080	77	108	3,072	760	87	66	364	556	6,169	-1,468
15	**1991**	946	1,071	933	16	14	419	389	1,252	396	142	7	9	130	0	5,726	0	1,080	77	94	1,695	609	171	66	390	574	4,758	969
16	**1992**	1,442	988	933	16	14	474	321	1,173	412	183	8	0	120	0	6,086	8	1,082	77	95	1,919	733	191	85	562	715	5,467	619
17	**1993**	1,883	1,177	933	16	14	466	431	1,164	406	177	9	0	79	0	6,755	2	1,080	77	94	1,886	643	184	103	715	915	5,699	1,056
18	**1994**	917	789	933	16	13	542	177	1,285	421	209	9	0	100	0	5,412	10	1,080	77	90	2,192	705	200	99	638	846	5,936	-524
19	**1995**	2,221	2,380	933	16	13	430	532	1,312	447	182	10	0	62	0	8,538	25	1,080	77	91	1,740	533	201	126	839	1,340	6,052	2,485
20	**1996**	1,301	1,830	933	16	13	393	369	1,461	397	212	10	0	55	0	6,991	47	1,082	77	86	1,593	456	194	138	858	1,514	6,046	945
21	**1997**	1,082	2,617	933	16	16	520	320	1,427	242	135	11	0	48	0	7,365	0	1,080	77	104	2,100	555	130	148	904	1,669	6,768	597
22	**1998**	2,503	3,171	933	16	12	427	585	1,758	390	173	13	0	48	0	10,029	80	1,080	77	79	1,727	489	180	191	1,246	2,328	7,478	2,551
23	**1999**	1,065	1,045	933	16	14	556	284	2,117	354	166	13	0	55	0	6,618	4	1,080	77	95	2,250	476	153	192	1,195	2,242	7,765	-1,147
24	**2000**	1,160	1,125	933	16	14	555	320	2,350	583	219	12	0	73	0	7,361	81	1,082	77	96	2,244	403	229	175	1,102	2,165	7,655	-294
25	**2001**	1,542	1,410	933	16	13	503	465	2,358	682	252	12	0	76	0	8,263	149	1,080	77	89	2,032	373	258	177	1,118	2,256	7,610	653
26	**2002**	465	853	933	16	16	658	164	2,196	540	247	11	0	71	0	6,170	75	1,080	77	105	2,667	440	226	155	943	1,827	7,594	-1,424
27	**2003**	297	832	933	16	15	630	124	2,080	338	193	11	0	80	0	5,549	2	1,080	77	100	2,554	463	170	134	839	1,560	6,979	-1,430
28	**2004**	654	953	933	16	14	560	193	2,008	302	152	10	0	88	0	5,883	0	1,082	77	93	2,269	395	142	122	759	1,429	6,368	-485
29	**2005**	1,398	879	933	16	13	550	189	2,082	679	227	11	0	87	0	7,065	90	1,080	77	89	2,225	415	255	115	833	1,409	6,588	476
30	**2006**	2,149	931	933	16	12	507	446	1,965	678	264	11	0	70	0	7,983	130	1,080	77	81	2,050	388	267	145	1,024	1,681	6,923	1,061
31	**2007**	235	889	933	16	16	761	131	1,943	575	255	10	0	77	0	5,840	80	1,080	77	108	3,094	573	237	129	826	1,347	7,550	-1,709
32	**2008**	985	1,698	933	16	16	557	285	1,778	276	181	10	0	68	0	6,803	5	1,082	77	107	2,253	472	158	126	807	1,408	6,496	307
33	**2009**	176	900	933	16	16	733	161	1,756	308	151	9	0	89	0	5,248	0	1,080	77	105	2,973	603	137	109	668	1,071	6,823	-1,574
34	**2010**	2,184	1,422	933	16	12	418	609	1,563	459	182	10	0	65	0	7,875	19	1,080	77	82	1,694	477	203	117	834	1,222	5,805	2,070
35	**2011**	1,258	1,751	933	16	14	556	223	1,582	574	224	11	0	54	0	7,195	92	1,080	77	92	2,249	529	233	136	954	1,477	6,920	275
36	**2012**	477	667	933	16	14	557	169	1,653	308	186	10	0	56	0	5,045	0	1,082	77	93	2,256	494	153	125	827	1,279	6,386	-1,341
37	**2013**	32	834	933	16	18	790	88	1,697	251	143	9	1	129	0	4,941	0	1,080	77	118	3,227	742	123	97	616	877	6,957	-2,016
38	**2014**	151	863	933	16	15	740	124	1,528	207	122	8	13	205	0	4,924	0	1,080	77	98	3,002	820	106	71	429	571	6,254	-1,330
39	**2015**	0	683	933	16	16	773	115	1,417	262	113	7	45	318	0	4,699	0	1,080	77	111	3,145	972	110	52	325	373	6,245	-1,545
40	**2016**	1,145	887	933	16	13	548	309	1,208	327	130	6	31	226	0	5,779	0	1,082	77	87	2,216	739	146	51	288	352	5,038	741
Average		**1,022**	**1,225**	**933**	**16**	**14**	**561**	**291**	**1,674**	**424**	**188**	**10**	**3**	**94**	**0**	**6,455**	**37**	**1,080**	**77**	**96**	**2,274**	**549**	**185**	**122**	**780**	**1,307**	**6,508**	**-53**

NCMA Annual Groundwater Balance - Scenario 1

Model Year	Hydrologic Year	INFLOWS [acre-ft]															OUTFLOWS [acre-ft]											CHANGE IN STORAGE
		Areal Recharge from Precip (rch pkg)	Streambed Percolation (model)	Return Flow from Muni Use (rch pkg)	Return Flow from Small Purveyors (rch pkg)	Return Flow from Golf Course Irrig. (rch pkg)	Return Flow from Ag (rch pkg)	Artificial Recharge (wel pkg)	Underflow from NMMA (model)	Underflow from Arroyo Grande Valley (model)	Underflow from Zone 5 (model)	Underflow from Zone 6 (model)	Underflow from Ocean (layer 2) (model)	Underflow from Offshore Aquifers (model)	CCB Injection (wel pkg)	TOTAL INFLOW	Rising Water Discharge to Streamflow (model)	Muni Pumping (wel pkg)	Small Purveyor Pumping (wel pkg)	Golf Pumping (wel pkg)	Ag Pumping (wel pkg)	Underflow to NMMA (model)	Underflow to Zone 5 (model)	Underflow to Zone 6 (model)	Underflow to Ocean (layer 2) (model)	Underflow to Offshore Aquifers (model)	TOTAL OUTFLOW	
1	1977	202	844	1,141	16	15	552	247	1,475	312	125	9	0	311	0	5,251	0	2,500	77	102	2,232	671	124	64	493	574	6,837	-1,586
2	1978	1,265	1,871	1,141	16	13	392	626	1,403	726	233	14	0	271	0	7,971	116	2,500	77	88	1,585	536	279	69	608	782	6,640	1,331
3	1979	1,364	974	1,141	16	14	556	293	1,565	568	257	11	0	265	0	7,026	72	2,500	77	95	2,248	528	239	73	689	790	7,311	-285
4	1980	1,222	1,549	1,141	16	15	502	350	1,757	627	244	11	0	285	0	7,721	86	2,504	77	102	2,031	480	249	74	669	944	7,217	504
5	1981	1,370	997	1,141	16	14	535	322	1,872	573	258	9	0	284	0	7,391	78	2,500	77	92	2,165	431	241	75	685	999	7,343	48
6	1982	1,295	1,227	1,141	16	11	411	326	1,932	544	226	10	0	300	0	7,437	47	2,500	77	72	1,662	381	224	74	677	1,066	6,780	657
7	1983	3,116	3,228	1,141	16	12	351	695	1,998	686	244	11	0	210	0	11,706	181	2,500	77	82	1,420	466	261	123	1,096	1,729	7,934	3,772
8	1984	284	912	1,141	16	16	631	145	2,235	366	219	9	0	199	0	6,174	13	2,504	77	107	2,556	483	176	113	917	1,437	8,383	-2,208
9	1985	252	769	1,141	16	16	751	150	2,318	301	171	8	0	285	0	6,179	0	2,500	77	110	3,049	451	145	81	683	1,105	8,199	-2,020
10	1986	1,411	1,096	1,141	16	14	544	262	2,188	385	169	9	0	301	0	7,537	0	2,500	77	93	2,198	383	177	74	677	1,093	7,272	265
11	1987	588	811	1,141	16	13	524	216	1,977	438	199	10	0	323	0	6,256	0	2,500	77	88	2,118	422	199	61	583	862	6,910	-654
12	1988	785	817	1,141	16	15	548	234	1,806	263	179	13	0	338	0	6,155	1	2,504	77	98	2,216	476	149	57	566	713	6,858	-703
13	1989	2	685	1,141	16	17	778	94	1,811	352	153	21	26	481	0	5,576	0	2,500	77	116	3,172	671	148	43	402	439	7,568	-1,992
14	1990	68	697	1,141	16	16	756	137	1,791	180	120	33	91	646	0	5,693	0	2,500	77	108	3,072	717	91	35	267	311	7,177	-1,484
15	1991	946	1,071	1,141	16	14	419	389	1,508	412	147	37	51	563	0	6,714	0	2,500	77	94	1,695	572	175	38	266	327	5,745	969
16	1992	1,442	989	1,141	16	14	474	321	1,393	430	188	29	4	471	0	6,913	8	2,504	77	95	1,919	658	194	48	394	388	6,285	628
17	1993	1,883	1,177	1,141	16	14	466	431	1,389	423	183	24	0	374	0	7,523	2	2,500	77	94	1,886	570	188	61	539	540	6,456	1,067
18	1994	917	789	1,141	16	13	542	177	1,512	438	214	21	1	415	0	6,198	9	2,500	77	90	2,192	637	203	54	466	483	6,711	-513
19	1995	2,221	2,394	1,141	16	13	430	532	1,553	466	188	17	0	294	0	9,267	24	2,500	77	91	1,740	485	206	75	657	906	6,762	2,504
20	1996	1,301	1,832	1,141	16	13	393	369	1,718	416	219	9	0	263	0	7,690	46	2,504	77	86	1,593	418	199	79	674	1,052	6,729	961
21	1997	1,082	2,664	1,141	16	16	520	320	1,648	260	142	9	0	206	0	8,024	0	2,500	77	104	2,100	495	136	89	721	1,167	7,390	634
22	1998	2,503	3,275	1,141	16	12	427	585	1,981	408	179	11	0	195	0	10,733	79	2,500	77	79	1,727	442	187	134	1,060	1,840	8,125	2,608
23	1999	1,065	1,045	1,141	16	14	556	284	2,363	372	176	11	0	198	0	7,242	3	2,500	77	95	2,250	442	160	134	1,015	1,735	8,413	-1,172
24	2000	1,160	1,125	1,141	16	14	555	320	2,621	602	228	10	0	246	0	8,039	79	2,504	77	96	2,244	388	237	116	919	1,673	8,334	-294
25	2001	1,542	1,411	1,141	16	13	503	465	2,634	702	261	10	0	247	0	8,945	148	2,500	77	89	2,032	362	265	117	931	1,762	8,284	662
26	2002	465	853	1,141	16	16	658	164	2,464	559	255	9	0	268	0	6,868	73	2,500	77	105	2,667	421	232	94	759	1,348	8,276	-1,407
27	2003	297	832	1,141	16	15	630	124	2,354	356	202	8	0	313	0	6,289	1	2,500	77	100	2,554	448	176	74	655	1,112	7,697	-1,408
28	2004	654	953	1,141	16	14	560	193	2,301	320	161	9	1	356	0	6,678	0	2,504	77	93	2,269	396	148	62	576	1,013	7,138	-460
29	2005	1,398	879	1,141	16	13	550	189	2,366	699	234	10	1	365	0	7,862	89	2,500	77	89	2,225	406	262	56	649	1,004	7,357	505
30	2006	2,149	931	1,141	16	12	507	446	2,238	698	272	9	0	289	0	8,709	128	2,500	77	81	2,050	371	273	85	834	1,231	7,630	1,079
31	2007	235	889	1,141	16	16	761	131	2,193	593	262	8	1	316	0	6,562	78	2,500	77	108	3,094	534	242	69	646	905	8,253	-1,691
32	2008	985	1,703	1,141	16	16	557	285	2,041	294	189	9	0	299	0	7,535	5	2,504	77	107	2,253	445	164	67	622	959	7,204	331
33	2009	176	900	1,141	16	16	733	161	1,998	325	159	11	7	369	0	6,010	0	2,500	77	105	2,973	556	142	52	495	667	7,568	-1,557
34	2010	2,184	1,422	1,141	16	12	418	609	1,821	477	189	16	0	333	0	8,640	18	2,500	77	82	1,694	442	208	65	650	812	6,548	2,092
35	2011	1,258	1,751	1,141	16	14	556	223	1,822	593	230	11	0	256	0	7,871	90	2,500	77	92	2,249	480	239	78	768	1,009	7,583	289
36	2012	477	667	1,141	16	14	557	169	1,907	326	193	9	0	292	0	5,768	0	2,504	77	93	2,256	458	158	66	645	834	7,091	-1,323
37	2013	32	834	1,141	16	18	790	88	1,921	267	151	16	16	448	0	5,739	0	2,500	77	118	3,228	676	128	46	454	508	7,734	-1,996
38	2014	151	863	1,141	16	15	740	124	1,751	221	129	31	65	619	0	5,865	0	2,500	77	98	3,002	757	111	35	307	289	7,176	-1,311
39	2015	0	683	1,141	16	16	773	115	1,627	276	118	44	123	814	0	5,747	0	2,500	77	111	3,145	888	114	30	231	171	7,267	-1,519
40	2016	1,145	887	1,141	16	13	548	309	1,444	342	134	49	111	766	0	6,904	0	2,504	77	87	2,216	678	148	34	196	195	6,135	769
Average		**1,022**	**1,232**	**1,141**	**16**	**14**	**561**	**291**	**1,917**	**440**	**195**	**15**	**12**	**352**	**0**	**7,210**	**37**	**2,501**	**77**	**96**	**2,274**	**513**	**190**	**72**	**629**	**919**	**7,308**	**-98**

NCMA Annual Groundwater Balance - Scenario 2

Model Year	Hydrologic Year	INFLOWS [acre-ft]															OUTFLOWS [acre-ft]											
		Areal Recharge from Precip (rch pkg)	Streambed Percolation (model)	Return Flow from Muni Use (rch pkg)	Return Flow from Small Purveyors (rch pkg)	Return Flow from Golf Course Irrig. (rch pkg)	Return Flow from Ag (rch pkg)	Artificial Recharge (wel pkg)	Underflow from NMMA (model)	Underflow from Arroyo Grande Valley (model)	Underflow from Zone 5 (model)	Underflow from Zone 6 (model)	Underflow from Ocean (layer 2) (model)	Underflow from Offshore Aquifers (model)	CCB Injection (wel pkg)	TOTAL INFLOW	Rising Water Discharge to Streamflow (model)	Muni Pumping (wel pkg)	Small Purveyor Pumping (wel pkg)	Golf Pumping (wel pkg)	Ag Pumping (wel pkg)	Underflow to NMMA (model)	Underflow to Zone 5 (model)	Underflow to Zone 6 (model)	Underflow to Ocean (layer 2) (model)	Underflow to Offshore Aquifers (model)	TOTAL OUTFLOW	CHANGE IN STORAGE
1	1977	202	844	1,141	16	15	552	247	1,424	311	124	7	0	172	900	5,956	0	2,500	77	102	2,232	686	124	80	488	759	7,049	-1,093
2	1978	1,265	1,871	1,141	16	13	392	626	1,290	722	232	8	0	137	900	8,613	117	2,500	77	88	1,585	553	279	93	619	1,052	6,965	1,648
3	1979	1,364	975	1,141	16	14	556	293	1,427	561	256	8	0	113	900	7,624	73	2,500	77	95	2,248	547	238	105	722	1,087	7,692	-68
4	1980	1,222	1,549	1,141	16	15	502	350	1,591	618	242	9	0	123	900	8,281	86	2,504	77	102	2,031	490	248	110	720	1,263	7,632	649
5	1981	1,370	998	1,141	16	14	535	322	1,694	563	255	9	0	114	900	7,931	79	2,500	77	92	2,165	435	239	114	749	1,329	7,779	152
6	1982	1,295	1,227	1,141	16	11	411	326	1,743	533	223	10	0	123	900	7,958	48	2,500	77	72	1,662	383	222	114	752	1,401	7,230	728
7	1983	3,116	3,176	1,141	16	12	351	695	1,832	674	241	12	0	109	900	12,274	183	2,500	77	82	1,420	489	258	165	1,183	2,143	8,499	3,775
8	1984	284	912	1,141	16	16	631	145	2,059	355	216	11	0	76	900	6,761	13	2,504	77	107	2,556	502	173	155	1,004	1,837	8,928	-2,166
9	1985	252	769	1,141	16	16	751	150	2,131	289	168	10	0	94	900	6,687	0	2,500	77	110	3,049	458	142	123	769	1,442	8,670	-1,983
10	1986	1,411	1,096	1,141	16	14	544	262	1,994	373	166	10	0	107	900	8,035	0	2,500	77	93	2,198	386	174	116	768	1,431	7,743	292
11	1987	588	810	1,141	16	13	524	216	1,786	426	196	9	0	104	900	6,730	0	2,500	77	88	2,118	428	196	102	675	1,178	7,362	-631
12	1988	785	816	1,141	16	15	548	234	1,624	251	176	9	0	111	900	6,627	1	2,504	77	98	2,216	494	146	95	660	1,024	7,316	-689
13	1989	2	685	1,141	16	17	778	94	1,649	341	150	8	11	201	900	5,994	0	2,500	77	116	3,172	701	145	72	479	699	7,960	-1,966
14	1990	68	697	1,141	16	16	756	137	1,627	170	117	7	53	296	900	6,003	0	2,500	77	108	3,072	745	89	50	319	508	7,468	-1,465
15	1991	946	1,071	1,141	16	14	419	389	1,331	401	145	8	21	231	900	7,035	0	2,500	77	94	1,695	591	173	52	330	542	6,055	980
16	1992	1,442	989	1,141	16	14	474	321	1,241	418	186	8	0	210	900	7,361	8	2,504	77	95	1,919	703	192	69	488	672	6,726	634
17	1993	1,883	1,177	1,141	16	14	466	431	1,232	411	181	9	0	155	900	8,017	2	2,500	77	94	1,886	611	185	87	639	862	6,942	1,074
18	1994	917	789	1,141	16	13	542	177	1,356	427	212	8	0	172	900	6,671	9	2,500	77	90	2,192	676	201	83	563	786	7,177	-506
19	1995	2,221	2,388	1,141	16	13	430	532	1,384	453	185	9	0	124	900	9,798	25	2,500	77	91	1,740	508	203	110	760	1,276	7,289	2,509
20	1996	1,301	1,832	1,141	16	13	393	369	1,541	404	215	9	0	106	900	8,241	47	2,504	77	86	1,593	438	196	122	779	1,436	7,279	962
21	1997	1,082	2,645	1,141	16	16	520	320	1,490	247	139	10	0	83	900	8,609	0	2,500	77	104	2,100	526	133	133	825	1,580	7,978	631
22	1998	2,503	3,226	1,141	16	12	427	585	1,822	396	177	12	0	96	900	11,313	80	2,500	77	79	1,727	466	183	176	1,166	2,263	8,718	2,595
23	1999	1,065	1,045	1,141	16	14	556	284	2,194	360	172	12	0	85	900	7,845	3	2,500	77	95	2,250	461	157	177	1,118	2,154	8,992	-1,147
24	2000	1,160	1,125	1,141	16	14	555	320	2,437	590	224	11	0	107	900	8,600	80	2,504	77	96	2,244	395	233	160	1,023	2,073	8,885	-285
25	2001	1,542	1,411	1,141	16	13	503	465	2,447	689	257	11	0	115	900	9,511	149	2,500	77	89	2,032	366	261	161	1,037	2,169	8,843	669
26	2002	465	853	1,141	16	16	658	164	2,283	546	251	10	0	98	900	7,402	74	2,500	77	105	2,667	431	228	138	863	1,723	8,807	-1,405
27	2003	297	832	1,141	16	15	630	124	2,168	344	198	10	0	110	900	6,785	2	2,500	77	100	2,554	454	172	118	760	1,457	8,194	-1,409
28	2004	654	953	1,141	16	14	560	193	2,103	308	157	9	0	127	900	7,135	0	2,504	77	93	2,269	392	145	105	680	1,334	7,600	-465
29	2005	1,398	879	1,141	16	13	550	189	2,174	686	231	10	0	135	900	8,323	90	2,500	77	89	2,225	409	258	98	753	1,322	7,823	500
30	2006	2,149	931	1,141	16	12	507	446	2,052	685	269	10	0	120	900	9,239	129	2,500	77	81	2,050	379	270	129	943	1,602	8,159	1,080
31	2007	235	889	1,141	16	16	761	131	2,022	581	258	9	0	116	900	7,076	79	2,500	77	108	3,094	555	239	112	748	1,253	8,765	-1,689
32	2008	985	1,702	1,141	16	16	557	285	1,859	282	185	9	0	108	900	8,045	5	2,504	77	107	2,253	456	161	110	727	1,316	7,717	328
33	2009	176	900	1,141	16	16	733	161	1,831	313	156	8	1	135	900	6,486	0	2,500	77	105	2,973	581	139	92	591	983	8,041	-1,555
34	2010	2,184	1,422	1,141	16	12	418	609	1,642	465	186	9	0	118	900	9,123	18	2,500	77	82	1,694	458	205	101	755	1,142	7,031	2,092
35	2011	1,258	1,751	1,141	16	14	556	223	1,655	581	227	10	0	101	900	8,433	91	2,500	77	92	2,249	505	235	120	874	1,394	8,138	295
36	2012	477	667	1,141	16	14	557	169	1,732	314	190	9	0	94	900	6,280	0	2,504	77	93	2,256	475	156	109	748	1,185	7,602	-1,322
37	2013	32	834	1,141	16	18	790	88	1,767	256	148	8	5	186	900	6,190	0	2,500	77	118	3,228	713	125	81	543	798	8,183	-1,993
38	2014	151	863	1,141	16	15	740	124	1,600	211	126	7	30	288	900	6,212	0	2,500	77	98	3,002	802	108	54	372	512	7,526	-1,314
39	2015	0	683	1,141	16	16	773	115	1,484	267	116	10	77	430	900	6,030	0	2,500	77	111	3,145	943	112	40	283	343	7,553	-1,523
40	2016	1,145	887	1,141	16	13	548	309	1,282	331	133	14	63	367	900	7,150	0	2,504	77	87	2,216	714	146	42	246	352	6,385	764
Average		**1,022**	**1,229**	**1,141**	**16**	**14**	**561**	**291**	**1,750**	**429**	**192**	**9**	**7**	**147**	**900**	**7,710**	**37**	**2,501**	**77**	**96**	**2,274**	**533**	**187**	**107**	**713**	**1,242**	**7,768**	**-58**

Table ES-6

NCMA Annual Groundwater Balance - Scenario 3

Model Year	Hydrologic Year	INFLOWS [acre-ft]															OUTFLOWS [acre-ft]											CHANGE IN STORAGE
		Areal Recharge from Precip (rch pkg)	Streambed Percolation (model)	Return Flow from Muni Use (rch pkg)	Return Flow from Small Purveyors (rch pkg)	Return Flow from Golf Course Irrig. (rch pkg)	Return Flow from Ag (rch pkg)	Artificial Recharge (wel pkg)	Underflow from NMMA (model)	Underflow from Arroyo Grande Valley (model)	Underflow from Zone 5 (model)	Underflow from Zone 6 (model)	Underflow from Ocean (layer 2) (model)	Underflow from Offshore Aquifers (model)	CCB Injection (wel pkg)	TOTAL INFLOW	Rising Water Discharge to Streamflow (model)	Muni Pumping (wel pkg)	Small Purveyor Pumping (wel pkg)	Golf Pumping (wel pkg)	Ag Pumping (wel pkg)	Underflow to NMMA (model)	Underflow to Zone 5 (model)	Underflow to Zone 6 (model)	Underflow to Ocean (layer 2) (model)	Underflow to Offshore Aquifers (model)	TOTAL OUTFLOW	
1	**1977**	202	844	1,176	16	15	552	247	1,558	317	128	23	2	582	0	5,661	0	4,330	77	102	2,232	646	122	55	492	490	8,546	-2,885
2	**1978**	1,265	1,871	1,176	16	13	392	626	1,608	744	234	45	0	644	0	8,634	115	4,330	77	88	1,585	514	277	49	551	552	8,137	497
3	**1979**	1,364	974	1,176	16	14	556	293	1,846	592	260	49	1	727	0	7,868	71	4,330	77	95	2,247	510	239	47	570	516	8,702	-835
4	**1980**	1,222	1,550	1,176	16	15	502	350	2,093	655	248	52	2	787	0	8,669	83	4,330	77	102	2,032	473	251	44	504	631	8,527	142
5	**1981**	1,370	997	1,176	16	14	535	322	2,240	604	262	51	5	820	0	8,413	76	4,330	77	92	2,165	428	245	42	487	671	8,613	-200
6	**1982**	1,295	1,227	1,176	16	11	411	326	2,328	576	231	56	3	863	0	8,518	45	4,330	77	72	1,662	393	229	41	454	729	8,033	485
7	**1983**	3,116	3,359	1,176	16	12	351	695	2,336	720	250	33	0	593	0	12,657	177	4,330	77	82	1,420	434	268	67	838	1,227	8,920	3,737
8	**1984**	284	913	1,176	16	16	631	145	2,596	400	228	26	0	649	0	7,080	12	4,330	77	107	2,556	462	183	50	662	970	9,408	-2,328
9	**1985**	252	769	1,176	16	16	751	150	2,712	334	179	45	22	861	0	7,284	0	4,330	77	110	3,049	455	152	36	449	736	9,394	-2,110
10	**1986**	1,411	1,096	1,176	16	14	544	262	2,603	420	177	56	22	910	0	8,706	0	4,330	77	93	2,198	405	185	38	433	745	8,505	201
11	**1987**	588	811	1,176	16	13	524	216	2,389	472	206	63	35	1,007	0	7,516	0	4,330	77	88	2,118	435	205	31	350	579	8,213	-696
12	**1988**	785	817	1,176	16	15	548	234	2,208	296	187	69	39	1,063	0	7,452	0	4,330	77	98	2,216	482	156	29	333	463	8,185	-733
13	**1989**	2	685	1,176	16	17	778	94	2,183	384	159	81	121	1,331	0	7,026	0	4,330	77	116	3,172	650	153	19	229	293	9,039	-2,013
14	**1990**	68	697	1,176	16	16	756	137	2,171	206	127	97	238	1,593	0	7,299	0	4,330	77	108	3,072	698	97	12	147	246	8,788	-1,489
15	**1991**	946	1,071	1,176	16	14	419	389	1,904	440	151	101	199	1,512	0	8,339	0	4,330	77	94	1,695	573	180	16	145	270	7,381	958
16	**1992**	1,442	989	1,176	16	14	474	321	1,740	460	191	91	93	1,345	0	8,352	8	4,330	77	95	1,919	615	198	25	208	267	7,741	612
17	**1993**	1,883	1,177	1,176	16	14	466	431	1,748	454	188	81	35	1,145	0	8,815	1	4,330	77	94	1,886	543	193	33	293	326	7,776	1,040
18	**1994**	917	789	1,176	16	13	542	177	1,868	468	218	80	59	1,238	0	7,562	8	4,330	77	90	2,192	606	207	27	243	304	8,084	-522
19	**1995**	2,221	2,395	1,176	16	13	430	532	1,913	498	194	66	9	912	0	10,375	23	4,330	77	91	1,740	459	212	40	374	551	7,897	2,479
20	**1996**	1,301	1,833	1,176	16	13	393	369	2,085	448	225	54	2	847	0	8,762	45	4,330	77	86	1,593	401	205	39	383	656	7,816	946
21	**1997**	1,082	2,692	1,176	16	16	520	320	1,978	293	150	43	0	715	0	9,001	0	4,330	77	104	2,100	452	143	39	427	708	8,380	621
22	**1998**	2,503	3,355	1,176	16	12	427	585	2,306	441	187	29	0	573	0	11,610	77	4,330	77	79	1,727	406	196	70	755	1,289	9,006	2,604
23	**1999**	1,065	1,045	1,176	16	14	556	284	2,715	405	187	22	0	626	0	8,112	3	4,330	77	95	2,250	418	169	62	717	1,203	9,325	-1,213
24	**2000**	1,160	1,125	1,176	16	14	555	320	3,006	636	237	30	0	727	0	9,002	77	4,330	77	96	2,244	390	246	50	619	1,173	9,302	-301
25	**2001**	1,542	1,411	1,176	16	13	503	465	3,024	737	269	29	1	716	0	9,902	146	4,330	77	89	2,032	369	274	51	627	1,256	9,252	650
26	**2002**	465	853	1,176	16	16	658	164	2,856	591	263	37	14	826	0	7,934	72	4,330	77	105	2,667	426	239	36	476	906	9,334	-1,400
27	**2003**	297	833	1,176	16	15	630	124	2,758	388	210	52	37	958	0	7,493	1	4,330	77	100	2,554	463	183	30	396	751	8,885	-1,393
28	**2004**	654	953	1,176	16	14	560	193	2,722	351	169	62	54	1,062	0	7,987	0	4,330	77	93	2,269	428	156	28	335	710	8,426	-439
29	**2005**	1,398	879	1,176	16	13	550	189	2,777	732	240	68	50	1,098	0	9,186	87	4,330	77	89	2,225	428	270	27	403	731	8,667	519
30	**2006**	2,149	931	1,176	16	12	507	446	2,635	731	278	55	4	869	0	9,809	127	4,330	77	81	2,050	383	280	45	536	833	8,742	1,067
31	**2007**	235	889	1,176	16	16	761	131	2,574	624	267	56	37	992	0	7,773	77	4,330	77	108	3,094	532	247	30	390	578	9,462	-1,689
32	**2008**	985	1,703	1,176	16	16	557	285	2,433	325	196	59	38	962	0	8,751	4	4,330	77	107	2,253	450	170	31	365	626	8,414	337
33	**2009**	176	900	1,176	16	16	733	161	2,385	355	166	68	82	1,150	0	7,382	0	4,330	77	105	2,973	555	148	23	281	435	8,928	-1,545
34	**2010**	2,184	1,422	1,176	16	12	418	609	2,213	509	195	71	30	1,042	0	9,898	17	4,330	77	82	1,694	442	215	34	383	525	7,799	2,099
35	**2011**	1,258	1,751	1,176	16	14	556	223	2,183	627	235	57	5	844	0	8,946	88	4,330	77	92	2,249	458	245	39	473	614	8,665	280
36	**2012**	477	667	1,176	16	14	557	169	2,287	357	201	59	23	978	0	6,980	0	4,330	77	93	2,256	452	165	30	373	516	8,292	-1,312
37	**2013**	32	834	1,176	16	18	790	88	2,280	296	158	76	103	1,294	0	7,162	0	4,330	77	118	3,227	645	134	20	254	333	9,138	-1,976
38	**2014**	151	863	1,176	16	15	740	124	2,101	247	136	95	209	1,575	0	7,448	0	4,330	77	98	3,002	712	117	12	170	213	8,731	-1,284
39	**2015**	0	683	1,176	16	16	773	115	1,955	301	124	110	295	1,816	0	7,379	0	4,330	77	111	3,145	818	119	9	126	136	8,870	-1,491
40	**2016**	1,145	887	1,176	16	13	548	309	1,824	368	137	114	292	1,768	0	8,595	0	4,330	77	87	2,216	666	151	12	102	168	7,810	785
Average		**1,022**	**1,238**	**1,176**	**16**	**14**	**561**	**291**	**2,278**	**470**	**201**	**60**	**54**	**1,001**	**0**	**8,383**	**36**	**4,330**	**77**	**96**	**2,274**	**502**	**196**	**35**	**409**	**623**	**8,578**	**-195**

Table ES-7

NCMA Annual Groundwater Balance - Scenario 4

Model Year	Hydrologic Year	INFLOWS [acre-ft] Areal Recharge from Precip (rch pkg)	Streambed Percolation (model)	Return Flow from Muni Use (rch pkg)	Return Flow from Small Purveyors (rch pkg)	Return Flow from Golf Course Irrig. (rch pkg)	Return Flow from Ag (rch pkg)	Artificial Recharge (wel pkg)	Underflow from NMMA (model)	Underflow from Arroyo Grande Valley (model)	Underflow from Zone 5 (model)	Underflow from Zone 6 (model)	Underflow from Ocean (layer 2) (model)	Underflow from Offshore Aquifers (model)	CCB Injection (wel pkg)	TOTAL INFLOW	OUTFLOWS [acre-ft] Rising Water Discharge to Streamflow (model)	Muni Pumping (wel pkg)	Small Purveyor Pumping (wel pkg)	Golf Pumping (wel pkg)	Ag Pumping (wel pkg)	Underflow to NMMA (model)	Underflow to Zone 5 (model)	Underflow to Zone 6 (model)	Underflow to Ocean (layer 2) (model)	Underflow to Offshore Aquifers (model)	TOTAL OUTFLOW	CHANGE IN STORAGE
1	1977	202	844	1,184	16	15	552	247	1,373	312	125	6	0	227	3,500	8,604	0	4,330	77	102	2,232	710	123	111	479	1,331	9,495	-891
2	1978	1,265	1,871	1,176	16	13	392	626	1,194	725	230	8	0	153	3,500	11,169	116	4,330	77	88	1,585	572	278	131	613	1,575	9,366	1,803
3	1979	1,364	975	1,176	16	14	556	293	1,320	563	254	8	0	149	3,500	10,188	73	4,330	77	95	2,247	573	237	142	722	1,640	10,137	50
4	1980	1,222	1,549	1,176	16	15	502	350	1,464	620	240	9	0	131	3,500	10,795	86	4,330	77	102	2,032	509	246	148	728	1,803	10,061	734
5	1981	1,370	998	1,176	16	14	535	322	1,558	564	254	9	0	122	3,500	10,437	79	4,330	77	92	2,165	452	238	152	764	1,875	10,224	213
6	1982	1,295	1,227	1,176	16	11	411	326	1,600	534	221	10	0	115	3,500	10,441	48	4,330	77	72	1,662	394	220	153	772	1,939	9,667	774
7	1983	3,116	3,172	1,176	16	12	351	695	1,701	674	239	12	0	78	3,500	14,742	183	4,330	77	82	1,420	514	256	204	1,210	2,664	10,940	3,803
8	1984	284	912	1,176	16	16	631	145	1,929	354	214	11	0	99	3,500	9,287	13	4,330	77	107	2,556	529	171	195	1,032	2,420	11,430	-2,143
9	1985	252	769	1,176	16	16	751	150	1,991	289	166	10	0	123	3,500	9,210	0	4,330	77	110	3,049	478	141	163	800	2,030	11,177	-1,967
10	1986	1,411	1,096	1,176	16	14	544	262	1,848	373	164	10	0	112	3,500	10,527	0	4,330	77	93	2,198	399	172	157	802	1,998	10,226	301
11	1987	588	810	1,176	16	13	524	216	1,648	426	195	10	0	134	3,500	9,256	0	4,330	77	88	2,118	447	194	142	709	1,772	9,878	-622
12	1988	785	816	1,176	16	15	548	234	1,494	251	175	9	0	153	3,500	9,174	1	4,330	77	98	2,216	523	145	135	696	1,635	9,857	-683
13	1989	2	685	1,176	16	17	778	94	1,533	341	149	8	5	253	3,500	8,558	0	4,330	77	116	3,172	738	144	113	508	1,319	10,517	-1,959
14	1990	68	697	1,176	16	16	756	137	1,510	170	116	7	36	324	3,500	8,531	0	4,330	77	108	3,072	778	88	91	336	1,105	9,985	-1,454
15	1991	946	1,071	1,176	16	14	419	389	1,208	401	144	7	12	245	3,500	9,548	0	4,330	77	94	1,695	623	171	90	358	1,122	8,561	987
16	1992	1,442	989	1,176	16	14	474	321	1,131	418	184	8	0	240	3,500	9,913	8	4,330	77	95	1,919	750	190	109	527	1,274	9,280	633
17	1993	1,883	1,177	1,176	16	14	466	431	1,119	411	179	9	0	175	3,500	10,555	2	4,330	77	94	1,886	652	183	128	680	1,452	9,484	1,071
18	1994	917	789	1,176	16	13	542	177	1,242	426	210	8	0	210	3,500	9,228	10	4,330	77	90	2,192	720	199	123	603	1,393	9,737	-509
19	1995	2,221	2,387	1,176	16	13	430	532	1,257	453	183	9	0	112	3,500	12,290	25	4,330	77	91	1,740	540	201	150	803	1,833	9,789	2,501
20	1996	1,301	1,832	1,176	16	13	393	369	1,409	403	213	10	0	107	3,500	10,743	47	4,330	77	86	1,593	462	194	163	820	2,010	9,782	960
21	1997	1,082	2,639	1,176	16	16	520	320	1,373	247	137	10	0	104	3,500	11,139	0	4,330	77	104	2,100	564	131	173	866	2,170	10,516	624
22	1998	2,503	3,214	1,176	16	12	427	585	1,695	395	175	12	0	71	3,500	13,780	80	4,330	77	79	1,727	495	181	217	1,210	2,807	11,203	2,578
23	1999	1,065	1,045	1,176	16	14	556	284	2,063	359	170	12	0	86	3,500	10,346	3	4,330	77	95	2,250	485	155	218	1,159	2,722	11,493	-1,147
24	2000	1,160	1,125	1,176	16	14	555	320	2,295	589	223	12	0	96	3,500	11,081	80	4,330	77	96	2,244	409	231	200	1,063	2,634	11,366	-285
25	2001	1,542	1,411	1,176	16	13	503	465	2,303	688	255	12	0	96	3,500	11,980	149	4,330	77	89	2,032	378	259	202	1,078	2,718	11,313	667
26	2002	465	853	1,176	16	16	658	164	2,147	546	250	11	0	114	3,500	9,915	74	4,330	77	105	2,667	449	227	179	903	2,307	11,317	-1,402
27	2003	297	832	1,176	16	15	630	124	2,033	343	196	10	0	132	3,500	9,305	2	4,330	77	100	2,554	473	171	159	799	2,046	10,709	-1,405
28	2004	654	953	1,176	16	14	560	193	1,959	307	156	10	0	137	3,500	9,635	0	4,330	77	93	2,269	404	143	146	719	1,916	10,098	-463
29	2005	1,398	879	1,176	16	13	550	189	2,032	685	230	10	0	129	3,500	10,807	90	4,330	77	89	2,225	422	256	139	794	1,885	10,308	500
30	2006	2,149	931	1,176	16	12	507	446	1,913	685	267	10	0	103	3,500	11,715	129	4,330	77	81	2,050	395	268	169	985	2,155	10,639	1,076
31	2007	235	889	1,176	16	16	761	131	1,898	580	257	9	0	150	3,500	9,618	79	4,330	77	108	3,094	585	237	153	788	1,855	11,306	-1,688
32	2008	985	1,702	1,176	16	16	557	285	1,728	281	183	10	0	126	3,500	10,565	5	4,330	77	107	2,253	480	159	151	768	1,906	10,237	327
33	2009	176	900	1,176	16	16	733	161	1,712	313	154	9	0	184	3,500	9,050	0	4,330	77	105	2,973	616	138	133	630	1,600	10,602	-1,552
34	2010	2,184	1,422	1,176	16	12	418	609	1,514	464	185	9	0	131	3,500	11,642	18	4,330	77	82	1,694	486	203	142	797	1,725	9,553	2,089
35	2011	1,258	1,751	1,176	16	14	556	223	1,533	580	225	10	0	110	3,500	10,952	91	4,330	77	92	2,249	538	233	160	917	1,974	10,662	290
36	2012	477	667	1,176	16	14	557	169	1,606	313	188	9	0	133	3,500	8,825	0	4,330	77	93	2,256	504	154	150	790	1,796	10,149	-1,325
37	2013	32	834	1,176	16	18	790	88	1,657	256	147	8	1	240	3,500	8,763	0	4,330	77	118	3,227	754	124	122	579	1,421	10,752	-1,990
38	2014	151	863	1,176	16	15	740	124	1,491	211	125	7	17	334	3,500	8,770	0	4,330	77	98	3,002	842	107	95	397	1,129	10,078	-1,308
39	2015	0	683	1,176	16	16	773	115	1,387	266	115	6	54	459	3,500	8,568	0	4,330	77	111	3,145	1,001	111	76	299	943	10,092	-1,524
40	2016	1,145	887	1,176	16	13	548	309	1,170	331	131	6	40	361	3,500	9,634	0	4,330	77	87	2,216	762	145	75	262	920	8,874	760
Average		**1,022**	**1,229**	**1,176**	**16**	**14**	**561**	**291**	**1,626**	**429**	**191**	**9**	**4**	**164**	**3,500**	**10,232**	**37**	**4,330**	**77**	**96**	**2,274**	**560**	**186**	**146**	**744**	**1,821**	**10,271**	**-39**

GEOSCIENCE

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Technical Memorandum

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From:	Dennis E. Williams, Ph.D., PG, CHG President GEOSCIENCE Support Services, Inc.	Johnson Yeh, Ph.D., PG, CHG Principal Geohydrologist GEOSCIENCE Support Services, Inc.
	Kapo Coulibaly, Ph.D. Project Geohydrologist GEOSCIENCE Support Services, Inc.	
Date:	June 15, 2018	
Subject:	**Groundwater Model Boundaries – City of Pismo Beach and SSLOCSD RGSP Phase 1B Hydrogeologic Evaluation**	

1.0 INTRODUCTION

GEOSCIENCE Support Services, Inc. (GEOSCIENCE) presents this technical memorandum (TM) in partial fulfillment of Task 2.1 (development of recommendations for expanding the extent of the Phase 1B model) and Task 2.3 (development of a 3-dimensional (3-D) lithologic model of the Phase 1B model). The model boundary conditions for the newly expanded model are also defined. The expanded boundary will allow for the evaluation of injection and extraction scenarios for both the City of Pismo Beach and South San Luis Obispo County Sanitation District (SSLOCSD). The recommended model area is appropriate for an accurate representation of current and future conditions. This TM was modified to address comments from the Nipomo Mesa Management Area (NMMA) Technical Group, Northern Cities Management Area (NCMA) Technical Group (through GSI Water Solutions, Inc.), and comments from Robert Collar of Golden State Water Company (GSWC). Specific responses to these comments are provided in Attachment A).

2.0 MODEL EXTENT

The Phase 1A and Phase 1B model extents are shown on Figure 1. The Phase 1A model (Cleath-Harris, 2017) was constructed to simulate injection and extraction of advanced-treated water from the City of Pismo Beach's Wastewater Treatment Plant (WWTP). The Phase 1B model will be used to evaluate injection and extraction scenarios with flows from the SSLOCSD and City of Pismo Beach WWTPs. Therefore, the proposed Phase 1B model area was expanded to encompass the entire NCMA, the entire NMMA, and part of the Santa Maria Valley Management Area (SMVMA). Ideally, a model extent should include natural groundwater basin boundaries or be large enough to avoid significant boundary effects during scenario runs. By incorporating the entire NMMA and part of SMVMA, the expanded model extent will allow scenarios in NCMA to be run without the risk of boundary effects. The larger extent will also allow for the incorporation of more data. This in turn will ensure that the behavior of the natural system is accurately captured.

3.0 BOUNDARY CONDITIONS

The boundary conditions and active area of the expanded model are shown on Figure 2. The active area of the model coincides with the boundaries of the groundwater basin in the north and northeast. These boundaries are based on local geology and California Department of Water Resources (DWR) groundwater basin boundaries. The main water-bearing formations are the Paso Robles Formation and the Careaga Sandstone, which constitute the deeper aquifer, and the dune sand, terrace deposits, and quaternary alluvium, which constitute the shallow aquifer (LSCE, 2017). The boundary conditions for the Phase 1B model include no-flow, general head, and constant head boundaries.

3.1 Mountain Front Recharge Boundaries

The water-bearing formations are flanked to the north and northeast by outcrops of older, consolidated formations (Pismo, Obispo, Franciscan, and Monterey Formations), which constitute the Temettate Ridge and San Luis range. Outcrops of Paso Robles Formation, Careaga Sandstone, and undifferentiated Tertiary formations form the Casmalia Hills to the southwest (Worts, 1951). The consolidated rocks have characteristically low yields and contribute limited groundwater to the downgradient groundwater basin (NMMA Technical Group, 2017). The consolidated formations (from oldest to youngest: Franciscan and Knoxville Formations, Monterey Shale and interbedded volcanics, Sisquoc Formation, and the Foxen Mudstone) have been described as essentially non-water-bearing (Worts 1951). Worts (1951) reported that a few wells were drilled in these formations for domestic and stock use, but were unable to yield sufficient water.

Even though these formations are known to have limited yield, the active model area could potentially be receiving inflow along the northeastern boundaries of consolidated rock outcrops in the form of mountain front recharge. The term “mountain front recharge” is frequently used to describe the contribution of water from surrounding mountains to groundwater recharge in adjacent basins, which occurs along the mountain front. The mountain front is positioned somewhere between the mountain block and the basin (Anderson, Woessner, and Hunt, 2015; Wilson and Guan, 2004). These contributions can also include underflow from the consolidated formations that constitute the mountains (Wilson and Guan, 2004).

Existing reports from the study area (FUGRO, 2015; GSI, 2017; LSCE, 2000; NMMA Technical Group, 2017) do not reference mountain front recharge or include an estimate of mountain front recharge in their water balance calculations. However, GEOSCIENCE has determined that it is conceptually sound to include mountain front recharge along the model boundaries that coincide with the Temattate Ridge in the northeast and the Casmalia and Solomon Hills in the southwest. As in semiarid climates, a significant component of recharge to basin aquifers occurs along the mountain front (Wilson & Guan, 2004). Additionally, some subsurface inflow comes from consolidated rocks surrounding the basin (DWR, 2004), which can also be included in the mountain front recharge term (Wilson & Guan, 2004). Initial estimates of mountain front recharge will be derived from previous studies with similar environments, rainfall, and runoff estimates from surface water basin extents. These initial input values will be submitted to the Technical Advisory Committee (TAC) for approval.

3.2 General Head Boundaries

The southern boundary of the active area of the model intersects the Santa Maria Groundwater Basin along the Santa Maria River and will be represented by a general head boundary (GHB) to simulate groundwater underflow across the boundary (Figure 2). The heads of the GHB will be derived from historical groundwater levels and varied throughout the calibration period. While the Wilmar Avenue Fault of the San Luis Range Fault System acts as a flow barrier between the northeastern outcrop and the groundwater basin, there is no evidence that this fault impedes flow in the alluvium of the Arroyo Grande and Pismo Creek areas (GSI, 2017). A more detailed analysis of water levels across the fault during the conceptual model development phase, which will include water level contouring, will help confirm the impact of the fault. For now, the quaternary alluvium at these two locations will be represented as GHBs, based on the NCMA report (GSI, 2017), with heads derived from historical water levels to simulate underflow from upgradient stream drainages (Figure 2).

3.3 Ocean Boundary

The northwestern boundary of the study area coincides with the Pacific Ocean and will be represented as a GHB to simulate underflow between the groundwater basin and the ocean. The heads will be set to sea level to represent the surface of the ocean. Unlike the southern GHB (Section 3.2), which will be simulated to the full depth of the model (top to bottom), the GHB here will only be assigned to the top of model layer 1 where it interfaces with the ocean (Figure 3). The remaining layers will not be assigned a CHB. The active layers will be extended into the Pacific Ocean. The extension of the layers into the ocean is based on DWR (1979), which estimates that the aquifer system extends oceanward 12 miles and that this offshore aquifer system holds a considerable amount of fresh water.

4.0 GROUNDWATER MODEL BOTTOM (BEDROCK SURFACE)

The bottom of the model will be modeled as a no-flow boundary. Therefore, the surface elevation of the formations which constitute this boundary need to be determined so that the bottom of the model can be spatially mapped. The bottom of the model is synonymous with the bedrock surface. Bedrock is defined as consolidated, low yield formations which underlie, and also generally flank, the main groundwater basin represented by water-bearing formations. Based on previous studies (, DWR, 1971 and 2002; FUGRO, 2015; Worts, 1951), the water-bearing formations and the low yield formations were determined and are presented below.

The water-bearing formations in the proposed model area from youngest to oldest include:

- Recent alluvium,
- Young and old dune sand,
- Paso Robles Formation, and
- Careaga Sandstone/Sand.

The low yield formations which constitute the bedrock include:

- Sisquoc Formation,
- Obispo Formation, and
- Franciscan Formations.

The following sections summarize the construction of the preliminary bedrock surface, which constitutes the base of the water-bearing formations and the bottom of the groundwater model.

4.1 Sources for Delineating the Bedrock Surface

A total of 23 cross-sections (Figure 4) were analyzed from four (4) different sources. These sources are:

- California Department of Water Resources 2002 Report (DWR, 2002)

This report contains three (3) cross-sections. They were constructed using lithologic and geophysical logs, existing reports, and geological maps. Seismic studies by PG&E were also used to refine the Oceano Fault.

- NMMA 2016 annual report (NMMA Technical Group, 2017)

  This report contains three (3) cross-sections. The cross-sections produced by the NMMA Technical Group were developed from water and oil well logs, geophysical surveys, existing reports, and geologic maps and were primarily intended for an evaluation of groundwater flow. Therefore, they are mainly located at the boundaries of the NMMA.

- Luhdorff & Scalmanini Consulting Engineers Modeling Report (LSCE, 2000), and

  LSCE developed four (4) cross-sections to support their modeling effort. Their cross-sections are mainly based on lithologic logs and previous reports.

- The Santa Maria Basin Characterization (SMBC) study (FUGRO, 2015).

  This report compiled an extensive list of geological and geophysical logs along with a detailed review of previous work to generate 13 cross-sections in the NCMA and NMMA areas.

4.2 Preliminary Bedrock Surface

The bedrock surface from the cross-sections described above were digitized and plotted in 3-D to check for discrepancies between various sources. An initial interpolation using Petrel software was also conducted and the preliminary bedrock surface is shown on Figure 5. Actual lithologic logs were only used to resolve significant discrepancies.

While some discrepancy was expected due to location uncertainties associated with cross-section image quality and georeferencing, most of the cross-sections were relatively comparable across various sources. For example, bedrock surface from DWR (2002) cross-sections and FUGRO (2015) cross-sections were relatively similar. In particular, the FUGRO (2015) Cross-Sections L-L' and M-M', which parallel DWR (2002) Cross-Section A-A', show the same deepening trends of the bedrock surface.

The only significant discrepancy in the bedrock surface was noted between LSCE (2000) Cross-Section A-A' and DWR (2002) Cross-Section A-A' – both the trend and magnitude of bedrock surface elevation differed, particularly at the intersection of both cross-sections. The DWR (2002) Cross-Section A-A' shows a general thickening of the aquifers and relatively deep bedrock. Conversely, the LSCE (2000) Cross-Section A-A' exhibits an upward trend of the bedrock surface, which resulted in a thinning of the aquifers and the bedrock becoming significantly shallower toward the ocean. The resulting difference between the two bedrock surfaces was approximately 700 ft. GEOSCIENCE used lithologic logs from nearby Division of Oil, Gas, and Geothermal Resources (DOGGR) wells to resolve these differences (Figure 6). The DOGGR logs show the top of the bedrock at depths of 1,175 ft (Leroy A-1), 1,480 ft (Leroy G-3A), and 1,175 ft (Union Sugar 2); which is more consistent with DWR (2002). Therefore, the DWR cross-section was used. For the remainder of the model domain, discrepancies were generally minor and the FUGRO report was generally given precedence because it is more comprehensive and more recent compared to the other sources. The points used to generate the bedrock surface are shown in Figure 7.

5.0 REFERENCES

Anderson, M. P., Woessner, W. W., and Hunt, R. J. 2015. Applied Groundwater Modeling: Simulation of Flow and Advective Transport. San Diego: Elsevier Science.

Cleath-Harris (Cleath-Harris Geologists). 2017. Groundwater Flow Analysis Regional Groundwater Sustainability Project Arroyo Grande/Tri-Cities Mesa Area. Prepared for City of Pismo Beach and Water Systems Consulting. Dated February 2017.

DWR (California Department of Water Resources). 2004. Santa Maria River Valley Groundwater Basin. Bulletin No. 118.

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FUGRO (FUGRO Consultants, Inc.). 2015. Santa Maria Groundwater Basin Characterization and Planning Activities Study, Final Report. Prepared for San Luis Obispo County Flood Control and Water Conservation District, dated December 30, 2015.

GSI (GSI Water Solutions, Inc.). 2017. Northern Cities Management Area 2016 Annual Monitoring Report. Prepared for the Northern Cities Management Area Technical Group. Dated April 25, 2017.

LSCE (Luhdorff & Scalmanini Consulting Engineers). 2017. 2016 Annual Report of Hydrogeologic Conditions, Water Requirements, Supplies and Disposition.

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NMMA Technical Group (Nipomo Mesa Management Area Technical Group). 2017. Nipomo Mesa Management Area, 9th Annual Report, Calendar Year 2016. Dated April 2017.

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

Worts, G.F. 1951. Geology and Ground-Water Resources of the Santa Maria Valley Area, California, USGS Water-Supply Paper 1000.

ATTACHMENT A: RESPONSES TO COMMENTS FROM GSWC, NMMA TECH. GROUP, AND GSI

Comments from Robert Collar (GSWC)	GEOSCIENCE Response
A-1. Seems like a reference for this model (Phase 1A model) should be cited. Please consider.	A reference has been added.
A-2. Many readers may not be familiar with this concept (Mountain Front Recharge). Therefore, because it is dismissed as unimportant, suggest describing briefly, providing a citation and reference, such as Wilson, J. L. and Guan, H. (2004) Mountain-Block Hydrology and Mountain-Front Recharge, in Groundwater Recharge in a Desert Environment: The Southwestern United States (eds J. F. Hogan, F. M. Phillips and B. R. Scanlon), American Geophysical Union, Washington, D. C.., describing if applicable, and then providing a more robust basis for dismissing.	A discussion and references were added to the TM explaining the concept of mountain front recharge (see Section 3.1). Also after consideration, even though no existing reference mentioned mountain front recharge in the area, GEOSCIENCE determined that it was conceptually sound to add a mountain front recharge component to the model. Initial estimates of mountain front recharge will be derived from previous studies with similar environments, rainfall, and surface water sub-basin extents. These initial input values will be fine-tuned during calibration and provided to the TAC for review.
A-3. Assigning no-flow boundaries to the contact between older alluvium and consolidated rocks along most of the northeastern model domain may or may not be an appropriate assumption. For example, Section 3.0 states that the main aquifers within the model domain are the Paso Robles and Careaga sands. Yet, in contrast, these same sands are depicted as outcropping east of the proposed no-flow boundary, east of the southern terminus of the Wilmar Avenue Fault and are assumed to be either aquicludes or aquitards at best. Please reconcile. If it can be demonstrated that the transmissivity and/or yield of wells to the east of the proposed no-flow boundary completed below any alluvium (i.e., in consolidated rock) are extremely low, then the assumption may be appropriate. But, it seems insufficient to simply state that materials east of the proposed no-flow boundary contribute limited groundwater to the aquifers west of the proposed boundary, particularly if it can be shown that some	As indicated by the updated geological map prepared in response to question **A-6** and shown on Figure 2, only small patches of the Paso Robles Formation are shown on the northern and northeastern boundary of the model. The model boundary was modified to include these. It should be noted that Worts (1951) reported that the Careaga Sand, which outcrops south of the model boundary, has a typically somewhat consolidated surface exposure – presumably due to cementation. However, this appears as sand in deep well logs in the valley, which would explain why the outcrops of seemingly water-bearing formations can be considered non- water-bearing outcrops. Worts (1951) also described the consolidated formations (Franciscan and Knoxville Formation, Monterey Shale and interbedded

Comments from Robert Collar (GSWC)	GEOSCIENCE Response
wells completed at depth east of the proposed no-flow boundary yield meaningful quantities of water. Please consider reviewing how inflow to relatively high transmissivity alluvium from relatively low transmissivity sedimentary bedrock in the Ojai Groundwater Basin is simulated (see https://www.dropbox.com/s/glzr9wndvf79bwa/Ojai%20Basin%20Groundwater%20Model%20Development_11-15-11.pdf?dl=0).	volcanics, Sisquoc Formation, and Foxen Mudstone) as essentially non-water-bearing. He reported that a few wells were drilled in these formations in the Nipomo area for domestic and stock use, but were unable to provide sufficient yield. DWR (1971) also reported that outcrops of sandstone members of the Pismo Formation only yielded small amount of water for domestic use. While estimating hydraulic conductivity from specific capacity data, FUGRO (2015) came up with an average of 0.14 ft/d using four (4) wells screened in the Sisquoc Formation and 0.10 ft/d in the undifferentiated Tertiary formations using two (2) wells, which would correlate to low yields. Cross-sections A-A' to D-D' from FUGRO (2015), which cover the width of the model domain, clearly show the northern edge of the model in direct contact with formations classified as bedrock. These cross-sections show the bedrock becoming shallower and water-bearing formations thinning. Therefore, the outcropping of water-bearing formations farther north should not have a significant impact on the boundary conditions. The approach used in the Ojai Groundwater Basin simulation will be considered during the conceptual model phase if enough water levels are available to define a meaningful general head boundary. Otherwise, the contribution of the consolidated rocks will be lumped into mountain front recharge as suggested by Wilson and Guan (2004).
A-4. The assignment of no-flow boundaries highlights the need to integrate this technical memorandum with the technical memorandum on bedrock and to better define what comprises bedrock throughout the	The top of the bedrock is defined as no-flow. See discussion in the updated boundary TM (Section 4.0).

Comments from Robert Collar (GSWC)	GEOSCIENCE Response
model domain for the purposes of numerical modeling. For example, there is no discussion in this technical memorandum of how to simulate the top of bedrock in the vertical dimension of the model. Please address.	
A-5. This document is not cited in the text of the technical memorandum (LSCE, 2000). Please cite or remove from this reference list.	The document was cited but with the wrong date (2016 instead of 2000). This was corrected in the updated TM.
A-6. Please provide a reference for the geology shown on this figure (Figure 2 of Model Boundary TM). In addition, it's not clear why the geology shown on this figure differs from the geology shown in the 2015 FUGRO report particularly in the eastern quadrant of the proposed model domain. Please provide a basis for not utilizing Dibblee's geology, as this affects the location of the proposed no-flow boundary in the eastern quadrant of the proposed model domain.	GEOSCIENCE obtained a total of five geologic maps. The current one obtained from our own archive of the Santa Maria trial and provided by LSCE at the time (2003), the Dibblee-based SLO County map which only covers SLO County and leaves out part of the model area, a DWR geologic map from the 2002 report (in PDF format) which also only covers NCMA and NMMA, the statewide geologic map, and a map recently provided by SMVMA after the boundary TM was issued, which is an updated version of the LSCE 2003 map with comparable spatial coverage. The LSCE (2003) map was initially chosen because it covered the whole project area. After reviewing the different maps available, it was noted that the old LSCE map used for the model boundary shows more discrepancies compared to the remaining three. Therefore, the SLO County map, which is based on Dibblee, will be used where available, while the map from SMVMA, the DWR map, and the statewide geology map will be used to fill in any gaps. The updated geology map is shown on Figure 2.
A-7. Please include the Phase 1A boundaries and boundary types on this figure, so that the reader can see where they differ from, or are the same as, the proposed Phase 1B boundaries. If this figure will be too busy with these additional boundaries, please consider adding them to Figure 1 instead.	The Phase 1A boundary was added to Figure 2.

Comments from Robert Collar (GSWC)	GEOSCIENCE Response
A-8. The 2015 Fugro report shows some wells screened within the Sisquoc and Franciscan Formations, so it is not clear why these formations are dismissed as non-yielding bedrock. The technical memorandum should provide a more robust basis for defining what constitutes bedrock and should also discuss the implications of the bedrock definition (e.g., is the top of bedrock assumed to be a no flow boundary?). For example, wells completed in the Sisquoc, Obispo, and Franciscan Formations should be tabulated along with their yields and other relevant information to demonstrate that they are completed in extremely low transmissivity materials, if this is the case. The assignment of no-flow boundaries in the model boundary technical memorandum highlights the need to integrate this bedrock surface technical memorandum with the technical memorandum on model boundaries and to better define what comprises bedrock throughout the model domain for the purposes of numerical modeling (e.g., is bedrock based on hydraulic properties or is bedrock simply based on formation name?). Please address.	This is now discussed in the updated TM (Section 3.1). The answer to question **A-3** addresses this question as well. The yield of wells completed in the Sisquoc, Franciscan, and Obispo Formations are not currently available to GEOSCIENCE and will be considered once obtained. However, as stated in question **A-2** and **A-3,** a flux term will be added to account for mountain front recharge. This should include contributions from the consolidated sediment, if any. For the time being, the low hydraulic conductivity of these formations (as evidenced by the estimates from the FUGRO 2015 report cited in our response to question **A-3)** is evidence of their potential low yield.
A-9. Extensive subsurface investigations have been conducted in the area of this discrepancy at the Unocal Guadalupe Oil Field (see http://geotracker.waterboards.ca.gov/profile_report.asp?global_id=SL203091246). However, the depth of these investigations is not known, though they could extend a couple hundred feet or more below ground surface. In addition, it may be possible that relatively deep water-supply wells with lithologic and geophysical logs have been drilled in this area since preparation of publications by LSCE and DWR in 2000 and 2002, respectively. Please evaluate to see if there are data available to help resolve the apparent discrepancy described above. Please also see the previous comment and determine whether different definitions of bedrock by DWR and LSCE might explain the 700-foot discrepancy described above.	Both LSCE and DWR define the bedrock as undifferentiated Tertiary formations, which corresponds to the description provided by Worts (1951). GEOSCIENCE recently uncovered a few logs from oil wells with lithology information in the area of the discrepancy (see Figure 5). This information supported the bedrock surface shown in DWR Cross-Section A-A'.

Comments from NMMA Technical Group	GEOSCIENCE Response
B-1. Boundary at ocean: Constant head at coastline may give some odd results. When there are artesian conditions in coastal monitoring wells, the model will have to have a very steep gradient from the wells to the coastline. This is not realistic.	See section 3.3.
B-2. A constant head of sea level does not take into account density of seawater. Triggers for NMMA coastal wells apply density difference – number can be substantially different from sea level.	See section 3.3.
B-3. Boundary at ocean: Phase 1a model has more realistic boundary on ocean side of model. Isn't something like that a better approach?	See section 3.3.
B-4. Boundary at ocean: Perhaps try a GHB instead? Try both GHB and constant head in sensitivity analysis?	See section 3.3.
B-5. Southeastern GHB: How will these heads be assigned in future scenario cases following model calibration	A combination of past hydrology and water use will be used.
B-6. Mountain front recharge: Many more-current models now consider mountain front recharge – it certainly has been shown to occur. Let's discuss.	See answer to question **A-2.**
B-7. As discussed during last conference call, show data points for bedrock surface.	Data points were derived from cross-sections, as shown on Figure 7.
B-8. There is an odd bedrock high "finger" that extends just west of, and parallel to, the NCMA/NMMA boundary. Cleath disagrees with that interpretation.	The 3-D figure is probably misleading. The bedrock is high in this area because these formations eventually outcrop a few miles north. What appears to be high bedrock is a sliver of the Paso Robles Formation overlying the Obispo Formation in this area (see geologic map on Figure 2). The Paso Robles Formation is relatively thin and the Obispo Formation is classified as bedrock. Because the Obispo Formation outcrops in the vicinity, it is bound to be high. The Fugro (2015) Cross-Section E-E', which ends just 4 miles southeast of this sliver, clearly shows a northward, upward trend of the Obispo Formation as it outcrops north of the cross-section.

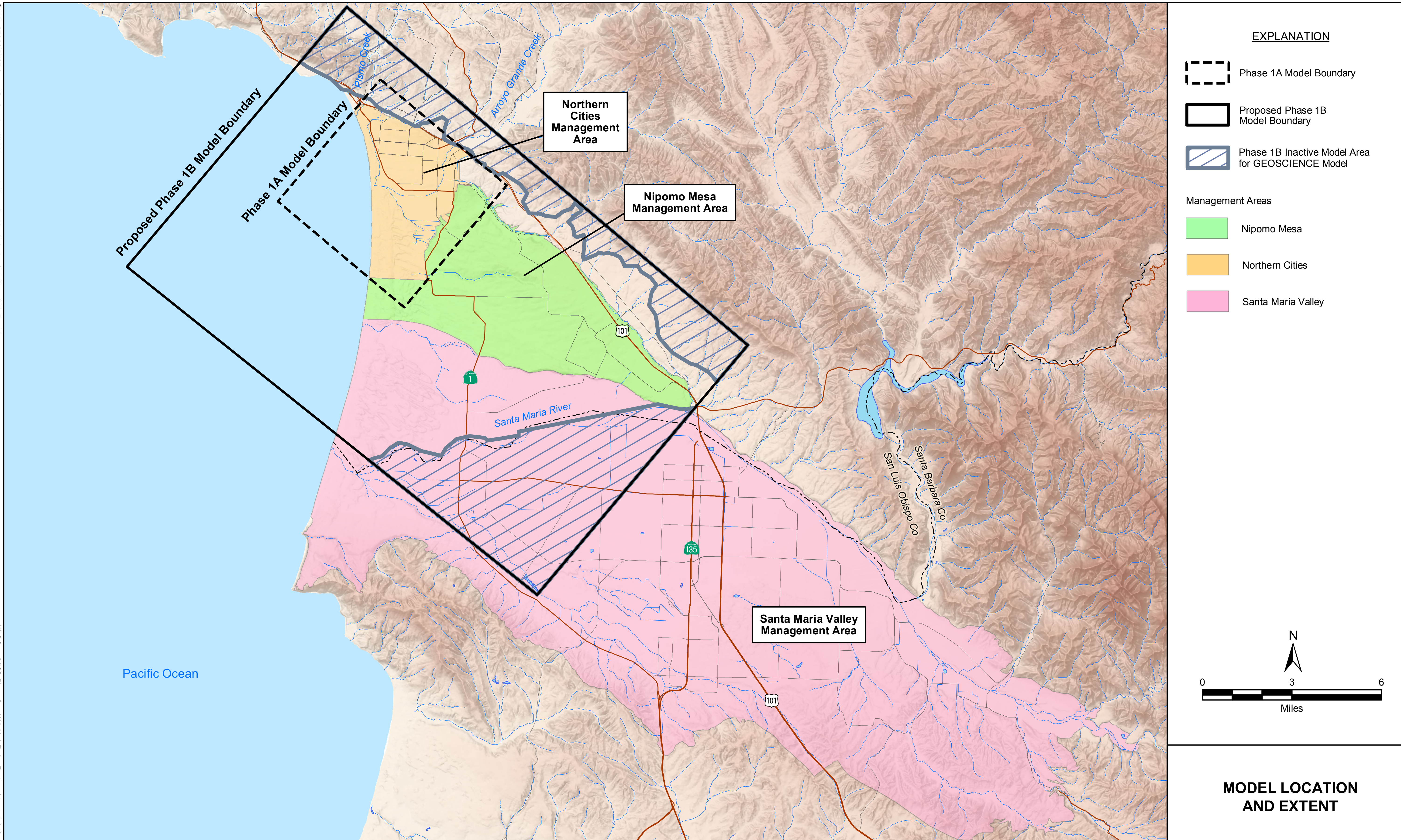
Comments from NMMA Technical Group	GEOSCIENCE Response
B-9. Have Santa Maria basin tech folks seen this TM? Probably good idea to get their input	Dan will reach out to them.
B-10. For your information: Cleath is doing a cross section along the eastern NMMA boundary. Might help to define that basin edge better.	We will definitely consider his final results if timing allows.
B-11. Would like to see the approach on estimating agricultural pumping through time. Will there be a TM on that?	This approach will be shared with the TAC during the water balance estimation phase.

Comments from GSI	GEOSCIENCE Response
C-1. We concur on placing the southeastern boundary at the location indicated on Figure 2, reasonably distant from the pumping centers in NCMA and NMMA.	We agree.
C-2. We are not familiar with the details of data in that area, but assume that adequate data will be available to accurately represent transient water levels in the area for each model layer.	GEOSCIENCE provided a presentation showing currently available water levels and water quality monitoring wells, which should help assess the details of data in this area. Also, Robert Collar from GSWC provided lithology located in the vicinity of this boundary, which should help.
C-3. Regarding the Fringe Areas labelled as Qt to the northeast of Highway 101 on Figure 2. From our work for SLO County, we know that these areas have a relatively thin and unsaturated deposit of older alluvium and terrace deposits atop Franciscan bedrock. All wells in these areas tap deeper bedrock. It is unlikely that this area will be necessary to represent in the ultimate groundwater model.	We will definitely consider it going forward.
C-4. Figure 2 indicates GHB boundaries where Pismo Creek and Arroyo Grande Creek join the larger basin. We believe this will be fine, but are aware that the new release of Groundwater Vistas 7 has an option for a Specified Gradient Boundary. Although it is probably not going to have a significant effect on the water budget, it may be worthwhile to look into the Specified Gradient Boundary to assess if it might be more appropriate.	We will look into implementing this approach.
C-5. With respect to representation of mountain front recharge that was discussed, we understand that there is no quantification of mountain front recharge that one could point to for justification, and that it is unlikely to be a significant component of recharge. However, the concept of mountain front recharge is a simple idea that lay people can understand; everyone can understand surface water flowing off a hillslope, so it may be advisable to include it. In the past, I have represented it by just applying a 1.5x or 2x of the precipitation-based recharge flux value to only the	See Section 3.1

Comments from GSI	GEOSCIENCE Response
first row or two of cells along the mountain front. This is unlikely to have a significant effect on the overall water budget, but this way you can say that you honored the conceptual model by including a representation of mountain front recharge.	
C-6. On Figure 2 that displays an oblique 3D view of the bedrock surface, please include all data control points used to generate this surface.	See Figure 7.
C-7. Questions that were discussed regarding the elevated ridge of bedrock along the NCMA/NMMA boundary may be partially explained when the data density of the control points is visible.	We concur. See Figure 7

FIGURES

GEOSCIENCE



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MODEL LOCATION AND EXTENT

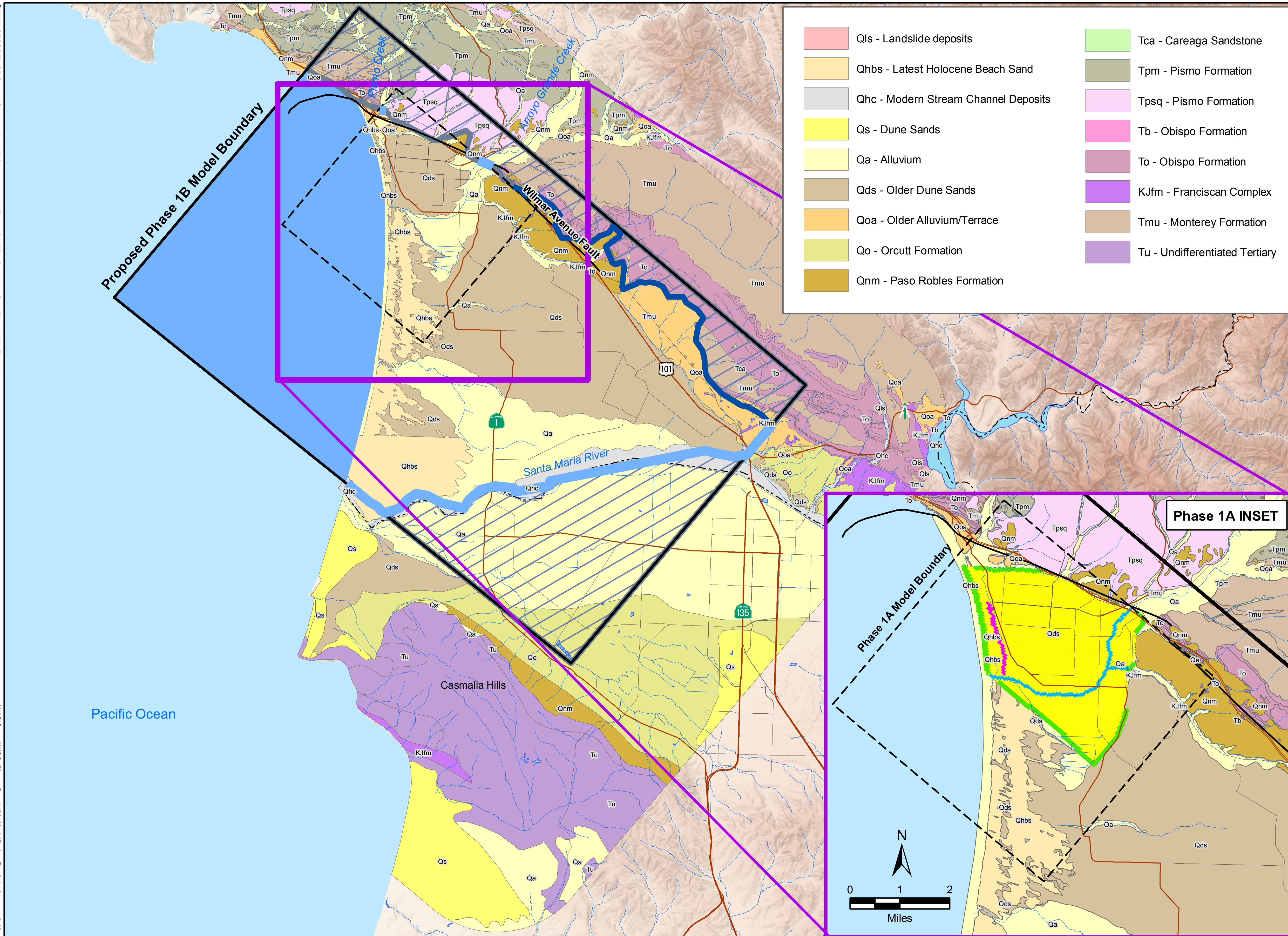
15-Jun-18

WATER SYSTEMS CONSULTING, INC.

FIGURE 1

GROUNDWATER MODEL BOUNDARIES - CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION

GEOSCIENCE



EXPLANATION

Phase 1B Legend

Proposed Phase 1B Model Boundary

Phase 1B Inactive Model Area for GEOSCIENCE Model

General Head Boundary

Mountain Front Recharge

No-Flow Boundary

Wilmar Avenue Fault

Source of Faults: (Fugro, 2015)
Source of Geology:
(County of San Luis Obispo, 2013; Dibblee, 1994; Dibblee and Ehrenspeck 1989; Dibblee and Minch, 2006a-d; LSCE, 2017; Ludington et al., 2007; and McLean, 1995)

N

0 3 6

Miles

Phase 1A Legend

Phase 1A Model Boundary

Drain Boundary

General Head Boundary

Stream Boundary

Phase 1A Active Cells

Wilmar Avenue Fault

PROPOSED GROUNDWATER MODEL BOUNDARY CONDITIONS

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15-Jun-18

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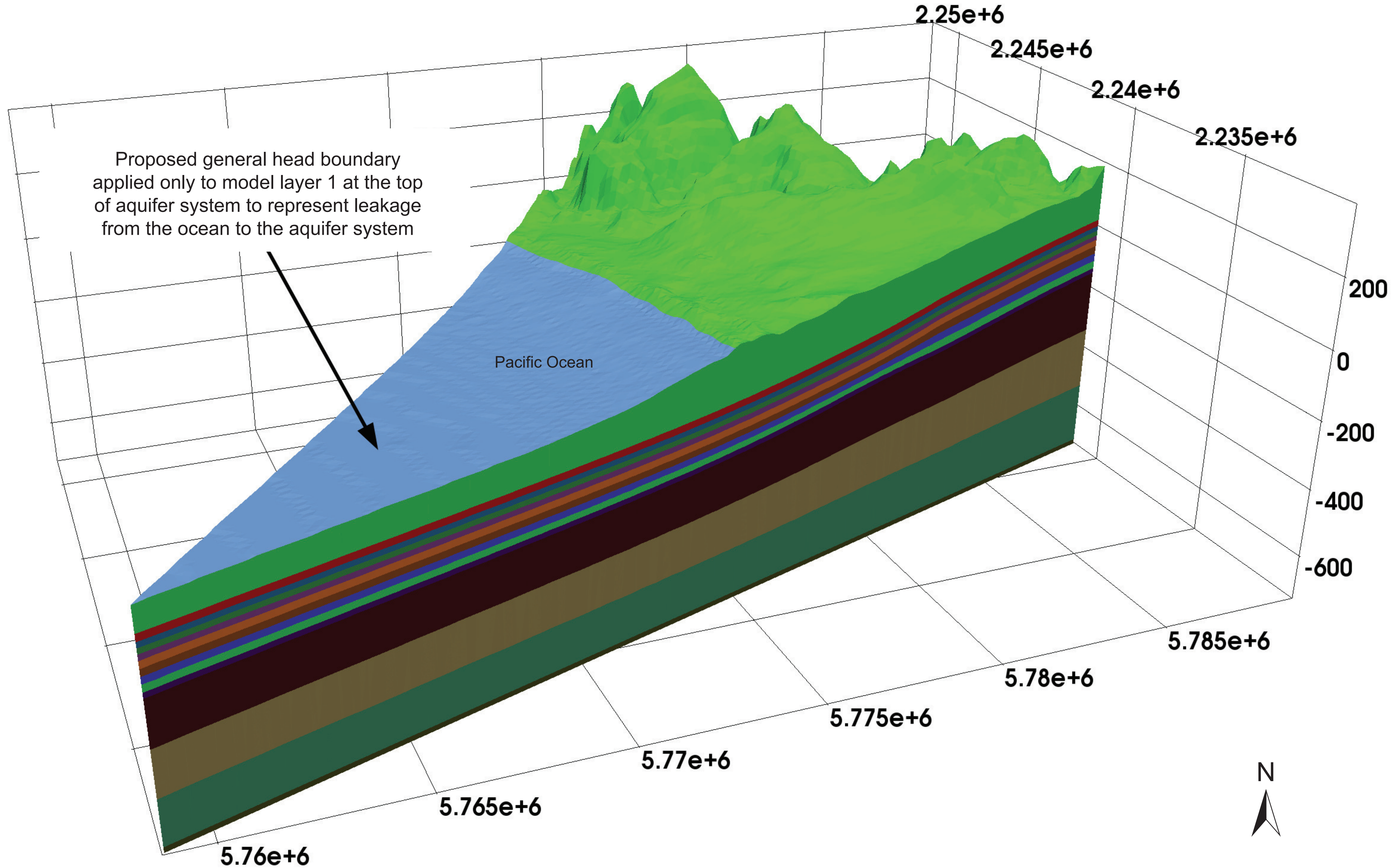
GROUNDWATER MODEL BOUNDARIES - CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION

FIGURE 2

GEOSCIENCE

EXPLANATION



W:\GIS_proj\WSC_Pismo_Beach\20_ModelBndys_Fig_3_3D_Ocean_bndy_cond_11X17_6-18.ai

15-Jun-18

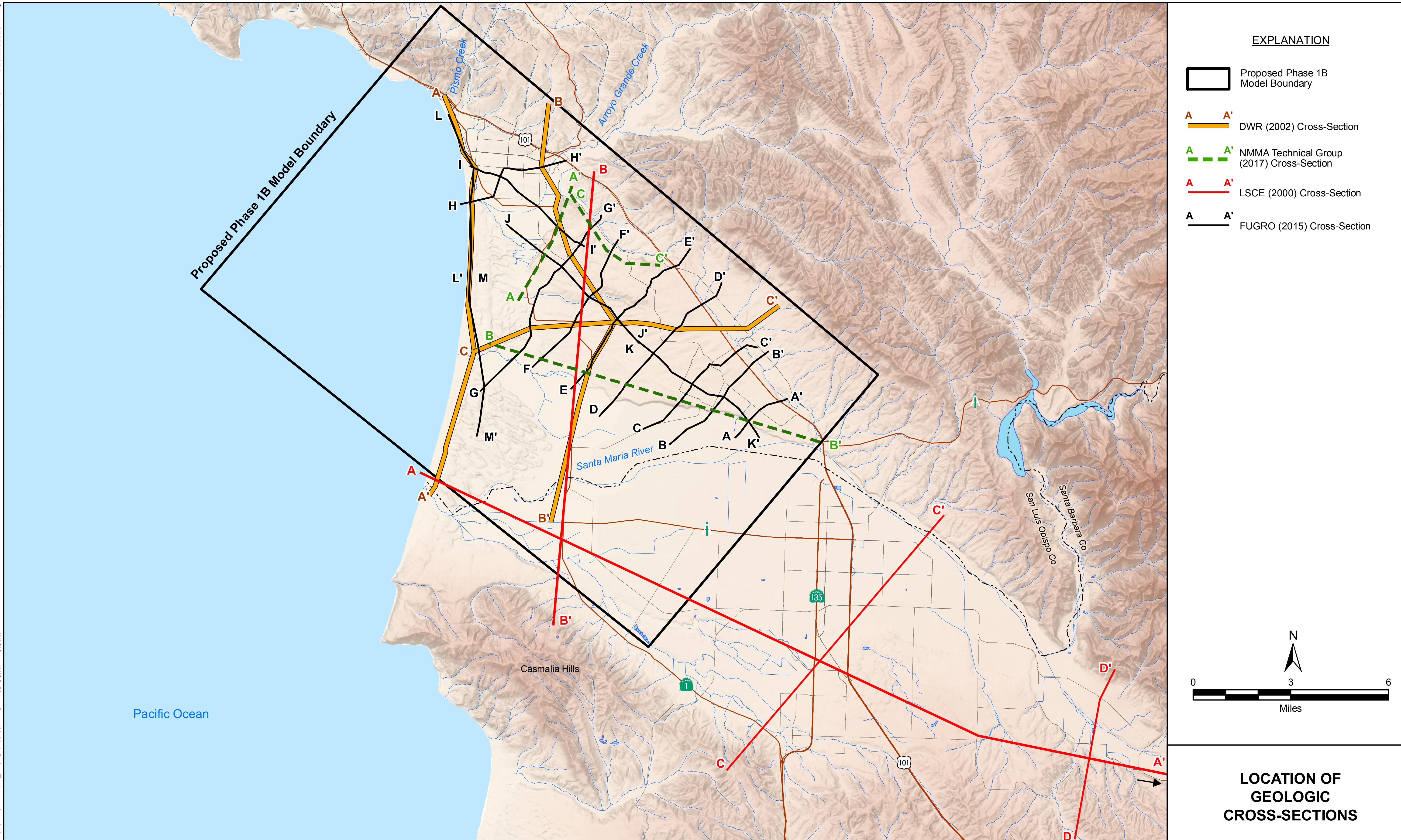
BOUNDARY CONDITION AT THE OCEAN

WATER SYSTEMS CONSULTING, INC.

GROUNDWATER MODEL BOUNDARIES - CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION

FIGURE 3

GEOSCIENCE



W:\GIS_proj\WSC_Pismo_Beach\20_ModelBndys_Fig_4_x-sec_locs_6-18.mxd

15-Jun-18

LOCATION OF GEOLOGIC CROSS-SECTIONS

FIGURE 4

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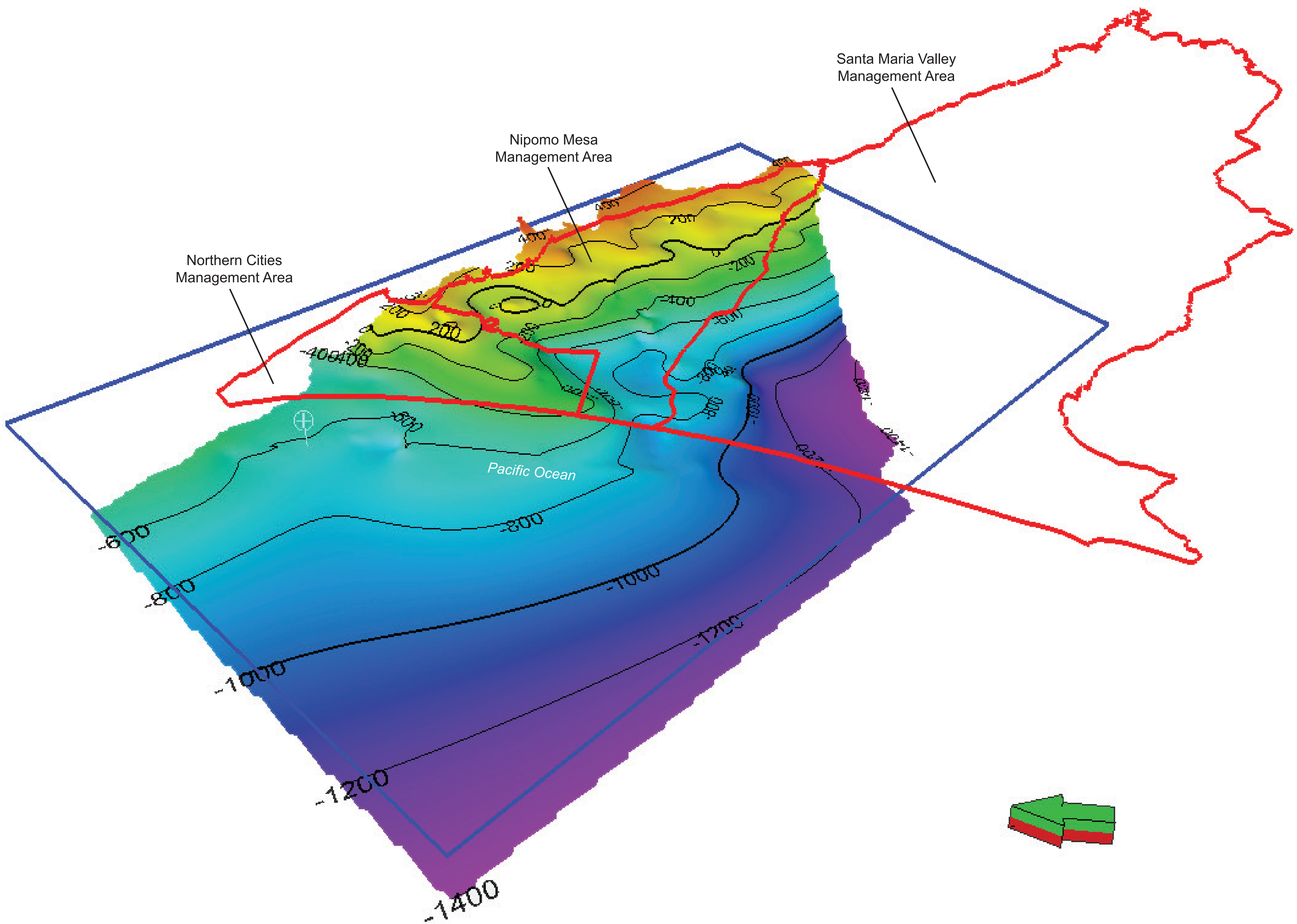
GROUNDWATER MODEL BOUNDARIES - CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION

GEOSCIENCE



EXPLANATION

Bedrock Elevation (ft amsl)

1000
750
500
250
0
-250
-500
-750
-1000
-1250
-1500
-1750
-2000
-2250

Management Boundary

Proposed RGSP Phase 1B Model Boundary

3-D VIEW OF THE BEDROCK SURFACE

W:GIS_proj\WSC_Pismo_Beach\20_ModelBndys_Fig_5_bedrock_surface_11X17_6-18.ai

15-Jun-18

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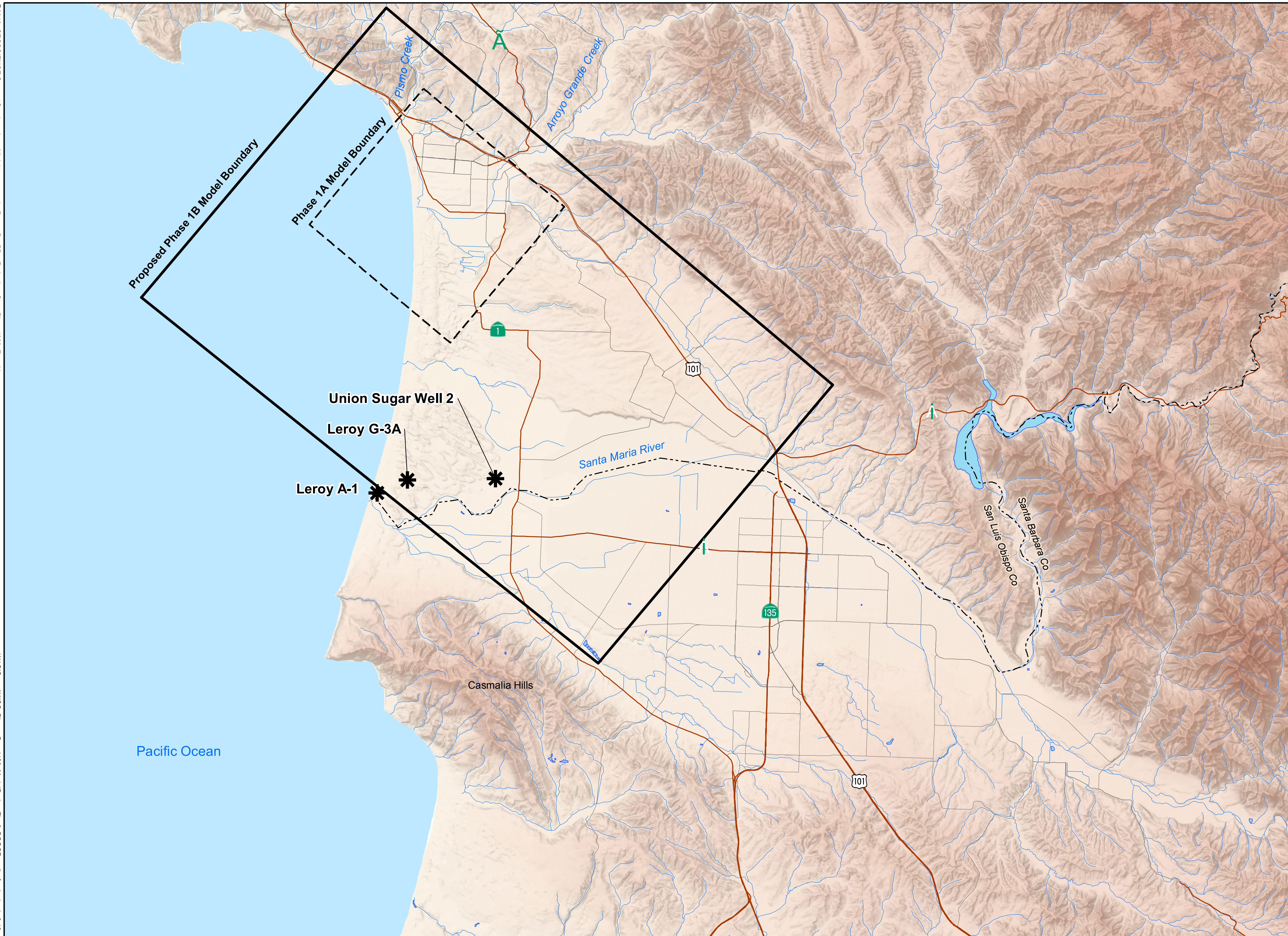
FIGURE 5

GROUNDWATER MODEL BOUNDARIES - CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION

GEOSCIENCE



EXPLANATION

Selected San Luis Obispo County DOGGR Well with Lithologic Information

Phase 1A Model Boundary

Proposed Phase 1B Model Boundary

N

0 3 6

Miles

LOCATION OF OIL WELLS USED TO REFINE BEDROCK SURFACE

W:\GIS_proj\WSC_Pismo_Beach\20_ModelBndys_Fig_6_DOGGR_wells_for_bedrock_6-18.mxd

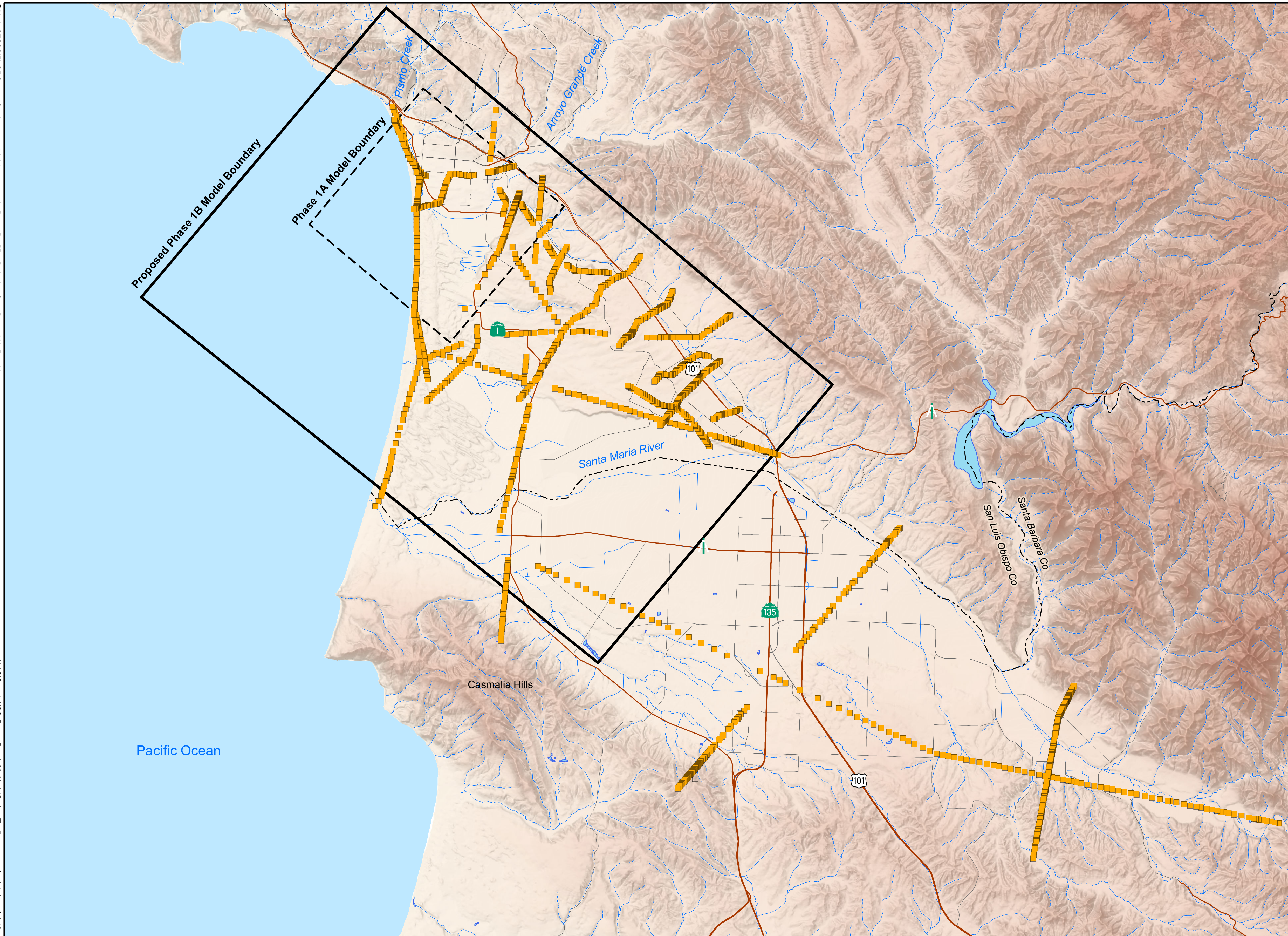
15-Jun-18

WATER SYSTEMS CONSULTING, INC.

FIGURE 6

GROUNDWATER MODEL BOUNDARIES - CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION

GEOSCIENCE



EXPLANATION

Location of Digitized Cross-Section Points Used to Interpolate Bedrock Surface

Phase 1A Model Boundary

Proposed Phase 1B Model Boundary

N

0 3 6

Miles

LOCATION OF DIGITIZED CROSS-SECTION POINTS USED TO INTERPOLATE BEDROCK SURFACE

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15-Jun-18

WATER SYSTEMS CONSULTING, INC.

FIGURE 7

GROUNDWATER MODEL BOUNDARIES - CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION

GEOSCIENCE

Technical Memorandum

GEOSCIENCE
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	Kapo Coulibaly, Ph.D. Project Geohydrologist GEOSCIENCE Support Services, Inc.	
Date:	January 16, 2018	
Subject:	**Agricultural Pumping Estimates – City of Pismo Beach and SSLOCSD RGSP Phase 1B Hydrogeologic Evaluation**	

1.0 INTRODUCTION

This technical memorandum (TM) is presented in partial fulfillment of Subtask 2.2: Water Balance. The water balance is a critical aspect of the conceptual model and involves the quantification of inflow and outflow terms from the groundwater basin. Agricultural pumping is a major outflow component. However, unlike the municipal pumping which is directly measured from metered water wells, agricultural pumping is largely unmetered and therefore needs to be estimated indirectly. This TM discusses the approach used by GEOSCIENCE Support Services, Inc. (GEOSCIENCE) to estimate agricultural pumping, and provides a preliminary estimate of annual agricultural production. A draft TM was issued December 6, 2017. Comments from the Technical Advisory Committee (TAC) are summarized in Attachment A and were incorporated in this final TM.

2.0 EXISTING ESTIMATES OF AGRICULTURAL PUMPING

Various studies in the area have estimated agricultural pumping using assorted techniques. These studies and their approaches are briefly summarized below and will also be used for comparison with GEOSCIENCE's results.

2.1 Northern Cities Management Area Agricultural Pumping Estimates

2.1.1 Water Balance Study

In 2007, Todd Engineers conducted a water balance study for the Northern Cities Management Area (NCMA) which included an estimate of agricultural pumping (2007). The objective of the study was to improve the understanding of the groundwater system as a basis for improved monitoring and management. Todd Engineers used applied water rates (acre-feet per acre) estimated by the Department of Water Resources (DWR), multiplied by the respective crop areas to calculate agricultural pumping. Total agricultural pumping was estimated to be 3,300 acre-feet per year (AFY) with a 30% return flow rate (990 AFY). Applied water and return flow rates were constant and were not adjusted with regard to rainfall or local climate, as no year-to-year estimates were made.

2.1.2 Annual Monitoring Reports

Estimates of agricultural pumping for the NCMA are also presented in the NCMA's Annual Monitoring Reports for 2008 through 2016 (Todd Engineers 2009 and 2010; GEI 2011, 2012, and 2013; FUGRO 2014, 2015, and 2016; and GSI 2017). The approach used to estimate agricultural pumping in the NCMA for the annual reports has changed over the years. From 2008 to 2013, applied water estimates per acre per crop type were obtained from the San Luis Obispo County Watermaster. For each crop, values were determined based on the demand level (i.e., low, high, and average), which in turn were directly related to the annual rainfall (i.e., wet, dry, or average year, respectively). These estimates were based on crop evapotranspiration, effective rainfall, leaching requirements, irrigation efficiency, and frost protection.

In 2014, an approach devised by the California State Polytechnic University, San Luis Obispo (Cal Poly San Luis Obispo) Irrigation and Training Research Center (ITRC) was used by FUGRO to estimate the agricultural applied water per acre per crop type. These values were based on a coastal climate zone. From 2014 to 2016, FUGRO (2015 and 2016) and GSI (2017) used the DWR's IWFM: Integrated Water Flow Model – Demand Calculator (IDC) and Consumptive Use Program (CUP) to develop their estimates of agricultural pumping. These programs use climate data (e.g., precipitation, humidity, air temperature, etc.), evapotranspiration (ET) by crop type, soil data, and maps of crop distribution as input. The output from these programs represents the estimated agricultural pumping (as applied water), deep percolation, and runoff. This approach produced an estimated agricultural pumping in the NCMA of 2,494 AF for 2016. An irrigation efficiency of 10% was assumed.

2.2 Nipomo Mesa Management Area Agricultural Pumping Estimates

The Nipomo Mesa Management Area Technical Group (NMMA TG) used the crop evapotranspiration guidelines from the Food and Agriculture Organization of the United Nations (FAO) Irrigation and Drainage Paper 56 (Allen et al. 1998), which includes rainfall and potential ET (ET_O). Using ET_O and a crop coefficient (K_C), a crop evaporative requirement (ET_C) was computed using the following equation (NMMA 2017).

$$ET_C = ET_O \times K_C$$

The applied water (AW_T) was then obtained by subtracting precipitation (P) from the ET_C.

$$AW_T = ET_C - P$$

Using this approach, the soil moisture was tracked and rainfall was only used to offset demand when soil moisture was depleted to a level less than half its full capacity (NMMA 2017).

The resulting applied water was multiplied by the surface area for individual crop types, based on crop distribution maps. These values were estimated on a daily time step using ET_O from the Nipomo California Irrigation Management Information System (CIMIS) station, located within the NMMA. The K_C values and crop distributions used in the annual reports were revised in 2013 (NMMA 2014), resulting in a change of estimated agricultural production compared to prior years. These values were derived from measured irrigation in portions of the NMMA and known water demands of various crop types in nearby regions. The agricultural pumping estimate for 2016 using this approach was 6,175 AF. The NMMA TG assumed that all water used in agricultural application is consumed through sustaining plant life or replenishing soil profile storage; there is no return flow.

2.3 Santa Maria Valley Management Area Agricultural Pumping Estimates

Agricultural pumping estimates in the Santa Maria Valley Management Area (SMVMA) were made with a combination of methods, depending on data availability. Luhdorff & Scalmanini Consulting Engineers (LSCE) adopted previously-used methods for their estimation of agricultural pumping during their development of a groundwater flow model for the SMVMA (LSCE 2000). CIMIS-provided estimates of K_C and ET_O values were used for rotational crops, strawberries, and pastures. Applied water values from DWR were used for the remaining crop types (except for hoop house and hydroponics). A graph correlating applied water by crop type to rainfall was developed. For hoop house and hydroponics (caneberries), applied water rates were simply extracted from local publications. Total agricultural demand (pumping) was estimated to be approximately 103,400 AF for 2016. Irrigation efficiency varies by crop type and ranges from 80% to 95% (LSCE 2014).

3.0 GEOSCIENCE APPROACH FOR ESTIMATING AGRICULTURAL PUMPING

3.1 Available Data

The data available for estimating agricultural pumping include:

- Crop distribution maps from 1996 through 2016 for the entire NCMA, NMMA, and SMVMA;
- Rainfall records from various stations for the modeling period (1977 – 2016);
- ET_O from 1983 through 2016 from CIMIS stations;
- Farmland Mapping and Monitoring Program maps;
- Existing K_C; and
- Applied water rates from previous reports and publications in the area.

3.2 Agricultural Pumping Computation Approach

3.2.1 Applied Water ET Type Curves

The approach proposed by GEOSCIENCE for estimating agricultural production is similar to the type curves used by LSCE in the SMVMA (Section 2.3). The basic principle behind these curves is that less water is used for irrigation during wet years and more water is used during drier years. The amount of water used per acre also varies by crop type – necessitating a different curve for each crop. Figure 1 shows a generic example of this type of curve. These curves were constructed by plotting the ET of applied water (ETAW) against annual precipitation. ETAW is the amount of water necessary to satisfy the annual water demand for an acre of a given crop. The result is a declining graph showing the change in water demand over various annual rainfall conditions.

However, because local climate variation can have a significant impact on applied water (due to ET variations), these curves were reconstructed using recent estimates of applied water in the NCMA (GSI 2017), NMMA (NMMA TG 2017), and SMVMA (LSCE 2017). A different set of curves will be used for each management area to reflect the variation in local climate. For instance, NCMA is low-lying and close to the coast. Therefore, ET is influenced by the effects of the marine layer. Crop ET within the marine layer can be as much as 25% lower than the same crop outside of the marine layer (GSI 2017). The extent of the marine layer inland can vary from 0.5 miles to as much as 4 or 5 miles, depending on topography (GSI 2017). These parameters were taken into account by GSI in their approach, resulting in a 12% adjustment of ET data from a CIMIS station located farther inland, which was used to estimate applied water in the NMMA.

During the development of these type curves, an effort was made to honor existing estimates, as long as they were in the general range of local values from literature and did not alter the trends in a way that would violate the assumption that the applied water demand generally declines with increasing total annual precipitation. Ultimately, more recent estimates derived from improved and revised procedures were given precedence. Previous studies in California and elsewhere were also used to ensure estimated applied water values and overall trends were reasonable (DWR 1975 and 1986; Doorenbos and Pruitt 1977).

3.2.2 Irrigation Efficiency Estimates

The type curves described in the previous section are used to determine the ETAW, or crop water demand. Irrigation efficiency affects the amount of water that must be used to meet a given crop's water demand. Therefore, the applied water (AW) may be estimated by adjusting irrigation ETAW with and assumed irrigation efficiency (IE), as follows:

AW = ETAW / IE

IE is highly dependent on the irrigation method, and there is a range between potential and actual performance (Carollo 2012). Poor design and management can turn a potentially high performance system into a low performance system. In addition, irrigation methods vary by crop type (refer to Table 3.1 below). Consequently, IE is very difficult to measure and is often estimated according to the system type, special practices, and distribution uniformities. In the NCMA 2015 and 2016 reports, GSI assumed a uniform IE of 90%. For the same years, LSCE varied the IE in the SMVMA by crop type, ranging from 80% to 95%. IE in the NMMA annual reports was assumed to be 100%. Another important factor to consider is that the IE for a given area can change over time as the price of water and pesticides rise or as new conservation policies combined with better irrigation methods are implemented, as noted in work done in San Luis Obispo County (GEOSCIENCE 2014). Table 3.2 below shows that IE in San Luis Obispo County improved from 63% in 1985 to a maximum of 85% in 2011. For this project, GEOSCIENCE will assume IE values from 2011 through 2016 based on those values used in the NCMA (90%) and SMVMA (85% to 95%), and an IE of 63% from 1977 through 1984.

Table 3.1: Irrigation Method Distribution in San Luis Obispo County (2012)

Crop Type	Percentage of Acreage with Irrigation System Type (%)		
	Surface	Sprinkler	Micro
Alfalfa	0	100	0
Citrus	0	20	80
Deciduous	0	20	80
Nursery	0	50	50
Pasture	0	100	0
Permanent	0	20	80
Vegetable	0	40	60
Vineyard	0	0	100

Source: Ken Peterson, Irrigation Specialist, personal communication, September 28, 2009, presented in GEOSCIENCE 2014

Table 3.2: Irrigation Efficiency in San Luis Obispo County Over Time

Crop Type	1980 - 1985	1986 - 1990	1991 - 1995	1996 - 1997	1998 - 2002	2003 - 2007	2008 - 2011
Alfalfa	63	65	68	72	70	70	70
Citrus	63	68	72	75	76	77	78
Deciduous	63	68	72	75	76	77	78
Nursery	63	65	67	70	70	70	70
Pasture	63	65	67	70	70	70	70
Vegetable	63	65	67	70	73	76	78
Vineyard	63	68	72	75	78	81	85

From GEOSCIENCE 2014

3.2.3 Applied Water Estimates

Once the ETAW curves are developed, the applied water demand per acre per crop can be estimated by using the annual total precipitation and looking up the corresponding annual applied ET demand for a given crop per acre. This value is then divided by the IE and multiplied by the crop acreage (from crop distribution maps) to obtain the total annual pumping estimate for this crop. Since estimates for agricultural pumping in the NMMA, NCMA, and SMVMA are only available from 2008 through 2016 and the model calibration period extends from 1977 to 2016, this method will be used to estimate applied water demand and agricultural pumping for the remaining time periods not covered by previous estimates.

Due to the variety of methods used to estimate agricultural pumping and the discrepancies between them (even within the same management area), not all previous estimates will be honored. In the NCMA, an effort will be made to honor the last two years (2015 and 2016) because these estimates were made more robust by taking into account local climate and using the IWFM. Similarly, estimates of agricultural pumping in the NMMA for the last four (4) years will be honored because they include newer and more reliable crop coefficients based on other estimates and measurements in the region (Section 2.3). However, IE values for the NMMA will be assumed to be similar to the ones used for the SMVMA, as an IE of 100% seems unrealistic. Almost all estimates for the SMVMA will be honored because the approach has been consistent from 2008 through 2016. Figure 2 shows the time periods where agricultural pumping estimates will be recomputed by GEOSCIENCE and where existing values will be used for all three management areas.

3.2.4 NCMA Applied ET and Agricultural Production Estimates

The type curves implemented for the NCMA are shown on Figure 3 along with previous estimates from NCMA annual reports from 2009 to 2016. Annual precipitation values were obtained from NCMA's annual reports and represent a composite of Pismo Beach and Oceano gaging stations. Some discrepancies exist due to the various methods used over the years. However, as explained previously, estimates from the last two years will be honored and used directly. Agricultural production from 1977 through 2014 will be estimated using the curves shown on Figure 3.

3.2.5 NMMA Applied ET and Agricultural Production Estimates

As discussed in Section 2.2, the approach used for estimating agricultural pumping in the NMMA changed in 2013 in an effort to improve estimates. Therefore, the type curves developed for the NMMA honored the last four years (2013-2016). These curves are shown on Figure 4 along with existing estimates of agricultural production from NMMA annual reports. It should be noted that annual report estimates prior to 2013 did not include grapes as a crop and only had "deciduous". From 2013 onward, grapes and deciduous crops were lumped into one category and a single applied water value per acre was used. Figure 4 shows that values of deciduous crops prior to 2013 fall closer to deciduous curves from the SMVMA while values for deciduous and grapes combined align better with the grapes (vineyard) type curve. Therefore, these two categories will be separated during agricultural pumping estimates whenever possible. Agricultural pumping will be estimated from 1977 through 2012 using the type curves shown on Figure 4, and existing values will be used from 2013 to 2016 (Figure2).

3.2.6 SMVMA Applied ET and Agricultural Production Estimates

LSCE used a consistent approach to estimate ETAW from 2009 to the present. Values from their work were used to develop the applied water type curves for the SMVMA. For a limited set of crops (including hoop house, hydroponic, and nursery), a constant value was used. The resulting applied water versus annual precipitation curves for the SMVMA are shown on Figure 5 along with existing estimates of agricultural pumping from SMVMA annual reports from 2009 to 2016. Two harvests per year were assumed for rotational crops and precipitation data from Santa Maria Airport station were used and are reflected in the applied water rates. Agricultural pumping estimates will be computed from 1977 through 2008 using the type curves shown on Figure 5, and existing values will be used from 2009 to 2016 (Figure 2).

4.0 COMPUTATION AND VERIFICATION OF AGRICULTURAL PRODUCTION

To verify the approach used by GEOSCIENCE, applied water volumes per acre for all three management areas (NCMA, NMMA, and SMVMA) were recomputed using the curves developed by GEOSCIENCE. Table 4.1 below compares the total NCMA agricultural production estimates from NCMA annual reports and GEOSCIENCE estimates, focusing on the two years that will not be re-estimated (2015 and 2016). Likewise, Table 4.2 compares agricultural production estimates for the NMMA by the NMMA TG and GEOSCIENCE, focusing on the last four years, which will be used as-is in the model. Table 4.3 compares LSCE and GEOSCIENCE estimates of agricultural production in the SMVMA.

Table 4.1: Comparison of Annual Agricultural Production Estimates in the NCMA

Year	NCMA Annual Report (AF)	GEOSCIENCE (AF)
2015	2,267	2,493
2016	3,008	3,184
Average	**2,638**	**2,839**

Table 4.2: Comparison of Annual Agricultural Production Estimates in the NMMA

Year	NMMA Annul Report (AF)	GEOSCIENCE (AF)
2013	6,175	6,334
2014	7,337	7,243
2015	7,234	7,137
2016	6,831	7,243
Average	**6,894**	**6,989**

Table 4.3: Comparison of Annual Agricultural Production Estimates in the SMVMA

Year	SMVMA Annual Report (AF)	GEOSCIENCE (AF)
2009	103,371	103,356
2010	115,749	115,857
2011	112,682	112,635
2012	115,972	116,939
2013	102,517	105,008
2014	96,387	96,356
2015	87,214	87,256
2016	98,085	109,108
Average	**103,997**	**105,814**

Overall, GEOSCIENCE estimates compare well to previous calculations by GSI, the NMMA TG, and LSCE. This is especially true considering the general uncertainty attached to estimating agricultural production.

4.1 Monthly Agricultural Production Estimates

Estimates for agricultural production presented above represent annual values. However, production rates will be applied in the model using monthly time steps. To address this issue, GEOSCIENCE proposes to distribute annual production based on monthly crop coefficients (K_C) and/or existing monthly applied water relationships. The 2016 NCMA Annual Monitoring Report contains a table showing monthly applied water per crop type (GSI 2017, Table 10, page 29). Similarly, the 2016 NMMA Annual Report contains a table with monthly K_C values (NMMA TG 2017, Table 2 in Appendix E). These values will be used to distribute annual production estimates on a monthly basis. Monthly relationships for the NMMA will also be used for the SMVMA, as monthly K_C values or applied water values for the NMMA were not available and the NMMA and SMVMA share a similar climate and crop types.

5.0 REFERENCES

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ATTACHMENT A: RESPONSES TO COMMENTS FROM NMMA TECH. GROUP AND GSI

Comments from Brad Newton (NMMA TG)	GEOSCIENCE Response
A-1. I made a few strike outs and additions to Sec 2.2 regarding our preparation of NMMA Ag Pumping Estimates.	These comments were incorporated into the current revised TM.
A-2. For the remainder of the report, I wonder what your opinion is on the use of these type curves, that they are significantly different for each area, and that the curves behave oddly over increasing rainfall (often go flat over higher rainfall amounts). It is well known that daily rainfall, sunshine, wind, matter most for ag irrigation requirements on a given soil type for a given crop. Why would not Geoscience just start with an ag water demand model (like FAO 56) and run daily data (readily available) for a number of years and then sum up to monthly time steps? That way we all can be assured that the method is the same for each field, but that the daily climate is the only independent variable. This approach is rational and is defensible. Can we get them to rethink their approach. Otherwise it seems like they are ingraining into the model the biggest uncertainty between TG approaches to estimate Ag Pumping.	GEOSCIENCE believes that a detailed study of agricultural pumping estimates to the level described by Brad is beyond the scope of this study, which is to build a monthly groundwater model. Also, as pointed out by Sam Schaefer (GSI), irrigation efficiency tends to be an even bigger factor of uncertainty, which would not necessarily be addressed by running a daily model based on the FAO paper. The only comprehensive climate data available are from the CIMIS Nipomo station which, because of its location away from the coast, would overestimate agricultural demand in the NCMA (for instance). An adjustment would have to be made as direct measurement aren't readily available at the coast (see Section 3.2.1) or farther inland in the Santa Maria Valley. These adjustments were already made by GSI while using the IDC approach and were incorporated into the type curves. Again, using a daily FAO model with CIMIS station data would not automatically address this issue. Data on the type curves were estimated by previous studies in the area using the same principle of dependency of agricultural demand on climate, but using averaged data, which we assume is a reasonable approach for a monthly time step. Ultimately, these type curves vary by area because of local variation (see Section 3.2.1). However, the SMVMA and NMMA have similar agricultural crop ET demands and share a lot of the same crops (LSCE 2016 and 2015). Therefore, the values aren't significantly

	different overall. Crop classification (crop groups) and irrigation efficiencies are the main differences.

Comments from Sam Schaefer (GSI)	GEOSCIENCE Response
B-1. SMMA – Good annual method for applied water as it accounts for crop water requirement and irrigation method efficiencies. Converting to the monthly use is ok with crop coefficients. However, going back in time and assigning applied water based on the relationship of each crop use to annual rainfall may not capture the reduction in applied water due to improved irrigation efficiency over time. Ag pumping in this area has a sizable range between wet, normal, and dry years, but, equally important is the change in applied water efficiency over time. In the annual report, they do recognize irrigation methods and efficiency, but, may not have considered improved irrigation methods over time. For every 5% improvement in DU or IE, the applied water would be reduced 5,000 to 6,000 AFY of GW pumping. Also, need to clarify if Geoscience recognizes the confined layer and drainage on the west side of the basin. Most likely the pumping number is estimated closer to actual pumping in the recent years compared to the past if they have kept the irrigation efficiency the same and not varied it going back in time. With the cost of water pumping and fertilizer rising in price dramatically over time, droughts, irrigated lands program, and other conservation pressures, the growers must be making management improvements. This consideration could be clarified by talking with the NRCS.	Mr. Schaefer's concerns about irrigation efficiency were addressed in this revised version of the TM in Section 3.2.2. Historical estimates of irrigation efficiency were found in previous studies and will be used to estimate applied water. GEOSCIENCE was not aware of the confining layer in the western part of the basin, but is aware of the continuous confinement along the coast in general. If confining layers are shallow, they can impact return flows but not necessarily the applied water. Therefore, GEOSCIENCE will address the confinement when addressing return flows, or adjust the return flow at the time of calibration.
B-2. NMMA – The Crop Water Requirement conversion to Applied Water need to be clarified to match with local irrigation practices. If the irrigation application method is not defined, it is unclear if the assumption of 100 percent irrigation efficiency can be met. This is not an equitable comparison with SMMA	GEOSCIENCE agrees with Mr. Schaefer and will apply the reported irrigation efficiencies published in the San Luis Obispo Water Master Plan (Carollo 2012) to the ETAW in the NMMA. Also, GEOSCIENCE will use a constant value for hoop house crops from the SMVMA approach.

and NCMA to compare a crop water requirement estimate to an applied water estimate. GEOSCIENCE needs to define the equation for AW and state if it is acceptable to reduce the equation to only Crop ET minus Precip. Some crops are grown in hoop houses, so how does precip reduce applied irrigation water delivered in a hoop house. What is calculated and documented in the NMMA report is the Crop's Water Requirement, not the AW of the irrigation practice to meet the Crop Water Requirement. One may be able to consider field testing by Mobile Irrigation Labs within the NMMA. In addition, consider the crops grown, the NMMA report states that over 60% of the crops may be berries. If this is the case, and berries are grown in hoop structures, how does rainfall enter the root zone and displace pumped ground water or a surface water source? I also suspect a portion of the true pumping number as applied water percs due to less than an 100% distribution uniformity to apply water using and irrigation method. If the deep perc encounters a restrictive layer, then it could also migrate horizontal to the local drainages and water is taken out of the balance by the vegetation in the drainage ways, downslope of the irrigation. It is a Mesa with elevation change and multiple textured layers, water can easily move laterally when not easy to move down due to lower hydraulic conductivity layer. Geoscience needs to be concerned the pumping number is likely estimated low by 5 to 35%.	These values do not depend on rainfall.

FIGURES

Example Type Curves of Applied Water vs. Annual Precipitation

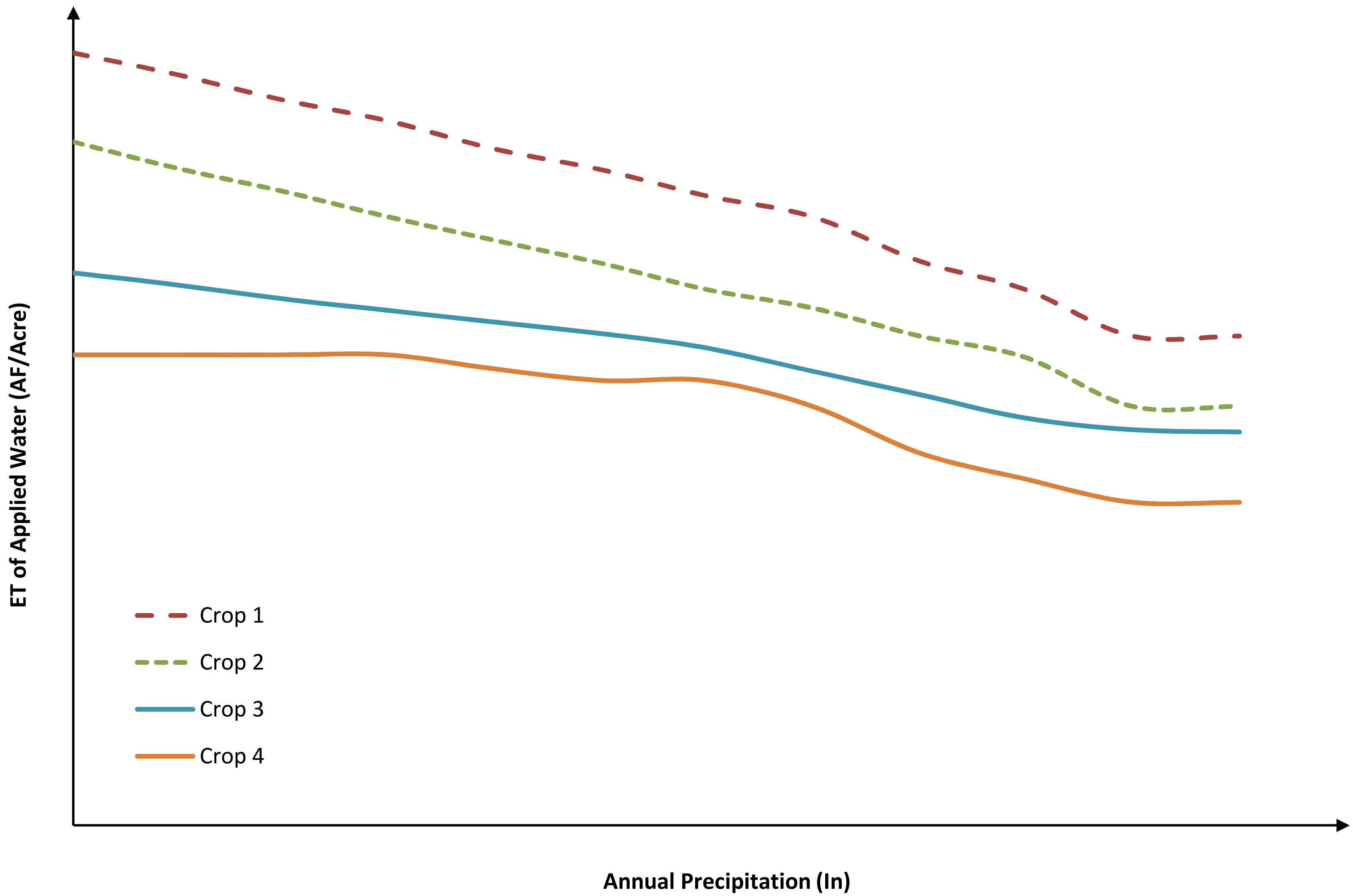

Figure 1

Use of Agricultural Pumping Estimates for Model Calibration

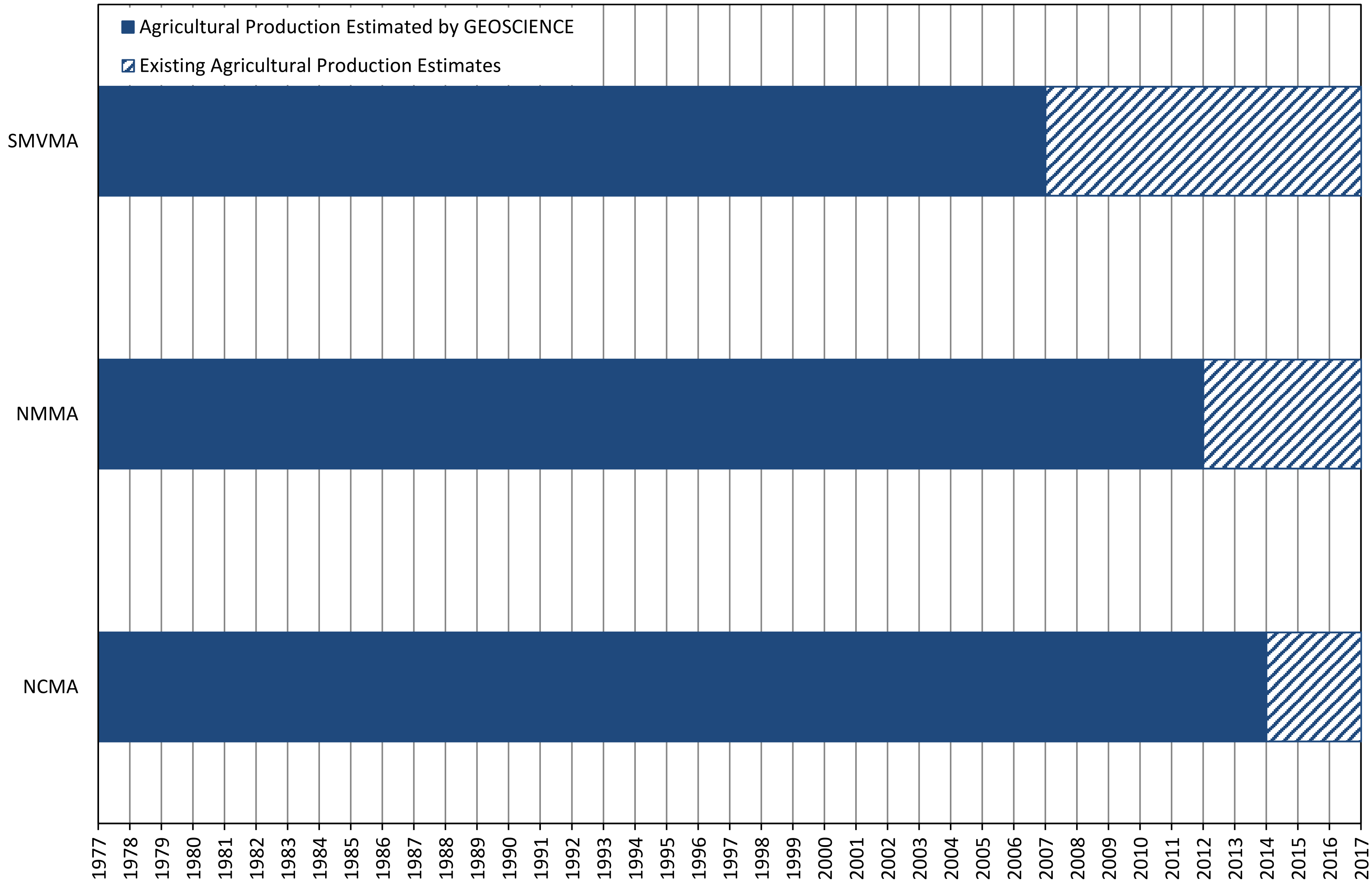

Figure 2

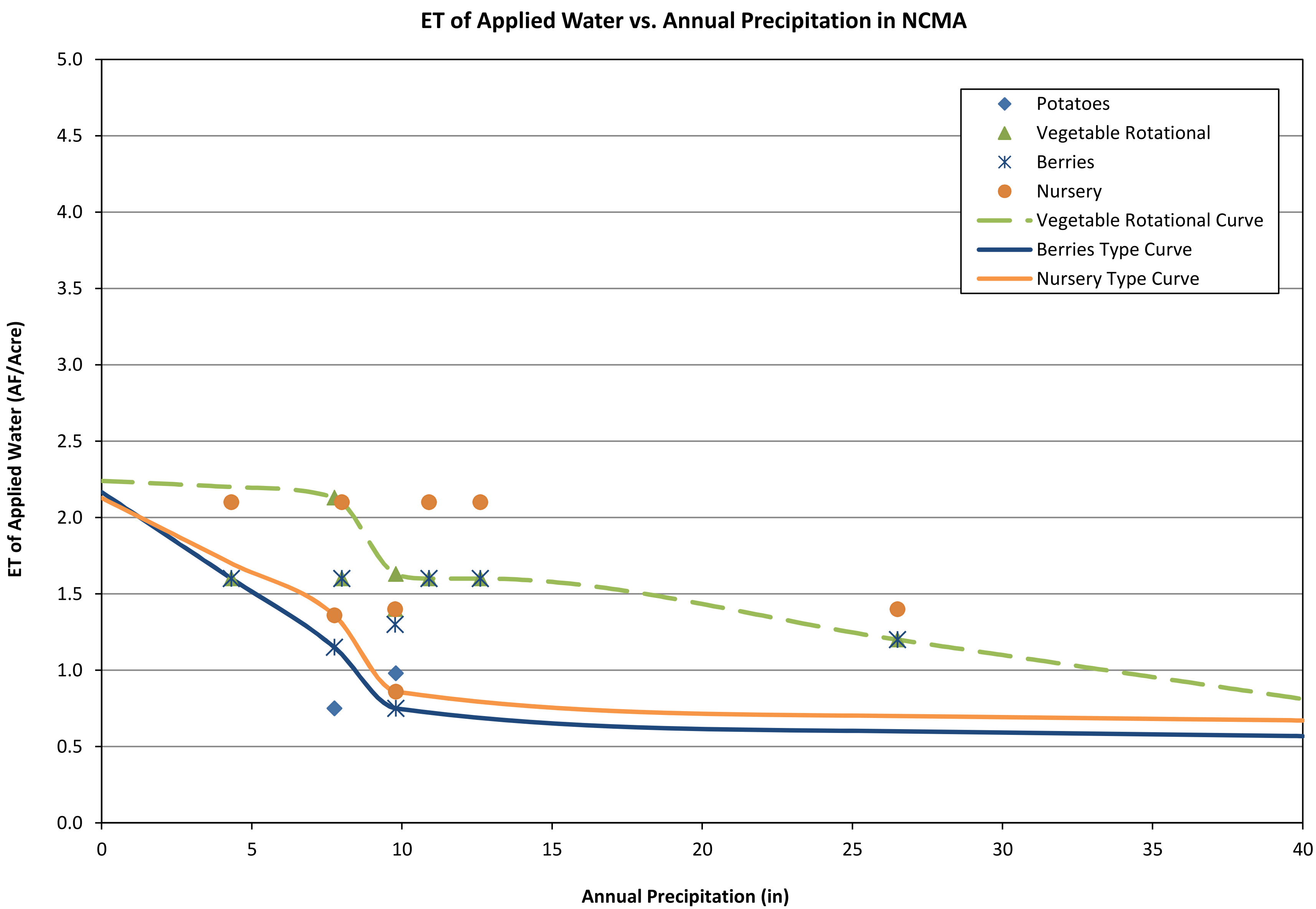
ET of Applied Water vs. Annual Precipitation in NCMA
ET of Applied Water (AF/Acre)
Annual Precipitation (in)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
0
5
10
15
20
25
30
35
40
Potatoes
Vegetable Rotational
Berries
Nursery
Vegetable Rotational Curve
Berries Type Curve
Nursery Type Curve

Figure 3

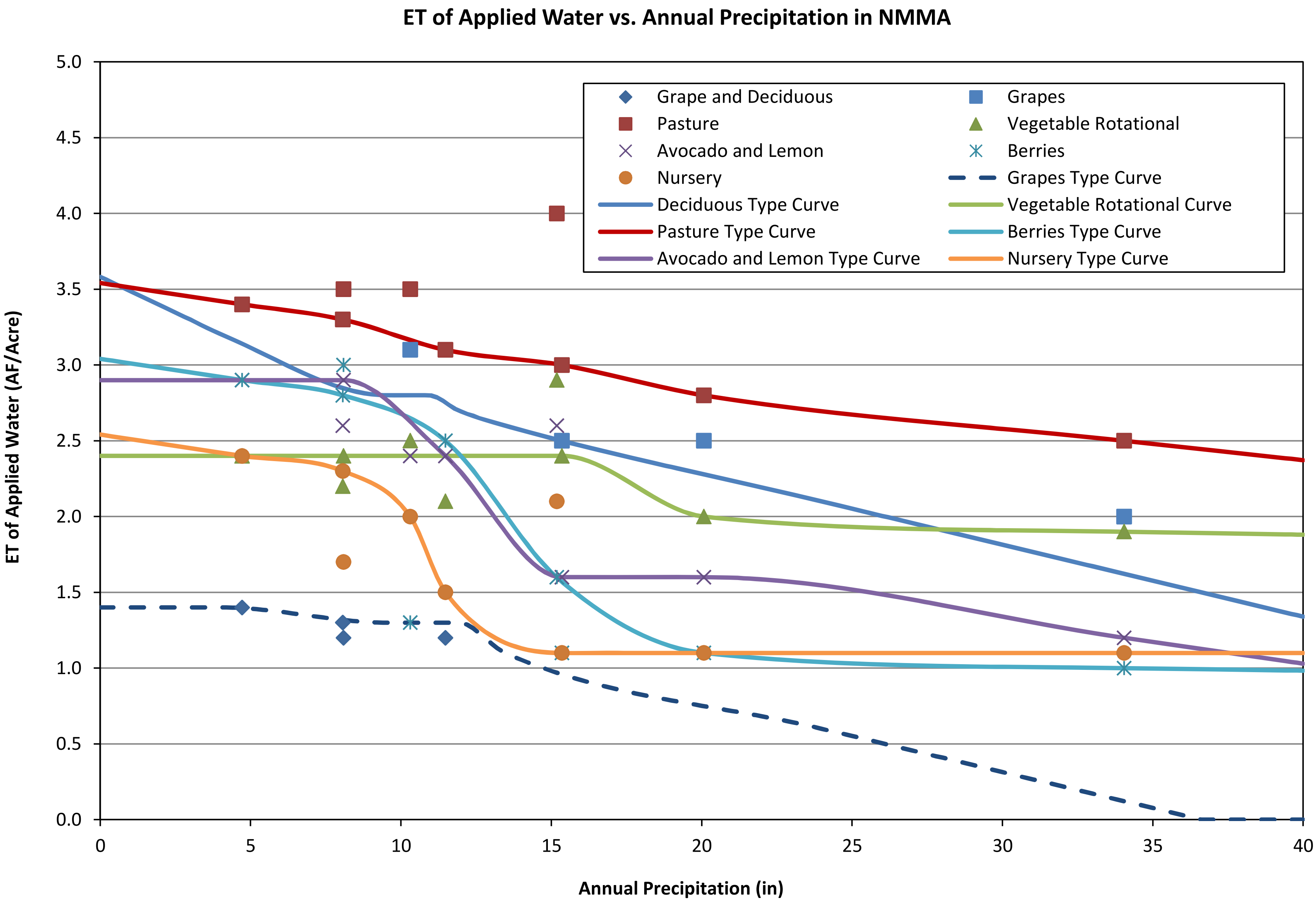
ET of Applied Water vs. Annual Precipitation in NMMA
Grape and Deciduous
Grapes
Pasture
Vegetable Rotational
Avocado and Lemon
Berries
Nursery
Grapes Type Curve
Deciduous Type Curve
Vegetable Rotational Curve
Pasture Type Curve
Berries Type Curve
Avocado and Lemon Type Curve
Nursery Type Curve
ET of Applied Water (AF/Acre)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
Annual Precipitation (in)

Figure 4

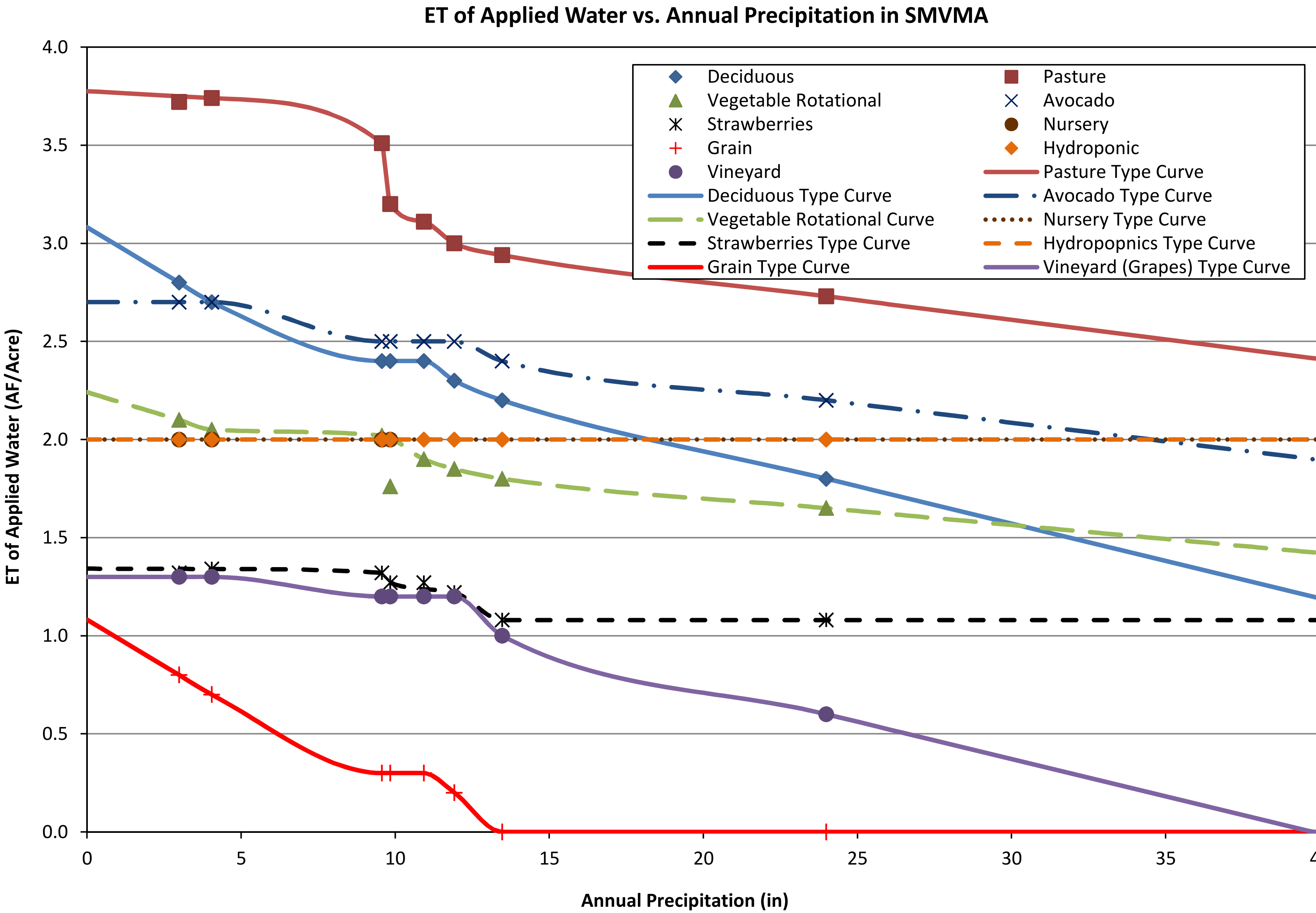
ET of Applied Water vs. Annual Precipitation in SMVMA
ET of Applied Water (AF/Acre)
Annual Precipitation (in)
Deciduous
Pasture
Vegetable Rotational
Avocado
Strawberries
Nursery
Grain
Hydroponic
Vineyard
Pasture Type Curve
Deciduous Type Curve
Avocado Type Curve
Vegetable Rotational Curve
Nursery Type Curve
Strawberries Type Curve
Hydropopnics Type Curve
Grain Type Curve
Vineyard (Grapes) Type Curve
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40

Figure 5

City of Pismo Beach and South San Luis Obispo County Sanitation District Regional Groundwater Sustainability Project Phase 1B Hydrogeologic Evaluation

Technical Memorandum No. 1: Conceptual Model

Prepared for:
Water Systems Consulting, Inc.

June 15, 2018

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GEOSCIENCE

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THIS DOCUMENT HAS BEEN CHECKED FOR COMPLETENESS, ACCURACY, AND CONSISTENCY BY THE FOLLOWING PROFESSIONALS:

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CITY OF PISMO BEACH AND SOUTH SAN LUIS OBISPO COUNTY SANITATION DISTRICT REGIONAL GROUNDWATER SUSTAINABILITY PROJECT PHASE 1B HYDROGEOLOGIC EVALUATION

TECHNICAL MEMORANDUM NO. 1: CONCEPTUAL MODEL

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TECHNICAL MEMORANDUM NO. 1: CONCEPTUAL MODEL

1.0 INTRODUCTION

1.1 Background

The Regional Groundwater Sustainability Project (RGSP) is a regional recycled water project that will reduce the risk of seawater intrusion and improve water supply sustainability in northwestern Santa Maria River Valley Groundwater Basin (Basin; see Figure 1). The project uses advanced-treated recycled water from the City of Pismo Beach and the South San Luis Obispo County Sanitation District (SSLOCSD) Wastewater Treatment Plants (WWTPs) as an injection water source. This water will then be injected in the Arroyo Grande-Tri-Cities Mesa portion of the Basin to establish a seawater barrier and improve the reliability of groundwater supplies in the region.

1.2 RGSP Phase 1B Groundwater Model

Water Systems Consulting (WSC) is in the process of conducting a Phase 1A and Phase 1B Hydrogeologic Evaluation of the RGSP. Phase 1A included an analysis of the injection and extraction of advanced-treated water from the City of Pismo Beach WWTP. As part of the RGSP Phase 1A, Cleath-Harris Geologists (CHG) constructed a groundwater flow model of the Northern Cities Management Area (NCMA) to evaluate the potential for injecting 1,000 acre-ft/yr of treated water (2017; refer to Figure 1 for location). The RGSP Phase 1A Model was constructed using the MODFLOW[1]-2005 and MODPATH computer codes and was used to run several scenarios analyzing potential injection well field configurations as well as injection and extraction scenarios for the City of Pismo Beach.

As part of the Phase 1B Hydrogeologic Evaluation, GEOSCIENCE Support Services, Inc. (GEOSCIENCE) has been tasked with expanding the RGSP model to include an evaluation of injection and extraction scenarios with flows from the SSLOCSD and City of Pismo Beach WWTPs. Inclusion of flows from the County Sanitation District's WWTP will substantially increase the amount of advanced-treated water

[1] MODFLOW is a block-centered, three-dimensional, finite-difference groundwater flow model developed by the USGS (McDonald and Harbaugh, 1988).

available for injection from approximately 650 AFY to 2,500 AFY. Therefore, the proposed RGSP Phase 1B Groundwater Model area was expanded to encompass the entire NCMA, the entire Nipomo Mesa Management Area (NMMA), and part of the Santa Maria Valley Management Area (SMVMA). Ideally, a model extent should include natural groundwater basin boundaries or be large enough to avoid significant boundary effects during scenario runs. By incorporating the entire NMMA and part of SMVMA, the expanded model extent will allow scenarios in NCMA to be run while minimizing the risk of boundary effects. The larger extent will also allow for the incorporation of more data, which facilitates the model's ability to capture the observed behavior of the natural system.

Specifically, expanding and enhancing the Phase 1A work includes the following activities:

- Evaluating existing groundwater characterization studies, groundwater models, and groundwater quality data,
- Constructing and calibrating the expanded Phase 1B Groundwater Model,
- Evaluating injection and extraction scenarios for the City of Pismo Beach and SSLOCSD WWTP flows, and
- Conducting an optional Anti-Degradation Analysis to comply with State Regulations.

This Technical Memorandum (TM) summarizes the conceptual model for the RGSP Phase 1B Groundwater Model, including proposed model extents and boundary conditions, the development of a three-dimensional (3-D) lithologic model, estimation of hydraulic conductivity values and other aquifer parameters, and the compilation and estimation of recharge and discharge terms. Data assessment and the methodologies and assumptions used to develop the conceptual model are also provided.

1.3 Data Review

Existing studies and datasets for the model area were collected and reviewed. These reports included:

- Santa Maria Groundwater Basin Characterization and Planning Activities Study Report (FUGRO, 2015a),
- NCMA, NMMA, and SMVMA Annual Reports,
- Water Balance Study for the Northern Cities (Todd Engineers, 2007),
- California Department of Water Resources (DWR) Hydrogeological Studies (11958, 1970, 1975, 1979, and 2002), and
- Historical groundwater, surface water, water quality, and climate data from public and private water agencies.

A complete list of references is provided in Section 4.0 of this report.

2.0 CONCEPTUAL MODEL OF THE PHASE 1B MODEL

The conceptual model includes an understanding of the geohydrology, groundwater flow directions, inflows (recharge), and outflows (discharge) for the RGSP Phase 1B Groundwater Model area. Developing a robust and geologically-accurate conceptual model is the crucial first step in the development of the Phase 1B Model and key to building a model that can be properly calibrated to observed data. This in turn will help produce a reliable predictive tool with which to run future scenarios.

2.1 Hydrogeologic Understanding

The RGSP Phase 1B Groundwater Model was developed for the unconsolidated to semi-consolidated water-bearing sediments of the NCMA, NMMA, and portion of the SMVMA in the northwestern Santa Maria Groundwater Basin (see Figure 1). The low yield formations which underlie and also generally flank the main groundwater basin include sedimentary, pyroclastic, volcanic, and metamorphic rocks (DWR, 2002 and 2004). Figure 2 shows the local geology along with the model domain and active area. Based on previous studies (Worts, 1951; DWR, 1971 and 2002; FUGRO, 2015a), the water-bearing formations in the proposed model area from youngest to oldest include:

- Recent alluvium,
- Old dune sand,
- Paso Robles Formation, and
- Careaga Sand and/or Careaga sandstone.

The non-water-bearing or low-yield formations which were classified as bedrock for modeling purposes include:

- Sisquoc Formation,
- Obispo Formation
- Monterey Formation
- Obispo Formation, and
- Franciscan Formations.

Recent dune sands and part of the older dune sands are largely unsaturated (DWR, 2002). The composite aquifer in the model area contains unconfined, semi-confined and perched zones, depending on the location and extent of discontinuous clay layers. The recent alluvium and Paso Robles Formation are the most productive and developed aquifer layers in the model area (DWR, 2002). The Paso Robles

Formation contains several aquifer zones identified by DWR (1970). The zones are separated by confining clays and silt at the coast and merge inland (FUGRO, 2015). The Pismo Formation, which is equivalent to the Careaga sandstone, is limited to the San Luis Hills where it is unconfined and tapped by domestic wells (DWR, 1970). It is located outside of the model domain.

Predominant groundwater flow in the area is toward the ocean. However, a pumping depression north of Oceano has been observed in the Paso Robles Formation since 1945 (FUGRO, 2015). In seven of the wells from selected hydrographs (Figure 3), groundwater levels have been declining in recent years. Some wells indicate a few cycles of decline and recovery. For example, groundwater levels in wells 19Q01, 28K02, 33K03, and 25F03 declined from the mid-1980s to the early 1990s, recovered from the early 1990s to the early 2000s, and steadily declined from the 2000s through 2016.

The presence of faults in the model area has important implications on groundwater flow because faults are often low permeability features that can restrict the movement of groundwater. Significant faults in the model area include the Wilmar Avenue Fault along the northern model boundary, the Oceano Fault, and the Santa Maria River Fault. The Wilmar Avenue Fault displaces the bedrock, Careaga Sand, and Paso Robles Formation, but does not appear to impede flow in the recent alluvium (FUGRO, 2015). Vertical offsets of geologic units of between 90 and 200 ft have also been observed in the subsurface along the Santa Maria River Fault.

In order to test whether or not these faults act as flow barriers, hydrographs from monitoring wells located on either side of the faults were compared for evidence of significant head differences. For wells to be properly used for this purpose, they have to be relatively close to the fault and to each other, and have comparable depth and screened intervals. Unfortunately, very few wells fit that description; only two wells were identified for the Santa Maria River Fault and six for the Oceano Fault. These wells and their hydrographs are shown on Figures 4 and 5, respectively. A head difference of approximately 40 ft was observed across the Santa Maria River Fault, suggesting that it could be acting as a flow barrier. All six wells across the Oceano Fault exhibit very comparable water levels and show no evidence that the Oceano Fault acts as a flow barrier. Therefore, only the Santa Maria River Fault will be represented as a horizontal flow barrier in the model (Figure 6). Though the Santa Maria River Fault will be represented as a hydraulic flow barrier, its effectiveness as a barrier will be varied along the length of the fault and the conductance will be determined by calibration. For the Wilmar Avenue Fault, only water levels in the alluvium were available on either side of the fault along the Arroyo Grande Creek. These measurements showed no significant water level differences. Observed gradients were well-correlated with topography. The impact of the Wilmar Avenue Fault on deeper layers could not be established, but should have minor impact on the model design as this fault is located at the northern edge of the model.

2.2 Three-Dimensional Lithologic Model

In order to define the extent of the groundwater flow system for the development of the Phase 1B Model, a three-dimensional (3-D) lithologic model was constructed to better identify the physical extents, thickness, continuity, and lithology of the geologic units within the model area. 3-D lithologic modeling assists in the development of a realistic conceptual model (i.e., model layers) and spatial distribution of aquifer parameters (i.e., hydraulic conductivity and storativity values) by using geostatistical techniques to approximate the spatial distribution and nature of heterogeneity of aquifer systems in the project area. This helps create a better understanding of groundwater flow and solute transport in the Phase 1B Model.

Petrel, a state-of-the-art, 3-D geologic modeling software developed by Schlumberger to assist with the development of model layers and aquifer parameters, was used to develop the lithologic model of the Phase 1B model area. Petrel uses a Sequential Indicator Simulator, ordinary kriging, and observed lithologic data from wells within the model area to estimate the type of lithology for each cell of the 3-D mesh.

The first step to developing the lithologic model was the construction of a basin geological structure model, which included the position of the bedrock, land surface elevations, and known faults and barriers responsible for lithologic lateral variations. The bedrock surface, which constitutes the base of the water-bearing formations and the bottom of the groundwater model, was delineated primarily based on 23 previously published cross-sections (DWR, 2002; FUGRO, 2015; LSCE, 2000; and NMMA Technical Group, 2017). Lithologic logs from Division of Oil, Gas, and Geothermal Resources (DOGGR) wells were also used to resolve a significant discrepancy between SMVMA cross-sections and DWR (2002) cross-sections after the bedrock surface was digitized and plotted in 3-D. The resulting bedrock surface is shown on Figure 7. Though fairly comprehensive, the lithological logs used in the lithologic model are not exhaustive; it is likely that other lithological logs exist but, being unknown, were not incorporated in this study.

The next step was to estimate the type of lithology at each cell of a 3-D mesh. A detailed mesh was constructed (225 rows by 219 columns and 395 layers, for a total of 19 million cells). This mesh is conformal at the base of the sediment package (i.e., bottom extent of aquifer) to the bedrock and at the top of the model to the surface elevation. More than 400 lithologic logs were compiled from the Santa Maria Basin Characterization Study (SMBC; FUGRO, 2015a) and were upscaled onto the grid (Figure 8). A sequential indicator simulation technique coupled with ordinary kriging was used to distribute the lithology in the grid cells. Figure 9 shows a 3-D view of the final lithologic model. The resulting model was checked against selected existing cross-sections from the SMBC (FF’, LL’, and MM’). Figures 10 through 12 provide cross-sectional views of the model-generated lithology in the Phase 1B Model along these three cross-sections.

2.3 Proposed Model Design

2.3.1 Model Code

The SEAWAT computer code will be used for the Phase 1B Model. The SEAWAT program was developed by the USGS (Guo and Langevin, 2002) to simulate three dimensional, variable-density, groundwater flow and solute transport in porous media. The source code for SEAWAT was developed by combining MODFLOW and MT3DMS[2] into a single program that solves the coupled flow and solute transport equations. Using this computer code will provide a more accurate prediction of seawater intrusion in the Santa Maria River Groundwater Basin than MODFLOW alone.

MODPATH software will be used to compute 3-D flow paths (i.e., particle tracking) using output from the groundwater flow model. MODPATH does not take dispersion, retardation, or half-life decay into account; the results of MODPATH simply provide an indication of the direction and rate of groundwater flow. Retention time of the recycled water from the recharge basin or injection well to the nearest production well can be calculated based on the MODPATH results.

2.3.2 Model Cells, Layers, and Stress Periods

The proposed Phase 1B Groundwater Model domain covers an area of approximately 197 square miles (125,857 acres) in the northwest portion of the Santa Maria Groundwater Basin, including the NCMA, NMMA, and portion of the SMVMA, as shown on Figure 1. The proposed finite-difference grid will consist of 610 rows in the northeast to southwest direction and 970 columns in the northwest to southeast direction along the model domain. The grid will be rotated at 40° clockwise to be consistent with the Phase 1A and minimize the number of model cells. Each model cell of the Phase 1B Model represents an area of 100 ft x 100 ft. The proposed stress period (i.e., time period) used to vary model fluxes, such as pumping and recharge, will occur monthly and the model will be calibrated from 1977 to 2016.

The conceptual groundwater model consists of ten model layers, which are discussed in detail in Section 2.3.4.1). These layers are:

---

2 MT3DMS is a Modular three-dimensional Multi-Species Transport model, is the second generation of the MT3D developed with funding from the U.S. Army Engineer Research and Development Center (Zheng and Wang, 1999).

- Layer 1 – Ocean floor (allows for vertical leakage from the ocean to the underlying aquifer (i.e., model layer 2))
- Layer 2 – Recent alluvium/old dune sand
- Layers 3 through 7 – Paso Robles Formation
- Layers 8 through 10 – Careaga Sand

Groundwater flow is assumed to occur primarily horizontally within each of the model layers while the layers maintain hydraulic connection to each other through vertical leakance. The Santa Maria River Fault will be modeled as lower permeability features using the Horizontal-Flow Barrier (HFB) package (Figure 6).

2.3.3 Boundary Conditions

The proposed boundary conditions and active area of the Phase 1B Model are shown on Figure 13. The active area of the model coincides with the boundaries of the groundwater basin in the north and northeast. These boundaries are based on local geology and DWR groundwater basin boundaries. The boundary conditions for the Phase 1B Model include no-flow, general head, and specified flux (e.g., mountain front recharge).

2.3.4 Aquifer Parameters

2.3.4.1 Model Layer Elevations

Land surface elevation, as determined from Digital Elevation Models (DEMs) for the 7.5” topographic quadrangles in the model area, was used as the top of model layer 2. Model layer 1 is a one-foot thick layer that is active only beneath the ocean to allow vertical leakage from the ocean to the underlying aquifer. The bottom elevation of layer 1 was assumed to be one foot below the top elevation. The bottom elevations for model layer 2 were determined based on the 3-D lithologic model.

As discussed in Section 2.1, aquifers within the model area are unconfined to semi-confined with spatially discontinuous aquitards. Developing a model layer structure for these conditions can be challenging. To help design the model layer structure accurately, GEOSCIENCE used the 3-D lithologic model and nested multi-level monitoring wells. Water levels at 11 locations along three cross-sections (Figure 14) were used to devise a vertical discretization of the aquifer system into ten model layers. Cross-Sections N-N’, O-O’, and P-P’ on Figures 15 through 17 show the screened intervals of the wells used and the delineation of the ten model layers. Cross-Sections N-N’ and O-O’ (Figures 15 and 16, respectively) confirm the findings from the SMBC (FUGRO, 2015) and DWR (2002) that confining clays and low hydraulic conductivity layers are relatively continuous at the coast. In contrast, Cross-Section P-P' (Figure 17) shows that the clay layers become patchier inland. Since it is not possible to pinch out or discontinue layers in SEAWAT, these confining units will be extended throughout the model but their properties will be adjusted to reflect changes in lithology.

2.3.4.2 Hydraulic Conductivity

According to published reports, horizontal hydraulic conductivity for the alluvium is expected to range from 270 ft/day to 600 ft/day (FUGRO, 2015). Horizontal hydraulic conductivity in the Paso Robles Formation is expected to range from 2 ft/day to 15 ft/day beneath the Nipomo Mesa and western part of the Basin, and from 13 ft/day to 50 ft/day in the Sisquoc Plain/Orcutt Upland/central valley areas. In the Careaga Sand, horizontal hydraulic conductivity has been estimated to be approximately 9.5 ft/day (Worts, 1951), and the dune sand is assumed to have a horizontal hydraulic conductivity of approximately 175 ft/day (FUGRO, 2015).

The majority of hydraulic conductivity estimates are located in the Paso Robles Formation or in both the Paso Robles Formation and Careaga Sand. Very few wells are exclusively screened in the Careaga Sand. The SMBC (FUGRO, 2015a) reported two sets of horizontal hydraulic conductivity estimates: hydraulic conductivity estimated from pumping test interpretation and hydraulic conductivity estimated from specific capacity. Pumping test data are more reliable, but specific capacity estimates can be helpful because they are usually readily available and provide a rough estimate of hydraulic conductivity in the absence of pumping test data. Figures 18 and 19 show the distribution of these two datasets by formation and magnitude. Overall, the hydraulic conductivity values derived from specific capacity (Figure 19) indicate that higher hydraulic conductivity values are located in the NCMA; hydraulic conductivities in the NMMA and SMVMA are relatively lower.

Hydraulic conductivity in the Phase 1B Model will be derived from a formula that relates hydraulic conductivity values to fractions of individual lithologies in each model cell. The formula used will be adjusted to fit hydraulic conductivities derived from pumping tests. The detailed description of the procedure relating pumping test derived hydraulic conductivities to lithology can be found in TM No. 2: Calibration Plan (GEOSCIENCE, 2018a).

2.3.4.3 Storativity

Storativity refers to the capacity of an aquifer to transfer water to and from storage (Anderson and Woessner, 1992). In groundwater models, this parameter is generally modeled through specific yield (unconfined aquifers) or specific storage (confined aquifers). Specific yield is the volume of water released from storage by an unconfined aquifer per unit surface area of aquifer per unit decline of the water table. Specific storage is the volume of water that a unit volume of aquifer releases from storage under a unit decline in head (Ferris et al., 1962). This is related to the compressibilities of water and the aquifer material. Both specific yield and specific storage values will be used in the Phase 1B Model. The type of storativity value used depended on the nature of the model layer through time (i.e., unconfined or confined).

Very few values of storativity in the Phase 1B Model area were available. Cleath (1996) reported a range of 0.002 to 0.003, which is indicative of semi-confined conditions. In areas where unconfined conditions prevail, specific yield values of 0.08 to 0.12 were reported for the Paso Robles Formation and Careaga Sand, while specific yield for the older dune sand is estimated to be approximately 0.13 (DWR 2002). Pumping tests conducted in 2014 during the SMBC study yielded values ranging from 0.0037 to 0.03 – also indicative of semi-confined to unconfined conditions (FUGRO, 2015). These estimates will be incorporated into the Phase 1B model and these initial storativity values will be modified during model calibration.

2.4 Groundwater Recharge and Discharge Terms

The groundwater budget, or water balance, for the model area is a critical aspect of the conceptual model. Recharge and discharge components for the Phase 1B Model are summarized in Table 2-1 below and discussed in the following sections.

Table 2-1. Recharge and Discharge Components of the Phase 1B Water Balance

Recharge (Inflows)	Areal Recharge from Precipitation
	Mountain Front Recharge
	Streambed Percolation
	Underflow Inflow
	Return Flow from Municipal Use (Indoor and Outdoor)
	Artificial Recharge
	Return Flows from Applied Water
Discharge (Outflows)	Municipal Pumping
	Private Rural Pumping
	Agricultural Pumping
	Discharge to River
	Evapotranspiration (ET)
	Underflow Outflow

2.4.1 Groundwater Inflow

2.4.1.1 Areal Recharge from Precipitation

Areal recharge is the deep percolation of direct precipitation on the ground surface which eventually recharges the aquifers within the groundwater basin. Recharge is dependent upon the type of soil and land use. Permeable soils and grassy areas allow more infiltration while less permeable soils and paved surfaces allow more runoff. Estimates of deep percolation of areal recharge were made using the U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS) Curve Number technique (USDA, 1986). Using this method, the SCS runoff equation is:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Where

Q = runoff (in),
P = precipitation (in),

S = potential maximum retention after runoff begins (in), and
I_a = initial abstraction (in).

Input data include Soil Survey maps, 1996 land use, DWR subbasins, precipitation information from four rainfall gages in the model area (see Figure 20), and potential evapotranspiration (ET_o) rates from the California Irrigation Management Information System (CIMIS) Nipomo station.

Estimated areal recharge for the period from 1977 through 2016 is shown on Figure 21. During this time period, percolation from areal recharge averaged 12,708 acre-ft/yr.

2.4.1.2 Mountain Front Recharge

While the consolidated to semi-consolidated rocks flanking the more permeable, water-bearing formations along the northeast model boundary typically have low yields and contribute limited groundwater to the downgradient groundwater basin, the active model area could potentially be receiving inflow along the northeastern boundaries of consolidated rock outcrops in the form of recharge from mountain front runoff (Figure 13). The term “mountain front recharge” is frequently used to describe the contribution of water from surrounding mountains to groundwater recharge in adjacent basins, which occurs along the mountain front. The mountain front is positioned somewhere between the mountain block and the basin (Wilson and Guan, 2004; Anderson et al., 2015). These contributions can also include underflow from the consolidated formations that constitute the mountains (Wilson and Guan, 2004).

Existing reports from the study area (FUGRO, 2015; GSI, 2017; LSCE, 2000; NMMA Technical Group, 2017) do not reference mountain front recharge or include an estimate of mountain front recharge in their water balance calculations. However, GEOSCIENCE has determined that it is conceptually sound to include mountain front recharge along the model boundaries that coincide with the Temattate Ridge to the northeast. As in semiarid climates, a significant component of recharge to basin aquifers occurs along the mountain front (Wilson and Guan, 2004). Also, some subsurface inflow comes from consolidated rocks surrounding the basin (DWR, 2004), which can also be included in the mountain front recharge term. Additional description of the mountain front recharge boundaries is presented in the Groundwater Model Boundaries TM (GEOSCIENCE, 2018b).

It was assumed that areal recharge that occurs in the mountainous portion of the subbasins (see mountain front runoff area on Figure 20) eventually becomes mountain front recharge. During the calibration period from 1977 through 2016, mountain front recharge averaged 962 acre-ft/yr (Figure 22).

2.4.1.3 Streambed Percolation

The main streams in the model area are the Arroyo Grande Creek, Los Berros Creek, and Santa Maria River (Figure 1). However, only the Arroyo Grande and Los Berros Creeks are located within the active model domain (Figure 13) and therefore will be fully modeled. Streambed percolation is ideally based on flow between streamflow gaging stations. Since there are insufficient data available to estimate streambed percolation in Los Berros Creek, estimates for this conceptual model were only conducted for Arroyo Grande Creek using the approach outlined in the Santa Maria Groundwater Basin Characterization and Planning Activities Study (FUGRO, 2015). Streamflow was analyzed for the U.S. Geological Survey (USGS) streamflow gage at Arroyo Grande Creek and at the 22nd Street Bridge gage (Figure 23). If flow was less than 5 cubic-ft per second (cfs), all of the streamflow was assumed to percolate. If streamflow was between 5 cfs and 10 cfs, percolation decreased from 5 cfs to 1.7 cfs, and if streamflow was greater than 10 cfs, percolation stabilized at 1.7 cfs. Average estimate streambed percolation for the period from 1977 through 2016 is shown on Figure 24 and averaged approximately 2,038 acre-ft/yr.

Both the Los Berros and Arroyo Grande Creeks will be fully modeled in the Phase 1B Model. Model-calculated streambed percolation from the calibrated model will be compared to these preliminary estimates.

2.4.1.4 Underflow Inflow

The southern boundary of the active model area intersects the Santa Maria River Valley Groundwater Basin along the Santa Maria River. This boundary will be represented by a general head boundary (GHB) to simulate groundwater underflow across the boundary and percolation from the Santa Maria River (Figure 25). The heads of the GHB will be derived from historical groundwater levels and varied throughout the calibration period. The Wilmar Avenue Fault of the San Luis Range Fault System is also thought to act as a flow barrier between the northeastern outcrop and the groundwater basin. However, there is no evidence that this fault impedes flow in the alluvium in the Arroyo Grande and Pismo Creek areas (GSI, 2017).

Subsurface inflow is also accounted for in the Arroyo Grande Creek. The estimated underflow is based on local groundwater levels and calculated using Darcy's Law, which relies on the groundwater gradient, hydraulic conductivity, and saturated underflow cross-sectional area. A preliminary estimate of underflow along the southern model boundary was not calculated. Due to the complexity of the water levels over the length of the boundary, it was difficult to determine a representative gradient and saturated thickness. Underflow inflow will be calculated by the calibrated model.

2.4.1.5 Artificial Recharge

Artificial groundwater recharge in the Phase 1B model area is achieved through the spreading of stormwater and treated wastewater from the City of Pismo Beach and SSLOCSD WWTPs. The locations of the stormwater and wastewater infiltration ponds are shown on Figure 26. Stormwater and wastewater recharge from 1977 through 2016 is shown on Figures 27 and 28, respectively. Stormwater recharge during this time period averaged approximately 747 acre-ft/yr while wastewater discharge averaged 335 acre-ft/yr. Total artificial recharge averaged approximately 1,082 acre-ft/yr.

2.4.1.6 Return Flow from Applied Water

Return flow refers to the amount of water that returns to the aquifer after application of water to the land surface in the form of irrigation, or from leaks in water and sewer lines. This includes the use of both groundwater and imported water.

2.4.1.7 Return Flow from Municipal Pumping

In the Phase 1B Model, return flows from municipal pumping includes landscape irrigation and leaks. Annual return flows from municipal water use was estimated by local agencies. The provided values ranged from 5% to approximately 12%. For missing years, an average value of 7.5% was assumed. As shown on Figure 29, return flow from municipal pumping averaged 2,040 acre-ft/yr from 1977 through 2016. It will also be assumed that 50% of the water distributed by municipalities is used outdoors and 50% of the outdoor use returns to the aquifer (25% of the water delivered). This water will be distributed evenly throughout the municipal service area.

2.4.1.8 Return Flow from Agricultural Pumping

Agricultural return flow from the irrigation of crops is dependent on irrigation efficiencies and soil types. Irrigation efficiencies used for agricultural pumping estimates varies spatially, by crop type, and as irrigation techniques change through time. Return flows were adjusted accordingly. Water in excess of crop demand as a result of inefficiencies in the irrigation system was assumed to return to the aquifer. However, the presence of shallow, low hydraulic conductivity layers could prevent excess water from returning to the aquifer. Therefore, return flow will be adjusted during model calibration. A summary of preliminary estimates of agricultural return flows is shown on Figure 30 and averages 9,680 acre-ft/yr for the period from 1977 through 2016.

2.4.2 Groundwater Outflow

2.4.2.1 Municipal and Private Rural Groundwater Pumping

Groundwater pumping represents a significant source of discharge from the Phase 1B Model. Municipal pumping records were obtained from public and private water agencies operating within the model area. The locations of municipal wells are shown on Figure 31, while total annual municipal pumping from 1977 to 2016 is provided on Figure 32. During this time period, municipal pumping averaged approximately 5,498 acre-ft/yr.

Pumping from private rural wells was also estimated. This estimated pumping is shown on Figure 33 and averages approximately 1,788 acre-ft/yr from 1977 through 2016.

2.4.2.2 Agricultural Pumping

Unlike municipal pumping which is directly measured from metered water wells, agricultural pumping is largely unmetered and therefore needed to be estimated indirectly. Various studies in the area have estimated agricultural pumping in the past using assorted techniques. The data available for estimating agricultural pumping include:

- Crop distribution maps from 1996 through 2016 for the entire NCMA, NMMA, and SMVMA;
- Rainfall records from various stations for the modeling period (1977 – 2016);
- ET_o from 1983 through 2016 from CIMIS stations;
- Farmland Mapping and Monitoring Program maps;
- Existing crop coefficients (K_Cs); and
- Applied water rates from previous reports and publications in the area.

Additional discussion on the estimation of agricultural pumping is provided in the Agricultural Pumping Estimates TM (GEOSCIENCE, 2018c).

2.4.2.2.1 Applied Water Evapotranspiration Type Curves

The approach used by GEOSCIENCE to estimate agricultural production is similar to the type curves used by Luhdorff & Scalmanini Consulting Engineers (LSCE) in the SMVMA, which correlated applied water by crop type to rainfall (LSCE, 2000). The basic principle behind these curves is that less water is used for irrigation during wet years and more water is used during drier years. The amount of water used per acre also varies by crop type – necessitating a different curve for each crop. These curves were constructed by plotting the evapotranspiration (ET) of applied water (ETAW) against annual precipitation. ETAW is the amount of water necessary to satisfy the annual water demand for an acre of a given crop. The result is a declining graph showing the change in water demand over various annual rainfall conditions.

However, because local climate variation can have a significant impact on applied water (due to ET variations), these curves were reconstructed using recent estimates of applied water in the NCMA (GSI, 2017), NMMA (NMMA Technical Group, 2017), and SMVMA (LSCE, 2017). A different set of curves were used for each management area to reflect the variation in local climate. For instance, NCMA is low-lying and close to the coast. Therefore, ET is influenced by the effects of the marine layer. Crop ET within the marine layer can be as much as 25% lower than the same crop outside of the marine layer (GSI, 2017). The extent of the marine layer inland can vary from 0.5 miles to as much as 4 or 5 miles, depending on topography (GSI, 2017). These parameters were taken into account by GSI in their approach, resulting in a 12% adjustment of ET data from a CIMIS station located farther inland, which was used to estimate applied water in the NMMA.

During the development of these type curves, an effort was made to honor existing estimates, as long as they were in the general range of local values from literature and did not alter the trends in a way that would violate the assumption that the applied water demand generally declines with increasing total annual precipitation. Ultimately, more recent estimates derived from improved and revised procedures were given precedence. Previous studies in California and elsewhere were also used to ensure estimated applied water values and overall trends were reasonable (DWR, 1975 and 1986; Doorenbos and Pruitt, 1977). The type curves used for the individual management areas are shown on Figures 34 through 36.

2.4.2.2.2 Irrigation Efficiency Estimates

The type curves described in the previous section are used to determine the ETAW, or crop water demand. Irrigation efficiency affects the amount of water that must be used to meet a given crop's water demand. Therefore, the applied water (AW) may be estimated by adjusting irrigation ETAW with and assumed irrigation efficiency (IE), as follows:

$$AW = ETAW / IE$$

IE is highly dependent on the irrigation method, and there is a range between potential and actual performance (Carollo, 2012). Poor design and management can turn a potentially high performance system into a low performance system. In addition, irrigation methods vary by crop type. Consequently, IE is very difficult to measure and is often estimated according to the system type, special practices, and distribution uniformities. In the NCMA 2015 and 2016 reports, GSI assumed a uniform IE of 90%. For the same years, LSCE varied the IE in the SMVMA by crop type, ranging from 80% to 95%. In the NMMA, the calculated agricultural pumping accounts for only water used by the crop. The use of an IE parameter would increase the calculated agricultural pumping amount and the disposition of that water would either be accounted for by evaporation from the soil or by return flow. Since the NMMA does not use an IE parameter, that water is assumed to remain in the aquifer. Another important factor to consider is that the IE for a given area can change over time as the price of water and pesticides rise or as new conservation policies combined with better irrigation methods are implemented. As noted in previous work conducted by GEOSCIENCE, IE in San Luis Obispo County improved from 63% in 1985 to a maximum of 85% in 2011 (2014). For this project, GEOSCIENCE will assume IE values from 2011 through 2016 based on those values used in the NCMA (90%) and SMVMA (85% to 95%), and an IE of 63% from 1977 through 1984.

2.4.2.2.3 Applied Water Estimates

Once the ETAW curves were developed, the applied water demand per acre per crop was estimated by using the annual total precipitation and looking up the corresponding annual applied ET demand for a given crop per acre. This value was then divided by the IE and multiplied by the crop acreage (from crop distribution maps) to obtain the total annual pumping estimate for this crop. Since estimates for agricultural pumping in the NMMA, NCMA, and SMVMA are only available from 2008 through 2016 and the model calibration period extends from 1977 to 2016, this method was used to estimate applied water demand and agricultural pumping for the remaining time periods not covered by previous estimates.

Due to the variety of methods used to estimate agricultural pumping and the discrepancies between them (even within the same management area), not all previous estimates were honored. In the NCMA, an effort was made to honor the last two years (2015 and 2016) because these estimates were made more robust by taking into account local climate and using DWR's IWFM: Integrated Water Flow Model – Demand Calculator (IDC) and Consumptive Use Program (CUP). Similarly, estimates of agricultural pumping in the NMMA for the last four (4) years were honored because they include newer and more reliable crop coefficients based on other estimates and measurements in the region. However, the method used by the NMMA TG differs from the other approaches, therefore the IE value is assumed to be similar to the ones used for SMVMA. Almost all estimates for the SMVMA were honored because the approach has been consistent from 2008 through 2016.

2.4.2.2.4 NCMA Applied ET and Agricultural Production Estimates

The type curves implemented for the NCMA are shown on Figure 34 along with previous estimates from NCMA annual reports from 2009 to 2016. Annual precipitation values were obtained from NCMA's annual reports and represent a composite of Pismo Beach and Oceano gaging stations. Some discrepancies exist due to the various methods used over the years. However, as explained previously, estimates from the last two years will be honored and used directly. The type curve shown on Figure 34 was used to estimate agricultural production from 1977 through 2014.

2.4.2.2.5 NMMA Applied ET and Agricultural Production Estimates

The approach used by the NMMA Technical Group for estimating agricultural pumping in the NMMA changed in 2013 in an effort to improve estimates. Therefore, the type curves developed for the NMMA honored the last four years (2013-2016). These curves are shown on Figure 35 along with existing estimates of agricultural production from NMMA annual reports. It should be noted that annual report estimates prior to 2013 did not include grapes as a crop and only had “deciduous”. From 2013 onward, grapes and deciduous crops were lumped into one category and a single applied water value per acre was used. Figure 35 shows that values of deciduous crops prior to 2013 fall closer to deciduous curves from the SMVMA while values for deciduous and grapes combined align better with the grapes (vineyard) type curve. Therefore, these two categories were separated during agricultural pumping estimates whenever possible. Agricultural pumping were estimated from 1977 through 2012 using the type curves shown on Figure 35, and existing values were used from 2013 to 2016.

2.4.2.2.6 SMVMA Applied ET and Agricultural Production Estimates

LSCE used a consistent approach to estimate ETAW from 2009 to the present. Values from their work were used to develop the applied water type curves for the SMVMA. For a limited set of crops (including hoop house, hydroponic, and nursery), a constant value was used. The resulting applied water versus annual precipitation curves for the SMVMA are shown on Figure 36 along with existing estimates of agricultural pumping from SMVMA annual reports from 2009 to 2016. Two harvests per year were assumed for rotational crops and precipitation data from Santa Maria Airport station were used and are reflected in the applied water rates. Agricultural pumping estimates were computed from 1977 through 2008 using the type curves shown on Figure 36, and existing values were used from 2009 to 2016. Agricultural pumping for non-crop or non-orchard uses was assumed to be negligible.

2.4.2.2.7 Computation and Verification of Agricultural Production

To verify the approach used by GEOSCIENCE, applied water volumes per acre for all three management areas (NCMA, NMMA, and SMVMA) were recomputed using the curves developed by GEOSCIENCE. Table 2-2 below compares the total NCMA agricultural production estimates from NCMA annual reports and GEOSCIENCE estimates, focusing on the two years that will not be re-estimated (2015 and 2016).

Likewise, Table 2-3 compares agricultural production estimates for the NMMA by the NMMA TG and GEOSCIENCE, focusing on the last four years, which will be used as-is in the model. Table 2-4 compares LSCE and GEOSCIENCE estimates of agricultural production in the SMVMA.

Table 2-2. Comparison of Annual Agricultural Production Estimates in the NCMA

Year	NCMA Annual Report (AF)	GEOSCIENCE (AF)
2015	2,267	2,493
2016	3,008	3,184
Average	**2,638**	**2,839**

Table 2-3. Comparison of Annual Agricultural Production Estimates in the NMMA

Year	NMMA Annual Report (AF)	GEOSCIENCE (AF)
2013	6,175	6,334
2014	7,337	7,243
2015	7,234	7,137
2016	6,831	7,243
Average	**6,894**	**6,989**

Table 2-4. Comparison of Annual Agricultural Production Estimates in the SMVMA[3]

Year	SMVMA Annual Report (AF)	GEOSCIENCE (AF)
2009	103,371	103,356
2010	115,749	115,857
2011	112,682	112,635
2012	115,972	116,939
2013	102,517	105,008
2014	96,387	96,356
2015	87,214	87,256
2016	98,085	109,108
Average	**103,997**	**105,814**

Overall, GEOSCIENCE estimates compare well to previous calculations by GSI, the NMMA TG, and LSCE. This is especially true considering the general uncertainty attached to estimating agricultural production.

The type curves and crop distribution maps for the individual management zones were then used to estimate the total agricultural pumping from 1977 to 2016 (Figure 37). During this time period, agricultural pumping in the Phase 1B Model area averaged 32,563 acre-ft/yr. As shown, agricultural pumping in 2016 is reduced from previous years in response to increased rainfall that year. Annual agricultural production will be distributed on a monthly basis based on monthly crop coefficients and/or existing monthly applied water relationships.

2.4.2.3 Underflow Outflow

The northwestern boundary of the study area coincides with the Pacific Ocean and will be represented as a GHB to simulate underflow between the groundwater basin and the ocean. The heads will be set to sea level to represent the surface of the ocean. Unlike the southern GHB (Section 2.4.1.4), which will be simulated to the full depth of the model (top to bottom), the GHB here will only be assigned to the top of model layer 1 where it interfaces with the ocean (Figure 38). The remaining layers will not be assigned a CHB. The active layers will be extended into the Pacific Ocean. The extension of the layers into the

3 Production estimates here were made for the entire SMVMA. Only a portion of the SMVMA is located within the active Phase 1B Model area.

ocean is based on DWR (1979), which estimated that the aquifer system extends oceanward 12 miles and that this offshore aquifer system holds a considerable amount of fresh water.

Underflow outflow will be calculated by the calibrated Phase 1B model. However, previous estimates of underflow outflow to the ocean from the Santa Maria River Valley area range between 1,800 acre-ft/yr in 1975 and 23,000 acre-ft/yr in 1985 (DWR, 2002). Approximately two-thirds of this flow is thought to occur in the alluvium (DWR, 2002).

2.4.2.4 Evapotranspiration (ET)

ET is the amount of water lost from the groundwater system through evaporation, plant transpiration, or both. It usually occurs where the groundwater is shallow (riparian areas and wetlands, etc.) or where plants are deeply rooted – allowing them to tap the groundwater. Previous reports in the area do not report estimates of ET, probably because groundwater in the model area is generally deep enough to preclude ET. However, because groundwater is likely shallow enough in riparian areas and closer to the coast, ET will be represented in the Phase 1B Model. ET in agricultural areas is taken into account by the applied ET calculation used to estimate agricultural pumping (Section 2.4.2.2).

In MODFLOW, ET is represented by assigning a maximum ET value and an extinction depth. Groundwater levels deeper than the extinction depth will not experience ET, while groundwater within the extinction depth range will incur ET losses. The amount of ET will vary linearly with the depth (i.e., the shallower the groundwater, the higher the ET). An initial extinction depth of 15 ft will be assumed. Maximum ET values and initial ET zones will be obtained from average monthly CIMIS potential ET (PET or ET_o) and CIMIS-delineated PET zones.

2.4.3 Changes in Groundwater Storage

The groundwater flow model is an analytical expression of the conservation of mass, namely:

Inflow = Outflow ± Δ Storage

The change in storage for the Phase 1B Model will be calculated as the difference between the sum of the recharge terms and sum of the discharge terms from the calibrated model.

A preliminary estimate of the change in storage was conducted by interpolating the head differences between 1977 and 2016 water level contours and assuming a specific yield of 0.1. The interpolated head differences are shown on Figure 39. As shown, head differences vary from 0 to -35 ft. This approach produces and estimated total change in storage of -29,293 acre-ft over the 40-year period. This estimate represents and average decline in groundwater storage of approximately 732 acre-ft/yr.

3.0 SUMMARY

The conceptual model for the RGSP Phase 1B Groundwater Model was developed based primarily on previous studies and the construction of a 3-D lithologic model of the unconsolidated alluvial and dune sediments of the NCMA, NMMA, and portion of the SMVMA in the northwestern Santa Maria Groundwater Basin. This conceptual model will guide the development of the Phase 1B Model, including the delineation of model layers, designation of initial aquifer parameters such as hydraulic conductivity and storativity, and allocation of recharge and discharge terms in the model area. This conceptual model is integral to building a model that can be properly calibrated to observed data, and be used as a predictive tool with which to run future scenarios.

A preliminary water balance for the model area is shown on Figure 40, which includes recharge and discharge terms that were determined using the methods described in this TM. However, because some of the recharge and discharge terms represent model-calculated values which will be calculated by the calibrated model, the water balance shown on Figure 40 is incomplete. Therefore, the change in groundwater storage is not shown. After model calibration, a sensitivity analysis will be conducted to assess which input parameters may have the greatest effect on the model simulation results (refer to GEOSCIENCE, 2018a).

The Phase 1B Model will be constructed based on the finalized conceptual model of the model area and approved model computer code, domain, number of layers, and cell size. Key model parameters such as hydraulic conductivity, storativity, effective porosity, and model layer elevations will be assigned to each of the model cells and maximum/minimum values will be established for use in the model calibration process. The model calibration process and results will be summarized in TM No. 3: Model Calibration.

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ATTACHMENT A: RESPONSES TO COMMENTS FROM THE TAC

Comments from GSI	GEOSCIENCE Response
A-1. Page 2, lines 6-7. Suggest changing "…without the risk of boundary effects…" to "…while minimizing the effect of model boundary conditions on model results in NCMA…" or something similar.	We agree and the change was implemented.
A-2. Figure 2, and general comment. The Nipomo Valley area north of Wilmar Avenue Fault is unsaturated Older Alluvium/Orcutt atop Monterey Obispo. Not sure it needs to be included in model	This area was made inactive and removed from the active model domain for the foreseeable future. Also, the lithological model confirmed that the alluvium in these areas is very thin and probably cannot sustain reasonable yield.
A-3. Page 3, Section 2.1. Neither the Pismo Formation nor the Monterey Formation are mentioned in discussion of "non-water-bearing" formations.	These formations were left out because they do not exist within the valley floor to the best of our knowledge (on the surface or down deep). Nevertheless, GEOSCIENCE included them in the final discussion. In addition, the Monterrey Formation was added to the "non-water-bearing" formations.
A-4. Page 4, lines 1-3. Statements "…groundwater levels have been declining in recent years…" and "Groundwater levels have been in steady decline from the 2000s through 2016." Are overly broad and need to be clarified. Several wells in Figure 3 do not show significant declining trend, like 32D11, 33K03 (except for recent drought decline), 9K02, etc. The general statement describing decline is not global throughout the study area. Trends appear to be different in different areas	This comment was clarified and made more descriptive and detailed.
A-5. Figure 3. a. It may be helpful to include NCMA/NMMA/SMVMA boundaries on this figure, and in general globally on all figures, for better geographic reference of conditions/data in different management areas. b. Consider using a common y-axis range for all graphs, so that relative quantity of fluctuations of	All of these changes were implemented.

Comments from GSI	GEOSCIENCE Response
hydrograph line is same in all; for example some graphs range from -40 to 80 ft msl, while others range from -40 to 120. c. Consider displaying data points on hydrograph lines (general for all hydrographs, if appropriate). d. Consider using an air photo for the base map for this figure so that geographic variations in land use (municipal vs. ag) is apparent.	
A-6. Figure 4. This is a very interesting and demonstrative graph making the argument for the effect of SMR fault on groundwater flow, even though it's based on just two points.	GEOSCIENCE agrees, but as stated in the Conceptual Review Meeting, these results are contingent upon the resolution of the water level discrepancies in the water levels provided by Steve Bachman.
A-7. Page 5, 3rd paragraph. I don't understand this software, but will be interested to hear discussion at the meeting of the rationale for having 395 layers in the lithologic model.	Lithological logs are described vertically with more detail. In some cases, a different lithology is described every 5 to 10 feet. To capture all of this information and avoid losing resolution, it is advisable to discretize the vertical dimension as much as possible by creating more layers. This level of detail is only used for the lithological model and will not be carried over to the groundwater model.
A-8. Page 6, Section 2.3.2. A 40-year calibration period seems pretty good, but will there be a steady-state run developed to estimate pre-development conditions?	A steady state calibration will be run for 1977 and mainly used to establish a stable, initial head. No pre-development conditions steady state calibration will be run.
A-9. Figures 10 and 11. Figure 11 (Cross Section L-L') displays a section crossing the Santa Maria River Fault that appears to display the block north of the fault being thrown <u>downward</u> in relation to the block south of the fault. Figure 10 (Cross Section F-F') section line also crosses Oceano and SMR faults, but	Both SMBC cross-sections show this "contradiction". While unlikely at such short distances (5.2 mi), such a discrepancy is possible.

Comments from GSI	GEOSCIENCE Response
appears to show the blocks on the northern side being thrown upward in relation to the southern block. Is this a contradiction?	
A-10. Figure 10 shows an apparent throw of 300 feet of the Paso/Careaga contact across the Oceano Fault. That seems like a lot. Is this supported by other data or studies?	Only the F-F' cross-section from SBMC shows this throw, but Cleath (1996) reports a 376 ft throw across the Oceano fault as well.
A-11. Figures 10, 11, 12, and other cross sections. Consider including cardinal direction labels (North, South) in addition to the section letter identifiers for better geographic reference.	The Figures were updated to reflect these comments.
A-12. Page 7, Boundary conditions, and Figure 13. Again, would like to discuss inclusion of areas north of the Wilmar Avenue Fault in the model.	Refer to response to comment A-2.
A-13. Figure 15, Figure 11. These cross sections both run north south along the coast, but Figure 11 is north on the left south on the right, but Figure 15 is oriented opposite. Consider making them consistent in orientation.	These changes were implemented.
A-14. Figure 15. Most of the model layer assignations seem to generally follow the trends visible in the lithologic model strata, but the Layer 3/Layer 4 lines doesn't appear to do so in the left side of the figure. Is there a reason for this?	While trends in the lithology strata are followed most of the time, GEOSCIENCE used its judgement and experience during the assignment of model layers. Initial layering imposed during the development of the lithological model (e.g., top-conformable, bottom-conformable, etc.) impacts the lithology interpolation algorithm. Therefore, seemingly uncorrelated strata could actually be correlated. This represents a limitation of the lithological modeling interpretation.
A-15. Pages 7-8, Hydraulic Conductivity. Paso Robles Formation estimates beneath Nipomo Mesa range	GEOSCIENCE agrees with this comment and this section was corrected and clarified.

Comments from GSI	GEOSCIENCE Response
from 2-15 feet/day, while Careaga is estimated at 9.5 feet per day. Are there really any areas where the K of the Careaga is expected to be greater than that of the Paso Robles Formation?	
A-16. Figures 18-19. Consider including a visual key to the colors in the legend, rather than text. This would make inspection of the figure easier.	This change was made to the figure.
A-17. Page 8, 2nd paragraph, last sentence. “Overall the hydraulic conductivity values derived from specific capacity (Figure 19) indicate that higher hydraulic conductivities are located in the NCMA and SMVMA…”. I concur with that statement in regard to NCMA, but I see nothing on Figures 18 or 19 to indicate that it’s true for SMVMA. Figure 18 shows no data points in SMVMA. Figure 19 shows a single data point in SMVMA, and it is of similar magnitude to those shown in NMMA. (Again, including the management agency boundaries would be helpful.)	GEOSCIENCE agrees and the section was corrected and clarified.
A-18. Section 2.4. Consider amending the report organization so that Recharge and Discharge terms are distinguished in separate outline sections.	This amendment was made.
A-19. Table 2-1, and Section 2.4.1. Consider separating discussion of Areal Recharge from Mountain Front Recharge. They are separate components of the conceptual model recharge, it seems like they should be discussed separately.	This change was implemented.
A-20. Will there be any discussion or inclusion of underflow inflow from the Pismo Formation across the Wilmar Avenue Fault in non-alluvial valley areas between Pismo Creek and Arroyo Grande Creek? From the Monterey Formation?	Underflow inflow from the Pismo and Monterey Formations in non-alluvial valley areas were included in the mountain front recharge term.
A-21. Figures 32, 37. Consider formatting these as stacked graphs that display the contributory amount of pumping in each management area	Graphs were left as individual charts to allow trends in the data to be distinguished for the purposes of the conceptual model. These

Comments from GSI	GEOSCIENCE Response
	graphs can be stacked for the calibration TM.
A-22. Figure 37. The discussion of agricultural pumping estimates is extensive and thorough, and the fact that Geosciences generally agree with previous estimates seems to corroborate the approach. I have no reason to question any of it, but I am somewhat surprised to see no upward trend of ag pumpage over the past 40 years. Separate from pumping estimates, is data available that shows any significant increase in irrigated acreage over this time period?	The data from irrigated acreage are relatively sparse and sometimes from different sources. The county provided data from 1998 to 2016. Data from 1984 to 1997 is derived from farmland mapping (FMMP), assuming crop type proportions remained the same as they were in 1998. And from 1977 to 1983, the crop acreages are assumed to be the same as 1984. Therefore, the irrigated acreage is not very consistent over time. Also, since the amount of precipitation impacts how much water is used, rainfall can dilute the effect of increasing acreage over time.
A-23. NMMA Ag pumpage. Figure 4-1 from the NMMA 2016 Annual Report indicates that the post-2013 Ag estimates under the new methodology are noticeably higher than the pre-2010 estimates. Did your type curve result in higher estimates for the NMMA ag pumpage from 1977-2010 compared to those that were previously published?	Yes, the estimates by GEOSCIENCE are consistently higher from 2008 to 2012 which is the period where published NMMA estimates are available.
A-24. Table 2-1. ET is included in Section 2.4.9, but is not included on Table 2-1	ET was added to Table 2-1.
A-25. Page 11, first line, appears to incorrectly reference Figure 17 discussing creeks in model area. Fig 17 is a model layering figure	This reference was corrected.
A-26. Page 12, Section 2.4.5.1, Return Flow from Municipal Pumping. How will the spatial distribution of this return flow be handled? Equal distribution throughout the municipal service area?	Yes, return flow from municipal pumping will be distributed evenly throughout the municipal service area.
A-27. Page 13, 1st line. How was pumping from private rural wells estimated? Per capita?	The data were originally obtained from the annual reports for each management area and were based on a per capita use.

Comments from GSI	GEOSCIENCE Response
A-28. Page 17, Table 2-3. “Annual” misspelled in second column header	The spelling of “annual” was fixed.
A-29. Page 18, Section 2.4.9. ET is discussed extensively in the ag pumping section. Is ET already handled conceptually in ag areas? Or will the ET package be applied to the entire model area?	The ET package will only be primarily applied to riparian areas. A few low-lying areas around the coast where groundwater is shallow may also be included. ET in agricultural areas is taken into account by the applied ET calculation used to estimate agricultural pumping.

Comments from the NMMA Tech. Group	GEOSCIENCE Response
B-1. Section 1.3. A list of 11 recommended reports was provided in 2017, but only 2 of these reports have been cited in the TM. Review of the other 9 reports, most of which describe groundwater modeling efforts in southern San Luis Obispo County by other investigators, is highly recommended (see attached list).	GEOSCIENCE could not find the recommended reports initially. However, these reports were later provided by NMMA, GSI, and Bob Collar. They were reviewed and are referenced in the updated and final conceptual model TM.
B-2. Section 2: The goal of any numerical modeling effort is to produce a properly-calibrated model that can be used as a reliable predictive tool. However, adequacy of the calibration and the ability of the model to reliably predict future conditions are highly dependent on a number of factors. Given the potential uncertainty and possible limitations associated with the subject model, and because the model has yet to be calibrated, any description of the model's accuracy and capabilities should be tempered throughout this document.	The language will be tempered as suggested.
B-3. Section 2.1. The use of the word unconsolidated in the first sentence of this paragraph is potentially confusing or misleading. While the model domain contains unconsolidated alluvium and (active) dune sediments, other hydrostratigraphic units yielding appreciable quantities of groundwater to wells might	Our understanding is that formations classified as high-yielding are, in fact, unconsolidated in the model domain. The only formation within the model domain which is semi-consolidated is the Careaga sand, or Careaga sandstone. Worts (1951) reports that the Careaga sand was

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be described as semi-consolidated or semi-lithified to lithified. The itemized lists of lithologic units that are part of the first paragraph of this section represent a good attempt at distinguishing between hydrostratigraphic units that are relatively transmissive and yield appreciable quantities of groundwater to wells from other, relatively low transmissivity units (e.g., the Obispo Formation). However, the hydrostratigraphic units in the model domain do not fall into 2 classic categories of relatively transmissive unconsolidated sediments overlying consolidated, lithified, or even crystalline rock of relatively low transmissivity (i.e., "bedrock"). Please clarify, so that the reader understands that some units such as the older dune sand, Paso Robles Formation, and Careaga sand may in fact be semi-consolidated, semi-lithified, or lithified (e.g., the 2015 Fugro report refers to the Careaga Sandstone), as these distinctions seem to separate the model domain into 3 categories: (i) unconsolidated, transmissive units (e.g., alluvium in the NCMA and alluvium associated with the Santa Maria River), (ii) semi-consolidated to lithified somewhat transmissive units, and (iii) consolidated, and possibly fractured, units of relatively low transmissivity.	observed to be lithified or semi-lithified in outcrops and was unconsolidated in wells and with depth. This was discussed in the boundary conditions TM, but additional language will be added for clarification since we agree that some formations classified as “bedrock” can be semi-consolidated or unconsolidated per SMBC cross-sections.
B-4. Section 2.1. Depiction of aquifers where hydraulic head differences indicate the presence of significant vertical hydraulic gradients should be clear in the TM. The apparent use of cross sections F-F’, L-L’, and M-M’ from the 2015 Fugro report, which attempted to characterize the geology of southern SLO County, is commendable, as is the addition/use of apparently new cross sections N-N’, O-O’, and P-P’. However, differentiation between a shallow and deeper aquifer, which have been identified in the NMMA based in part of significant hydraulic head differences between these two aquifers, is not	While the conceptual model TM was being written, significant discrepancies between reference points for the same well from different sources made it difficult to distinguish aquifers based on water levels. Steve Backman from the NMMA-TG was in the process of helping solve these discrepancies. Unfortunately, the NMMA could not help resolve the reference point discrepancies for the wells used to characterize groundwater level offset across the Santa Maria River Fault. GEOSCIENCE assumes that the Santa Maria

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depicted or clear in Figures 10 (cross section F-F') and 17 (cross section P-P'), as would be expected. This is especially important, given the need to avoid analyzing groundwater levels from two different aquifers in a manner that might be misinterpreted, for example in relation to how faulting might or might not impede groundwater flow.	Fault is a flow barrier based on previous reports (DWR 2002, RWCB, 2012). Model calibration will also help determine if this assumption is realistic.
B-5. Section 2.1. Please consider revising the second to last sentence of this paragraph to read as follows: Vertical offsets of geologic units of between 90 to 200 ft have also been observed in the subsurface along the Santa Maria River Fault. Consider eliminating the phrase "which is a barrier to flow for units below the old dune sand," because, unless this is based on an as yet un-cited source, this conclusion is not discussed until the last paragraph in this section.	Revision and clarification will be provided.
B-6 Section 2.1. The basis for assigning a "horizontal flow boundary" condition to the Santa Maria River fault should be based on a relatively robust analysis, given the likely significance of such a designation. This should include an analysis of location, elevation, and construction data associated with the wells shown on Figure 4. For example, NCMA and NMMA representatives have spent a fair bit of time improving the accuracy of well locations and elevations in their respective databases. In at least one case, there was a discrepancy of about 25 feet in the wellhead elevation for a particular well between the NCMA and NMMA databases. This highlights the need to have definitive locations and elevations for each well shown in Figure 4, where a purported 40-foot head difference across the Santa Maria River fault has been observed. In addition, both of the subject wells appear to have been constructed using cable tool drilling methods (i.e., one has neither an impermeable sanitary [i.e., 50-foot-deep] or deep	We agree with most of the comments here and most of the suggestions were considered during the investigation but were not reported. More detailed discussions about the analysis will be provided in the updated conceptual model TM. We would like to clarify that making the SMR fault a flow barrier does not mean that it will have the same effectiveness along its entire length. Its conductance will be varied during calibration and its conductance will vary along its extent. Because suitable curated wells were not available, groundwater level contours in the DWR 2002 report will be used to determine what portion(s) of the fault are believed to impede groundwater flow. Conductance of these segments will be adjusted during model calibration.

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seal and both have no filter pack). Along these lines, the perforated intervals in one well (-11J01) are between 257-267, 287-297, and 303-313 feet bgs. And, the perforated intervals for the other well (-12J04) are slightly deeper: 326-336 and 352-353 feet bgs. Therefore, any analysis should evaluate how well construction might influence the measured groundwater levels in these two wells. The representativeness of the subject well pair should also be evaluated and described. For example, it is also worth noting that the distance between each well on either side of Santa Maria River fault is about 1,600 feet and the separation between each well along the trace of the Santa Maria River fault is about 500 feet (see Figure 4). In contrast, the length of Santa Maria River fault that is designated as "horizontal flow boundary," is about 67,000 feet and the subject well pair is located roughly in the middle of the trace of the Santa Maria River fault. Yet, the purported conditions associated with this relatively-closely-spaced well pair are being extrapolated along the entire length of the fault, which may or may not be appropriate, depending on the available data. Finally, the groundwater elevations in the subject wells, along with the interpretation of their behavior relative to the Santa Maria River fault, should be compared with the conceptual understanding of regional groundwater flow directions and the locations of significant groundwater pumping to ensure that they make sense. For example, hydrographs shown on the inset in Figure 4 seem to be counterintuitive for this portion of the model domain. For example, well -11J01 is reportedly located on the south side of the Santa Maria River fault, closer to municipal wells operated by the Nipomo Community Services District, where one might expect lower groundwater elevations to be	

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observed. Yet, reported groundwater elevations in this well are higher than those in well -12J04, which is located on the north side of the Santa Maria River fault.	
B-7. Section 2.1. If appropriate, please revise the Arroyo Grande River reference to read: Arroyo Grande Creek.	Revision was implemented.
B-8. Section 2.2. The reference in the first sentence to "alluvial groundwater flow system" seems to imply that groundwater flow will only occur in active cells in the model that are alluvial in nature. This is in contrast to the fact that groundwater flow occurs in some semi-consolidated, semi-lithified, or lithified hydrostratigraphic units in the model domain that may or may not be alluvial in nature and are certainly not geologically recent alluvium. Please clarify.	We agree and clarification was provided.
B-9. Section 2.2. Please clarify the use of the term "crystalline basement rock" in the first sentence in this paragraph, as it seems to conflict with the list of units described in Section 2.1 as bedrock, which appear to be sedimentary (i.e., Sisquoc and Obispo Formations) or metamorphic (i.e., fractured, lithified, subduction zone-related accretionary wedge materials) in nature. Please also consider referencing the November 2017 model boundaries TM in this section.	We agree and clarification was provided.
B-10. Section 2.2. The TM states that more than 400 lithologic logs were compiled from the Santa Maria Basin Characterization Study (SMBC; FUGRO, 2015a). However, the SMBC study covered only about 2/3 of the model domain (i.e., the active cells north of the Santa Maria River). Therefore, the basis of the lithologic model in the portion of the model domain between the NMMA and Santa Maria River (e.g., number and source of lithologic logs) should be	Clarifications will be made.

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described. In addition, not all available lithologic logs (e.g., well log numbers 39692, 156767, 511078, 511086, and 782407 [the latter penetrated "green silty clay" at 420 feet and "sandy blue clay and sandstone stringers" at 470 feet, to the total depth of 520 feet bgs, which may or may not be associated with Franciscan Formation materials], which are associated with GSWC's Cypress Ridge system and the Cypress Ridge golf course) were utilized as part of the SMBC study. Therefore, it might also be worth mentioning that the lithologic log dataset used for the lithologic model is fairly comprehensive but is not entirely complete or exhaustive.	
B-11. Section 2.3.2. The first sentence in this paragraph indicates that groundwater flow is assumed to occur primarily horizontally within each of the model layers. However, cross sections depicted in Figures 10, 11, 12, 15, 16, and 17 indicate that some of the hydrostratigraphic units dip and possess a non-horizontal fabric suggestive of an anisotropic distribution of hydraulic conductivity. Therefore, potential impacts associated with the possibility that some of the groundwater flow within the model domain may not be strictly horizontal and vertical should be described.	MODFLOW is a 3-D modeling code that models flow both horizontally and vertically. What is implied here is that the bulk of the flow, as suggested by regional flow direction and published groundwater contours, is mainly horizontal but not exclusively horizontal. Also, it is not clear which of the Figures listed suggests a non-horizontal flow, especially when the ratio of horizontal to vertical scale varies from 10 to 20 (this might make slopes appear steeper than they truly are).
B-12. Section 2.3.4.1. See the comment associated with Section 2.1 (Depiction of aquifers …) and revise Section 2.3.4.1 accordingly.	This section will be revised accordingly.
B-13. Section 2.3.4.2. Please depict or clarify the location of the "Sisquoc Plain/Orcutt Upland/central valley areas." In addition, please provide a source or citation for the statement indicating that "dune sand is assumed to have a horizontal hydraulic conductivity of approximately 175 ft/day."	It is not clear why these areas need to be depicted or delineated. This value comes from the SMBC report (FUGRO 2015)
B-14. Section 2.3.4.2. Hydraulic conductivity	The distribution of the hydraulic conductivity is

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estimates based on field measurements, as depicted in Figures 18 and 19, are essentially non-existent for the area between the NMMA and Santa Maria River, or about one third of the model domain. Please describe whether, and what, field measurements will be utilized for this area and if not, how this will impact development and use of the groundwater model. Please also see the comment associated with Section 1.3 regarding hydraulic conductivity data that might be available from other groundwater modeling work that may have been performed in the area between the NMMA and Santa Maria River. In addition, please consider revising the last sentence in this paragraph, as it refers to the SMVMA, where data are essentially lacking. Finally, please consider removing the coloring of the symbols in the legend of Figures 18 and 19, to avoid the reader immediately associating the legend symbols with the Paso Robles Formation.	detailed in the calibration report, which was submitted to WSC in February 2018. The coloring was removed.
B-15. Section 2.3.4.2. In light of the data associated with, and described in, Figures 18 and 19, it is worth noting that the percentage of Clean Gravel shown on cross section O-O' (Figure 16) is greater than on any of the other cross sections in the TM. And, this is consistent with the last sentence of paragraph 2 in Section 2.3.4.2 (i.e., higher hydraulic conductivities in the NCMA may be due to greater amounts of gravel). This apparent match between the lithologic model and field measurements suggests that it is worth evaluating whether the field measurements and lithologic model throughout the model domain, as illustrated via cross sections in the TM, are consistent with published reports on sedimentological and depositional environment models of the major hydrostratigraphic units in the area, such as the Paso Robles Formation. Such an evaluation could prove useful, in that it could provide a stronger basis and	The distribution of lithology will be used to estimate hydraulic conductivity and populate the model. The reader will be referred to the calibration plan TM for more details about this procedure.

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foundation for assignment of aquifer properties at the beginning of and during model calibration. Whereas the lithologic model seems to provide a relatively robust basis for initial-, and calibrated-, aquifer properties assigned to hydrostratigraphic layers in the NCMA and NMMA portions of the model, it is worth it to consider whether there are opportunities to improve upon the properties initially, and ultimately, assigned to model layers south of the NMMA.	
B-16. Section 2.4. Table 2-1 may be incomplete in that the following discharge terms are not included: Evapotranspiration (cited in Section 2.4.9 of the TM), Streambed Seepage (i.e., upward groundwater flow into streams through the streambed, which may occur in Black Lake Canyon in the NMMA [see Chipping, 1994 reference]), and Spring Flow (e.g., groundwater discharge as springs, which is depicted on the Oceano 7.5' Quadrangle topographic map at the base of the Nipomo Mesa about 3,000 feet east of Pipeline Lake, or possibly into the various dune lakes in the area, themselves). Please clarify or explain if, and why, these water budget components are not applicable.	Clarification was made.
B-17. Section 2.4.1. Please make sure that Tematatte Ridge, Casmalia Hills, and Solomon Hills are all labeled on an appropriate figure so that the reader can locate them	Labels were added for the Temattate Ridge.
B-18. Section 2.4.1. Estimates of annual mountain front recharge exceeding 500 acre-feet in 1978, 1983, and 1998 (see Figure 22) are consistent with above-normal rainfall during these years. However, above normal rainfall in the region also occurred in 1995, 2005-2006, and 2010-2011. So, it is not clear why the annual amount of mountain front recharge in these latter years is significantly less than 500 acre-feet.	1978 is probably impacted by the assumed initial moisture which was set at half the maximum soil moisture capacity. 1983 and 1998 occur at the end of a wet period with potentially a lot of moisture in the soils which help with infiltration. Conceptually the SCS approach assumes that the soil capacity should be filled before infiltration occurs. High

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Please clarify or reconcile this apparent discrepancy.	background moisture favors high infiltration. Also the distribution of rainfall impacts infiltration. Consecutive rainy months are conducive to more recharge as opposed to spaced out rain events.
B-19. Section 2.4.2. The statement about lack of streamflow data for Los Berros Creek seems to imply that streambed percolation or seepage will not be simulated in the model. Please clarify, as it seems like, if there is sufficient evidence that these processes may be occurring, one or both of these should be simulated during model calibration, even if streamflow data are not available.	Los Berros creek will be simulated. More language will be added to clarify this.
B-20. Section 2.4.3. Please consider splitting the last sentence in two, or else clarify, as it is not clear if the citation of GSI, 2017 applies to the statement that the Wilmar Avenue fault is a flow barrier, the statement that this fault does not impede groundwater flow in alluvium, or both statements.	The statement was clarified.
B-21. Section 2.4.3. There should be a brief discussion, or perhaps a reference to the November 2017 model boundaries TM if appropriate, about inflow from bedrock, even if determined to be absent.	The inflow from bedrock is assumed to be part of the mountain front recharge and a reference to the Model Boundaries TM will be added.
B-22. Section 2.4.4. Whereas Figure 26 shows the locations of wastewater recharge in the NMMA, this paragraph does not include any accounting of the amounts of wastewater recharge at these facilities. Please reconcile. For example, about 5-6 acre-feet of wastewater discharge to an unlined basin near the Cypress Ridge golf course occurred in 2016 and 2017. In addition, while Figure 26 shows the locations of stormwater infiltration ponds in the NCMA, GSWC is under the impression that flood control or stormwater runoff basins, potentially managed by	GEOSCIENCE would gladly add these data if they can be provided in a timely fashion. The request for infiltration pond data was discussed during the weekly meeting and it was determined that only NCMA had stormwater ponds (Steve Bachman input from NMMA-TG). In any case, it should be emphasized that from a regional groundwater modeling perspective, the amount of water infiltrated in stormwater ponds is relatively negligible and should have minimal impact on calibration. However, this is

Comments from the NMMA Tech. Group	GEOSCIENCE Response
San Luis Obispo County, exist in the NMMA. One of these is located approximately as follows: 35°01'26.94"N, 120°29'27.30"W. Please clarify whether these should be included as points of groundwater recharge as part of this water budget component. Finally, the assumed amount of wastewater recharged annually over the model calibration period should be based on logical factors. The trend in the amount of wastewater recharged annually over time displayed on Figure 28 (i.e., constant volumes from 1977 to 2008) does not seem to be consistent with what one would expect, assuming an increase in development and population growth in the region over time (e.g., see the 2/9/18 TM prepared by GSWC for its Cypress Ridge system).	valuable information which will be documented for future iterations of the model. The existing wastewater data didn't exhibit any trend related to population increase. For instance, the available data from 2010 to 2016 increased initially and then decreased. Because the change was relatively minimal, GEOSCIENCE assumed that an average would be a representative estimate rather than using a trend that was not supported by the data. However GEOSCIENCE contacted the individual WWTP for past discharge records and is awaiting the data to update the water balance.
B-23. Section 2.4.5. It is not clear whether, or how, return flow from water pumped for commercial/industrial uses (e.g., golf courses or plant nurseries), or from rural domestic wells for that matter, will be accounted for and simulated during model calibration. Please clarify or discuss briefly	A discussion was added to address these issues.
B-24. Section 2.4.5.1. It is not clear how septic system return flows will be accounted for and simulated during model calibration, assuming that they are part of the applied water return flow. For example, the Cypress Ridge golf course community portion of GSWC's Cypress Ridge system generated roughly 49 acre-feet of wastewater discharge in 2009 from 375 connections/customers. Assuming minor losses during treatment and that an equivalent amount of wastewater was generated for the remainder of GSWC's customers (about 536), who use septic systems for wastewater disposal, roughly 70 acre-feet of wastewater would have been discharged to septic systems in the remainder of GSWC's Cypress Ridge system service area in 2009.	Data on septic users were not available. However, contributions from septic systems were considered negligible.

Comments from the NMMA Tech. Group	GEOSCIENCE Response
Based on this example, it seems like there should be some discussion of how municipal and rural domestic pumping septic system return flows in applicable portions of the model domain will be simulated. In addition, similar to Section 2.4.4 of the TM, this section should show, or describe in more detail, the locations (e.g., un-sewered areas) of return flow from applied water.	
B-25. Section 2.4.6. Figure 31 should include GSWC Cypress Ridge system wells and doesn't appear to include commercial/industrial/irrigation wells used to supply water for irrigating some golf courses in the region. Depending on the amount of production from some of these (e.g., golf course) wells, they should be depicted on this or another figure and discussed briefly, because it is not clear how they will be accounted for as part of the water budget and during calibration of the model. In addition, please include municipal pumping wells in the area between the NMMA and Santa Maria River if applicable.	The locations of these wells (irrigation/ commercial/ industrial) are currently not available to GEOSCIENCE. GEOSCIENCE will use the centroid of the polygons delineating these properties as a proxy well location. There is no known municipal well in the area between the NMMA and Santa Maria. Pumping in this area is largely agricultural; the location for these wells has not been provided and couldn't be located.
B-26. Section 2.4.6. The assumed amount of annual production from rural domestic wells over the model calibration period should be based on logical factors. The trend in annual rural domestic well pumping over time displayed on Figure 33 (i.e., constant annual production volumes from 1977 to 2008) does not seem to be consistent with what one would expect, assuming an increase in development and population growth in the region over time (e.g., see the 2/9/18 TM prepared by GSWC for its Cypress Ridge system). It is worth noting that the numerical groundwater model will require a greater degree of accuracy with respect to the annual amount of pumping from wells within the model domain compared to annual reports prepared by the NCMA and NMMA parties. This is in part due to the spatial component of groundwater	More discussion was added to address the rural water pumping amount and its spatial distribution.

Comments from the NMMA Tech. Group	GEOSCIENCE Response
pumping associated with the model (e.g., the location of calibration wells versus pumping wells/nodes), which is less critical when tabulating annual production volumes in the NCMA and NMMA annual reports. Therefore, the amount of rural domestic well pumping over time, which presumably includes production from small water system wells, should be defensible and described in more detail. This detail should include how pumping was estimated. For example, municipal pumping is based on measurements using meters (see Section 2.4.7) and estimation of agricultural pumping amounts is described in detail in Section 2.4.7. But, it is unclear how domestic well pumping amounts were arrived at	
B-27. Section 2.4.6. With respect to small system wells, there were about at least 12 wells producing a total of roughly 250 acre-feet/years of groundwater in the NMMA based on information available in 2009. In addition, there appear to be possibly 9 other small system wells in the NMMA. These include wells operated by Ball Tagawa Growers, Greenhart Farms, Dana Elementary School, and the Mesa Dunes Mobile Home community, to name a few, according to information available via the following websites: http://geotracker.waterboards.ca.gov/gama/ and https://sdwis.waterboards.ca.gov/PDWW/index.jsp. Based on these examples, please clarify whether, and how, the municipal pumping water budget component will account for small water system wells over the model calibration period.	Additional information about the small systems was provided by Bob Collar from GSWC, but the location and extraction rates over time was not available. GEOSCIENCE will take into account the extra 250 AFY unaccounted for during the water balance discussion in the model calibration report. In addition, future phases and iteration of the model can be refined with additional information, and the small systems can be incorporated.
B-28. Section 2.4.7. Consider citing the January 2018 Agricultural Pumping Estimates TM in this section.	TM reference was added.
B-29. Section 2.4.7. Similar to the locations of municipal pumping wells in Figure 31, the locations of agricultural pumping wells should be shown. In addition, while the TM presents a somewhat detailed	The distribution of annual agricultural pumping will mirror the crop coefficient proportion, as these vary on a monthly basis and quantify the water needs of individual crops. This was briefly

Comments from the NMMA Tech. Group	GEOSCIENCE Response
description of how the annual amounts of agricultural groundwater pumping have been estimated, there is no information on how the annual production volumes will be varied temporally on a monthly time-step, let alone how the pumping will be assigned to different model layers. This lack of detail, unless included in the final version of the TM, highlights the need to present a robust sensitivity analysis and uncertainty analysis alongside the calibrated model. Any analysis would also include an assessment of the accuracy of estimated agricultural pumping volumes throughout the model domain and calibration period. For example, Faunt, C.C., ed., 2009 (Groundwater Availability of the Central Valley Aquifer, California: U.S. Geological Survey Professional Paper 1766, 225 p.), who utilized the U.S. Geological Survey FMP2 package for MODFLOW to help simulate unmetered agricultural pumping on a regional scale in California's Central Valley, presents a good discussion of the uncertainty and accuracy associated with estimates of agricultural groundwater pumping. And, the results of their work in the Central Valley showed that the relative percent difference (RPD) between annual agricultural groundwater pumping simulated by the model and agricultural groundwater pumping estimated using power usage data, could be up to about 25 percent (see Figure C22, Faunt, C.C., ed., 2009). Whereas the areal size of the Central Valley model is significantly greater than the Phase 1B model, this discussion highlights the potential uncertainty that might be associated with the use of estimates instead of actual metered agricultural pumping amounts.	discussed in the dedicated agricultural pumping estimation TM. A more detailed discussion will be added here as well. Also, a sensitivity analysis involving agricultural pumping was proposed at the conceptual model TM discussion meeting and will be conducted after the calibration. It is clear that regardless of the method used to estimate the agricultural pumping, uncertainty remains because it is virtually impossible to factor in local practices, irrigation system maintenance, and irrigation efficiency over time. Therefore, a sensitivity analysis is the most appropriate approach. Most reports state that the bulk of agricultural pumping is from the Paso Robles Aquifer. Therefore, the estimated agricultural pumping will be extracted from the Paso Robles Aquifer.
B-30. Section 2.4.7. It is not clear if the agricultural pumping water budget component includes pumping for non-crop or non-orchard uses. For example, the current area of the Cypress Ridge golf course in the	Non-crop pumping was not estimated and was assumed to be negligible, as no major report included estimates in their water balances (including the water balance study of 2007).

Comments from the NMMA Tech. Group	GEOSCIENCE Response
NMMA was apparently used as a dairy farm from 1974 through 1987. The dairy operation included flushing of cow pens with pumped groundwater, collecting the runoff in a pond co-located with the current Cypress Ridge wastewater treatment facility emergency discharge pond, and irrigating the central portion of the farm with the nutrient-rich wastewater. And, at least 2 of the 4 wells at the farm reportedly pumped a combined volume of about 300 acre-feet/year in 1982 and 1983. In another case, one of GSWC's Cypress Ridge system wells was installed for a plant nursery and potentially used at times between 1976 and 1986, though the annual amount of groundwater pumped, if any, is not currently known. Finally, a roughly 40 acre property at the southwest corner of Los Berros Road and El Campo Road in the NMMA may have operated, from at least around 1965 to the mid 2000s, as Egg City, Incorporated (most of the hen houses appear to have been demolished by 2009 based on review of satellite images available via Google Earth). And, a couple of small wells were reportedly used there. Based on these examples, please clarify whether, and how, the agricultural pumping water budget component will account for pumping for non-crop or non-orchard uses over the model calibration period.	
B-31. Section 2.4.7.2. The authors state that the irrigation method affects IE, yet they make no mention of where and what method is being used in the various MAs. Then they assume an IE for NMMA where drip irrigation is the predominant method and report a 90% IE for NCMA where sprinklers are the predominant method.	The irrigation efficiencies were based on estimates from NMMA, NCMA, SMVMA, and various other reports, since GEOSCIENCE had no direct access to IE estimation on the ground. A more detailed discussion can be found in the agricultural pumping estimation TM which was reviewed by NMMA.
B-32. Section 2.4.10. Change in storage calculation -- the procedure presented will compare a calibrated amount derived from the model with an estimate	The specific yield will be revised to reflect the average of the locally estimated values (0.1). A specific yield of 0.15 is a common value used in

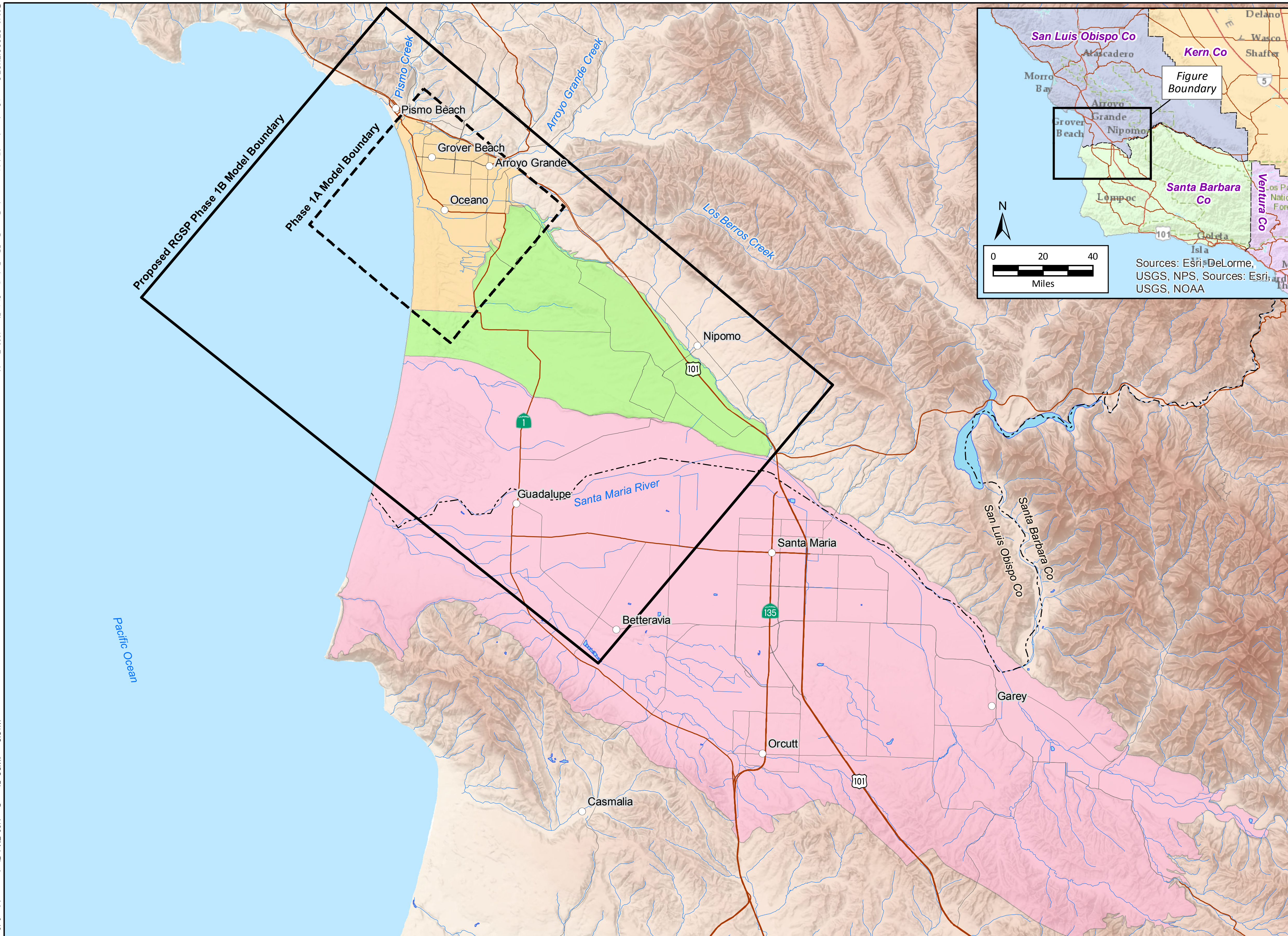
Comments from the NMMA Tech. Group	GEOSCIENCE Response
from integrating groundwater elevation contours. The integration uses a specific yield of 0.15 which is significantly larger than reported in Section 2.3.4.3 where old Dune is given a specific yield of 0.13, Paso Robles is given 0.08 to 0.12, and semi-confined conditions are given a range of storativity from 0.002 to 0.03. Furthermore, the argument for calibrating Southern Boundary Underflow Inflow is that the complexity of water levels over the length of the boundary makes it too hard, yet the authors were able to do so for a change in storage calculation.	alluvial aquifers. Storage change calculations are done very differently than flow across a boundary. Flow across a boundary is calculated using Darcy's law, which assumes that the gradient is perpendicular to the boundary. If this assumption isn't met, the perpendicular component of the velocity (or gradient) should be estimated. With the velocity vector intersecting the boundary at various angles, such an estimate would incur a lot of uncertainty.
B-33. Section 2.4.10. Removal or revision of Figure 39 might be necessary for a variety of reasons. For example, it is not clear if the contours in this figure take into account the presence of both a shallow, unconfined, aquifer and a deeper, confined aquifer, over much of the NMMA, and the fact that the specific yield and storativity of these aquifers, respectively, is likely to differ by a few orders of magnitude, let alone not be uniform throughout the model domain. In addition, the area spanned by the well data points within the NCMA and NMMA seems to be about one third of the area encompassed by the 0 foot contour, which suggests that a significant amount of interpolation has occurred during generation of the contours, which in turn may reflect a lower degree of accuracy associated with the change in storage estimate. Further, it is not clear whether the change in storage estimate is too high, because it is based on contours that fall within the area of inactive or no-flow model cells just east of Highway 101, north of the intersection of Highway 101 and Los Berros Creek. Please clarify.	This estimate is not meant to be an input to the model or an absolute estimate. It is a ballpark estimate which serves as an independent check and is mainly focused on the depression observed in the Paso Robles Aquifer, which is the main pumping aquifer. Water levels from the shallow aquifer were not considered and only water levels from 1977 and 2016 were included in the analysis. The model results will produce a more reliable estimate.
B-34. Section 3. See the comments associated with Section 2 and revise the last sentence in the first	These sentences were revised.

Comments from the NMMA Tech. Group	GEOSCIENCE Response
paragraph of Section 3 accordingly	
B-35. Section 3. The section describes why the gross water budget shown in Figure 40 is incomplete. However, incompleteness of the water budget might also be due to unaccounted for groundwater pumping within the model domain. In fact, roughly 550 acre-feet/year of unaccounted for pumping, at a minimum, may be present (see comments associated with Section 2.4.6, paragraph 2, and Section 2.4.7, paragraph 1), which could lead to unintended consequences. For example, model layer hydraulic conductivities might need to be unjustifiably lowered during the calibration process to match simulated hydraulic heads with actual hydraulic heads that are lower due to the unaccounted-for pumping. Alternatively, a groundwater flow-impeding fault, which acts like a no flow boundary, might need to be unjustifiably introduced into the model during the calibration process to achieve a match between simulated hydraulic heads and actual hydraulic heads that are lower due to the unaccounted-for pumping. Therefore, the TM needs to better describe how all relevant pumping, not to mention all other water budget components, will be accounted for and accurately quantified. One way to assess the significance of unaccounted for pumping or portions of various water budget components, not to mention the accuracy of the various water budget components, is to consider the target rate of the proposed Phase 1B recharge project(s): 2,500 acre-feet/year. In light of this annual volume, perhaps unaccounted for portions of water budget components, or the accuracy of over- or underestimated water budget components themselves, should be no more than an order of magnitude lower, or 250 acre-feet. This sort of viewpoint highlights the need for a robust sensitivity	A distinction should be made between incompleteness and underestimation. By incomplete, we mean that some terms were not estimated altogether (e.g., ET, underflow inflow, etc). These terms will be estimated by the calibrated model. However, well extraction was estimated. It can be argued that some wells were missed or that the extraction volumes were underestimated. GEOSCIENCE believes that the biggest source of uncertainty in the water budget is agricultural pumping. The average agricultural pumping is 33,000 AFY. A 10% error would dwarf the 550 AFY mentioned in this comment. Therefore, GEOSCIENCE will dedicate more effort to the sensitivity analysis of the model to agricultural pumping. GEOSCIENCE does not believe that a 550 to 1500 AFY gap in a water budget estimate would produce a dramatic effect in a model of this size. The Santa Maria River Fault will not be modeled as a no-flow boundary since there is no evidence of it being fully impermeable. Instead, it will be assigned a lower conductance that still allows flow through. Also, as mentioned in the response to comment **B-6,** the conductance will be varied along the fault. With the uncertainty attached to agricultural estimates (pumping and return flows), urban return flow estimates, rural pumping and return flow estimates, various underflows, and mountain front recharge estimates, it is extremely difficult and probably unrealistic to narrow down the accuracy of the water budget within 250 AFY with any certainty.

Comments from the NMMA Tech. Group	GEOSCIENCE Response
analysis, not to mention uncertainty analysis, associated with the calibrated model.	
B-36. Section 3. The section seems to imply that, at a minimum, certain model parameters, including hydraulic conductivity, storativity, and effective porosity, will be varied during the model calibration process. However, the TM seems to list at least one other parameter that will be varied during the model calibration process: agricultural pumping return flows (Section 2.4.5.2). Given this, it is not clear if there are other parameters that might be used to help achieve calibration of the model. Because the calibration process can result in non-unique solutions, it is important that changes made to the model during the calibration process be justified and supported by underlying data and information, to the extent possible. In addition, the TM also lists several water budget components, which are preferably or ideally inputs to a model, that will be outputs from the model, including streambed percolation (Section 2.4.2), groundwater inflow (Section 2.4.3), groundwater outflow (Section 2.4.8), and evapotranspiration (Figure 40). As a result, the TM should provide a brief summary of these calibration and water budget component items and discuss, at least conceptually at this point, how they will affect the accuracy of the calibrated model and subsequent simulations using the calibrated model.	The calibration approach is detailed in the calibration TM and the reader is referred to it for more details. Also, the calibration process and the choice of parameters to be varied during calibration will be discussed with the TAC. Not all of the budget components estimated in the conceptual model TM will be used as input for the model. Some terms were estimated to provide an independent value with which to compare to model results (i.e., river percolation, change in storage). Additional language will be added to the conceptual model TM to clarify this point.

FIGURES

GEOSCIENCE



GENERAL PROJECT LOCATION

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15-Jun-18

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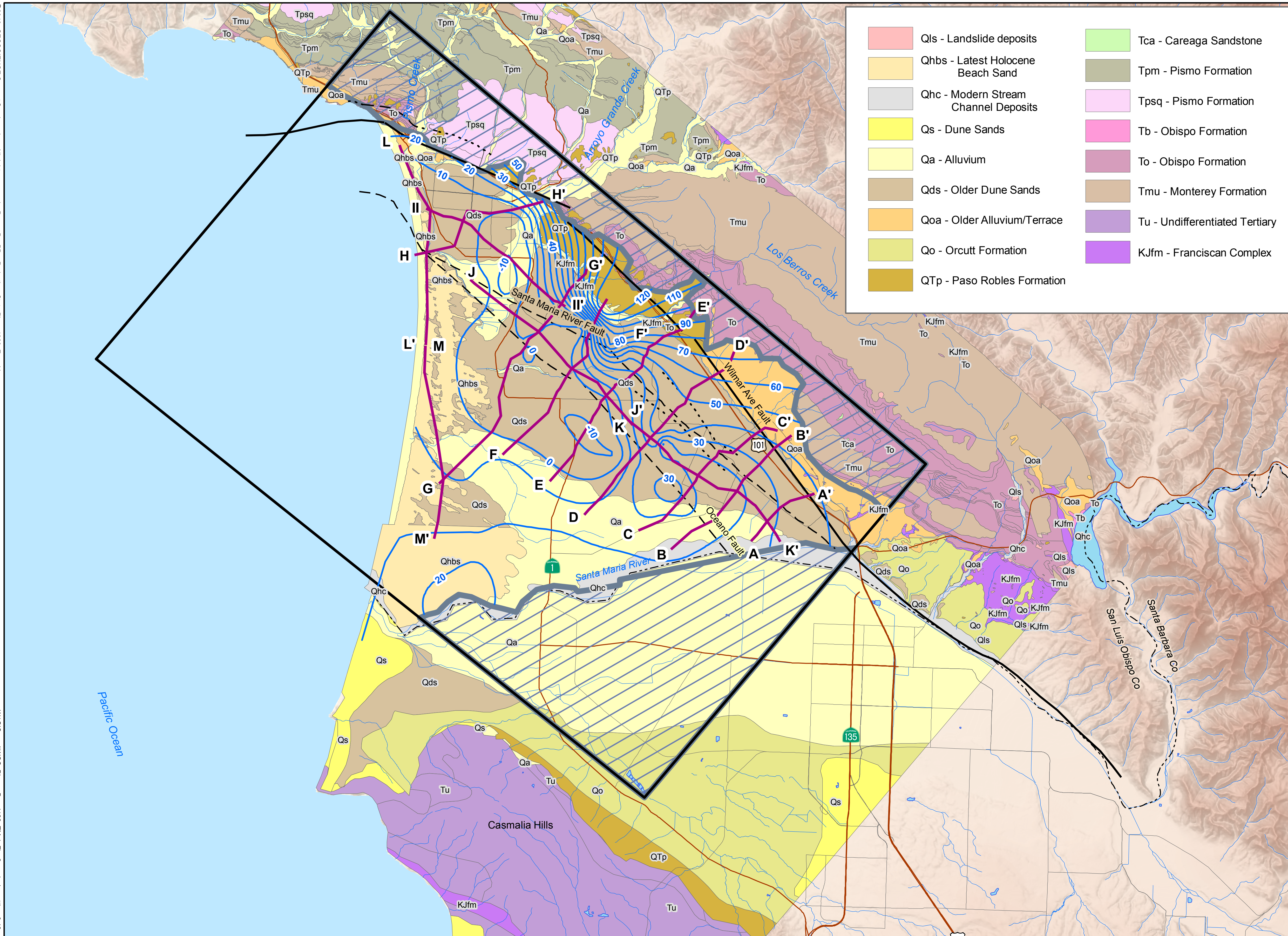
FIGURE 1

CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 1: CONCEPTUAL MODEL

GEOSCIENCE



EXPLANATION

Proposed RGSP Phase 1B Model Boundary

Phase 1B Inactive Model Area for GEOSCIENCE Model

Fault - Confirmed

Fault - Approximate

Fault - Concealed

Source of Faults:
(Fugro, 2015)

Source of Geology:
(County of San Luis Obispo, 2015; Dibblee, 1994; Dibblee and Ehrenspeck 1989; Dibblee and Minch, 2006a-d; LSCE, 2017; Ludington et al., 2007; and McLean, 1995)

N

0 2.5 5

Miles

GEOLOGIC SETTING

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15-Jun-18

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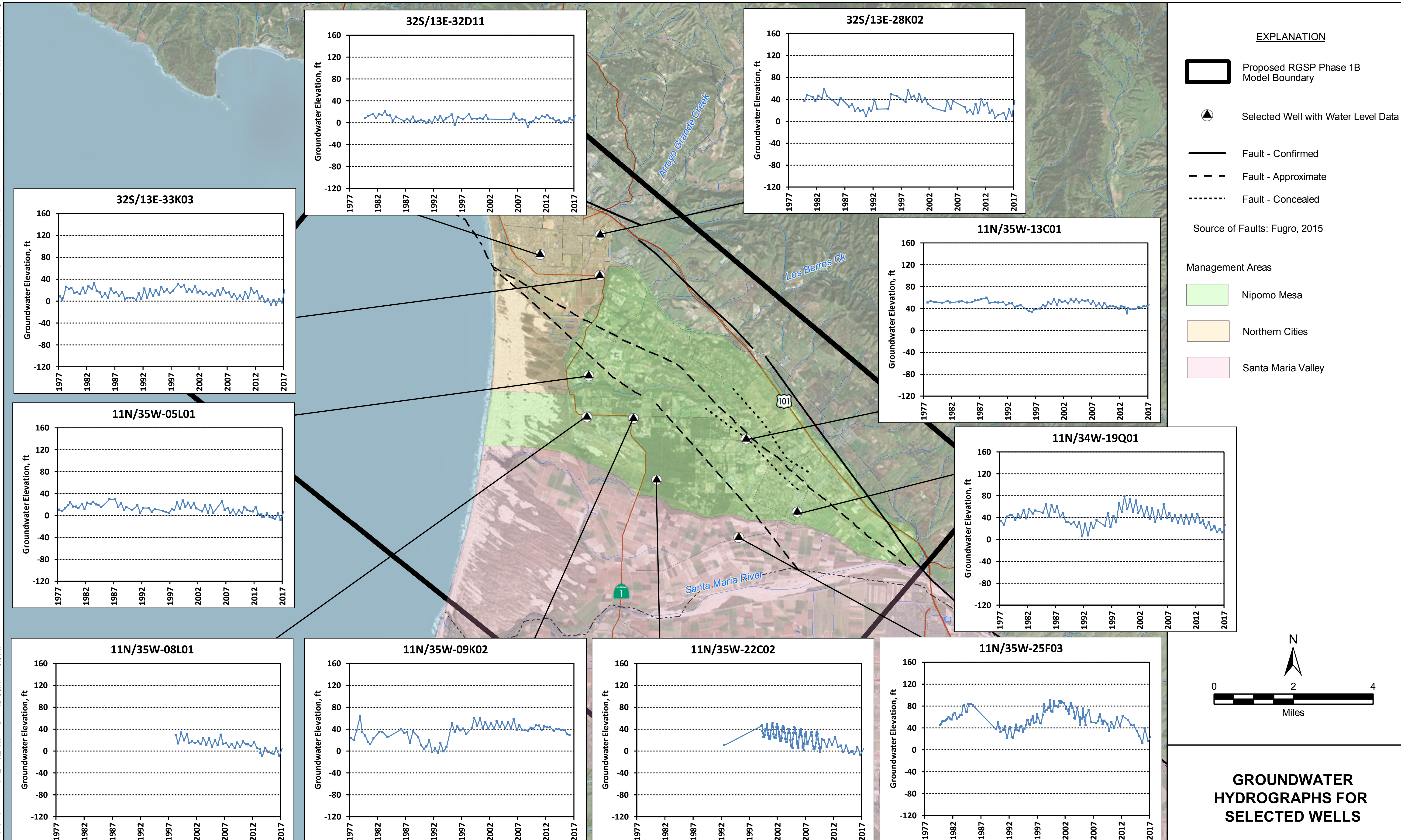
FIGURE 2

CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 1: CONCEPTUAL MODEL

GEOSCIENCE



GROUNDWATER HYDROGRAPHS FOR SELECTED WELLS

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15-Jun-18

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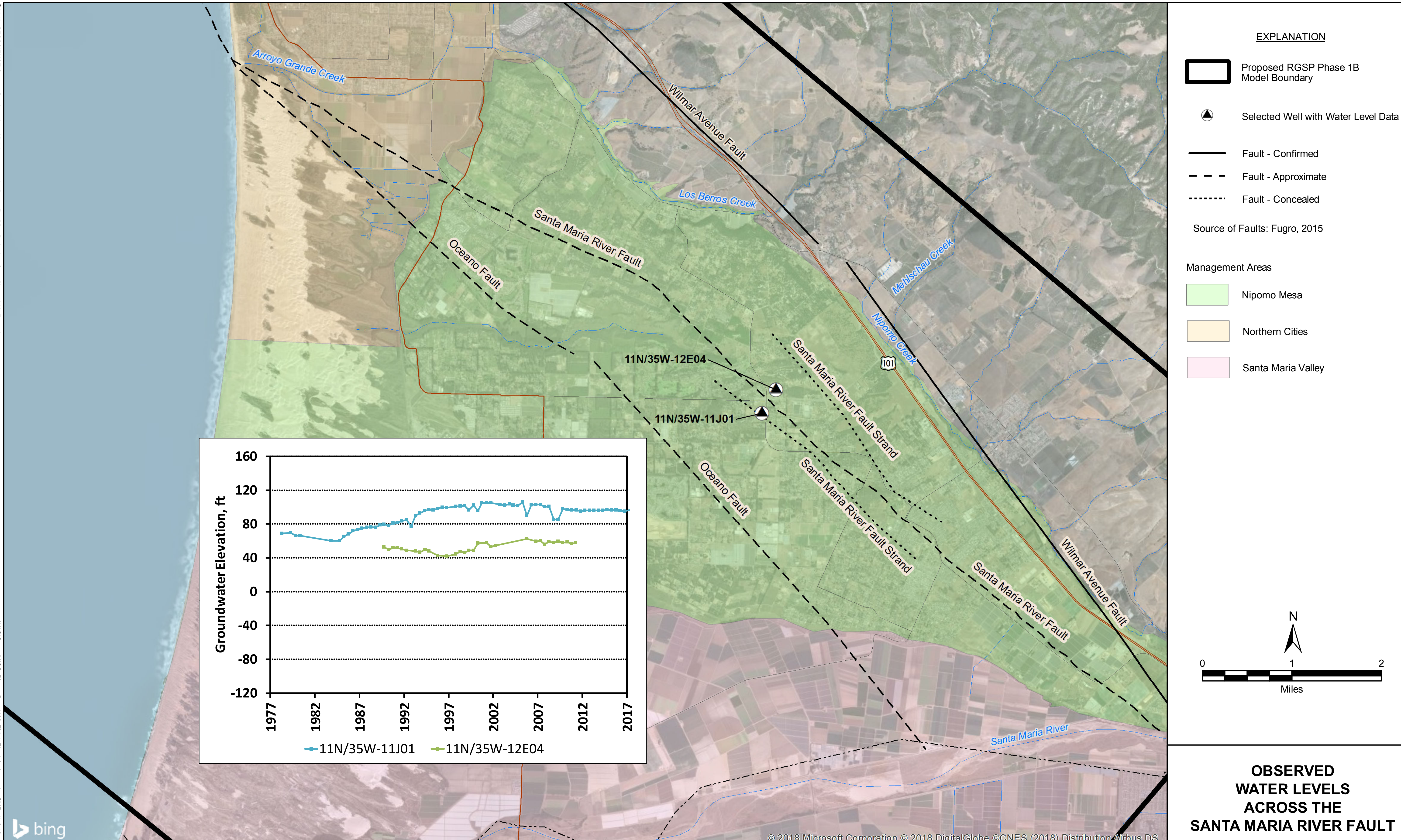
FIGURE 3

CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 1: CONCEPTUAL MODEL

GEOSCIENCE



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15-Jun-18

OBSERVED WATER LEVELS ACROSS THE SANTA MARIA RIVER FAULT

FIGURE 4

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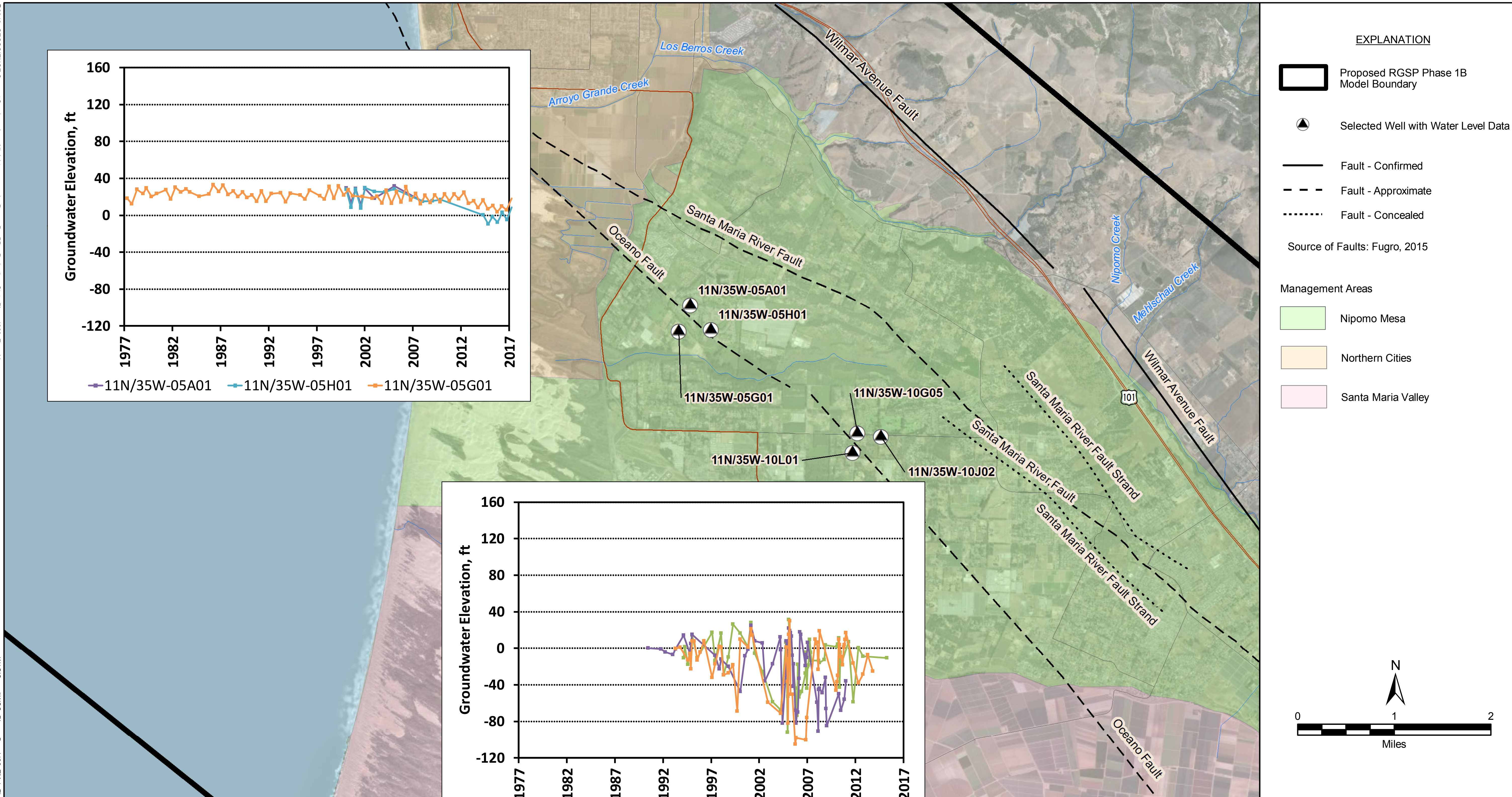
CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 1: CONCEPTUAL MODEL

GEOSCIENCE



OBSERVED WATER LEVELS ACROSS THE OCEANO FAULT

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15-Jun-18

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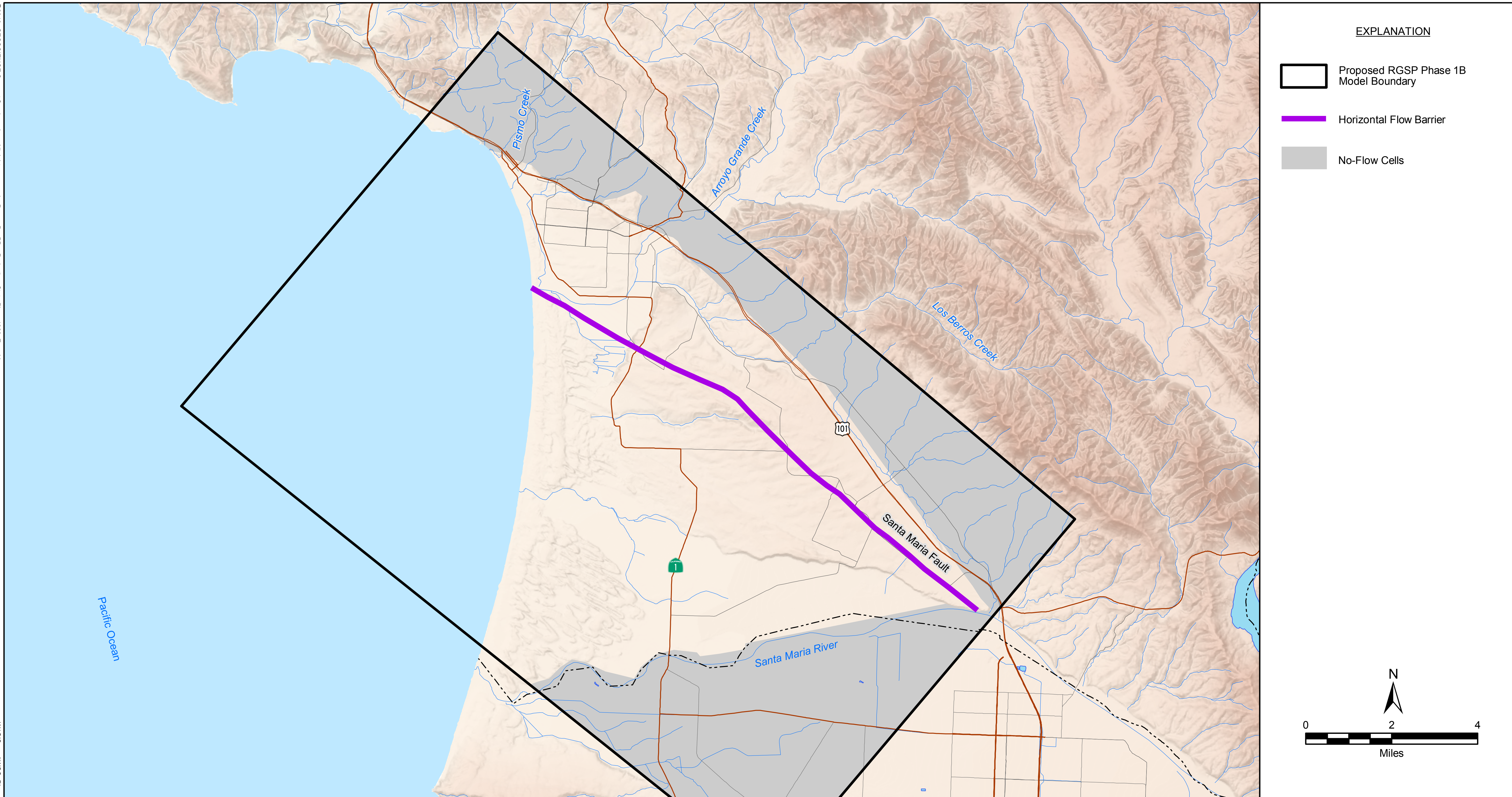
FIGURE 5

GEOSCIENCE



HORIZONTAL FLOW BARRIER

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15-Jun-18

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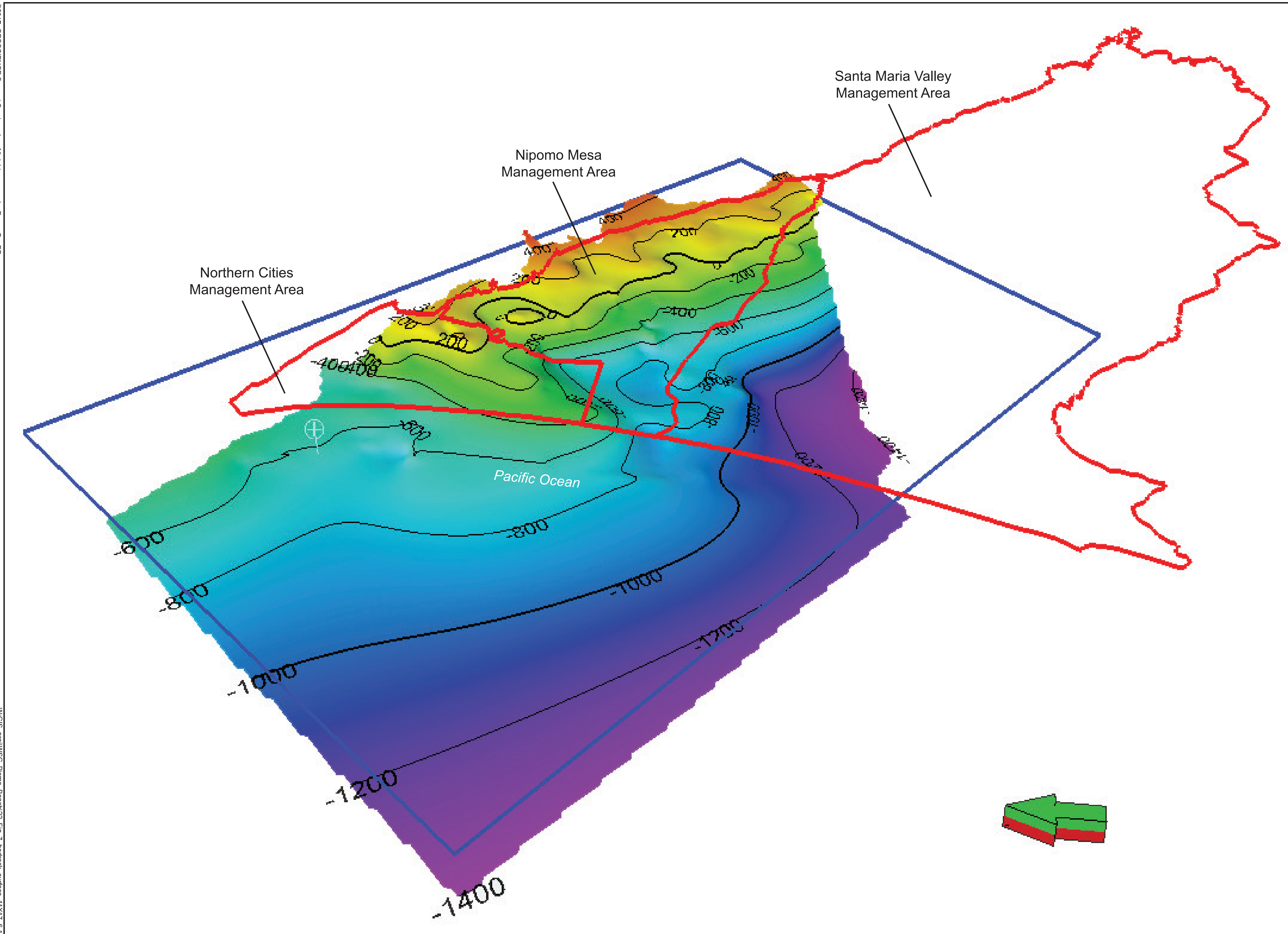
FIGURE 6

CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 1: CONCEPTUAL MODEL

GEOSCIENCE



3-D VIEW OF THE BEDROCK SURFACE

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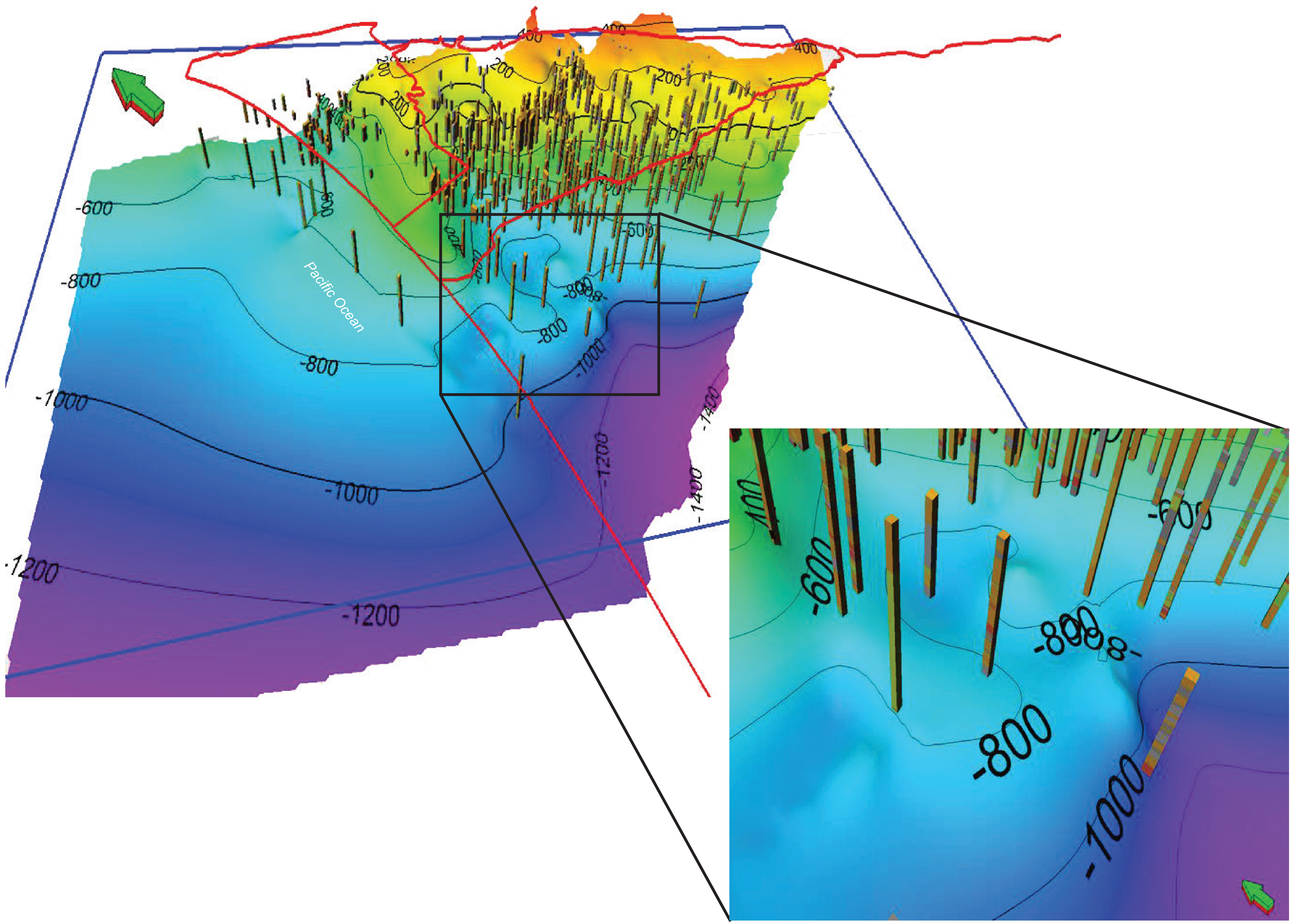
15-Jun-18



EXPLANATION

Facies

- Sandstone
- Sandstone/Shale
- OH
- Clay
- Silty Clay
- Silt
- Sand and Clay
- Clayey Sand
- Silty Sand
- Sand (<5% silt)
- Clean Sand
- Clayey Gravel
- Silty Gravel
- Clean Gravel

UPSCALED LITHOLOGIC LOGS IN 3-D REFINED GRID

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15-Jun-18

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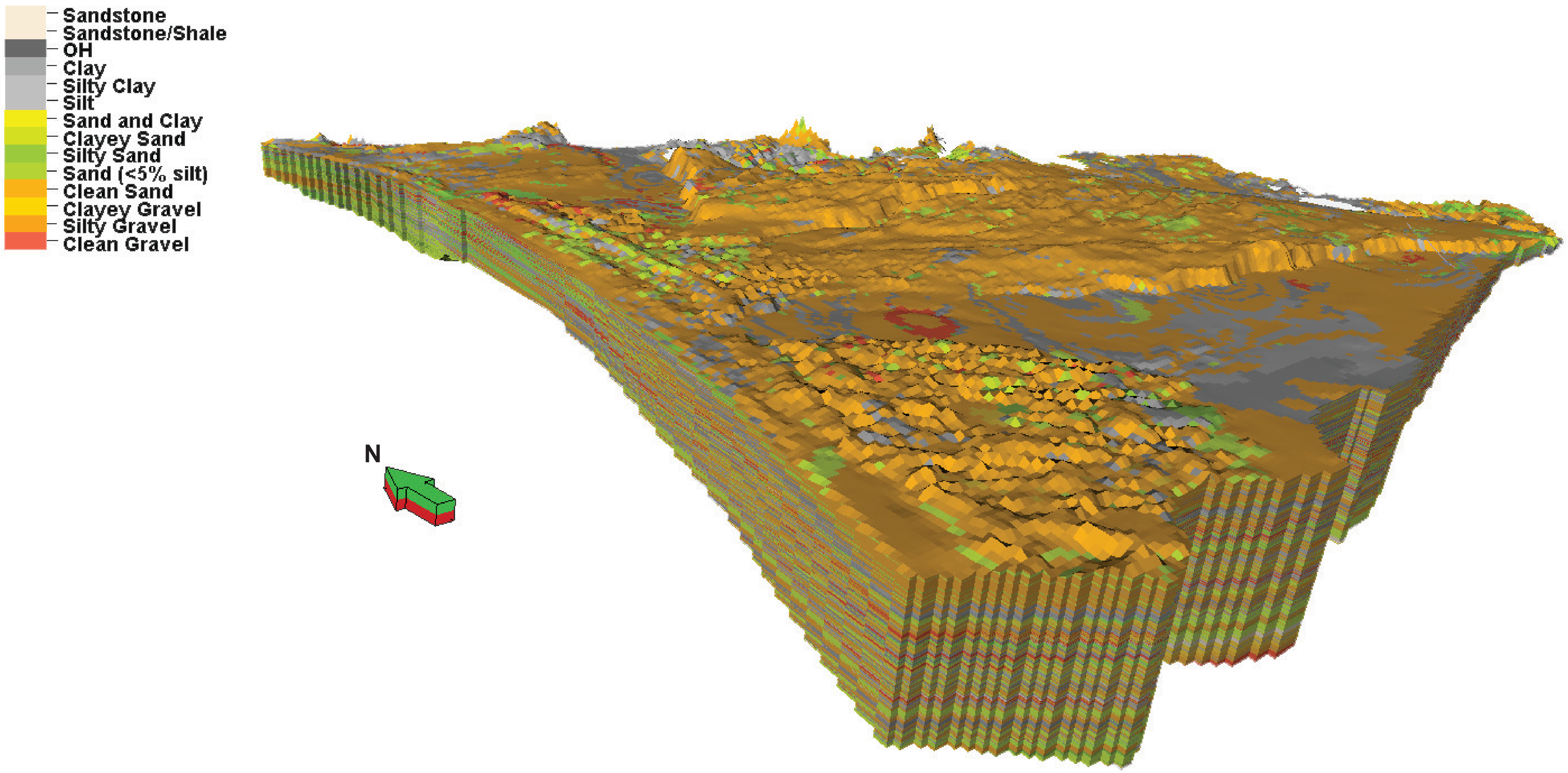
CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 1: CONCEPTUAL MODEL

FIGURE 8

GEOSCIENCE

EXPLANATION



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3-D VIEW OF THE LITHOLOGIC MODEL

15-Jun-18

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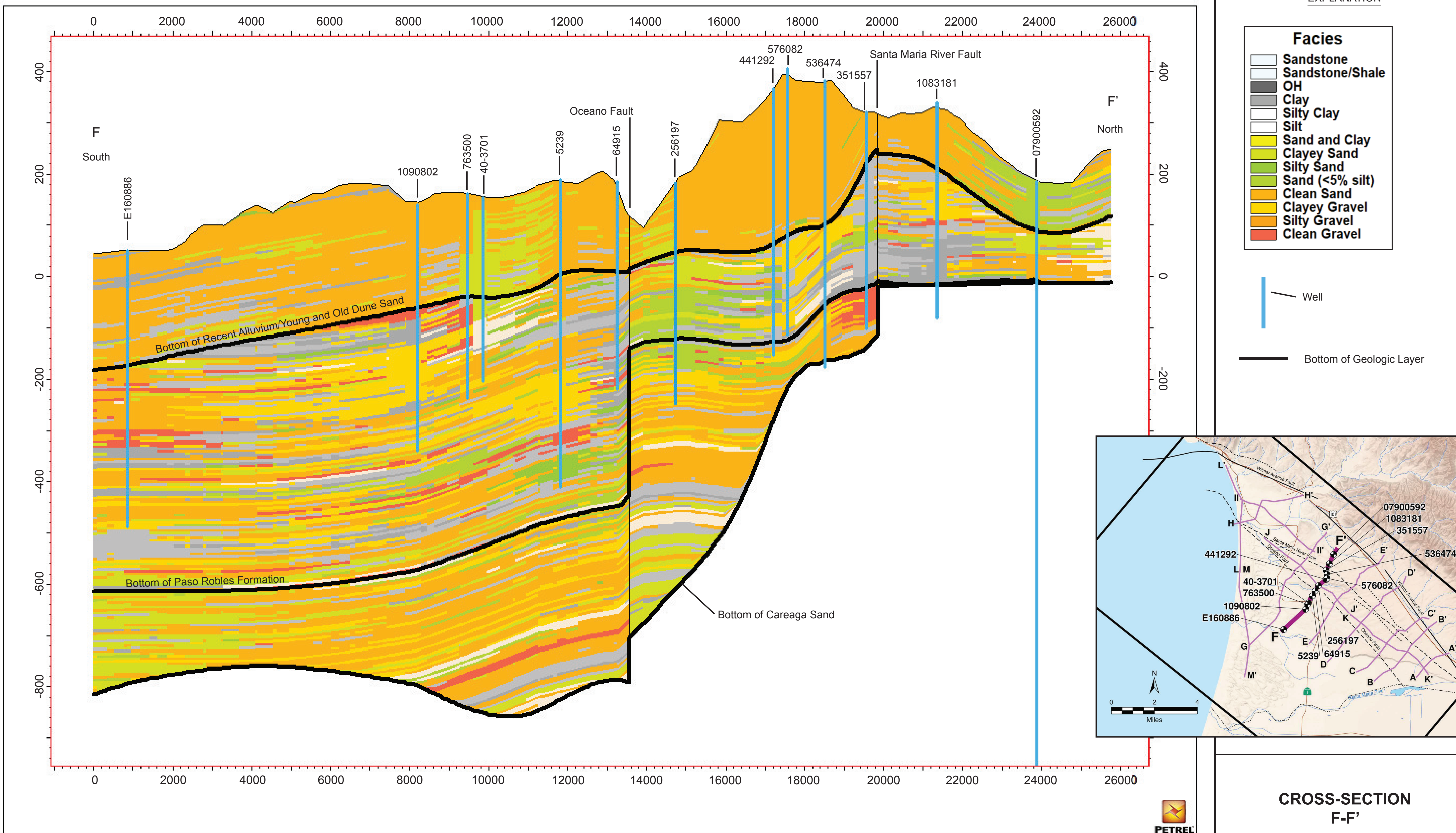
FIGURE 9

CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 1: CONCEPTUAL MODEL

GEOSCIENCE



CROSS-SECTION
F-F'

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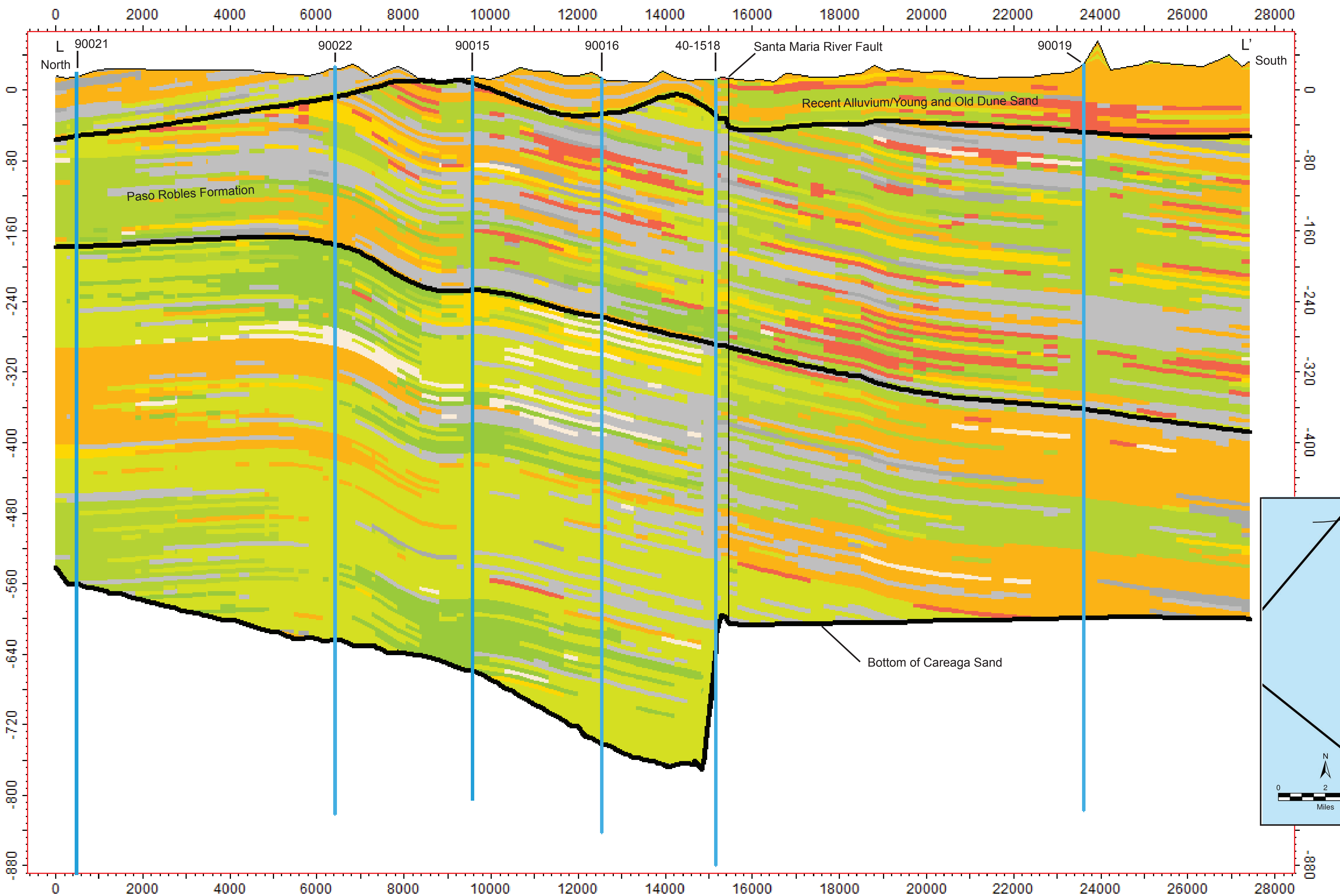
15-Jun-18



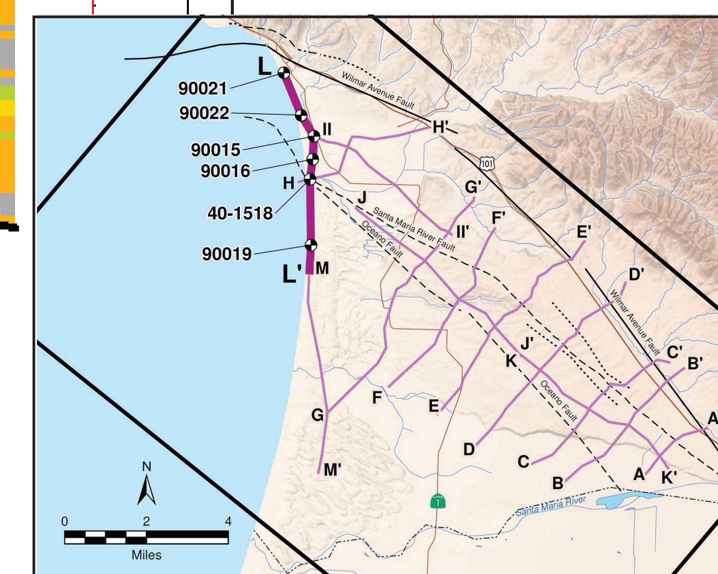
EXPLANATION

Facies

- Sandstone
- Sandstone/Shale
- OH
- Clay
- Silty Clay
- Silt
- Sand and Clay
- Clayey Sand
- Silty Sand
- Sand (<5% silt)
- Clean Sand
- Clayey Gravel
- Silty Gravel
- Clean Gravel

Well

Bottom of Geologic Layer



CROSS-SECTION L-L'

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15-Jun-18

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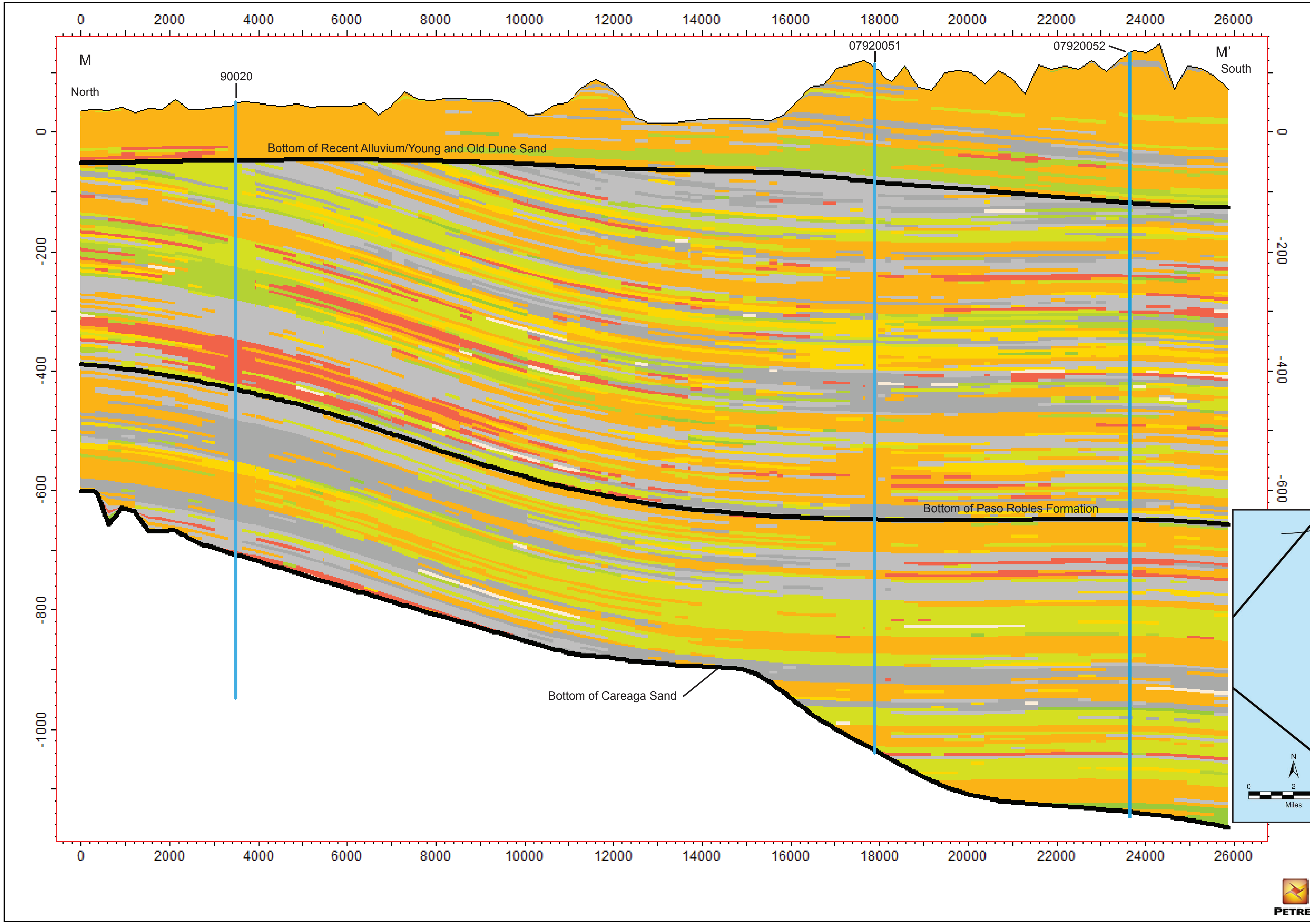
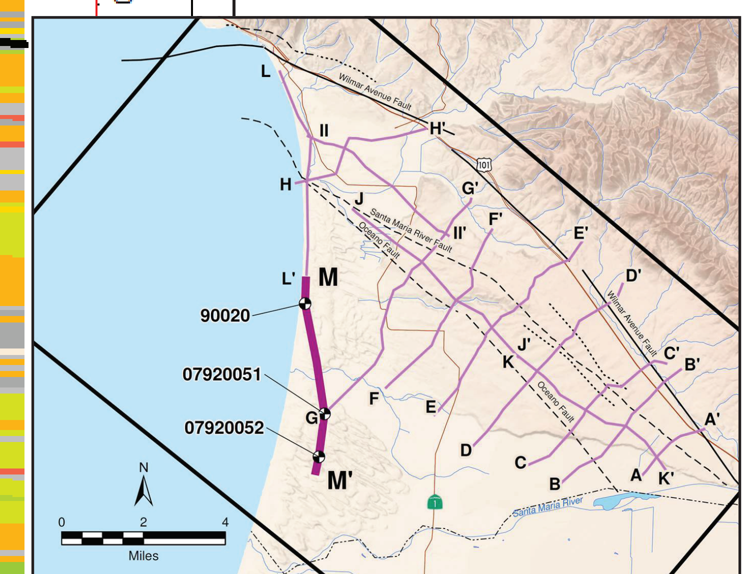
CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 1: CONCEPTUAL MODEL

FIGURE 11

GEOSCIENCE





CROSS-SECTION
M-M'

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15-Jun-18

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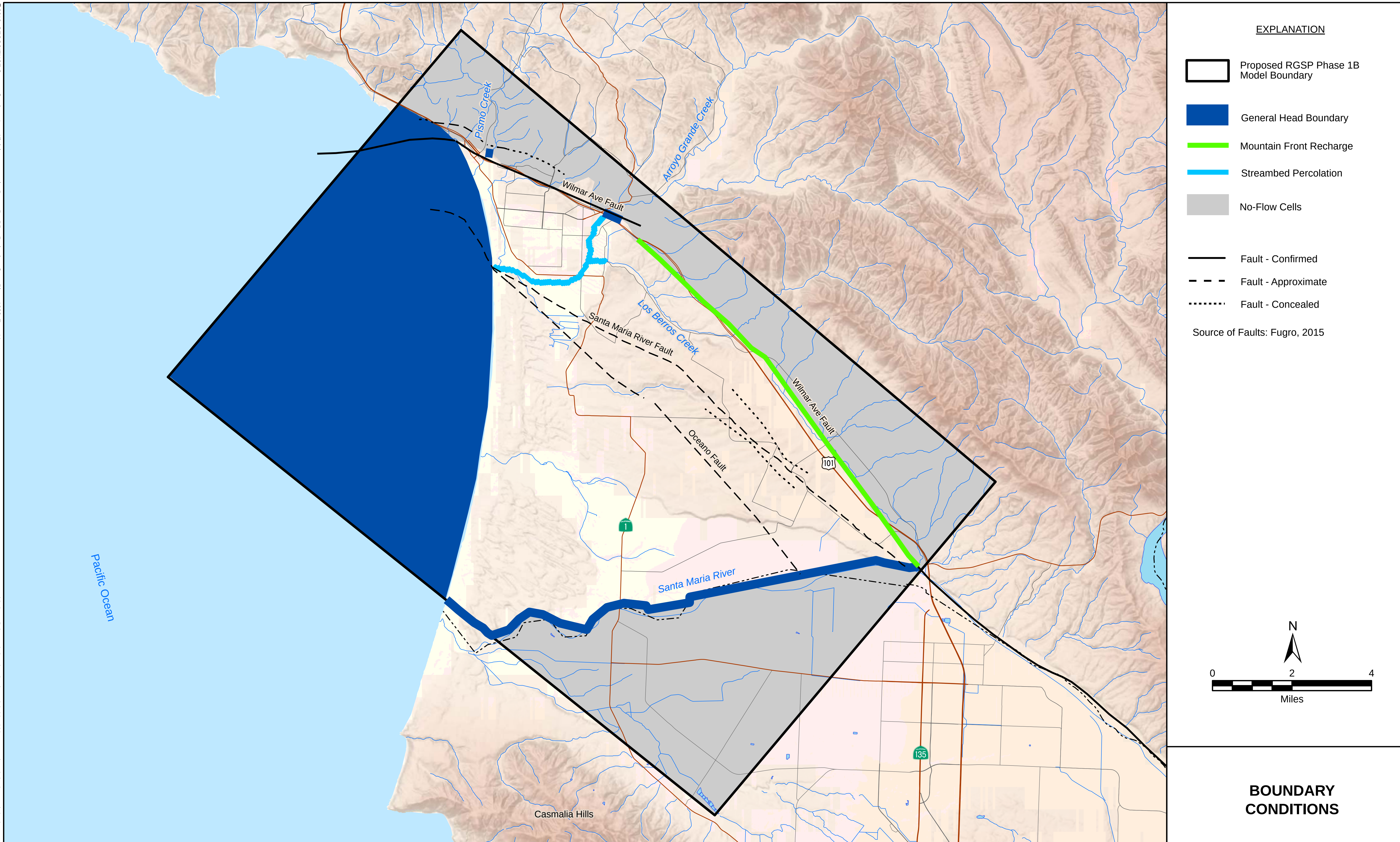
CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 1: CONCEPTUAL MODEL

FIGURE 12

GEOSCIENCE



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BOUNDARY CONDITIONS

15-Jun-18

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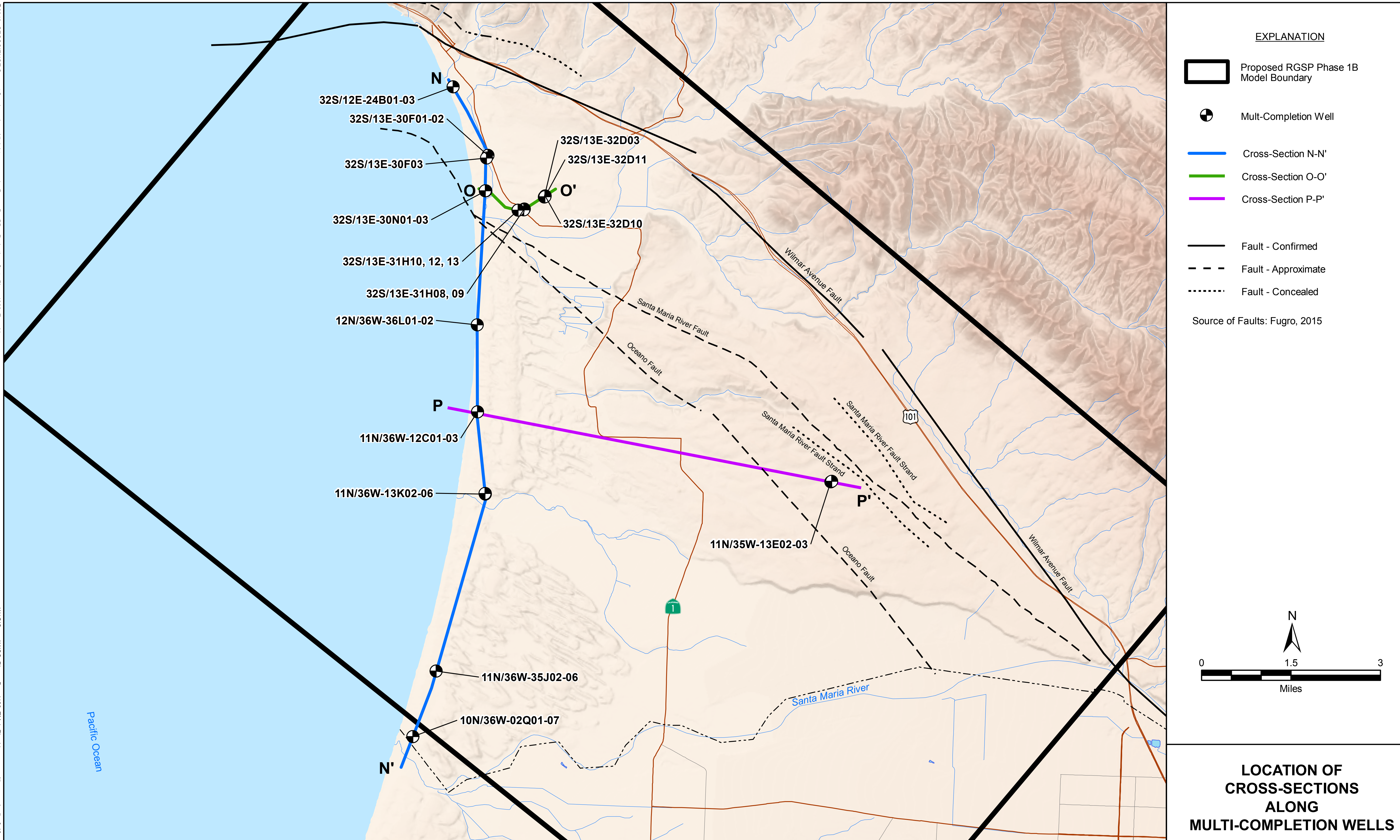
CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 1: CONCEPTUAL MODEL

FIGURE 13

GEOSCIENCE



W:\GIS_proj\WSC_Pismo_Beach\22_TM-1_Fig_14_x-sec_multiscreenedwells_6-18.mxd

15-Jun-18

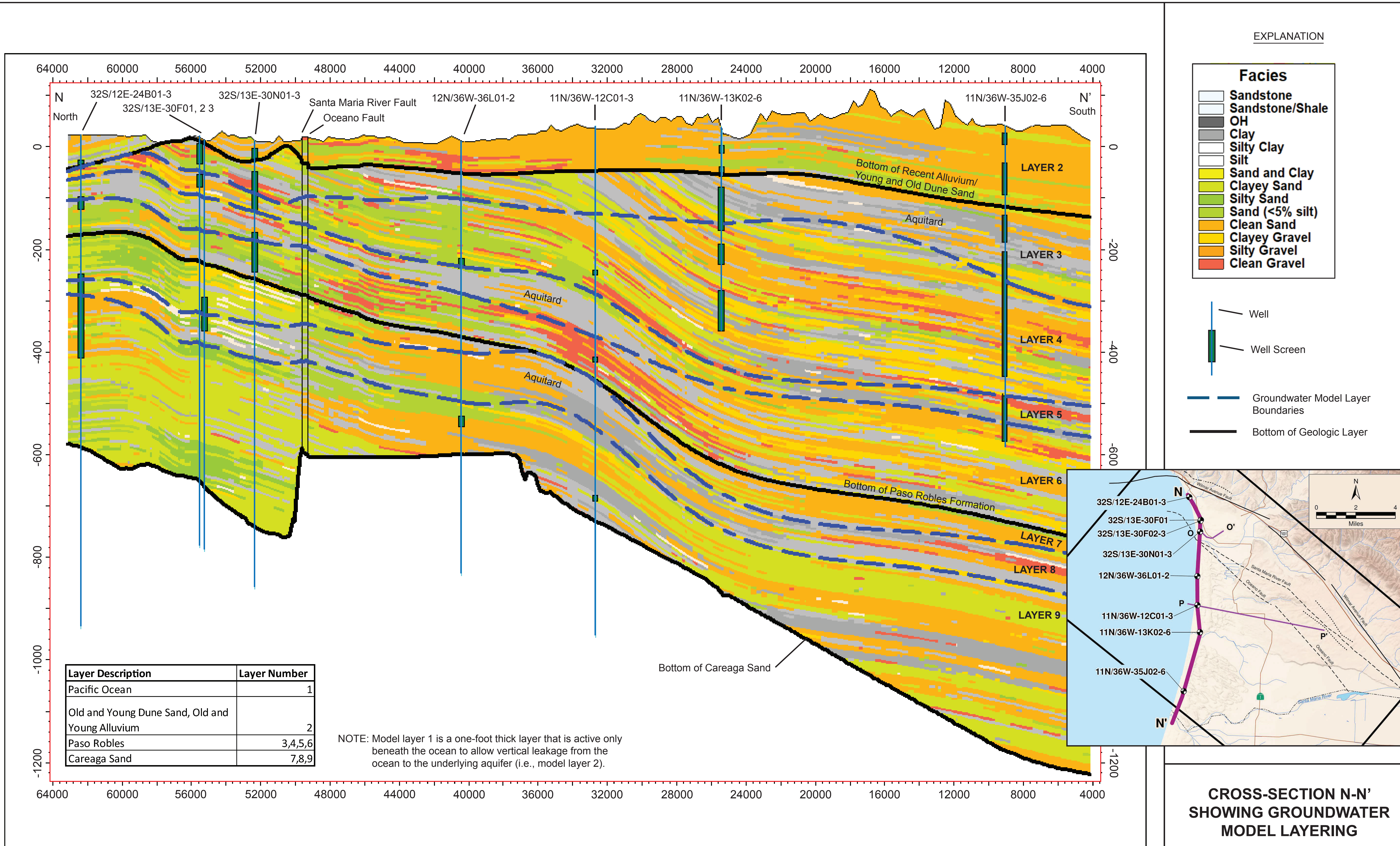
LOCATION OF CROSS-SECTIONS ALONG MULTI-COMPLETION WELLS

FIGURE 14

WATER SYSTEMS CONSULTING, INC.

CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 1: CONCEPTUAL MODEL

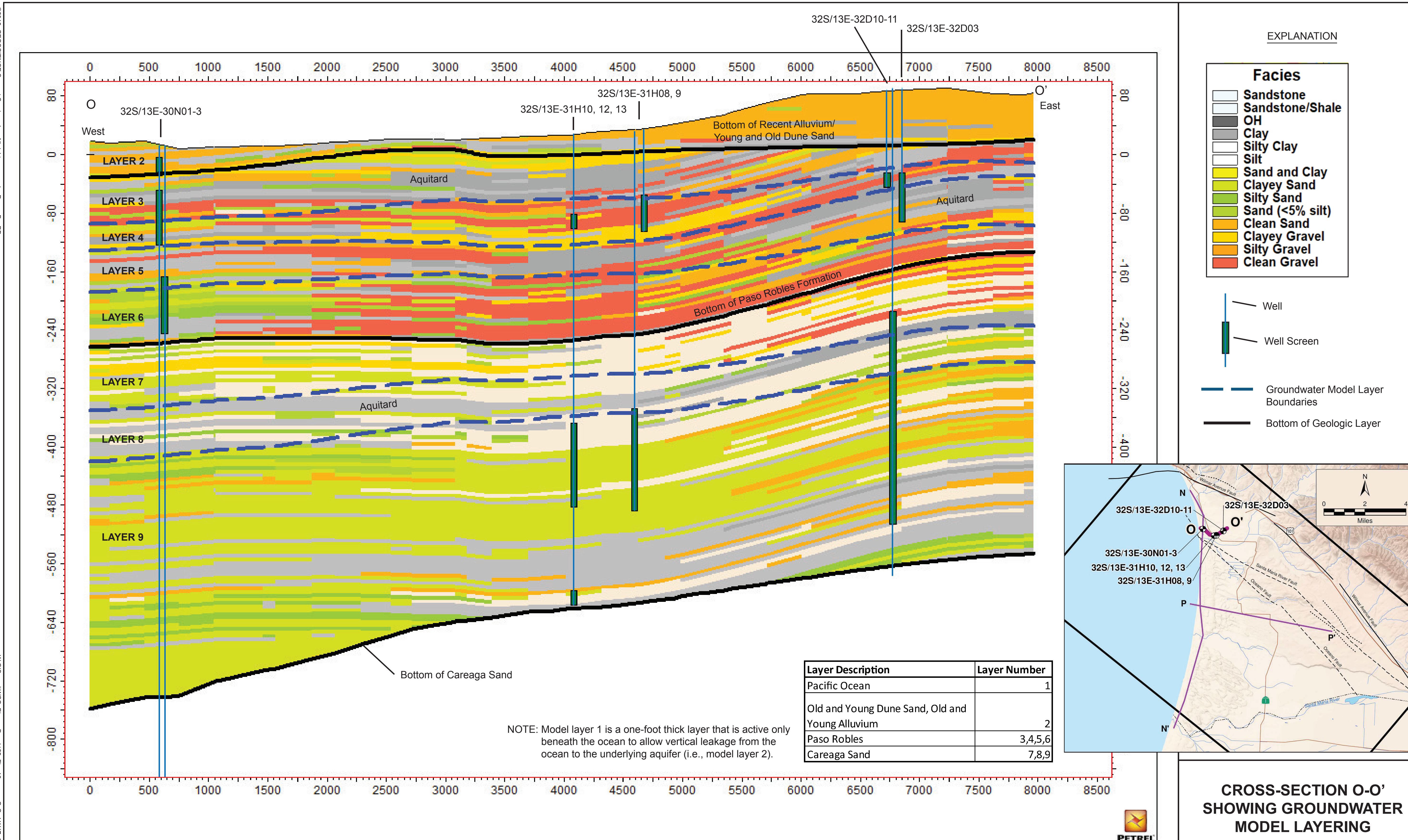
GEOSCIENCE



CROSS-SECTION N-N' SHOWING GROUNDWATER MODEL LAYERING

W:GIS_proj\WSC_Pismo_Beach\22_Fig_15_x-sec_N-N_11X17_6-18.ai

15-Jun-18



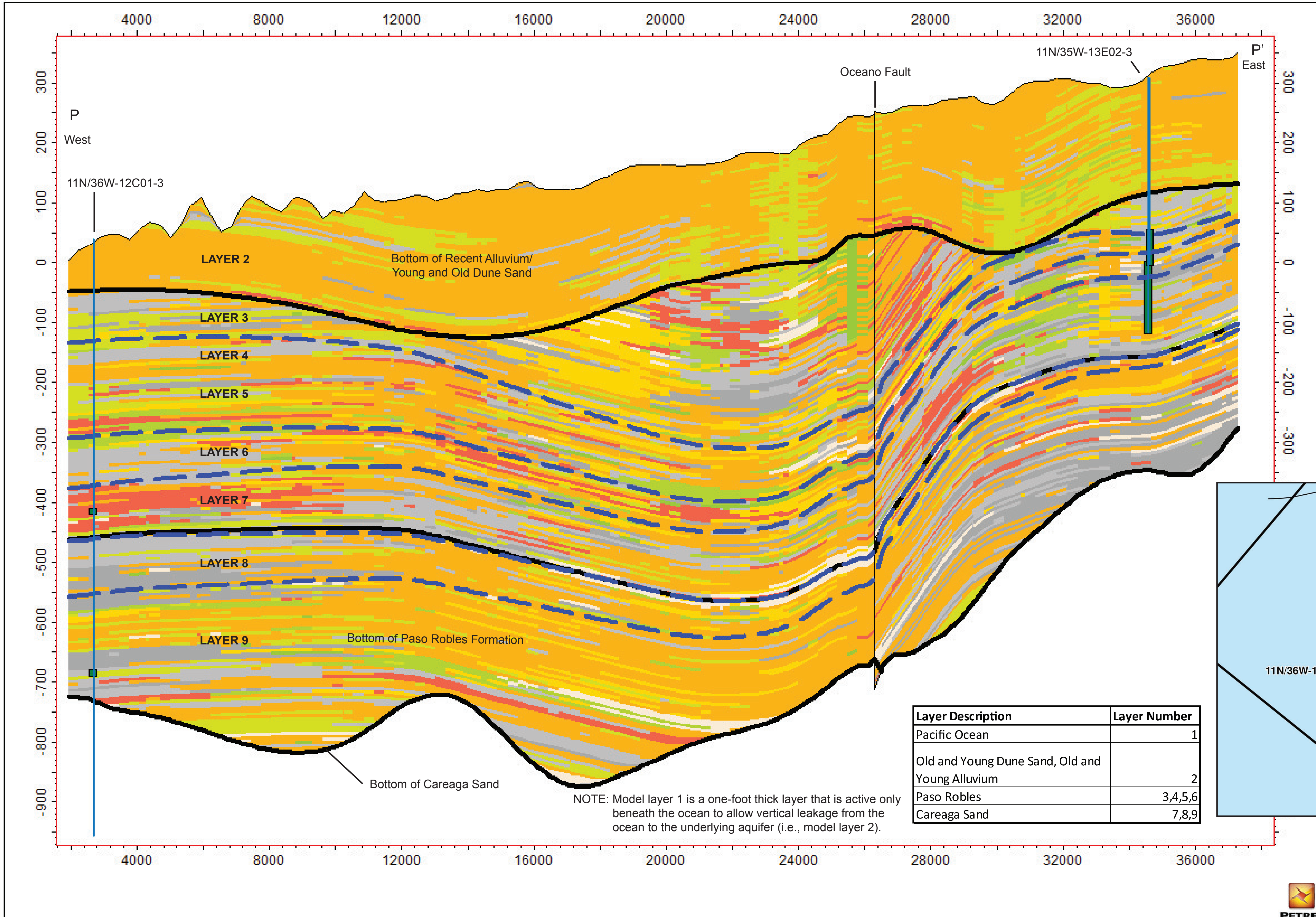
Layer Description	Layer Number
Pacific Ocean	1
Old and Young Dune Sand, Old and Young Alluvium	2
Paso Robles	3,4,5,6
Careaga Sand	7,8,9

NOTE: Model layer 1 is a one-foot thick layer that is active only beneath the ocean to allow vertical leakage from the ocean to the underlying aquifer (i.e., model layer 2).

CROSS-SECTION O-O' SHOWING GROUNDWATER MODEL LAYERING

W:GIS_proj\WSC_Pismo_Beach\22_Fig_16_x-sec_O-O_11X17_6-18.ai

15-Jun-18

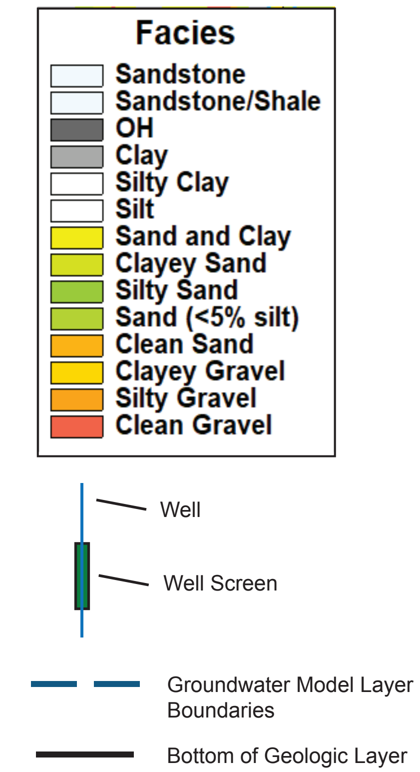


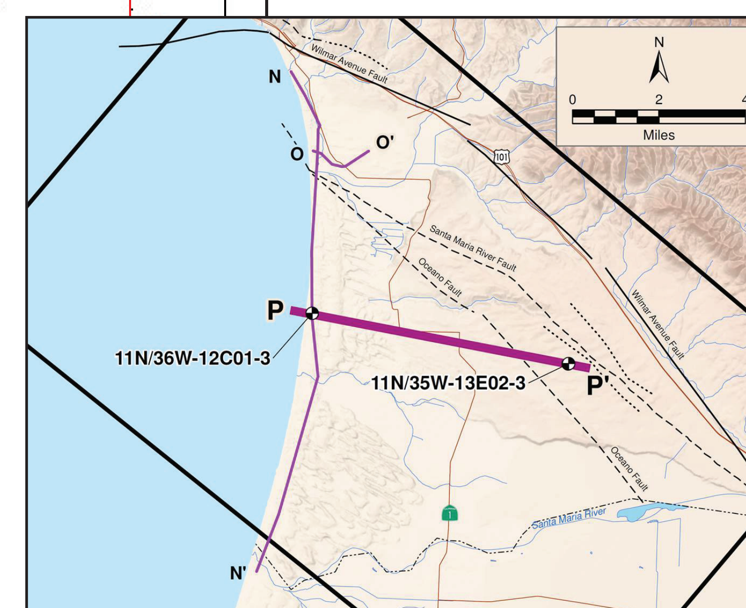
NOTE: Model layer 1 is a one-foot thick layer that is active only beneath the ocean to allow vertical leakage from the ocean to the underlying aquifer (i.e., model layer 2).

Layer Description	Layer Number
Pacific Ocean	1
Old and Young Dune Sand, Old and Young Alluvium	2
Paso Robles	3,4,5,6
Careaga Sand	7,8,9

PETREL

EXPLANATION



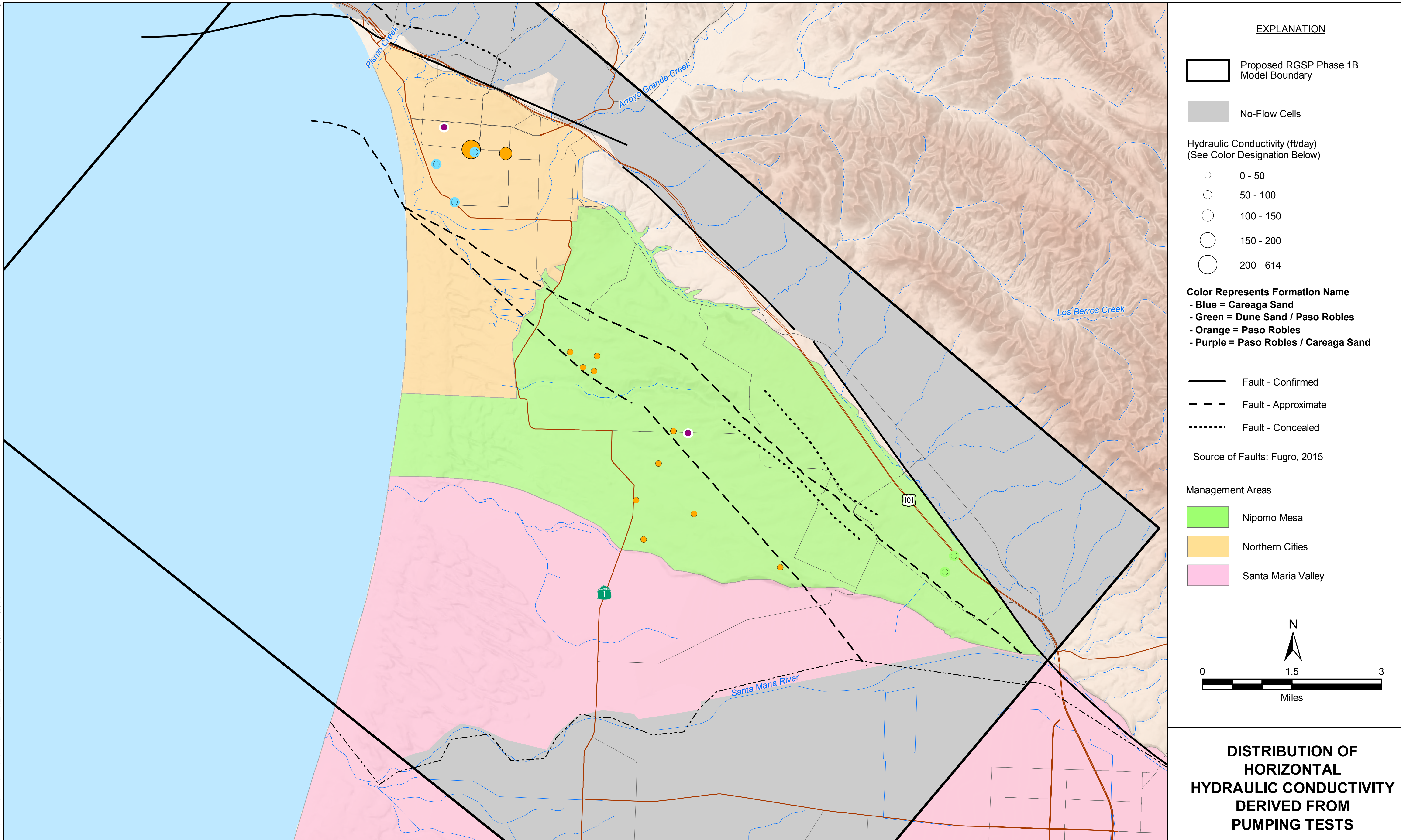


CROSS-SECTION P-P' SHOWING GROUNDWATER MODEL LAYERING

15-Jun-18

FIGURE 17

GEOSCIENCE



DISTRIBUTION OF HORIZONTAL HYDRAULIC CONDUCTIVITY DERIVED FROM PUMPING TESTS

W:\GIS_proj\WSC_Pismo_Beach\22_TM-1_Fig_18_horiz_hyd_cond_pumpingtests_6-18.mxd

15-Jun-18

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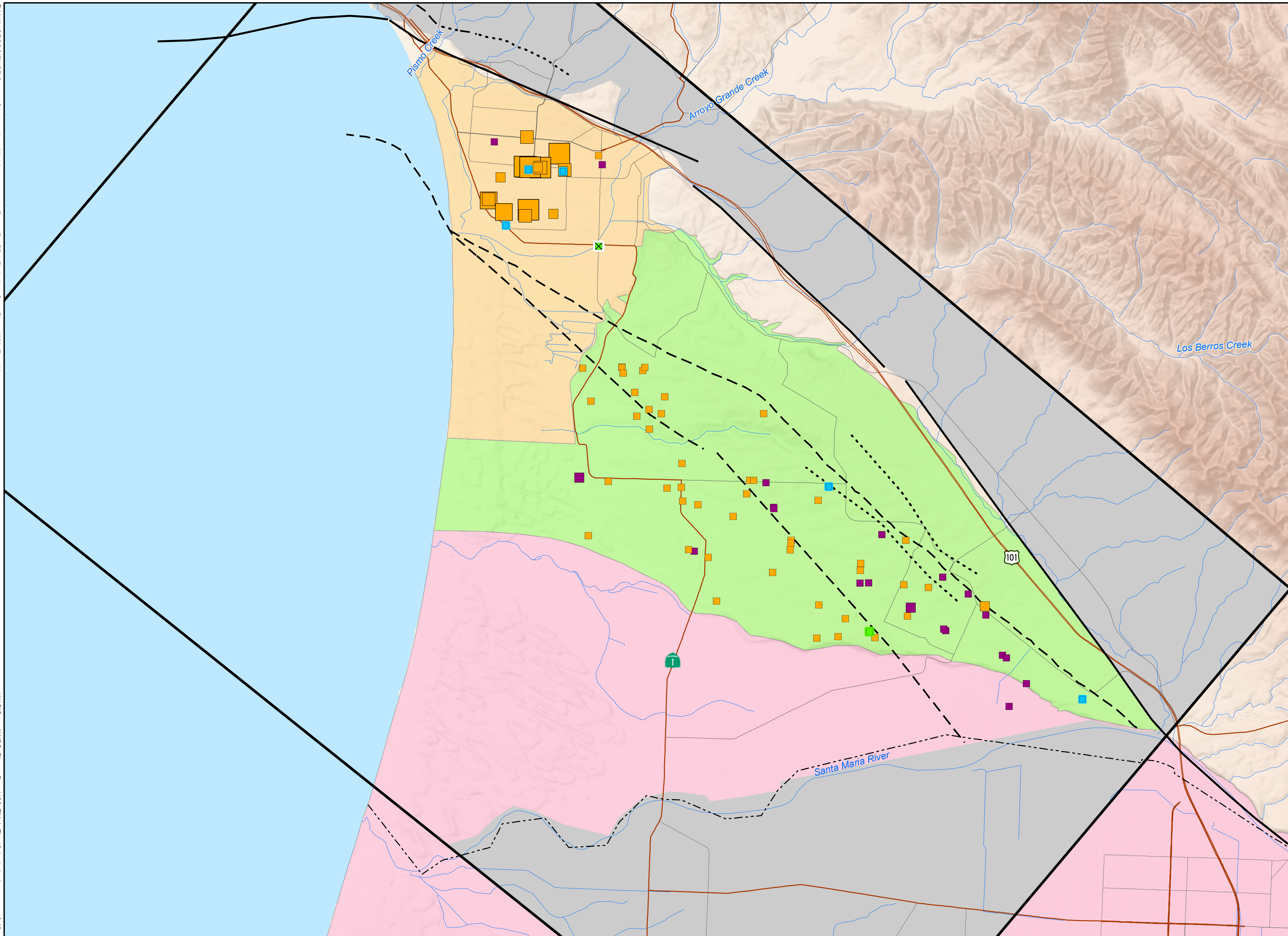
CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 1: CONCEPTUAL MODEL

FIGURE 18

GEOSCIENCE



W:\GIS_proj\WSC_Pismo_Beach\22_TM-1_Fig_19_horiz_hyd_spec_cap_6-18.mxd

DISTRIBUTION OF HORIZONTAL HYDRAULIC CONDUCTIVITY DERIVED FROM SPECIFIC CAPACITY

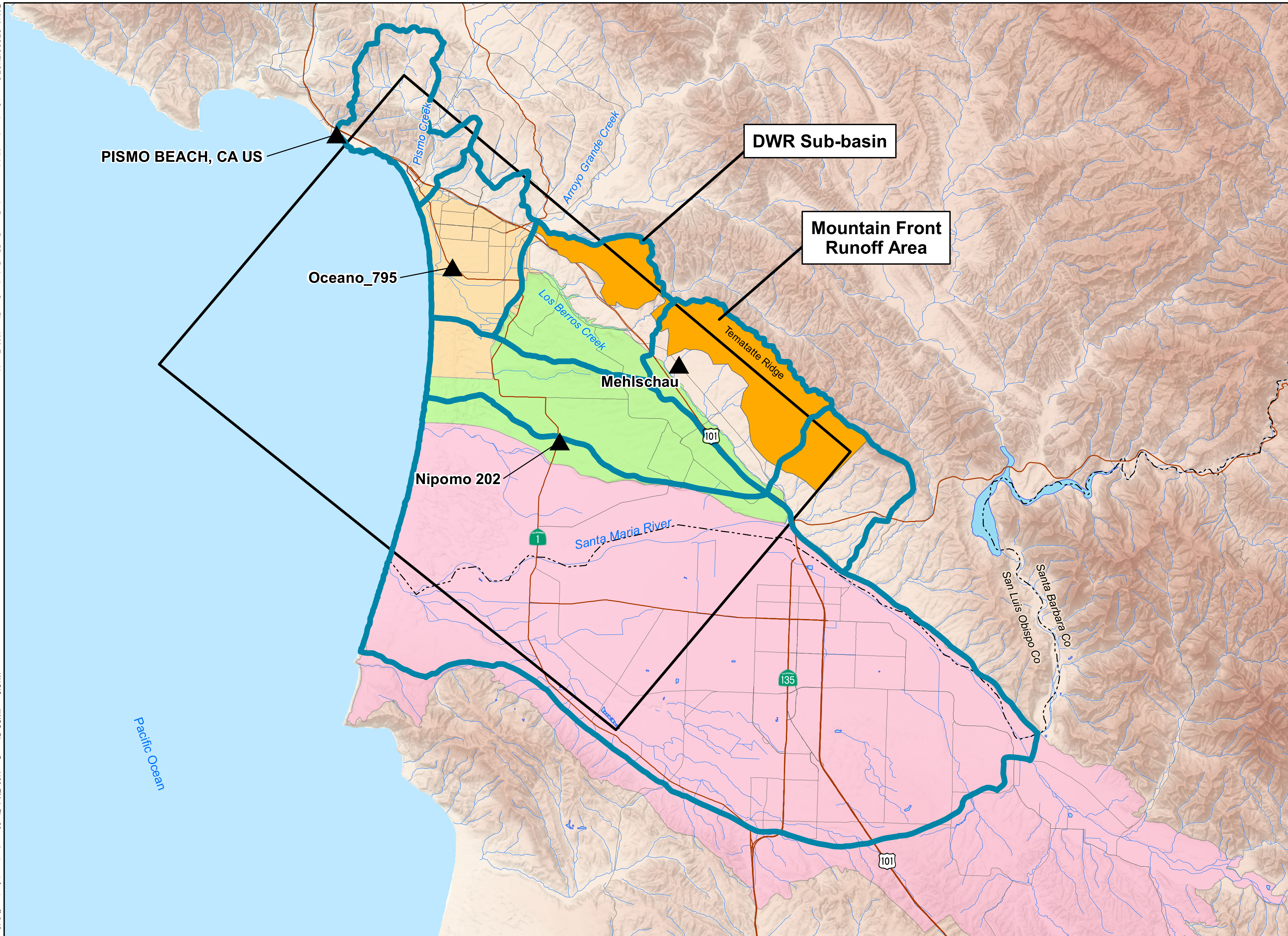
15-Jun-18

WATER SYSTEMS CONSULTING, INC.

FIGURE 19

CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 1: CONCEPTUAL MODEL

GEOSCIENCE



W:\GIS_proj\WSC_Pismo_Beach\22_TM-1_Fig_20_precip_stns_mtnfrontrunoff_6-18.mxd

15-Jun-18

LOCATION OF PRECIPITATION STATIONS AND MOUNTAIN FRONT RUNOFF AREAS

FIGURE 20

GEOSCIENCE

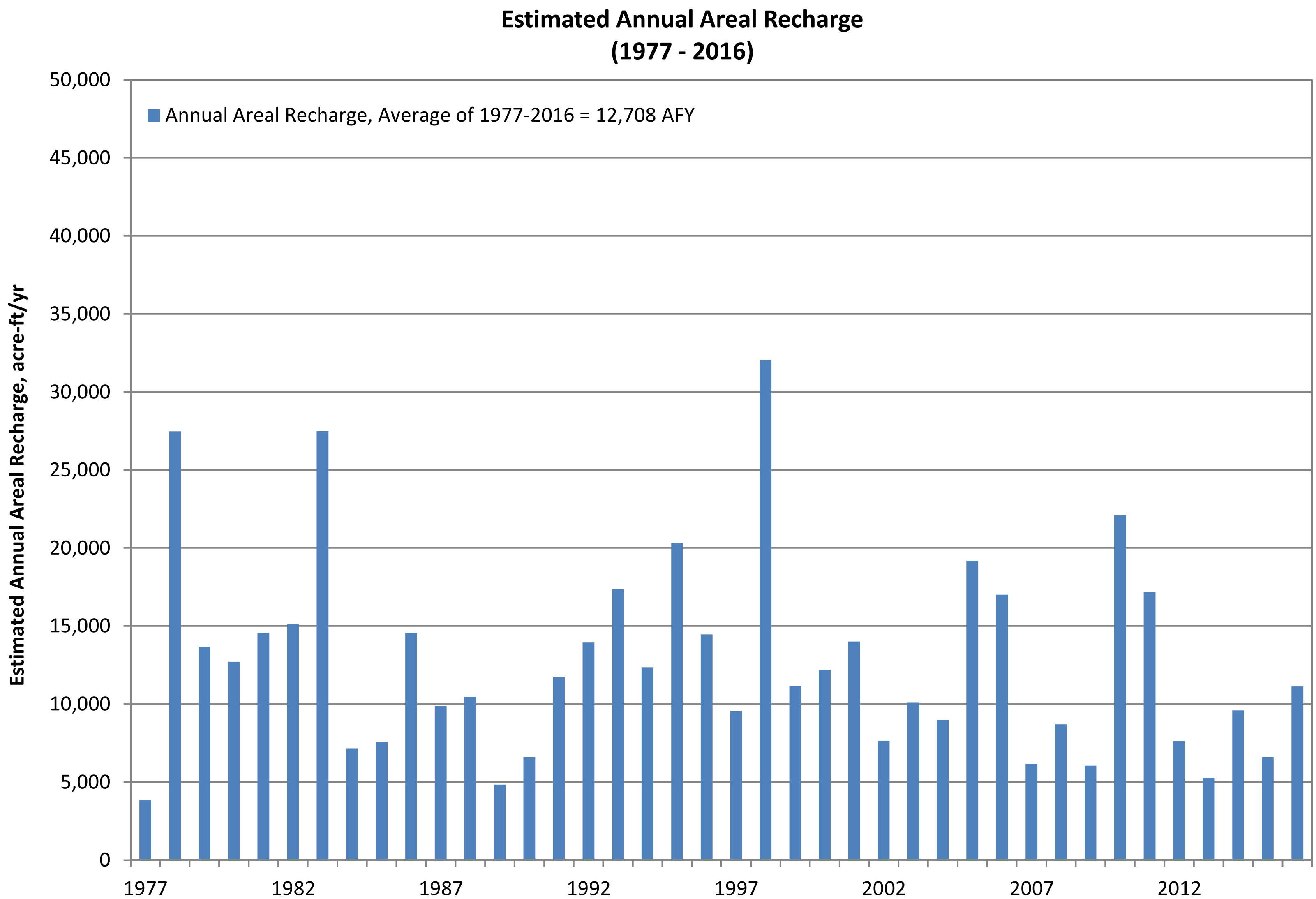

Estimated Annual Areal Recharge
(1977 - 2016)
Annual Areal Recharge, Average of 1977-2016 = 12,708 AFY
Estimated Annual Areal Recharge, acre-ft/yr
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1977
1982
1987
1992
1997
2002
2007
2012

Figure 21

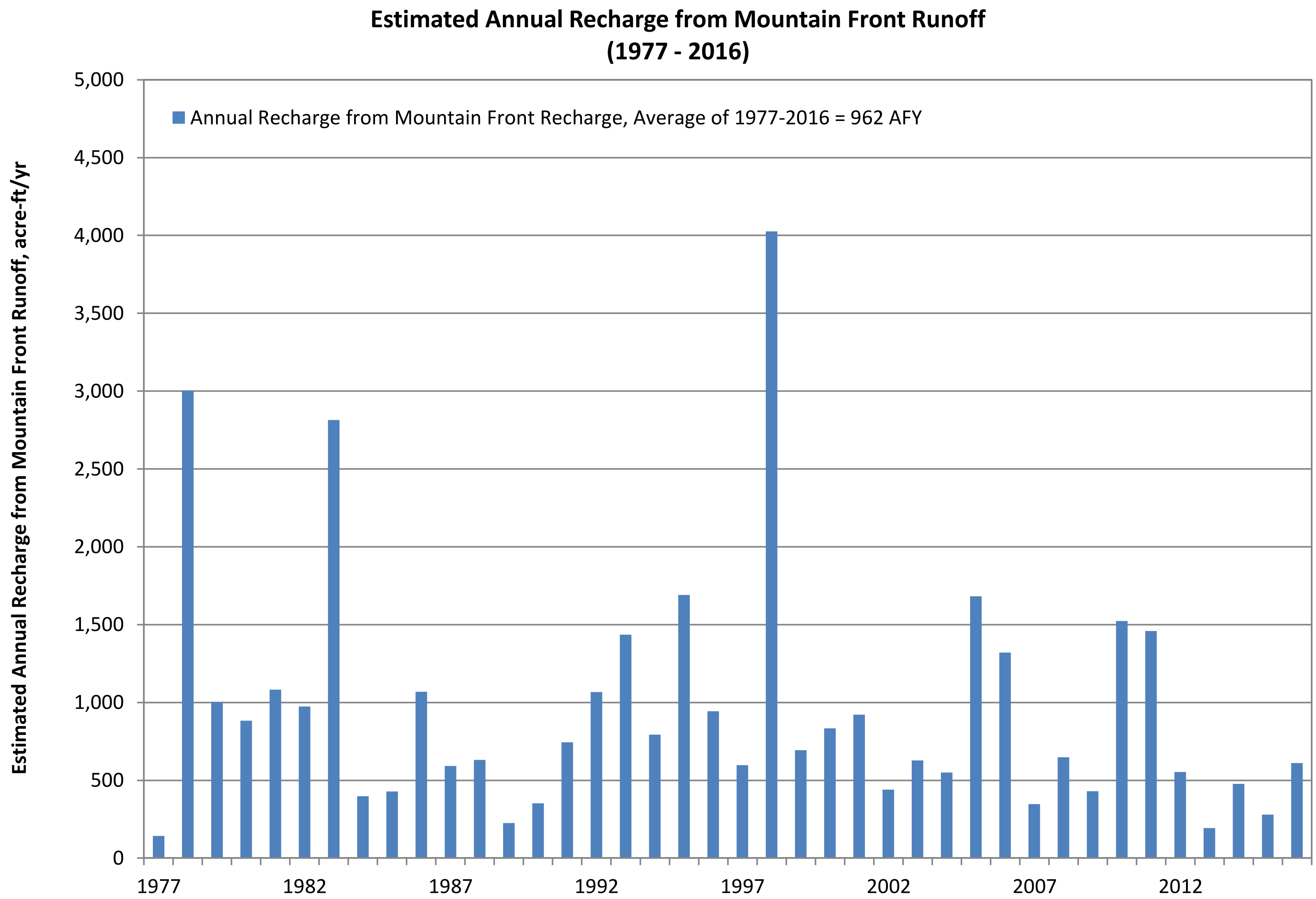
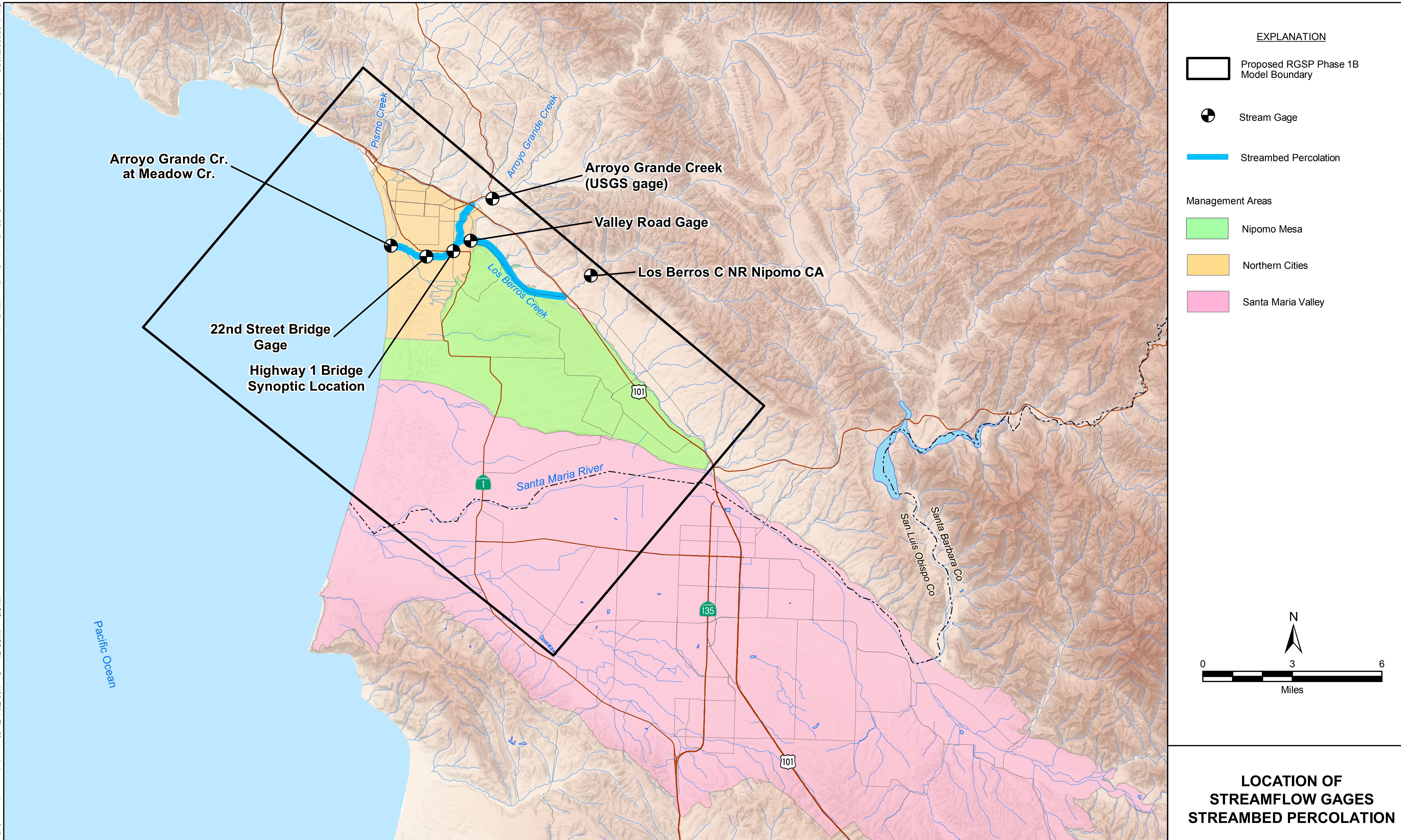

Estimated Annual Recharge from Mountain Front Runoff
(1977 - 2016)
Annual Recharge from Mountain Front Recharge, Average of 1977-2016 = 962 AFY
Estimated Annual Recharge from Mountain Front Runoff, acre-ft/yr
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1977
1982
1987
1992
1997
2002
2007
2012

Figure 22



LOCATION OF
STREAMFLOW GAGES
STREAMBED PERCOLATION

W:\GIS_proj\WSC_Pismo_Beach\22_TM-1_Fig_23_streambed_perc_gaging_stns_6-18.mxd

15-Jun-18

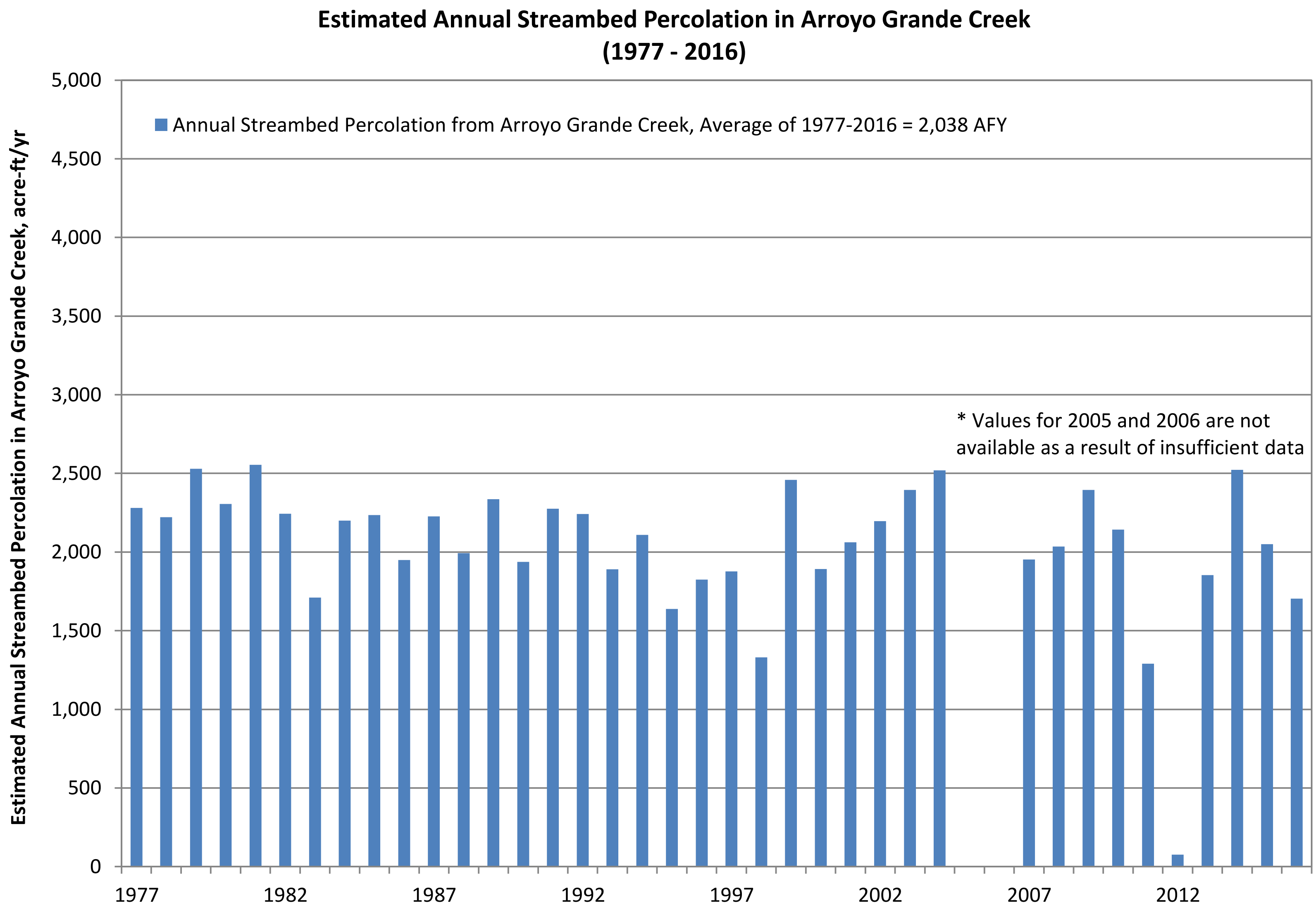
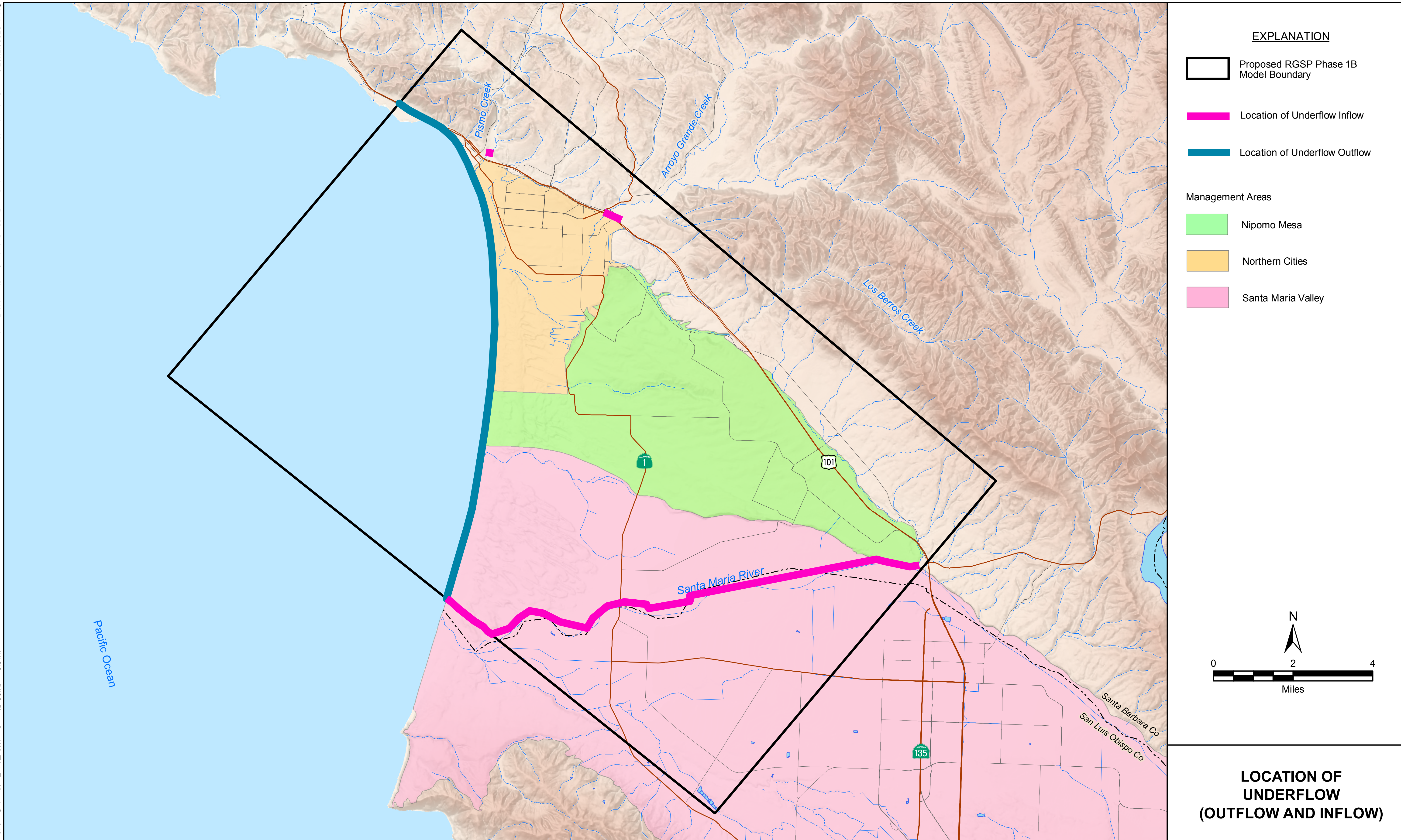

Estimated Annual Streambed Percolation in Arroyo Grande Creek
(1977 - 2016)
Annual Streambed Percolation from Arroyo Grande Creek, Average of 1977-2016 = 2,038 AFY
* Values for 2005 and 2006 are not available as a result of insufficient data
Estimated Annual Streambed Percolation in Arroyo Grande Creek, acre-ft/yr
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1977
1982
1987
1992
1997
2002
2007
2012

Figure 24



W:\GIS_proj\WSC_Pismo_Beach\22_TM-1_Fig_25_underflow_6-18.mxd

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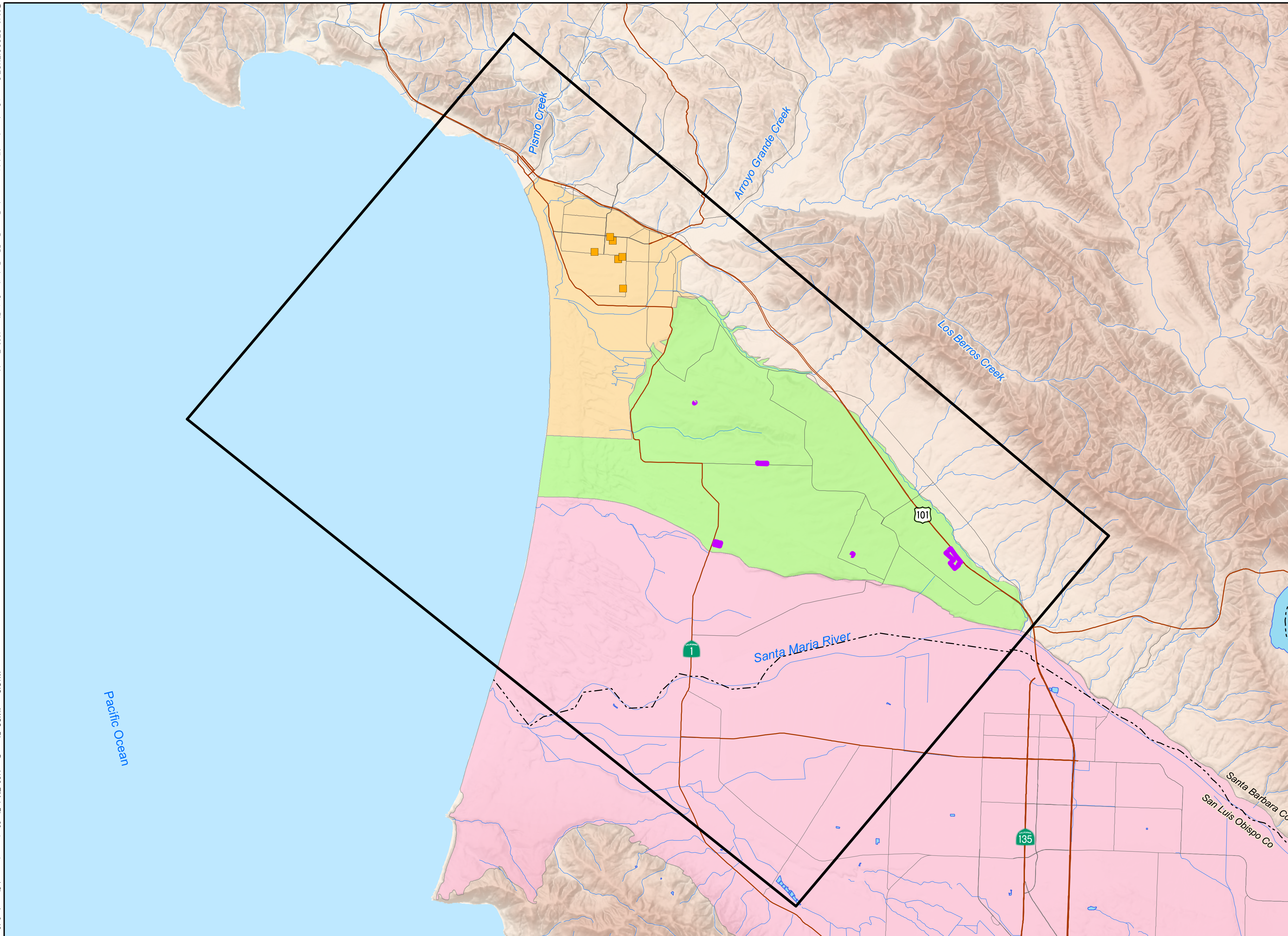
FIGURE 25

CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 1: CONCEPTUAL MODEL

GEOSCIENCE



W:\GIS_proj\WSC_Pismo_Beach\22_TM-1_Fig_26_stormwater_ww_infil_ponds_6-18.mxd

LOCATION OF STORMWATER AND WASTEWATER INFILTRATION PONDS

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WATER SYSTEMS CONSULTING, INC.

FIGURE 26

CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 1: CONCEPTUAL MODEL

GEOSCIENCE

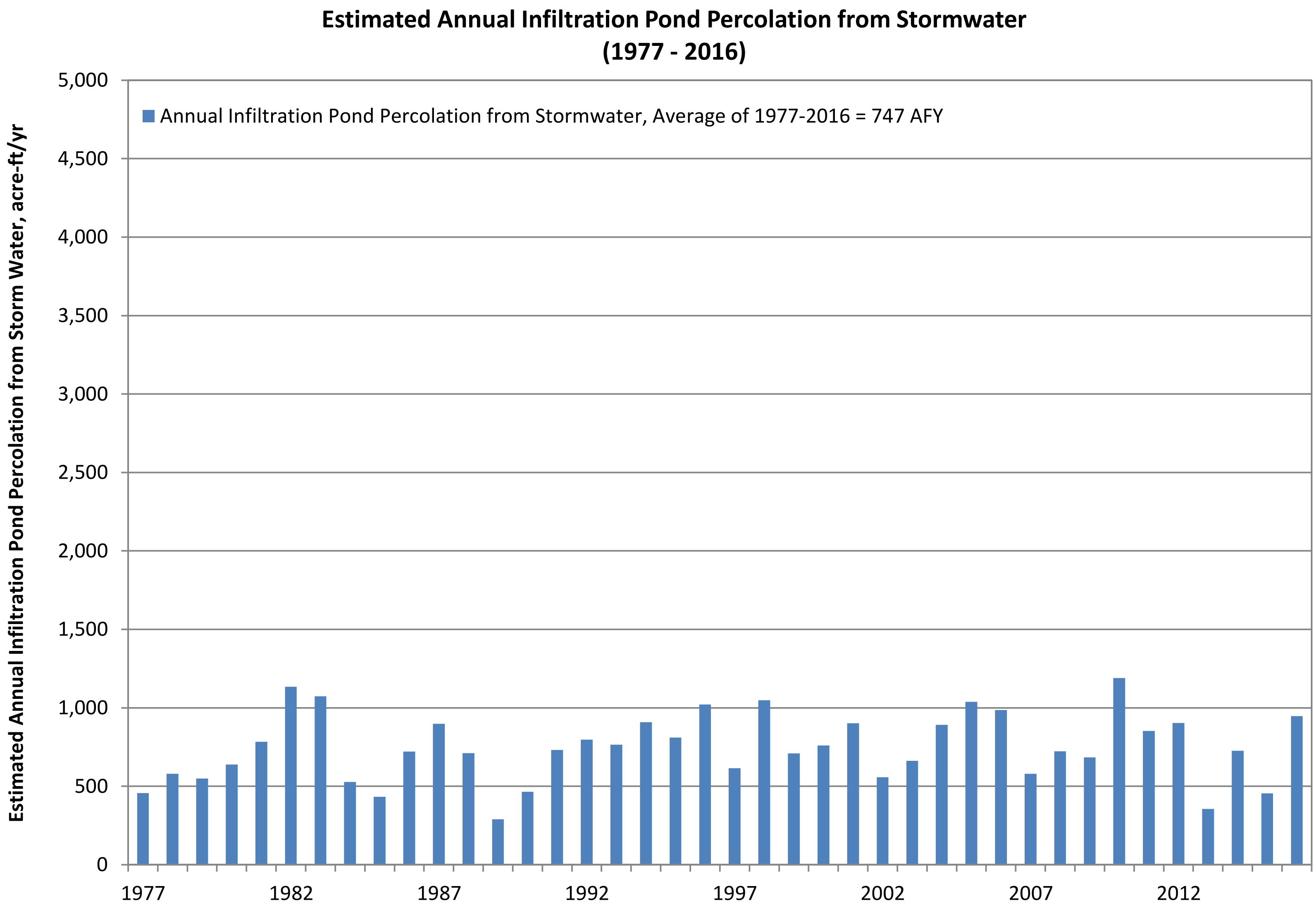

Estimated Annual Infiltration Pond Percolation from Stormwater
(1977 - 2016)
Annual Infiltration Pond Percolation from Stormwater, Average of 1977-2016 = 747 AFY
Estimated Annual Infiltration Pond Percolation from Storm Water, acre-ft/yr
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1977
1982
1987
1992
1997
2002
2007
2012

Figure 27

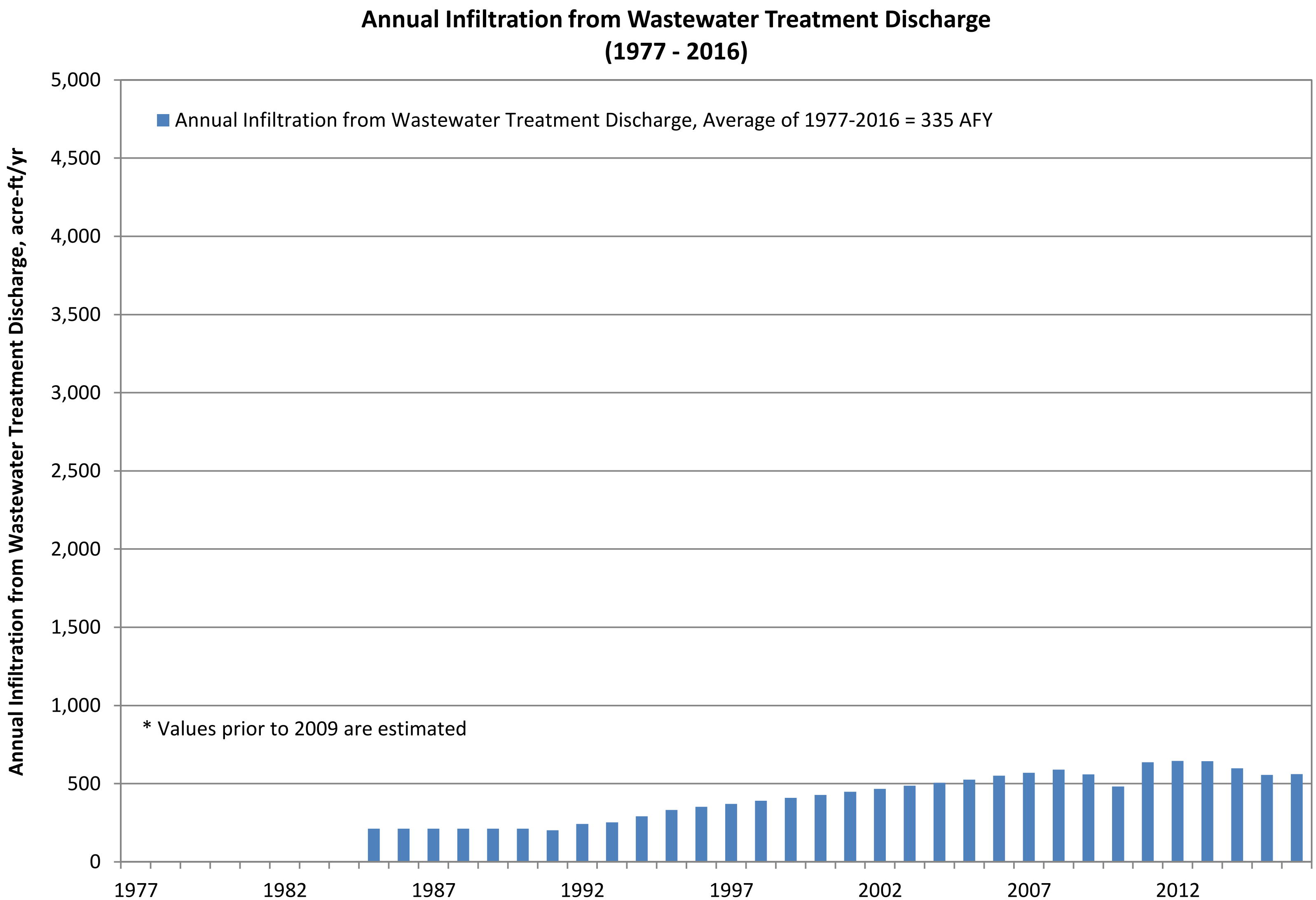

Annual Infiltration from Wastewater Treatment Discharge
(1977 - 2016)
Annual Infiltration from Wastewater Treatment Discharge, Average of 1977-2016 = 335 AFY
Annual Infiltration from Wastewater Treatment Discharge, acre-ft/yr
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
* Values prior to 2009 are estimated
1977
1982
1987
1992
1997
2002
2007
2012

Figure 28

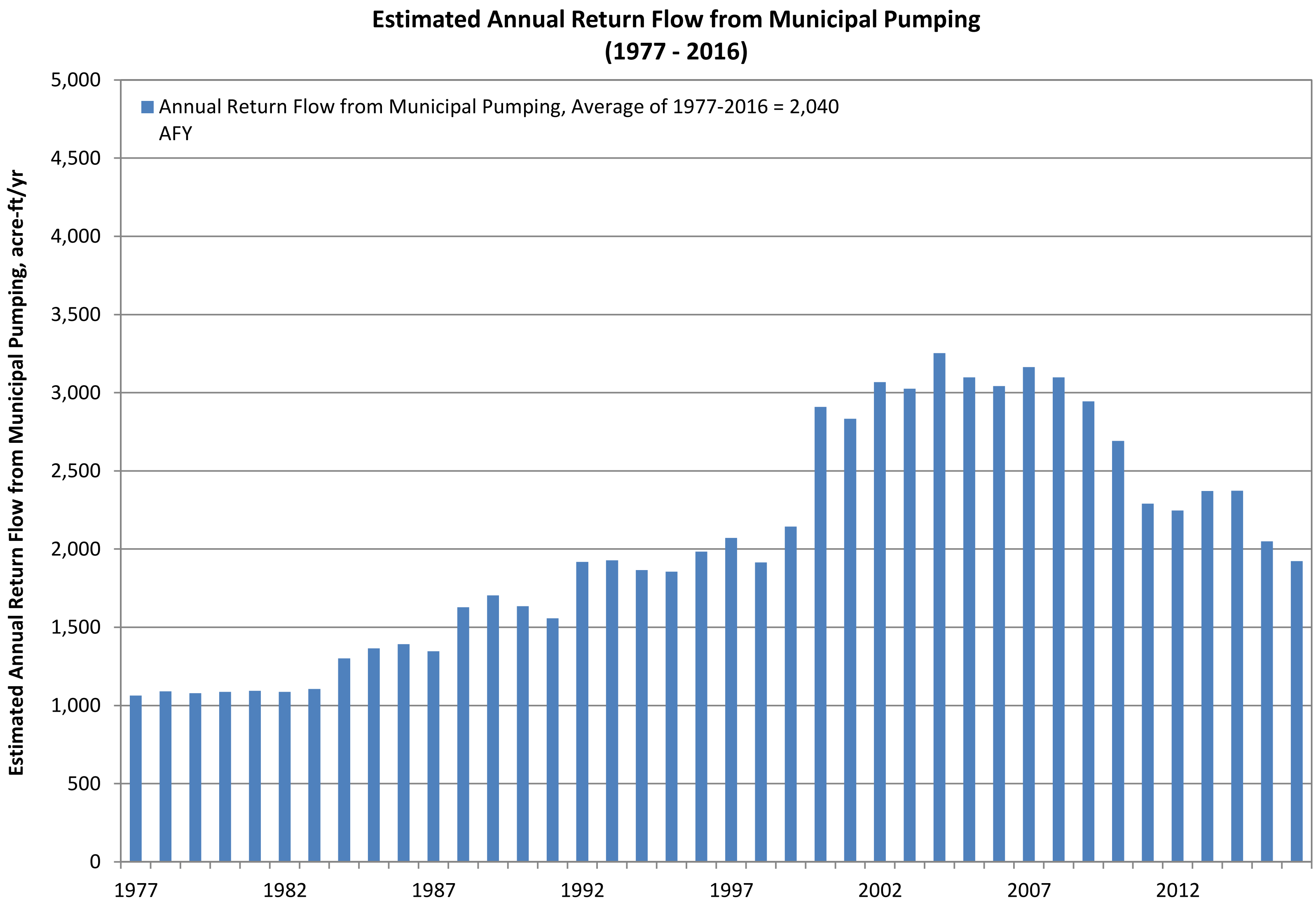

Estimated Annual Return Flow from Municipal Pumping
(1977 - 2016)
Annual Return Flow from Municipal Pumping, Average of 1977-2016 = 2,040 AFY
Estimated Annual Return Flow from Municipal Pumping, acre-ft/yr
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1977
1982
1987
1992
1997
2002
2007
2012

Figure 29

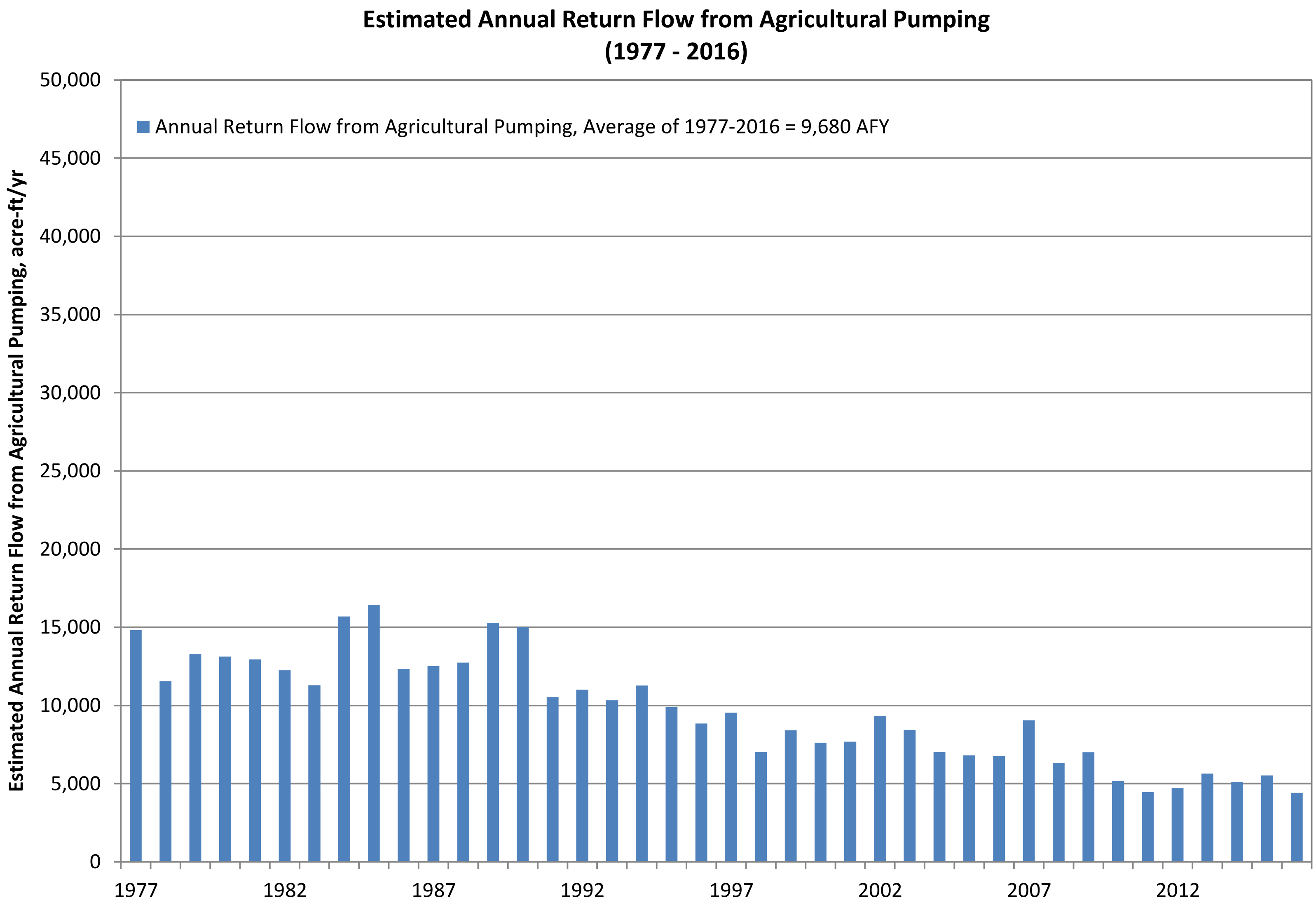
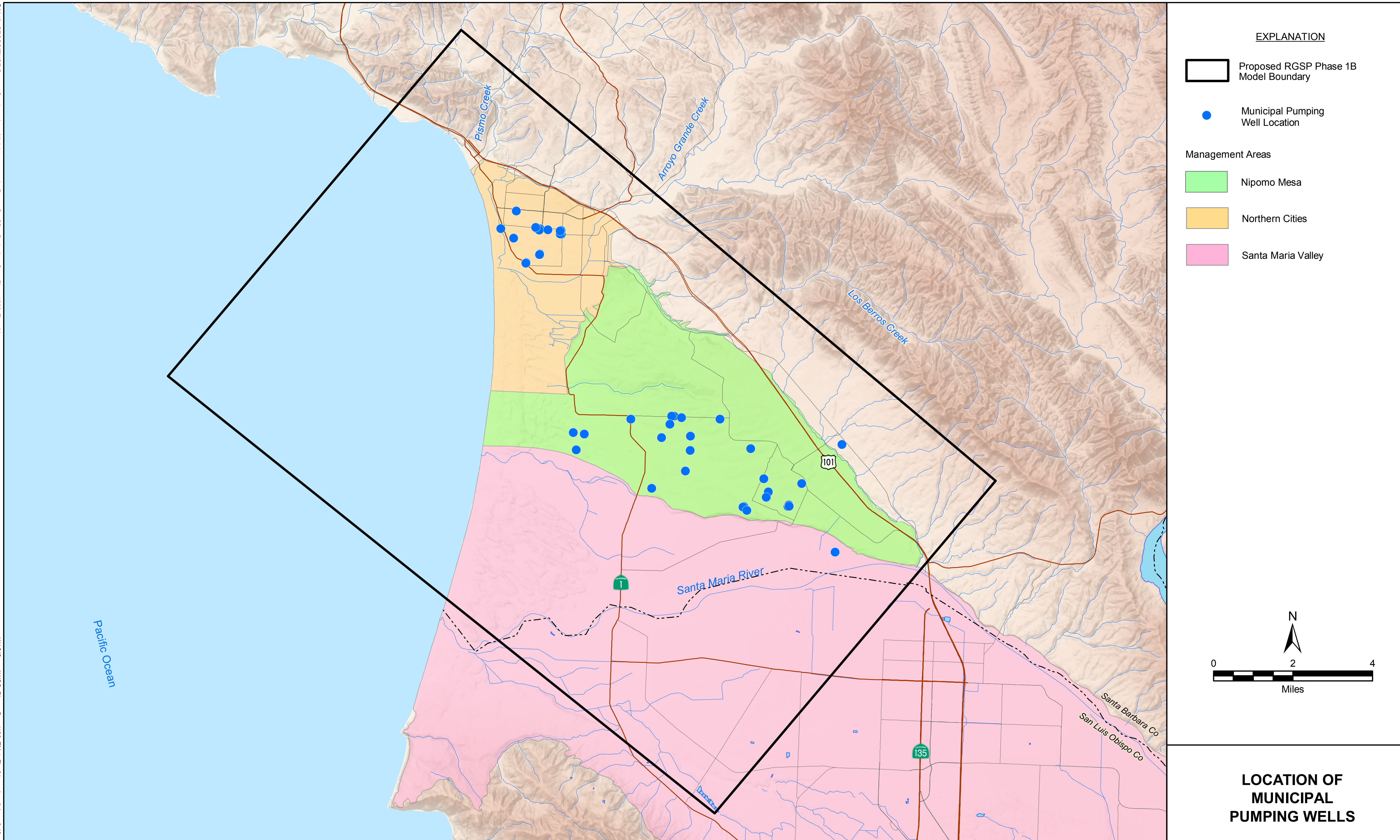

Estimated Annual Return Flow from Agricultural Pumping
(1977 - 2016)
Annual Return Flow from Agricultural Pumping, Average of 1977-2016 = 9,680 AFY
Estimated Annual Return Flow from Agricultural Pumping, acre-ft/yr
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1977
1982
1987
1992
1997
2002
2007
2012

Figure 30



LOCATION OF MUNICIPAL PUMPING WELLS

W:\GIS_proj\WSC_Pismo_Beach\22_TM-1_Fig_31_prod_well_locs_6-18.mxd

15-Jun-18

WATER SYSTEMS CONSULTING, INC.

FIGURE 31

CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 1: CONCEPTUAL MODEL

GEOSCIENCE

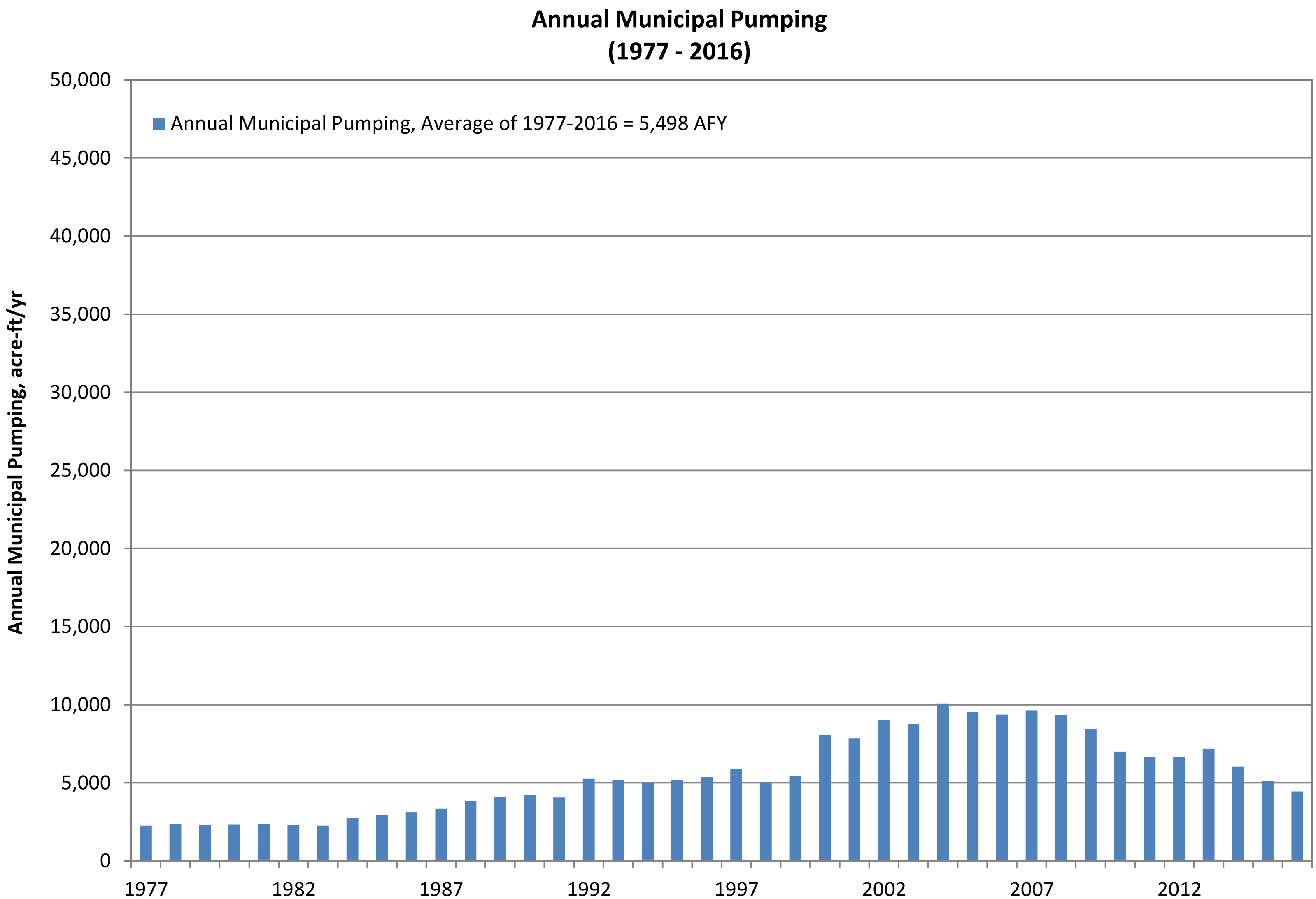

Annual Municipal Pumping
(1977 - 2016)
Annual Municipal Pumping, Average of 1977-2016 = 5,498 AFY
Annual Municipal Pumping, acre-ft/yr
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1977
1982
1987
1992
1997
2002
2007
2012

Figure 32

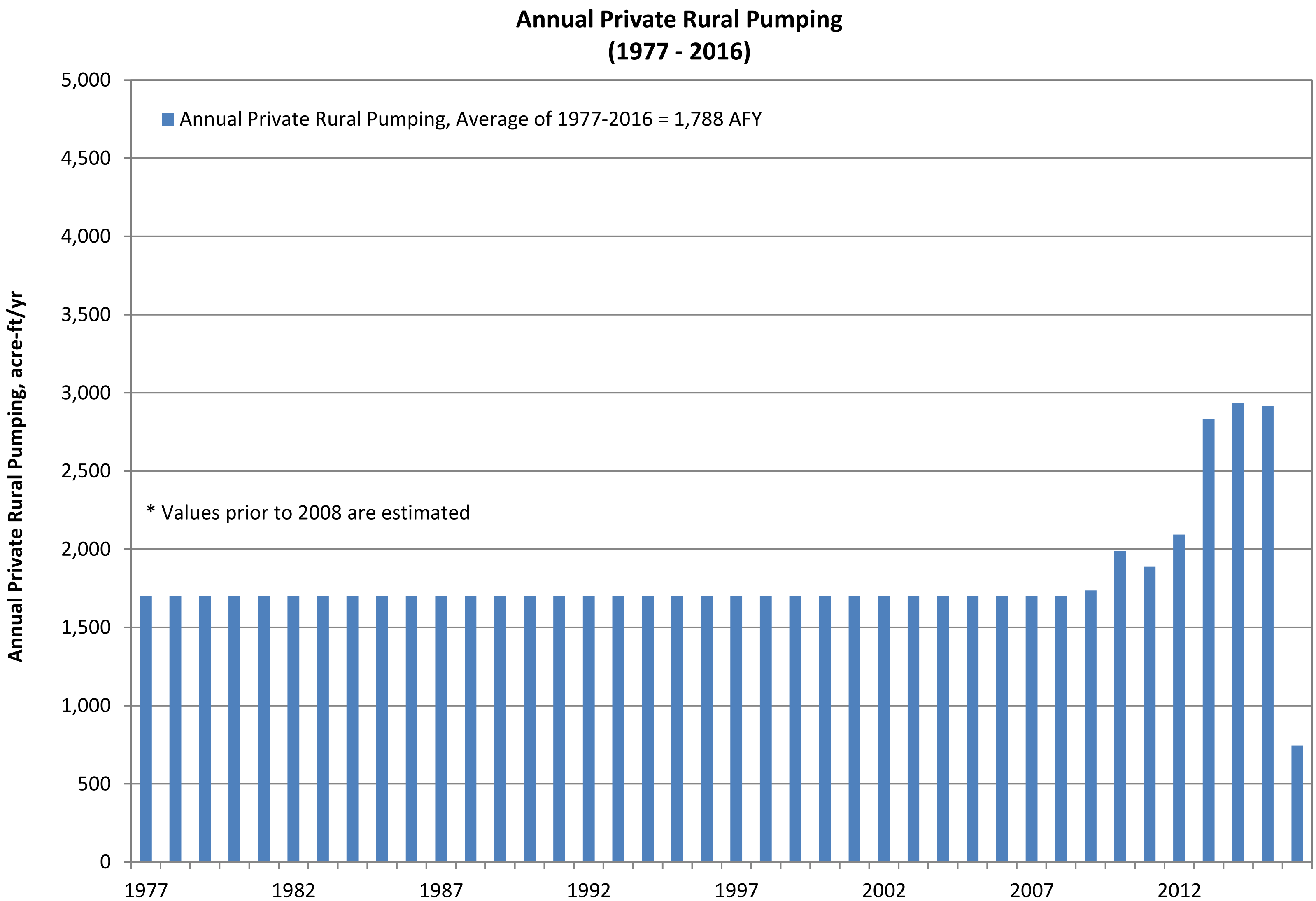

Annual Private Rural Pumping
(1977 - 2016)
Annual Private Rural Pumping, Average of 1977-2016 = 1,788 AFY
* Values prior to 2008 are estimated
Annual Private Rural Pumping, acre-ft/yr
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1977
1982
1987
1992
1997
2002
2007
2012

Figure 33

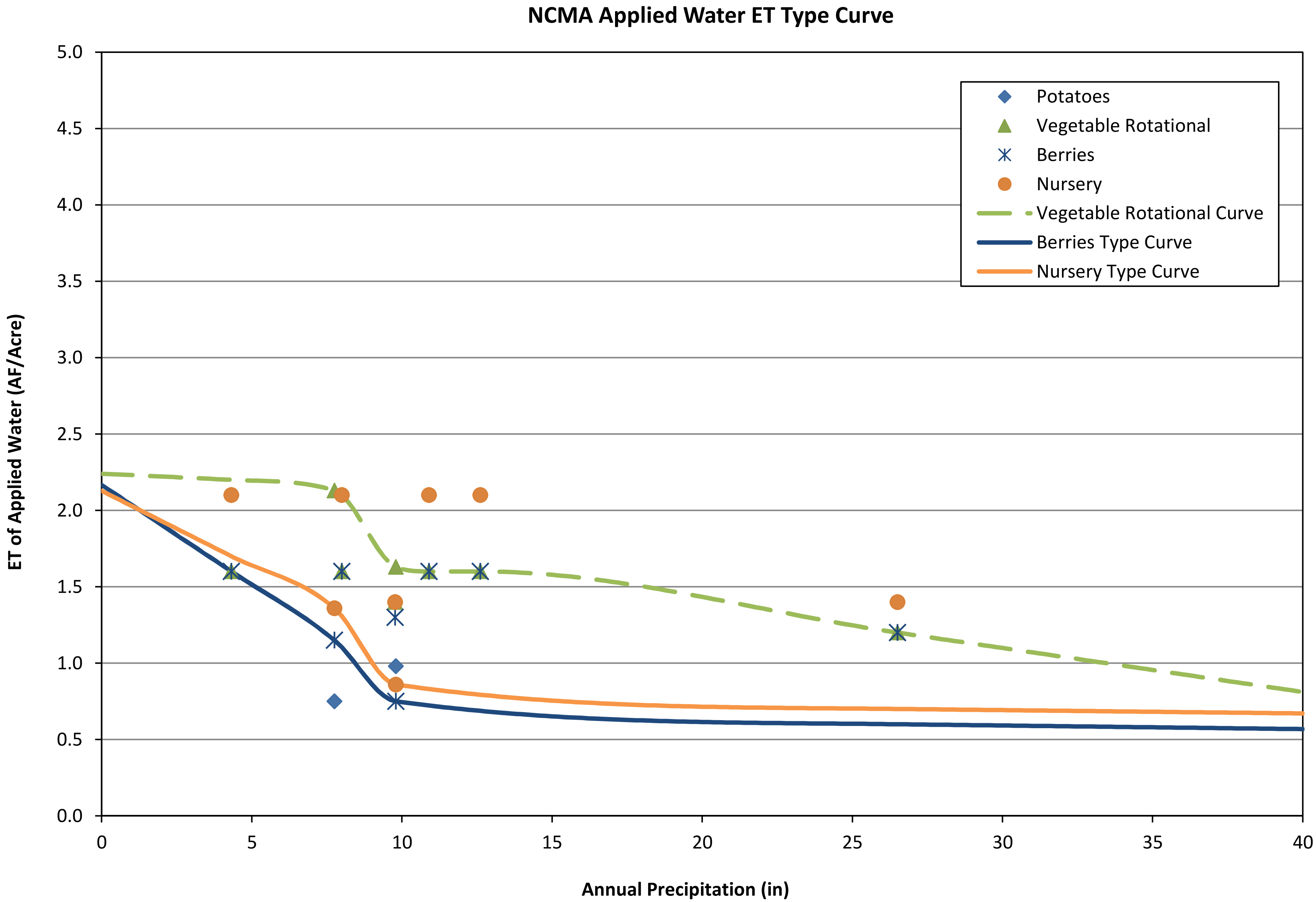

NCMA Applied Water ET Type Curve
ET of Applied Water (AF/Acre)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
Annual Precipitation (in)
Potatoes
Vegetable Rotational
Berries
Nursery
Vegetable Rotational Curve
Berries Type Curve
Nursery Type Curve

Figure 34

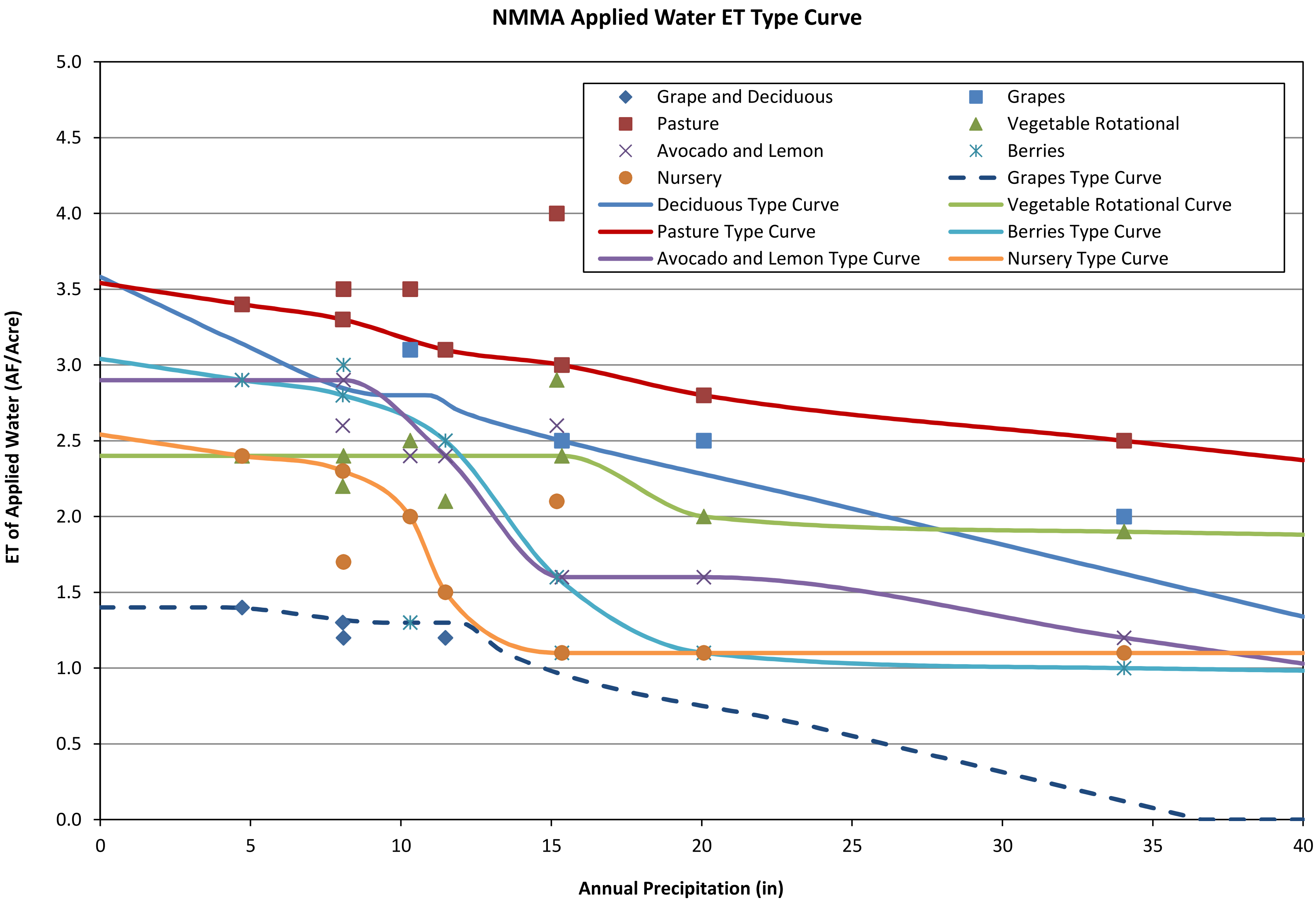

NMMA Applied Water ET Type Curve
ET of Applied Water (AF/Acre)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
Annual Precipitation (in)
Grape and Deciduous
Grapes
Pasture
Vegetable Rotational
Avocado and Lemon
Berries
Nursery
Grapes Type Curve
Deciduous Type Curve
Vegetable Rotational Curve
Pasture Type Curve
Berries Type Curve
Avocado and Lemon Type Curve
Nursery Type Curve

Figure 35

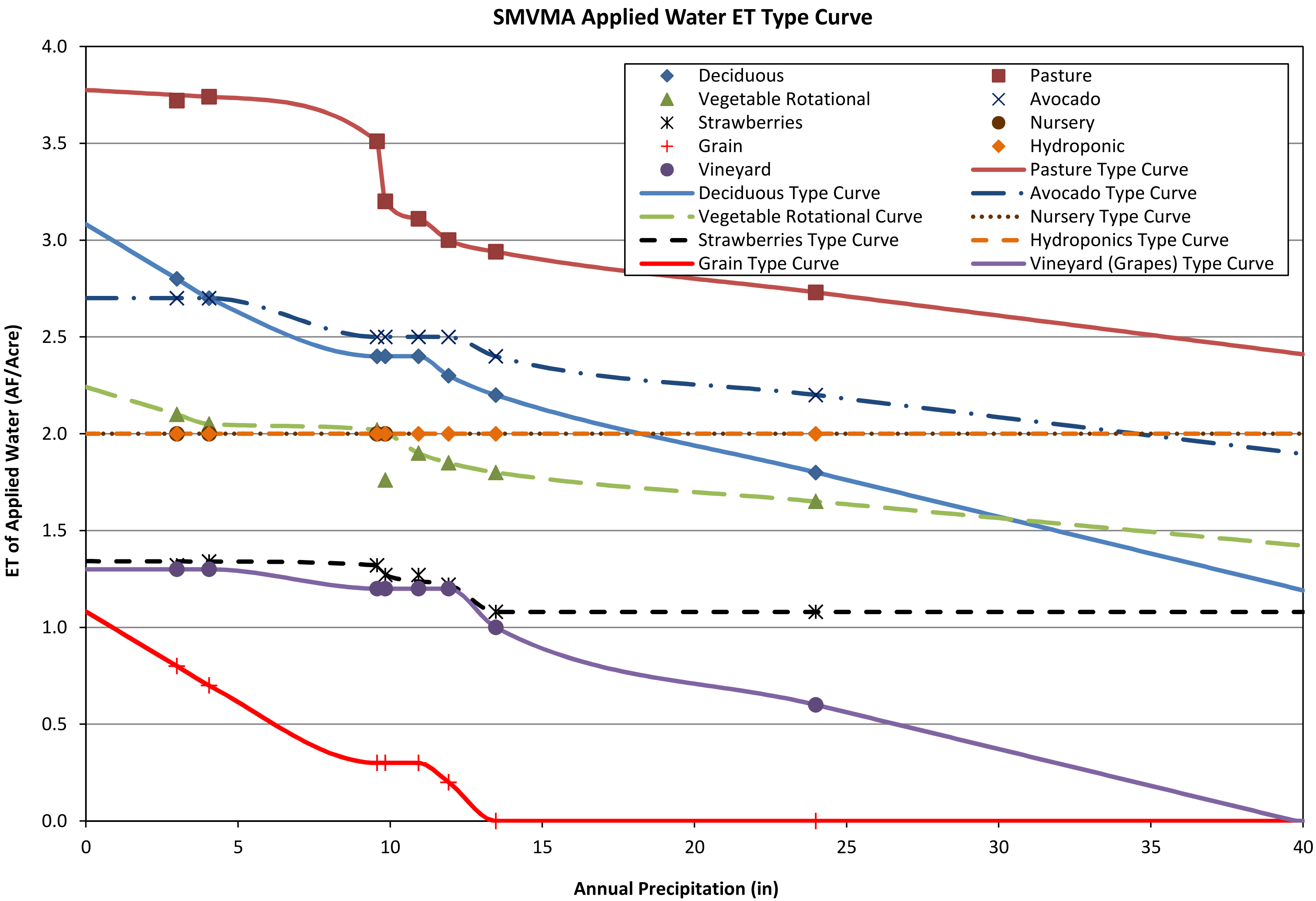

SMVMA Applied Water ET Type Curve
ET of Applied Water (AF/Acre)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
Annual Precipitation (in)
Deciduous
Pasture
Vegetable Rotational
Avocado
Strawberries
Nursery
Grain
Hydroponic
Vineyard
Pasture Type Curve
Deciduous Type Curve
Avocado Type Curve
Vegetable Rotational Curve
Nursery Type Curve
Strawberries Type Curve
Hydroponics Type Curve
Grain Type Curve
Vineyard (Grapes) Type Curve

Figure 36

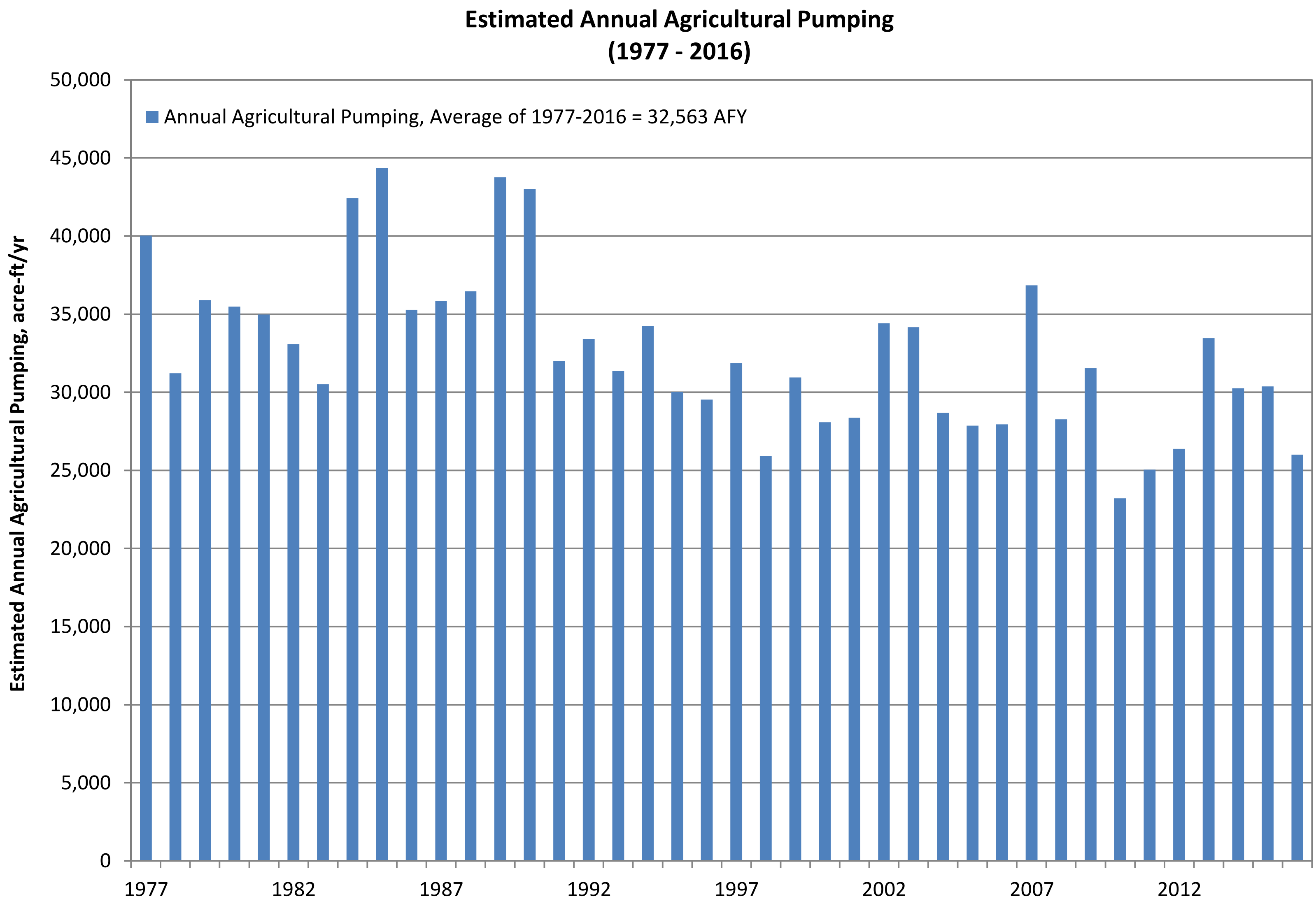
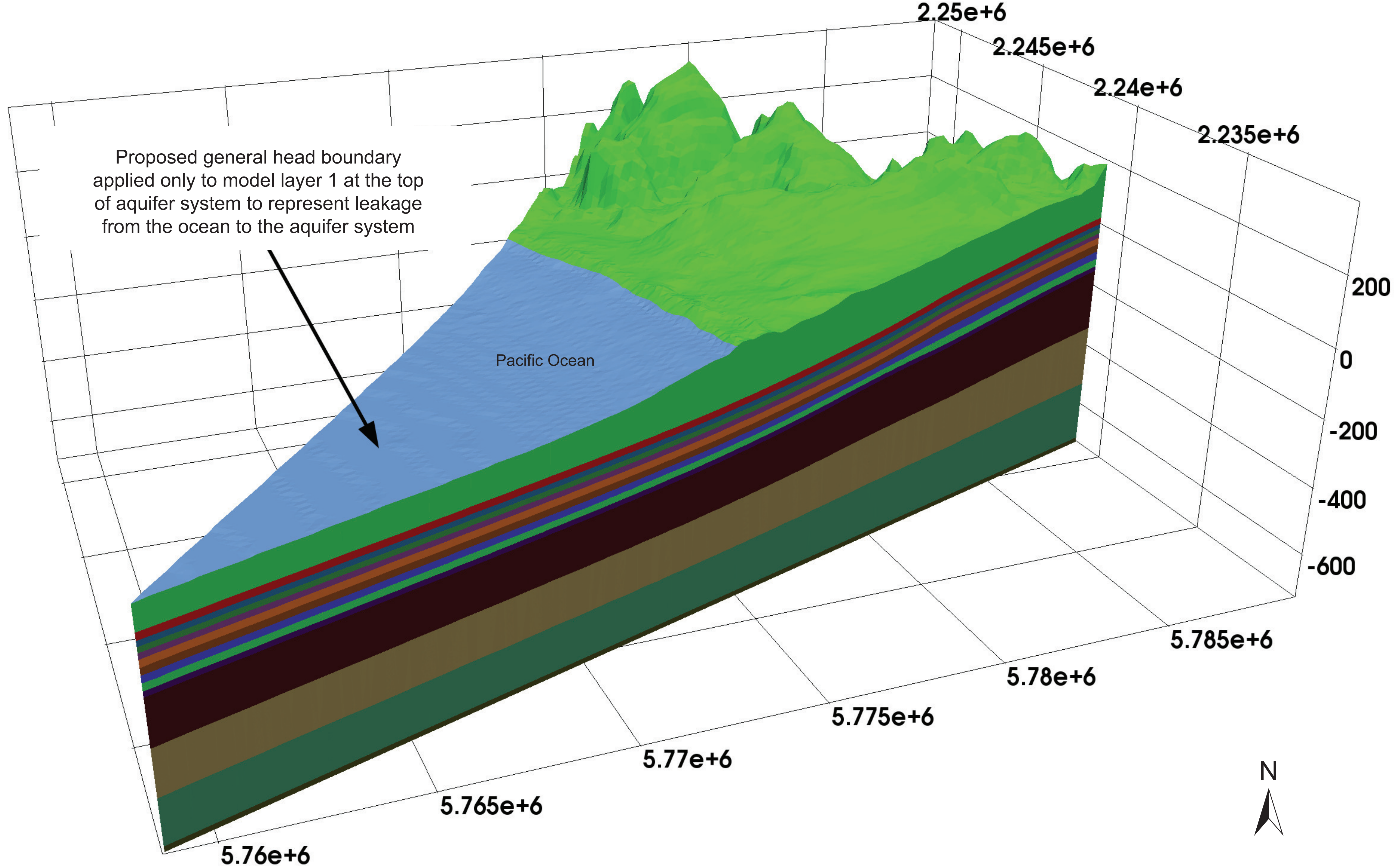

Estimated Annual Agricultural Pumping
(1977 - 2016)
Annual Agricultural Pumping, Average of 1977-2016 = 32,563 AFY
Estimated Annual Agricultural Pumping, acre-ft/yr
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1977
1982
1987
1992
1997
2002
2007
2012

Figure 37



EXPLANATION

BOUNDARY CONDITION AT THE OCEAN

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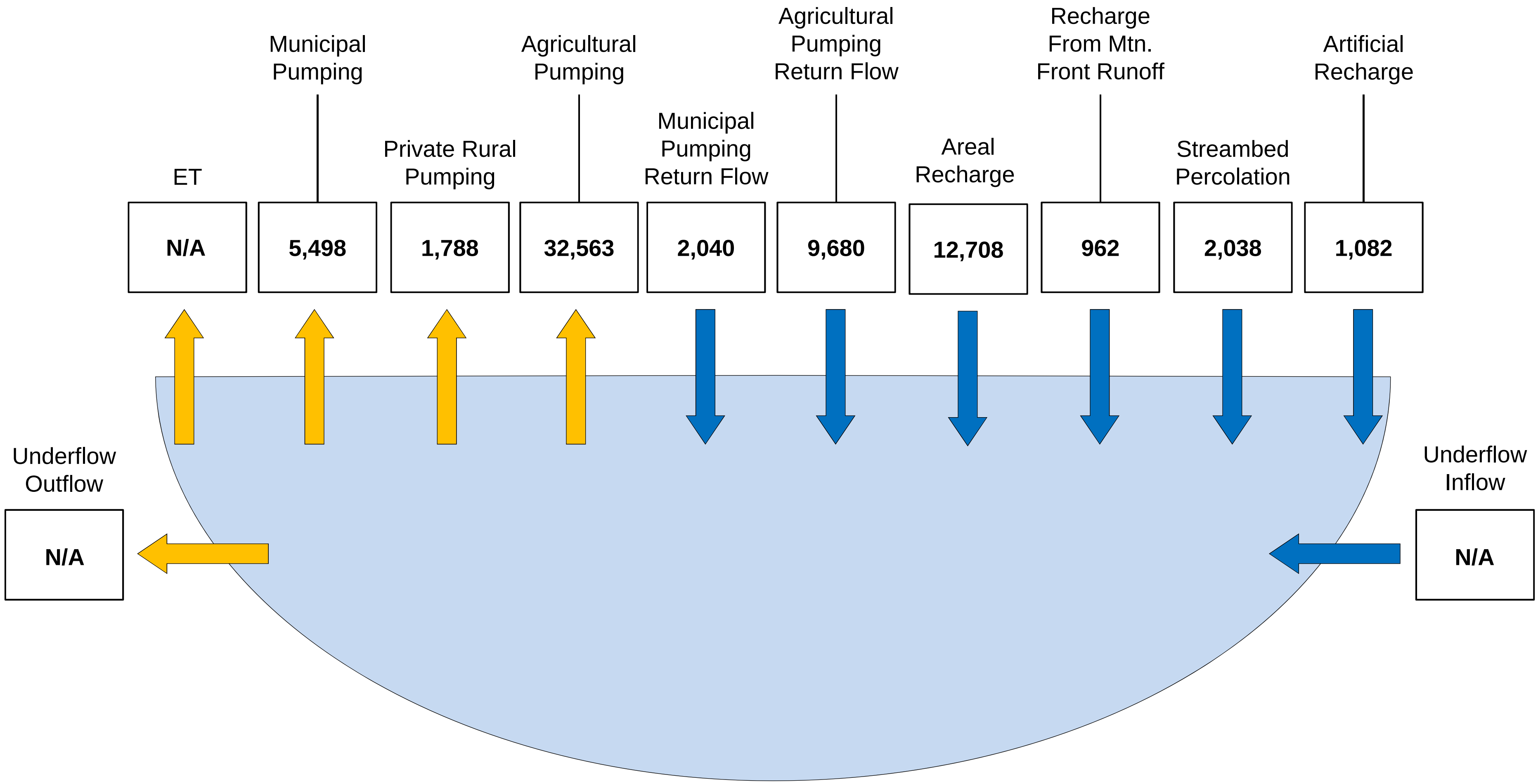
15-Jun-18



N/A = No previous estimates available. Will be calculated by the calibrated model
All values in acre-ft/yr

AVERAGE ANNUAL GROUNDWATER BUDGETS PHASE 1B MODEL ACTIVE AREA (1977-2016)

X:\Projects\WSC\Phase_1B\TMs\4) TM No. 1 Conceptual Model\Figures\Figure_40_20180207.pptx Drawn By: EL

15-Jun-18

GEOSCIENCE

GEOSCIENCE Support Services, Inc., **Ground Water Resources Development**
P.O. Box 220, Claremont, CA 91711 | P (909) 451-6650 | F (909) 451-6638 | www.gssiwater.com

City of Pismo Beach and South San Luis Obispo County Sanitation District Regional Groundwater Sustainability Project Phase 1B Hydrogeologic Evaluation

Technical Memorandum No. 2: Calibration Plan

Prepared for:
Water Systems Consulting, Inc.

June 15, 2018

GEOSCIENCE Support Services, Inc., **Ground Water Resources Development**
P.O. Box 220, Claremont, CA 91711 | P (909) 451-6650 | F (909) 451-6638 | www.gssiwater.com

CITY OF PISMO BEACH AND SOUTH SAN LUIS OBISPO COUNTY SANITATION DISTRICT
REGIONAL GROUNDWATER SUSTAINABILITY PROJECT
PHASE 1B HYDROGEOLOGIC EVALUATION

TECHNICAL MEMORANDUM NO. 2: CALIBRATION PLAN

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FIGURES and TABLES

FIGURES

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CITY OF PISMO BEACH AND SOUTH SAN LUIS OBISPO COUNTY SANITATION DISTRICT
REGIONAL GROUNDWATER SUSTAINABILITY PROJECT
PHASE 1B HYDROGEOLOGIC EVALUATION

TECHNICAL MEMORANDUM NO. 2: CALIBRATION PLAN

1.0 INTRODUCTION

The Santa Maria Groundwater Basin is facing various management challenges related to water supply sustainability and the threat of seawater intrusion. The Regional Groundwater Sustainability Project (RGSP) is a regional recycled water project that will address some of these challenges by reducing the risk of seawater intrusion and improving water supply sustainability. As part of the Phase 1B Hydrogeologic Evaluation, GEOSCIENCE Support Services, Inc. (GEOSCIENCE) has been tasked with expanding the existing RGSP Phase 1A Model to include an evaluation of injection and extraction scenarios with flows from the South San Luis Obispo County Sanitation District (SSLOCSD) and City of Pismo Beach wastewater treatment plants (WWTPs). This technical memorandum (TM) presents a summary of the anticipated calibration objectives, approach, and procedures for the RGSP Phase 1B groundwater model. Comments on the draft TM No. 2 were received from the Northern Cities Management Area (NCMA) Technical Group (through GSI Water Solutions, Inc.) and the TM was modified to address these comments. Specific responses to these comments are provided in Attachment A).

1.1 Flow and Solute Transport Model Calibration Objectives

The objectives of the model calibration process are to ensure that the calibrated flow and solute model provides satisfactory agreement between model results and the hydrologic conditions observed in the Project area, and that the model will be capable of producing reliable predictive results for use in the support of groundwater management and water quality remediation programs.

1.2 Flow and Solute Transport Model Calibration Approach

The calibration process involves the “history matching” approach whereby model parameters are adjusted within allowable limits until the model provides a reasonable match between simulated and measured values of groundwater elevation. The calibration process will be conducted in general accordance of the guidelines documented in “Standard Guide for Comparing Ground-Water Flow Model

Simulations to Site-Specific Information" (ASTM, 1993), "Standard Guide for Calibrating a Ground-Water Flow Model Application" (ASTM, 2002) and "Guidelines for Evaluating Ground-Water Flow Models" (Reilly and Harbaugh, 2004), and will focus on areas of key groundwater management. These areas include the NCMA and the potential injection well locations.

1.3 Background of Existing Groundwater Models

Three main groundwater models were developed in the Project area over the last few years. The Santa Maria Valley Groundwater Basin Model developed by Luhdorff & Scalmanini, Consulting Engineers (LSCE, 2000) covers the entire Santa Maria Valley Management Area (SMVMA) and part of the Nipomo Mesa Management Area (NMMA). It was calibrated from Fall 1944 to Spring 1997 with 6-month stress periods and consisted of six model layers with a uniform cell size of 2,000 ft by 2,000 ft. The remaining models are centered around the NCMA: the NCMA Groundwater Model (Wallace, 2016) and the RGSP Phase 1A Model (CHG, 2017). The NCMA Groundwater Model has three model layers and a cell size of 127 ft by 127 ft. It included both a steady state and a transient calibration period and was calibrated from 1986 to 2004 with a monthly stress period. The Phase 1A Model is the most recent model and also the most discretized, with a cell size of 200 ft by 200 ft and 13 model layers. The model extent is shown on Figure 1. It was calibrated from Spring 2005 to Fall 2015 with 6-month stress periods. All three models were purely groundwater flow models and did not contain a solute transport model component.

2.0 MODEL EXPANSION AND GRID REFINEMENT

The RGSP Phase 1B Model represents an expansion of the Phase 1A Model, and covers the entire NCMA and NMMA, and part of SMVMA (Figure 1). For the Phase 1B Model, the cell size was refined to 100 ft by 100 ft with ten model layers. The finer grid will improve injection well siting. The calibration period was also expanded to cover the period from January 1977 through December 2016 with a monthly stress period. This longer period covers more cycles of wet and dry hydrologic conditions. Model layers were derived mainly from a lithological model constructed by GEOSCIENCE and previous cross-sections from the Santa Maria Basin Characterization (SMBC) study (FUGRO, 2015) and the California Department of Water Resources (DWR, 2002). Priority was given to the definition of the aquitards and aquifers at the coast where confinement is more continuous and the threat of seawater intrusion requires more detailed layer definition.

The model code used for the RGSP Phase 1B Model will be SEAWAT, which was developed by the U.S. Geological Survey (USGS; Guo and Langevin, 2002). The packages expected to be used beyond the basic MODFLOW packages include Evapotranspiration (EVT), Streamflow Routing (SFR), Recharge (RCH), Horizontal Flow Barrier (HFB), Multi-Node Well (MNW), Well (WEL), and the General Head Boundary (GHB). MODPATH software will be used to compute three-dimensional (3-D) flow paths (i.e., particle tracking) and calculate retention times of recycled water for nearby production wells.

2.1 Model Layers

Ten model layers were defined for the following hydrostratigraphic units:

- Layer 1 – Ocean floor (allows for vertical leakage from the ocean to the underlying aquifer (i.e., model layer 2))
- Layer 2 – Recent alluvium/old dune sand
- Layers 3 through 7 – Paso Robles Formation
- Layers 8 through 10 – Careaga Sand

2.2 Locations of Groundwater Barriers

In the existing models, groundwater barriers were not represented either because not enough information was available to characterize the faults (location and impact on flow) or because they covered an area where the potential barriers (faults) were not present. The RGSP Phase 1B Model will incorporate a horizontal flow barrier along the Santa Maria Fault (Figure 2).

2.3 Aquifer Hydraulic Parameters

Model aquifer parameters include horizontal hydraulic conductivity, vertical hydraulic conductivity, and storativity. The hydraulic conductivity will initially be developed using data from the lithologic model and pumping tests. These initial values will then be adjusted during model calibration. The horizontal hydraulic conductivity for each model cell of layer "K" ($K_{i,j,k}$) will be calculated using the following equation:

$$K_{i,j,k} = K_{avei,j,k} \ x \ K_{adjhi,j,k} \ x \ K_{adjvi,j,k}$$

Where:

- $K_{i,j,k}$ = Horizontal hydraulic conductivity for model cell i,j of layer k, ft/day;
- $K_{avei,j,k}$ = Weighted average horizontal hydraulic conductivity for model cell i,j of layer k calculated based on the lithologic types and thickness from the lithologic model, ft/day;
- $K_{adjhi,j,k}$ = Adjusted factor for model cell i,j of layer k to represent the sorting and facies of the lithologic sediments; and
- $K_{adjvi,j,k}$ = Adjusted factor for model cell i,j of layer k to account for the decrease in hydraulic conductivity with depth.

$K_{adjhi,j,k}$ will be obtained from the lithologic model and will be adjusted during model calibration. $K_{adjvi,j,k}$ will be assigned an initial value of "1" and will then also be adjusted during model calibration. GEOSCIENCE will ultimately use professional judgment to make the final adjustments to the spatial variation of depositional facies. The following describes the approach that will be used to estimate $K_{avei,j,k}$.

2.3.1 Calculate Hydraulic Conductivity based on Lithologic Types

Hydraulic conductivities derived from pumping tests and specific capacities were obtained from the SMBC (FUGRO, 2015; see Figures 3 and 4, respectively). Therefore, the first step to estimating the weighted average horizontal hydraulic conductivity for each model cell is to calculate the average horizontal hydraulic conductivity for well screen interval(s) based on lithologic types. The original borehole lithological logs were evaluated to establish 15 lithologic types. A set of hydraulic conductivity values (K_m = K_1, K_2,…K_{15}) were assigned to each lithologic type. Physical descriptions and probable ranges of hydraulic conductivity values for the 15 lithologic types are listed in Table 1.

For each well, the hydraulic conductivity of the screened interval based on lithologic type (K_L), in ft/day, can be calculated from:

$$K_L = \frac{K_1 b_1 + K_2 b_2 + \cdots + K_{15} b_{15}}{b_1 + b_2 + \cdots + b_{15}}$$

Where:

K_m = hydraulic conductivity assigned to lithologic type m, in ft/day; and
b_m = the total thickness of lithologic type m, in ft, ($b_1 + b_2 + \ldots + b_{15}$ = total screened interval).

2.3.2 Determine an Average K_m Value for each Lithologic Type ($K_{m,ave}$)

For each well, the assigned K_m values will be adjusted so that the calculated K_L would approximate the hydraulic conductivity value derived from the pumping tests and specific capacity for that well (K_P). This establishes a narrower range of K_m values for each lithologic type. An example linear correlation between K_L and K_P is shown on Figure 5. This correlation has an R^2 (goodness-of-fit) of 0.86, indicating a relatively good correlation between the K_L and K_P. The average hydraulic conductivity ($K_{m,ave}$) and associated standard deviation for each lithologic type are shown on Figure 6 for this example.

2.3.3 Calculate $K_{avei,j,k}$

Following the calculation of average hydraulic conductivity for each lithologic type, the weighted average horizontal hydraulic conductivity for each model cell of each model layer ($K_{avei,j,k}$) will be calculated using the following equation:

$$K_{avei,j,k} = \frac{K_{1,ave} b_{1i,j,k} + K_{2,ave} b_{2i,j,k} + \cdots + K_{15,ave} b_{15i,j,k}}{b_{1i,j,k} + b_{2i,j,k} + \cdots + b_{15i,j,k}}$$

Where:

$K_{avei,j,k}$ = Weighted average horizontal hydraulic conductivity for model cell i,j of layer k, ft/day;
$K_{m,ave}$ = Average horizontal hydraulic conductivity for lithologic type m, ft/day; and
b_m = Total thickness of lithologic type m for model cell i,j of layer k, ft.

2.4 Model Recharge and Discharge Terms

The recharge and discharge terms of the RGSP Phase 1B Model will be based on TM No.1 : Conceptual Model (GEOSCIENCE, 2018), in which the water budget terms and their preliminary estimates are outlined.

3.0 MODEL CALIBRATION

3.1 Calibration Approach

Calibration is the process of adjusting the model parameters to produce the best-fit between simulated and observed groundwater system responses. During the process of calibration, model parameters are adjusted using reasonable anticipated values until model-generated water levels and concentrations match historical observations. Parameters to potentially be adjusted are: horizontal and vertical hydraulic conductivity, storativity, streambed conductance, dispersivity, effective porosity, and fault conductance.

The RGSP Phase 1B Model calibration will consist of:

- Steady-state flow calibration (1977), and
- Transient flow and solute calibration from 1977 through 2016 using monthly stress periods.

3.2 Steady-State Flow Calibration (1977)

The goals of steady-state calibration will be to model the overall water balance and an acceptable water level distribution based on observed water levels. The initial calibration will be conducted under 1977 steady-state conditions using a trial-and-error approach as described by Danskin and others (2005). The calibration process may be assisted with a parameter estimation program, such as PEST.

Model-generated water levels will be prepared and compared to measured levels in the calibration target wells. A scatter plot of modeled versus observed water levels will be generated, displaying calibration statistics such as mean residual, maximum residual, minimum residual, standard deviation and relative error. A histogram of water level residuals (i.e., measured levels less model-generated levels) will also be prepared.

In general, steady-state model calibration is acceptable with a relative error (the standard deviation of the groundwater level residuals[1] divided by the observed head range) of 10% (Zheng and Bennett, 2002). The model performance in key areas of groundwater management will also be assessed independently of the overall model performance. If the calibration goals are achieved, then the steady-state water levels will be used as initial water levels for the transient model run.

---

1 "Residual" = measured – modeled

3.3 Transient Flow and Solute Transport Calibration (1977 - 2016)

The transient calibration goals will be to model the overall water balance and an acceptable distribution of head and total dissolved solids (TDS) concentrations based on observed data. The transient model calibration will be performed from 1977 through 2016 using a monthly stress period to provide a reasonable match between the simulated and measured values of groundwater elevation and TDS concentrations. Similar to the steady-state calibration, a trial-and-error method will be used, which may be assisted by a parameter estimation program such as PEST.

Hydrographs and chemographs of model-generated water levels and TDS concentrations will be prepared and used for the comparison of measured levels in calibration target wells. The agreement between model-generated water levels and TDS concentrations and measured water levels and concentrations will be used to provide a graphical representation of the calibration results. Scatter plots of modeled versus observed water levels and concentrations will be generated, displaying calibration statistics such as mean residual, maximum residual, minimum residual, standard deviation, and relative error. A histogram of water level and TDS concentration residuals (i.e., measured levels less model-generated levels) will also be prepared.

Transient model calibration will also be considered acceptable if the relative error is less than 10%. The model performance in key areas of groundwater management will be assessed independently of the overall model performance to ensure quality simulation in areas of Project importance (e.g., NCMA and potential injection well locations).

4.0 CALIBRATION TARGETS

A model calibration target consists of measured groundwater elevations or groundwater quality concentrations at specific well locations. The calibration target set to be used for the flow and solute transport calibration contains a representative distribution of wells in the study area. A preliminary set of calibration targets is summarized in Tables 2 and 3 and are shown on Figures 7 and 8 for water levels and TDS, respectively. Wells in the calibration set have acceptable water level and well construction data. Observed streamflow at the 22nd Street Bridge gage will also be used for flow calibration (Figure 9).

It is anticipated that all targets will be used for the groundwater flow and solute transport model calibration. However, some targets may be removed due to the close proximity of other targets with better well construction details or more comprehensive water level datasets. Wells may also be removed from the target set due to the close proximity of poorly understood fluxes – usually near a boundary condition of the model (e.g., well located next to a fault). If, during calibration, a well shows continued deviation from the model results and shows anomalous groundwater elevation values relative to other nearby wells, it may also be removed from the calibration process. All wells removed from the calibration process will be documented with the reason(s) for the exclusion noted.

5.0 SENSITIVITY ANALYSIS

The purpose of a sensitivity analysis is to assess which input parameters have the greatest effects on a model's simulation results. To assess the sensitivity of model results to individual model input parameters, each parameter will be varied separately while the others remain constant. Parameters to be varied for the model sensitivity analysis are:

- Return flow,
- Areal recharge from precipitation,
- Agricultural pumping,
- Horizontal hydraulic conductivity,
- Vertical hydraulic conductivity,
- Primary and secondary storage coefficients,
- General head boundary conductance,
- Hydraulic characteristic values of the HFBs,
- Streambed conductance,
- Dispersivity, and
- Effective porosity.

6.0 CALIBRATION REPORTING

The results of the model development, calibration, and sensitivity analysis will be submitted to the technical advisory committee (TAC) for review. All comments and resolutions will be documented.

Model calibration results will be expressed both quantitatively and qualitatively. Quantitative techniques to evaluate the calibration results include calculating potentiometric head, streamflow, and concentration residuals (using residual statistics such as maximum and minimum residual, residual mean, weighted residuals, and second order statistics), assessing correlation among residuals (e.g., listings, scattergrams, spatial correlation plots, temporal correlation, etc.), and calculating groundwater flow residuals (e.g., water budget and mass balance, vertical gradients, and groundwater flow paths). Qualitative considerations during calibration will include an assessment of general flow features, comparison with distinct and similar hydrologic conditions, and input hydraulic properties. The calibration results will be summarized in the form of maps, figures, and tables, and will include both regional and zonal statistics for the individual management areas.

A water balance analysis over the model calibration period will also be included in the report. Each flux term (i.e., recharge and discharge) and change in storage for the Phase 1B Model area will be quantified. In addition, model-calculated underflow will be summarized.

7.0 REFERENCES

ASTM, 1993, Standard Guide for Comparing Ground-Water Flow Model Simulations to Site Specific Information, American Society for Testing and Materials, D 54490-93, 5 p.

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Wallace, B.M., 2016. NCMA Groundwater Model Using USGS MODFLOW-2005/PEST. Master Thesis Presented to the Faculty of California Polytechnic State University, San Luis Obispo.

Zheng, C. and Bennett, G.D., 2002. Applied Contaminant Transport Modeling, Second Edition.

ATTACHMENT A: RESPONSES TO COMMENTS FROM GSI

Comments from GSI	GEOSCIENCE Response
A-1. Page 3, Section 2.0. It is stated that the calibration period will cover the 40-year period from 1977-2016, with monthly stress periods. Are there any wells that offer existing data on a monthly time step (water level or water quality)? If not, I don't understand what is gained by having a monthly time step in calibration.	Water levels are not always provided as monthly readings. However, critical inputs to the model like groundwater pumping, recharge, and river infiltration are typically monthly or daily. In addition, a fair amount of quarterly and monthly water levels are available.
A-2. Page 6, Section 3.2. Is it reasonable to generate a steady-state model in a time period when there is already significant pumping stresses to the system? I understand that the primary purpose of this steady-state simulation is simply to generate reasonable initial heads for the transient calibration period. However, personally, I have had problems in the past trying to initiate steady-state runs at a time when significant water level declines have already occurred, and have had to revert to a more traditional approach where pre-development conditions are simulated in the steady-state model, and use large (decade plus) time steps to condition the model to be stable at the time I wanted my "real" transient calibration to occur. I will be interested in hearing about your experience.	The steady state calibration here is primarily conducted for the purpose of establishing initial head for the transient calibration. Starting the model with interpolated water levels often results in model instabilities and unrealistic early water levels. In addition, the steady state calibration is a good check of model soundness and how realistic boundaries and water balance terms are.
A-3. Table 2. That is a lot of wells with available calibration data. Although many or most are included in the "monthly transient" category, I wonder again how many of these wells actually have monthly data.	These wells will be further analyzed and QA/QC'd. Only key wells and wells with good quality, long-term good water levels will be used. In addition, wells screened in multiple layers may or may not be used for the model calibration because of the composite nature of water levels in these wells.
A-4. In general this is a sound and well explained plan describing initial parameter estimation, calibration locations, and calibration plan.	Comment noted.

FIGURES

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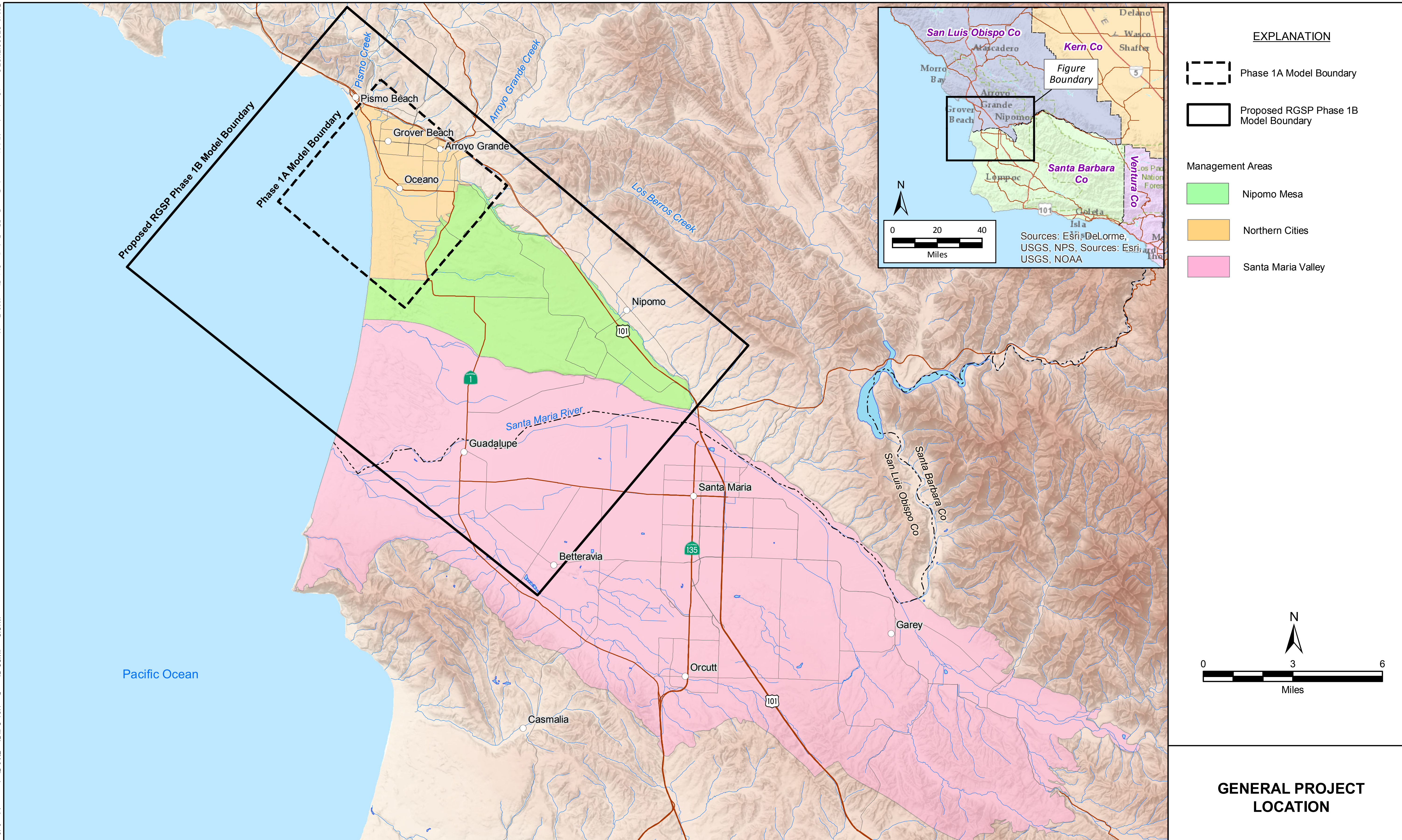

GENERAL PROJECT LOCATION

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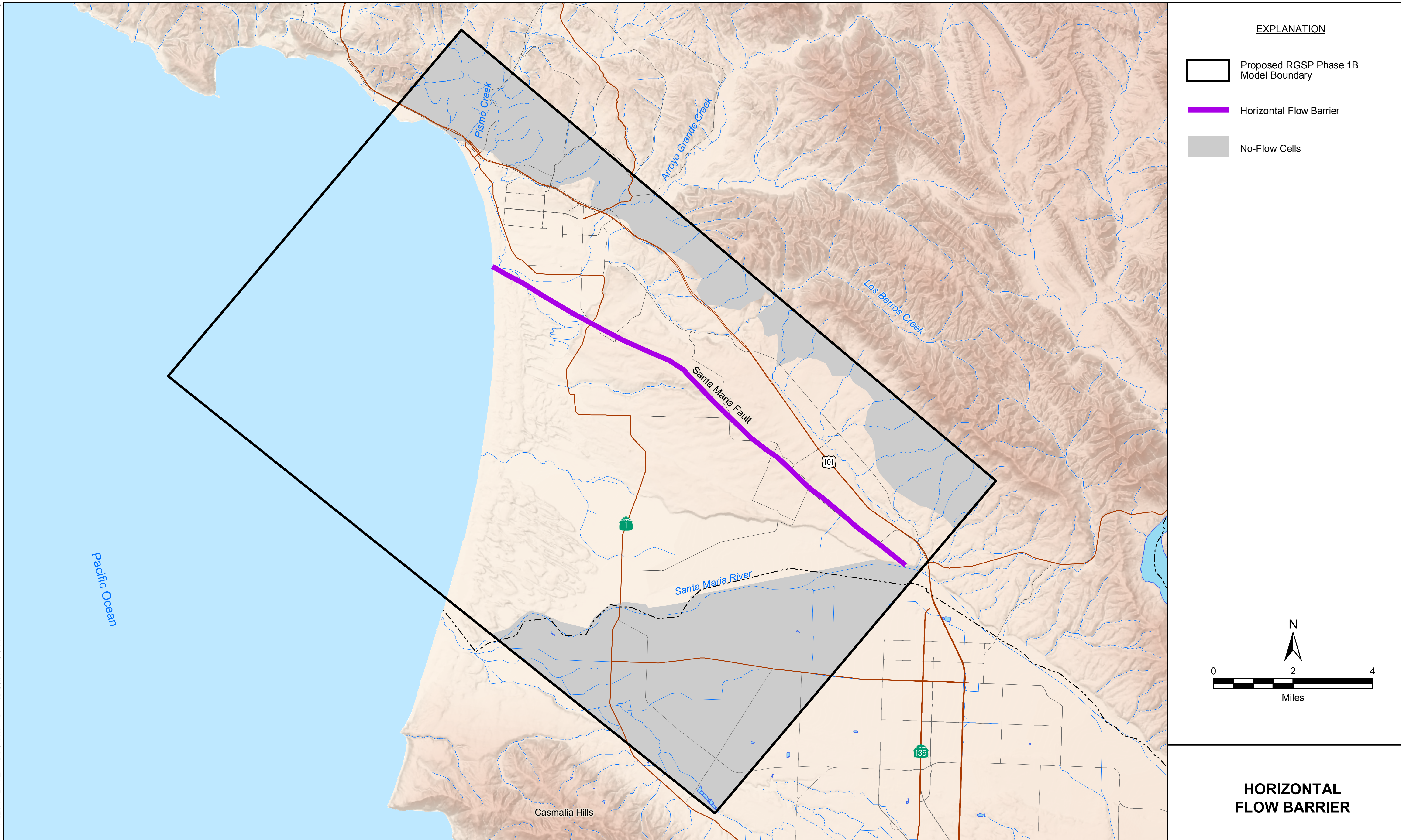

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15-Jun-18

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FIGURE 2

CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 2: CALIBRATION PLAN

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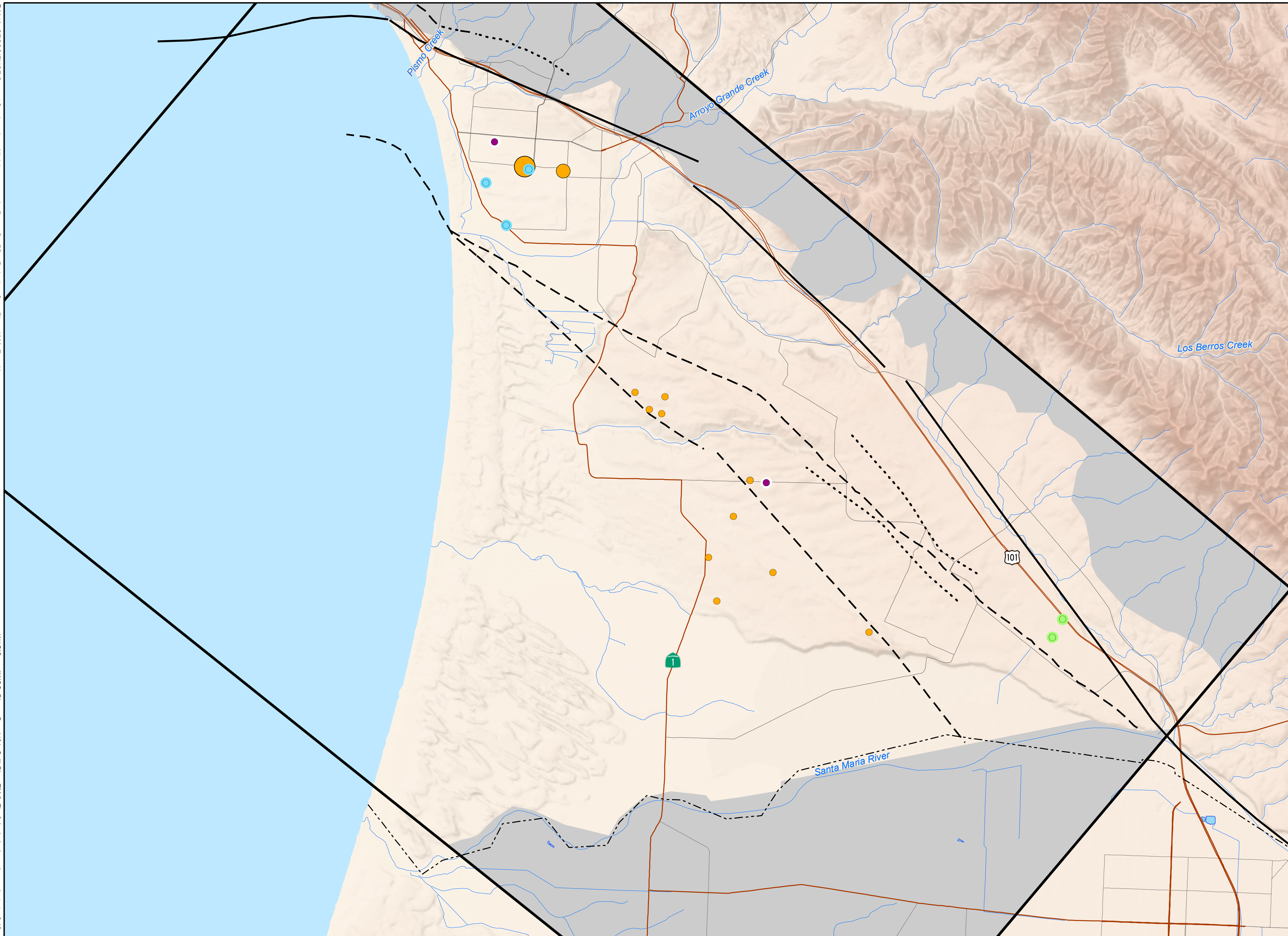

EXPLANATION

Proposed RGSP Phase 1B Model Boundary

No-Flow Cells

Hydraulic Conductivity (ft/day)

- 0 - 50
- 50 - 100
- 100 - 150
- 150 - 200
- 200 - 614

Color Represents Formation Name
- Blue = Careaga Sand
- Green = Dune Sand / Paso Robles
- Orange = Paso Robles
- Purple = Paso Robles / Careaga Sand

Fault - Confirmed

Fault - Approximate

Fault - Concealed

Source of Faults: Fugro, 2015

N

0 1.5 3

Miles

DISTRIBUTION OF HORIZONTAL HYDRAULIC CONDUCTIVITY DERIVED FROM PUMPING TESTS

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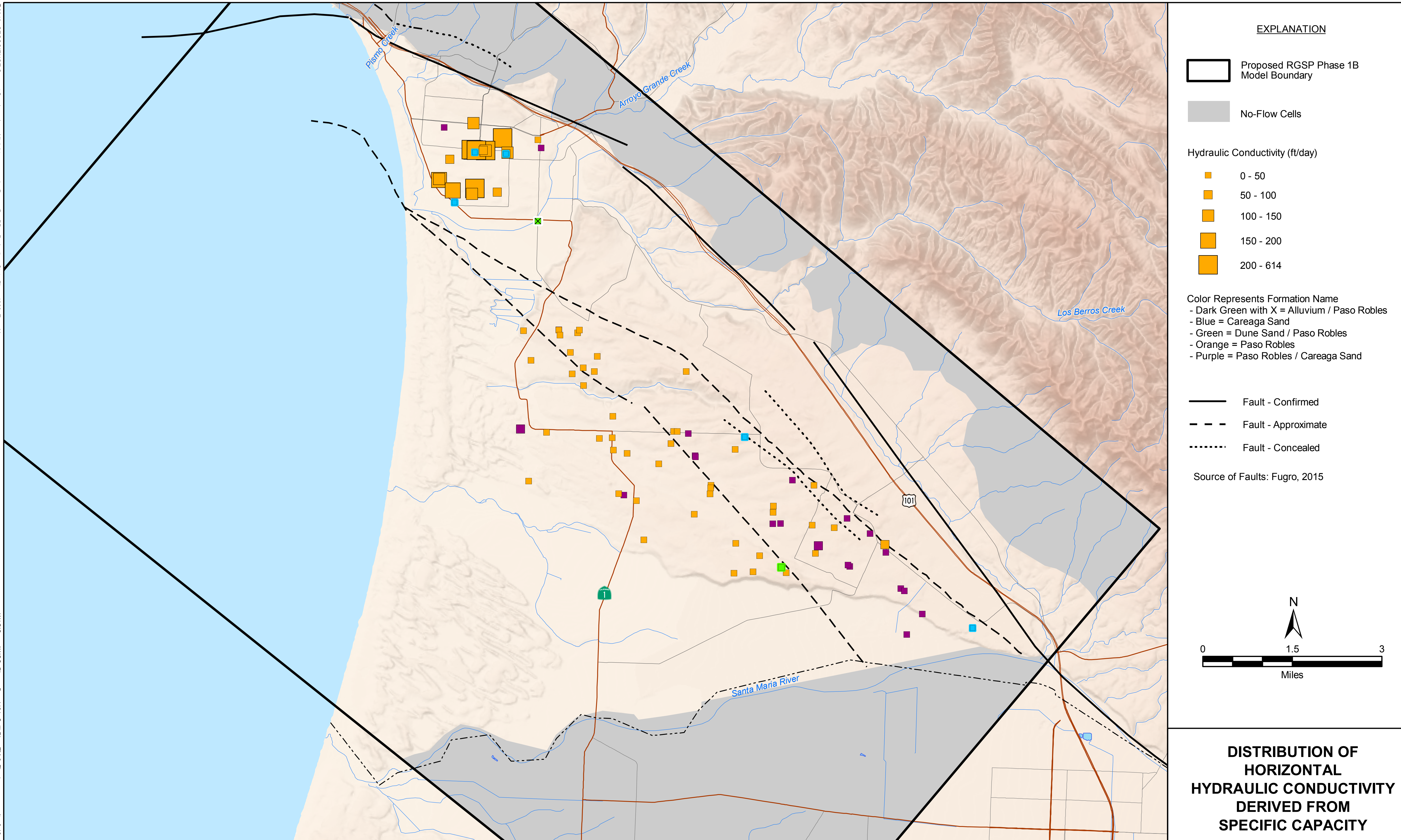
FIGURE 3

CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 2: CALIBRATION PLAN

GEOSCIENCE



DISTRIBUTION OF HORIZONTAL HYDRAULIC CONDUCTIVITY DERIVED FROM SPECIFIC CAPACITY

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FIGURE 4

CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 2: CALIBRATION PLAN

GEOSCIENCE

Example of Hydraulic Conductivity Values Estimated Based on Specific Capacity and Constant Rate Pumping Test Data Versus Estimated Based on Lithologic Types

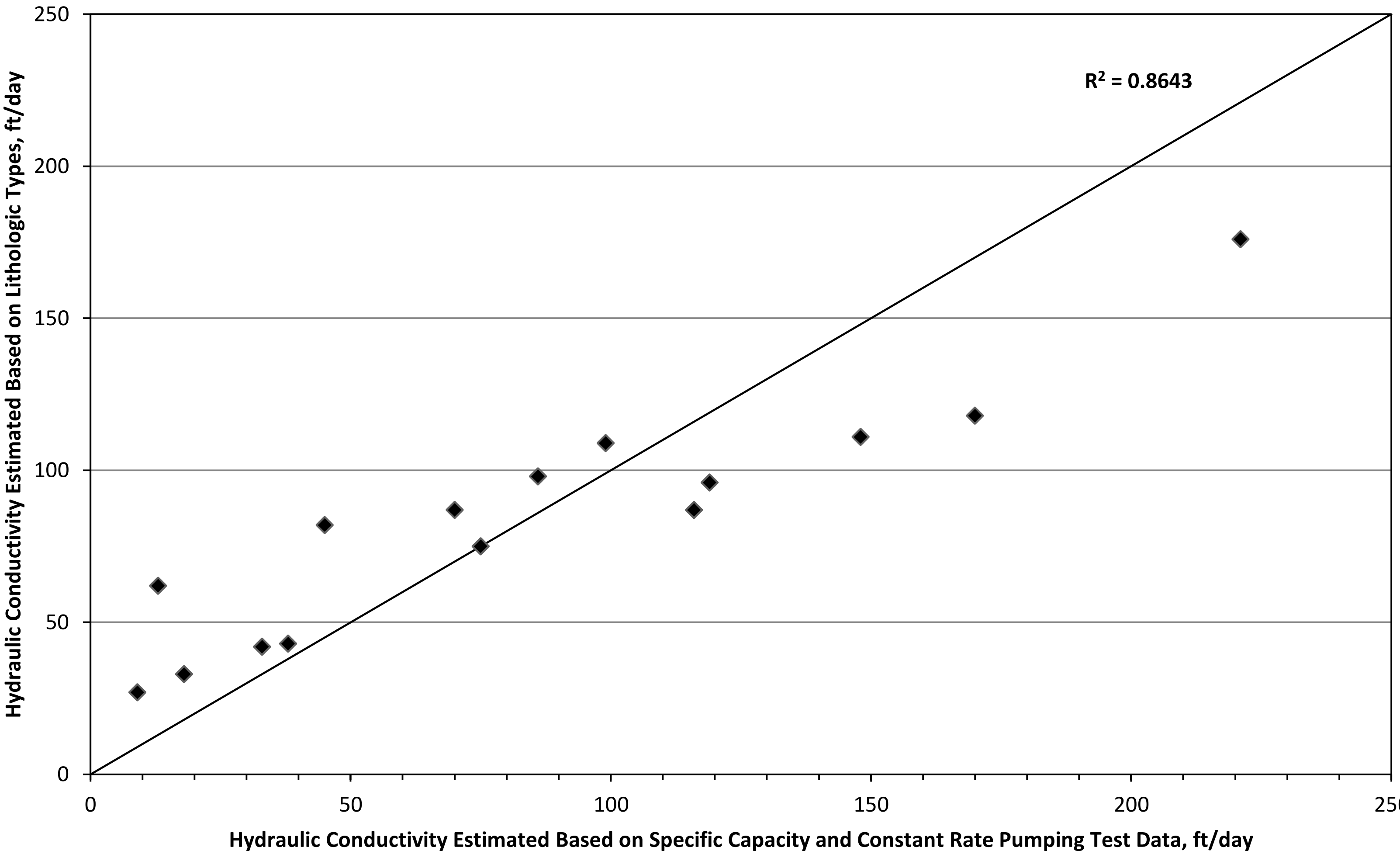
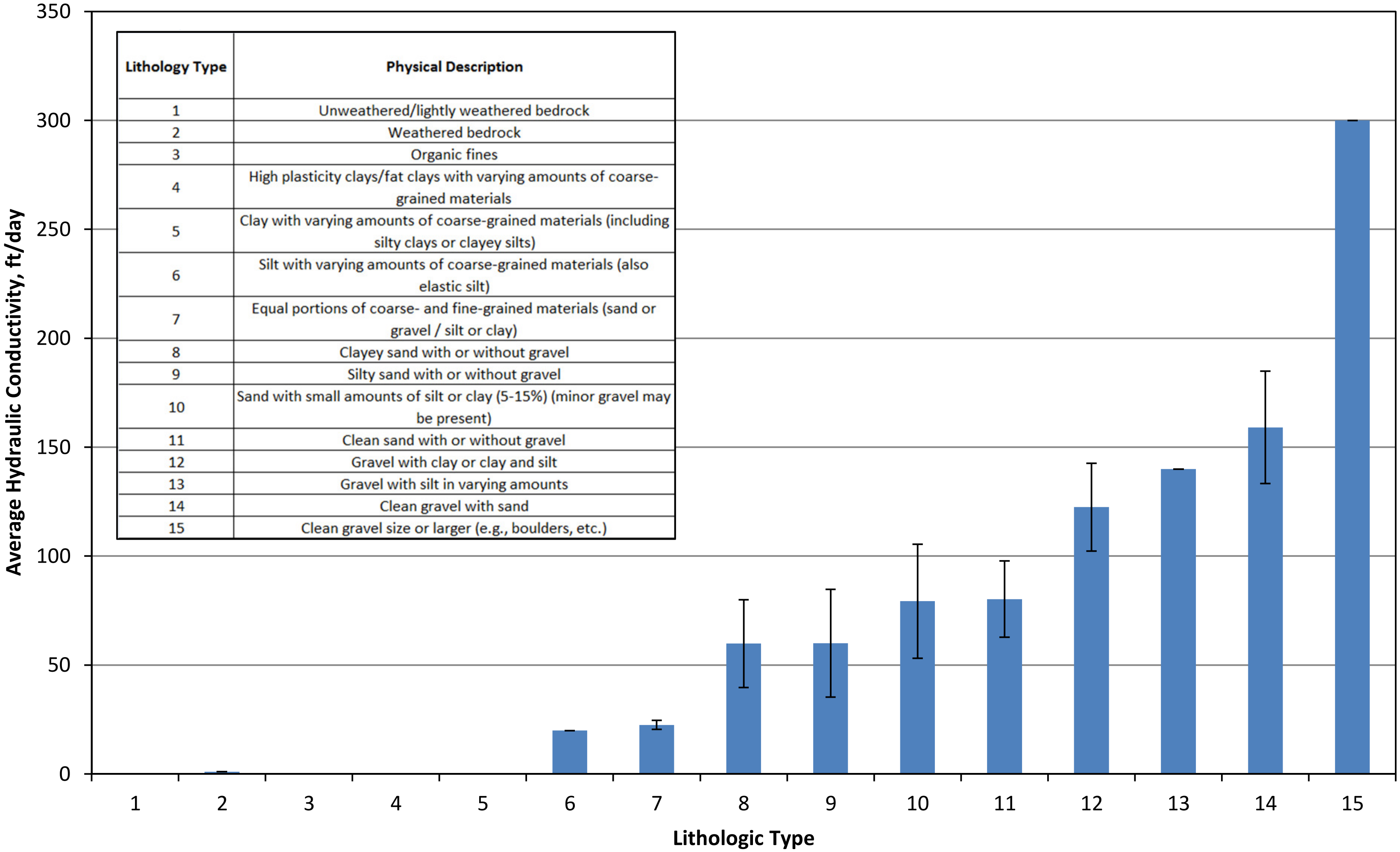


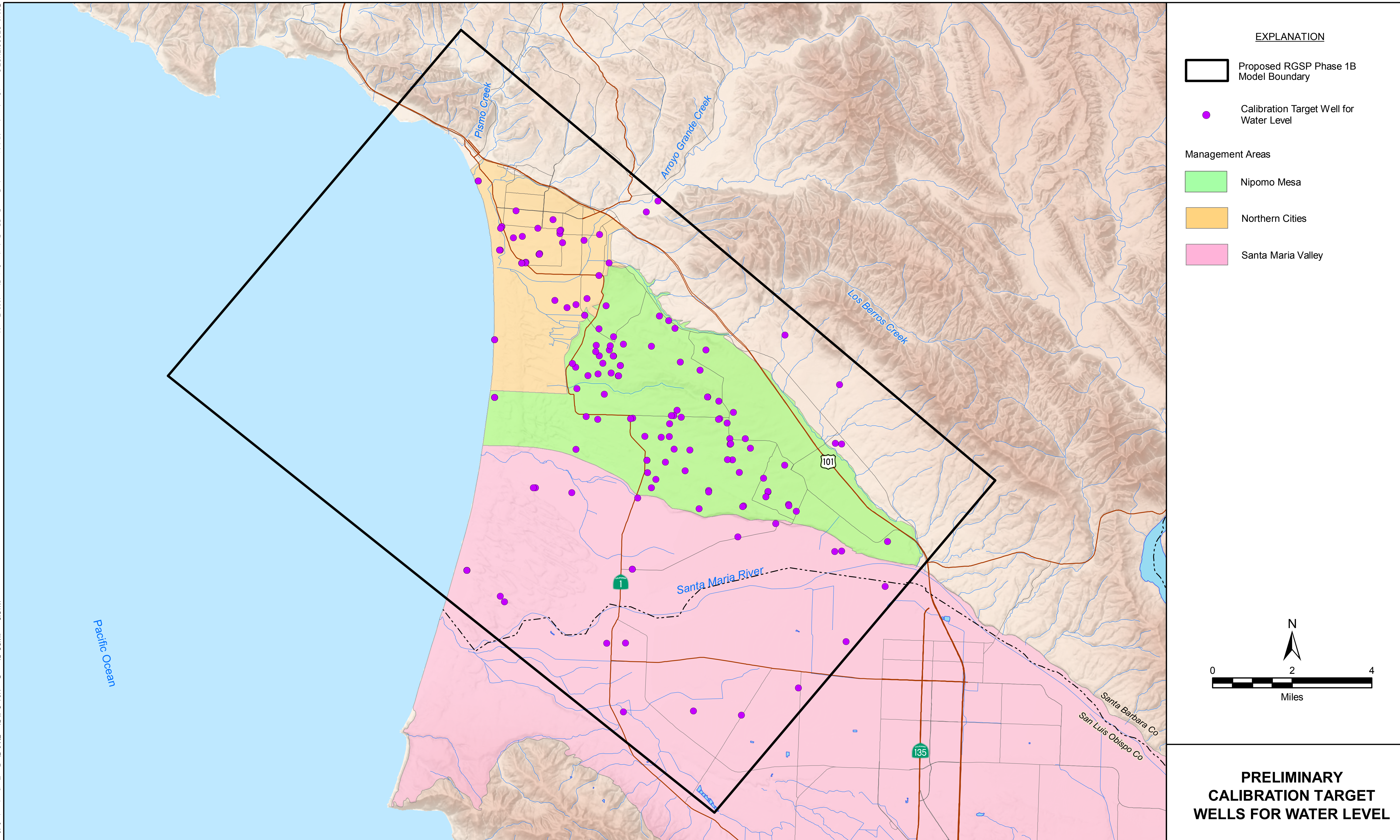
Figure 5

Example of Average Hydraulic Conductivity and Associated Standard Deviation for Lithologic Type (Derived from Specific Capacity and Constant Rate Pumping Test Data)



Lithology Type	Physical Description
1	Unweathered/lightly weathered bedrock
2	Weathered bedrock
3	Organic fines
4	High plasticity clays/fat clays with varying amounts of coarse-grained materials
5	Clay with varying amounts of coarse-grained materials (including silty clays or clayey silts)
6	Silt with varying amounts of coarse-grained materials (also elastic silt)
7	Equal portions of coarse- and fine-grained materials (sand or gravel / silt or clay)
8	Clayey sand with or without gravel
9	Silty sand with or without gravel
10	Sand with small amounts of silt or clay (5-15%) (minor gravel may be present)
11	Clean sand with or without gravel
12	Gravel with clay or clay and silt
13	Gravel with silt in varying amounts
14	Clean gravel with sand
15	Clean gravel size or larger (e.g., boulders, etc.)

Figure 6



PRELIMINARY CALIBRATION TARGET WELLS FOR WATER LEVEL

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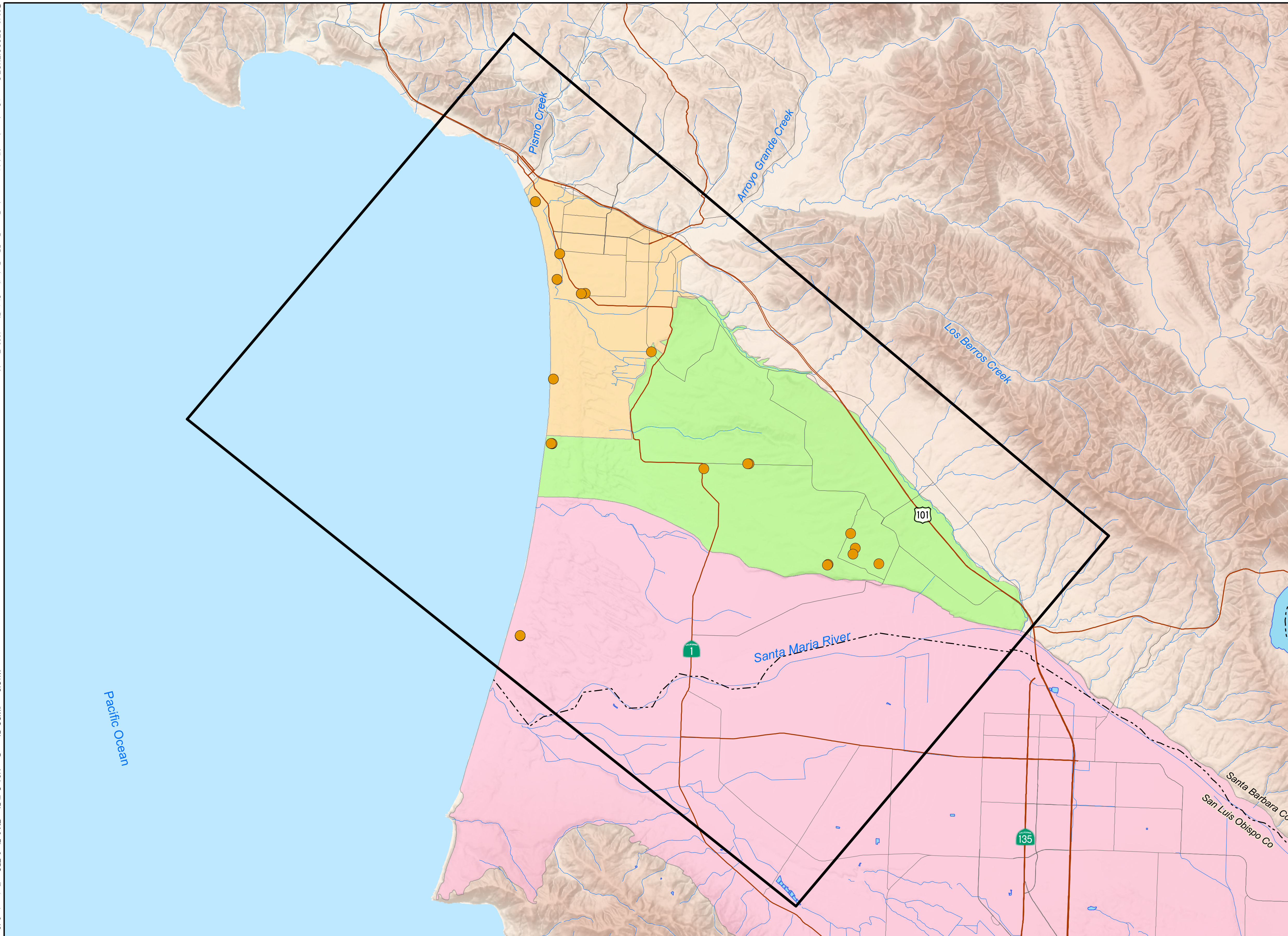
FIGURE 7

CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 2: CALIBRATION PLAN

GEOSCIENCE



PRELIMINARY CALIBRATION TARGET WELLS FOR TDS

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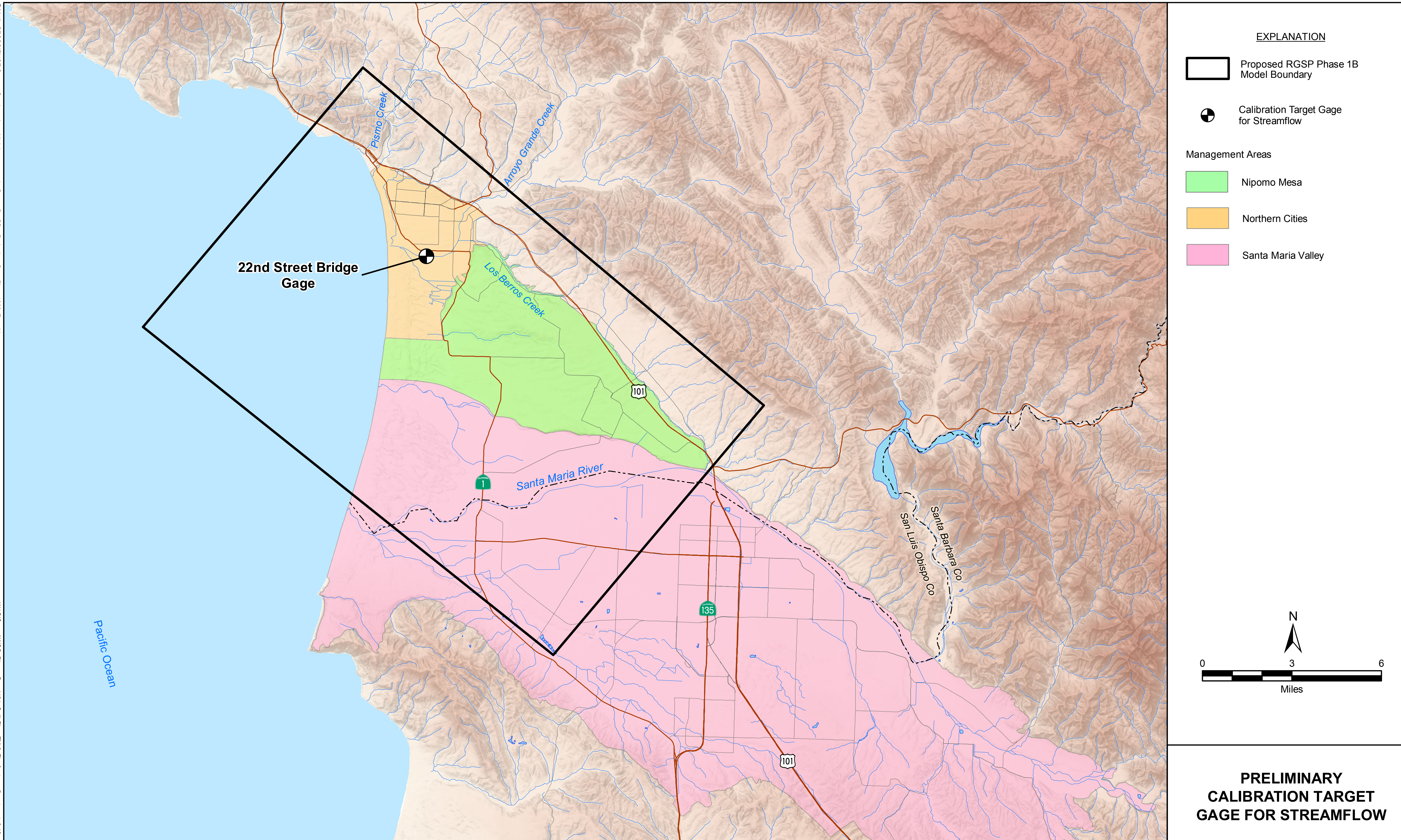
FIGURE 8

CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 2: CALIBRATION PLAN

GEOSCIENCE



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PRELIMINARY CALIBRATION TARGET GAGE FOR STREAMFLOW

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FIGURE 9

CITY OF PISMO BEACH AND SSLOCSD RGSP PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 2: CALIBRATION PLAN

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TABLES

GEOSCIENCE

Ranges of Horizontal Hydraulic Conductivity for Lithologic Types

Lithology Type	Physical Description	Likely Minimum Hydraulic Conductivity [ft/day]	Likely Maximum Hydraulic Conductivity [ft/day]
1	Unweathered/lightly weathered bedrock	1E-08	0.00006
2	Weathered bedrock	1	10
3	Organic fines	1.00E-05	1.00E-04
4	High plasticity clays/fat clays with varying amounts of coarse-grained materials	1.00E-05	1.00E-04
5	Clay with varying amounts of coarse-grained materials (including silty clays or clayey silts)	0.01	1
6	Silt with varying amounts of coarse-grained materials (also elastic silt)	0.1	30
7	Equal portions of coarse- and fine-grained materials (sand or gravel / silt or clay)	0.1	30
8	Clayey sand with or without gravel	3	300
9	Silty sand with or without gravel	3	300
10	Sand with small amounts of silt or clay (5-15%) (minor gravel may be present)	3	300
11	Clean sand with or without gravel	3	300
12	Gravel with clay or clay and silt	3*	300
13	Gravel with silt in varying amounts	3*	300
14	Clean gravel with sand	3*	300
15	Clean gravel size or larger (e.g., boulders, etc.)	300	3,000

Source: Documentation of Spreadsheets for the Analysis of Aquifer-Test and Slug-Test Data by Keith J. Halford and Eve L. Kuniansky U.S. Geological Survey Open-File Report 02-197

* The likely minimum hydraulic conductivity for these gravel types has been reduced by an order of magnitude from the original values to account for the possibility that the drill log description underestimates the amount of mixed fine-grained material in the sample.

Table 1

Preliminary Calibration Target Wells - Water Level

State Well Number / Well Name	Range of Available Water Level Data		Calibration Target Type
09N/32W-07A01	1977	2006	SS / Monthly Transient
09N/32W-16L01	1977	2016	SS / Monthly Transient
09N/32W-19A01	1978	1992	Monthly Transient
09N/32W-23K01	1978	2016	Monthly Transient
09N/33W-05A01	2003	2007	Monthly Transient
09N/33W-06G01	2004	2015	Monthly Transient
09N/33W-14F01	1978	1978	Monthly Transient
09N/33W-24L01	1978	2017	Monthly Transient
09N/34W-03A02	1977	2016	SS / Monthly Transient
09N/34W-03F01	1977	1978	SS / Monthly Transient
09N/34W-09R01	1977	2017	SS / Monthly Transient
09N/34W-15Q01	1977	1986	SS / Monthly Transient
10N/33W-07M01	1978	2017	Monthly Transient
10N/33W-18G01	1977	2012	SS / Monthly Transient
10N/33W-19B01	1977	2017	SS / Monthly Transient
10N/33W-19K01	1977	2017	SS / Monthly Transient
10N/33W-20H01	1977	2016	SS / Monthly Transient
10N/33W-21P01	1981	2017	Monthly Transient
10N/33W-21R01	1977	2017	SS / Monthly Transient
10N/33W-27G01	1977	2017	SS / Monthly Transient
10N/33W-28A01	1977	2017	SS / Monthly Transient
10N/33W-28F01	1978	2007	Monthly Transient
10N/33W-30G01	1977	2017	SS / Monthly Transient
10N/34W-09D01	2003	2017	Monthly Transient
10N/34W-13C01	1977	2017	SS / Monthly Transient
10N/34W-13G01	1977	2014	SS / Monthly Transient
10N/34W-14D01	1983	1985	Monthly Transient
10N/34W-14E04	1977	2017	SS / Monthly Transient
10N/34W-14E05	1991	2008	Monthly Transient
10N/34W-20H03	1978	2017	Monthly Transient
10N/34W-23R02	1989	2005	Monthly Transient
10N/34W-24K01	1977	2017	SS / Monthly Transient
10N/34W-24K03	1977	2017	SS / Monthly Transient
10N/34W-34G02	1977	2017	SS / Monthly Transient
10N/35W-09E05	1977	2014	SS / Monthly Transient

Preliminary Calibration Target Wells - Water Level

State Well Number / Well Name	Range of Available Water Level Data		Calibration Target Type
10N/35W-09F01	1977	2017	SS / Monthly Transient
10N/35W-14P01	1983	2016	Monthly Transient
10N/35W-18F02	1977	2017	SS / Monthly Transient
10N/35W-21B01	1977	2017	SS / Monthly Transient
10N/35W-24B01	1977	2015	SS / Monthly Transient
10N/36W-01B01	1977	2017	SS / Monthly Transient
10N/36W-01H01	1977	2017	SS / Monthly Transient
10N/36W-02Q01	1977	2016	SS / Monthly Transient
10N/36W-02Q03	1977	2016	SS / Monthly Transient
10N/36W-02Q04	1977	2016	SS / Monthly Transient
10N/36W-02Q07	1977	2016	SS / Monthly Transient
11N/34W-05J01	1978	2017	Monthly Transient
11N/34W-17A02	1990	2017	Monthly Transient
11N/34W-17B04	1977	2017	SS / Monthly Transient
11N/34W-18P03	1985	2017	Monthly Transient
11N/34W-19E01	2006	2009	Monthly Transient
11N/34W-19E02	2010	2017	Monthly Transient
11N/34W-19L03	2011	2014	Monthly Transient
11N/34W-19L04	1997	2014	Monthly Transient
11N/34W-19Q01	1977	2017	SS / Monthly Transient
11N/34W-27E01	1977	2017	SS / Monthly Transient
11N/34W-29R01	1977	2017	SS / Monthly Transient
11N/34W-29R02	1994	2017	Monthly Transient
11N/34W-30D02	1977	1988	SS / Monthly Transient
11N/34W-33J01	2003	2017	Monthly Transient
11N/35W-02F01	1977	2016	SS / Monthly Transient
11N/35W-03B01	1977	2017	SS / Monthly Transient
11N/35W-04CR4	2000	2015	Monthly Transient
11N/35W-04CR6	2000	2009	Monthly Transient
11N/35W-04CR8	2000	2015	Monthly Transient
11N/35W-04D01	2015	2016	Monthly Transient
11N/35W-04E01	2015	2017	Monthly Transient
11N/35W-04E02	2016	2017	Monthly Transient
11N/35W-04RWC	2015	2015	Monthly Transient
11N/35W-05A01	2000	2017	Monthly Transient

Preliminary Calibration Target Wells - Water Level

State Well Number / Well Name	Range of Available Water Level Data		Calibration Target Type
11N/35W-05B01	2016	2017	Monthly Transient
11N/35W-05B02	2015	2017	Monthly Transient
11N/35W-05E02	2015	2017	Monthly Transient
11N/35W-05G01	1977	2017	SS / Monthly Transient
11N/35W-05H01	2000	2017	Monthly Transient
11N/35W-05L01	1977	2017	SS / Monthly Transient
11N/35W-05N02	1977	2013	SS / Monthly Transient
11N/35W-05R01	1977	2017	SS / Monthly Transient
11N/35W-06HS	2015	2017	Monthly Transient
11N/35W-08K01	1978	1987	Monthly Transient
11N/35W-08L01	1998	2017	Monthly Transient
11N/35W-09K02	1977	2017	SS / Monthly Transient
11N/35W-09K05	1980	2017	Monthly Transient
11N/35W-10G01	1977	2017	SS / Monthly Transient
11N/35W-10G04	1998	2017	Monthly Transient
11N/35W-10G05	1994	2017	Monthly Transient
11N/35W-10J02	1990	2011	Monthly Transient
11N/35W-10L01	1993	2017	Monthly Transient
11N/35W-11B01	1977	2017	SS / Monthly Transient
11N/35W-11C01	1977	2012	SS / Monthly Transient
11N/35W-11C02	1977	2016	SS / Monthly Transient
11N/35W-11J01	1978	2017	Monthly Transient
11N/35W-11J02	1977	2006	SS / Monthly Transient
11N/35W-11J03	1990	2006	Monthly Transient
11N/35W-12E04	1989	2011	Monthly Transient
11N/35W-13C01	1977	2017	SS / Monthly Transient
11N/35W-13D01	1997	2017	Monthly Transient
11N/35W-13E02	1977	2017	SS / Monthly Transient
11N/35W-13E03	1977	2017	SS / Monthly Transient
11N/35W-13G01	1990	2017	Monthly Transient
11N/35W-13M02	1993	2017	Monthly Transient
11N/35W-14E01	1999	2017	Monthly Transient
11N/35W-14J01	1993	2017	Monthly Transient
11N/35W-15C	2006	2009	Monthly Transient
11N/35W-15D01	1999	2017	Monthly Transient

Preliminary Calibration Target Wells - Water Level

State Well Number / Well Name	Range of Available Water Level Data		Calibration Target Type
11N/35W-15G01	2000	2010	Monthly Transient
11N/35W-15L	2006	2009	Monthly Transient
11N/35W-15R01	1999	2017	Monthly Transient
11N/35W-16A	2006	2009	Monthly Transient
11N/35W-16Ja-	1999	2008	Monthly Transient
11N/35W-16Jb-	1999	2015	Monthly Transient
11N/35W-16R	2006	2009	Monthly Transient
11N/35W-17E01	1977	2017	SS / Monthly Transient
11N/35W-19E02	1977	1983	SS / Monthly Transient
11N/35W-19E03	2007	2016	Monthly Transient
11N/35W-20E01	1977	2017	SS / Monthly Transient
11N/35W-21K01	1977	1992	SS / Monthly Transient
11N/35W-22C02	1992	2017	Monthly Transient
11N/35W-22M01	1999	2017	Monthly Transient
11N/35W-23G01	2011	2017	Monthly Transient
11N/35W-23L01	1988	2006	Monthly Transient
11N/35W-24A01	1996	2016	Monthly Transient
11N/35W-24D01	1977	1998	SS / Monthly Transient
11N/35W-24J01	1983	2017	Monthly Transient
11N/35W-24L01	1977	2016	SS / Monthly Transient
11N/35W-24L02	1996	2017	Monthly Transient
11N/35W-25F03	1979	2017	Monthly Transient
11N/35W-33G03	2011	2017	Monthly Transient
11N/36W-12C01	1977	2017	SS / Monthly Transient
11N/36W-12C02	1977	2017	SS / Monthly Transient
11N/36W-12C03	1977	2017	SS / Monthly Transient
11N/36W-35J02	1977	2017	SS / Monthly Transient
11N/36W-35J03	1977	2017	SS / Monthly Transient
11N/36W-35J04	1977	2017	SS / Monthly Transient
11N/36W-35J05	1977	2017	SS / Monthly Transient
11N/36W-35J06	1977	2017	SS / Monthly Transient
12N/34W-31F01	1978	2017	Monthly Transient
12N/35W-27N03	1977	2017	SS / Monthly Transient
12N/35W-29L01	1978	1987	Monthly Transient
12N/35W-29N01	1977	2017	SS / Monthly Transient

Preliminary Calibration Target Wells - Water Level

State Well Number / Well Name	Range of Available Water Level Data		Calibration Target Type
12N/35W-29R03	1977	2017	SS / Monthly Transient
12N/35W-30K03	1977	2017	SS / Monthly Transient
12N/35W-30P02	1977	2017	SS / Monthly Transient
12N/35W-32C03	2011	2017	Monthly Transient
12N/35W-32G01	1977	2017	SS / Monthly Transient
12N/35W-32Q02	1977	1979	SS / Monthly Transient
12N/35W-32R01	2015	2016	Monthly Transient
12N/35W-33J02	1978	2017	Monthly Transient
12N/35W-33L01	1977	2017	SS / Monthly Transient
12N/35W-33M01	1977	1996	SS / Monthly Transient
12N/35W-34C03	1977	2017	SS / Monthly Transient
12N/35W-34G08	1978	2017	Monthly Transient
12N/35W-35P03	1981	2017	Monthly Transient
12N/36W-36L01	1977	2017	SS / Monthly Transient
12N/36W-36L02	1977	2017	SS / Monthly Transient
31S/14E-31L02	1978	1999	Monthly Transient
32S/12E-24B01	1977	2017	SS / Monthly Transient
32S/12E-24B02	1977	2017	SS / Monthly Transient
32S/12E-24B03	1977	2017	SS / Monthly Transient
32S/13E-12C03	1977	2015	SS / Monthly Transient
32S/13E-12C04	1977	1979	SS / Monthly Transient
32S/13E-12F04	1977	1995	SS / Monthly Transient
32S/13E-12F05	1981	2017	Monthly Transient
32S/13E-12P04	1988	2013	Monthly Transient
32S/13E-13D04	1981	2003	Monthly Transient
32S/13E-13D05	1977	1994	SS / Monthly Transient
32S/13E-14R02	1977	2017	SS / Monthly Transient
32S/13E-19Q02	1977	2017	SS / Monthly Transient
32S/13E-22R03	1977	2017	SS / Monthly Transient
32S/13E-23C01	1977	2001	SS / Monthly Transient
32S/13E-23M07	1977	2003	SS / Monthly Transient
32S/13E-28K02	1979	2017	Monthly Transient
32S/13E-28L01	1977	2017	SS / Monthly Transient
32S/13E-29B01	1977	2002	SS / Monthly Transient
32S/13E-29E02	1977	2017	SS / Monthly Transient

Preliminary Calibration Target Wells - Water Level

State Well Number / Well Name	Range of Available Water Level Data		Calibration Target Type
32S/13E-29G02	1977	2017	SS / Monthly Transient
32S/13E-29G14	1977	2017	SS / Monthly Transient
32S/13E-29G15	1982	2017	Monthly Transient
32S/13E-29J02	1977	2000	SS / Monthly Transient
32S/13E-30F01	1977	2017	SS / Monthly Transient
32S/13E-30F02	1977	2017	SS / Monthly Transient
32S/13E-30F03	1977	2017	SS / Monthly Transient
32S/13E-30K14	1977	1977	SS / Monthly Transient
32S/13E-30K19	1997	2017	Monthly Transient
32S/13E-30N01	1977	2017	SS / Monthly Transient
32S/13E-30N02	1977	2017	SS / Monthly Transient
32S/13E-30N03	1977	2017	SS / Monthly Transient
32S/13E-31H08	1984	2017	Monthly Transient
32S/13E-31H09	1984	2017	Monthly Transient
32S/13E-31H10	1983	2017	Monthly Transient
32S/13E-31H12	1983	2017	Monthly Transient
32S/13E-31H13	1983	2017	Monthly Transient
32S/13E-32D03	1977	2017	SS / Monthly Transient
32S/13E-32D10	2005	2015	Monthly Transient
32S/13E-32D11	1979	2017	Monthly Transient
32S/13E-33A05	1977	2017	SS / Monthly Transient
32S/13E-33K03	1977	2017	SS / Monthly Transient
Humane Society Irrig	2015	2015	Monthly Transient
Landfill EW-1A	2015	2015	Monthly Transient
Landfill MW-10	2015	2015	Monthly Transient
Landfill MW-1R	2015	2015	Monthly Transient
Los Flores MW-1	2015	2015	Monthly Transient
Los Flores MW-5	2015	2015	Monthly Transient
SM 7S	2015	2015	Monthly Transient
SMRV-0059	2012	2016	Monthly Transient
SMRV-0303	2011	2016	Monthly Transient
SMRV-0330	2012	2016	Monthly Transient
Taylor Irrig	2015	2015	Monthly Transient
WWTP UMW-1	2015	2015	Monthly Transient

Preliminary Calibration Target Wells - TDS

State Well Number / Well Name	Range of Available TDS Data	
11N/35W-10G04	1987	2000
11N/35W-24J01	1982	1999
11N/36W-12C01	1996	2017
11N/36W-12C02	1996	2017
11N/36W-12C03	1996	2017
11N/36W-35J02	1977	2016
11N/36W-35J03	1977	2016
11N/36W-35J04	1977	2016
11N/36W-35J05	1977	2016
12N/35W-32C03	2012	2016
12N/36W-36L01	1996	2016
12N/36W-36L02	1996	2016
32S/12E-24B01	1996	2016
32S/12E-24B02	1996	2016
32S/12E-24B03	1996	2016
32S/13E-30F01	2009	2016
32S/13E-30F02	1996	2016
32S/13E-30F03	1996	2016
32S/13E-30N01	2009	2016
32S/13E-30N02	1996	2016
32S/13E-30N03	1996	2016
32S/13E-31H09	2011	2016
32S/13E-31H10	1983	2016
32S/13E-31H13	1983	2016

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City of Pismo Beach and South San Luis Obispo County Sanitation District Central Coast Blue Phase 1B Hydrogeologic Evaluation

Technical Memorandum No. 3: Model Calibration

Prepared for:
Water Systems Consulting, Inc.

May 14, 2019

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CITY OF PISMO BEACH AND SOUTH SAN LUIS OBISPO COUNTY SANITATION DISTRICT
CENTRAL COAST BLUE
PHASE 1B HYDROGEOLOGIC EVALUATION

TECHNICAL MEMORANDUM NO. 3: MODEL CALIBRATION

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APPENDICES

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A	Comments Received and GEOSCIENCE Responses for Draft TM No. 3: Model Calibration
B	Supplemental Calibration Hydrographs

CITY OF PISMO BEACH AND SOUTH SAN LUIS OBISPO COUNTY SANITATION DISTRICT
CENTRAL COAST BLUE
PHASE 1B HYDROGEOLOGIC EVALUATION

TECHNICAL MEMORANDUM NO. 3: MODEL CALIBRATION

1.0 INTRODUCTION

1.1 Background

Central Coast Blue (CCB) is a regional recycled water project that will reduce the risk of seawater intrusion and improve water supply sustainability in northwestern Santa Maria River Valley Groundwater Basin (Basin; see Figure 1). The project uses advanced-treated recycled water from the City of Pismo Beach and the South San Luis Obispo County Sanitation District (SSLOCSD) Wastewater Treatment Plants (WWTPs) as an injection water source. This water will then be injected in the Arroyo Grande-Tri-Cities Mesa portion of the Basin to establish a seawater barrier and improve the reliability of groundwater supplies in the region.

1.2 Purpose and Scope

As part of the Phase 1B Hydrogeologic Evaluation, GEOSCIENCE Support Services, Inc. (GEOSCIENCE) has been tasked with expanding the existing Phase 1A Model (CHG, 2017), that was developed for what was then known as the Regional Groundwater Sustainability Project (RGSP), to include an evaluation of injection and extraction scenarios with flows from the SSLOCSD and City of Pismo Beach WWTPs. The following tasks are included in the development of the CCB Phase 1B groundwater flow and solute transport model (Phase 1B Model) and evaluation of Project scenarios:

- Task 0 – Project Management
- Task 1 – Data Assessment
- Task 2 – Conceptual Model
- Task 3 – Model Construction
- Task 4 – Model Calibration and Sensitivity Analysis
- Task 5 – Scenario Evaluation
- Task 6 – Model Report
- Task 7 – Anti-Degradation Analysis (optional)

This technical memorandum (TM) presents a summary of the construction and calibration of the Phase 1B Model (Tasks 3 and 4). Model calibration of the Phase 1B Model represents a collaborative process by which the model development and calibration was modified based on feedback from the Technical Advisory Committee (TAC). Members of the TAC included representatives of the Nipomo Mesa Management Area Technical Group (NMMA TG), GSI (representing the Northern Cities Management Area (NCMA)), and Water Systems Consulting, Inc. (WSC). Comments received on draft versions of TM No. 3, along with responses, are provided in Appendix A.

1.3 Existing Groundwater Models

Four main groundwater models were developed in the Project area over the last few years. The Santa Maria Valley Groundwater Basin Model developed by Luhdorff & Scalmanini, Consulting Engineers (LSCE, 2000) covers the entire Santa Maria Valley Management Area (SMVMA) and part of the Nipomo Mesa Management Area (NMMA). It was calibrated from fall 1944 to spring 1997 with 6-month stress periods and consisted of six model layers with a uniform cell size of 2,000 ft by 2,000 ft. Cleath and Associates developed a model in 1996 covering most of NMMA comprising two layers and a grid size of 1000 ft by 1000 ft. It was calibrated from 1977 to 1994.

The remaining models are centered around the Northern Cities Management Area (NCMA): the NCMA Groundwater Model (Wallace, 2016) and the Phase 1A Model (CHG, 2017). The NCMA Groundwater Model has three model layers and a cell size of 127 ft by 127 ft. It included both a steady state and a transient calibration period and was calibrated from 1986 to 2004 with a monthly stress period. The Phase 1A Model is the most recent model and also the most discretized, with a cell size of 200 ft by 200 ft and 13 model layers. The model extent is shown on Figure 1. It was calibrated from spring 2005 to fall 2015 with 6-month stress periods. All three models were purely groundwater flow models and did not contain a solute transport model component.

Other, more local models with limited extent were also reviewed. They include a local groundwater flow model for the former Union Oil Company of California (UNOCAL) Guadalupe oil field, which was designed as a local model to assess contaminant transport (PMGC, 2000). This six layer model had 240 rows and 200 columns. A crude one layer model was also developed by Chipping Geological Services (1994) to estimate the impact of domestic wells in the Black Lake Canyon area. This model was not very detailed however, as only one model layer was represented and very simplistic assumptions were made regarding layer structure, inflows, and outflows.

2.0 CCB PHASE 1B GROUNDWATER FLOW AND SOLUTE TRANSPORT MODEL

2.1 Conceptual Model

The conceptual understanding of the geohydrology, groundwater flow directions, inflows (recharge), and outflows (discharge) for the CCB Phase 1B Groundwater Model area was developed from available datasets and existing studies, as detailed in TM No. 1: Conceptual Model (GEOSCIENCE, 2018a).

The Phase 1B Model was developed for the unconsolidated to semi-consolidated water-bearing sediments of the NCMA, NMMA, and portion of the SMVMA in the northwestern Santa Maria Groundwater Basin (see Figure 1). The main water-bearing formations are the Paso Robles Formation and the Careaga Sand, which constitute the deeper aquifer, and the dune sand, terrace deposits, and quaternary alluvium, which constitute the shallow aquifer (LSCE, 2017). The low-yield formations which underlie and also generally flank the main groundwater basin are considered impermeable and are not part of the modeled groundwater flow system. The conceptual groundwater model consists of ten model layers:

- Layer 1 – Ocean floor (allows for vertical leakage from the ocean to the underlying aquifer (i.e., model layer 2) and inflow and outflow from the surficial aquifer (recent alluvium/young and old dune sand)
- Layer 2 – Recent alluvium/young and old dune sand
- Layers 3 through 7 – Paso Robles Formation
- Layer 8 through 10 – Careaga Sand

The boundaries between layers were delineated from the 3-D Lithologic Model developed for the Phase 1B Model area, and from previous cross-sections from the Santa Maria Basin Characterization (SMBC) study (FUGRO, 2015) and the California Department of Water Resources (DWR, 2002). Groundwater flow is assumed to occur primarily horizontally within each of the model layers while the layers maintain hydraulic connection to each other through vertical leakance. Layers 3, 5, 7, and 9 were considered to be primarily aquitards, although these layers can have relatively high hydraulic conductivity in various locations due to the lateral discontinuities of low permeability beds. The Santa Maria River Fault was also modeled as a lower permeability feature using the Horizontal-Flow Barrier (HFB) package.

2.2 Model Codes

2.2.1 SEAWAT

The Phase 1B Model was constructed using SEAWAT, a block-centered, finite-difference groundwater flow code developed by the United States Geologic Survey (USGS; Guo and Langevin, 2002). SEAWAT simulates three-dimensional (3-D), variable-density, groundwater flow and solute transport in porous media. The source code for SEAWAT was developed by combining MODFLOW and MT3DMS[1] into a single program that solves the coupled flow and solute transport equations. Using this computer code will provide a more accurate prediction of seawater intrusion in the Santa Maria River Groundwater Basin than MODFLOW alone. Each of the codes that make up SEAWAT are run separately at first; the flow model was calibrated using MODFLOW and an MT3D model was run using flow results from MODFLOW. Both codes were then integrated into SEAWAT for a final run.

2.2.2 MODPATH

MODPATH software was not used during the calibration phase, but it was used during the scenario evaluation to compute 3-D flow paths (i.e., particle tracking) using output from the groundwater flow model. MODPATH does not take dispersion, retardation, or half-life decay into account; the results of MODPATH simply provide an indication of the direction and rate of groundwater flow. Retention time of the recycled water from the recharge basin or injection well to the nearest production well can be calculated based on the MODPATH results.

2.2.3 Model Pre- and Post-Processors

The pre- and post-processors used to manipulate model input and output data arrays include the following:

- GIS (Geographical Information System);
- Groundwater Vistas; and
- Proprietary software developed by GEOSCIENCE.

The GIS software used was ESRI ArcMap 10.5. Groundwater Vistas, which was developed by Environmental Simulations, Inc., is a Windows graphical user interface for 3-D groundwater flow and

1 MT3DMS is a Modular three-dimensional Multi-Species Transport model, is the second generation of the MT3D developed with funding from the U.S. Army Engineer Research and Development Center (Zheng and Wang, 1999).

transport modeling. Various freely available and common tools (e.g., R, Microsoft Excel, etc.) were used to prepare MODFLOW model input data for the Well package, GHB package and Recharge package.

2.3 Model Cells, Layers, and Stress Periods

The CCB Phase 1B Model represents an expansion of the Phase 1A Model, and covers the entire NCMA and NMMA, and part of SMVMA (Figure 1). By incorporating the entire NMMA and part of SMVMA, the expanded model extent allowed scenarios in the NCMA to be run with a reduced risk of boundary effects. The larger extent also allowed for the incorporation of more data. This in turn helps ensure that the behavior of the natural system is more accurately captured.

The Phase 1B Model domain covers an area of approximately 197 square miles (125,857 acres) in the northwest portion of the Santa Maria Groundwater Basin. The finite-difference grid consists of 600 rows in the northeast-to-southwest direction and 932 columns in the northwest-to-southeast direction along the model domain and has ten model layers. The grid is rotated at 40° clockwise to be consistent with Phase 1A modeling and to minimize the number of model cells. Each model cell of the Phase 1B Model represents an area of 100 ft x 100 ft (Figure 2), which represents a finer resolution than the Phase 1A model. This finer grid improves the resolution of physical features, such as local faults and basin boundaries, as well as the location of wells – including injection well siting. The stress period (i.e., time period) used to vary model fluxes, such as pumping and recharge, occurred monthly.

2.4 Boundary Conditions

A boundary condition is any external influence or effect that acts either as a source or sink, adding or removing water from the groundwater flow system. The boundary conditions used in the Phase 1B Model are no-flow (inactive), wells, general head boundaries (GHB), and stream (Figure 3). The active area of the model coincides with the boundaries of the groundwater basin in the north and northeast. These boundaries are based on local geology (Figure 4) and DWR groundwater basin boundaries.

Well boundary conditions, or specified flux, are used to simulate mountain front recharge, pumping, stormwater infiltration, and WWTP infiltration. Since the model area does not continue to the natural southern edge of the basin, a GHB was used along the southern boundary of the active model area to simulate the observed long-term trends in groundwater levels over time. Groundwater elevation trends from wells near the GHB were used to simulate groundwater elevations at the model boundary. A GHB was also used to simulate the Pacific Ocean (model layer 1) and the model connection to the Arroyo Grande Creek alluvial valley.

2.5 Three-Dimensional Lithologic Model

Developing a robust, geologically accurate conceptual model for the Phase 1B Model area was a critical first step for model construction. Therefore, as part of the development of the Phase 1B Model, a 3-D lithologic model was constructed to better identify the physical extents, thickness, continuity, and lithology of the geologic units within the NCMA, NMMA, and portion of the SMVMA (Figure 5). The construction of the 3-D lithologic model, which is detailed in TM No. 1: Conceptual Model (GEOSCIENCE, 2018a), was based on 23 previously-published cross-sections (DWR, 2002; FUGRO, 2015; LSCE, 2000; and NMMA Technical Group, 2017) and more than 400 lithologic logs from the SMBC Study (FUGRO, 2015) and Division of Oil, Gas, and Geothermal Resources (DOGGR) wells.

Lithology was estimated using a geostatistical sequential indicator simulation technique coupled with ordinary kriging and observed lithology. Results from the 3-D lithologic model were used to define model layers and estimate aquifer parameters (i.e., hydraulic conductivity and storativity values). Figures 6 through 8 provide cross-sectional views of the model-generated lithology in the Phase 1B Model area.

2.6 Aquifer Parameters

2.6.1 Model Layer Elevations

Land surface elevation, as determined from Digital Elevation Models (DEMs) for the 7.5” topographic quadrangles in the model area, was used as the top of model layer 2. Model layer 1 is a one-foot thick layer that is active only beneath the ocean to allow vertical leakage from the ocean to the underlying aquifer and layer 2, which is the alluvium/ dune sand aquifer, to allow discharge to the ocean. The bottom elevation of layer 1 was assumed to be one foot below the top elevation. The bottom elevations for model layer 2 were determined based on the 3-D lithologic model.

Aquifers within the model area are generally unconfined to semi-confined, as well as confined with spatially discontinuous aquitards. Developing a model layer structure for these conditions can be challenging. To help design the model layer structure accurately, GEOSCIENCE used the 3-D lithologic model and information from nested multi-level monitoring wells. Water levels at 11 locations along three cross-sections (Figure 9) were used to devise a vertical discretization of the aquifer system into nine model layers. Cross-Sections N-N’, O-O’, and P-P’ on Figures 10 through 12 show the screened intervals of the wells used and the delineation of the nine model layers. Layer 1 was later added to the SEAWAT model to represent the ocean, as stated in Section 2.1. Since it is not possible to pinch out or discontinue layers in SEAWAT, discontinuous layers of clay (representing confining units) were extended throughout the model area. For these layers, aquifer properties were adjusted to reflect changes in lithology.

Figure 13 shows the bottom elevation of Phase 1B Model layers while Figure 14 shows model layer thicknesses. The thickness of model layer 2 ranges from approximately 1 ft to 400 ft in the middle of the groundwater basin. Layer 3 is relatively thin and ranges from 1 ft to 200 ft. For most of the model domain it ranges from 1 ft to 100 ft. Layers 5 and 7 are very similar in thickness to layer 3. Layers 4 and 6 range in thickness from 1 to 400 ft. Layer 6 is thicker in the center of the model area while layer 4 thickens to the southeast. Layer 10 is the thickest layer, with thickness ranging from 1 to 700 ft. Most of the model layers are thinner to the northeast of the Santa Maria River Fault due to the northeastern compartment of the fault being lifted. The Careaga Sand (model layer 8 to 10) is thin or inexistent in this area. A thickness of 1 ft was usually used when the actual geological layer represented pinches out or was non-existent at a specific location.

2.6.2 Hydraulic Conductivity

The spatial distribution of hydraulic conductivity values was determined based on local geology and the results from the 3-D lithological model. Initial horizontal hydraulic conductivity values were estimated based on data from the lithologic model and pumping tests, as described in TM No. 2: Calibration Plan (GEOSCIENCE, 2018b). For each well with pumping test data and screened interval information, the thickness of each lithology type along the screen was used to estimate an average hydraulic conductivity for the well using published typical values for each lithology (Table 2-1) and the formula below.

$$K_{ave} = \frac{K_{1,ave}b_1 + K_{2,ave}b_2 + \cdots + K_{15,ave}b_{15}}{b_1 + b_2 + \cdots + b_{15}}$$

Where:

K_{ave} = Weighted average horizontal hydraulic conductivity for a given well, ft/day;
$K_{m,ave}$ = Average horizontal hydraulic conductivity for lithologic type m, ft/day; and
b_m = Total thickness of lithologic type m within the screen of a given well.

Values for each lithology were varied within the range of the published values until a good match between the estimated hydraulic conductivity and the pumping test derived value was obtained. Figure 15 shows the measured hydraulic conductivities from pumping test data versus the estimated hydraulic conductivity derived from observed lithology. The resulting estimates for each lithology type are shown in Table 2-1.

The percentage of each lithology types per model cells was extracted from the lithological model and used to estimate the hydraulic conductivity in every cell using the formula below.

$$K_{i,j,k} = Pct1, ijk \times K_1 + Pct1, ijk \times K_1 + \cdots + Pct15, ijk \times K_{15}$$

Where:

$K_{i,j,k}$ = Weighted average horizontal hydraulic conductivity for model cell i,j of layer k, ft/day;

K_m = Estimated horizontal hydraulic conductivity for lithologic type m, ft/day; and

Pct_m = Percentage of lithologic type m for model cell i,j of layer k, ft.

Table 2-1. Hydraulic Conductivity Ranges and Fitted Estimates

Lithology Code	Description	Typical Values (FUGRO, 2015)		Estimated Value (ft/d)
		Minimum Value (ft/d)	Maximum Value (ft/d)	
1	Sandstone	0.00008.5	1.7	1.7
2	Weathered bedrock	1	10	1
3	Organic fines	0.00001	0.0001	0.0000535
4	High plasticity clays/fat clays with varying amounts of coarse-grained materials	0.00001	0.0001	0.00001
5	Clay with varying amounts of coarse-grained materials (including silty clays or clayey silts)	0.01	1	0.01
6	Silt with varying amounts of coarse-grained materials (also elastic silt)	0.1	30	3
7	Equal portions of coarse- and fine-grained materials (sand or gravel / silt or clay)	0.1	30	7
8	Clayey sand with or without gravel	3	150	10
9	Silty sand with or without gravel	3	150	15
10	Sand with small amounts of silt or clay (5-15%) (minor gravel may be present)	3	150	20
11	Clean sand with or without gravel	3	150	20
12	Gravel with clay or clay and silt	100	200	100
13	Gravel with silt in varying amounts	100	200	100
14	Clean gravel with sand	100	200	100
15	Clean gravel size or larger (e.g., boulders, etc.)	100	300	100

The hydraulic conductivity values were then iteratively adjusted within pre-established upper and lower bounds during model calibration in order to minimize the residuals between the measured and model-generated groundwater levels. The calibrated horizontal hydraulic conductivity values are shown on Figure 16. As expected, model layers 3, 5, 7, and 9 have overall lower hydraulic conductivities since they often act as aquitards. Layer 4 (upper Paso Robles) generally has the highest hydraulic conductivity. Portions of the model beneath the ocean were not assigned initial hydraulic conductivities based on lithology. Instead, hydraulic conductivity values were assigned from estimated averages and adjusted during calibration.

Vertical hydraulic conductivity was used to simulate vertical leakage between layers and was adjusted during calibration as well. The calibrated vertical hydraulic conductivity values are shown on Figure 17.

2.6.3 Storativity

Specific storage is the volume of water that a unit volume of aquifer (or aquitard) releases from storage under a unit decline in water level, and is related to the compressibility of the water and aquifer (or aquitard). In a confined aquifer, the specific storage has a great effect on the storativity (or volume of water released from storage per unit surface area of the aquifer or aquitard per unit decline in hydraulic head). However, aquifer compression and water expansion in unconfined conditions yield relatively little water from storage so the storativity is controlled primarily by its specific yield, or drainable porosity (i.e., gravity drainage).

Both specific yield and specific storage values were used in the Phase 1B Model. The type of storativity value used depends on the nature of the model layer through time (i.e., unconfined or confined). When the water level drops below the top of a layer (e.g., Layer 2 or 3), it is treated as being unconfined and the model applies the assigned specific yield. If the water level remains above the top of the layer, it is treated as being confined and specific storage is used. For deeper layers which are never dewatered during the course of the calibration run, the assigned specific yield value is never used.

Initial estimates of storativity were based on previous studies and pumping test data (refer to GEOSCIENCE, 2018a for additional information). The model storativity values were then modified during model calibration within pre-established upper and lower bounds in order to match the observed groundwater levels in the model area. Some water levels in the Santa Maria River flood plain and in the Cienega Valley show evidence of semi-confined behavior. Therefore, specific yield was reduced to reflect this characteristic. The final calibrated specific yield and specific storage values are shown on Figures 18 and 19, respectively.

2.6.4 Horizontal-Flow Barriers

The Santa Maria River Fault was simulated in the Phase 1B Model as a partial barrier to groundwater flow. This feature was initially determined to restrict the movement of groundwater from observed offsets in groundwater levels in wells on either side of the fault (GEOSCIENCE, 2018a). However, due to reference point discrepancies for these measurements, they were ultimately deemed unreliable. Despite this, previous hydrogeological investigations provided evidence that the Santa Maria River Fault acted as a partial flow barrier, so it was modeled as such in the Phase 1B Model (DWR, 2002; Worts, 1951).

The Santa Maria River Fault was simulated using the HFB package by assigning a hydraulic conductivity value along the barrier. This value was varied along the length of the fault, as determined through model calibration (Figure 20). Model results show that the eastern portion of the Santa Maria River Fault is a more effective flow barrier compared to the western portion. The division between these two parts of the fault was initially inferred from the DWR (1975) salt water intrusion report and slightly modified during calibration based on input from the TAC.

2.6.5 Dispersivity

During model calibration, it was found that a longitudinal dispersivity of 15 ft resulted in a good match between model-calculated and measured TDS concentrations. The horizontal transverse dispersivity was assumed to be 1.5 ft, while the vertical transverse dispersivity was assumed to be 0.15 ft.

2.6.6 Effective Porosity

The SEAWAT model code of the Phase 1B Model uses equations based on effective porosity. Effective porosity is defined as the total porosity minus the specific retention (in unconfined aquifers) or storativity (in confined aquifers) (Sara, 2003). More specifically, it is used to correct the total porosity to account for the dead-end and isolated pore spaces in which velocity is zero. In this case, effective porosity represents the porosity that is required to achieve agreement between observed and model-calculated travel times. It is not a value that can be measured readily in the field, so it is determined through model calibration (Zheng and Bennett, 2002; Zheng and Wang, 1999; Sara, 2003) a value of 0.11 was obtained after calibration.

2.7 Model Recharge and Discharge

The groundwater flow model is an analytical expression of the conservation of mass, namely:

Inflow = Outflow ± Δ Storage

Recharge (inflow) and discharge (outflow) components in the Phase 1B Model include the following terms:

Table 2-2. Model Recharge and Discharge Terms

	Model Term	MODFLOW Package Used
Recharge	Areal Recharge from Precipitation	Recharge Package
	Mountain Front Recharge	Well Package
	Streambed Percolation	Streamflow Routing (SFR) Package
	Return Flow from Municipal Use	Recharge Package
	Return Flow from Agricultural Use	Recharge Package
	Return Flow from Golf Course Irrigation	Recharge Package
	Artificial Recharge	Well Package
	Underflow Inflow	General Head Boundary (GHB)
Discharge	Municipal Pumping	Multi-Node Well (MNW) Package
	Small Purveyor Pumping	Well Package
	Agricultural Pumping	Well Package
	Golf Course Pumping	Well Package
	Underflow Outflow to the Ocean and Offshore Aquifers	General Head Boundary (GHB)

2.7.1 Groundwater Recharge Terms

2.7.1.1 Areal Recharge from Precipitation

Estimates of deep percolation of areal recharge were made using the U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS) curve number technique (USDA, 1986). Using this method, the SCS runoff equation is:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Where

Q = runoff (in),
P = precipitation (in),
S = potential maximum retention after runoff begins (in), and
I_a = initial abstraction (in).

Input data include Soil Survey maps, 1996 land use, DWR subbasins, precipitation information from four rainfall gages in the model area, and potential evapotranspiration (ET_o) rates from the California Irrigation Management Information System (CIMIS) Nipomo station (GEOSCIENCE, 2018a). It is important to note that changes in land use (i.e., increased urbanization since the 1970s) influence the amount of permeable and impermeable area, therefore impacting the amount of recharge from areal precipitation. 1996 land use represented the most recent land use data available for the region and was therefore used for model calibration. During the calibration effort, the TAC agreed that the estimated areal recharge from precipitation was probably too high. Therefore, this value was revised to reflect increased urbanization and to help alleviate the shortcomings related to limited land use data. However, the basin-wide, regional scale of the model helps minimize uncertainty related to local land use changes.

Estimated areal recharge for the period from 1977 through 2016 is shown on Figure 21. During this time period, percolation from areal recharge averaged 4,385 acre-ft/yr.

2.7.1.2 Mountain Front Recharge

The more permeable, water-bearing formations are flanked to the north and northeast by outcrops of older, less permeable, consolidated and semi-consolidated formations (Pismo, Obispo, Franciscan, and Monterey Formations), which constitute the Temettate Ridge and San Luis range. Outcrops of Paso Robles Formation, Careaga Sandstone, and undifferentiated Tertiary formations form the Casmalia Hills to the southwest (Worts, 1951). Even though these formations are known to have limited yield, the active model area could potentially be receiving inflow along the northeastern boundaries of consolidated rock outcrops in the form of mountain front recharge. Mountain front recharge, which represents a combination of runoff and underflow from the surrounding low-yield rocks, was discussed in more detail in TM No. 1: Conceptual Model (GEOSCIENCE, 2018a). Return flows from the Nipomo Valley area (to the northeast) could also be contributing to the underflow.

It was assumed that areal recharge that occurs in these mountain areas eventually becomes mountain front recharge. Therefore, the SCS curve method was used initially to estimate areal recharge in these mountains and applied as mountain front recharge. This estimated value was then adjusted per the recommendation of the TAC. DWR (1975) estimated that the Santa Maria Groundwater Basin receives recharge from the Nipomo Valley Subbasin through the bedrock, potentially across the Wilmar Avenue Fault. This flux term was also lumped into the mountain front recharge. DWR estimated an average of 500 acre-ft/yr subsurface inflow from Nipomo Valley Subbasin. This value represents the geometric average of the minimum and maximum estimate of 160 acre-ft/yr and 1,600 acre-ft/yr for water years 1975, 1985, and 1995. The location of the mountain front recharge is shown on Figure 3 and coincides with the Nipomo Valley Subbasin footprint along the Santa Maria Groundwater Basin and extends farther northwest. During the calibration period from 1977 through 2016, mountain front recharge in the NMMA averaged 1,004 acre-ft/yr (Figure 22).

2.7.1.3 Streambed Percolation

The Arroyo Grande and Los Berros Creeks are located within the active model domain of the Phase 1B Model[2]. Streambed percolation from these creeks was simulated using the Streamflow Routing Package. The Streamflow Routing Package assigns recharge to stream cells that are sequentially numbered in the downstream direction. The cells used to represent the location of the Arroyo Grande and Los Berros Creeks are shown on Figure 3 in model layer 2. Model input for the routing package includes stream inflow, stream channel geometry, and streambed conductance.

While no studies have been conducted to evaluate streambed percolation as a source of recharge in the NMMA, shallow agricultural pumping wells completed in the alluvium along Los Berros Creek suggests that at least some recharge from streambed percolation is occurring. Hoover and Associates (1985) conducted a study to measure the infiltration from the Arroyo Grande Creek and reported an average percolation between 1,000 acre-ft/yr and 2,000 acre-ft/yr. They also reported that most of the percolation occurs between a school north of the Los Berros Creek junction and the 22nd Street Bridge gage. Therefore, a higher hydraulic conductivity was assigned to this portion of the streambed. Active calibration to the flow in the Arroyo Grande Creek was not pursued as it was determined that the available measured flow from the 22nd Street Bridge gage was unreliable due to the fact that the gage does not capture the full width of the creek. However, percolation volumes were kept within the range of published values.

Net model-calculated recharge from streambed percolation was 1,185 acre-ft/yr in the NCMA and 193 acre-ft in the NMMA for the period from 1977 through 2016 (see Figure 23).

[2] Oso Flaco Creek located in the NMMA is mainly fed from agricultural runoff and affects local, alluvial and perched aquifers that were not modeled by the regional Phase 1B Model. Therefore, this creek was not simulated.

2.7.1.4 Return Flow from Municipal Use

Return flow refers to the amount of water that returns to the aquifer after application of water to the land surface in the form of irrigation, or from leaks in water and sewer lines. Recharge from septic system returns was assumed to be negligible. Return flow from the use of municipal water (including both groundwater and imported water) was incorporated into the Phase 1B Model using the Recharge Package. Distribution of return flow was dependent upon the location and purpose of water usage (i.e., applied water and leaky distribution pipes).

Estimated return flow from leaky distribution pipes was provided by local agencies, and ranged from 5% to approximately 12%. For years without estimated return flow, an average value of 7.5% was assumed. For return flow from municipal use (including both groundwater and imported water), it was assumed that 50% of the water delivered by municipalities is used outdoors. Of this, 50% is assumed to return to the aquifer (25% of the water delivered). As shown on Figure 24, return flow from municipal use averaged 1,151 acre-ft/yr in the NCMA, 676 acre-ft/yr in the NMMA, and 0 acre-ft/yr in the SMVMA from 1977 through 2016.

2.7.1.5 Return Flow from Small Purveyors

Location of small purveyor pumping was obtained from the San Luis Obispo website and historical information provided by Golden State Water Company (GSWC; through Robert Collar). For most of the small purveyors, the number of connections was available and a water use of 0.5 acre-ft/year per connection was assumed. Pumping was distributed evenly throughout the year. Other non-agricultural water users were also included in small purveyor pumping. These include dairies and poultry farms, and water use was determined based on available head counts or estimates of the number of chickens, cows, etc. The rate of return flow for small purveyors was assumed to be the same as domestic water use, or 25% of the extracted volume. Loss due to distribution leaks was assumed negligible due to the relatively small coverage of these systems. During the model calibration period from 1977 through 2016, return flow from small purveyors averaged 10 acre-ft/yr in the NCMA and 95 acre-ft/yr in the NMMA (Figure 25).

2.7.1.6 Return Flow from Agricultural Use

Agricultural return flow from the irrigation of crops is dependent on irrigation efficiencies and soil type, which vary spatially, by crop type, and through time. Applied water in excess of crop demand as a result of inefficiencies in the irrigation system was assumed to return to the aquifer. Agricultural return flow averaged 1,196 acre-ft/yr in the NCMA, 1,488 acre-ft/yr in the NMMA, and 6,981 acre-ft/yr in the SMVMA for the period from 1977 through 2016 (Figure 26).

2.7.1.7 Return Flow from Golf Course Irrigation

Return flow in the Phase 1B Model area is also generated from irrigation of the Pismo Beach Golf Course, Monarch Dunes, Cypress Ridge, and Black Lake golf courses. All golf courses return flows were lumped with the municipal return flows except for the Pismo Beach Golf Course. Pumping for the Pismo Beach Golf Course was not available and was estimated by using standard crop evapotranspiration rates for a grassy area. During the model calibration period (1977 through 2016), return flow from golf course irrigation at Pismo Beach Golf Course averaged 14 acre-ft/yr in the NCMA and 165 acre-ft/yr in the NMMA (Figure 27).

2.7.1.8 Artificial Recharge

In the Phase 1B Model area, artificial recharge includes the spreading of stormwater and treated wastewater from the City of Pismo Beach and SSLOCSD WWTPs. The locations of the stormwater and wastewater infiltration ponds are shown on Figure 3. Discharge requirements for the Nipomo Community Services District Southland Wastewater Treatment Facility (Order No. R3-2012-0003; Regional Board 2012) found that spreading in the WWTP infiltration ponds, located in the northern portion of the NMMA, did not reach the water table due to the presence of very low permeability materials in the subsurface. This same report documented the fact that the infiltrated water formed a localized egg-shaped perched aquifer. Because this flux never reached the surficial aquifer being modeled, the flux from Southland was removed from the model. In other locations where no evidence of such impediment was documented, infiltration was applied to the next active layer when layer 2 was dry to avoid dry cell issues which would cause the model to ignore injection wells that represent these fluxes. Artificial recharge from 1977 through 2016 averaged approximately 280 acre ft/yr in the NCMA and 21 acre ft/yr in NMMA (Figure 28).

2.7.1.9 Underflow Inflow

The southern boundary of the active model area intersects the Santa Maria River Valley Groundwater Basin along the Santa Maria River. This boundary is represented by a GHB to simulate groundwater underflow across the boundary and percolation from the Santa Maria River (Figure 3). Subsurface inflow is also accounted for in the Arroyo Grande Creek using a GHB. A small amount of underflow from the Pismo Formation is also thought to occur in the northern model area, along the model boundary with the hills between Pismo and Arroyo Grande Creeks. Todd Engineers (2007) reported that, based on a review of water levels and groundwater contours from DWR (2002), there is little groundwater flow into the basin across the northern boundary of the NCMA. Therefore, this underflow was assumed to be negligible. The model-calculated underflow inflow through the GHBs in the SMVMA averaged 23,149 acre-ft/yr for the time period from 1977 through 2016 (Figure 29). Underflow from Arroyo Grande Creek Valley was estimated to average 400 acre-ft/yr over the same time period.

2.7.2 Groundwater Discharge Terms

2.7.2.1 Municipal Pumping

Groundwater pumping represents a significant source of discharge from the Phase 1B Model. Municipal pumping records were obtained from public and private water agencies operating within the model area. The locations of municipal wells are shown on Figure 30. Pumping for each well was assigned to model layers based on screen interval information. For wells screened in multiple aquifers, a portion of the well's total production was apportioned to each aquifer according to the screened interval of the well and the transmissivity. Annual municipal pumping from 1977 through 2016 is provided on Figure 31, which averaged approximately 1,600 acre-ft/yr for the NCMA, and 4,113 acre-ft/yr for the NMMA. No municipal pumping was reported for the portion of SMVMA covered by the model.

2.7.2.2 Small Purveyor Pumping

During the model calibration period from 1977 through 2016, small purveyor pumping averaged 49 acre-ft/yr in the NCMA and 371 acre-ft/yr in the NMMA (Figure 32).

2.7.2.3 Agricultural Pumping

Unlike municipal pumping which is directly measured from metered water wells, agricultural pumping is largely unmetered and was therefore estimated indirectly. Various studies in the area have estimated agricultural pumping in the past using assorted techniques. Type curves for different crop types were established for each management zone. These curves illustrate the relationship between agricultural water demand (or the evapotranspiration of applied water) and annual precipitation, and were used along with assumed irrigation efficiencies to develop estimates of agricultural pumping (refer to GEOSCIENCE 2018a for additional information). Agricultural pumping locations were based on land use and are shown on Figure 3. In the Vienega Valley and part of NCMA, actual agricultural well locations were determined using a combination of detailed aerial photo (Google Earth) analysis and existing well log locations. Estimated pumping was then distributed to these wells.

Based on recommendations from the TAC and available screened intervals for a handful of agricultural wells, the agricultural pumping was distributed between layers according to an area-specific scheme. In the NCMA, 100% of the pumping was assumed to occur from the alluvium in the Cienega Valley area, while 100% of the pumping was assumed to occur from the Paso Robles Formation outside of the Cienega Valley. In the NMMA, 80% of the pumping was assumed from the Paso Robles and 20% from the upper Careaga Sands (layer 8). No pumping occurred in the dune sand or alluvium. In the SMVMA, the three main aquifers (Recent Alluvium/ Young and Old Dune Sand, Paso Robles Formation, and Careaga Sand) were pumped at 30%, 50%, and 20%. Pumping from wells completed in the Careaga Sand was assigned to the upper part (model layer 8). Total agricultural pumping during the period from 1977 through 2016 averaged 2,999 acre-ft/yr in the NCMA, 4,466 acre-ft/yr in the NMMA, and 23,103 acre-ft/yr in the SMVMA (Figure 33).

2.7.2.4 Golf Course Pumping

During the model calibration period (1977 through 2016), pumping for golf course irrigation averaged 96 acre-ft/yr in the NCMA (Figure 34). This pumping only reflects that from the Pismo Beach Golf Course. Additional golf course pumping in the NMMA – Cypress Ridge, Monarch Dunes, and Blacklake – was not provided independently of municipal pumping and so are included in the values provided for municipal wells.

2.7.2.5 Underflow Outflow to the Ocean and Offshore Aquifer

While water level contours indicate that the primary groundwater flow direction is towards the ocean, a localized reversal of groundwater gradients from groundwater pumping can cause seawater intrusion. Underflow outflow to the ocean proper is anticipated to occur only through the interface of model layer 2 with the coast. Underflow across the coastal line in the other model layers is assumed to continue through the aquifer offshore. As documented in the Santa Maria Valley Characterization Study (Fugro, 2015) and by DWR (1979), this offshore aquifer extends upwards of 10 miles from the shoreline. Underflow inflow and outflow to the ocean and offshore aquifer represent model-calculated values. During the model calibration period from 1977 through 2016, underflow outflow to the ocean through model layer 2 averaged 1,092 acre-ft/yr in the NCMA, 274 acre-ft/yr in the NMMA, and 1,029 acre-ft/yr in the SMVMA. (Figure 35). During this same time period, underflow outflow to offshore aquifers averaged 1,490 acre-ft/yr in the NCMA, 533 acre-ft/yr in the NMMA, and 3,793 acre-ft/yr in the SMVMA (Figure 36).

2.8 Model Calibration

2.8.1 Calibration Process

The method of calibration used for the Phase 1B Model was the industry standard "history matching" technique, which involves adjusting model parameters to produce the best-fit between simulated and observed groundwater system responses. During the process of calibration, model parameters are adjusted using reasonable anticipated values until model-generated water levels and concentrations match historical observations. Parameters that were adjusted during model calibration include:

- Horizontal and vertical hydraulic conductivity,
- Storativity,
- Streambed conductance,
- Mountain front recharge,
- HFB conductance,
- Dispersivity, and
- Effective porosity.

These parameters were chosen to help minimize non-uniqueness. Basically, parameters with more reliable estimates or established estimation techniques are kept constant while more uncertain ones are varied for calibration. Hydraulic parameters (hydraulic conductivity, storage, conductance, etc.) are usually poorly known as most estimates are point estimates over a large area and inferred spatially. Therefore, they are typically the parameters estimated by calibration.

The CCB Phase 1B Model calibration consisted of:

- Steady-state flow calibration (1977), and
- Transient flow and solute transport calibration from 1977 through 2016 using monthly stress periods.

In addition, the model was calibrated in a multi-step process involving external review of initial calibration results by the TAC and implementation of revisions to the model as part of subsequent calibration efforts. From a calibration quality perspective, it was decided to prioritize a reflection of local understanding of the regional area over matching localized observations.

2.8.2 Steady-State Flow Model Calibration (1977)

Initial steady-state calibration of the Phase 1B Model was carried out for the beginning of the model period (i.e., 1977). This model run is not intended to be a stand-alone predictive tool and should not be utilized for prediction purposes due to the high uncertainty associated with the lack of water level data from 1977. Rather, the goal of steady-state calibration is to model an acceptable water level distribution based on observed water levels. This also serves as a reality check for model boundaries and various fluxes. The resultant parameter values for the steady-state calibration were thereafter used as initial values for the transient calibration. In addition, starting from a steady state water level distribution helps ensure that the model run starts with a more stable water level – minimizing convergence and unrealistic early runtime water level fluctuation issues.

The steady-state calibration process used water level measurements from 63 calibration target wells to match model-calculated head values against the measured values (Figure 37). Figure 38 shows a scatter plot of measured versus model-calculated water levels. As can be seen, most of the points are clustered around a diagonal line (representing where measured water levels match model-calculated water levels), or at least fall within one standard deviation of the residuals. This reflects a good match between measured and model-calculated water levels. In addition, the relative error is below 10% which is a good indicator of goodness of fit (Environmental Simulations, Inc., 1999). Figure 39 shows the spatial distribution of the residuals. Most of the water levels that are underestimated by the model are located north of the Santa Maria River Fault where the major aquifers tend to thin. Here, some perched aquifer conditions might exhibit more local trends rather than a regional behavior. These areas are usually not contoured by the NMMA-TG, and GEOSCIENCE was advised by the TAC not to try to match these water levels. Figure 40 shows model-calculated steady state water levels for all three major aquifers. The simulated steady state water levels show the overall regional flow direction is towards the ocean.

Water level residual statistics are summarized in the table below.

Table 2-3. CCB Phase 1B Groundwater Flow Model Steady-State Calibration Statistics (1977)

Statistic	Value
Mean Residual[1]	5.7 ft
Absolute Mean Residual	19.8 ft
Minimum Residual	-29.3 ft
Maximum Residual	76.9 ft
Standard Deviation of Residual	19.1 ft
Relative Error[2]	**6.4 %**

[1] Residual = measured head less predicted head

[2] Relative Error = standard deviation of the residuals divided by the observed head range

Relative error of the residuals (i.e., standard deviation of the residuals divided by the observed head range) was also calculated to evaluate the model calibration quantitatively. Common modeling practice is to consider a good fit between historical and model predicted data if the relative error is below 10%

(Environmental Simulations, Inc., 1999). As seen in the table above, the relative error for the steady state calibration is 6.4%, which is below the recommended error of 10%.

2.8.3 Transient Flow Model Calibration (1977-2016)

The transient model calibration covers the period from January 1977 through December 2016 with a monthly stress period[3]. The results of the initial steady-state calibration provided initial aquifer parameter estimates and groundwater elevations for the transient flow model calibration (Figure 40). 7,280 measured water levels from a total of 136 target wells were used for the transient flow model calibration (Figure 41). However, given uncertainty in many of the measured water levels, transient model calibration focused on a second set of target wells composed of key wells that were considered more reliable by both the NCMA and NMMA. A scatter plot of model-calculated water levels versus measured water levels is shown on Figure 42a for all target wells and on Figure 42b for key, or curated, wells used by both the NCMA and NMMA for establishing groundwater contours.

Figure 43 shows a histogram of water level residuals of 7,280 water level measurements from the 136 wells, and Figure 44 shows the spatial distribution of residuals (for all target wells) for the last 10 years of the model calibration period (average of 2007 through 2016). In addition, the distribution of water level residuals for all target wells through time was plotted on Figure 45. Figure 45 shows that the average water level residual is randomly distributed over the calibration period and is not particularly correlated with wet or dry periods.

Transient flow calibration statistics are summarized in the following table.

[3] Stress period is the time length used to change model parameters such as pumping and natural recharge.

Table 2-4. CCB Phase 1B Groundwater Flow Model Transient Calibration Statistics (1977-2016)

Statistic	All Target Wells	Key Wells
Mean Residual[1]	2.2 ft	-1.1 ft
Absolute Mean Residual	16.4 ft	9.6 ft
Minimum Residual	-22.5 ft	-35.7 ft
Maximum Residual	97.2 ft	61.8 ft
Standard Deviation of Residual	16.4 ft	9.6 ft
Relative Error[2]	8.6%	8.5 %

[1] Residual = measured head less predicted head

[2] Relative Error = standard deviation of the residuals divided by the observed head range

As shown in Figures 42a and 42b, the water level residuals for the transient calibration are mainly clustered around a straight line. The calibration is further supported by a relative error 8.6% for all target wells and 8.5% for key wells, which is below the recommended error of 10%. While the relative error is similar using all target wells and just the key wells, the standard deviation of the residual is significantly lower when only considering key wells. Some of the higher residuals are located at target wells located north of the Santa Maria River Fault. At the recommendation of the TAC, less effort was put into calibrating the Phase 1B Model in this area because there is still quite a bit of uncertainty associated with the hydrogeology in this area. It is not clear if these aquifers are continuous with regional aquifers. This should be addressed through future generations of the model.

Selected hydrographs for the Recent Alluvium/Young and Old Dune Sand, Paso Robles Formation, and Careaga Sand aquifers are shown on Figures 46 through 48, respectively. Other calibration hydrographs are provided in Appendix B. In general, the patterns of the model-simulated and measured water levels are similar in that the model appears to capture the long- and short-term temporal trends in groundwater levels in most parts of the model area. Model-calculated water levels in Spring 2016 (April 2016) and Fall 2016 (October 2016) are shown on Figure 49 and Figure 50.

Similar to what was stated in Section 2.8.2, most of the large residuals occurred north of the Santa Maria River Fault where uncertainty regarding aquifer behavior is high and the TAC advised to not pursue exact matching. Wells in agricultural areas may also show some discrepancies as actual location of pumping wells, pumping rates, and pumping distribution over time were not known. Many well locations were inferred from parcel centroids and a handful of known well locations and screens.

Summaries of the average annual water budgets for the NCMA, NMMA, and SMVMA from 1977 through 2016 are provided as Figures 51 through 53 and detailed in Tables 1 through 3. As shown, the calibration period shows a higher annual total outflow than total inflow in each management area, resulting in an annual average change in groundwater storage of approximately -36 acre-ft/yr in the NCMA, -566 acre-ft/yr in the NMMA, and -511 acre-ft/yr in the SMVMA. This is generally evidenced by slightly declining water levels in much of the model area. In the NMMA, the majority of the storage decline has occurred in recent years – with water levels being relatively steady for the majority of the simulation period (refer to Tables 1 through 3 for annual changes in groundwater storage).

It should be noted that from a groundwater basin standpoint, the deficit may be a bit higher since domestic wells and rural pumping were not accounted for and were assumed negligible. This is especially true in NMMA, where rural pumping is generally higher than in the NCMA. The annual and cumulative changes in groundwater storage are shown on Figure 54.

2.8.4 Stream Flow Calibration

For the reasons described in Section 2.7.1.3, calibration to flow data from the Arroyo Grande Creek was not pursued.

2.8.5 Variable Density Flow Calibration (1977-2016)

2.8.5.1 TDS Solute Transport Model Assumptions

A few assumptions were made to estimate TDS loads from the water budget components and boundaries. Because these loads are not known, they contribute to uncertainty in the TDS solute transport model. The initial concentration was estimated using very sparse data that were averaged both temporally and spatially, because most TDS concentration data did not go back as far as 1977. In addition, all the available data were aggregated by aquifer, yielding three basic distributions for the Alluvium/Dune Sand, the Paso Robles Formation, and the Careaga Sands. For agricultural return flow, an evapoconcentration factor of 3 was assumed – indicating that TDS concentrations in agricultural return flows is three (3) times that of the initial water used for irrigation due to the effects of ET. Typical evapoconcentration values range from 3 to 5. In addition, because the concentration of the water used for irrigation was unknown, the maximum contaminant level (MCL) of 500 mg/l was used as an initial value. Therefore, the TDS concentration of agricultural return flow was assumed to be 1,500 mg/l. For GHBs, the concentration of underflow over time was not available. Instead, it was assigned an initial concentration that coincided with the location. Areal recharge and streambed percolation were considered relatively fresh and were assigned a concentration of 500 mg/l based on average TDS values from Lopez Reservoir. A baseline concentration of 400 mg/L was assumed for urban flows, with a return flow concentration of 800 mg/l, assuming an evapoconcentration factor of 2.

2.8.5.2 Solute Transport Model Implementation

The solute transport model relies on data from the groundwater flow model (e.g., seepage velocities and flow directions). The flow in and out of each model cell is read by SEAWAT and used to track concentrations of TDS.

The solute transport model calibration process used measurements from calibration targets shown on Figure 55 to match model-simulated TDS concentrations against measured values. Wells screened in more than one layer were not used for calibration as their concentration would be a mix of various layers. Model parameters (i.e., effective porosity and dispersivity) were adjusted until a good match between measured and model-generated TDS concentrations were achieved. The 1977 initial conditions for TDS were based on measured concentrations or estimated from historical concentration trends (Figure 56).

Measured versus model-generated TDS concentrations through time for target wells along the coast and inland are shown on Figures 57 and 58, respectively. Model-calculated TDS concentrations at the end of the calibration period (2016) are shown on Figure 59.

Calibration statistics used for water levels are not well suited for solute transport modeling because of the following reasons: (1) concentration values can vary over many orders of magnitude, (2) concentration measurements are often scarce spatially, and (3) simulated point concentration depends on the particular representation of heterogeneity in the model, though the prediction of interest maybe averaged (Hill and Tiedeman, 2007). Therefore, the assessment of goodness of fit was done visually. The model did not capture the TDS spike observed in Fall 2009 due to the fact that the location of the saltwater-freshwater interface was unknown. An iterative procedure which tests various locations of the interface until a good match can be achieved can be implemented. However, WSC agreed that such an approach would be time consuming and still have some associated uncertainty. A second phase will include a geophysical survey which will help identify the actual location of the saltwater-freshwater interface. This information will then be used to update and refine the model. In addition, even though the model did not predict the elevated TDS in Fall 2009, it predicted an increase of inflow from offshore aquifers during the period from 2004 through 2010 (Tables 1 through 3). It is possible that the TDS spike is due to this inflow from offshore aquifers, assuming that the offshore portions of the aquifers have higher TDS concentrations but that inflow is not necessarily directly from the ocean. This shows that the model can be used to predict saltwater intrusion by quantifying the change in inflow from the ocean and the offshore portions of the aquifers.

2.9 Sensitivity Analysis

A sensitivity analysis was performed on the calibrated Phase 1B Model. The purpose of the sensitivity analysis is to assess the model input parameters which have the greatest effects on the model's simulation results. For this analysis, the model's sensitivity was evaluated after first increasing the value of model input parameters by 50 percent (relative to the calibrated input value) and then decreasing the value of model input parameters by 50 percent. The following input parameters were varied for this analysis using a systematic approach:

- Areal Recharge
- Specific Yield
- Specific Storage
- Horizontal Hydraulic Conductivity, and
- Vertical Hydraulic Conductivity.

A sensitivity run was also made simulating the Santa Maria River Fault as a non-impediment to flow in order to assess the effect this fault has on simulated water levels.

The sensitivity analysis also included an assessment of the accuracy of estimated agricultural pumping volumes throughout the model domain and calibration period. To do so, estimated agricultural pumping was varied by 20%. This percentage was chosen as it approximately represents the amount of uncertainty that might be expected from estimating unmetered agricultural pumping on a regional scale (Faunt, 2009).

Figure 60 shows the normalized sensitivity for selected model parameters. Normalized sensitivity is the difference between the sum of squared residuals from the sensitivity run and the calibration run, divided by the sum of squared residuals of the calibration run. The greater the normalized sensitivity value, the more sensitive the parameters to the model residuals (i.e., the difference between model-generated and measured groundwater levels). Input parameter sensitivity is dictated by the magnitude of impact on groundwater level residuals resulting from increasing or decreasing the value of the input parameter.

The sensitivity analysis demonstrates the sensitivity of the model simulations and provides some indication as to the uncertainty of model input values. The sensitivity analysis indicates that the model is most sensitive to the presence of the Santa Maria River Fault as a groundwater flow barrier, increases in areal recharge, and decreases in specific storage. The model is also relatively sensitive to increases in agricultural pumping, which is one of the flux terms with the greatest amount of uncertainty.

3.0 MODEL LIMITATIONS AND UNCERTAINTY

The CCB Phase 1B Groundwater Flow and Solute Transport Model is a useful tool for evaluating water levels and water quality of the aquifer systems. However, it is a simplified approximation of a complex geohydrologic system. The accuracy of a model prediction is dependent upon the assumptions used. A reliable groundwater model depends upon accurate and abundant sources of measured data and a satisfactory calibration and/or validation period. Often, in absence of complete or accurate records, model input represents estimated and/or averaged values (e.g., private pumping, agricultural pumping, mountain front recharge, etc.). Specifically, sources of uncertainty in the model include:

- Uncertainty in recorded water levels (differences in observed elevation of up to 30 ft for the same well, same date, same measurement, but different source),
- High water levels north of the Santa Maria River Fault,
- The hydraulic influence of the Santa Maria River Fault and Wilmar Avenue Fault,
- The change in areal recharge in precipitation through time due to increased urbanization,
- Unknown sources of pumping not accounted for in the current version of the model (e.g., Woodlands Mutual Water Company beginning in 2016, Guadalupe Cooling Company in the SMVMA, rural domestic pumping, agricultural pumping for non-crop/non-orchard purposes, etc.),
- Streambed percolation from smaller or intermittent creeks/streams not currently accounted for in the model (e.g., Oso Flaco Creek),
- Return flow estimates,
- Unreliable Arroyo Grande Creek discharge at the 22nd Street Bridge,
- Potential effect of recharge from septic systems,
- Potential effect of Black Lake Canyon as an area of outflow for shallow groundwater, and the
- Lack of good information the location and extent of the perched aquifers.

Agricultural pumping, hydraulic conductivity of the Santa Maria Fault and the aquifers structure north of the Santa Maria River faults carry the most uncertainty. Further studies and data collection to improve accuracy for these parameters and features would help improve the model.

From a regional groundwater modeling perspective, it is expected that the model will not be able to match all wells in all parts of the model area due to local variability and uncertainty in observations. The goal of the model calibration was to match key wells with regional trends and improve the model over time through subsequent phases as more details are obtained and data becomes available. Therefore, the uncertainties mentioned above should be investigated further in future versions of the regional model. Future use of an extended data set and calibration period should continue to improve the accuracy and reliability of the model.

4.0 FUTURE MODEL EXPANSION AND IMPROVEMENTS

The model boundaries for the Phase 1B Model were determined by data constraints and inputs from the TAC. The TAC determined that the Willmar Avenue Fault was the effective northeastern boundary of the groundwater basin, separating the fringe areas. However, because the boundaries along the fringe areas are general head boundaries or locations of mountain front recharge, the model can be easily extended to include these areas as no new inflow terms would need to be created and the current conceptual model would still be valid. Recent studies of the fringe areas by GSI (2018) can help with future model revisions. Extending the model to include Ziegler Canyon and Southern Bluff would necessitate extending the model southward to include a larger portion of the SMVMA.

In addition, estimates of recharge terms such as mountain front recharge and recharge from areal precipitation could be improved by integrating a precipitation runoff or surface water model component to the groundwater flow model. This would include subsurface flows in the unsaturated zone and more accurately reflect recharge both temporally and spatially, rather than using a lumped approach such as the SCS curve method utilized for this Phase 1B Model. However, given the lack of quality data for Arroyo Grande Creek discharge within the model domain, the calibration of an integrated surface water/ groundwater model would be difficult and carry a lot of uncertainty. Additional information necessary for adding a surface water component to the Phase 1B groundwater flow model include updated land use (preferably multiple land use files to address changes in land use through time), soil type information, and stream channel characteristics (e.g., channel geometry, lining, etc.). Collection of good quality discharge data should be should be conducted before such an effort is undertaken. In addition, further review of geology and the creation of additional cross-sections, particularly in the northern NMMA where perched aquifer units and springs are present, could also help refine shallow layers and capture the complex hydrogeology in this area.

5.0 CONCLUSIONS

The Phase 1B Model was created to support a future basin-wide groundwater/surface water flow model by refining the current (Phase 1A) model with additional approved data and analysis and by expanding the model to cover the entire NCMA and NMMA, and part of the SMVMA. The Phase 1B Model was calibrated for the period from January 1977 through December 2016. Through use of a three-dimensional lithologic model, the locations of the model layer boundaries and hydraulic conductivities were able to be defined for a more accurate representation of the aquifer system. The calibrated flow model has a relative error of 8.6%, which is below the recommended error of 10%. In addition, despite the fact that the model did not predict the elevated TDS observed in 2009, it predicted the increase of inflow from offshore aquifers, which can be used to assess the potential for saltwater intrusion during scenario runs. A geophysical survey scheduled for Phase 2 will be used to refine and update the model by providing a more accurate location of the saltwater-freshwater interface.

6.0 REFERENCES

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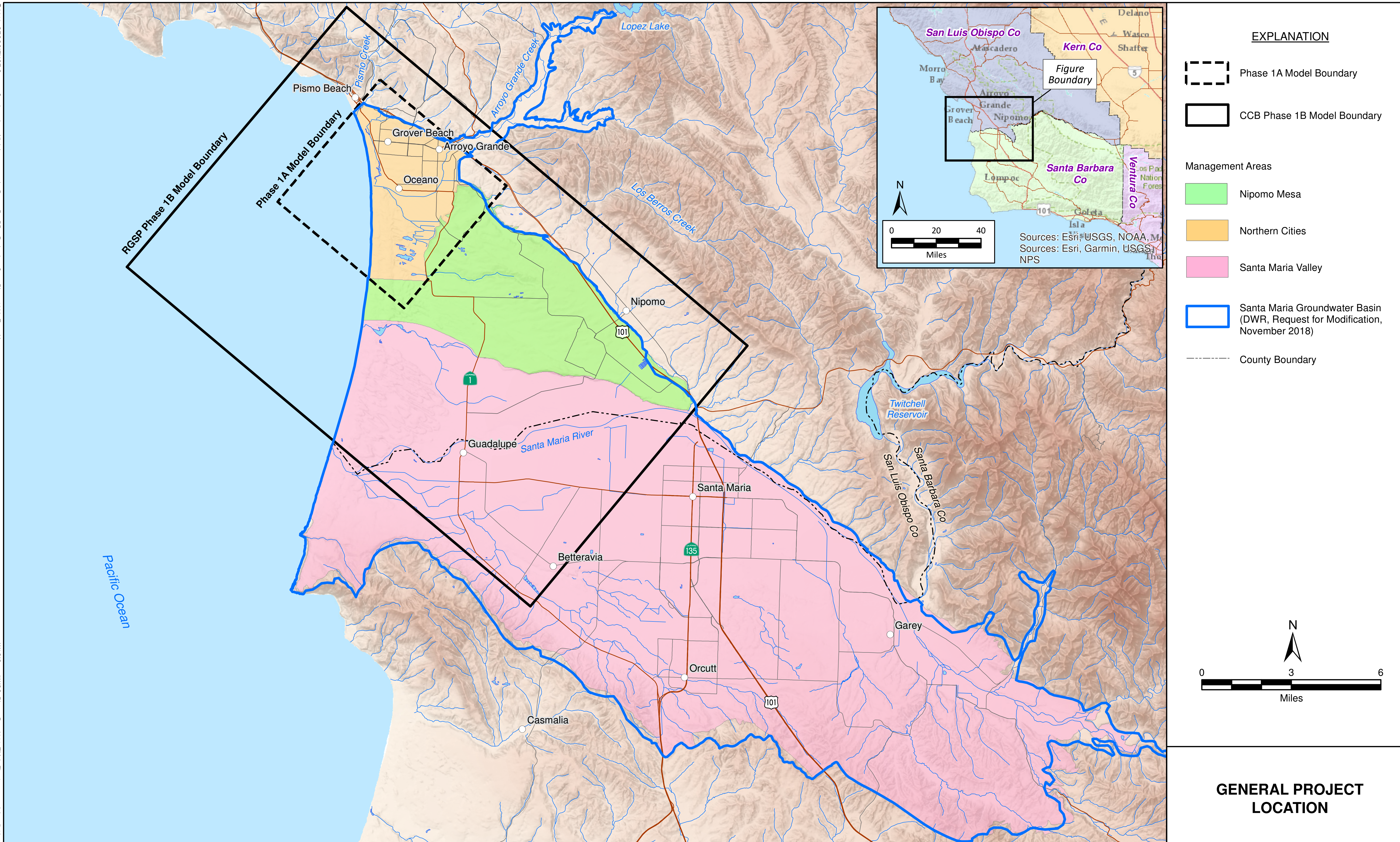
FIGURES

GEOSCIENCE



GENERAL PROJECT LOCATION

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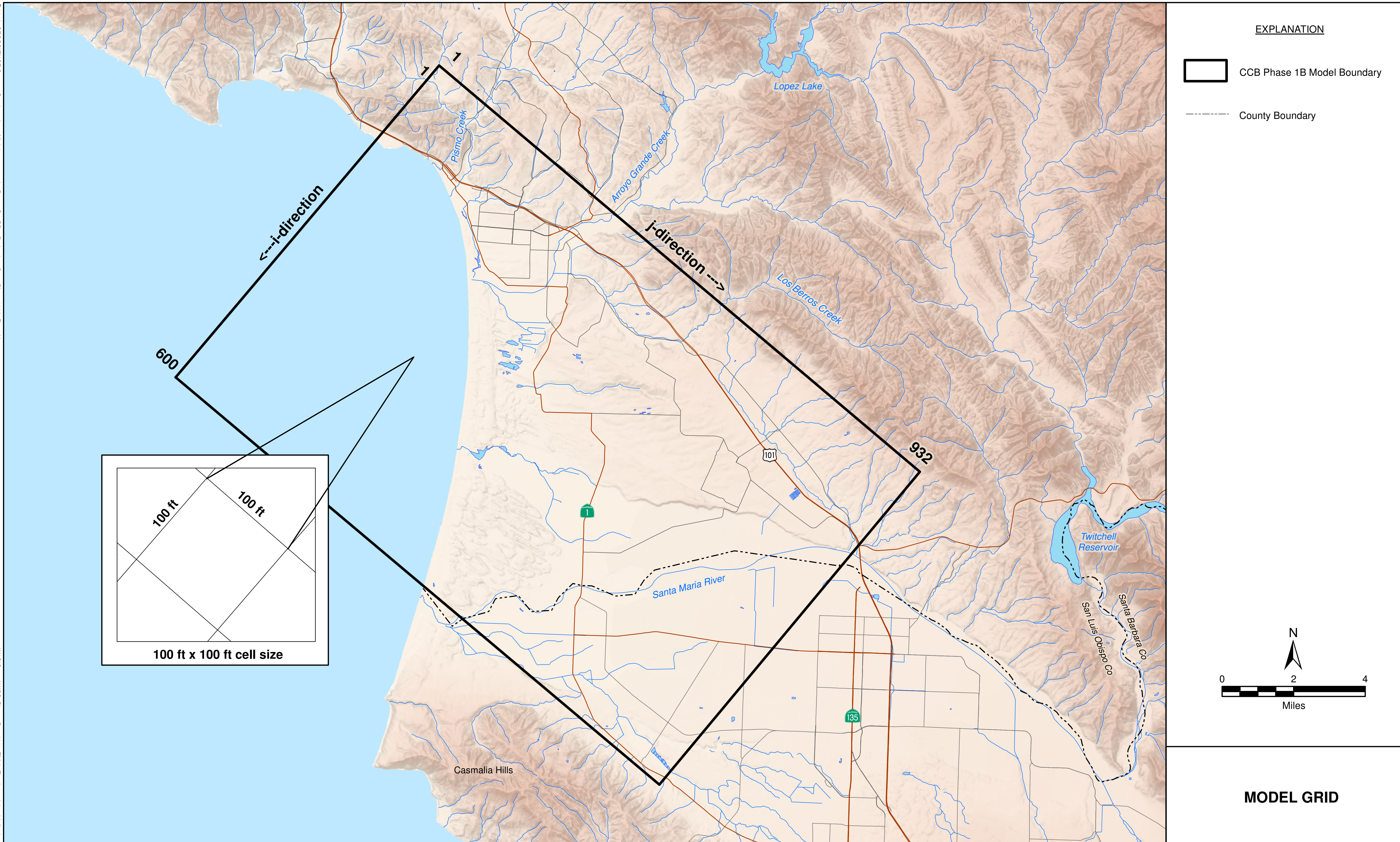
FIGURE 1

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE



MODEL GRID

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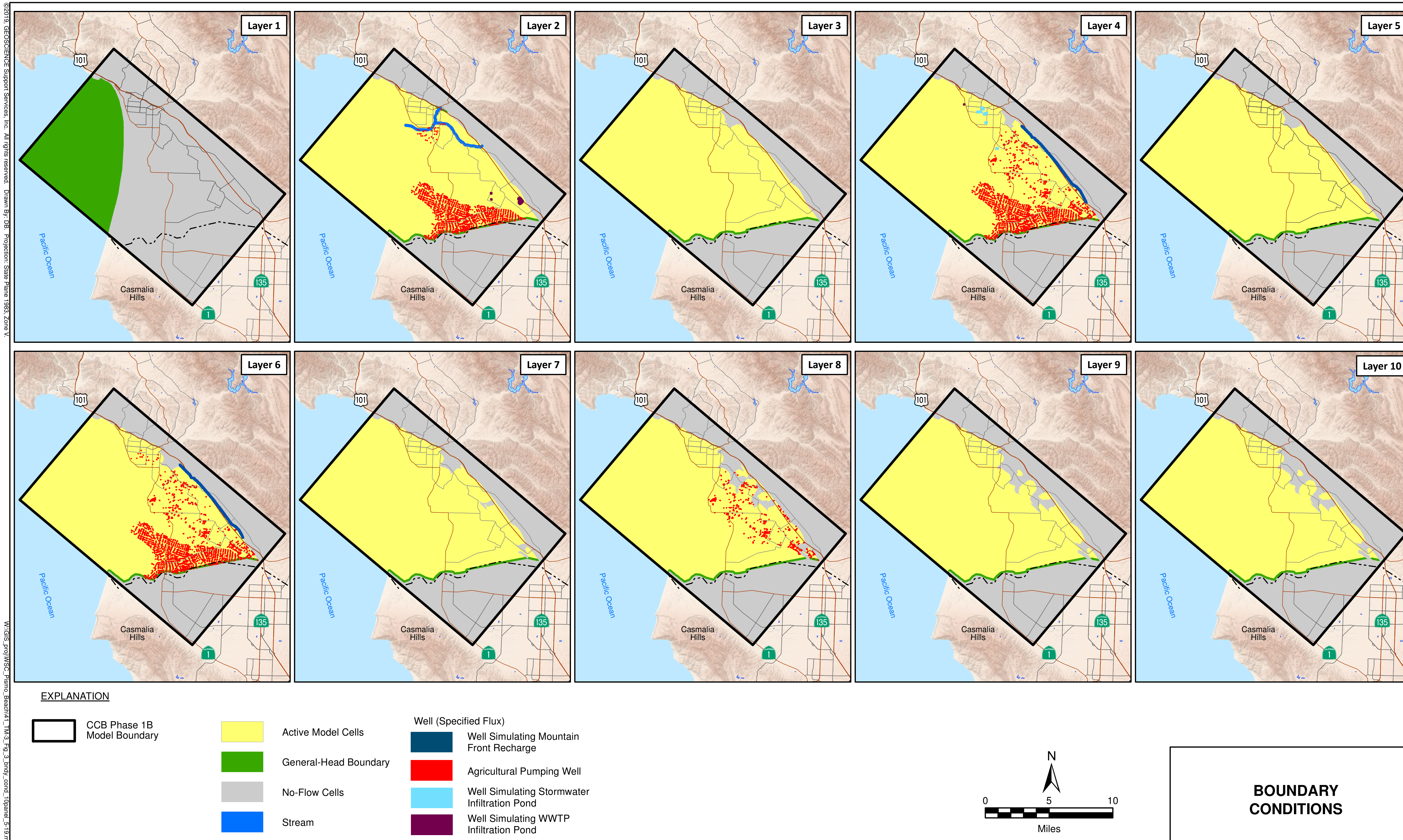
FIGURE 2

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE



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BOUNDARY CONDITIONS

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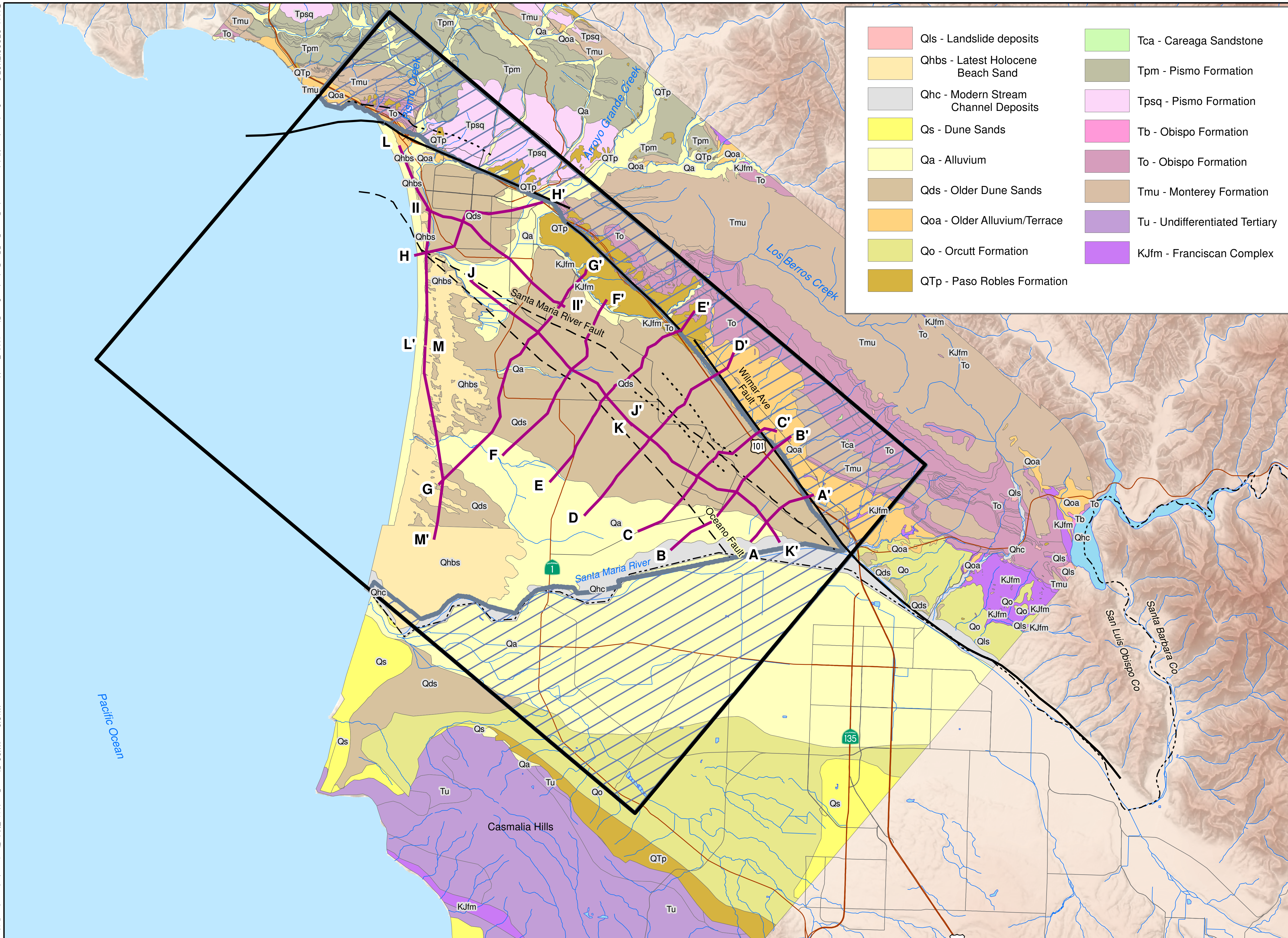
FIGURE 3

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE



EXPLANATION

CCB Phase 1B Model Boundary

CCB Phase 1B Inactive Model Area for GEOSCIENCE Model

Cross-Section Line

Fault - Confirmed

Fault - Approximate

Fault - Concealed

Source of Faults:
(Fugro, 2015)

Source of Geology:
(County of San Luis Obispo, 2015; Dibblee, 1994; Dibblee and Ehrenspeck 1989; Dibblee and Minch, 2006a-d; LSCE, 2017; Ludington et al., 2007; and McLean, 1995)

N

0 2.5 5

Miles

GEOLOGIC SETTING

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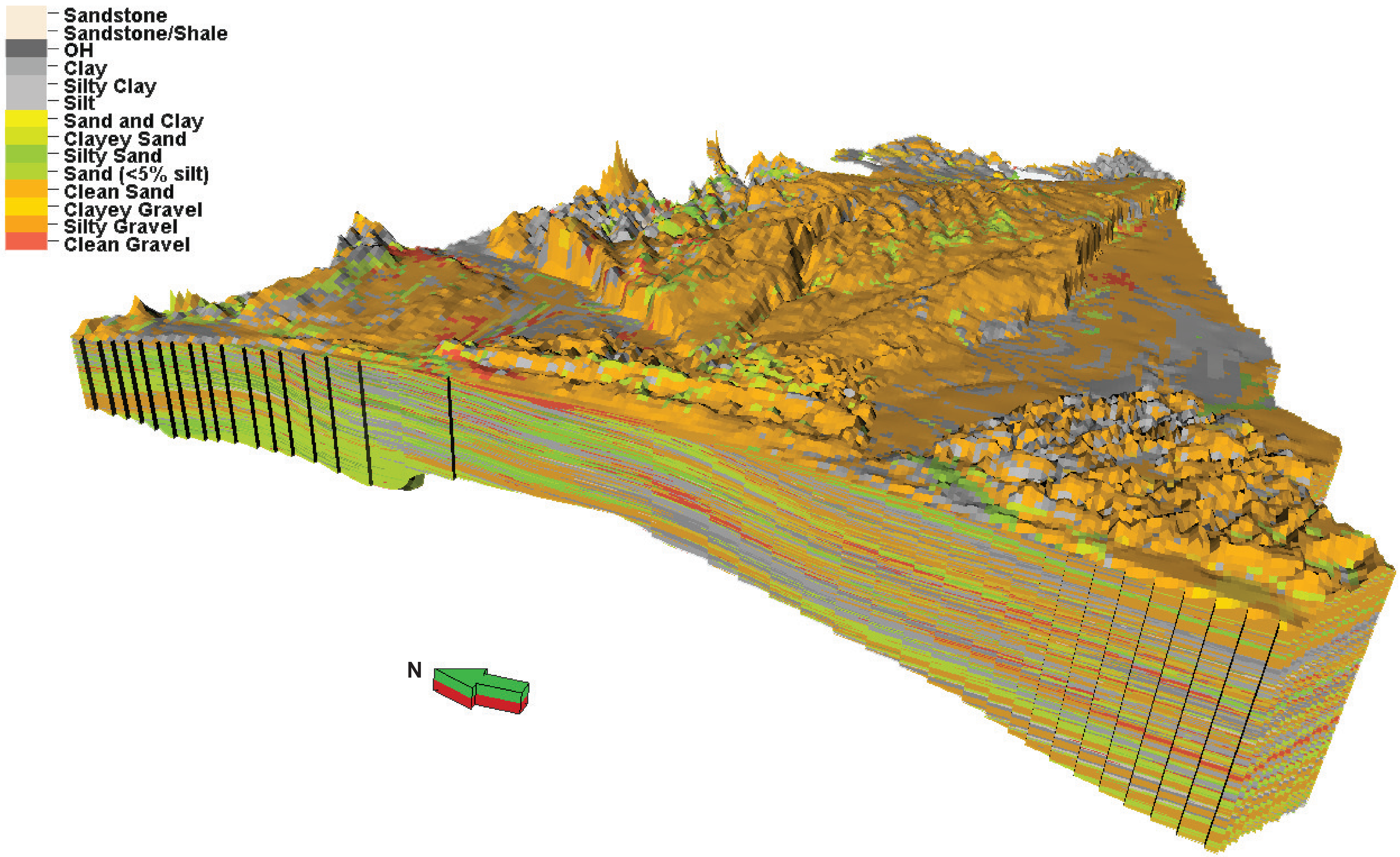
FIGURE 4

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE

EXPLANATION



3-D VIEW OF THE LITHOLOGIC MODEL

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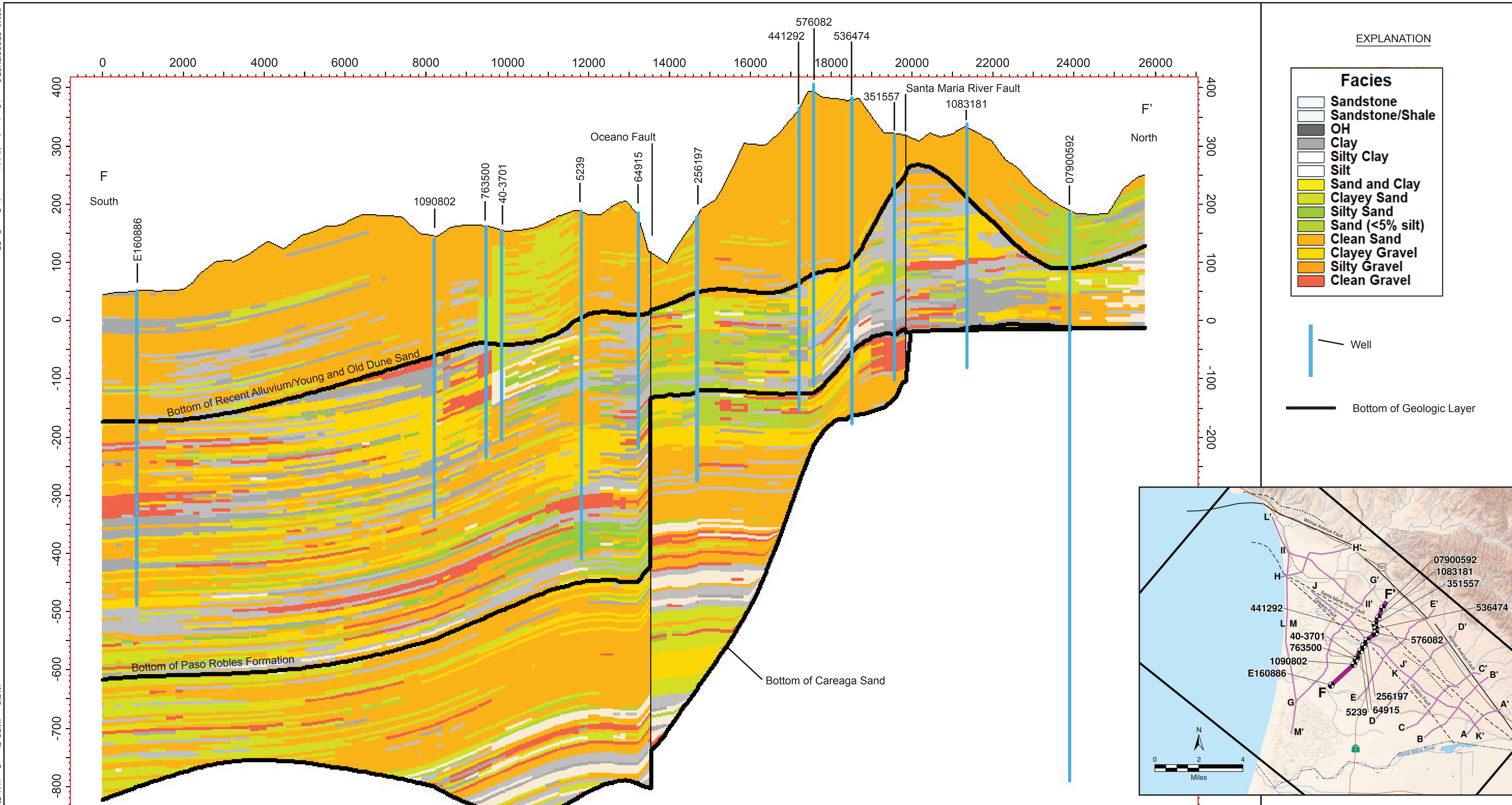
CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

FIGURE 5

GEOSCIENCE



CROSS-SECTION F-F'

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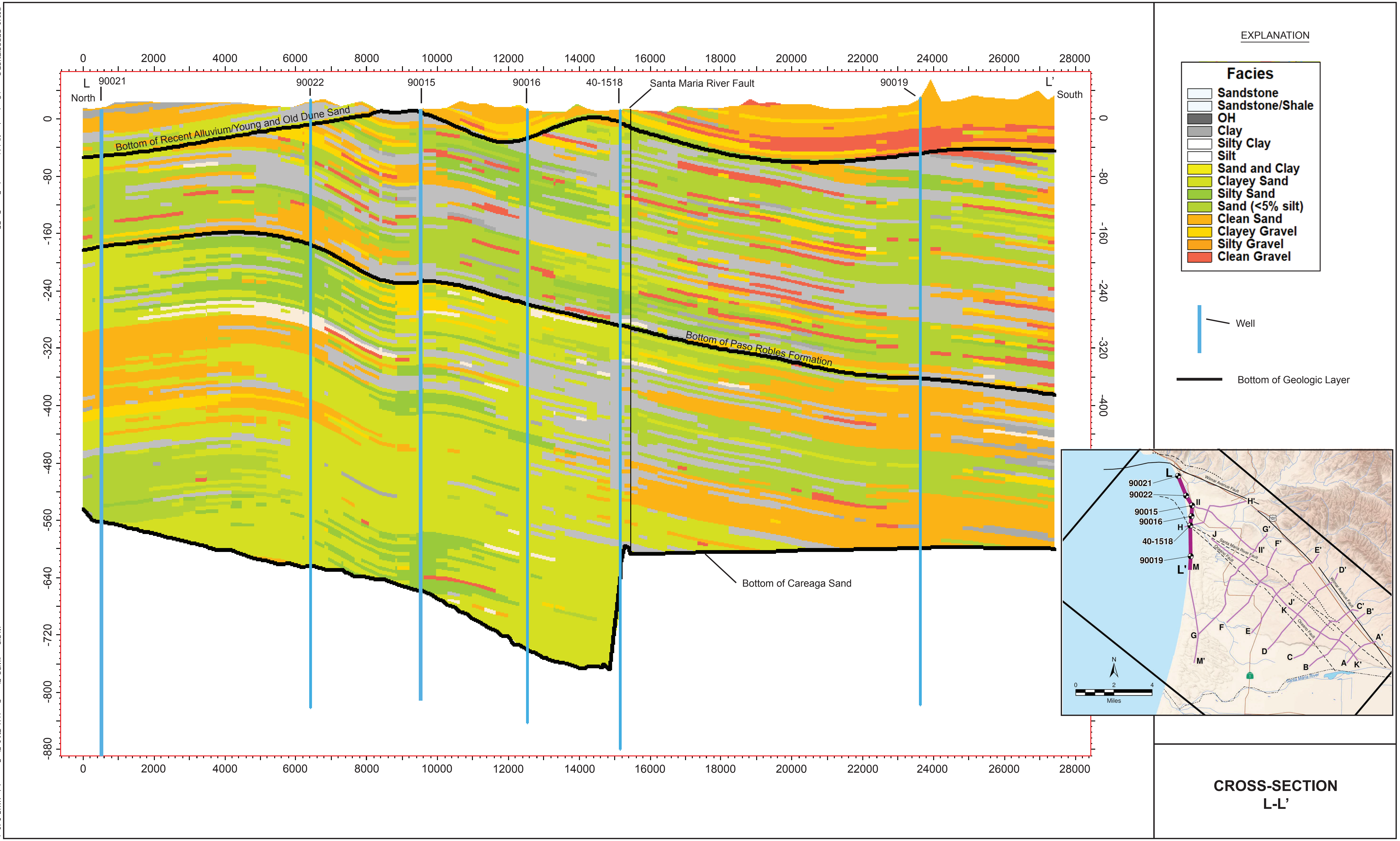
CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

FIGURE 6

GEOSCIENCE



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CROSS-SECTION L-L'

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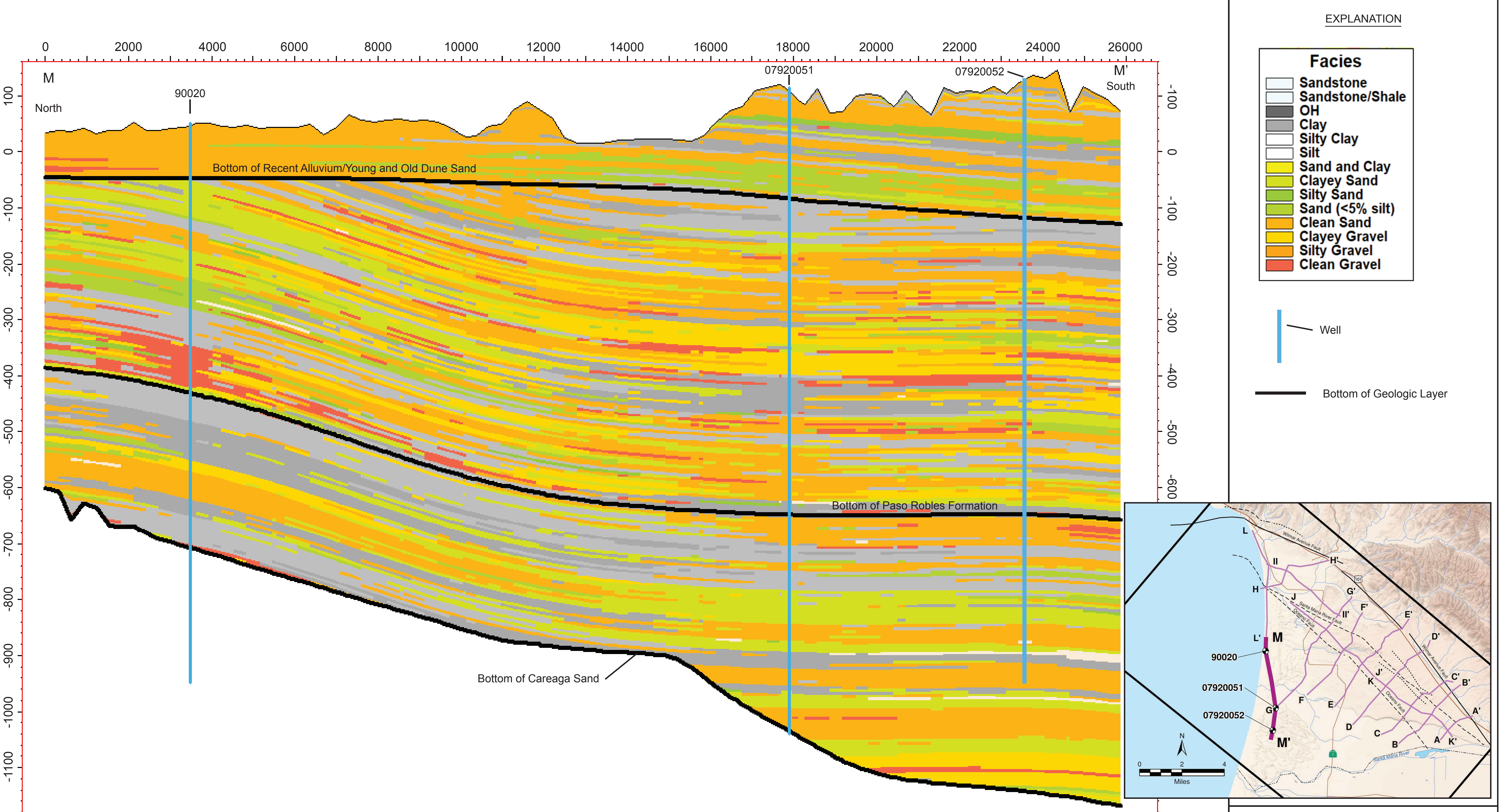
CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

FIGURE 7

GEOSCIENCE



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CROSS-SECTION M-M'

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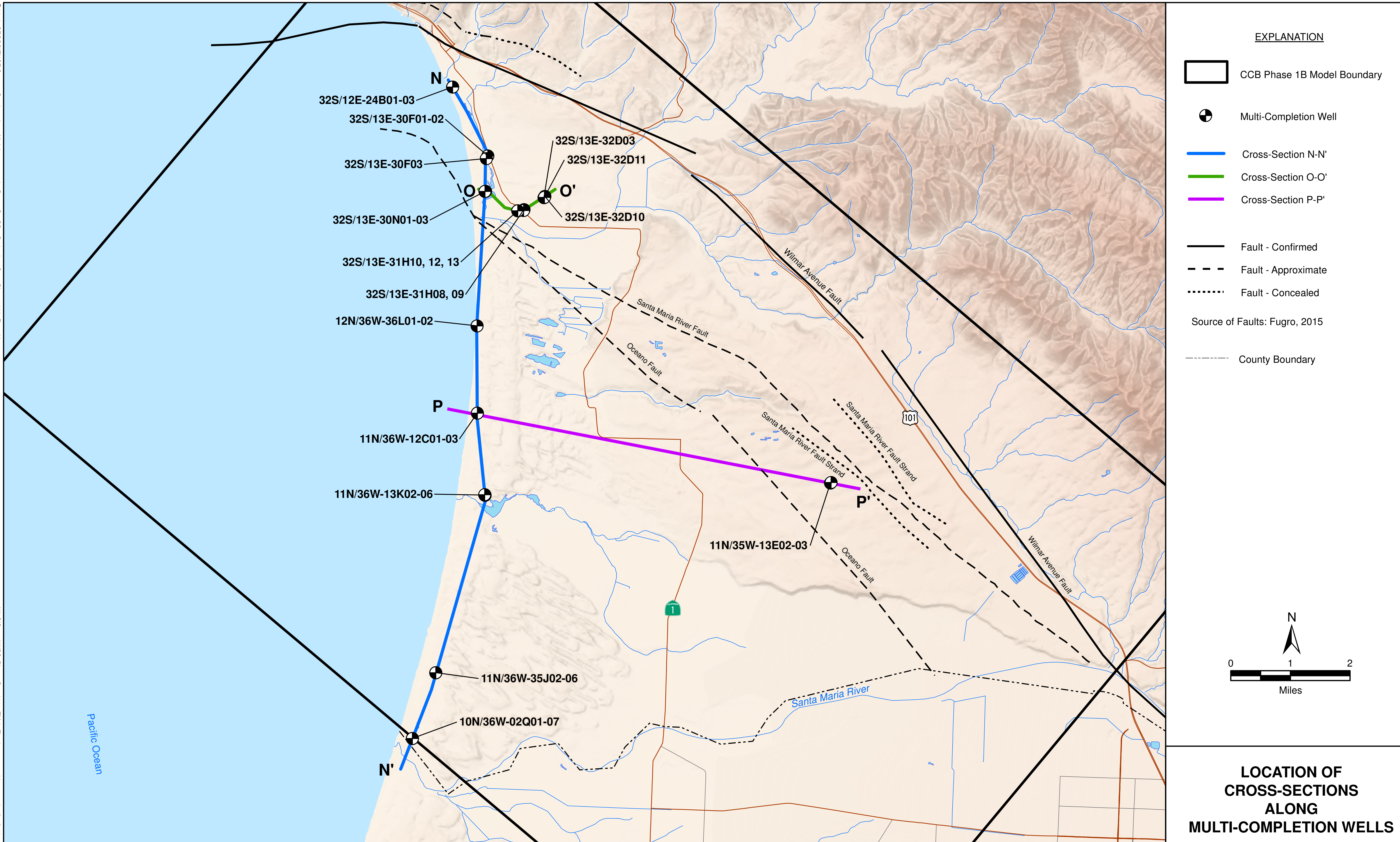
CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

FIGURE 8

GEOSCIENCE



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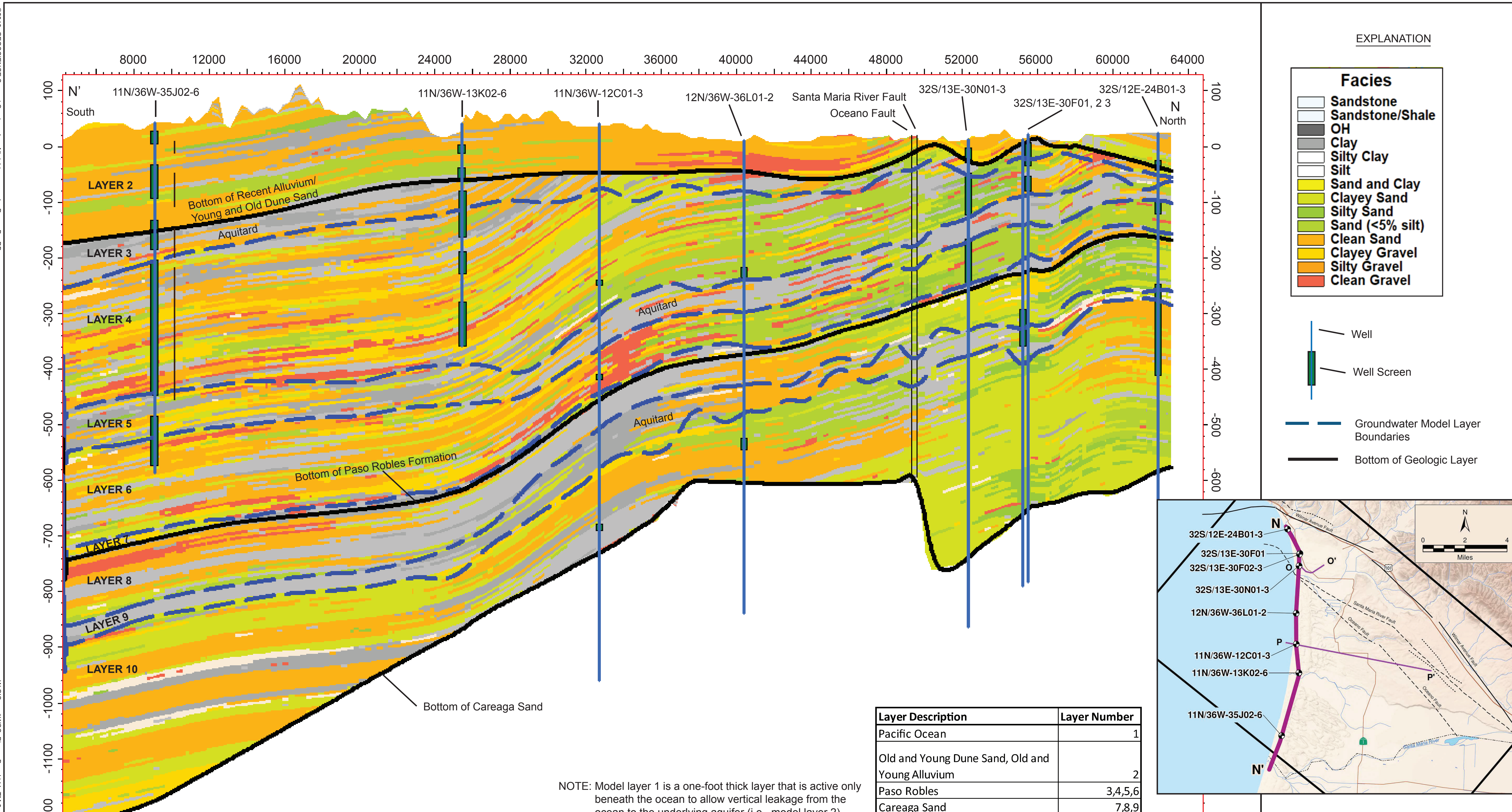
LOCATION OF CROSS-SECTIONS ALONG MULTI-COMPLETION WELLS

FIGURE 9



Layer Description	Layer Number
Pacific Ocean	1
Old and Young Dune Sand, Old and Young Alluvium	2
Paso Robles	3,4,5,6
Careaga Sand	7,8,9

CROSS-SECTION N-N' SHOWING GROUNDWATER MODEL LAYERING

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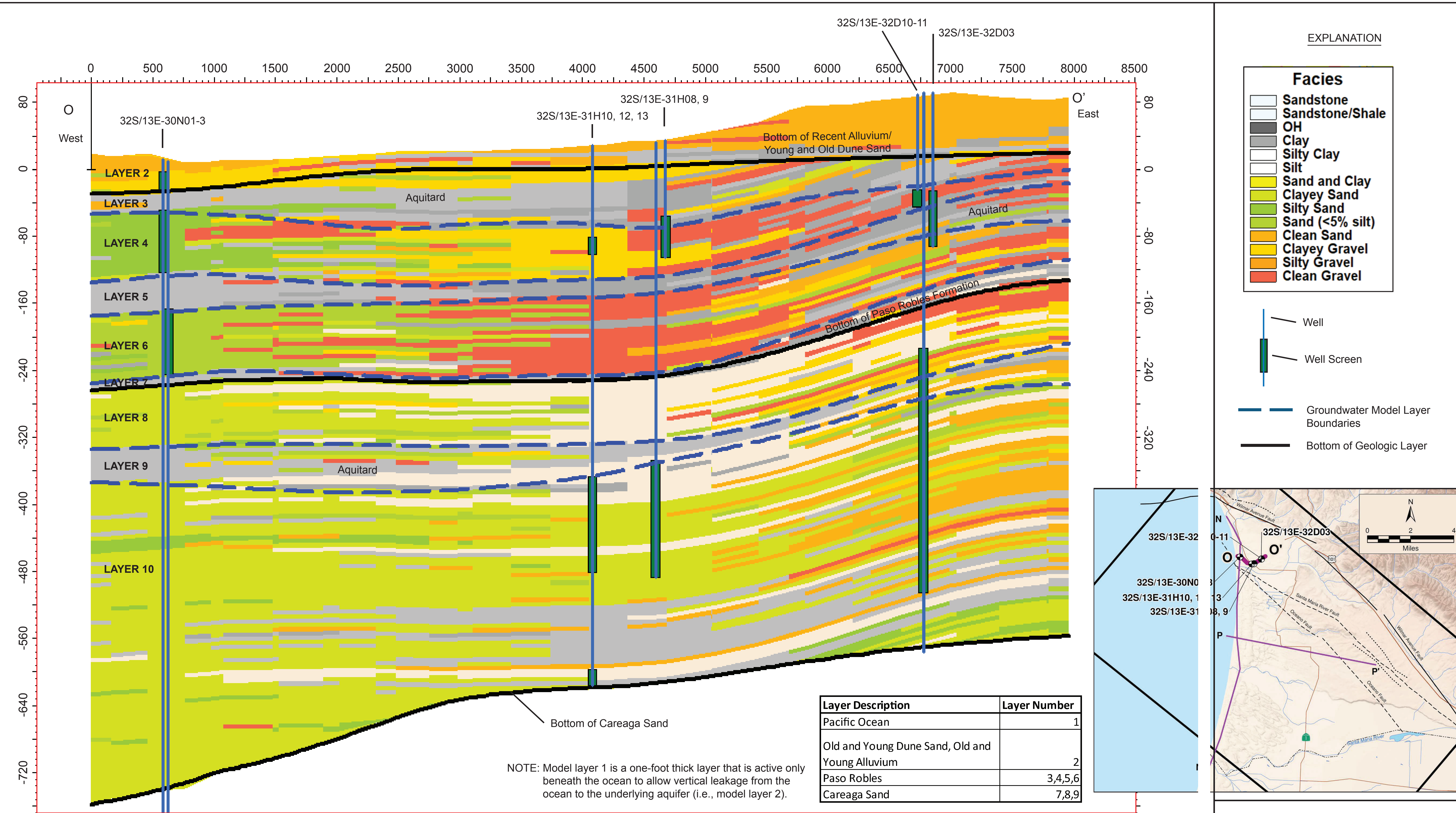

Layer Description	Layer Number
Pacific Ocean	1
Old and Young Dune Sand, Old and Young Alluvium	2
Paso Robles	3,4,5,6
Careaga Sand	7,8,9

NOTE: Model layer 1 is a one-foot thick layer that is active only beneath the ocean to allow vertical leakage from the ocean to the underlying aquifer (i.e., model layer 2).

CROSS-SECTION O-O' SHOWING GROUNDWATER MODEL LAYERING

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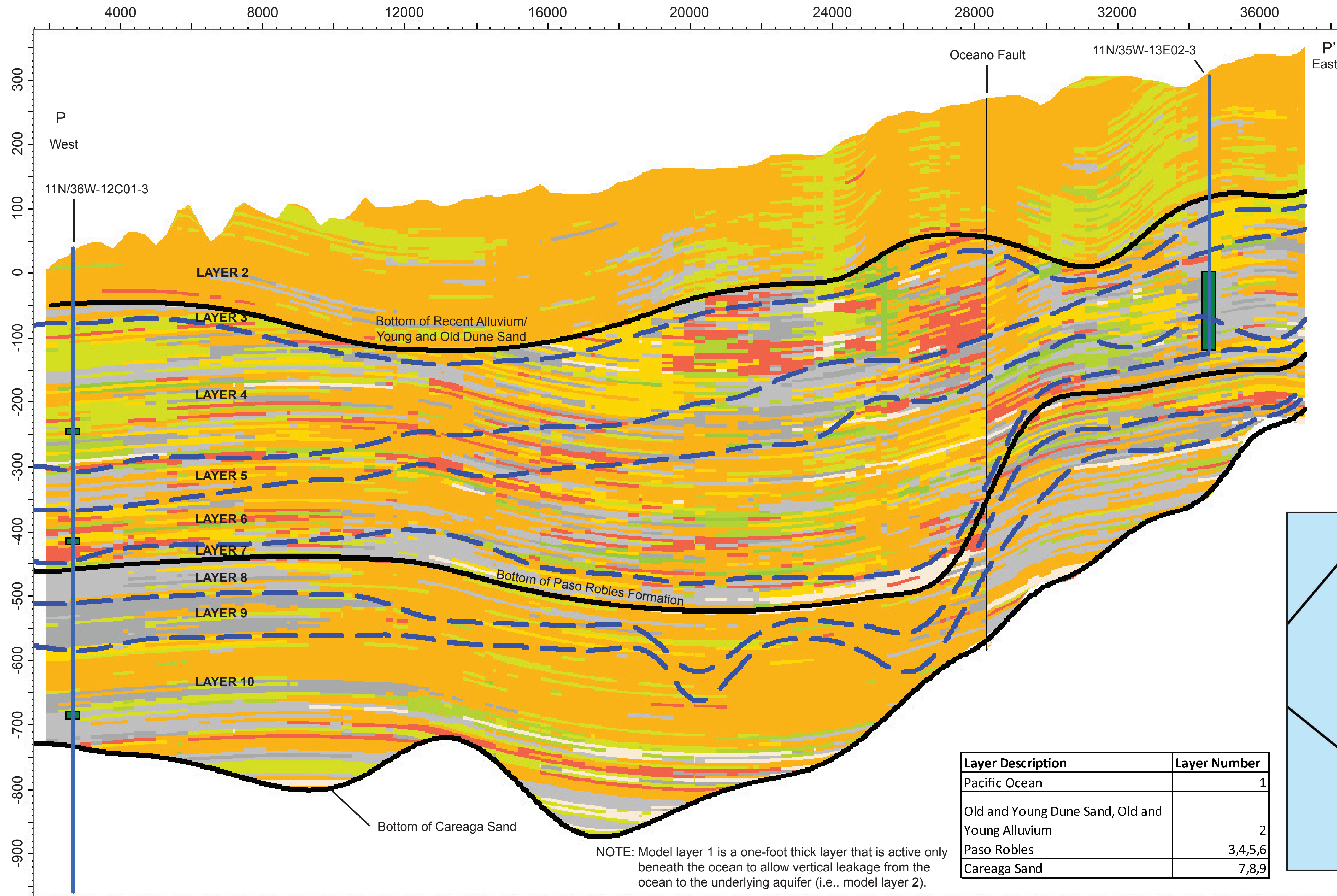
CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

FIGURE 11

GEOSCIENCE



Layer Description	Layer Number
Pacific Ocean	1
Old and Young Dune Sand, Old and Young Alluvium	2
Paso Robles	3,4,5,6
Careaga Sand	7,8,9

NOTE: Model layer 1 is a one-foot thick layer that is active only beneath the ocean to allow vertical leakage from the ocean to the underlying aquifer (i.e., model layer 2).

EXPLANATION

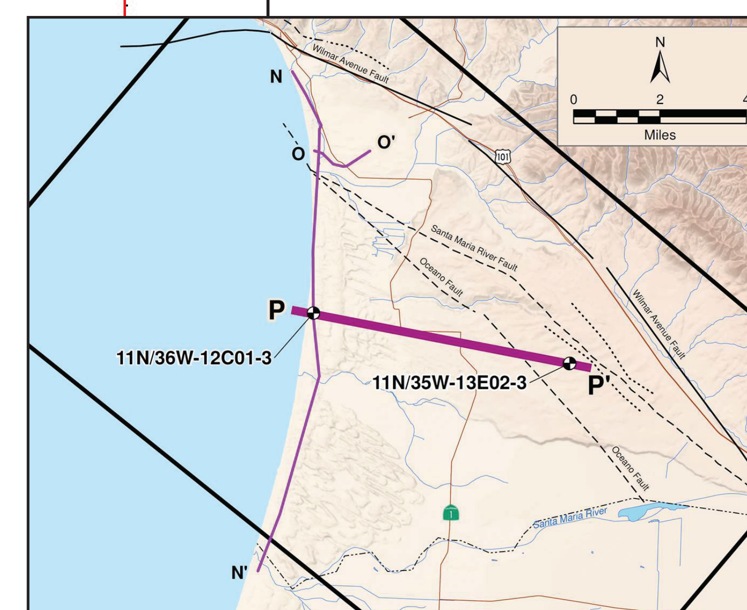
Facies
- Sandstone
- Sandstone/Shale
- OH
- Clay
- Silty Clay
- Silt
- Sand and Clay
- Clayey Sand
- Silty Sand
- Sand (<5% silt)
- Clean Sand
- Clayey Gravel
- Silty Gravel
- Clean Gravel

Well

Well Screen

Groundwater Model Layer Boundaries

Bottom of Geologic Layer



CROSS-SECTION P-P' SHOWING GROUNDWATER MODEL LAYERING

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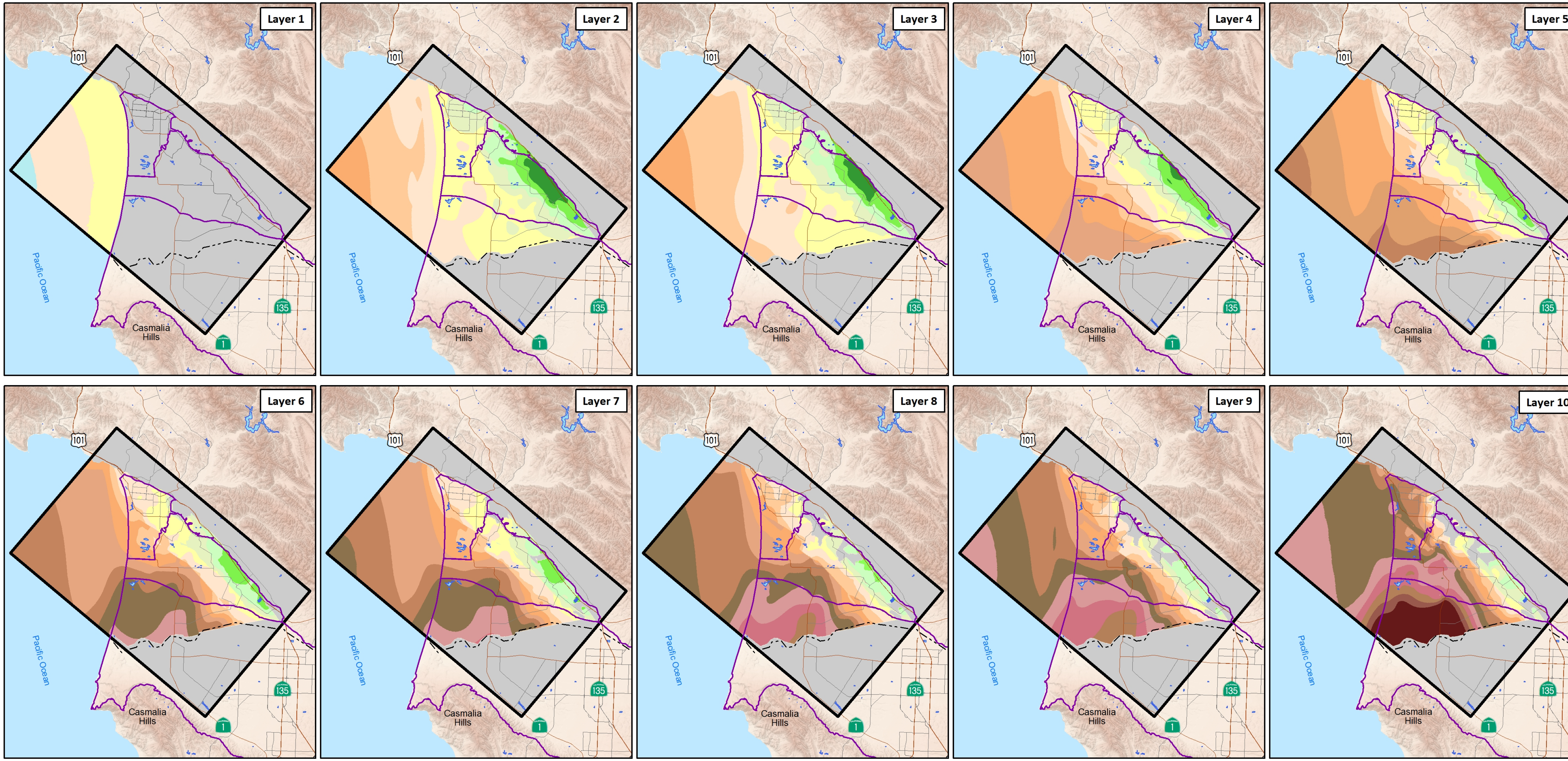


EXPLANATION

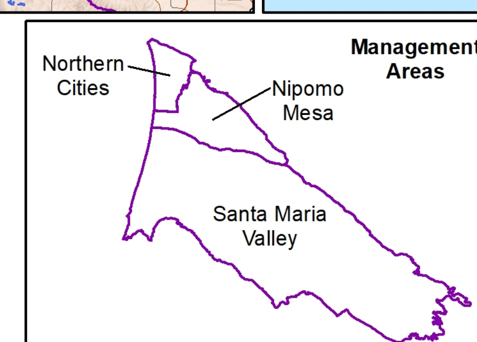
CCB Phase 1B Model Boundary

No-Flow Cells

County Boundary

Bedrock Elevation (ft amsl)

-1,530 - -1,100	-800 - -700	-400 - -300	0 - 100
-1,100 - -1,000	-700 - -600	-300 - -200	100 - 200
-1,000 - -900	-600 - -500	-200 - -100	200 - 300
-900 - -800	-500 - -400	-100 - 0	300 - 400



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BOTTOM MODEL LAYER ELEVATIONS

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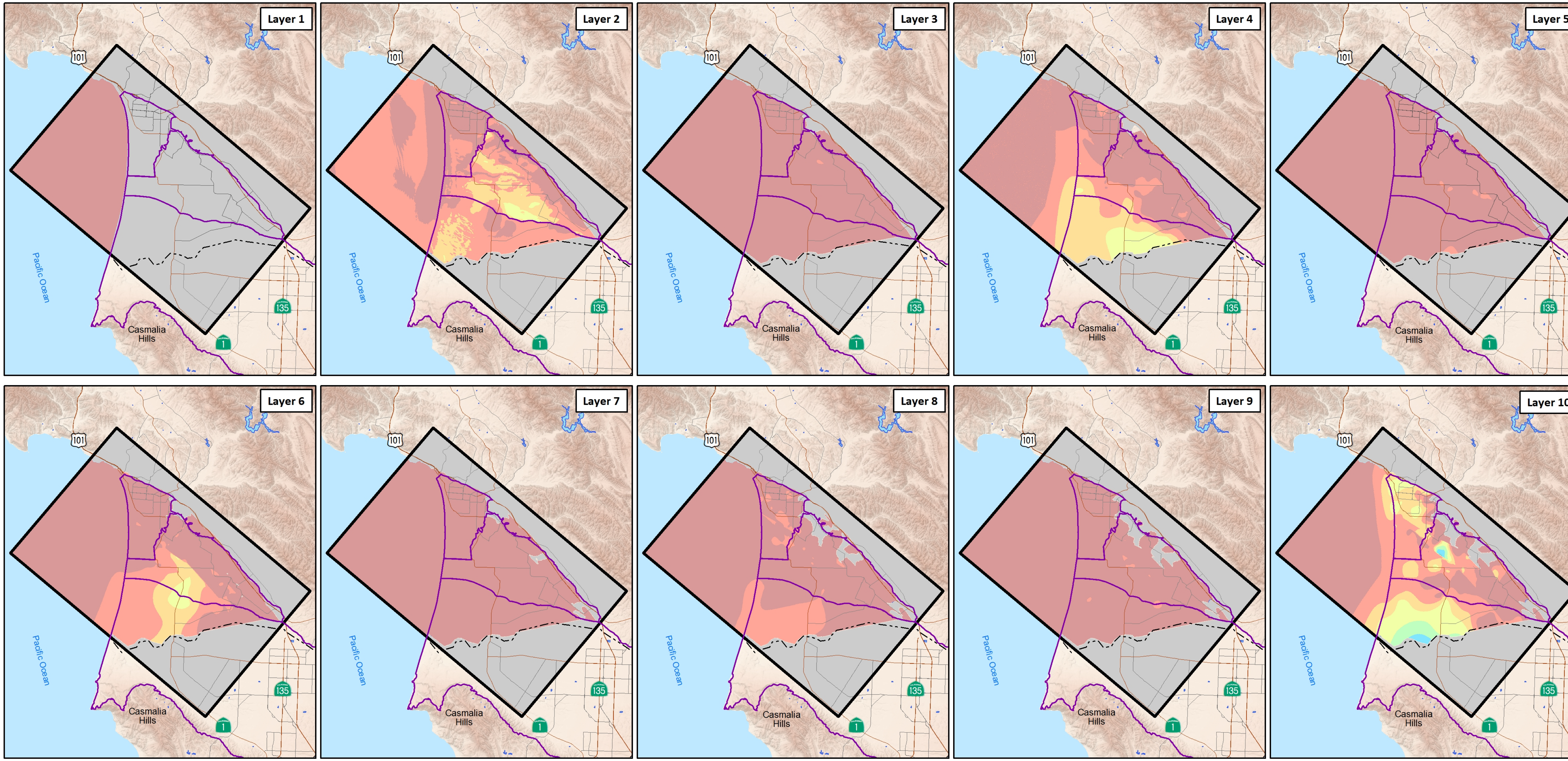
FIGURE 13

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE



EXPLANATION

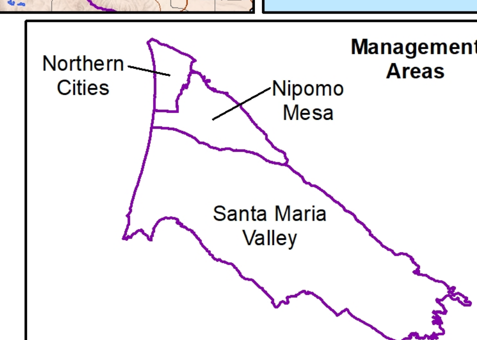
CCB Phase 1B Model Boundary

No-Flow Cells

County Boundary

Layer Thickness (ft)

0 - 100
100 - 200
200 - 300
300 - 400
400 - 500
500 - 600
600 - 700



N

0 5 10

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MODEL LAYER THICKNESS

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FIGURE 14

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE

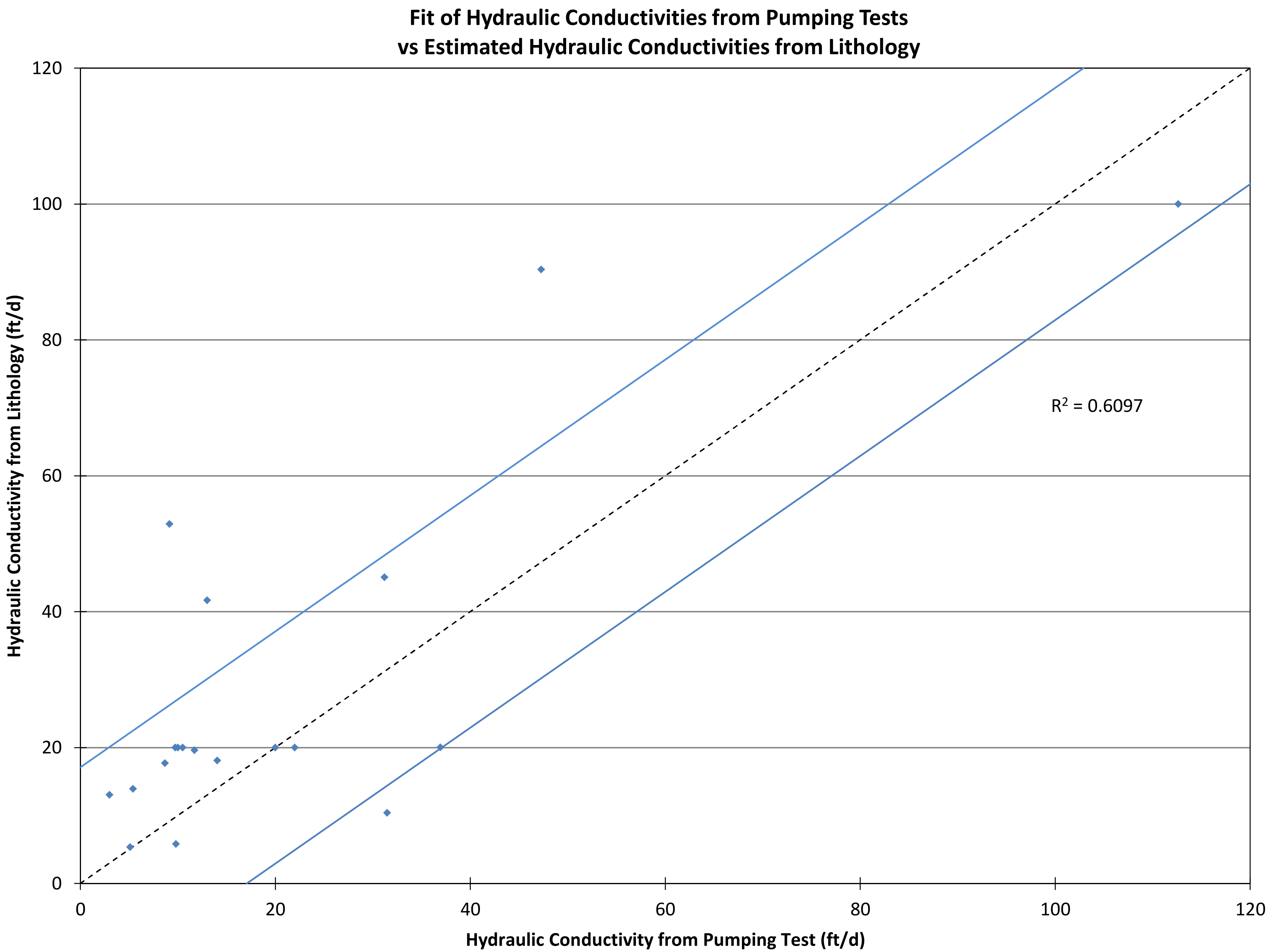
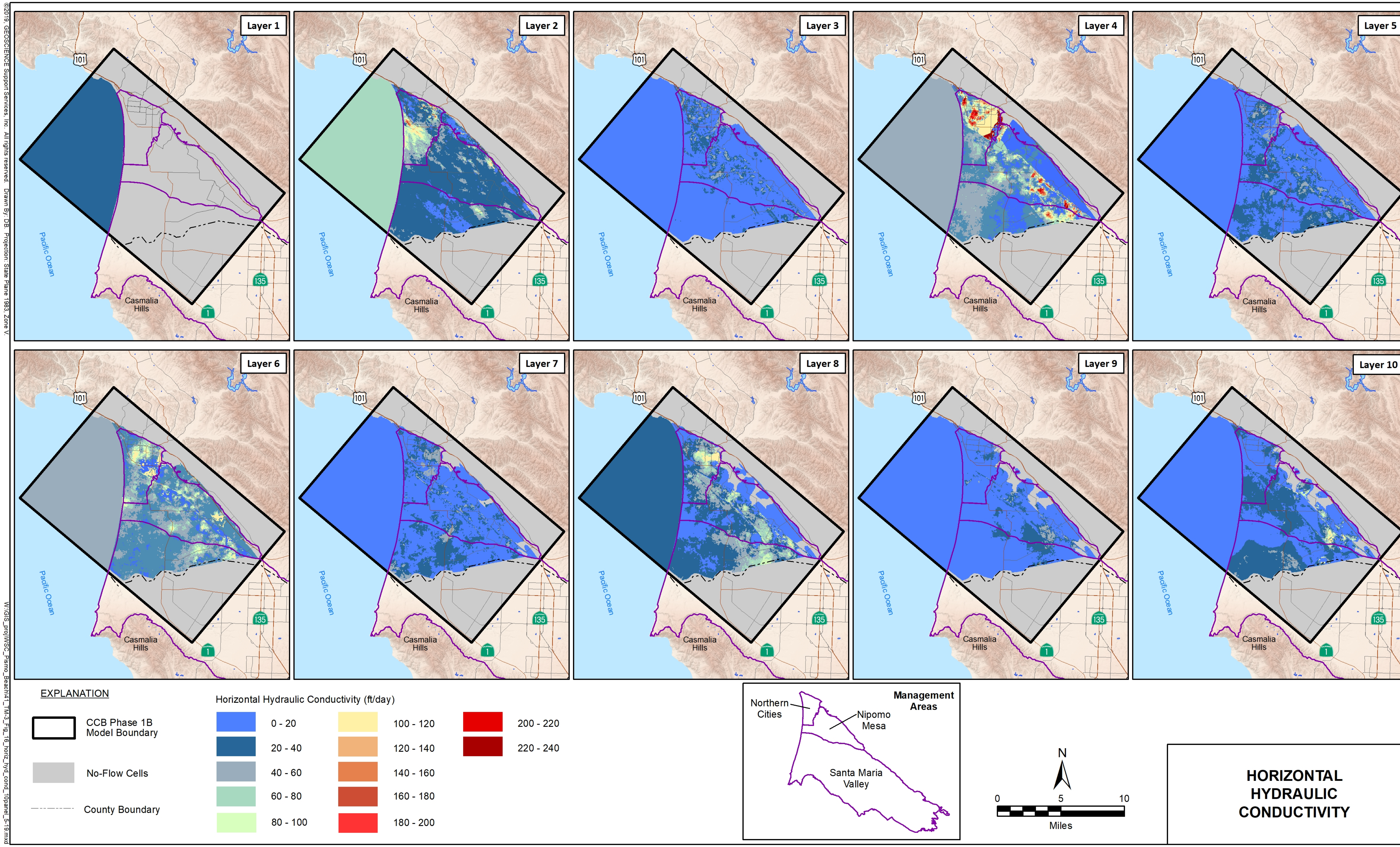

Fit of Hydraulic Conductivities from Pumping Tests
vs Estimated Hydraulic Conductivities from Lithology
Hydraulic Conductivity from Lithology (ft/d)
Hydraulic Conductivity from Pumping Test (ft/d)
R^2 = 0.6097
0
20
40
60
80
100
120

Figure 15



HORIZONTAL HYDRAULIC CONDUCTIVITY

W:\GIS_proj\WSC_Pismo_Beach\41_TM-3_Fig_16_horiz_hyd_cond_10panel_5-19.mxd

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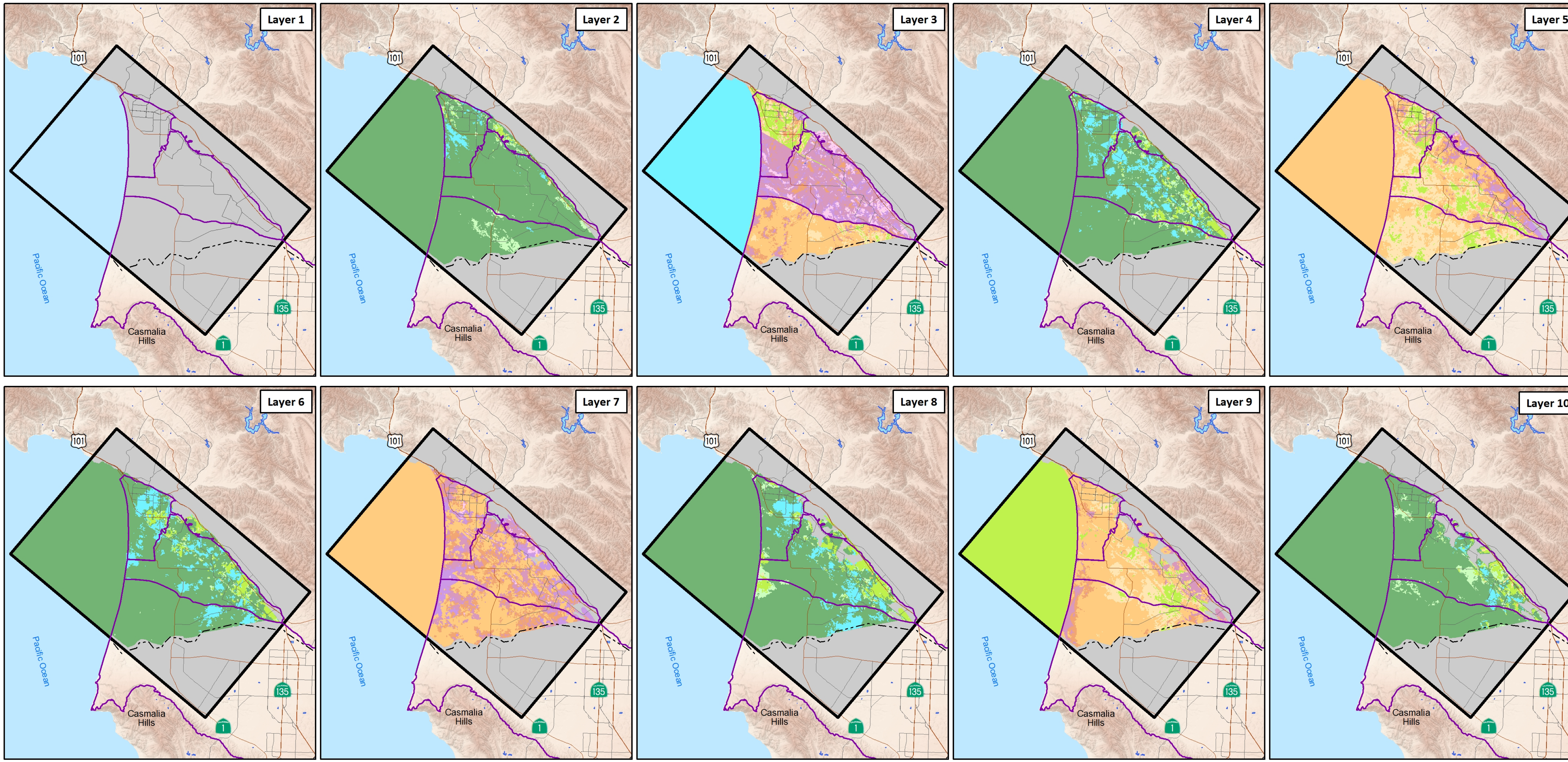
FIGURE 16

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE



EXPLANATION

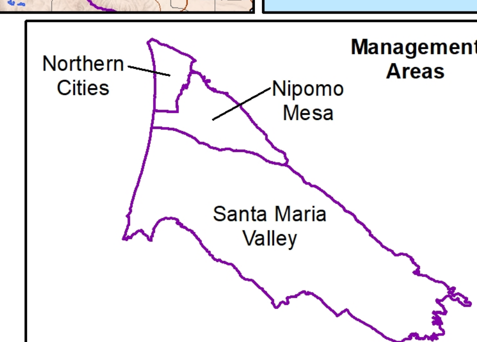
CCB Phase 1B Model Boundary

No-Flow Cells

County Boundary

Vertical Hydraulic Conductivity (ft/day)

- 0 - 0.00005
- 0.00005 - 0.0001
- 0.0001 - 0.0005
- 0.0005 - 0.001
- 0.001 - 0.005
- 0.005 - 0.01
- 0.01 - 0.05
- 0.05 - 0.1
- 0.1 - 0.5
- 0.5 - 1.0
- 1.0 - 5.0
- 5.0 - 24



N

0 5 10

Miles

VERTICAL HYDRAULIC CONDUCTIVITY

W:\GIS_proj\WSC_Pismo_Beach\41_TM-3_Fig_17_vert_hyd_cond_10panel_5-19.mxd

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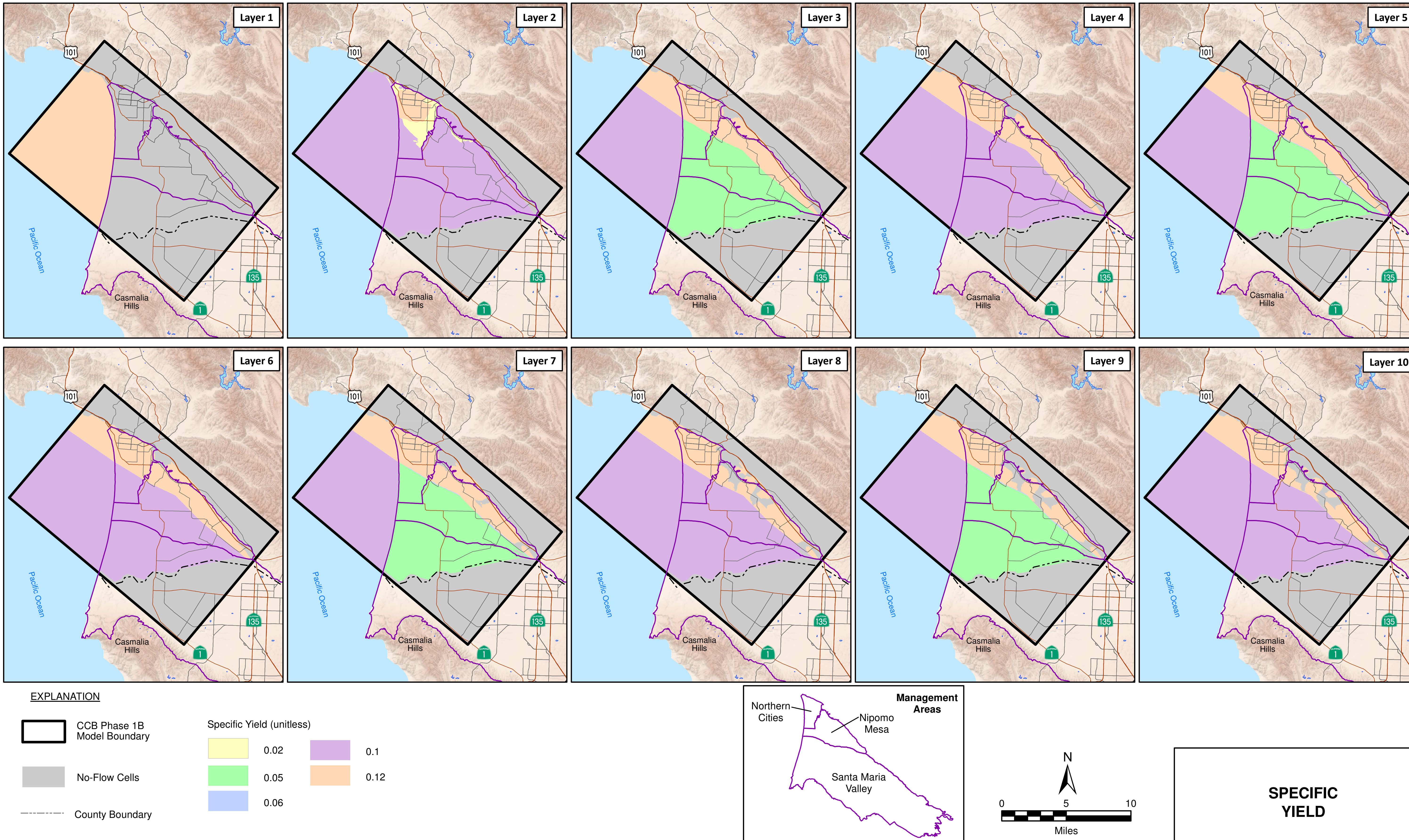
FIGURE 17

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE



SPECIFIC YIELD

W:\GIS_proj\WSC_Pismo_Beach\41_TM-3_Fig_18_spec_yield_10panel_5-19.mxd

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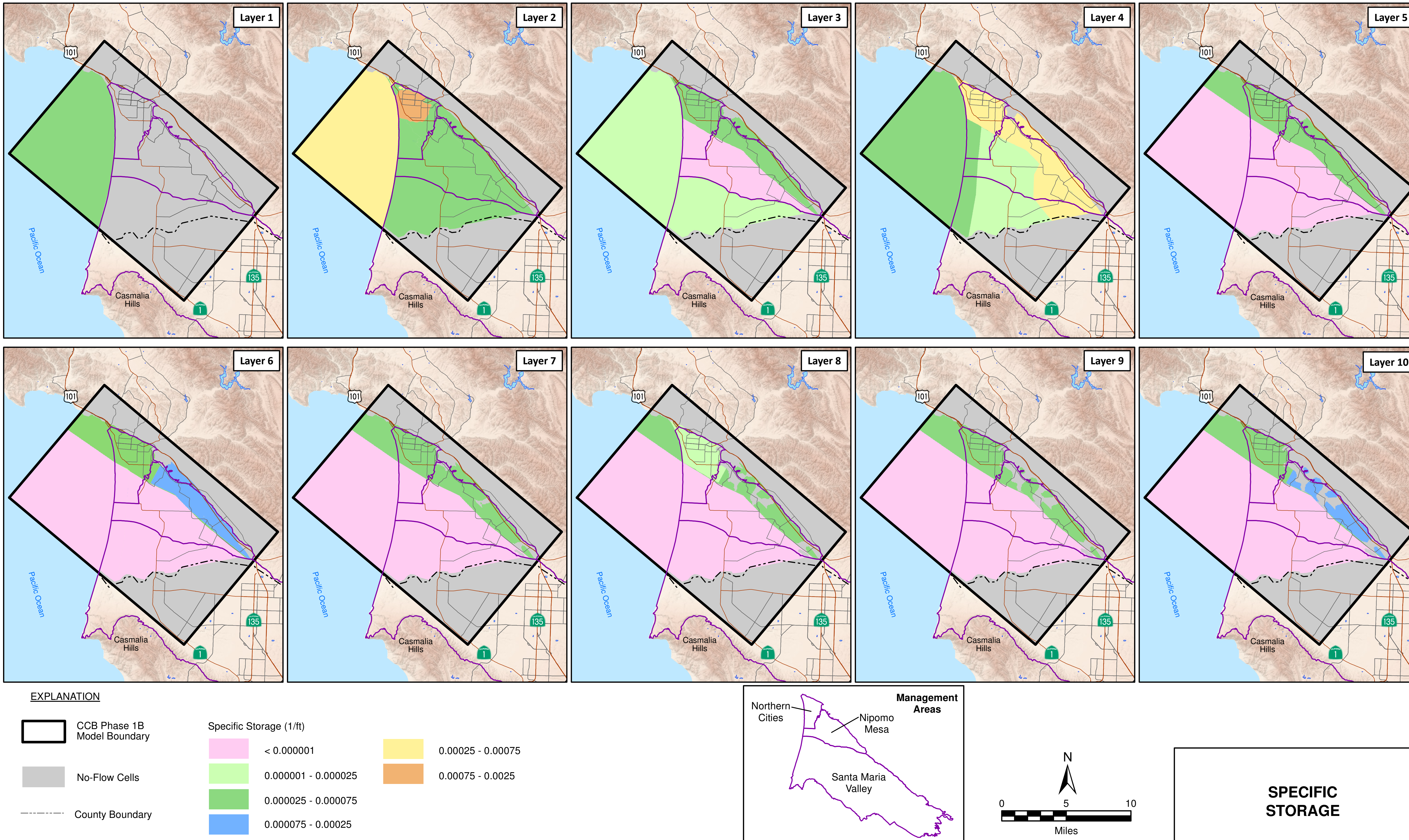
WATER SYSTEMS CONSULTING, INC.

FIGURE 18

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE



W:\GIS_proj\WSC_Pismo_Beach\41_TM-3_Fig_19_spec_storage_10panel_5-19.mxd

SPECIFIC STORAGE

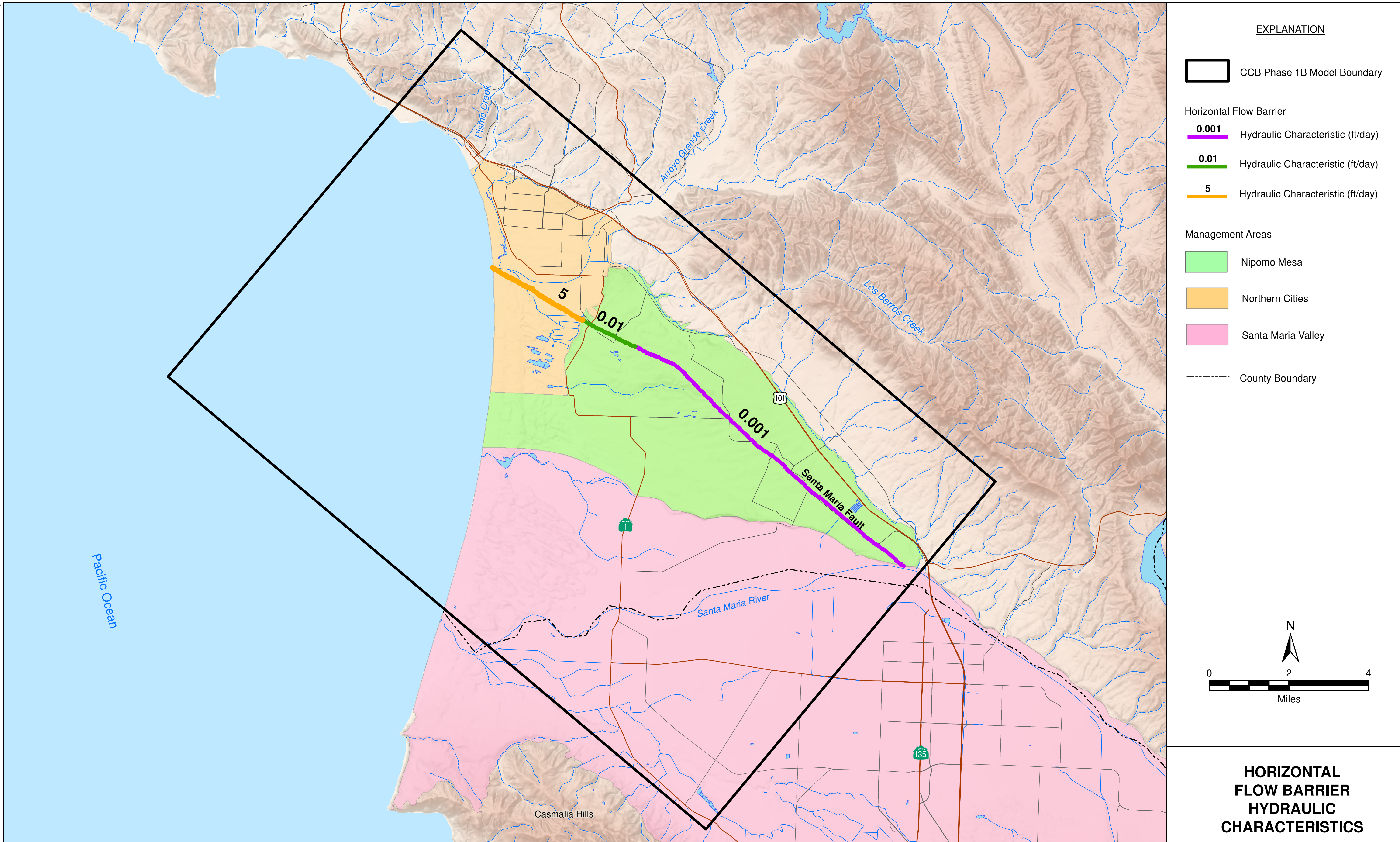
14-May-19

WATER SYSTEMS CONSULTING, INC.

FIGURE 19

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE



W:\GIS_proj\WSC_Pismo_Beach\4_TM-3_Fig_20_HFB_hyd_characterics_5-19.mxd

14-May-19

HORIZONTAL FLOW BARRIER HYDRAULIC CHARACTERISTICS

FIGURE 20

WATER SYSTEMS CONSULTING, INC.

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE

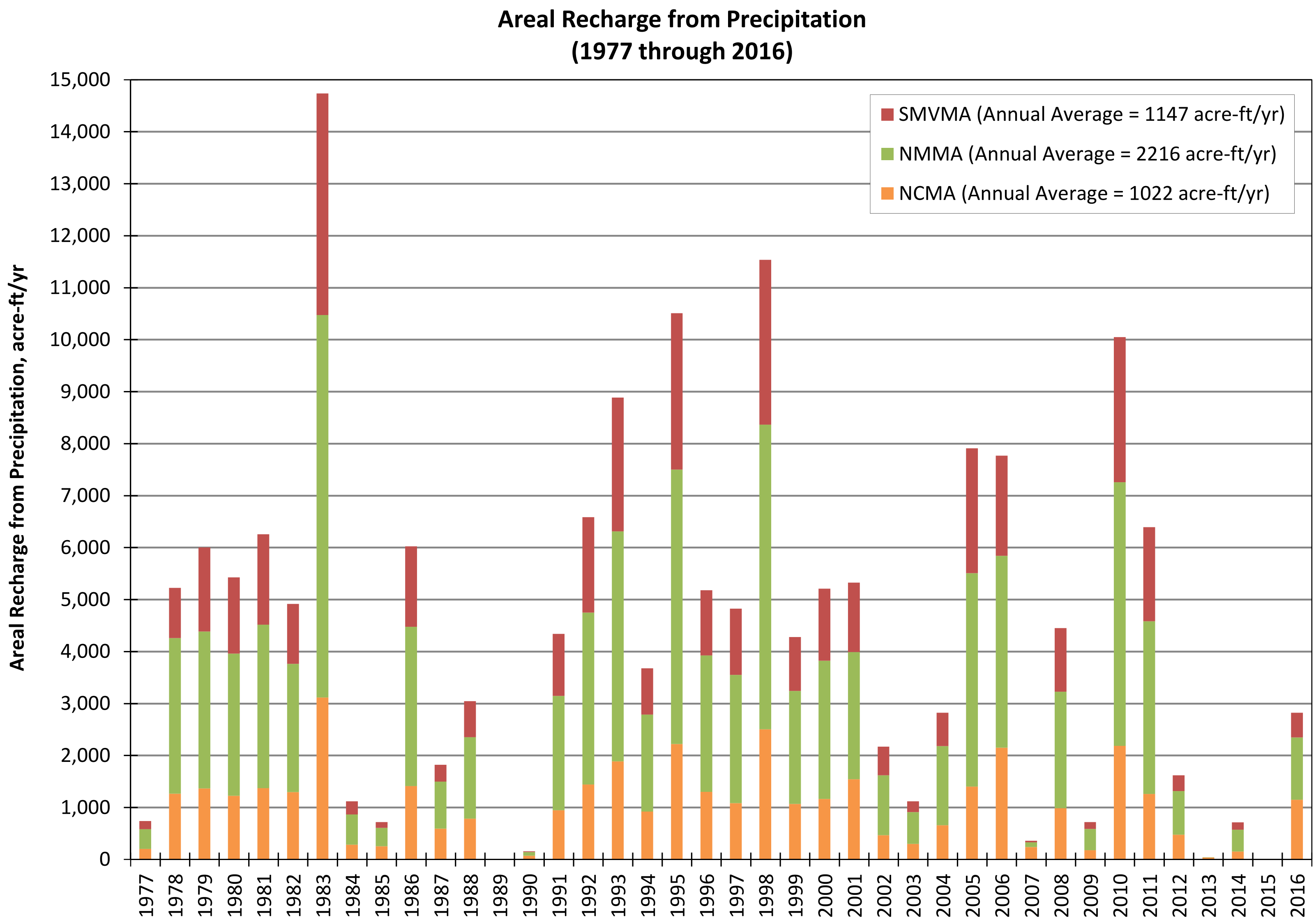

Areal Recharge from Precipitation
(1977 through 2016)
Areal Recharge from Precipitation, acre-ft/yr
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
SMVMA (Annual Average = 1147 acre-ft/yr)
NMMA (Annual Average = 2216 acre-ft/yr)
NCMA (Annual Average = 1022 acre-ft/yr)
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

Figure 21

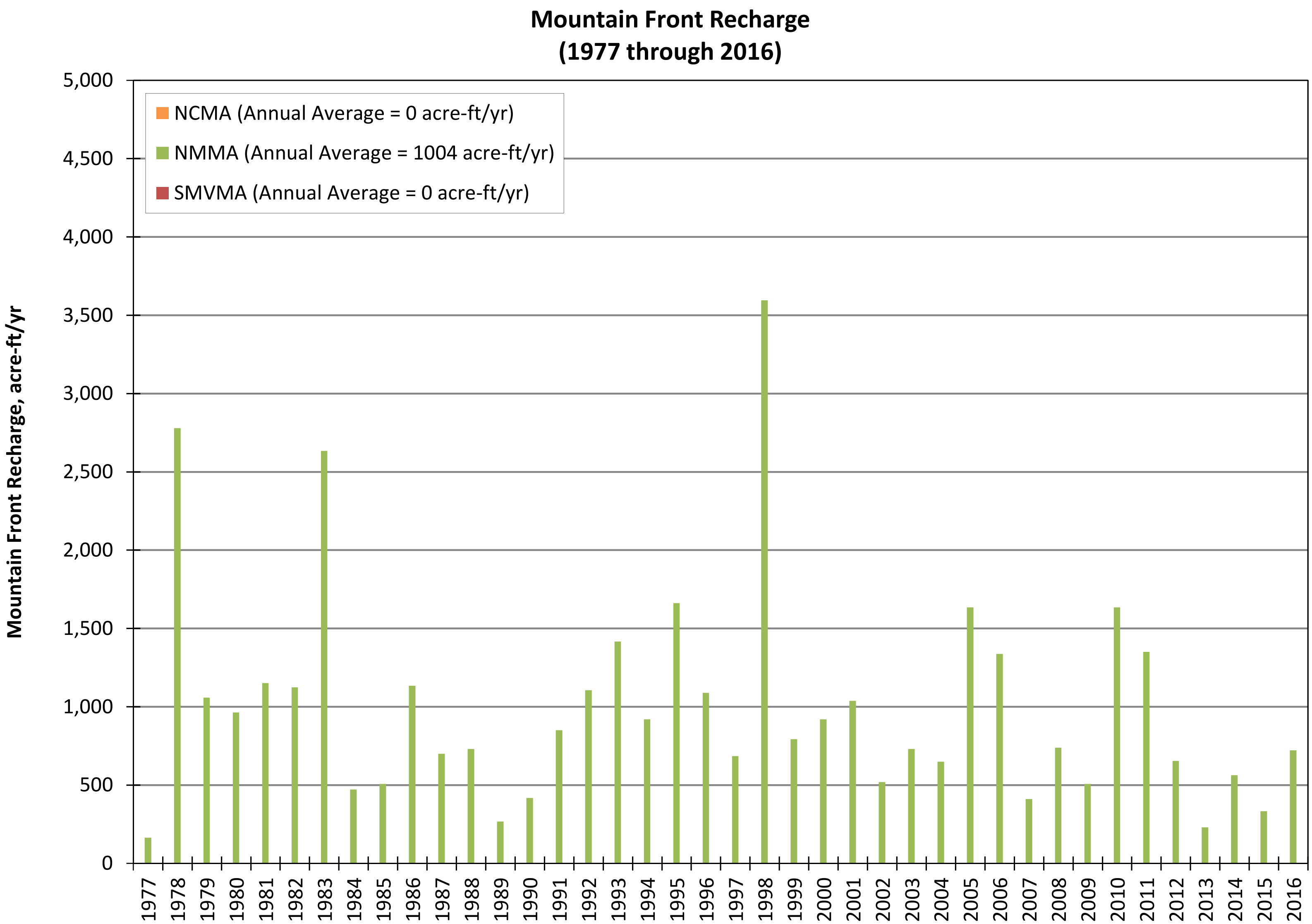

Mountain Front Recharge
(1977 through 2016)
NCMA (Annual Average = 0 acre-ft/yr)
NMMA (Annual Average = 1004 acre-ft/yr)
SMVMA (Annual Average = 0 acre-ft/yr)
Mountain Front Recharge, acre-ft/yr
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

Figure 22

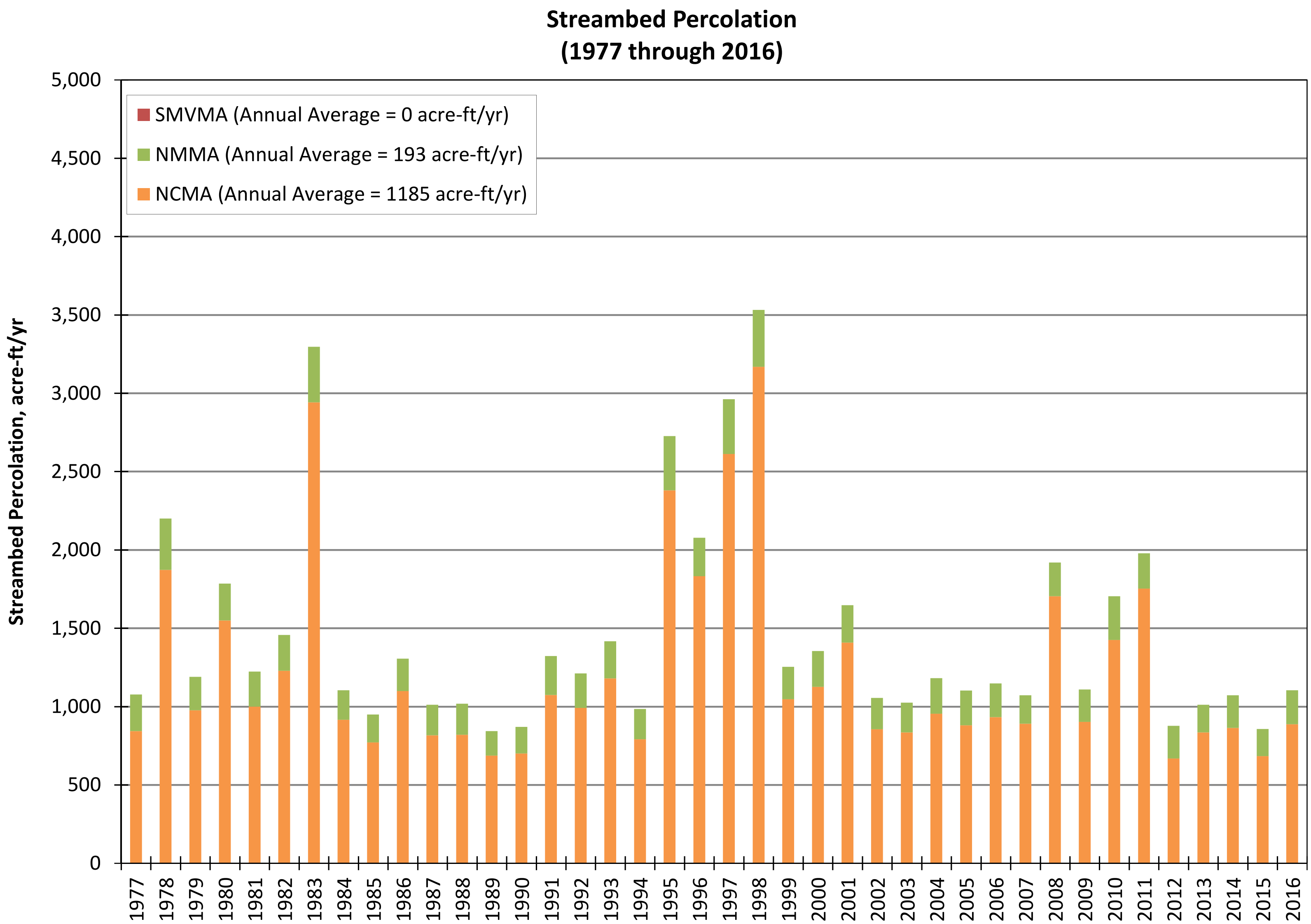

Streambed Percolation
(1977 through 2016)
SMVMA (Annual Average = 0 acre-ft/yr)
NMMA (Annual Average = 193 acre-ft/yr)
NCMA (Annual Average = 1185 acre-ft/yr)
Streambed Percolation, acre-ft/yr
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

Figure 23

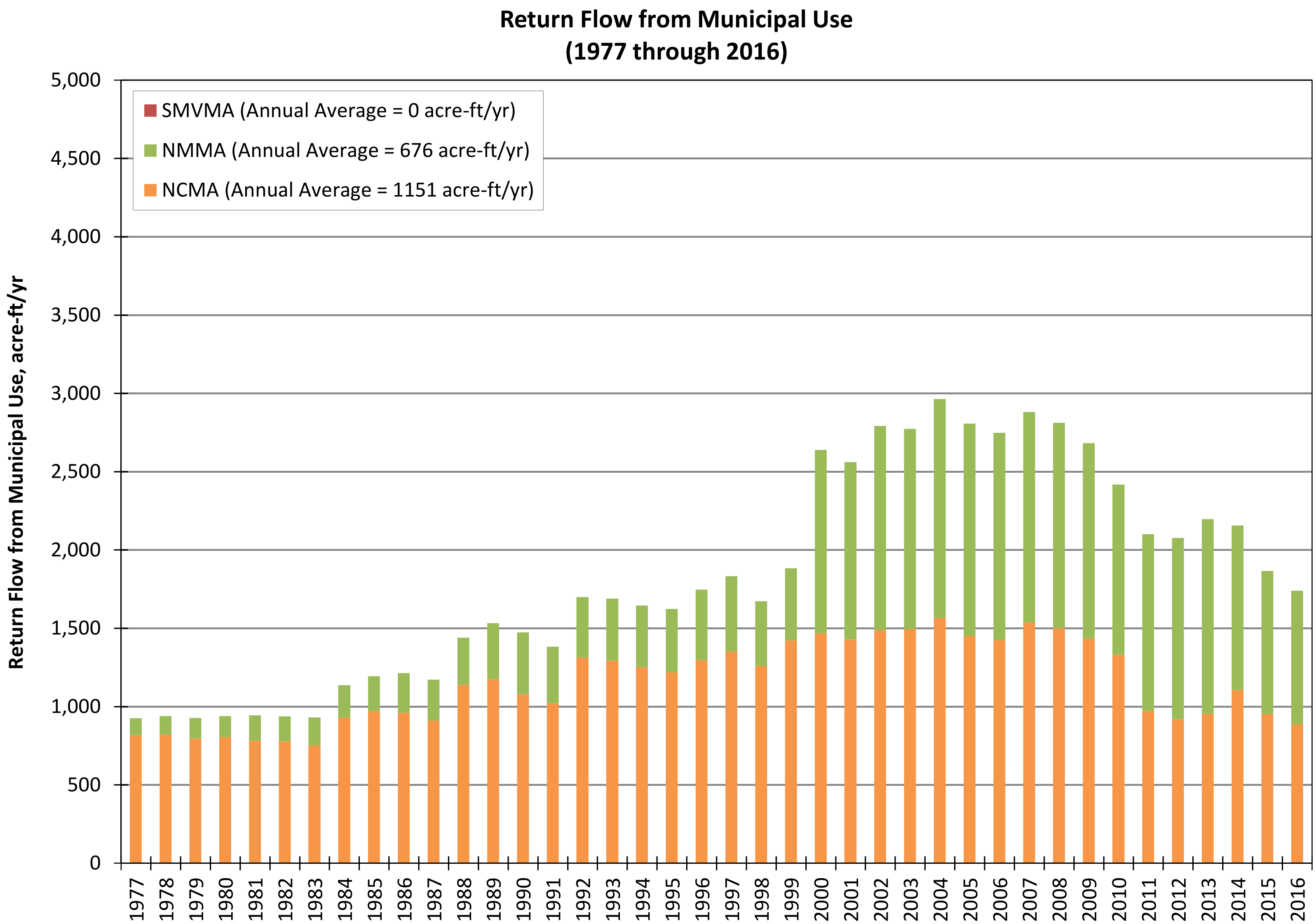
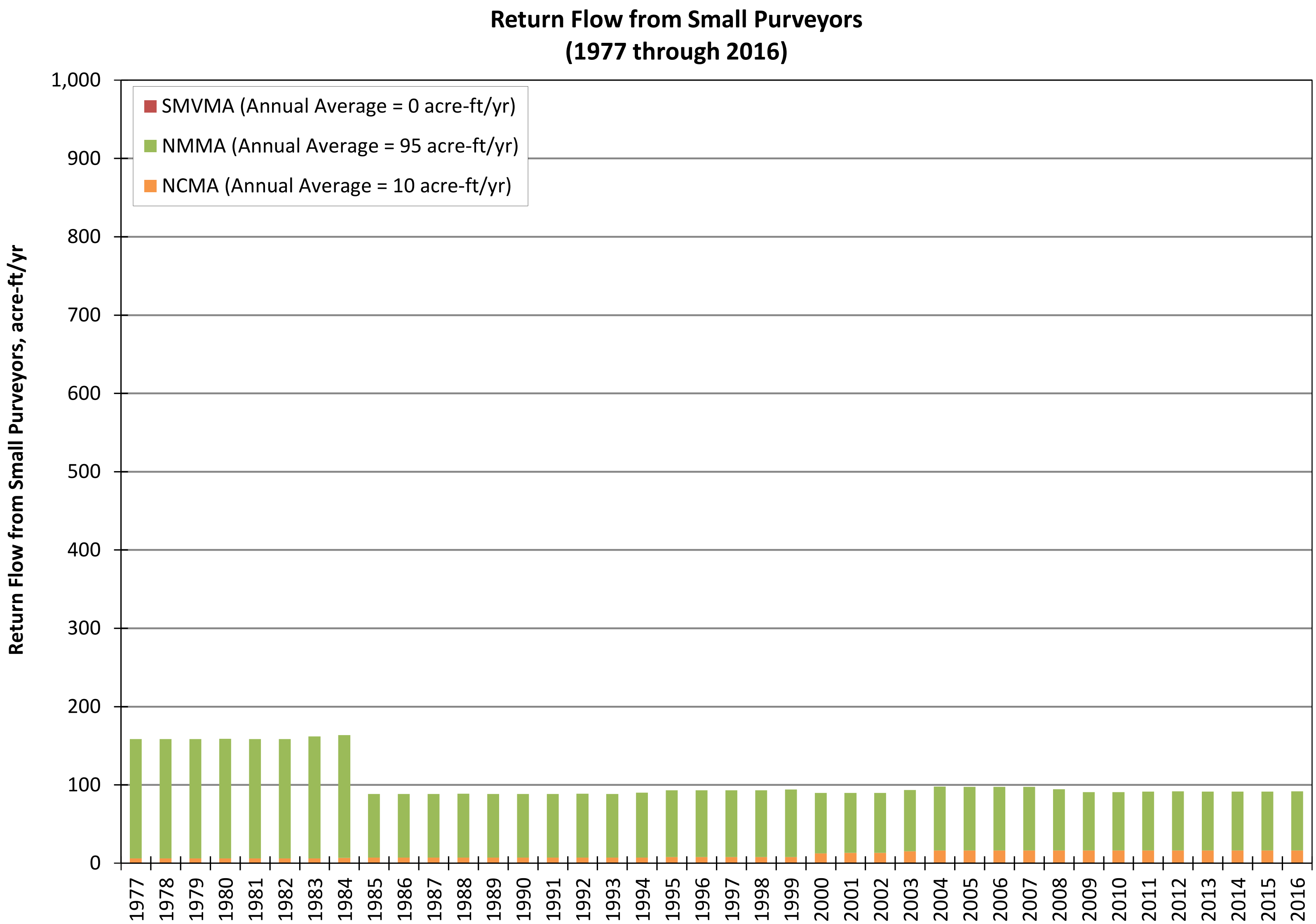

Return Flow from Municipal Use
(1977 through 2016)
SMVMA (Annual Average = 0 acre-ft/yr)
NMMA (Annual Average = 676 acre-ft/yr)
NCMA (Annual Average = 1151 acre-ft/yr)
Return Flow from Municipal Use, acre-ft/yr
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

Figure 24


Return Flow from Small Purveyors
(1977 through 2016)
SMVMA (Annual Average = 0 acre-ft/yr)
NMMA (Annual Average = 95 acre-ft/yr)
NCMA (Annual Average = 10 acre-ft/yr)
Return Flow from Small Purveyors, acre-ft/yr
1,000
900
800
700
600
500
400
300
200
100
0
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
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2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

Figure 25

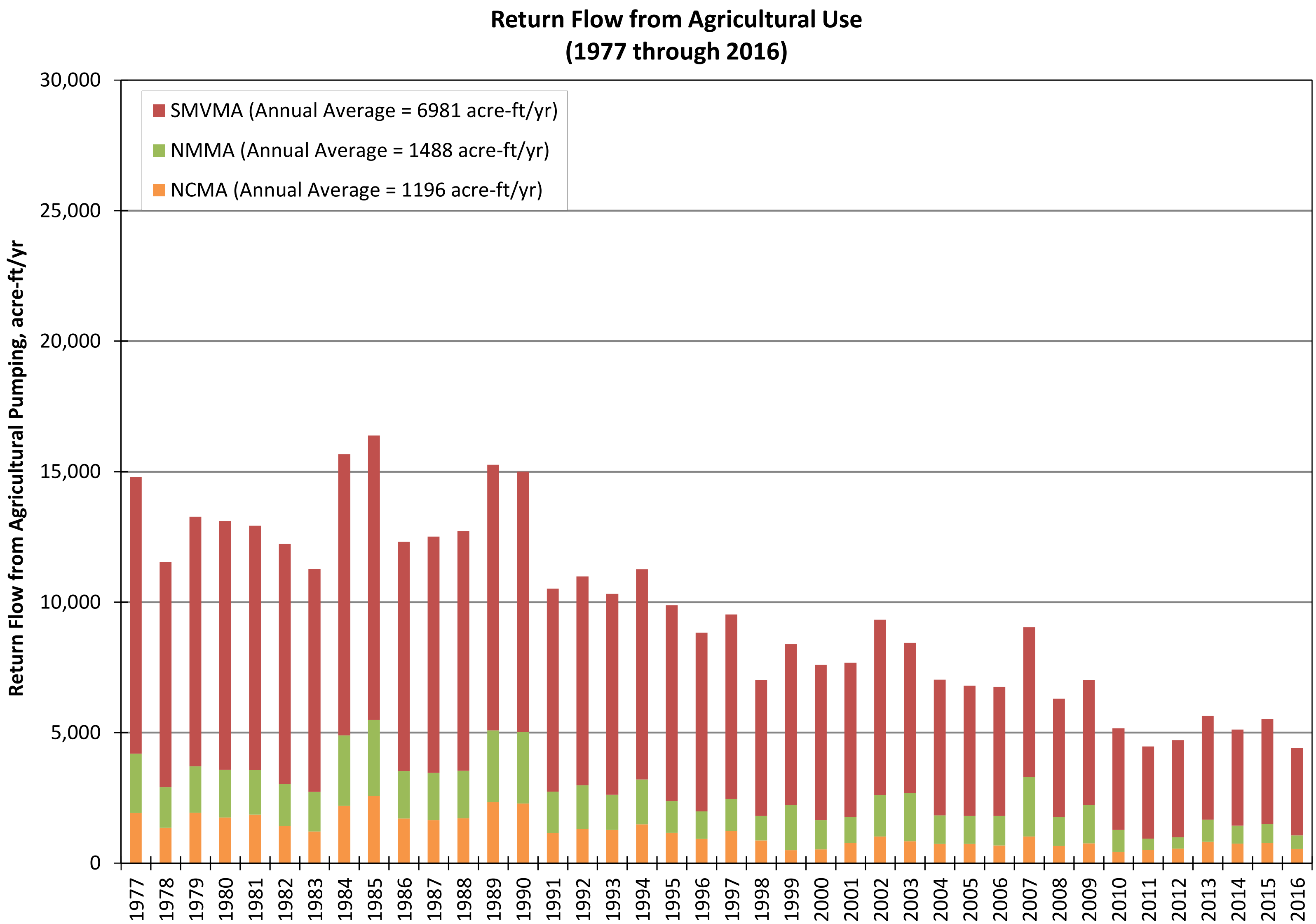

Return Flow from Agricultural Use
(1977 through 2016)
SMVMA (Annual Average = 6981 acre-ft/yr)
NMMA (Annual Average = 1488 acre-ft/yr)
NCMA (Annual Average = 1196 acre-ft/yr)
Return Flow from Agricultural Pumping, acre-ft/yr
30,000
25,000
20,000
15,000
10,000
5,000
0
1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

Figure 26

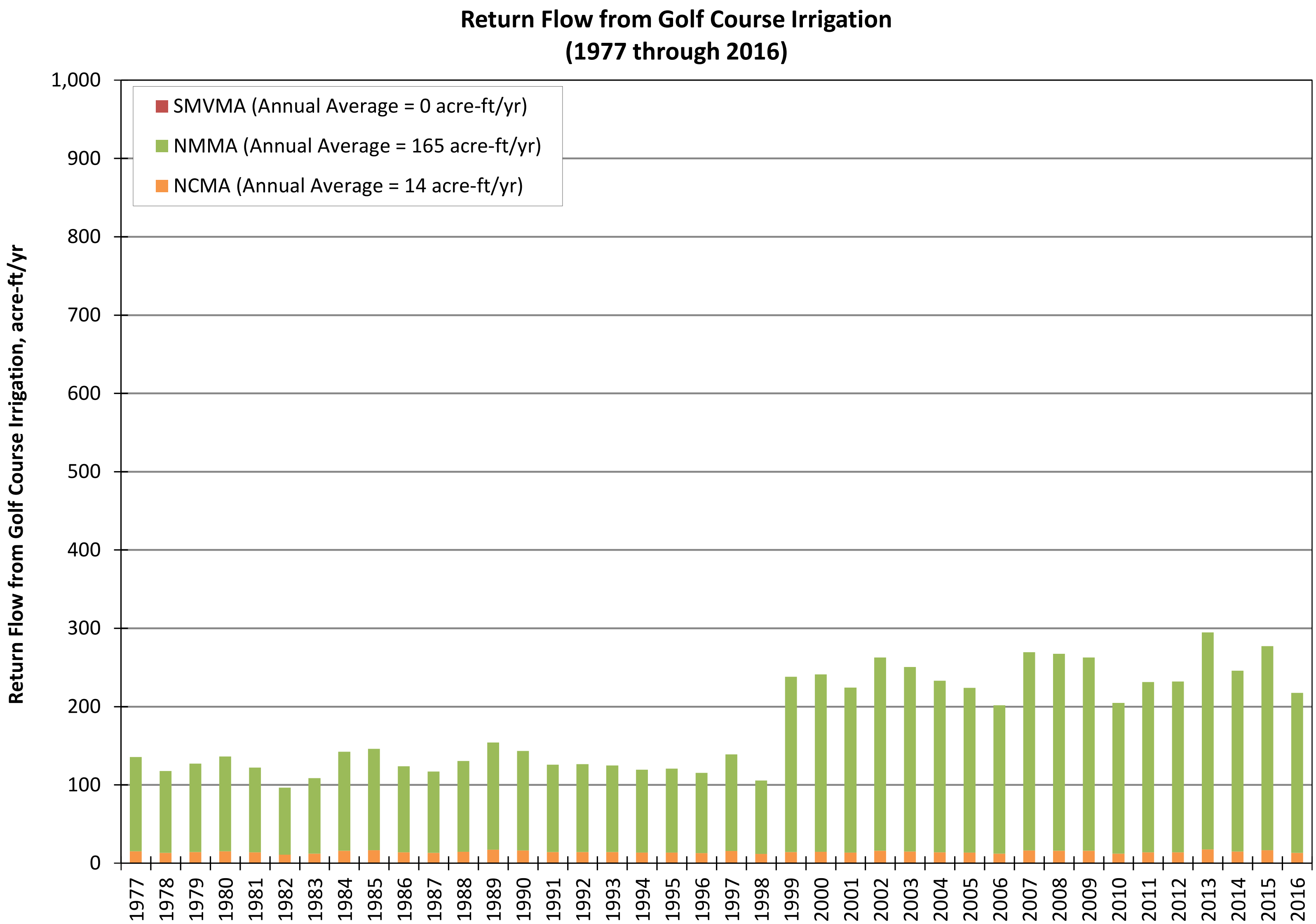

Return Flow from Golf Course Irrigation
(1977 through 2016)
SMVMA (Annual Average = 0 acre-ft/yr)
NMMA (Annual Average = 165 acre-ft/yr)
NCMA (Annual Average = 14 acre-ft/yr)
Return Flow from Golf Course Irrigation, acre-ft/yr
1,000
900
800
700
600
500
400
300
200
100
0
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

Figure 27

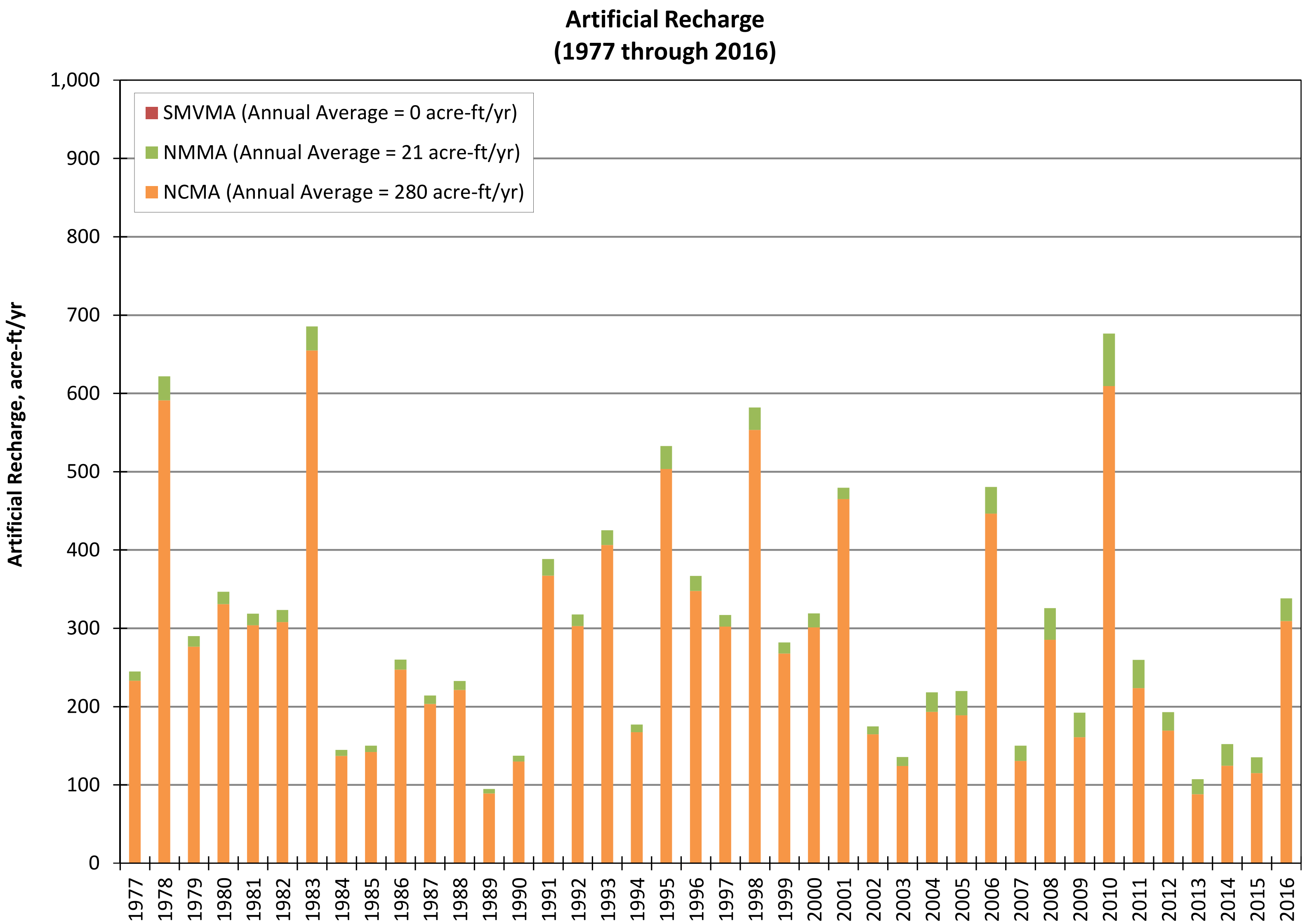

Artificial Recharge
(1977 through 2016)
SMVMA (Annual Average = 0 acre-ft/yr)
NMMA (Annual Average = 21 acre-ft/yr)
NCMA (Annual Average = 280 acre-ft/yr)
Artificial Recharge, acre-ft/yr
1,000
900
800
700
600
500
400
300
200
100
0
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

Figure 28

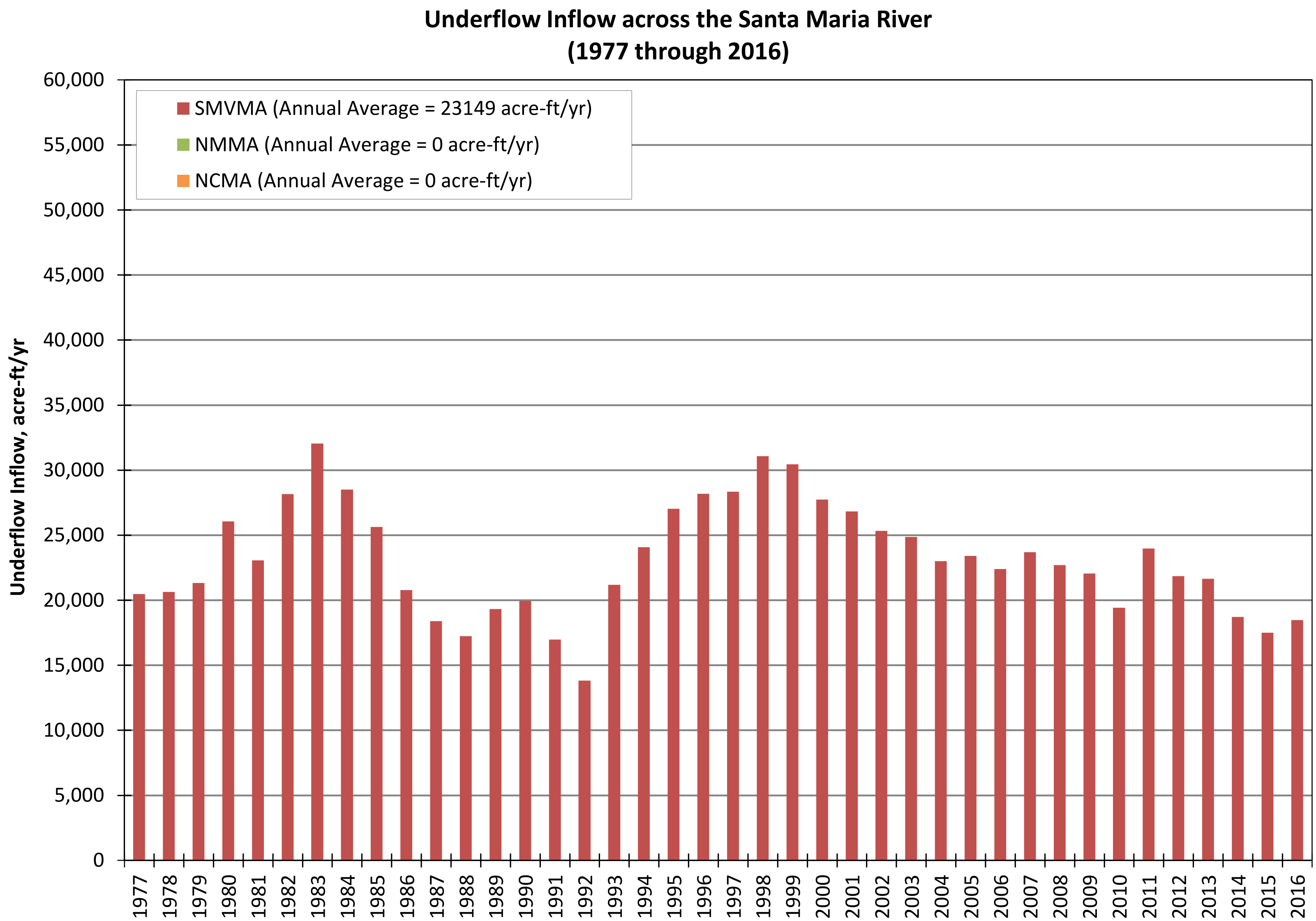
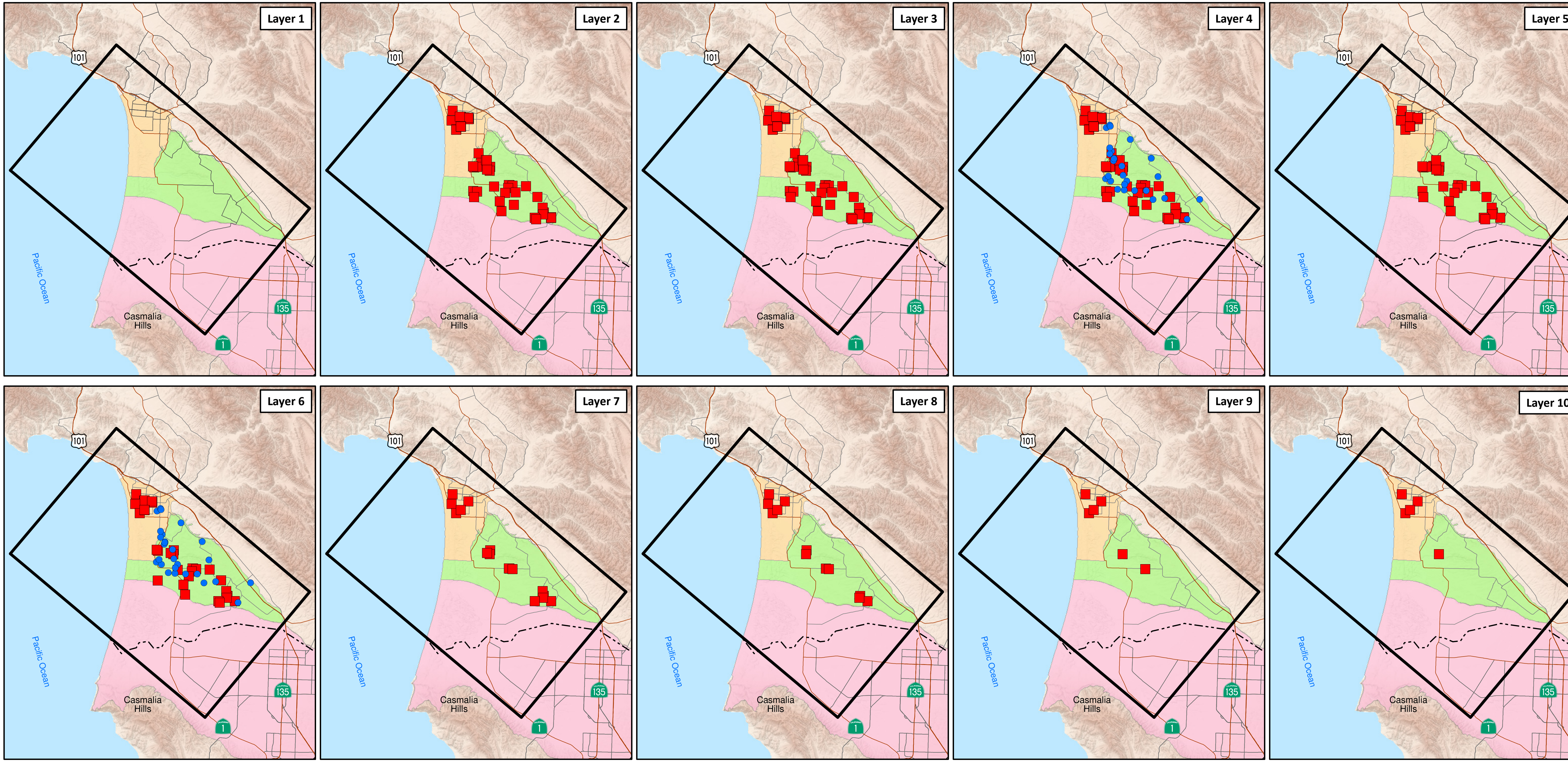

Underflow Inflow across the Santa Maria River
(1977 through 2016)
SMVMA (Annual Average = 23149 acre-ft/yr)
NMMA (Annual Average = 0 acre-ft/yr)
NCMA (Annual Average = 0 acre-ft/yr)
Underflow Inflow, acre-ft/yr
60,000
55,000
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

Figure 29



EXPLANATION

CCB Phase 1B Model Boundary

Pumping Well

Small Water System Pumping Well

Management Areas

Nipomo Mesa

Northern Cities

Santa Maria Valley

N

0 5 10

Miles

LOCATION OF MUNICIPAL PUMPING

W:GIS_proj\WSC_Pismo_Beach\41_TM-3_Fig_30_Municipal_wells_10panel_5-19.mxd

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FIGURE 30

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE

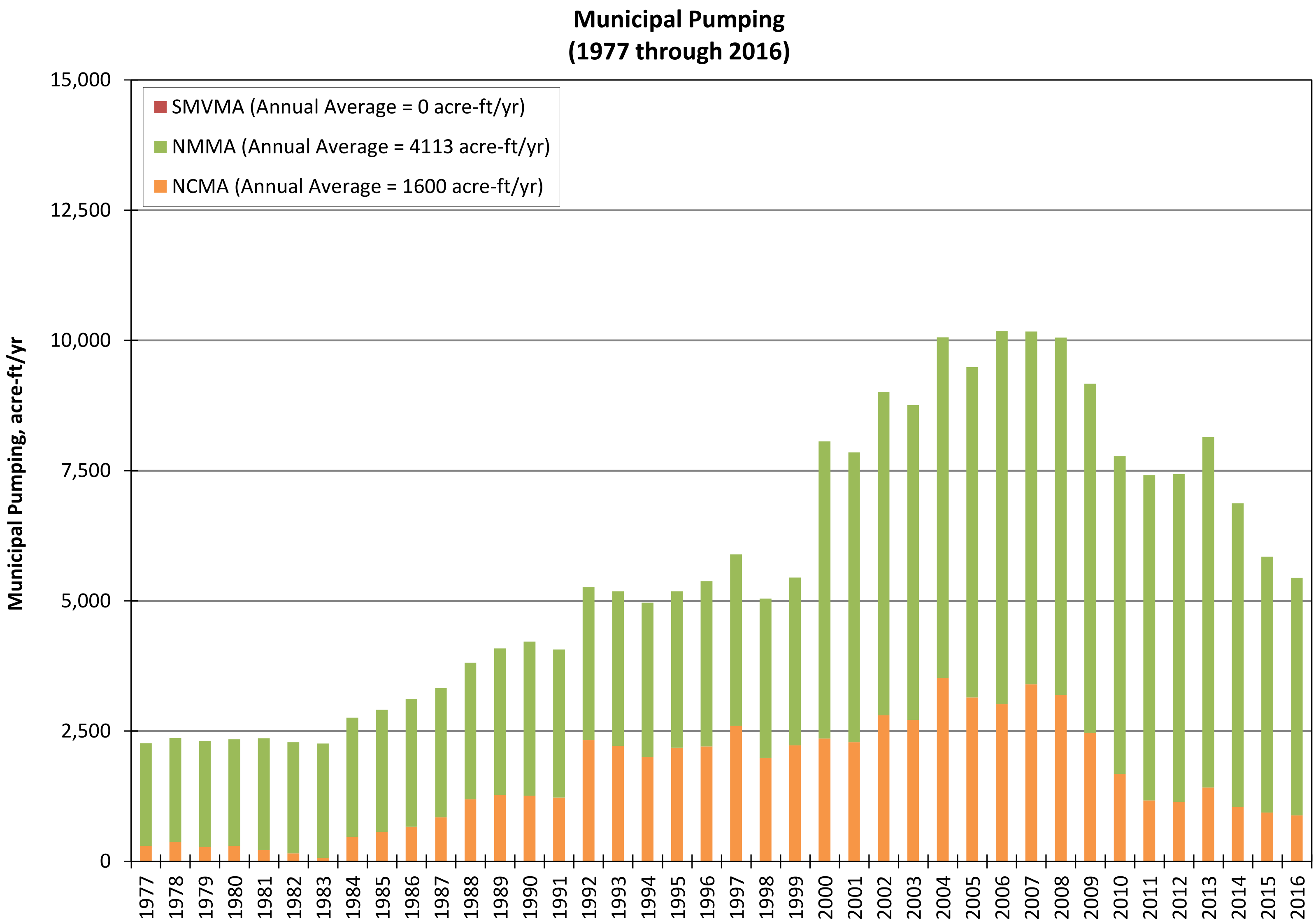

Municipal Pumping
(1977 through 2016)
SMVMA (Annual Average = 0 acre-ft/yr)
NMMA (Annual Average = 4113 acre-ft/yr)
NCMA (Annual Average = 1600 acre-ft/yr)
Municipal Pumping, acre-ft/yr
15,000
12,500
10,000
7,500
5,000
2,500
0
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

Figure 31

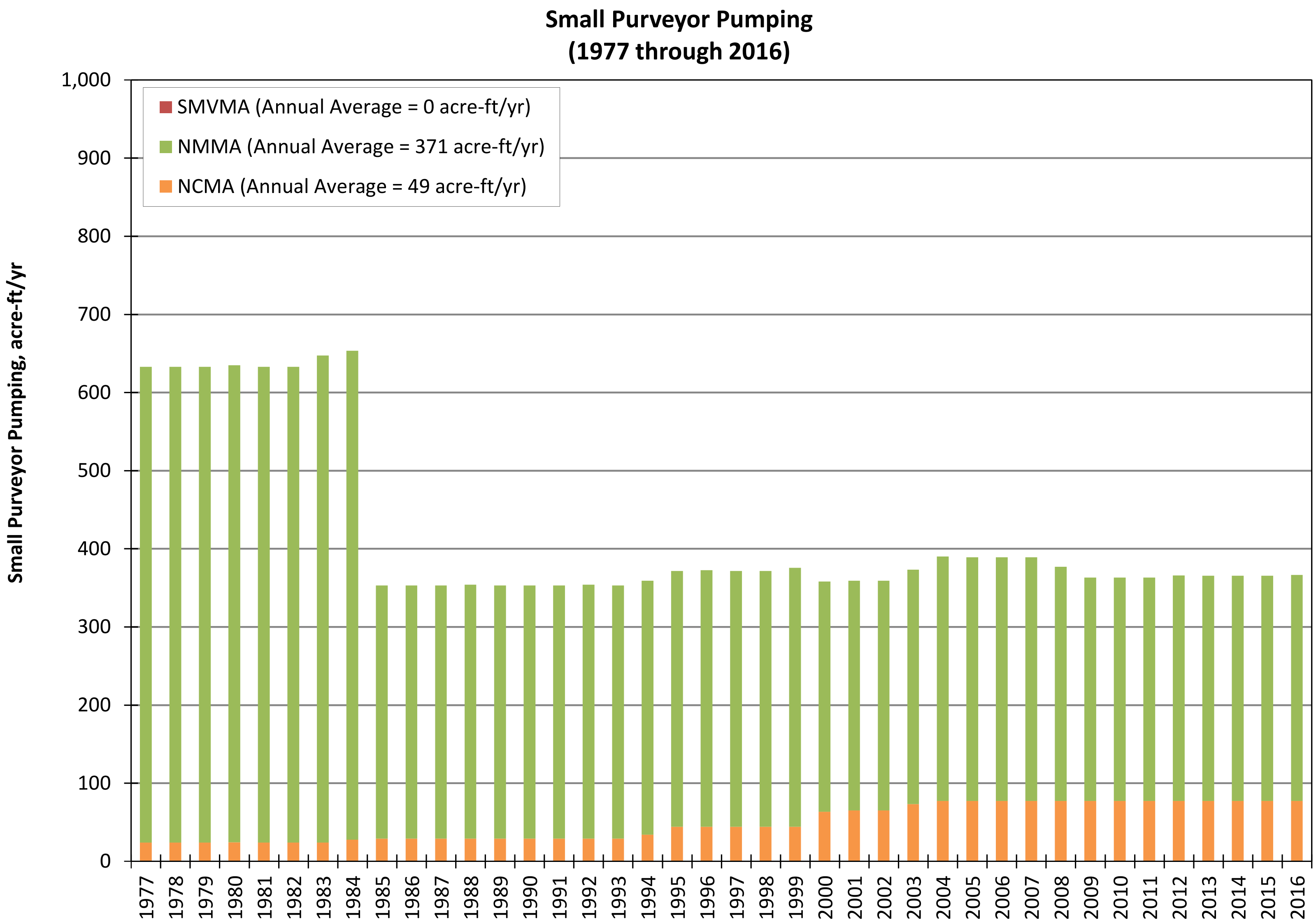

Small Purveyor Pumping
(1977 through 2016)
SMVMA (Annual Average = 0 acre-ft/yr)
NMMA (Annual Average = 371 acre-ft/yr)
NCMA (Annual Average = 49 acre-ft/yr)
Small Purveyor Pumping, acre-ft/yr
1,000
900
800
700
600
500
400
300
200
100
0
1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

Figure 32

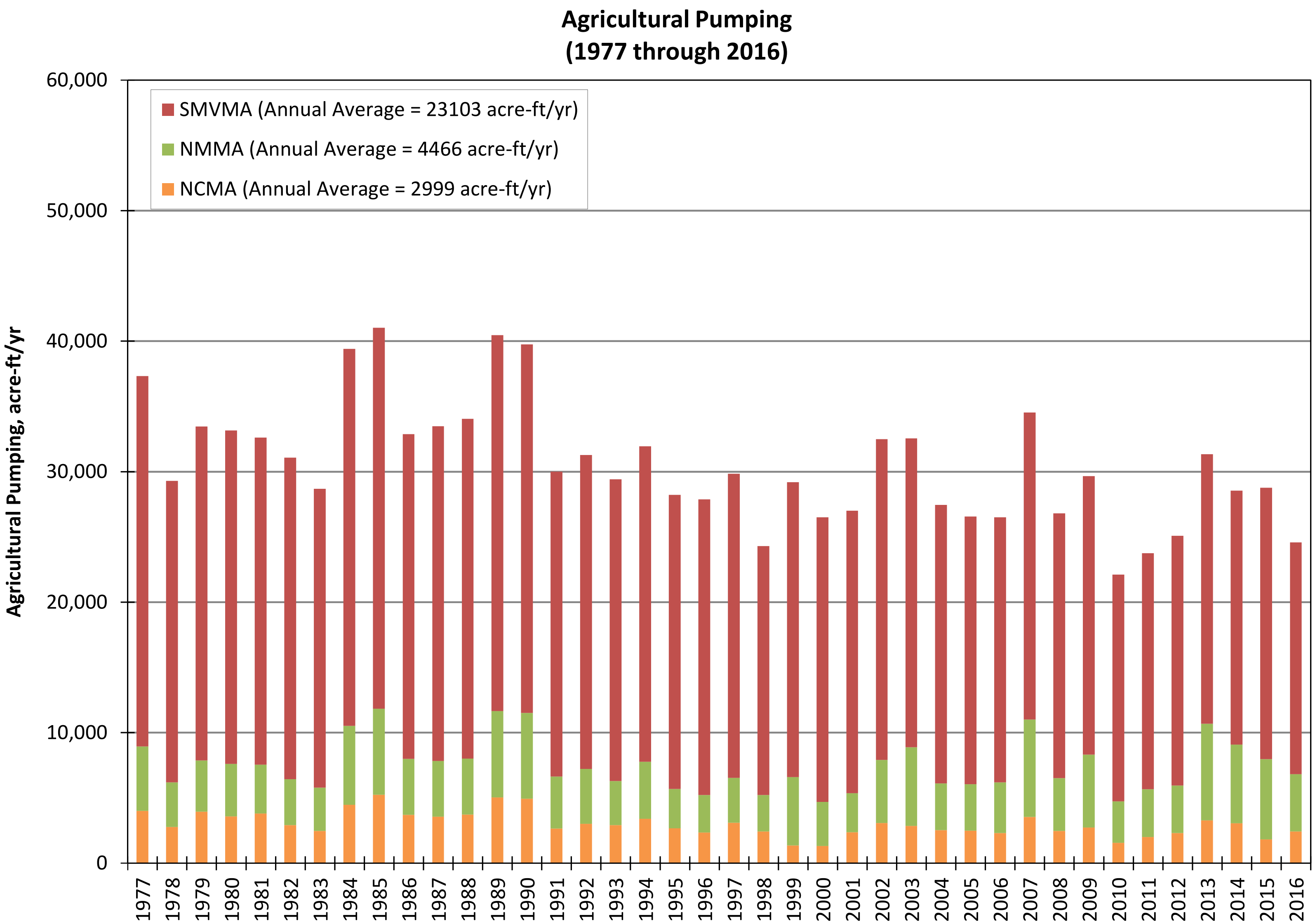

Agricultural Pumping
(1977 through 2016)
SMVMA (Annual Average = 23103 acre-ft/yr)
NMMA (Annual Average = 4466 acre-ft/yr)
NCMA (Annual Average = 2999 acre-ft/yr)
Agricultural Pumping, acre-ft/yr
60,000
50,000
40,000
30,000
20,000
10,000
0
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

Figure 33

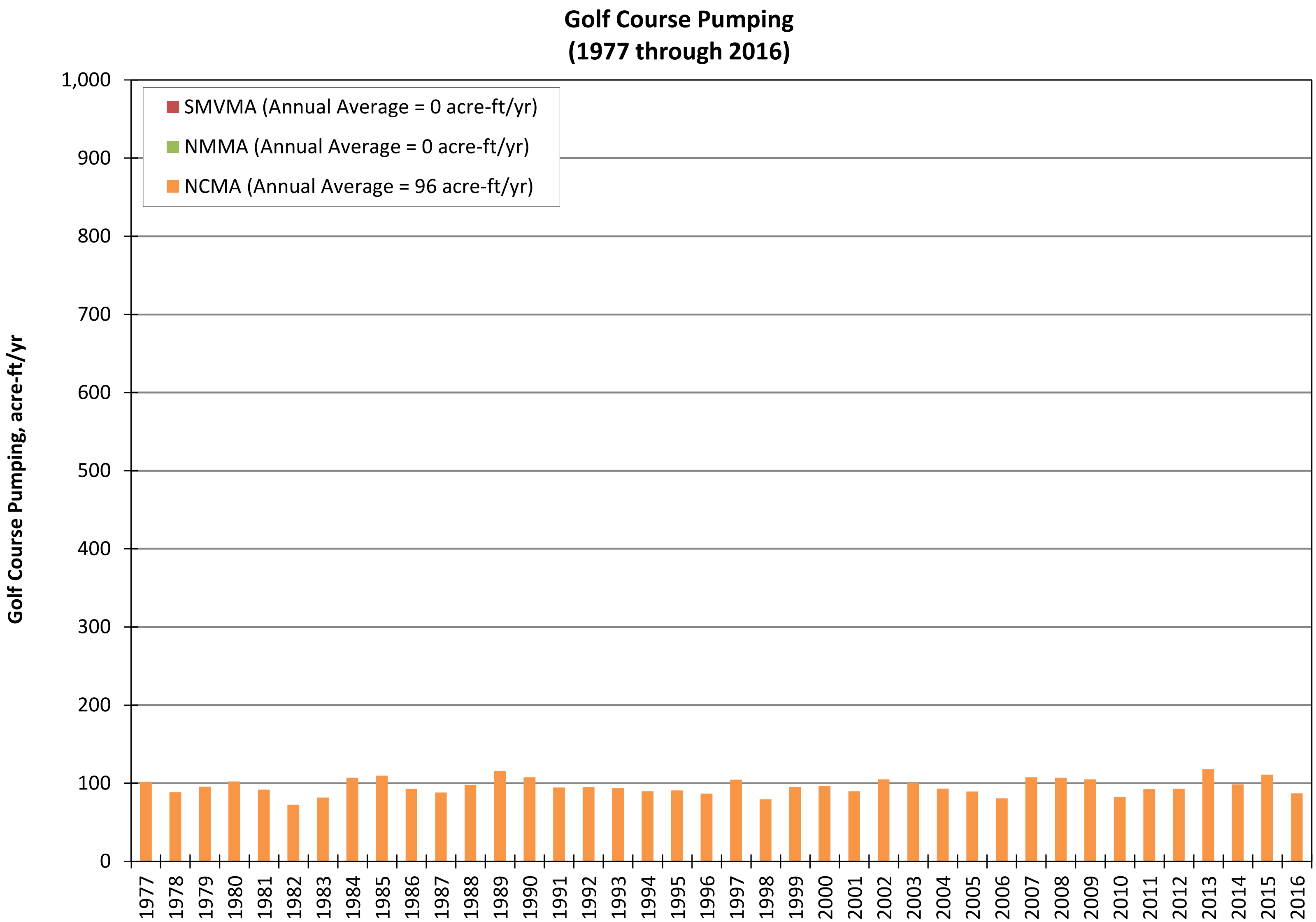

Golf Course Pumping
(1977 through 2016)
SMVMA (Annual Average = 0 acre-ft/yr)
NMMA (Annual Average = 0 acre-ft/yr)
NCMA (Annual Average = 96 acre-ft/yr)
Golf Course Pumping, acre-ft/yr
1,000
900
800
700
600
500
400
300
200
100
0
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

Figure 34

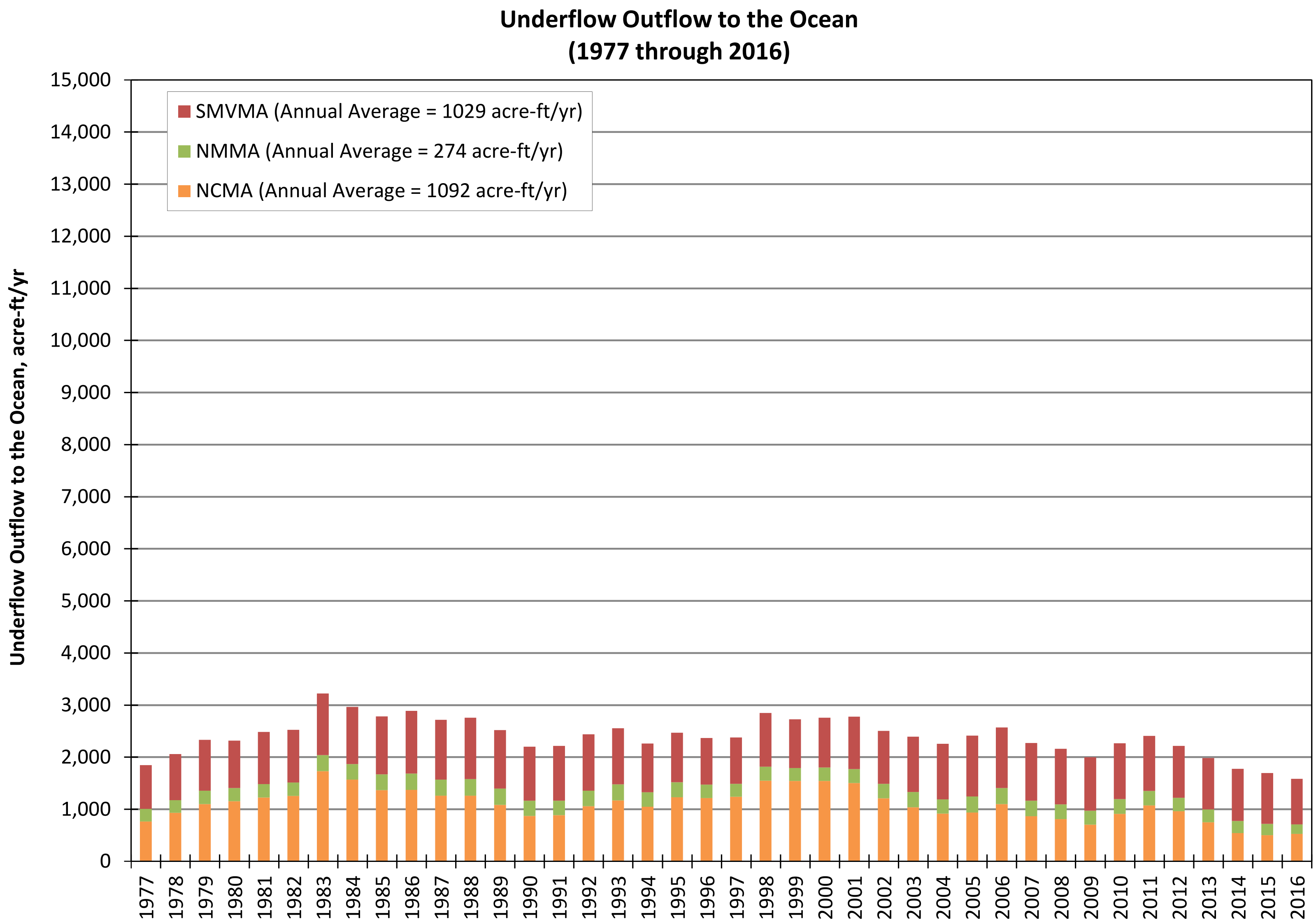

Underflow Outflow to the Ocean
(1977 through 2016)
SMVMA (Annual Average = 1029 acre-ft/yr)
NMMA (Annual Average = 274 acre-ft/yr)
NCMA (Annual Average = 1092 acre-ft/yr)
Underflow Outflow to the Ocean, acre-ft/yr
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

Figure 35

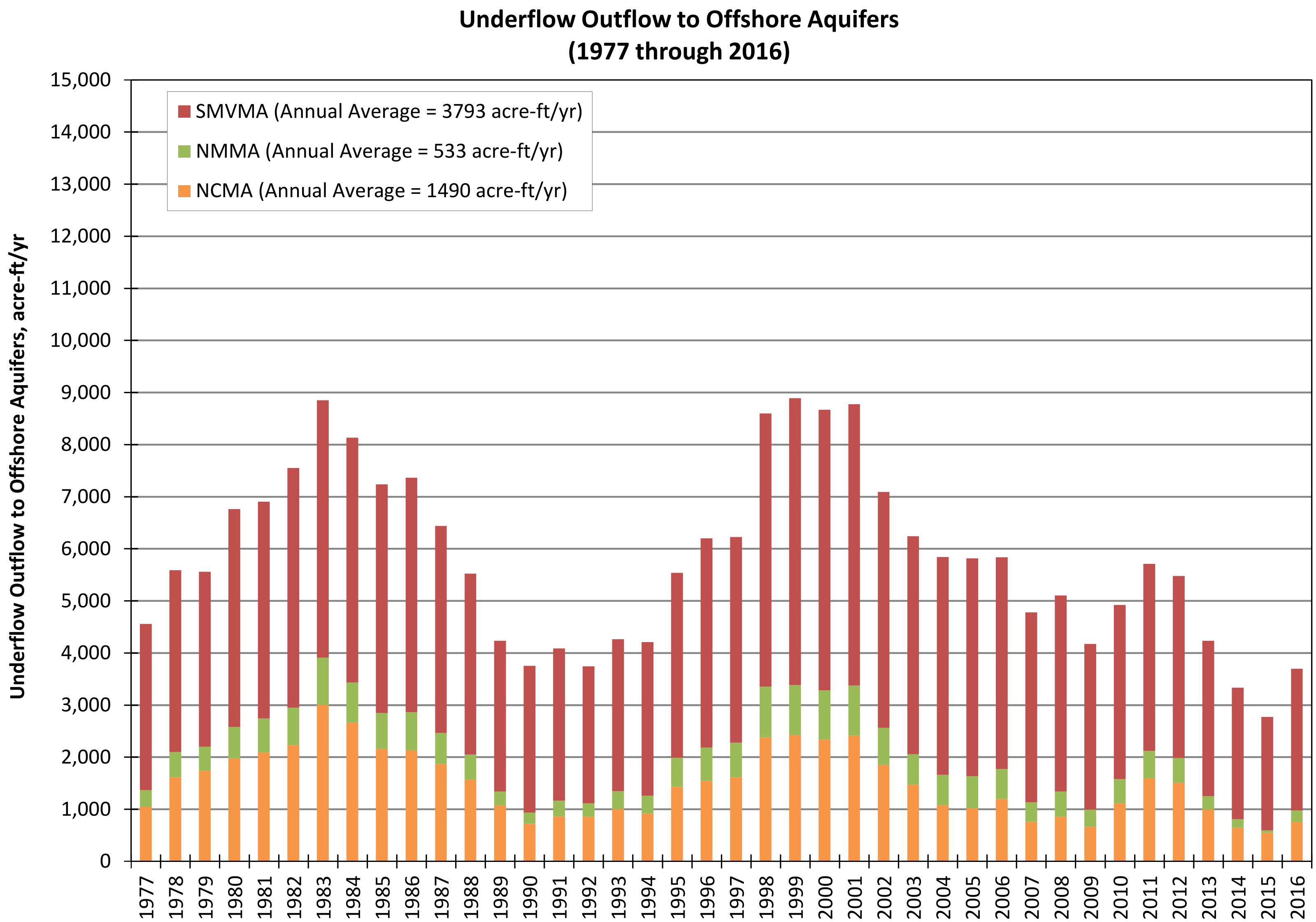
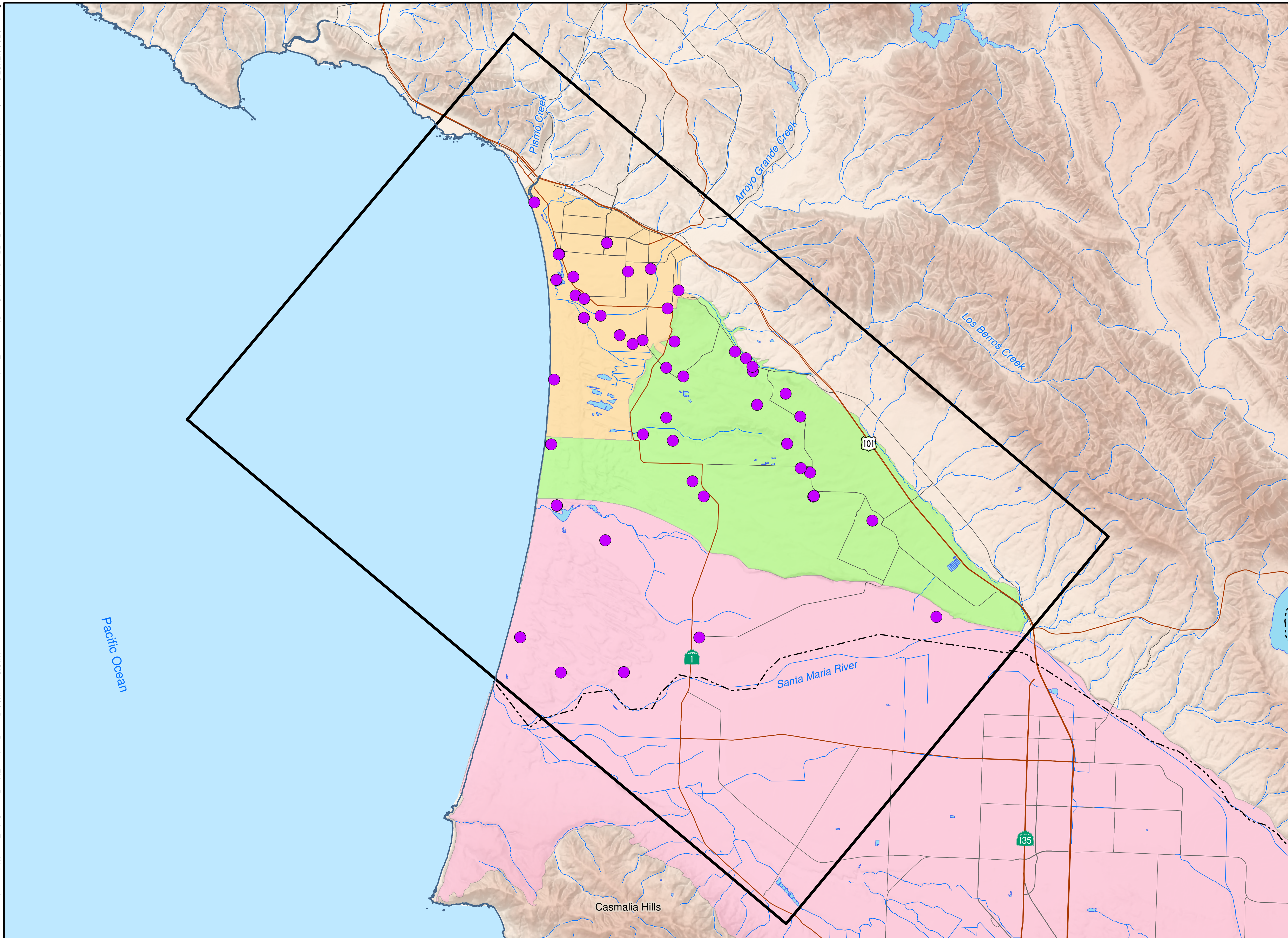

Underflow Outflow to Offshore Aquifers
(1977 through 2016)
SMVMA (Annual Average = 3793 acre-ft/yr)
NMMA (Annual Average = 533 acre-ft/yr)
NCMA (Annual Average = 1490 acre-ft/yr)
Underflow Outflow to Offshore Aquifers, acre-ft/yr
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

Figure 36



W:\GIS_proj\WSC_Pismo_Beach\41_TM-3_Fig_37_Calib_Target_Wells_steadystate_5-19.mxd

GROUNDWATER FLOW MODEL CALIBRATION TARGET WELLS - STEADY-STATE CALIBRATION

14-May-19

FIGURE 37

GEOSCIENCE

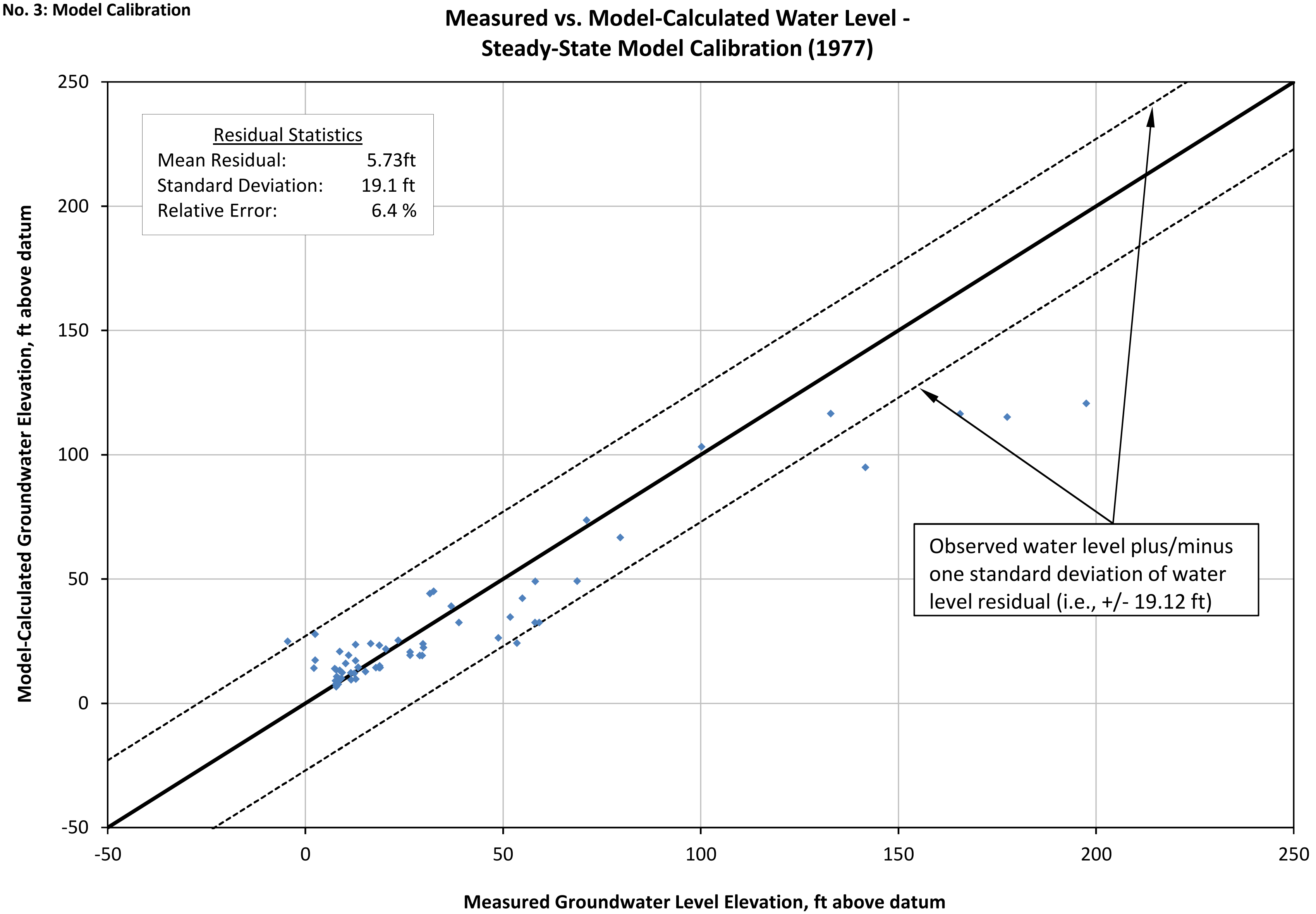
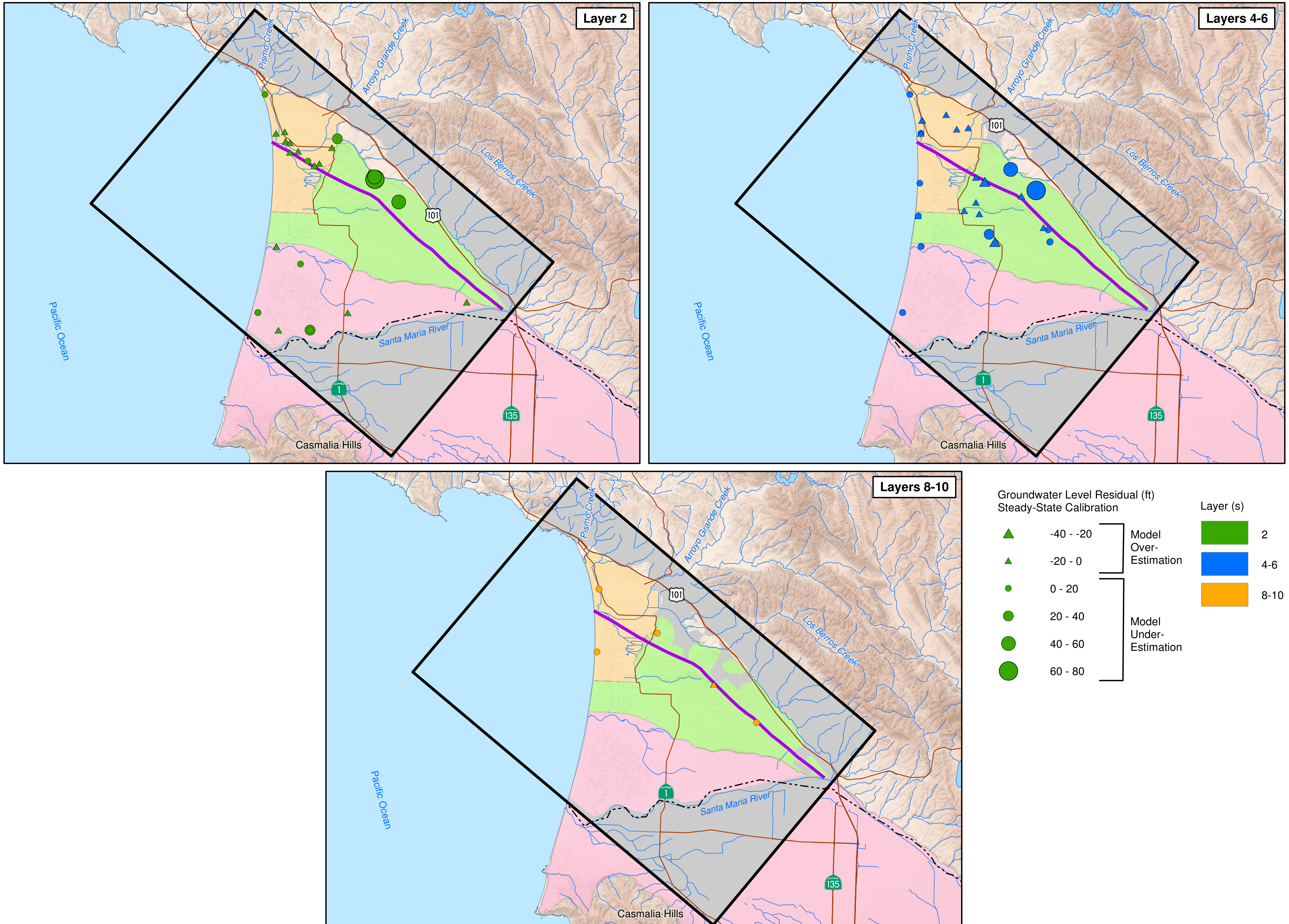

Measured vs. Model-Calculated Water Level -
Steady-State Model Calibration (1977)
Residual Statistics
Mean Residual: 5.73ft
Standard Deviation: 19.1 ft
Relative Error: 6.4 %
Observed water level plus/minus one standard deviation of water level residual (i.e., +/- 19.12 ft)
Model-Calculated Groundwater Elevation, ft above datum
Measured Groundwater Level Elevation, ft above datum
250
200
150
100
50
0
-50
-50
0
50
100
150
200
250

Figure 38



SPATIAL DISTRIBUTION OF STEADY-STATE CALIBRATION RESIDUALS

W:\GIS_proj\WSC_Pismo_Beach\41_TM-3_Fig_39_GW_level_steadystate_residuals_3panel_5-19.mxd

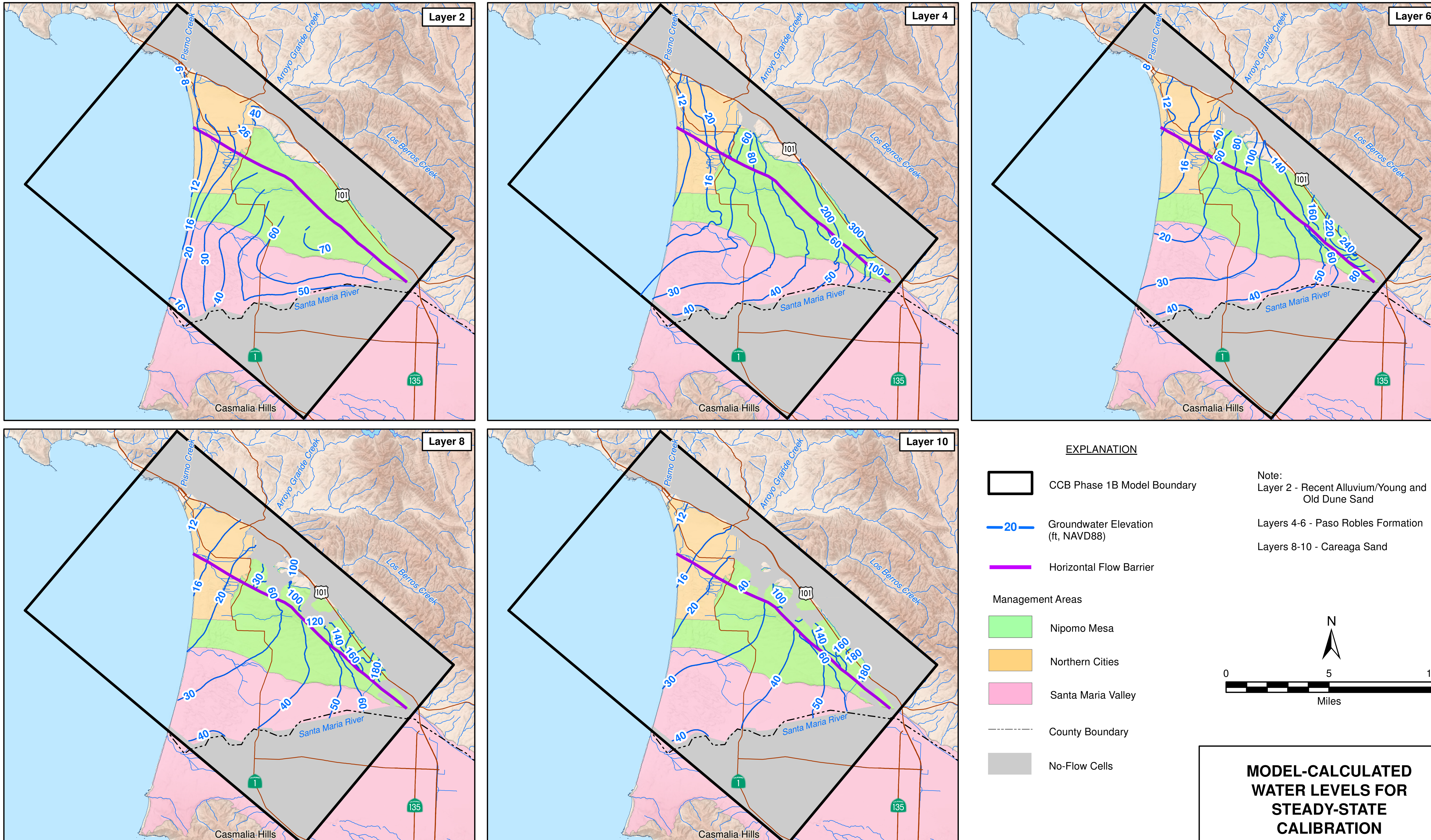
14-May-19

WATER SYSTEMS CONSULTING, INC.

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

FIGURE 39

GEOSCIENCE



W:\GIS_proj\WSC_Pismo_Beach\41_TM-3_Fig_40_WL_steadystate_5panel_5-19.mxd

MODEL-CALCULATED WATER LEVELS FOR STEADY-STATE CALIBRATION (1977)

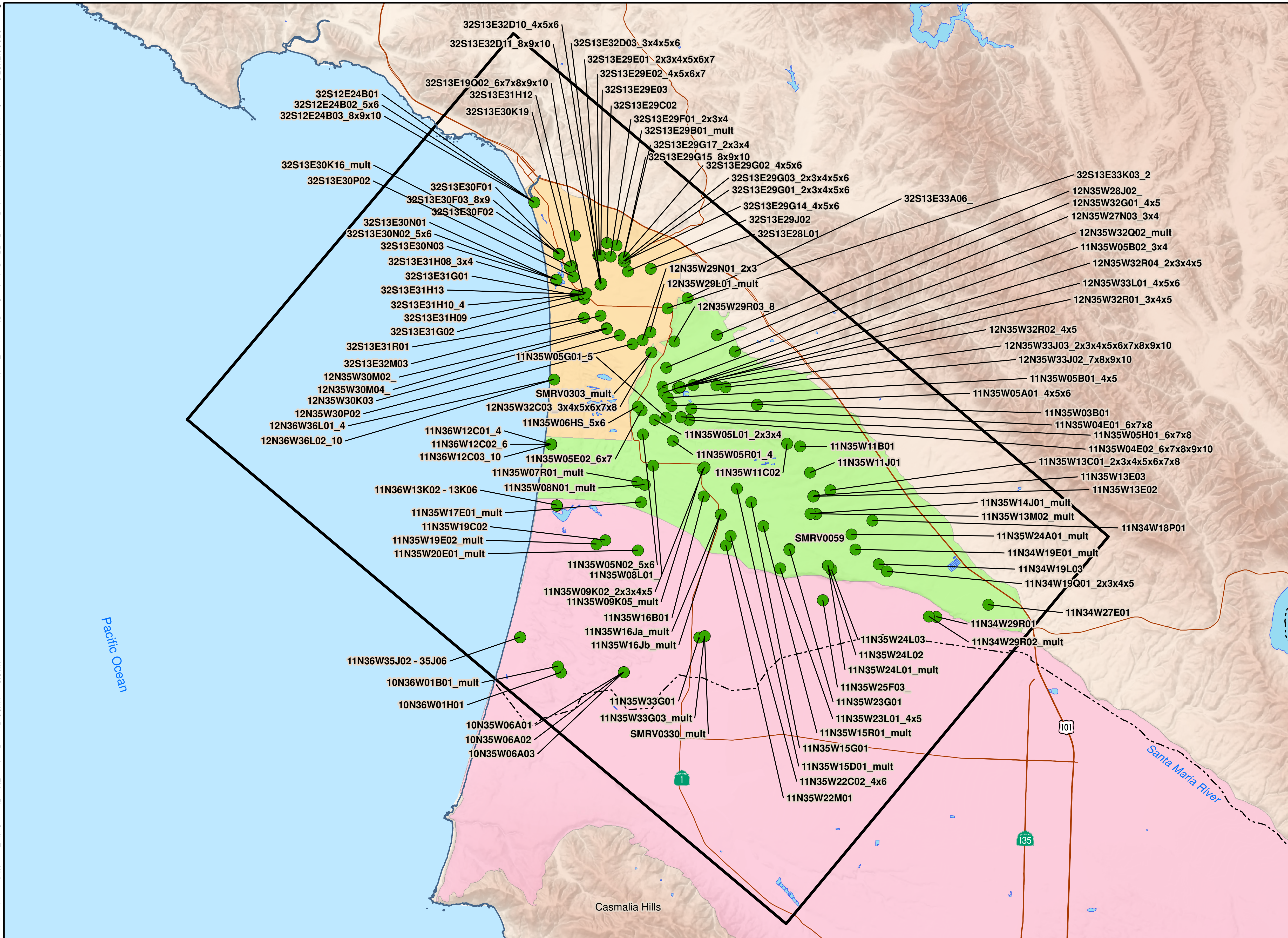
14-May-19

WATER SYSTEMS CONSULTING, INC.

FIGURE 40

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE



EXPLANATION

CCB Phase 1B Model Boundary

Transient Calibration Target Well

Management Areas

Nipomo Mesa

Northern Cities

Santa Maria Valley

County Boundary

Note:

N

0 2 4

Miles

GROUNDWATER FLOW MODEL CALIBRATION TARGET WELLS - TRANSIENT CALIBRATION

W:\GIS_proj\WSC_Pismo_Beach\41_TM-3_Fig_41_Calib_Target_Wells_transient_5-19.mxd

14-May-19

Measured vs. Model-Calculated Water Levels - Transient Model Calibration (1977 through 2016) using All Target Wells

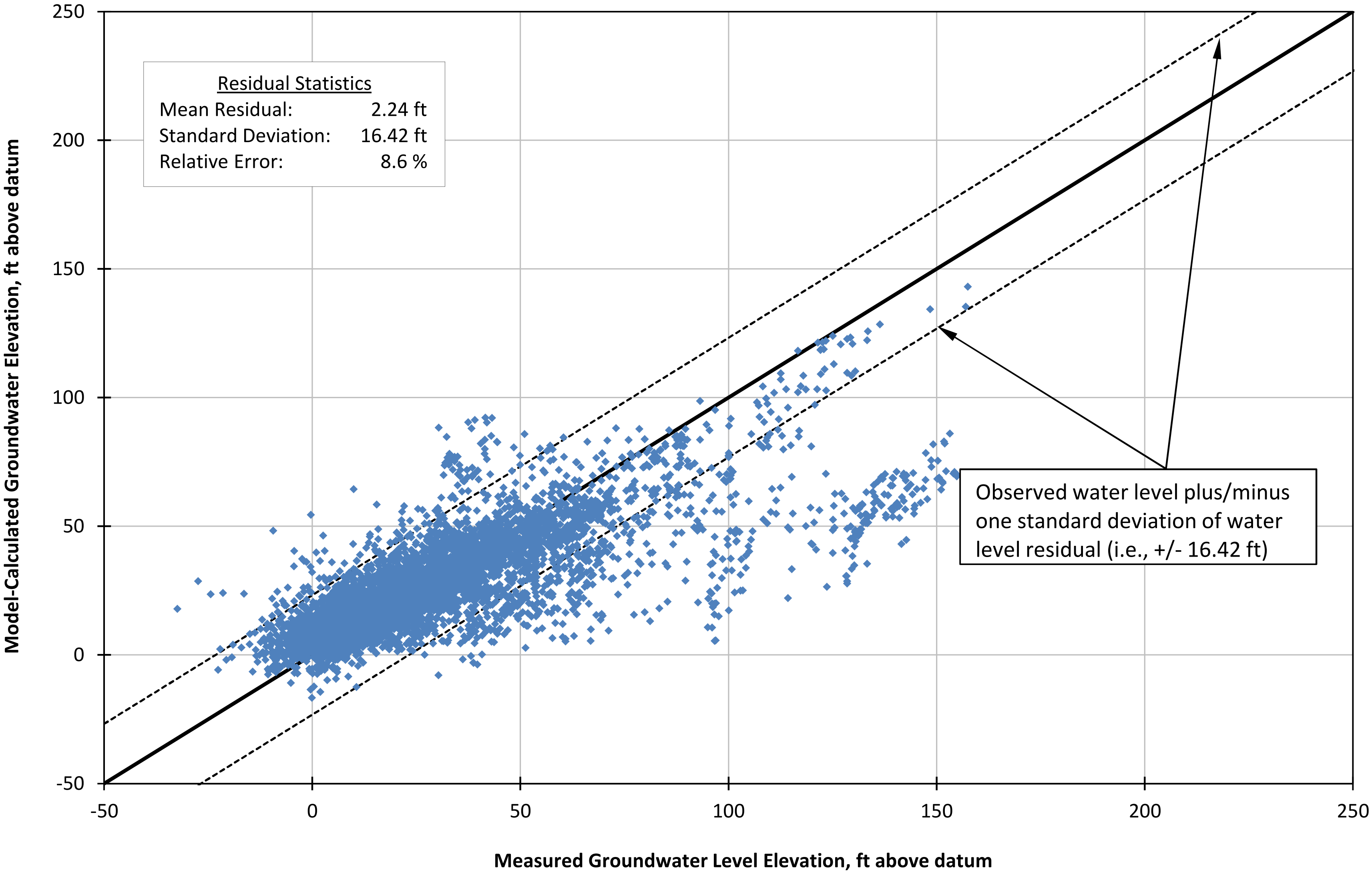


Figure 42a

Measured vs. Model-Calculated Water Levels - Transient Model Calibration (1977 through 2016) using Key Wells

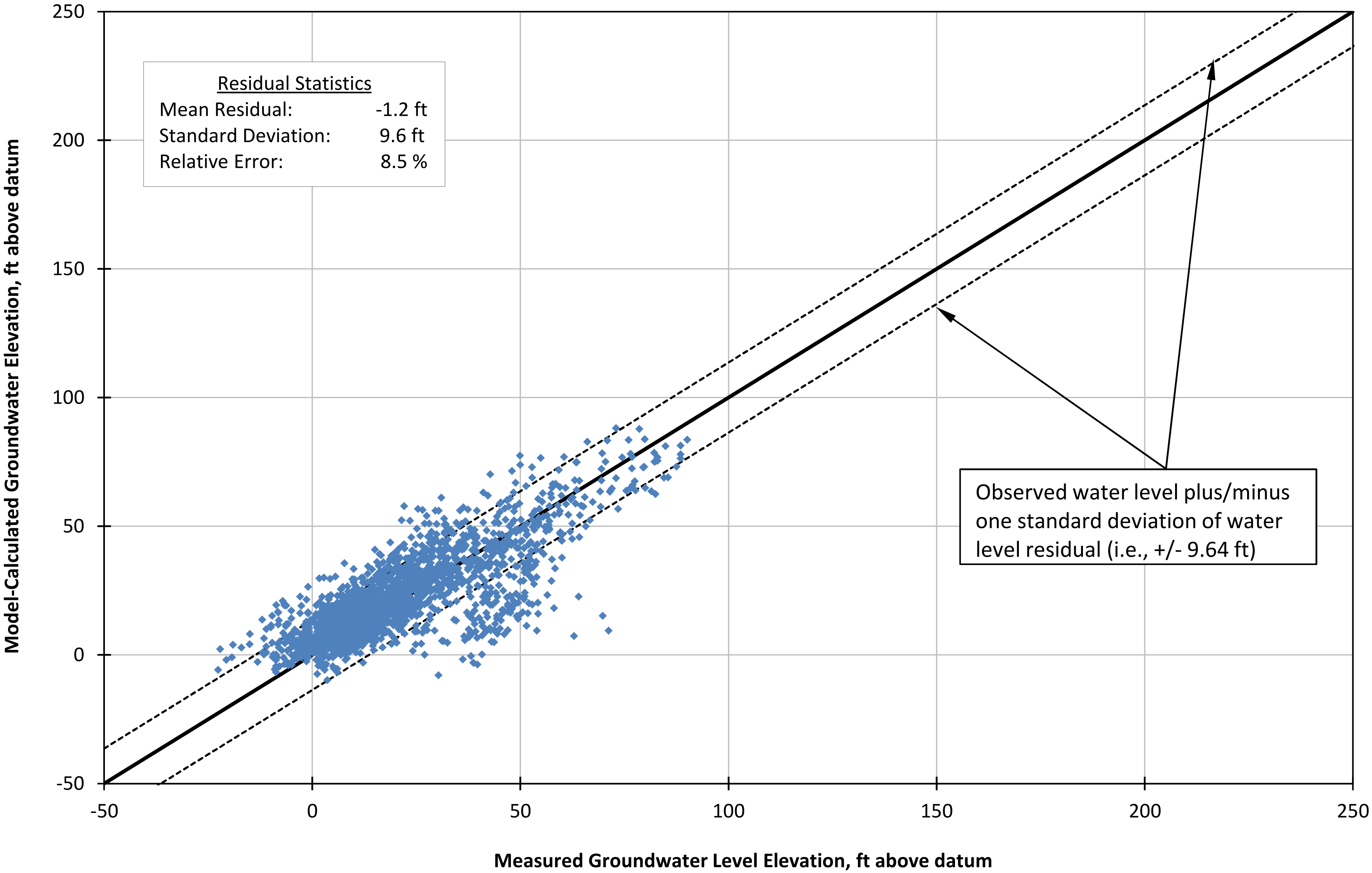


Figure 42b

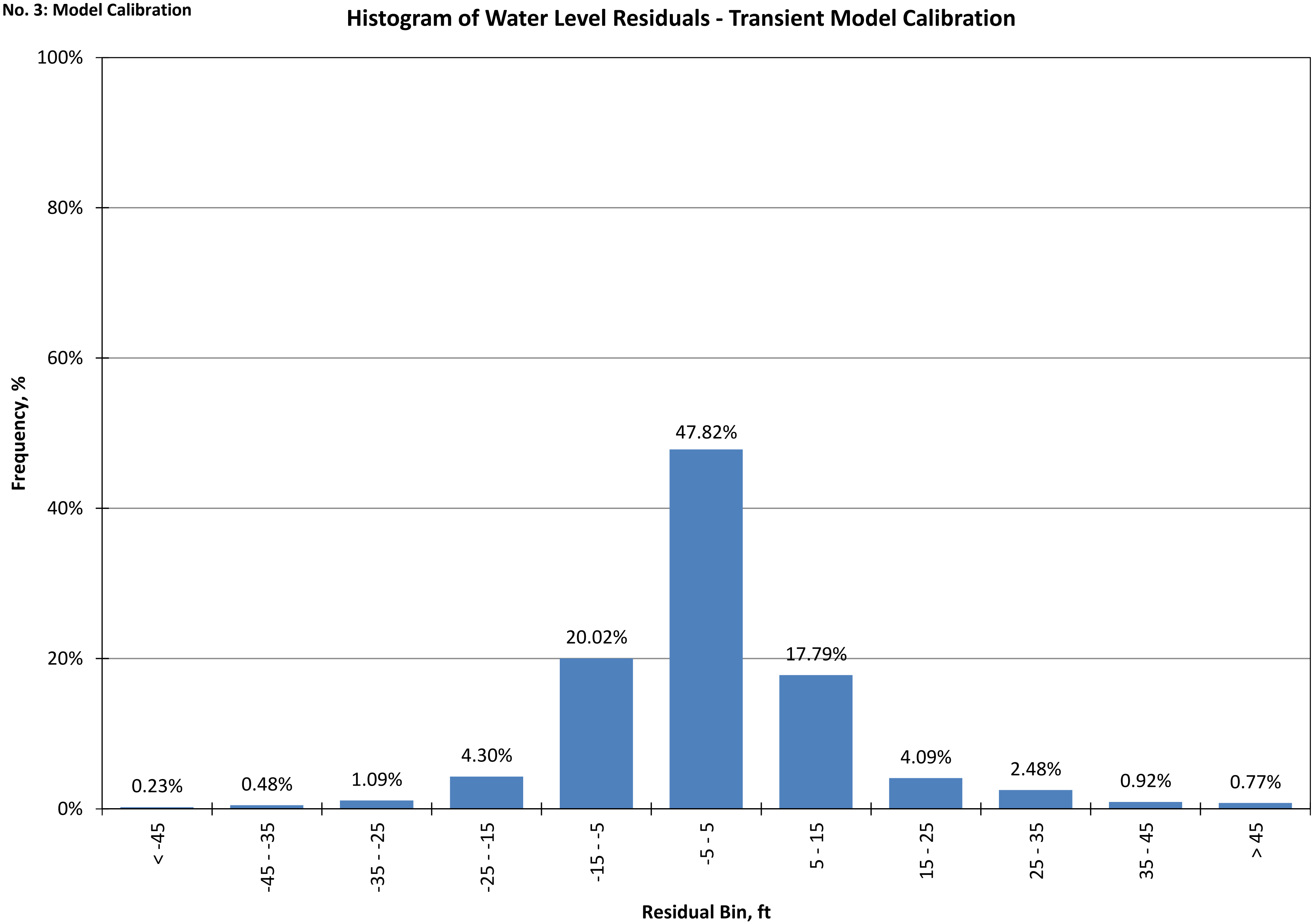
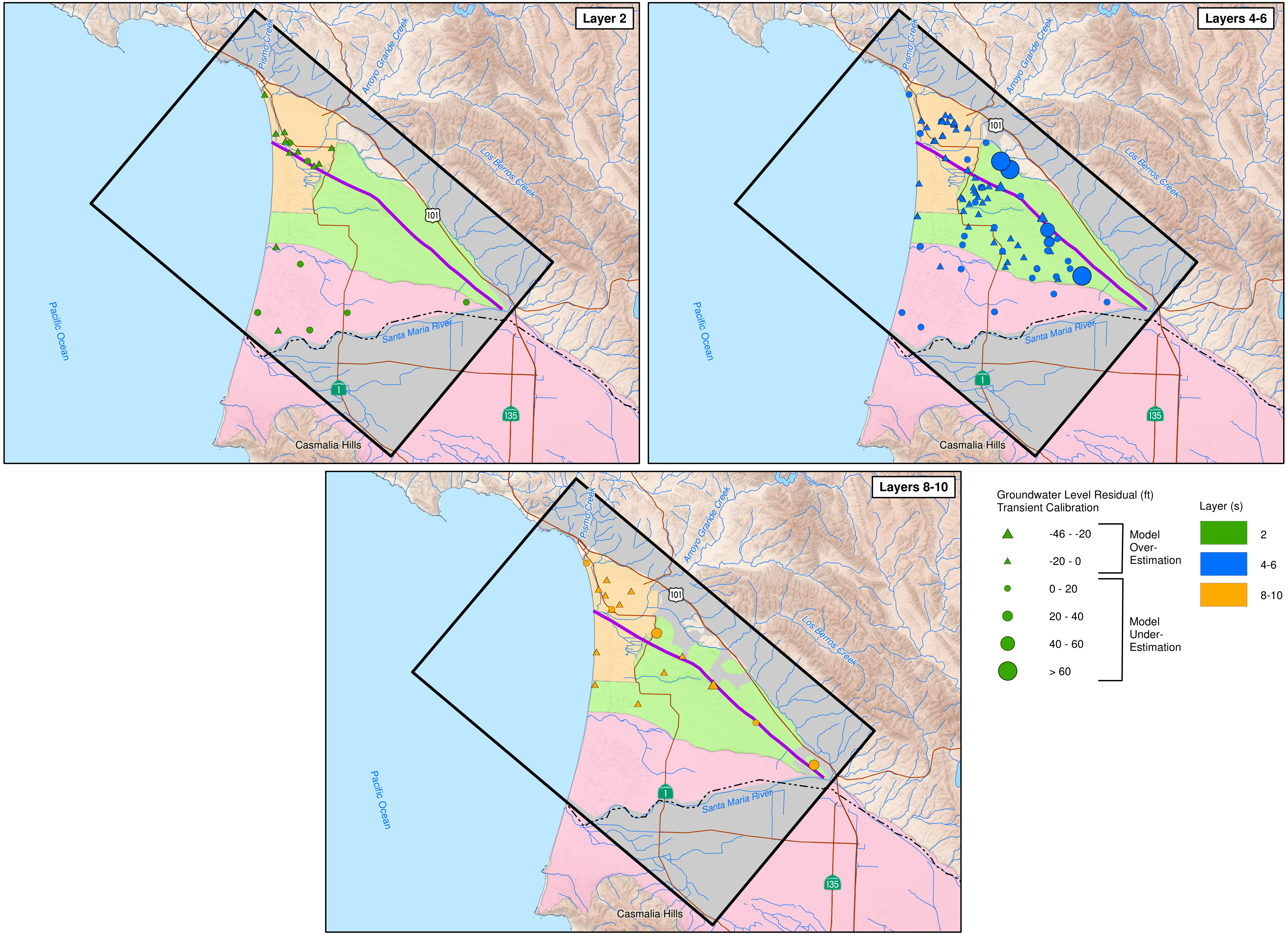

Histogram of Water Level Residuals - Transient Model Calibration
Frequency, %
100%
80%
60%
40%
20%
0%
0.23%
0.48%
1.09%
4.30%
20.02%
47.82%
17.79%
4.09%
2.48%
0.92%
0.77%
< -45
-45 - -35
-35 - -25
-25 - -15
-15 - -5
-5 - 5
5 - 15
15 - 25
25 - 35
35 - 45
> 45
Residual Bin, ft

Figure 43



EXPLANATION

CCB Phase 1B Model Boundary

Horizontal Flow Barrier

No-Flow Cells

Management Areas

Nipomo Mesa

Northern Cities

Santa Maria Valley

County Boundary

Note:
Layer 2 - Recent Alluvium/Young and Old Dune Sand

Layers 4-6 - Paso Robles Formation

Layers 8-10 - Careaga Sand

SPATIAL DISTRIBUTION OF TRANSIENT CALIBRATION RESIDUALS (AVERAGE OF 2007 THROUGH 2016)

W:\GIS_proj\WSC_Pismo_Beach\41_TM-3_Fig_44_GW_level_transient_residuals_3panel_5-19.mxd

14-May-19

FIGURE 44

WATER SYSTEMS CONSULTING, INC.

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE

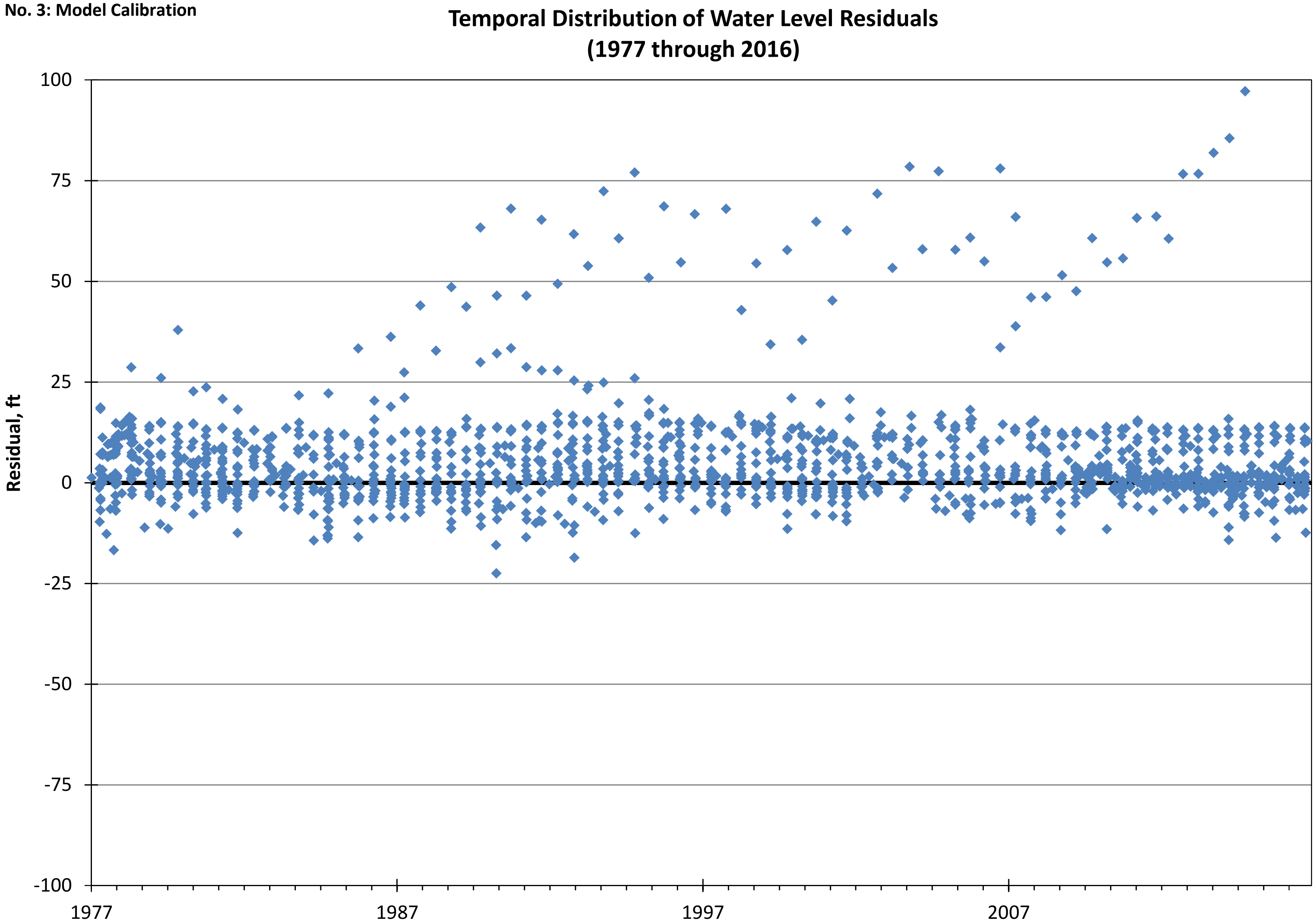
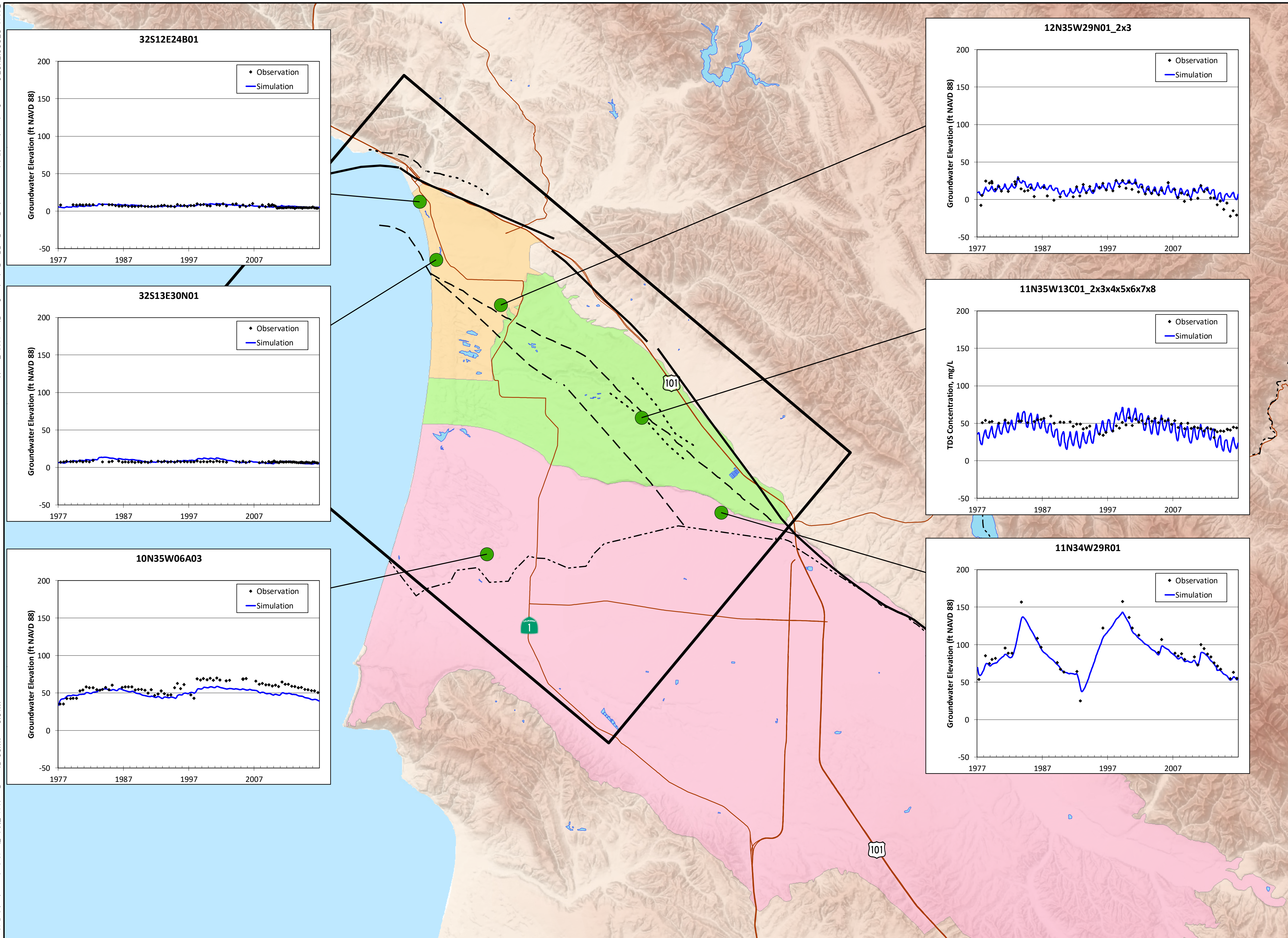

Temporal Distribution of Water Level Residuals
(1977 through 2016)
Residual, ft
100
75
50
25
0
-25
-50
-75
-100
1977
1987
1997
2007

Figure 45



EXPLANATION

CCB Phase 1B Model Boundary

Well Used for Hydrograph

Observed

Simulated

Management Areas

Nipomo Mesa

Northern Cities

Santa Maria Valley

County Boundary

N

0 3 6

Miles

SELECTED HYDROGRAPHS RECENT ALLUVIUM / YOUNG AND OLD DUNE SAND (MODEL LAYER 2)

W:\GIS_proj\WSC_Pismo_Beach\41_TM-3_Fig_46_hydrographs_L2_5-19.mxd

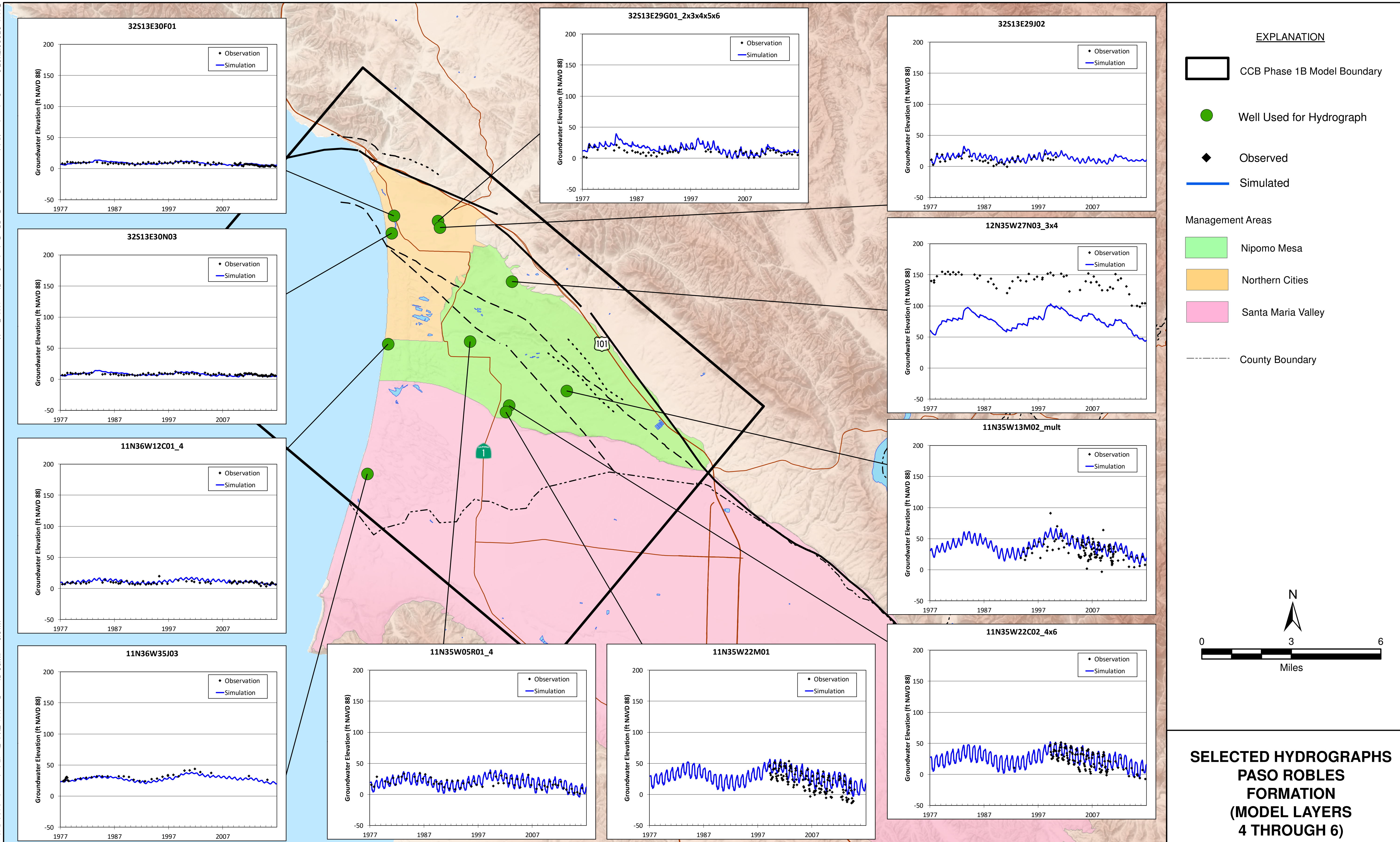
14-May-19

WATER SYSTEMS CONSULTING, INC.

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

FIGURE 46

GEOSCIENCE



SELECTED HYDROGRAPHS PASO ROBLES FORMATION (MODEL LAYERS 4 THROUGH 6)

W:\GIS_proj\WSC_Pismo_Beach\4_TM-3_Fig_47_hydrographs_L4-L6_5-19.mxd

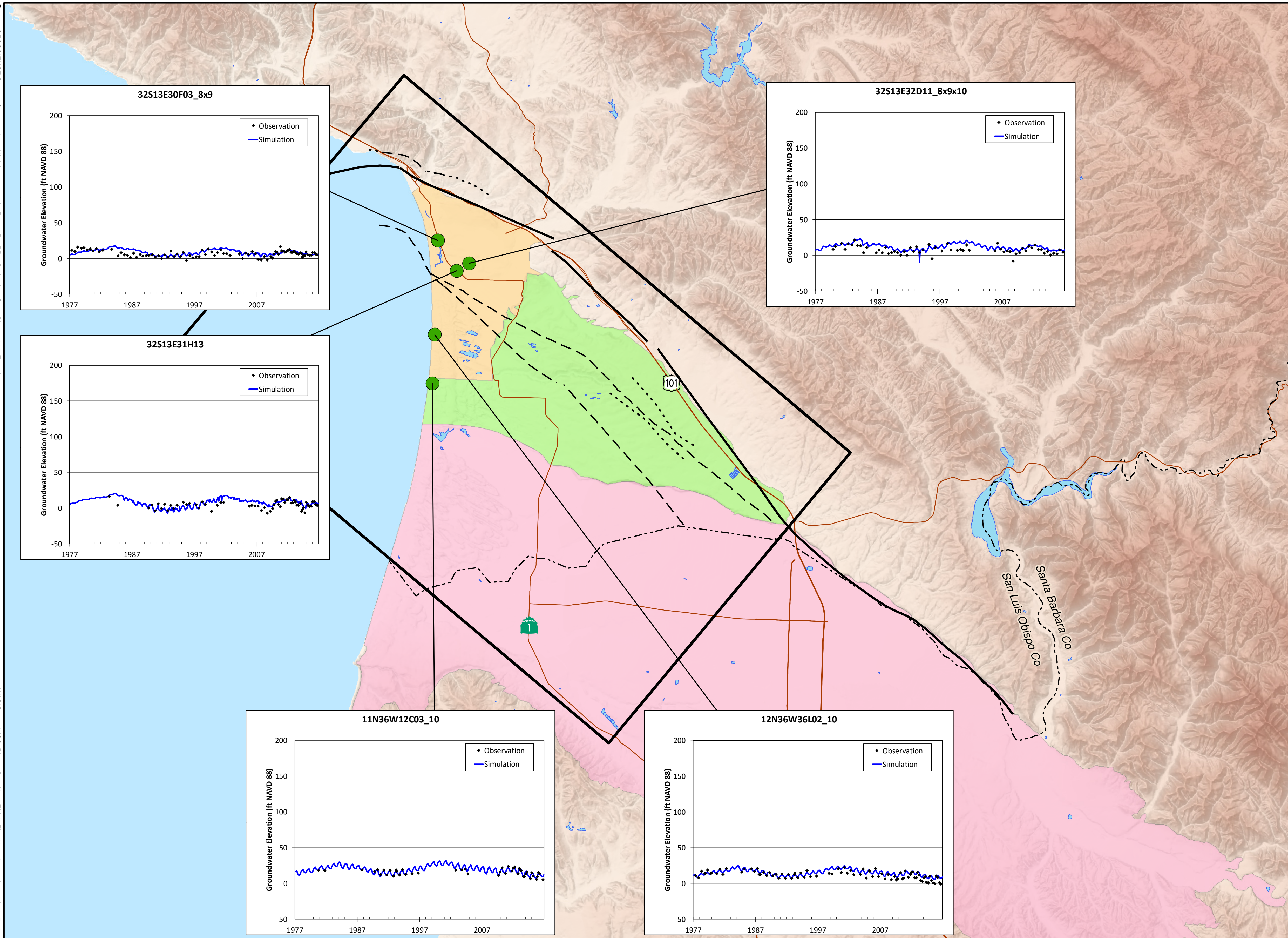
14-May-19

WATER SYSTEMS CONSULTING, INC.

FIGURE 47

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE



SELECTED HYDROGRAPHS CAREAGA SAND (MODEL LAYERS 8 THROUGH 10)

W:\GIS_proj\WSC_Pismo_Beach\41_TM-3_Fig_48_hydrographs_L8-L10_5-19.mxd

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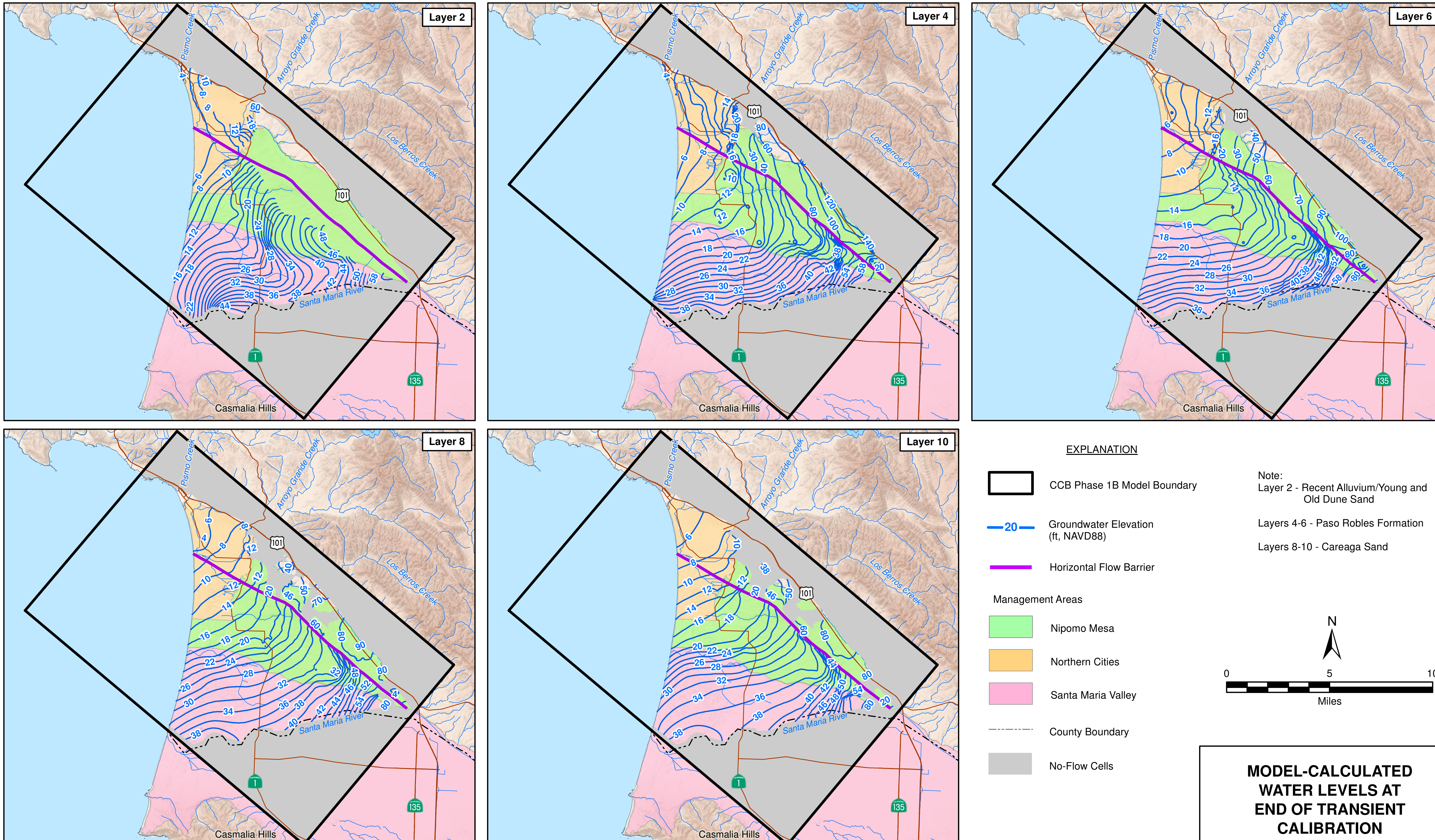
WATER SYSTEMS CONSULTING, INC.

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

FIGURE 48

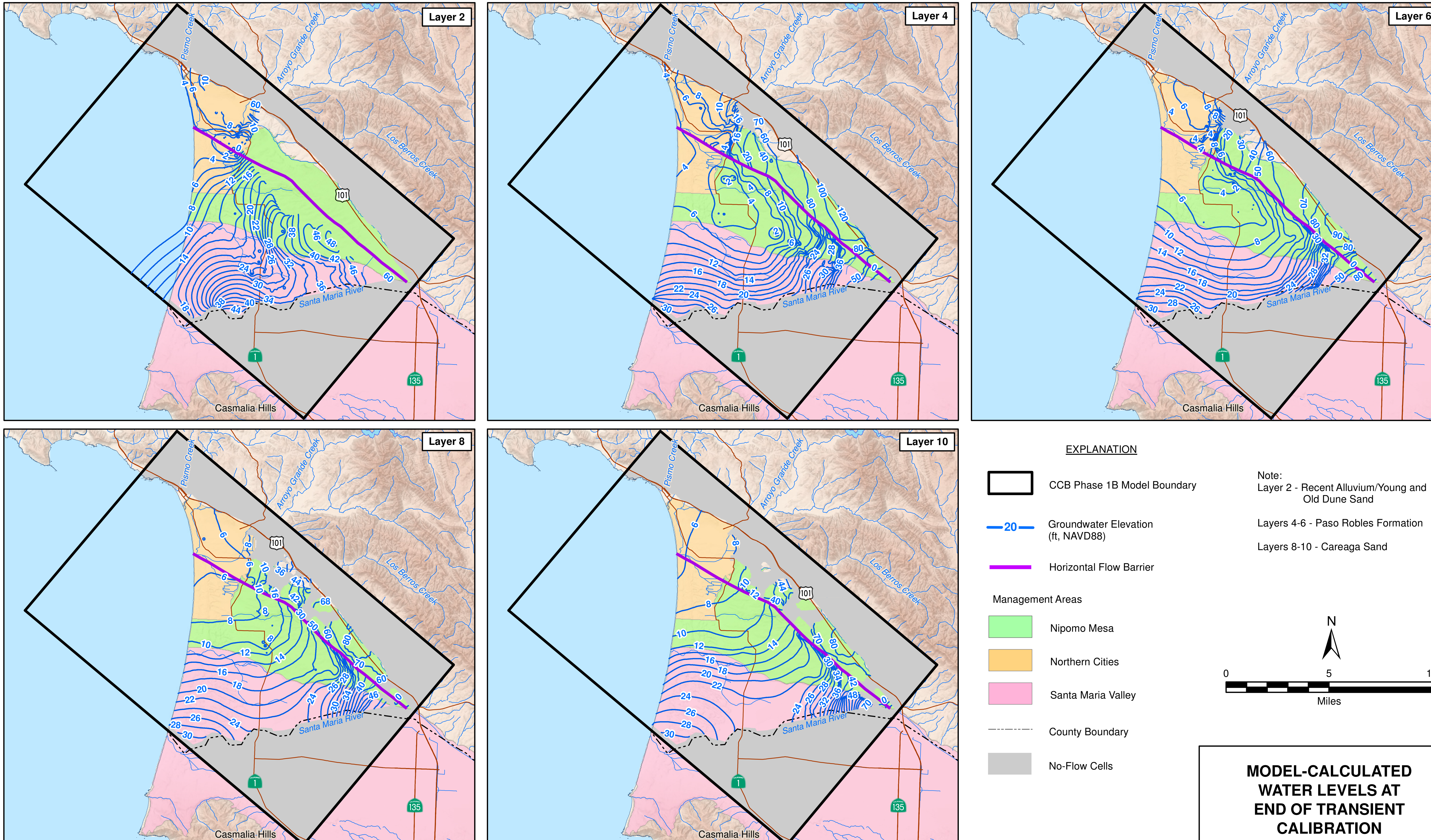
GEOSCIENCE

W:\GIS_proj\WSC_Pismo_Beach\41_TM-3_Fig_49_WL_transient_Spring2016_5panel_5-19.mxd



MODEL-CALCULATED WATER LEVELS AT END OF TRANSIENT CALIBRATION (SPRING 2016)

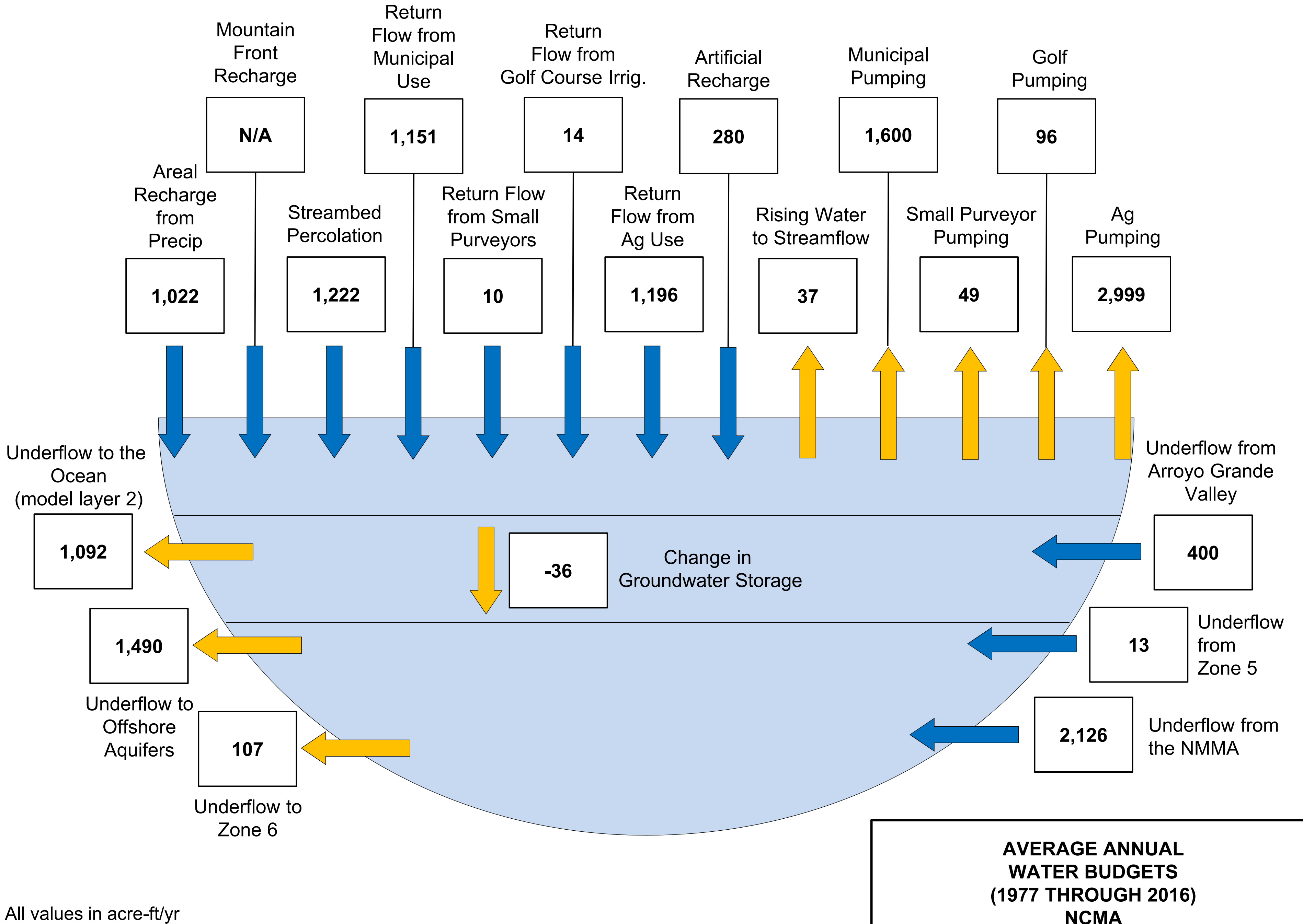
14-May-19



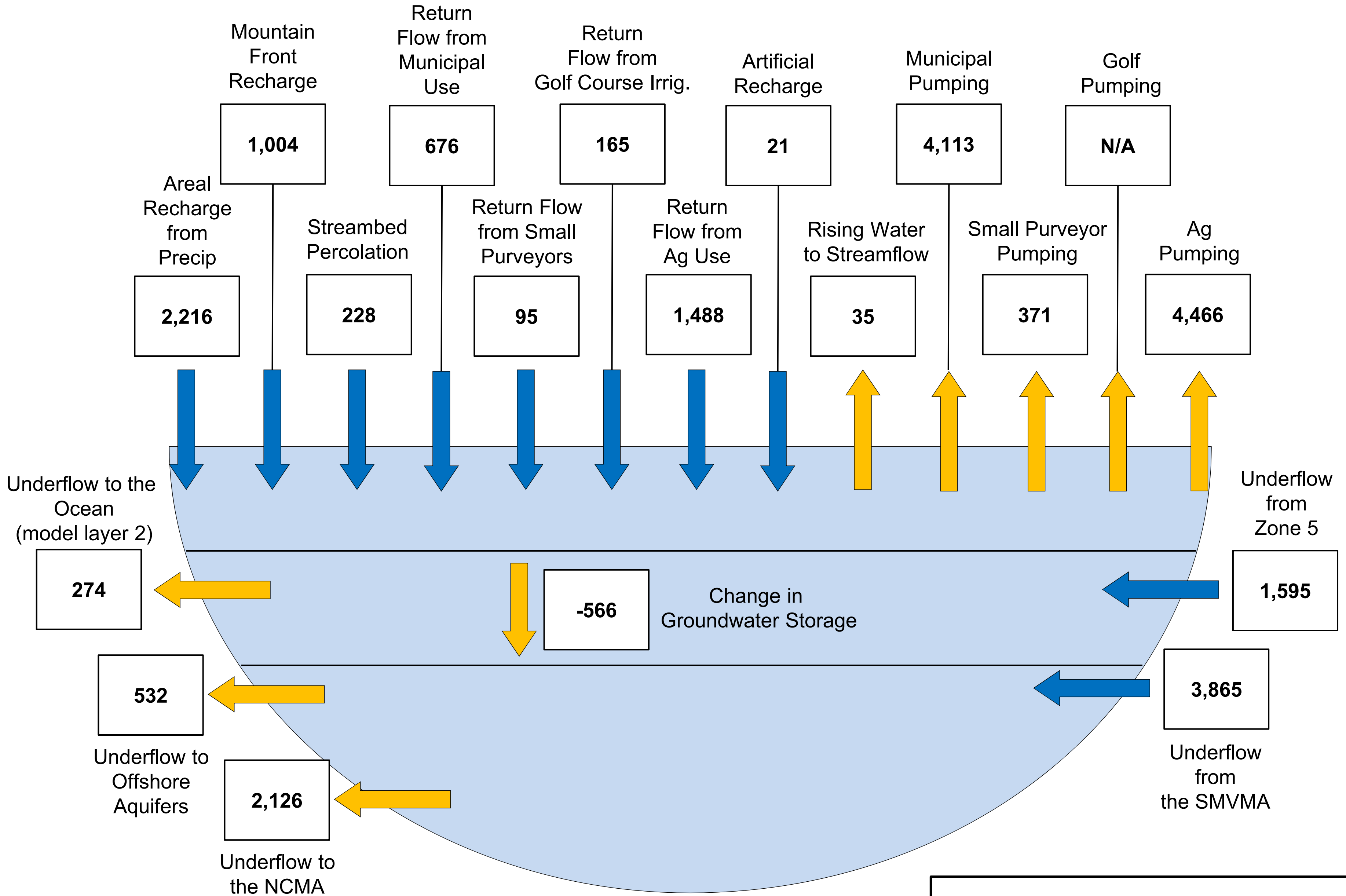
MODEL-CALCULATED WATER LEVELS AT END OF TRANSIENT CALIBRATION (FALL 2016)

14-May-19

FIGURE 50



AVERAGE ANNUAL WATER BUDGETS (1977 THROUGH 2016) NCMA



AVERAGE ANNUAL WATER BUDGETS (1977 THROUGH 2016) NMMA

All values in acre-ft/yr

X:\Projects\WSC\Phase_1B\TMs\6) TM No. 3 Model Calibration\Final\Figures

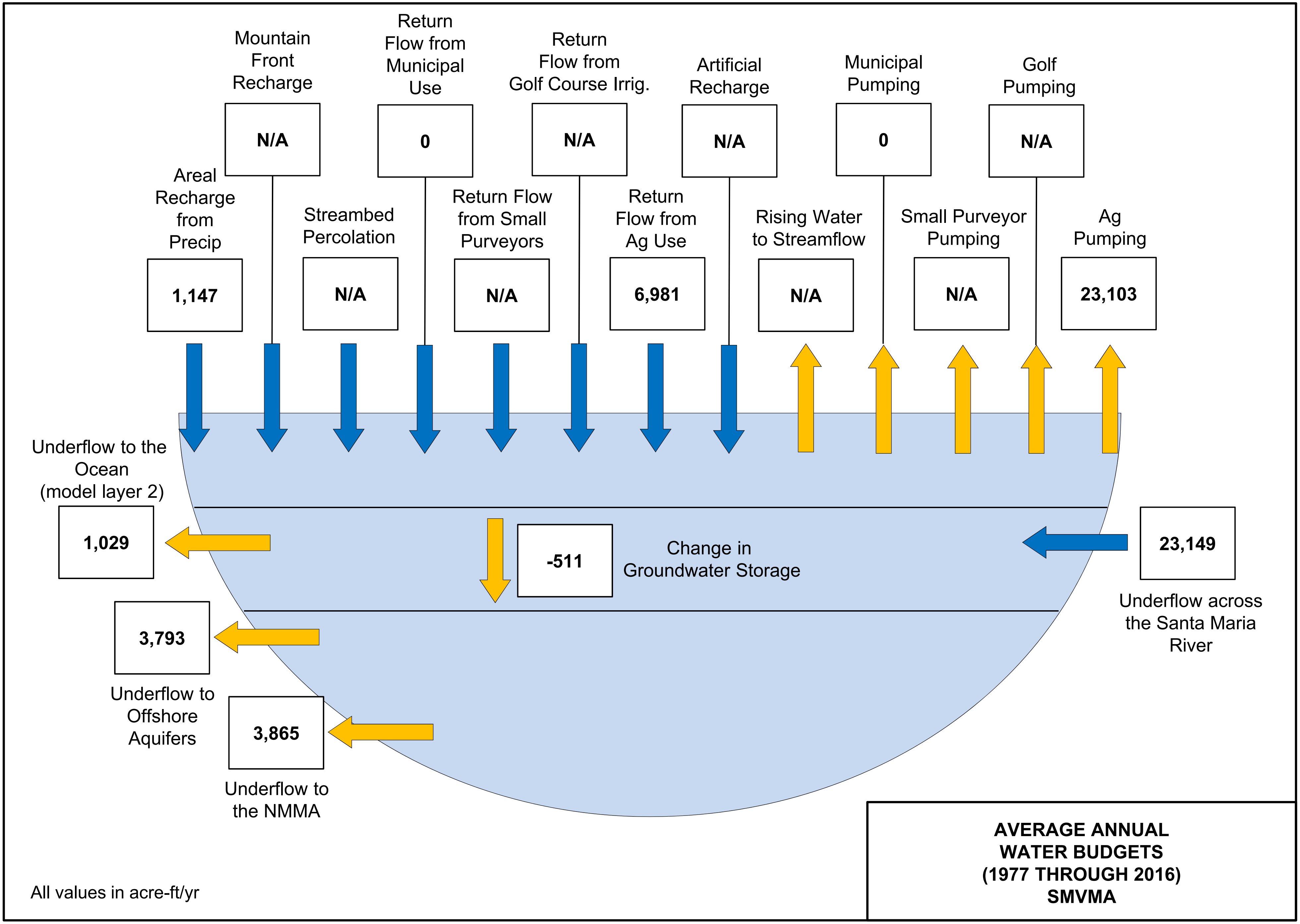
14-May-19

WATER SYSTEMS CONSULTING, INC.

FIGURE 52

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION – TM 3: MODEL CALIBRATION

GEOSCIENCE



AVERAGE ANNUAL WATER BUDGETS (1977 THROUGH 2016) SMVMA

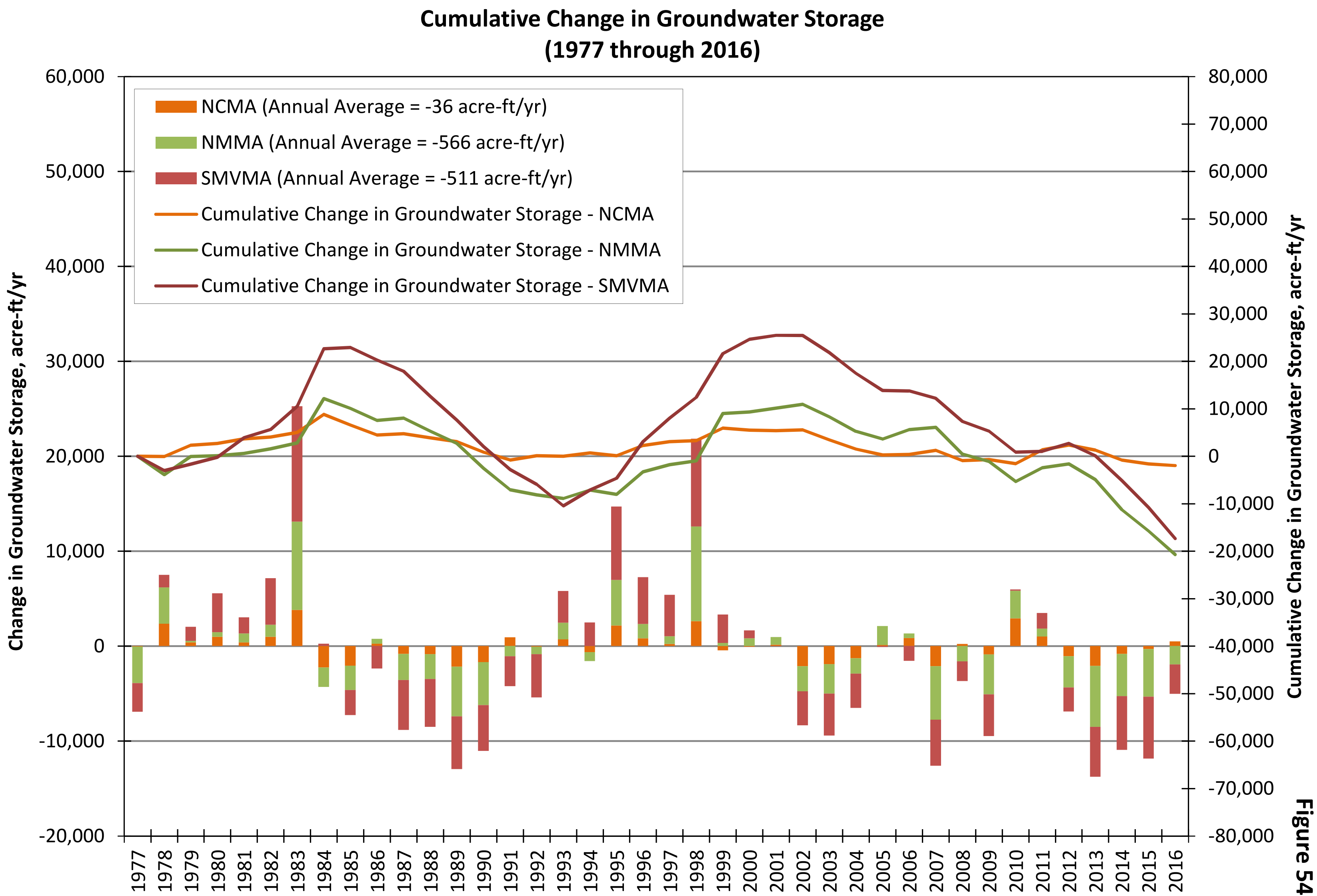
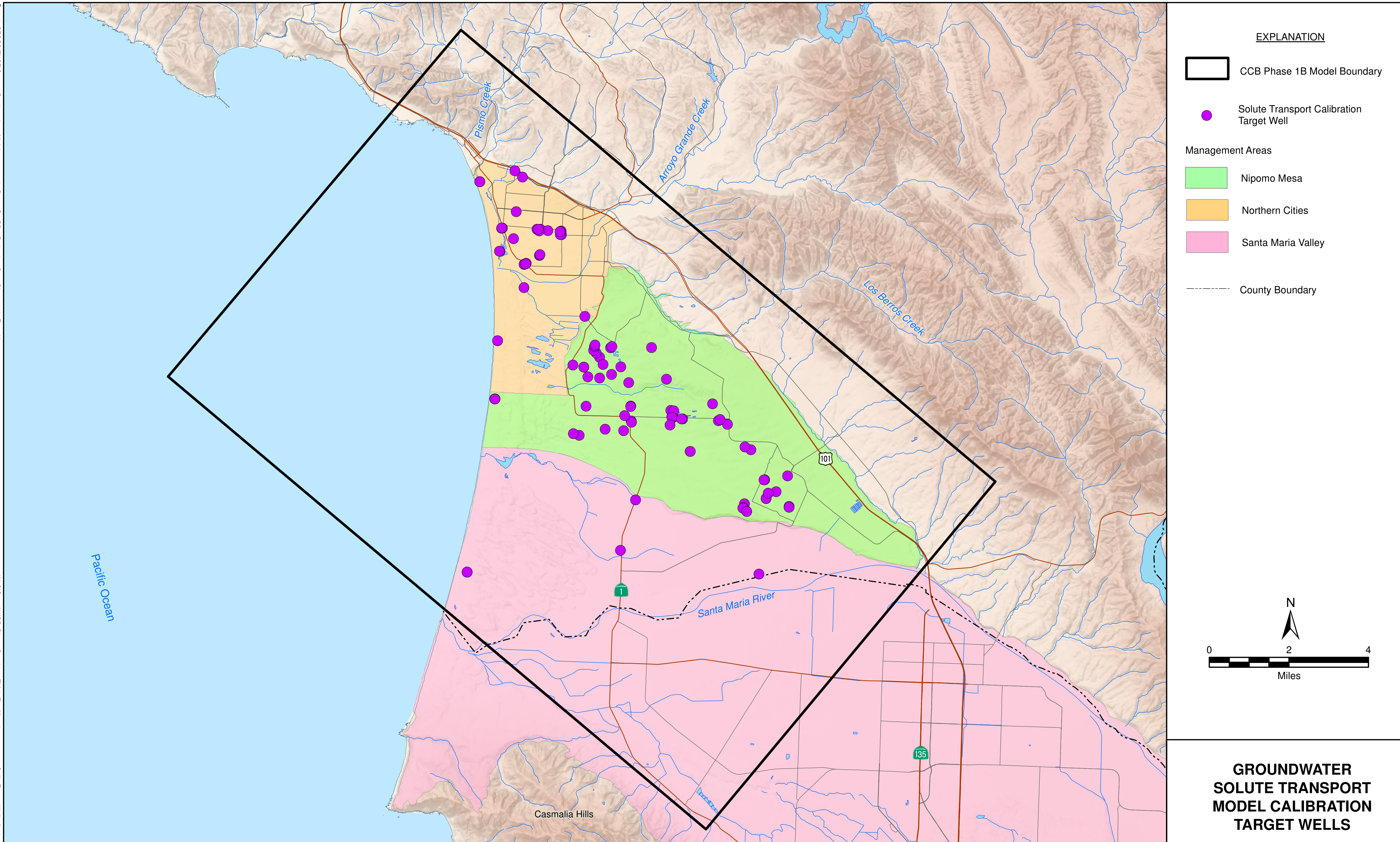

Cumulative Change in Groundwater Storage
(1977 through 2016)
NCMA (Annual Average = -36 acre-ft/yr)
NMMA (Annual Average = -566 acre-ft/yr)
SMVMA (Annual Average = -511 acre-ft/yr)
Cumulative Change in Groundwater Storage - NCMA
Cumulative Change in Groundwater Storage - NMMA
Cumulative Change in Groundwater Storage - SMVMA
Change in Groundwater Storage, acre-ft/yr
Cumulative Change in Groundwater Storage, acre-ft/yr
60,000
50,000
40,000
30,000
20,000
10,000
0
-10,000
-20,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
-10,000
-20,000
-30,000
-40,000
-50,000
-60,000
-70,000
-80,000
1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

Figure 54

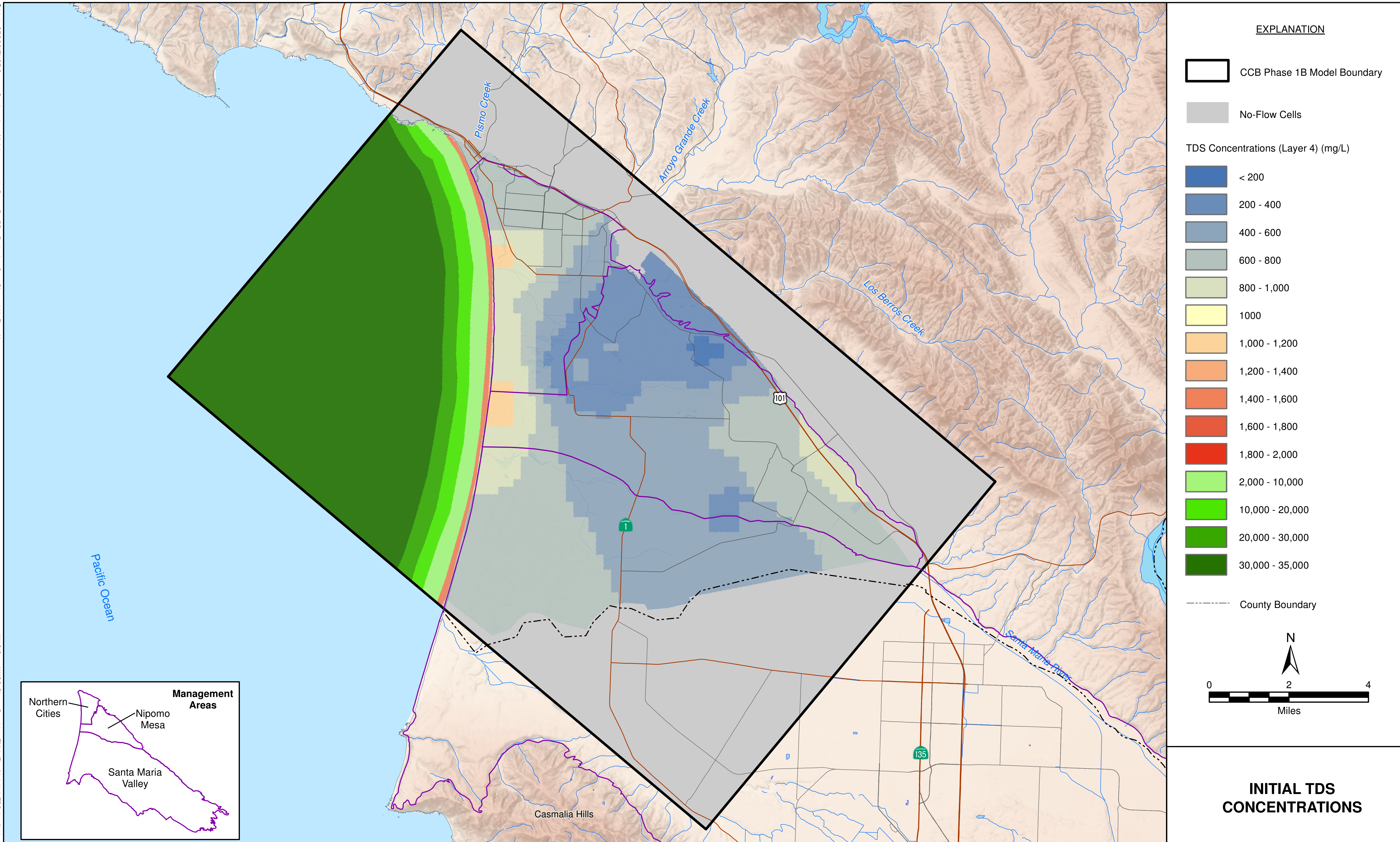


W:\GIS_proj\WSC_Pismo_Beach\41_TM-3_Fig_55_solute-transport_Calib_Target_Wells_5-19.mxd

GROUNDWATER SOLUTE TRANSPORT MODEL CALIBRATION TARGET WELLS

14-May-19

FIGURE 55



W:\GIS_proj\WSC_Pismo_Beach\41_TM-3_Fig_56_initial_TDS_L4_5-19.mxd

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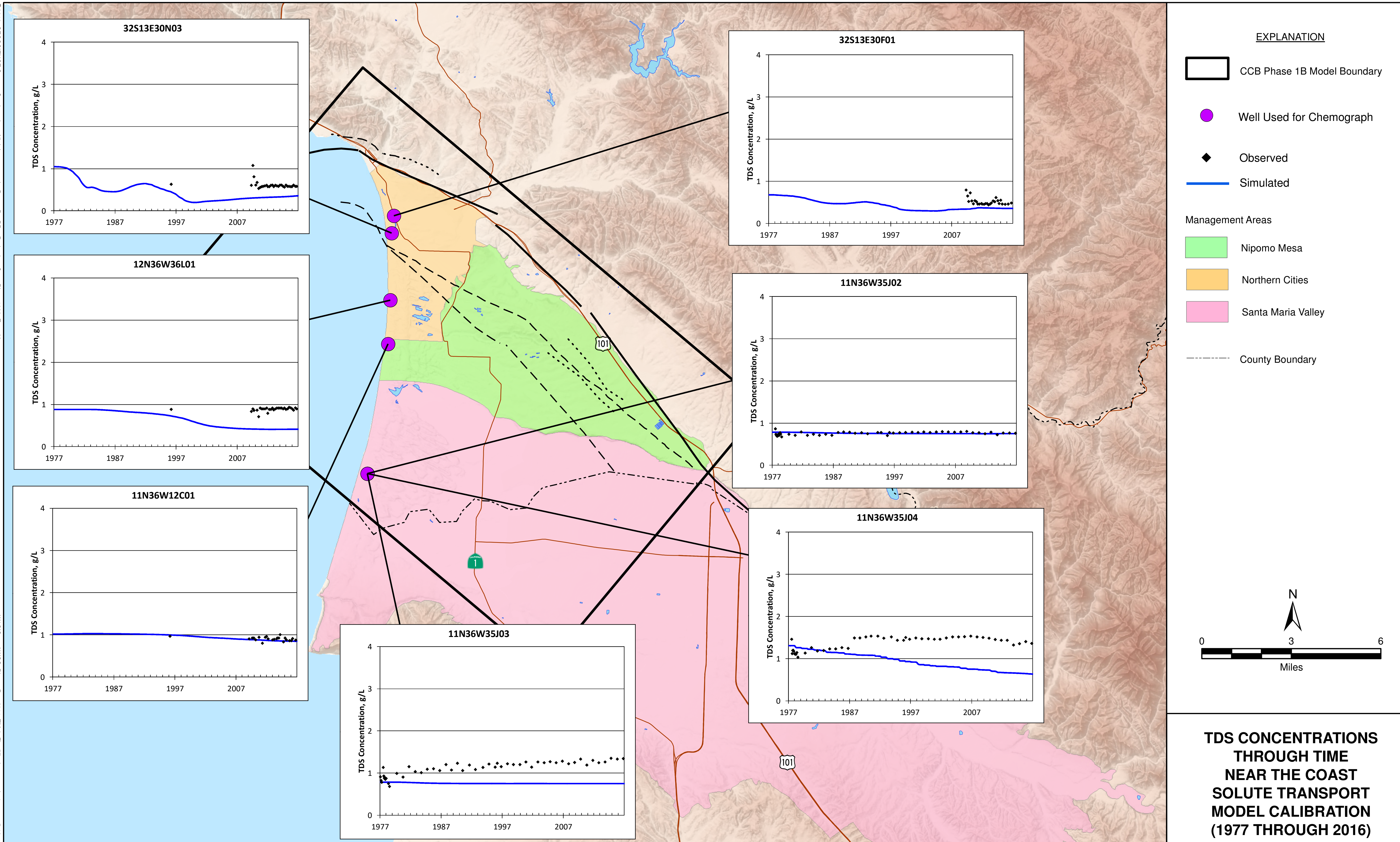
INITIAL TDS CONCENTRATIONS

FIGURE 56

WATER SYSTEMS CONSULTING, INC.

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE



TDS CONCENTRATIONS THROUGH TIME NEAR THE COAST SOLUTE TRANSPORT MODEL CALIBRATION (1977 THROUGH 2016)

W:\GIS_proj\WSC_Pismo_Beach\41_TM-3_Fig_57_chemograph_1_coast_5-19.mxd

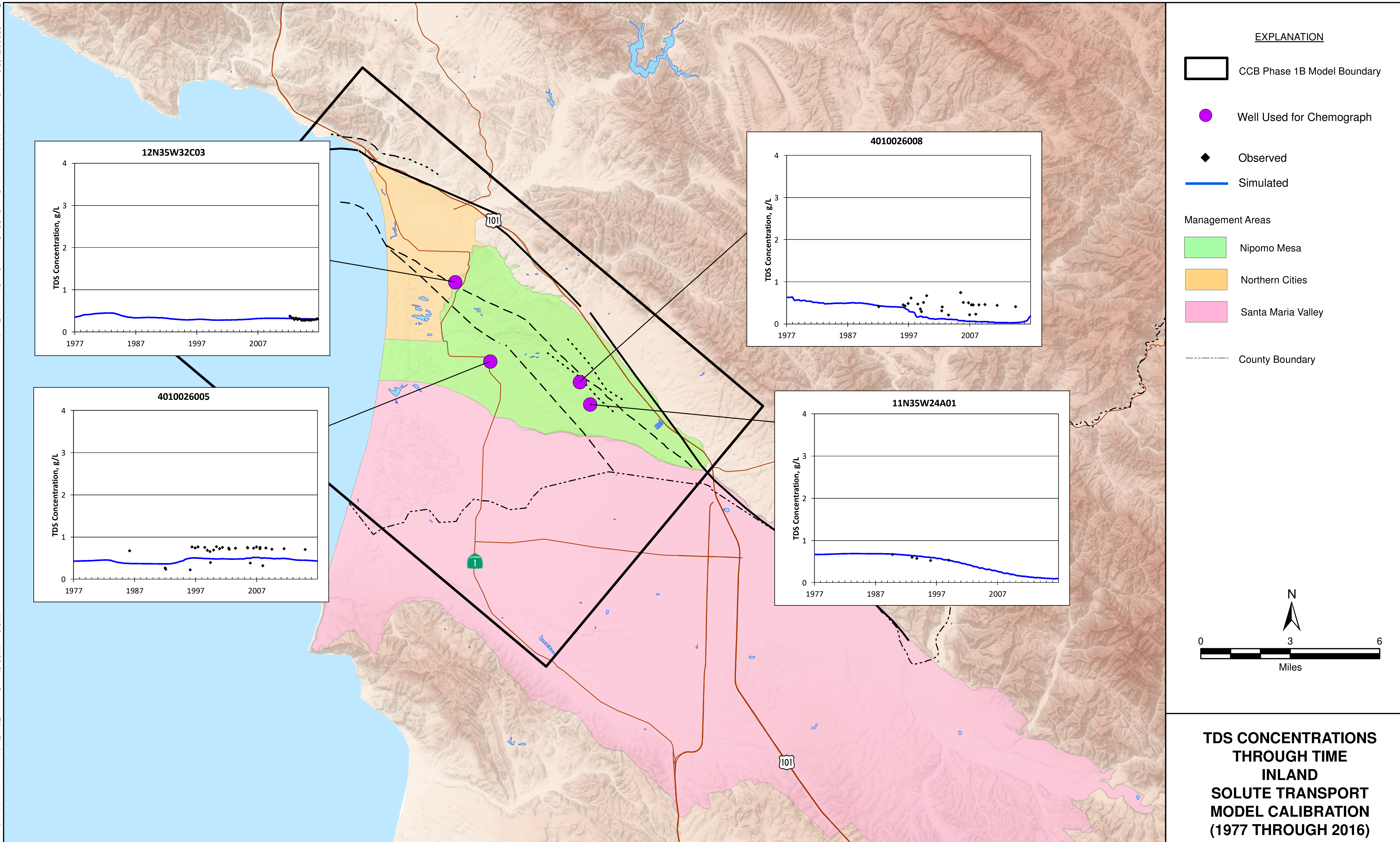
14-May-19

FIGURE 57

WATER SYSTEMS CONSULTING, INC.

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE



W:\GIS_proj\WSC_Pismo_Beach\41_TM-3_Fig_58_chemograph_2_inland_5-19.mxd

TDS CONCENTRATIONS THROUGH TIME INLAND SOLUTE TRANSPORT MODEL CALIBRATION (1977 THROUGH 2016)

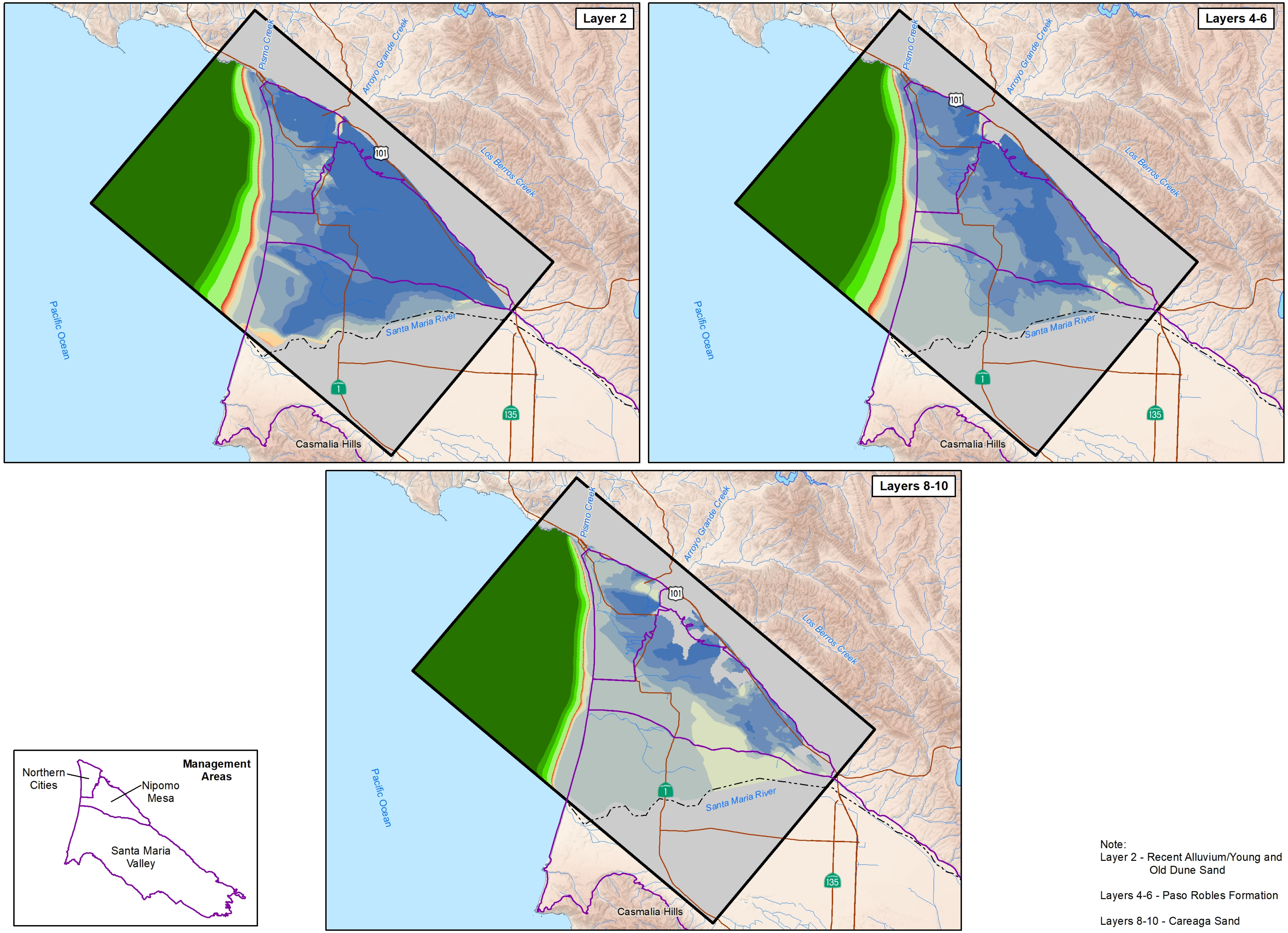
14-May-19

FIGURE 58

WATER SYSTEMS CONSULTING, INC.

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

GEOSCIENCE



EXPLANATION

CCB Phase 1B Model Boundary

No-Flow Cells

TDS Concentrations (g/L)

- < 200
- 200 - 400
- 400 - 600
- 600 - 800
- 800 - 1,000
- 1000
- 1,000 - 1,200
- 1,200 - 1,400
- 1,400 - 1,600
- 1,600 - 1,800
- 1,800 - 2,000
- 2,000 - 10,000
- 10,000 - 20,000
- 20,000 - 30,000
- 30,000 - 35,000

County Boundary

N

0 4 8

Miles

Note:
Layer 2 - Recent Alluvium/Young and Old Dune Sand

Layers 4-6 - Paso Robles Formation

Layers 8-10 - Careaga Sand

MODEL-CALCULATED TDS CONCENTRATIONS AT END OF CALIBRATION PERIOD (2016)

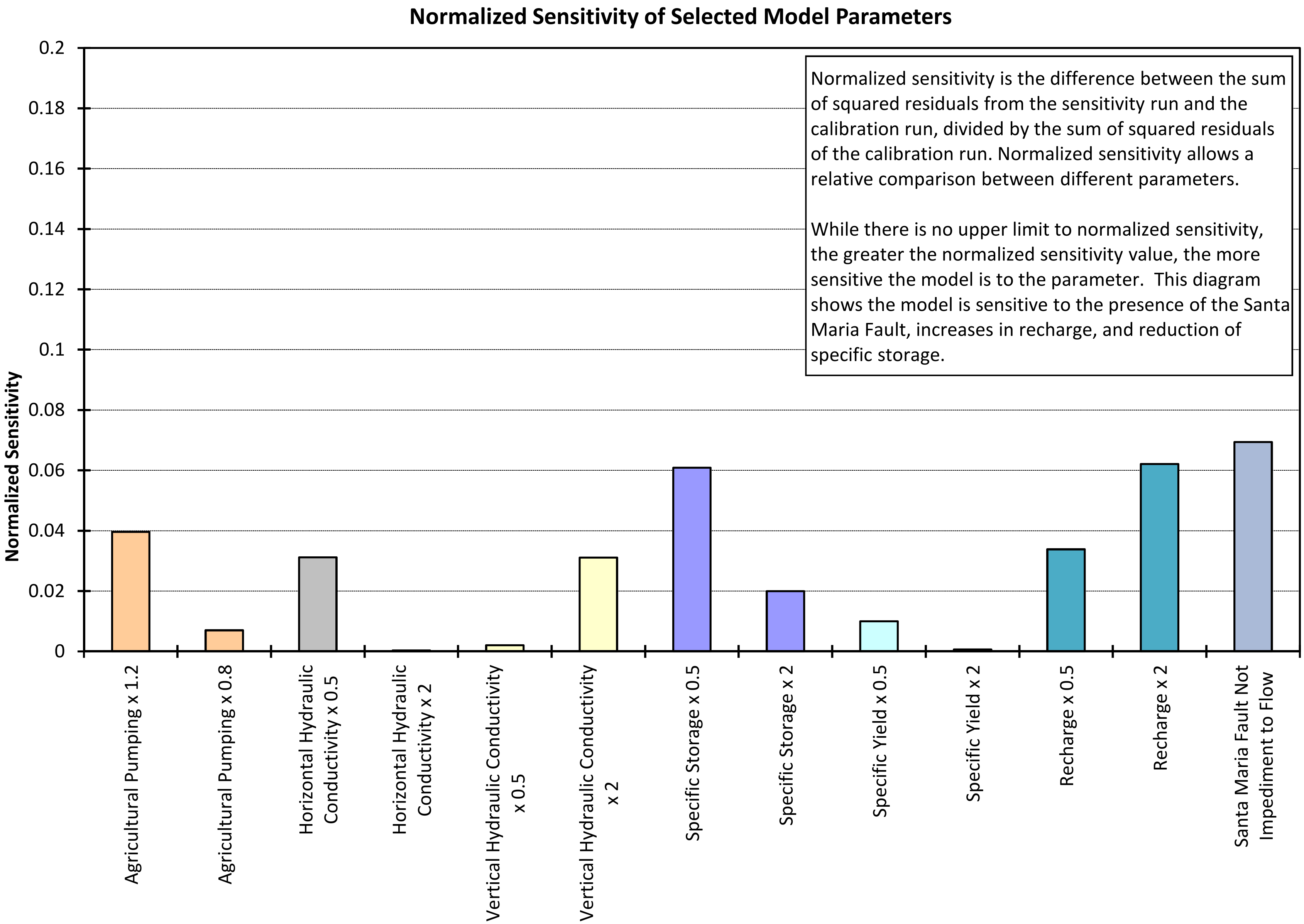

Normalized Sensitivity of Selected Model Parameters
Normalized Sensitivity
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Normalized sensitivity is the difference between the sum of squared residuals from the sensitivity run and the calibration run, divided by the sum of squared residuals of the calibration run. Normalized sensitivity allows a relative comparison between different parameters.
While there is no upper limit to normalized sensitivity, the greater the normalized sensitivity value, the more sensitive the model is to the parameter. This diagram shows the model is sensitive to the presence of the Santa Maria Fault, increases in recharge, and reduction of specific storage.
Agricultural Pumping x 1.2
Agricultural Pumping x 0.8
Horizontal Hydraulic Conductivity x 0.5
Horizontal Hydraulic Conductivity x 2
Vertical Hydraulic Conductivity x 0.5
Vertical Hydraulic Conductivity x 2
Specific Storage x 0.5
Specific Storage x 2
Specific Yield x 0.5
Specific Yield x 2
Recharge x 0.5
Recharge x 2
Santa Maria Fault Not Impediment to Flow

Figure 60

TABLES

Table 1

CCB Phase 1B Groundwater Model Calibration – NCMA Groundwater Balance (1977 - 2016)

	INFLOWS [acre-ft]													OUTFLOWS [acre-ft]											
Year	Areal Recharge from Precip (rch pkg)	Streambed Percolation (model)	Return Flow from Muni Use (rch pkg)	Return Flow from Small Purveyors (rch pkg)	Return Flow from Golf Course Irrig. (rch pkg)	Return Flow from Ag (rch pkg)	Artificial Recharge (wel pkg)	Underflow from NMMA (model)	Underflow from Arroyo Grande Valley (model)	Underflow from Zone 5 (model)	Underflow from Ocean (layer 2) (model)	Underflow from Offshore Aquifers (model)	TOTAL INFLOW	Rising Water Discharge to Streamflow (model)	Muni Pumping (wel pkg)	Small Purveyor Pumping (wel pkg)	Golf Pumping (wel pkg)	Ag Pumping (wel pkg)	Underflow to NMMA (model)	Underflow to Zone 5 (model)	Underflow to Zone 6 (model)	Underflow to Ocean (layer 2) (model)	Underflow to Offshore Aquifers (model)	TOTAL OUTFLOW	CHANGE IN STORAGE
1977	202	843	815	6	15	1,920	233	2,320	307	109	0	167	6,937	0	292	24	102	3,999	408	111	66	762	1,211	6,974	-37
1978	1,265	1,872	821	6	13	1,353	591	2,183	713	213	0	85	9,114	121	373	24	88	2,765	393	259	108	931	1,699	6,761	2,354
1979	1,364	975	796	6	14	1,929	276	2,297	526	239	0	55	8,476	69	270	24	95	3,945	451	210	130	1,097	1,794	8,087	390
1980	1,222	1,549	804	6	15	1,744	331	2,502	585	224	0	61	9,044	84	293	24	102	3,567	451	220	140	1,153	2,034	8,067	978
1981	1,370	999	782	6	14	1,860	304	2,622	523	239	0	56	8,774	77	216	24	92	3,804	454	212	148	1,225	2,145	8,396	378
1982	1,295	1,228	777	6	11	1,420	308	2,705	487	206	0	56	8,498	42	149	24	72	2,902	448	196	153	1,255	2,284	7,525	973
1983	3,116	2,942	752	6	12	1,208	655	2,893	648	227	0	45	12,504	197	67	24	82	2,468	646	234	205	1,728	3,043	8,693	3,811
1984	284	915	929	7	16	2,189	137	2,970	297	199	0	43	7,986	9	465	27	107	4,473	556	142	194	1,567	2,701	10,242	-2,257
1985	252	771	971	7	16	2,565	142	3,027	244	154	0	83	8,232	0	561	29	110	5,242	492	114	156	1,365	2,240	10,308	-2,075
1986	1,411	1,098	960	7	14	1,712	247	3,040	332	153	0	82	9,055	0	661	29	93	3,699	462	148	146	1,367	2,209	8,814	241
1987	588	815	910	7	13	1,643	203	2,769	379	185	0	94	7,606	0	846	29	88	3,549	403	170	130	1,256	1,960	8,433	-827
1988	785	819	1,138	7	15	1,718	221	2,559	203	166	0	148	7,778	0	1,188	29	98	3,714	408	121	104	1,258	1,713	8,635	-856
1989	2	686	1,175	7	17	2,331	89	2,378	304	142	0	229	7,359	0	1,272	29	116	5,034	513	120	77	1,080	1,301	9,541	-2,181
1990	68	699	1,077	7	16	2,280	130	2,319	136	112	0	352	7,195	0	1,261	29	108	4,924	512	68	47	871	1,068	8,887	-1,693
1991	946	1,073	1,020	7	14	1,155	367	2,130	369	135	0	332	7,549	0	1,221	29	94	2,644	367	151	46	882	1,188	6,622	927
1992	1,442	990	1,313	7	14	1,310	303	2,023	385	175	0	337	8,299	6	2,326	29	95	3,002	447	166	63	1,056	1,191	8,381	-82
1993	1,883	1,179	1,292	7	14	1,269	406	2,157	384	170	0	318	9,080	0	2,212	29	94	2,908	411	163	73	1,169	1,316	8,376	704
1994	917	791	1,251	7	13	1,480	167	2,264	399	202	0	309	7,800	6	2,003	34	90	3,388	410	178	68	1,044	1,220	8,440	-640
1995	2,221	2,379	1,219	8	13	1,165	503	2,449	427	174	0	255	10,813	21	2,178	44	91	2,670	454	182	96	1,229	1,684	8,650	2,163
1996	1,301	1,831	1,295	8	13	925	348	2,690	376	207	0	262	9,257	45	2,203	44	86	2,334	427	176	100	1,215	1,801	8,431	826
1997	1,082	2,612	1,350	8	16	1,229	302	2,612	226	132	0	249	9,818	0	2,600	44	104	3,098	440	111	103	1,240	1,862	9,602	215
1998	2,503	3,168	1,257	8	12	868	553	3,143	387	173	0	197	12,270	82	1,984	44	79	2,431	571	169	154	1,546	2,573	9,634	2,636
1999	1,065	1,047	1,423	8	14	489	268	3,252	334	160	0	153	8,212	2	2,224	44	95	1,357	511	140	169	1,541	2,572	8,655	-442
2000	1,160	1,125	1,466	13	14	519	301	3,191	546	216	0	150	8,702	77	2,358	63	96	1,317	461	215	162	1,543	2,483	8,775	-73
2001	1,542	1,407	1,427	13	13	776	465	3,308	661	253	0	134	10,000	154	2,284	65	89	2,354	445	245	168	1,499	2,547	9,850	150
2002	465	854	1,486	13	16	1,018	164	3,106	506	249	0	126	8,001	71	2,799	65	105	3,078	468	211	139	1,208	1,978	10,121	-2,120
2003	297	835	1,493	15	15	837	124	2,986	304	195	0	154	7,254	0	2,709	73	100	2,844	510	154	113	1,038	1,626	9,167	-1,913
2004	654	953	1,565	16	14	739	193	3,017	277	156	0	327	7,911	0	3,517	77	93	2,524	456	128	81	915	1,405	9,195	-1,285
2005	1,398	879	1,450	16	13	733	189	3,161	681	234	0	368	9,121	91	3,147	77	89	2,478	481	255	56	936	1,383	8,994	127
2006	2,149	932	1,424	16	12	671	446	2,972	681	272	0	313	9,889	132	3,011	77	81	2,307	485	270	80	1,095	1,505	9,043	845
2007	235	889	1,537	16	16	1,022	131	2,919	563	261	0	361	7,950	76	3,397	77	108	3,527	608	237	64	865	1,117	10,075	-2,126
2008	985	1,704	1,500	16	16	659	285	2,796	254	186	0	350	8,751	2	3,196	77	107	2,457	451	155	61	810	1,202	8,518	232
2009	176	901	1,434	16	16	757	161	2,656	296	153	0	271	6,836	0	2,466	77	105	2,729	515	137	56	703	933	7,721	-885
2010	2,184	1,424	1,329	16	12	429	609	2,427	448	181	0	173	9,232	16	1,678	77	82	1,547	428	204	86	911	1,285	6,314	2,918
2011	1,258	1,753	971	16	14	502	223	2,363	575	219	0	109	8,002	92	1,169	77	92	2,004	444	232	118	1,071	1,699	6,998	1,004
2012	477	668	919	16	14	554	169	2,401	291	177	0	81	5,767	0	1,138	77	93	2,292	423	146	121	958	1,586	6,834	-1,067
2013	32	834	953	16	18	818	88	2,223	231	137	0	120	5,470	0	1,414	77	118	3,277	614	115	95	746	1,108	7,562	-2,092
2014	151	863	1,105	16	15	745	124	2,036	176	116	0	174	5,521	0	1,039	77	98	3,047	571	100	70	539	816	6,357	-836
2015	0	684	952	16	16	773	115	1,596	227	98	0	159	4,636	0	933	77	111	1,825	649	104	62	499	703	4,962	-326
2016	1,145	887	887	16	13	548	309	1,662	293	121	0	126	6,007	0	880	77	87	2,425	426	132	72	524	880	5,503	505
Average	**1,022**	**1,222**	**1,151**	**10**	**14**	**1,196**	**280**	**2,603**	**400**	**183**	**0**	**187**	**8,268**	**37**	**1,600**	**49**	**96**	**2,999**	**477**	**170**	**107**	**1,092**	**1,677**	**8,304**	**-36**

CCB Phase 1B Groundwater Model Calibration – NMMA Groundwater Balance (1977 - 2016)

Year	Inflows [acre-ft]															OUTFLOWS [acre-ft]										CHANGE IN STORAGE
								Artifical Recharge																		
	Areal Recharge from Precip (rch pkg)	Mountain Front Recharge (wel pkg)	Streambed Percolation (model)	Return Flow from Muni Use (rch pkg)	Return Flow from Small Purveyors (rch pkg)	Return Flow from Golf Course Irrig. (rch pkg)	Return Flow from Ag (rch pkg)	Storm Water Ponds (wel pkg)	WWTP Ponds (wel pkg)	Underflow from Zone 5 (model)	Underflow from NCMA (model)	Underflow from SMVMA (model)	Underflow from Ocean (layer 2) (model)	Underflow from Offshore Aquifers (model)	TOTAL INFLOW	Rising Water Discharge to Streamflow (model)	Muni Pumping (wel pkg)	Small Purveyor Pumping (wel pkg)	Ag Pumping (wel pkg)	Underflow to Zone 5 (model)	Underflow to NCMA (model)	Underflow to SMVMA (model)	Underflow to Ocean (layer 2) (model)	Underflow to Offshore Aquifers (model)	TOTAL OUTFLOW	
1977	378	163	234	110	152	120	2,272	10	2	1,280	408	4,836	0	135	10,101	5	1,970	609	4,935	392	2,320	3,047	244	453	13,973	-3,873
1978	2,994	2,778	327	117	152	105	1,559	29	2	3,450	393	4,425	0	86	16,418	38	1,994	609	3,421	516	2,183	3,013	242	569	12,586	3,832
1979	3,022	1,057	214	132	152	113	1,784	12	2	2,218	451	4,291	0	86	13,534	41	2,042	609	3,924	430	2,297	3,236	258	547	13,383	151
1980	2,734	962	235	134	153	121	1,832	14	2	2,051	451	4,971	0	83	13,743	42	2,049	611	4,041	412	2,502	2,652	250	687	13,244	498
1981	3,145	1,150	224	162	152	108	1,707	13	2	2,086	454	4,941	0	76	14,221	41	2,142	609	3,745	400	2,622	2,722	258	725	13,264	956
1982	2,469	1,123	230	160	152	85	1,611	13	2	2,034	448	5,620	0	76	14,024	39	2,138	609	3,529	393	2,705	2,273	257	795	12,739	1,284
1983	7,356	2,634	353	177	156	96	1,516	29	2	3,498	646	6,625	0	54	23,142	62	2,195	623	3,318	530	2,893	2,940	309	965	13,833	9,308
1984	579	470	189	206	157	126	2,702	6	2	1,827	556	7,335	0	74	14,230	43	2,292	626	6,038	433	2,970	2,739	300	848	16,287	-2,058
1985	354	506	178	221	81	130	2,922	6	2	1,705	492	7,060	0	85	13,742	42	2,346	324	6,593	414	3,027	2,471	302	775	16,292	-2,550
1986	3,066	1,133	208	254	81	110	1,812	11	2	2,104	462	5,786	0	75	15,104	40	2,455	324	4,284	422	3,040	2,901	313	809	14,589	515
1987	909	698	197	260	81	104	1,810	9	2	1,704	403	5,163	0	88	11,428	34	2,482	324	4,275	398	2,769	2,911	309	683	14,184	-2,755
1988	1,568	730	198	302	82	116	1,818	9	2	1,724	408	4,554	0	98	11,608	35	2,622	325	4,295	387	2,559	3,096	319	580	14,219	-2,612
1989	0	267	157	357	81	137	2,754	4	2	1,415	513	5,137	0	165	10,988	35	2,814	324	6,605	370	2,378	2,926	316	433	16,201	-5,213
1990	71	417	171	396	81	127	2,740	5	2	1,366	512	5,463	0	190	11,542	38	2,954	324	6,573	345	2,319	2,798	291	410	16,052	-4,511
1991	2,199	849	249	362	81	112	1,580	19	2	1,599	367	4,599	0	128	12,146	35	2,842	324	3,988	336	2,130	2,853	281	434	13,224	-1,078
1992	3,306	1,105	220	386	82	112	1,672	13	2	1,888	447	3,958	0	137	13,328	38	2,936	325	4,224	341	2,023	3,519	298	396	14,098	-769
1993	4,427	1,415	238	397	81	111	1,345	17	2	2,233	411	4,102	0	103	14,882	40	2,973	324	3,371	372	2,157	3,120	308	449	13,114	1,768
1994	1,867	919	194	394	83	106	1,725	7	2	1,850	410	4,932	0	119	12,609	34	2,965	325	4,378	349	2,264	2,481	280	464	13,540	-931
1995	5,276	1,661	347	403	85	107	1,209	27	2	2,594	454	5,220	0	78	17,465	46	3,003	327	3,012	446	2,449	2,468	288	633	12,672	4,793
1996	2,624	1,088	246	451	85	102	1,051	17	2	1,994	427	6,150	0	84	14,322	35	3,173	328	2,875	375	2,690	2,363	258	727	12,824	1,498
1997	2,465	684	350	482	85	123	1,232	13	2	1,745	440	6,621	0	81	14,323	43	3,291	327	3,427	385	2,612	2,446	244	740	13,516	807
1998	5,862	3,595	363	414	85	94	937	27	2	4,364	571	7,336	0	63	23,713	54	3,058	327	2,793	595	3,143	2,482	269	1,037	13,760	9,953
1999	2,174	792	207	460	86	224	1,732	12	2	2,271	511	7,902	0	86	16,459	40	3,221	331	5,239	476	3,252	2,269	250	1,051	16,130	329
2000	2,660	920	228	1,172	77	227	1,126	16	2	2,100	461	7,956	0	100	17,044	36	5,704	295	3,368	457	3,191	1,872	259	1,050	16,232	812
2001	2,446	1,038	240	1,133	77	211	994	12	2	2,052	445	7,784	0	103	16,537	37	5,563	294	3,009	450	3,308	1,737	268	1,062	15,728	809
2002	1,152	519	201	1,306	77	247	1,587	8	2	1,632	468	7,885	0	135	15,218	32	6,211	294	4,818	436	3,106	1,831	277	846	17,851	-2,632
2003	612	730	189	1,279	78	236	1,842	9	2	1,832	510	8,248	0	159	15,727	33	6,049	300	6,028	446	2,986	1,935	290	746	18,813	-3,086
2004	1,527	649	228	1,399	81	219	1,089	23	2	1,635	456	7,757	0	158	15,222	32	6,542	313	3,575	427	3,017	1,918	273	740	16,836	-1,614
2005	4,106	1,635	222	1,357	81	210	1,076	29	2	2,567	481	7,105	0	145	19,016	39	6,337	312	3,572	486	3,161	2,069	306	760	17,042	1,974
2006	3,691	1,337	214	1,323	81	190	1,140	26	8	2,459	485	7,410	0	145	18,509	39	7,167	312	3,877	492	2,972	2,132	310	724	18,025	485
2007	95	410	181	1,343	81	253	2,287	12	8	1,720	608	8,238	0	196	15,432	27	6,772	312	7,464	439	2,919	2,246	295	574	21,047	-5,615
2008	2,243	738	216	1,311	78	251	1,109	32	8	1,779	451	7,473	0	161	15,850	33	6,857	300	4,046	411	2,796	2,087	282	648	17,461	-1,611
2009	411	507	207	1,248	75	247	1,475	23	8	1,519	515	7,837	0	190	14,260	29	6,702	286	5,572	387	2,656	2,047	264	518	18,461	-4,201
2010	5,071	1,634	279	1,087	75	193	845	59	8	2,262	428	6,308	0	137	18,386	38	6,097	286	3,182	423	2,427	2,143	284	601	15,480	2,906
2011	3,323	1,350	224	1,129	75	218	433	28	8	2,541	444	6,851	0	115	16,739	33	6,241	286	3,647	457	2,363	1,941	281	642	15,891	848
2012	837	653	209	1,158	76	218	433	17	7	1,705	423	6,677	0	120	12,532	25	6,294	289	3,642	402	2,401	1,905	257	598	15,813	-3,281
2013	5	229	176	1,242	75	277	854	9	10	1,414	614	8,131	0	181	13,217	20	6,725	289	7,395	389	2,223	1,894	248	443	19,626	-6,410
2014	420	563	209	1,051	75	231	687	17	10	1,513	571	7,226	0	192	12,765	22	5,834	289	6,036	397	2,036	1,996	236	356	17,202	-4,437
2015	0	332	172	914	75	261	720	10	11	1,340	649	6,339	0	226	11,049	19	4,911	289	6,145	367	1,596	2,222	219	273	16,040	-4,991
2016	1,202	721	217	852	76	205	507	17	12	1,467	426	5,914	0	152	11,768	23	4,559	289	4,388	343	1,662	1,876	181	375	13,698	-1,930
Average	**2,216**	**1,004**	**228**	**676**	**95**	**165**	**1,488**	**17**	**4**	**2,013**	**477**	**6,304**	**0**	**122**	**14,809**	**35**	**4,113**	**371**	**4,466**	**418**	**2,603**	**2,439**	**274**	**654**	**15,374**	**-566**

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Table 3

CCB Phase 1B Groundwater Model Calibration – SMVMA Groundwater Balance (1977 - 2016)

Year	INFLOWS [acre-ft]								OUTFLOWS [acre-ft]							CHANGE IN STORAGE
	Areal Recharge from Precip (rch pkg)	Return Flow from Muni Use (rch pkg)	Return Flow from Ag (rch pkg)	Underflow from NMMA (model)	Underflow Across the SM River (model)	Underflow from Ocean (layer 2) (model)	Underflow from Offshore Aquifers (model)	TOTAL INFLOW	Muni Pumping (wel pkg)	Ag Pumping (wel pkg)	Underflow across the SM River (model)	Underflow to NMMA (model)	Underflow to Ocean (layer 2) (model)	Underflow to Offshore Aquifers (model)	TOTAL OUTFLOW	
1977	157	0	10,597	3,020	26,565	0	1,077	41,416	0	28,389	6,108	4,810	837	4,272	44,415	-2,999
1978	964	0	8,620	2,972	23,466	0	1,030	37,053	0	23,094	2,841	4,384	886	4,520	35,726	1,327
1979	1,617	0	9,552	3,196	24,150	0	1,055	39,570	0	25,588	2,840	4,251	977	4,411	38,066	1,504
1980	1,466	0	9,528	2,613	28,108	0	934	42,651	0	25,544	2,054	4,933	913	5,117	38,561	4,090
1981	1,740	0	9,353	2,678	25,994	0	892	40,657	0	25,057	2,947	4,897	998	5,058	38,958	1,699
1982	1,152	0	9,194	2,235	30,233	0	826	43,641	0	24,632	2,086	5,582	1,010	5,431	38,741	4,900
1983	4,266	0	8,546	2,840	34,294	0	706	50,651	0	22,896	2,256	6,525	1,182	5,646	38,505	12,146
1984	254	0	10,776	2,626	31,223	0	839	45,718	0	28,887	2,729	7,222	1,094	5,536	45,467	251
1985	112	0	10,893	2,404	29,026	0	864	43,299	0	29,182	3,399	6,993	1,111	5,252	45,936	-2,637
1986	1,547	0	8,787	2,851	25,002	0	856	39,044	0	24,884	4,228	5,736	1,206	5,357	41,411	-2,368
1987	324	0	9,054	2,862	22,664	0	996	35,900	0	25,641	4,279	5,115	1,151	4,970	41,156	-5,256
1988	691	0	9,186	3,051	21,005	0	1,089	35,022	0	26,033	3,773	4,509	1,180	4,564	40,058	-5,035
1989	0	0	10,173	2,887	22,738	0	1,298	37,096	0	28,810	3,428	5,098	1,120	4,189	42,645	-5,549
1990	14	0	9,974	2,758	22,804	0	1,222	36,772	0	28,247	2,859	5,422	1,036	4,039	41,604	-4,831
1991	1,196	0	7,780	2,813	19,925	0	1,018	32,732	0	23,371	2,956	4,559	1,050	3,939	35,875	-3,143
1992	1,836	0	8,001	3,475	17,762	0	1,016	32,090	0	24,050	3,944	3,914	1,081	3,647	36,636	-4,546
1993	2,571	0	7,701	3,084	22,971	0	974	37,302	0	23,132	1,804	4,066	1,075	3,893	33,970	3,332
1994	890	0	8,048	2,447	25,634	0	1,183	38,201	0	24,175	1,574	4,898	937	4,132	35,716	2,485
1995	3,009	0	7,502	2,427	28,258	0	976	42,171	0	22,534	1,233	5,180	950	4,527	34,425	7,746
1996	1,254	0	6,853	2,307	29,527	0	1,082	41,023	0	22,660	1,353	6,094	892	5,096	36,095	4,927
1997	1,278	0	7,061	2,359	29,829	0	1,013	41,540	0	23,302	1,483	6,534	893	4,962	37,175	4,365
1998	3,172	0	5,213	2,368	33,112	0	670	44,535	0	19,069	2,046	7,222	1,032	5,916	35,284	9,251
1999	1,040	0	6,173	2,180	32,552	0	1,097	43,042	0	22,599	2,109	7,813	933	6,604	40,058	2,984
2000	1,386	0	5,952	1,809	29,978	0	1,322	40,447	0	21,805	2,242	7,893	951	6,707	39,597	850
2001	1,338	0	5,909	1,698	29,110	0	1,251	39,306	0	21,632	2,290	7,745	1,007	6,652	39,326	-20
2002	553	0	6,716	1,792	27,723	0	1,478	38,263	0	24,594	2,397	7,846	1,019	6,005	41,861	-3,598
2003	207	0	5,761	1,912	27,237	0	1,504	36,619	0	23,674	2,380	8,224	1,064	5,687	41,030	-4,410
2004	638	0	5,195	1,896	25,412	0	1,395	34,537	0	21,357	2,408	7,734	1,065	5,573	38,138	-3,601
2005	2,407	0	4,989	2,028	25,374	0	1,256	36,054	0	20,496	1,969	7,064	1,172	5,441	36,142	-89
2006	1,928	0	4,944	2,105	24,387	0	1,244	34,607	0	20,314	1,997	7,383	1,165	5,311	36,168	-1,561
2007	26	0	5,727	2,220	25,796	0	1,446	35,215	0	23,540	2,114	8,213	1,108	5,090	40,065	-4,850
2008	1,221	0	4,536	2,064	24,588	0	1,333	33,742	0	20,295	1,902	7,450	1,066	5,093	35,805	-2,064
2009	130	0	4,775	2,025	23,939	0	1,472	32,340	0	21,344	1,901	7,815	1,029	4,651	36,740	-4,399
2010	2,790	0	3,895	2,114	21,473	0	1,319	31,590	0	17,374	2,060	6,279	1,071	4,663	31,446	144
2011	1,810	0	3,528	1,913	25,492	0	1,189	33,932	0	18,097	1,534	6,823	1,055	4,778	32,287	1,645
2012	301	0	3,720	1,875	23,957	0	1,162	31,015	0	19,147	2,114	6,647	1,000	4,655	33,563	-2,547
2013	0	0	3,973	1,878	23,605	0	1,258	30,713	0	20,666	1,971	8,114	987	4,238	35,976	-5,264
2014	140	0	3,688	1,973	20,988	0	1,239	28,028	0	19,449	2,274	7,203	999	3,766	33,690	-5,662
2015	0	0	4,027	2,197	20,000	0	1,231	27,455	0	20,787	2,510	6,314	972	3,410	33,994	-6,539
2016	474	0	3,356	1,851	20,729	0	1,022	27,433	0	17,758	2,273	5,889	877	3,744	30,541	-3,109
Average	**1,147**	**0**	**6,981**	**2,395**	**25,666**	**0**	**1,121**	**37,310**	**0**	**23,103**	**2,517**	**6,260**	**1,029**	**4,914**	**37,821**	**-511**

APPENDIX A

Comments Received and GEOSCIENCE Responses for

Draft TM No. 3: Model Calibration

GEOSCIENCE

Comments Received and GEOSCIENCE Responses for Draft TM No. 3: Model Calibration

No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
1	San Luis Obispo County	-	-	It may be appropriate in future modeling efforts to integrate a distributed hydrologic model or precipitation runoff model with a groundwater flow model to simulate the impacts of precipitation on surface water and groundwater flow. This could include subsurface flows in the unsaturated zone to more accurately reflect recharge both temporally and spatially, rather than using a lumped approach such as the Soil Conservation Service (SCS) curve method utilized in this Phase 1B modeling to estimate runoff from rainfall with its inherent limitations.	GEOSCIENCE agrees that a distributed surface water hydrologic model would be a valuable tool to improve areal recharge estimate and to quantify water in the vadose zone. But for the current phase GEOSCIENCE believes the SCS curve approach was reasonable and provided a level of accuracy reasonable for the current objective of the model.
2	San Luis Obispo County	2.7.1.3	14	The modeling of the Arroyo Grande Creek streambed is an important component of the overall recharge analysis since the creek is one of the primary contributors of recharge in the Northern Cities Management Area (NCMA). Additional flow data collection will be necessary to further refine the modeling of streambed percolation in future phases, which we understand is beyond the scope of this current study. County staff question the assertion by GEOSCIENCE that "… it was determined that the available measured flow from the USGS gage and the 22nd Street Bridge gage were inaccurate and abnormally high." because it is unclear what the assumptions are since there is a gaged tributary (Los Berros Creek at Quail Lane) to the Arroyo Grande Creek located between the USGS gage and the 22nd Street Bridge gage. Additionally, the 22nd Street Bridge gage and the Los Berros (Quail Lane) gage only measure creek stage levels. Neither location has a rating curve to estimate flow consistently. Therefore, the data may be insufficient to complete the percolation analysis. If so, it would be more appropriate to state that the data is "insufficient" rather than "inaccurate and abnormally high".	A rating curve for the 22nd Street Bridge was obtained from the SMBC, and used to estimate discharge rates. Hence this conclusion was based on large discrepancies between the USGS gage and the 22nd Street Bridge gage. This rating curve is probably less reliable compared to the USGS rating curve. This remark was incorporated into the report. It should be emphasized that care was taken by GEOSCIENCE to keep the percolation within published ranges (Water Balance study, Hoover study, etc)
3	San Luis Obispo County	2.7.1.4	14	"As shown on Figure 24, return flow from municipal use averaged 1,215 acre-ft/year in the NCMA, 460 acre-ft/year in the NMMA, and 24 acre-ft/year in the SMVMA from 1977 through 2016." Figure 24 and Table 2 both show NMMA has a municipal return flow of 669 acre-ft/year rather than 460 acre-ft/year as quoted above. The amount of return flow from municipal use in NMMA is not consistent among the text write-up in Section 2.7.1.4, Table 2, and Figure 24.	This is a typo and was corrected.
4	San Luis Obispo County	2.7.1.9	16	The estimated alluvium underflow inflow of 50 acre-feet/year from Arroyo Grande Creek Valley seems low considering that the width and depth of the valley alluvium are about 3,000 and 62 feet, respectively, which is substantial in cross-sectional area, near the northern boundary of the NCMA. The BBMR Technical Report prepared by GSI, Inc (2018) estimated that the underflow inflow is about 2,000 acre-feet/year. The "Water Resources of the Arroyo Grande-Nipomo Mesa Area" report by the DWR (2002) estimated that the underflow ranged from 420 to 4,200 acre-feet/year between 1975 and 1995.	The current flow from the Arroyo Grande Creek Valley is 400 AFY after the model was modified following various suggestions by the TAC. Also the Water Balance study estimated this flux to be 200 AFY. GSI agreed to keep this value for the current phase.
5	San Luis Obispo County	2.7.2.3	17	"Various studies in the area have estimated agricultural pumping in the past using assorted techniques." The methodology used for estimating agricultural pumping should be consistent across management areas and described in the report so that the resulting water balances for each management area may be accurately estimated and reasonably compared.	The approach used to estimate the agricultural pumping was consistent across the various management areas but was adjusted in NCMA to account for the proximity of the ocean and the influence of the marine layer as suggested by the TAC.
6	San Luis Obispo County	2.8.1	18	The model parameters which were adjusted in the calibration process are listed in this section. It would be helpful to include descriptions of why these parameters were selected for calibration and not others and a table comparing the calibrated parameter values to the initially estimated values.	Additional write up and a table were added to address this comment.

Comments Received and GEOSCIENCE Responses for Draft TM No. 3: Model Calibration

No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
7	San Luis Obispo County	2.8.5.2	22	The solute transport model calibration process used measurements from 11 calibration target wells to match model-simulated TDS concentrations against measured values (Figure 55).” The solute transport calibration target wells shown in Figure 55 are far more than 11 calibration target wells as stated in the above quoted text. Figure 55 displays only four calibration target wells representing the Santa Maria Valley Management Area (SMVMA) water quality conditions. This is a large irrigated area with substantial groundwater pumping. The confidence level on the water quality model results in this area may need to be further evaluated. It seems worth noting that the simulated TDS concentration distribution maps in Figure 59 indicate that the production wells in the NMMA have minimal impact on TDS concentrations, even though a higher TDS concentration in the irrigated portion of the NMMA is to be expected since irrigation water is considered a major source of TDS loading.	The 11 solute transport calibration targets shown on Figure 55 were shown for illustration purposes. All the other targets were added as appendices. Fewer solute transport targets were available for the SMVMA. The NMMA area TDS distribution was based on available measurements which show consistently that TDS in the area remains below 1,000 mg/l. However, these values were revisited to address this comment.
8	San Luis Obispo County	2.9	23	The sensitivity analysis indicates that specific storage, horizontal conductivity, and agricultural pumping are parameters that have greater impact on model results. The memorandum should include discussions on the rationale regarding the sensitivity levels of the three model input parameters resulting from the model simulations.	A discussion was added.
9	San Luis Obispo County	2.9	23	The uncertainty factor in estimating the model input parameters are discussed in a qualitative manner throughout the various sections of the draft Technical Memorandum. However, quantifying the uncertainties of these estimated input parameters would be helpful for the modeler and model end users to identify the data gaps and levels of uncertainty, and determine which parameters have greater uncertainties and if any can be mitigated by further refinement to improve model results if necessary. It would also be critical for future predictive scenarios to evaluate the impact of parameter uncertainty on model outputs. Such an analysis will provide a certain measure of confidence to the decision- maker regarding the likelihood that a well calibrated model with its many inherent uncertainties can still yield reasonably good results to support effective groundwater management decisions.	A quantitative discussion of the uncertainty was added.
10	San Luis Obispo County	-	-	The Phase 1B analysis should be treated as foundational information to support a future basin-wide groundwater/surface water flow model by refining the current model with additional improved data and analysis and expanding the model to include the Arroyo Grande Creek Valley fringe area and/or other fringe areas as applicable. A discussion should be included on how this current model may be expanded and refined to a basinwide groundwater/surface water flow model and what additional data is needed for the effort.	A discussion was added.
1	NCMA TG	2.7.2.4	17	Page 17: Golf Course pumping is indicated to average 113 AFY. This seems very low, on the Mesa alone are Cypress Ridge- 18 holes, Monarch dunes- 27 holes, Blacklake, 27 holes. My experience says golf course water requirements are roughly 300 AFY per 18 holes. That would say pumping on the Mesa alone for golf course irrigation could exceed 1200 AFY. Use of average numbers here is misleading because Monarch Dunes and Cypress Ridge are relatively new and Blacklake did not exist at the start of the study period (1977).	GEOSCIENCE’s statement on page 17 actually reads “ ..113 acre-ft/yr in NCMA”. This number is for the Pismo Beach Golf Course only, which is a 9-hole course built in the 1960s in NCMA. The remaining golf courses, which are located in the NMMA were not estimated separately because the pumping for these courses was lumped with pumping provided for municipal wells. Because it was impractical for GEOSCIENCE to separate irrigation from domestic use, no separate golf pumping was reported in the NMMA

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2	NCMA TG	2.7.2.5	18	At the top of page 18 it is indicated that underflow to offshore aquifers from NCMA is estimated to be 2531 AFY. Does this infer that there may be a substantial reservoir of fresh water in confined or semi confined aquifers off shore? The total underflow to ocean and offshore aquifers stated for NCMA, NMMA and SMVA is substantially less than the roughly 20,000 AFY total reported earlier. Can you explain the difference?	As documented in the Santa Maria Valley Characterization Study and by DWR (1979), the fresh water aquifer extends offshore—possibly up to 10 miles. Based on input and recommendation from the TAC, specifically GSI, the areal recharge was revised and reduced, leading to less outflow to the ocean (See attached updated Table 1 to 3)
3	NCMA TG	2.8.3	21	At page 21 the report indicates that the average change in storage, 1977- 2016 for NMMA is -686 AFY and one would infer that the total change in storage over the 39 year period was -26,754 AF for NMMA. Here use of average numbers is misleading because during much of the study period NMMA was essentially in balance, therefore the majority of the negative change in storage has occurred more recently. When referring to the change in storage noted in the middle of page 21, a statement is made that "This is generally evidenced by slightly declining water levels." The foregoing quote is simply wrong related to NMMA. One of many examples that could be given is that DWR 1979 figure 11 shows GWS elevation at Willow Road and Highway 1 to be + 49 feet (NGVD 29*), yet NMMA's calendar year 2016 Annual Report shows GWS at this same spot to be -2 feet (NGVD 29), a decline of 51 feet. A close look at these two documents will also show that the GWS under what is now NMMA ranged from + 9 feet to + 98 feet over a ten square mile area in 1975 that by Fall 2016 was at -2 feet (NGVD 29) for the same ten square mile area.	This model covers the period from 1977 to 2016. It is possible that from 1977 onward, no such decline was observed (Figure 1) as the water levels mentioned here are from 1975. We agree that averages can be misleading but they also give a general picture of changes. Year-to-year values are also provided in Tables 1, 2, and 3. Also, though these two documents show a dramatic change, it should be noted that contours (especially related to snapshots in time) do not always give an accurate picture of the change in storage over long periods of time. Rather, longer time series of well-distributed water levels tend to give a better and more accurate picture of the aquifer. In addition, the long-term water levels in the NMMA generally don't show this dramatic change consistently, except in the last 10 to 15 years. Figure 1 shows wells in NMMA with long-term water level records. Very few show a sustained decline to the magnitude exhibited by the snapshots of 1975 and 2016. On Figure 3, some wells show very steep water level decline but rebound within a few days or months.
4	NCMA TG	2.6.3	11	The effective porosity is indicated to be 0.12 on page 11 of this report and Figure 18 indicates Specific Yield numbers for layers 1-10, which one could reasonably infer to be 10-12% for NMMA, very similar numbers which DWR 2002 presented for NMMA (12%). . Can you explain how the Specific Yield numbers of roughly 12% presented in Figure 18 correlate to the Specific Storage numbers for the same layers which range from .000001 to .000025 on Figure 19? I am aware of the definitions, but a layman's explanation would be helpful.	A layman's explanation was added to the discussion.
5	NCMA TG	-	-	I come away with the impression that Geoscience does not think that groundwater contours prepared by DWR, NMMA, NCMA or other professionals can be relied upon to make assessments regarding groundwater in storage. The contours prepared by DWR in their 1979 and 2002 reports were plotted using individual well water level data provided by the County via the list of wells monitored by them and is essentially the same data currently in use by the various consultants studying the basin. Some wells have been added or deleted including more recently as a result of collaboration between NCMA and NMMA consultants. Those recent changes are not reflected in exhibits older than 2017.	We apologize for the misunderstanding. However, the point GEOSCIENCE is making is that snapshots of water levels between two points in time can reliably be used to make assessment regarding groundwater storage, assuming the distribution of wells is the same. A more accurate estimate can be made by looking at well distributed water levels over a longer period of time which ensured consistent water levels.

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6	NCMA TG	-	-	Figure 10, DWR 1979 shows groundwater contours for Fall 1965 in what I would describe as the general center of NMMA, northerly of the intersection of Highway 1 and Willow Road to range approximately from 20 to 50 feet above mean sea level and higher to the east. Figure 11 DWR 1979 shows groundwater contours for Fall 1975 in what I would describe as the general center of NMMA, northerly of the intersection of Highway 1 and Willow road to range approximately from 10 to 50 feet above man sea level and higher to the east. Figure 6-6, 2016 Fall Groundwater Contours, (Page 54 NMMA Annual report for 2016) shows groundwater contours in what I would describe as the general center of NMMA, northerly of the intersection of Highway 1 and Willow Road to be approximately 0 and below, not reaching 20 until far to the east. For convenience, NMMA has provided the actual water levels for each of the wells utilized to prepare these contours on the same diagram. At present, I believe that for the most part, many of these same wells were used by DWR for their 1979 and 2002 reports as well as preparation of contours for NCSD in 1999 by Science Applications International Corporation. Keep in mind that in order to make the numbers shown on Figure 6-6 NMMA 2016 (NAVD 88) to be equivalent to the contours shown on Figures 10 and 11 DWR 79 (NGVD 29), subtract approximately 2-1/2 feet from the numbers on Figure 6-6. A back of the envelope review of the above would say that the GWS in the general center of NMMA has fallen from the range of 20 to 50 feet above MSL in 1965 to approximately 0 MLLW or minus 2-1/2 MSL in 2016. To be brief, I won't include Plate A-1 or Plate 14 from DWR 2002, but these plates depict Spring 1995 and 2000 groundwater contours in NCMA and NMMA, but both show 40 foot contours running through what I would describe as the general center of NMMA and then the existence of deepening depressions to the east of the intersection of Highway 1 and Willow Road.	Here, the point was that our model only quantifies changes from 1977 through 2016. Therefore, changes in 1965 and 1975 won't be accounted for. But the model does show that the NMMA loses 26,000 AF over the 40-year model calibration period. Cumulative storage change for the past 10 years (2006-2016) amounts to about 31,000 AF. So the storage loss is captured and quantified by the model.

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7	NCMA TG	-	-	A review of Figure 7-1 Key Wells Index (Page 62 NMMA 2016 Annual Report) indicates that the index has fallen approximately 22 feet from 1975 to 2016. After further review of Figures 1-3 of Geoscience's response I am wondering if the hydrographs presented are representative. I count 24 hydrographs on these three figures but a rough count of wells shown on Page 29 of NMMA 2016 Annual report yields about 45 wells within NMMA, each with elevations attached. To these, add those wells monitored within NCMA and SMVMA which are used for the purpose of this study. When I plot historic elevation data on just one of the hydrographs, that for Well 11N35W09K05 from the above list, I do not get good agreement with that hydrograph as presented. I chose this one hydrograph for examination because that is the location of NMMA Key Well 11N35W-9, located at the intersection of Highway 1 and Willow Road, which is routinely monitored by NMMA. From 2008 through 2017, numerical groundwater elevations are shown in NMMA's Annual Reports for that location. I am wondering if NMMA's Key Well, 11N35W-9 is the same as 11N35W09K05 or are adjacent and not the same. Of some interest, both DWR and Science Applications International Corporation independently plotted groundwater surface elevations at 11N35W-9 in Spring 1995 of 40 feet and 50 feet, respectively. One might reasonably conclude that the GWS was about +45 at that location in the Spring of 1995, yet has hovered near 0 MLLW from fall 2012 to the present.	GEOSCIENCE worked with Steve Bachman to resolve water level discrepancies noted for NMMA key wells. The NMMA key well dataset used for the annual report was requested from Steve Bachman.
8	NCMA TG	-	-	Although Geoscience's answer to [GSI's comment] 2 is not in response to my comments, I have the following concern regarding that response: Geoscience indicates in part that DWR 1979 indicated that NMMA groundwater storage above sea level was 172,000 AF in 1975 and "This dwarfs agricultural withdrawals." A more detailed examination would reveal that by their 2002 report, DWR had reduced their estimate of groundwater in storage above sea level in NMMA to 83,000 AF as of 1985 and to 77,000 AF by 1995. More important, in round numbers, NMMA pumping in 1985 was only about 6,300 AFY, Just a little over DWR's 2002 high estimate of the dependable yield for NMMA of 6,000 AFY. Again in round numbers, NMMA pumping continued to increase to roughly 8,200 AFY in 1995, 10,800 AFY in 2005, 15,500 AFY in 2015, dropping to about 12,700 AFY in 2016. From the above, it is quite easy to see why there has been essentially NO groundwater in storage above Mean Lower Low Water in large portions of NMMA in the fall of 2014, 2015, 2016 or 2017 and as we will likely soon see, 2018. When groundwater levels are at 0 NAVD 88 (Mean Lower Low Water), they are approximately 2- 1/2 feet BELOW MEAN SEA level.	This reply was in response to the overall change of storage being positive in spite of 30,000 AF of agricultural pumping, not exclusively in the NMMA. This comment has since been clarified (see updated response to GSI comment 2). The bulk of the positive change of storage is from the SMVMA which is connected to a boundary and represents only a portion of the SMVMA with no municipal pumping. The NMMA and NCMA clearly show a negative change of storage. The model captures these dramatic storage declines in the NMMA, as stated in the response to item 2 of this comment (NCMA comment 5).

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No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
1	GSI	2.8.3	21	The TM states that 119 transient calibration targets are used in the model. Since this TM is the comprehensive discussion of calibration, we think it appropriate to include an appendix that includes all the hydrographs for inspection.	All hydrographs are now provided in Appendix B. Below are a few notes to help with the interpretation of the hydrographs: -By the TAC recommendation very little effort was put into calibrating against wells north of the Santa Maria River faults; -Per Steve Bachman's recommendation wells 14J01, 10J02, 13G01, 10G05, and 10G01 are probably pumping water level rather than static water level (only static water levels are targeted for calibration)
2	GSI	2.8.3	-	Figure 54 displays cumulative storage throughout the transient calibration period. It is noteworthy that most of the time in this 40-year period (~1978-1990, 1997- 2010) is spent above the zero level on the 2nd y-axis. In other words, the system being modeled has net positive storage during these periods, despite there being approximately 30,000 AFY of agricultural pumpage. It does not seem reasonable that there would be a net positive storage at this level of pumping. There are documented cones of depression in NCMA, SMVMA, and particularly NMMA over the 1977-2016 period. If, even with significant pumping and documented cones of depression there is net positive storage, this reinforces our previously stated concern that there is too much inflow being applied to the model through the various inflow components.	GEOSCIENCE reduced the recharge by half, as suggested by GSI. The updated hydrographs, change in storage, and water balance are shown in Tables 1 to 3 and updated Figure 54. Overall, reducing the recharge made the calibration worse (especially coastal wells) and barely improved the higher water levels in the NMMA. The attached results were generated after the model was recalibrated by adjusting model parameters to bring the calibration back to pre recharge reduction levels while maintaining the low recharge values. The main changes noted in the water balance are: -Less outflow to the ocean -The cumulative change in storage stays negative in the NMMA and NCMA from 1977 to 1983 -The SMVMA gains a bit more storage, probably due to increased inflow from the eastern GHB boundary -The average change of storage in all management areas changed slightly. These results suggest that the bulk of the storage being added in SMVMA may be due to the eastern GHB. However, this boundary should have limited effect on the NMMA and NCMA as it is relatively far away. This is precisely the reason for making the model large enough to minimize boundary effects.
3	GSI	2.8.3	-	On Figure 47, what is the meaning of the "_mult" appended to the well names of several of the wells? Please include in legend.	"_mult" indicates wells that are screened in more than one layer and therefore might be representative of a combination of water level rather than a water level for a given layer. This will be added to the legend.

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No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
4	GSI	2.8.3	-	Many of the transient calibration hydrographs (Figure 47) in the Paso Robles Formation (primary supply aquifer) in the NMMA appear to consistently overestimate water levels in the central part of the Mesa by 20 or 30 feet over the past 20 years (05L01, 15D01, 15R01). Additional hydrographs in this area would be instructive. If the water levels are consistently overestimated in the Mesa (that is, an overestimation of recharge or inflow), this will minimize representation of the documented cone of depression in this area and subsequently overestimate the modeled representation of flow from NMMA to NCMA.	The overall trend is more important than the absolute water level for storage change since storage change is the compilation of month-to-month changes in water levels. If the overall trend is captured, the impact on storage change is minimized. The absolute mean residuals for the wells mentioned are 5.9 ft for 05L01, 13.5 ft for 15D01, and 11.02 ft for 15R01, which are reasonable values even if some residual values are high here and there. Also, while the model does underestimate water levels in other places in the NMMA, it is not biased one way or the other as evidenced by a low mean residual of 3.37 ft. Higher water levels usually stem from higher initial water levels or lower withdrawals rather than higher recharge. As stated in previous reports, not all outflows from the NMMA were tabulated, rural water withdrawals were not estimated, and actual agricultural pumping locations where unknown. These limitations may prevent the model from catching the low points since withdrawals are less focused but still the correct amount might be withdrawn. All hydrographs are now provided in Appendix B with a map showing their locations.
5	GSI	-	-	We calculated Areal Recharge as a flux value (inches/year) for both NCMA and NMMA, and calculated this flux as a percentage of rainfall. In NMMA this value averages 16% of rainfall. In NCMA this areal recharge is 18% of rainfall. These values have been reduced significantly from previous iterations of the model, which we feel is appropriate. However, given the observations in comment 2 (so much inflow that there's barely any cumulative storage loss) and comment 4 (Mesa hydrographs consistently and significantly overestimating water levels), perhaps this value is still too high? A value of 16-18% of rainfall as recharge is within the range of published values, but a more typical value of 8-10% of rainfall as recharge may be more appropriate. Was an attempt made to reduce areal recharge (for example, halving the current values) throughout the model domain and observe the effect on the hydrographs and the calibration statistics? Like what happens if you halve the areal recharge? Based on our previous comments, it appears that a reduction in areal recharge that it would improve the hydrographs and statistics.	See response to GSI comment 2. The main takeaway from this point and the previous one is that there is potentially too much inflow to the model. GEOSCIENCE believes that if this assertion is agreed upon, other inflow should also be looked at. The municipal return flows, which the TAC set at 25% of the water delivered to users, is significantly higher than the percentages used in general practice. The water balance study (Todd Engineers, 2007) reports a value around 5%, Hydrometrics reports 3% in Santa Cruz (2017), and 11% is reported in the Antelope Valley SNMP report (2014). Agricultural return flows can also be considered for adjustment.
6	GSI	2.8.3	21	Table 2-4. Please include the Absolute Mean Residual.	The absolute mean residual was added to the TM.
7	GSI	-	-	The model may be suitable for the stated objective of evaluating injection wells locations. However, we feel the model may need additional revisions before it can be used for regional groundwater management.	GEOSCIENCE would like to work with GSI to address the issue and bring the model to a level where it can be used for regional groundwater management, if possible.
1	NMMA TG	1.2	2	There are a few places in the TM where a TAC, which is assumed to stand for Technical Advisory Committee, is referenced (i.e., Sections 2.7.2.3, 2.8.2, and 2.8.3). Because some important modeling decisions were apparently based on input from the TAC, the TAC members and the role of the TAC should be listed and described briefly in Section 1.2 of the TM.	TAC members and their role were listed as prescribed.

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No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
2	NMMA TG	2.6.2	7	Estimated hydraulic conductivities from lithology are systematically higher than hydraulic conductivities from pumping tests (Figure 15). Artificially increasing groundwater flow rates through a given system requires an increase in the volume of water in order to match modeled groundwater elevations to observed groundwater elevations. This may explain the variance between modeled water balance volumes and observations.	Hydraulic conducty is known to be log-normally distributed and can vary by a few order of magnitudes at short distances. Also, pumping tests are point measurements which are conducted at a different scale than the regional model, hence the differences. Finally, these parameters have been revised based on the TAC recommendation. Recalibration with the TAC-recommended lower areal recharge recommended resulted in lower modeled hydraulic conductivity (see updated TM3 Figure 16 and 17)
3	NMMA TG	2.6.3	10	What is the material difference between Primary and Secondary storage? Primary parameters are similar to confined aquifers and Secondary are similar to unconfined aquifers, yet they both occur in the same layer. Why is the SMR flood plain a lower specific yield (8%) compared to all the remaining layers where specific yield is 10%? Similarly, why does specific storage have no spatial variability (vertical or horizontal).	Primary storage is the specific storage and secondary storage is the specific yield. From a MODFLOW perspective, all layers are assigned both values. For convertible layers (Layer 2 and Layer 3), when the water level drops below the top of the layer, they are treated as unconfined and the specific yield is used by the model. If the water level stays above the top of the layer, then the specific storage is used and the layer is treated as confined. For deeper layers which are never dewatered during the course of the calibration run, the specific yield is never used. Some water levels in the SMR and the Cienega Valley show evidence of semi-confined behaviors. In addition, reports of artesian wells in the Cienega Valley by farmers (personal communications) also suggest semi-confined behavior. Therefore, the specific yield was reduced to match this behavior, as by default MODFLOW would use an unconfined storage coefficient (specific yield).
4	NMMA TG	2.6.3	10	There is no legend category matching the light purple color shown in portions of the NCMA in layer 2 of the model (Figure 19). Please revise Figure 19 accordingly.	Figure was revised

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No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
5	NMMA TG	2.6.4	10	Several lines of evidence, including the results of the model calibration process, suggest that the justification for modeling the Santa Maria River fault as an impediment to groundwater flow is not warranted. For example, no geologic evidence is provided to indicate that low hydraulic conductivity fault gouge has been generated along the Santa Maria River fault. It should be noted that about 12,000 linear feet of the fault, mostly within the NCMA, was previously assigned a hydraulic conductivity of 0.1 feet/day during the calibration process. The hydraulic conductivity along this portion of the fault was subsequently increased during the additional calibration effort by a factor of 50, to 5 feet/day (Figure 20). Further, about 10,000 linear feet of the fault, primarily within the NMMA, was previously assigned a hydraulic conductivity of 0.00001 feet/day during the calibration process. The hydraulic conductivity along this portion of the fault was subsequently increased during the additional calibration effort by a factor of 500,000, to 5 feet/day. In addition, a majority of the fault, or about 40,000 linear feet within the NMMA, was previously assigned a hydraulic conductivity of 0.00001 feet/day during the calibration process. The hydraulic conductivity along this portion of the fault was subsequently increased during the additional calibration effort by a factor of 100, to 0.001 feet/day (Figure 20). Finally, about 5,000 linear feet of the fault within the southeastern portion of the NMMA was previously assigned a hydraulic conductivity of 0.00001 feet/day during the calibration process. This portion of the fault is now no longer modeled as an impediment to groundwater flow. These changes to how the Santa Maria River fault behaves hydraulically, consistently suggest that it either does not impede groundwater flow or that modeling of the fault as an impediment to groundwater flow might not be necessary to achieve satisfactory calibration results in this portion of the model domain.	GEOSCIENCE agrees that the modeling of the Santa Maria River Fault as an impediment to groundwater flow, or not, is subject to various interpretations. The choice to model it as a groundwater flow barrier is based on various DWR and USGS studies in the area. The wells used to establish water level differences across the fault, which were provided by TAC member Steve Bachman, were later deemed unreliable because of reference point discrepancies. Therefore, the choice was solely based on compelling previous studies. Because the influx north of the fault is fairly low (1,000 AFY on average, or lower depending on estimates), the conductance of the fault has very little impact on water levels south of the fault - only water levels located north of the fault are affected in a significant manner when the fault is removed as an impediment to flow. In any case, the model was run without the fault as a sensitivity analysis and results can be found in the updated TM 3. The initial conductance values used and described in this comment were deemed too low by the TAC. At the suggestion of the TAC, these values were revised. After further review of existing reports and modeled water level contours, these new values were adopted and approved by the TAC.

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No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
5 (cont)	NMMA TG	2.6.4	10	As the main line of evidence that the Santa Maria River fault impedes groundwater flow, the modeling team has previously cited groundwater elevation differences in wells to the north and south. Specifically, groundwater elevation contours prepared by DWR (2002) were cited. In addition, groundwater elevations over time measured in wells 11N/35W-12E04 and 11N/35W-11J01, located about 1,600 feet apart across the fault in the central portion of the NMMA, were also cited (Geoscience, February 2018; Figure 4). However, well -11J01 is reportedly located on the south side of the Santa Maria River fault, closer to municipal wells operated by the Nipomo Community Services District, where one might expect lower groundwater elevations to be observed. Yet, reported groundwater elevations in this well are higher than those in well -12J04, which is located on the north side of the Santa Maria River fault. Further, the observed groundwater elevation differences in the two wells are not consistent with the conceptual understanding of the NMMA, as well as the current model calibration results, which show that groundwater elevations in Paso Robles Formation aquifers north of the Santa Maria River fault are higher than those in Paso Robles Formation aquifers south of the fault. Instead, groundwater elevations in the cited wells may reflect completion of well -11J01 in the Paso Robles Formation aquifers and completion of well -12J04 in the deeper Careaga Formation aquifers, where groundwater elevations are lower.	See response above.

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No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
5 (cont)	NMMA TG	2.6.4	10	It should also be noted that groundwater elevation contours, like those developed by DWR (2002) are subject to interpretation. Moreover, DWR did not have insights from the current model, which confirms that there are vertical downward hydraulic gradients between the three different aquifers in the area (Figures 49 and 50). Without this insight, it is possible that contouring of significantly different groundwater elevations in two different aquifers could mistakenly be interpreted to be evidence of some impediment to horizontal groundwater flow between wells. These considerations indicate that alternative explanations to observed differences in groundwater elevations in wells in the area may negate the need to impart an impediment to horizontal groundwater flow within the model domain. For example, the facies data depicted on cross sections F-F’ and P-P’ (Figures 6 and 12, respectively) suggest that generally lower hydraulic conductivity materials are present north of the Santa Maria River fault, compared to south of the fault. Therefore, it is possible that such hydraulic conductivity contrasts, coupled with smaller amounts of groundwater pumping from wells north of the fault, might explain the observed groundwater elevations in wells, as an alternative to simulating the Santa Maria River fault as an impediment to groundwater flow. In fact, not modeling of the Santa Maria River fault as an impediment to groundwater flow would be consistent with previous groundwater models in the area (LSCE, 2000; Wallace, 2016; CHG, 2017). Based on the foregoing arguments, modeling of the Santa Maria River fault as an impediment to groundwater flow should not be the default. Instead, modeling of the Santa Maria River fault as an impediment to groundwater flow should be part of an alternatives analysis. Because the current model simulates the Santa Maria River fault as an impediment to groundwater flow, it is necessary to evaluate the alternative, which is that the Santa Maria River fault does not impede groundwater flow. This evaluation should be designed to assess how acceptable calibration of the model can be achieved without simulating the Santa Maria River fault as an impediment to groundwater flow.	See response above.
6	NMMA TG	2.7.1.1	13	Areal recharge from precipitation was apparently based on 1996 land use data. However, land use since the mid-1970s in the NCMA and NMMA has become more urbanized over the model calibration period, which could have led to greater amounts of runoff and ultimately losses of some storm water to the Pacific Ocean. Therefore, it is not clear if the potential for increased runoff over time, and associated decreases in local recharge from precipitation in the NCMA and NMMA compared to the SMVMA portion of the model domain, have been factored in to the estimated amounts of areal recharge spatially and temporally during calibration of the model. Please confirm whether this is the case so that potential impacts to the model's calibration can be assessed.	Areal recharge is based on rainfall, soil type, and 1996 land use, as no updated landuse data were available for the area. A request was made to the NMMA-TG to obtain an updated land use map of the NMMA (referenced in their annual report), but unfortunately it was never received by GEOSCIENCE. Regardless, recharge for regional models like the CCB Phase 1B model are computed basin-wide, which should minimize uncertainty related to local landuse changes. In addition, estimated recharge was revised based at the recommendation of the TAC to help alleviate shortcomings related to the limitation in the land use data.

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No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
7	NMMA TG	2.7.1.1	13	Review of Figure 21, along with Tables 1, 2, and 3, indicates that there was either no, or virtually no, recharge throughout the model domain in 2013 and 2015, in contrast to non-trivial amounts of mountain front recharge during these same years (Table 2), which originated ultimately from precipitation. Presumably the limited rainfall during these years was less than the amounts of evapotranspiration, resulting in no net recharge to the underlying groundwater aquifers. If this is the case, please consider describing this, to let the reader know. Otherwise, please review the estimated amounts of areal recharge from precipitation and revise accordingly.	Mountain front recharge (MFR) was discussed in more detail in TM1 as being a combination of runoff and underflow from seemingly low-yield rocks. Therefore it is not solely dependent on rainfall. MFR was initially estimated and later adjusted during calibration. Also return flows from agriculture irrigation in the Nipomo Valley area could be contributing to the underflow.
8	NMMA TG	2.7.1.2	13	Mountain front recharge is 1,013 AFY (Table 2), which is contrary to the understanding that the Wilmar Ave fault is a barrier to flow.	See response to NMMA comment 7. Also, the Wilmar Avenue as an impediment to flow might explain the low flow from MFR despite the long boundary.
9	NMMA TG	2.7.1.2	13	The annual amounts of mountain front recharge along the eastern boundary of the NMMA in Table 2 appear to be consistent with the SCS curve methodology described in this section, in that their variation mimics the variation in the amounts of areal recharge from precipitation in the NCMA, NMMA, and SMVMA portion of the model domain (see Tables 1, 2, and 3). However, as noted in May 2018, the Santa Maria River Valley Groundwater Basin Fringe Area Study, which was prepared for San Luis Obispo County, suggests that the amount of groundwater applied to irrigate crops in the Nipomo Valley fringe area east of the NMMA is significant, at about 4,000 acre-feet/year. Therefore, it might be possible that groundwater pumping east of the NMMA might intercept inflow to the NMMA, thereby reducing the estimated amounts of mountain front recharge into the active model domain. In light of this, please assess the degree to which amounts of mountain front recharge currently assigned to the NMMA portion of the model might need to be reduced during additional calibration efforts.	Further data collection and analysis is needed to establish the amount of MFR intercepted by pumping in the NMMA and is beyond the scope of the Phase1B Model, which is focused on helping locate and optimize injection wells in the costal NCMA. However, a later phase will gather more data and could potentially address these issues if sufficient data are available.
10	NMMA TG	2.7.1.2	13	The average amount of annual mountain front recharge listed in Table 2 and depicted in Figure 22 appears to have decreased by about 20 percent, from 1,235 af to 1,035 af, during the most recent calibration efforts. It is not clear why this would be the case, which raises questions about the accuracy and/or validity of model inputs. Although it is not necessary to revise the TM, please provide an explanation for the decreased mountain front recharge, to allow assessment of the validity of the estimates used to calibrate the model.	As stated in previous responses, various improvements and modifications were conducted in response to TAC recommendations, which resulted in different values for different parameters. MFR was a calibration parameter and was adjusted to help improve model calibration.
11	NMMA TG	2.7.1.2	13	Streambed percolation is 460 AFY (Table 2), however no studies have been conducted to evaluate streambed percolation as contributing to the aquifers under the NMMA.	This is correct but the existence of agricultural pumping wells along the Los Berros Creek in the alluvium suggest some recharge from the creek. However, GEOSCIENCE agrees that further studies can help confirm this fact.
12	NMMA TG	2.7.1.2	13	Oso Flaco creek, which is comparable in length to Los Berros and Arroyo Grande creeks, has apparently existed for many years and is sampled by the state of California to assess water quality. However, unlike the latter creeks, Oso Flaco Creek was not simulated using the model. Even if Oso Flaco creek is fed mainly by agricultural runoff from the SMVMA portion of the model domain, it seems like it should contribute recharge to the underlying shallow aquifer (i.e., model layer 2) and be simulated as such. Please either simulate, or provide justification for not simulating and discuss how the lack of simulation might affect model results (i.e., calibration, water balance components, etc.).	Los Berros Creek is a tributary of the Arroyo Grande Creek which is a major feature of the CCB Phase 1B model, so it was necessary to include it. As stated by this comment, the Oso Flaco Creek is mainly fed by agricultural runoff which makes it difficult to estimate discharge. It is also mainly connected to the dune sand which contains shallow and/or perched aquifers. These aquifers were not modeled by this model as they were considered local aquifers and the focus of this model is mainly on regional aquifers.

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13	NMMA TG	2.7.1.4	14	Whereas the return flows from municipal pumping in the NCMA reportedly averaged about 1,215 af/year and did not exceed the average annual municipal pumping of 1,600 af over the calibration period, Table 1 shows that annual return flows from 1977 to 1988, not to mention from 2014 to 2016, exceeded annual amounts of municipal pumping. That return flows exceed the amount of groundwater pumped only seems plausible if some of the municipal supply is not groundwater, for example if some of the municipal water supplies are imported from outside of the model domain. Please clarify whether this is the case. In addition, Figure 24 (see also Table 3) suggests that there are small, finite amounts, of return flows from municipal pumping in the SMVMA portion of the model domain. However, Figure 31 (see also Table 3) indicates that there is no municipal pumping in the SMVMA portion of the model domain. That municipal return flows in the SMVMA portion of the model domain exceed 0 af/year is not plausible when there is no municipal pumping, unless some of the water supplied to this portion of the model domain is not groundwater. This should also be clarified. Finally, it is not clear if the municipal return flows in the NMMA portion of the model domain reflect decreased groundwater production by NCSD in 2015 and 2016, concurrent with delivery of 321 and 758.5 af of imported water respectively in these years via the Nipomo Supplemental Water Project (i.e., Table 2 should reflect municipal return flows in 2015 and 2016 from imported water, despite decreased groundwater production during these years).	Yes, imported water was factored into the computation, which explains why return flows exceed extracted amounts in the NCMA. Municipal return flows from the SMVMA were due to a small overlap in GIS files between the boundaries of municipal service areas and management area boundaries. This was corrected. Imported water amounts in the NMMA were adjusted accordingly.
14	NMMA TG	2.7.1.4	14	The average amount of annual municipal return flow listed in Figure 24 appears to have decreased by about 5 percent, from 2,040 af to 1,908 af, during the most recent calibration efforts. It is not clear why this would be the case, which raises questions about the accuracy and/or validity of model inputs. Although it may not be necessary to revise the TM, please provide an explanation for the decreased municipal return flows, to allow assessment of the validity of the estimates used to calibrate the model.	This is probably due to rounding errors and the recomputation of service area surface areas. This was addressed.
15	NMMA TG	2.7.1.6	15	Agricultural return flow is 29% of pumping in the NMMA (Table 2). This may be overestimated for the NMMA where nearly all the irrigation is conducted by drip line. Little to no irrigation occurs as field flooding or overhead spray irrigation (except during setting of strawberries). Please provide backup information on this estimate.	Irrigation efficiency values were obtained from a study by the county and also looked at changes over time. Therefore, values can seem high as past practices were less efficient.
16	NMMA TG	2.7.1.6	15	The average amount of annual agricultural return flow listed in Figure 26 appears to have decreased by about 3 percent, from 9,680 af to 9,437 af, during the most recent calibration efforts. It is not clear why this would be the case, which raises questions about the accuracy and/or validity of model inputs. Although it may not be necessary to revise the TM, please provide an explanation for the decreased agricultural return flows, to allow assessment of the validity of the estimates used to calibrate the model.	As stated in in the response to NMMA-TG comment 14, these small differences may be caused by rounding errors. In addition, the model adjusts pumping when water level drops below a given threshold and some portion of the surficial aquifer dries.
17	NMMA TG	2.7.1.7	15	The average amount of annual golf course return flow listed in Figure 27 appears to have decreased by about 97 percent, from 480 af to 14 af, during the most recent calibration efforts. It is not clear why this significant decrease would have occurred, which raises questions about the accuracy and/or validity of model inputs. Although it may not be necessary to revise the TM, please provide an explanation for the decreased golf course return flows, to allow assessment of the validity of the estimates used to calibrate the model.	This was a typo and was corrected. The golf return flow was initially estimated using the surface area of the course and applying similar techniques as the agricultural return flows. It was then decided to lump the return flow of the golf with municipal return flow as no pumping separation between golf and municipal per well was provided in the NMMA. Hence the two dramatically different numbers.

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18	NMMA TG	2.7.1.8	15	It is not clear if the model adequately represents recharge of recycled water at NCSD's Southland WWTP. One the one hand, it appears that recharge is applied to the surface of model layer 2. In addition, it is reported in the TM that recycled water has not been observed to have reached the regional groundwater table, possibly due to relatively low permeability materials in the subsurface. On the other hand, there is an implication that recharge of recycled water is applied to model layer 4, which seems to be consistent with the presence of either Paso Robles or Careaga Formation materials at a depth of around 50 feet bgs based on previous cross sections through the area (Fugro, 2015). Clarification should be provided so that the reader knows exactly how recharge at the Southland WWTP is applied to the model. It should be noted that NCSD has reportedly discharged between 474 and 639 af/year of effluent into the subsurface at the Southland WWTP since 2008, but it is not clear if this recharge is documented in Table 2 of the TM. It is not clear whether the application of this much water at this specific location in the model is reflected in the simulated versus observed groundwater elevations (e.g., in Figures 49 or 50), when the hydraulic conductivity of layer 3 and layer 4 materials in this area seems to be equal to or less than 20 feet/day (see Figure 16). Please clarify whether or not the model adequately represents recharge of recycled water at NCSD's Southland WWTP.	The report cited (Order No. R3-2012-0003; Regional Board 2012) documented the fact the infiltrated water at the South Land facility never reached the aquifer, but instead formed a localized perched aquifer. Based on this information, the recycled water at this facility was not included in the model. However, other locations were included even when the surficial aquifer was dry if no evidence of a flow impediment in the subsurface was known. This was accomplished by moving wells representing these fluxes to the next active layer.
19	NMMA TG	2.7.1.8	16	The average amount of annual artificial recharge listed in Figure 28 appears to have decreased by about 66 percent, from 1,083 af to 378 af, during the most recent calibration efforts. It is not clear why this significant decrease would have occurred, which raises questions about the accuracy and/or validity of model inputs. Please provide an explanation for the decreased artificial recharge, to allow assessment of the validity of the estimates used to calibrate the model.	As the recharge from areal precipitation was adjusted a few times by the TAC, the stormwater infiltration was also adjusted since the values obtained from the estimate of runoff and infiltration are also applied to the stormwater spreading estimates. Therefore, adjusting the SCS curve numbers to correct recharge would also impact runoff, which in turn impacts infiltration.
20	NMMA TG	2.7.1.9	16	The simulated average amount of annual inflow to aquifers along the general head boundary coinciding with the Santa Maria River, which is listed in Figure 29, as output by the model, appears to have decreased by about 24 percent, from 27,807 af to 21,056 af (i.e., a difference of 6,751 af), during the most recent calibration efforts. It is possible that this is related to reduced hydraulic conductivities in the southwestern portion of layer 4 of the model (see Figure 16 compared to Figure 16 of the May 11, 2018 TM). Please provide an explanation for the decreased inflow to aquifers along the general head boundary coinciding with the Santa Maria River to explain how changes in the model's properties influence fluxes throughout the model domain.	The model was recalibrated overall based on TAC recommendations in terms of pumping distribution, recharge amounts, fault hydraulic conductivity, etc., leading to various fluxes and parameters being changed during recalibration.
21	NMMA TG	2.7.2.1	16	The Woodlands Mutual Water Company (MWC) produced 228 af of groundwater from model Layer 2 in 2016, but the location(s) of this pumping do not appear to be shown (Figure 30). Please show the location(s) of the Woodlands MWC well(s) in layer 2, which began operation in 2016, and indicate whether or not this pumping was simulated using the model. If not, please include this unaccounted-for pumping and adjust the model properties as necessary to achieve acceptable calibration of the model. For example, it may be necessary to increase model layer hydraulic conductivities that might have been unjustifiably lowered during the calibration process to match simulated groundwater elevations with actual groundwater elevations that were lower due to the unaccounted-for pumping.	These wells were included and were added to the figure.

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22	NMMA TG	2.7.2.1	16	No municipal pumping is reported for the SMVMA portion of the model domain. However, one, likely large, drinking water well has been permitted by the state (system No. 4000555), close to a well at 35°0'0.57", -120°34'14.48", and is operated by the Guadalupe Cooling Company. Guadalupe Cooling is a produce cooling facility that is part of the Western Precooling system of coolers. They cool a full range of vegetables, including broccoli, lettuce, cauliflower, and celery, as well as berries. Guadalupe Cooling utilizes vacuum cooling, hydro-vac cooling, pressure cooling, and icing techniques (http://www.freshkist.com/WP/cooling/guadalupe-cooling/), and might use significant quantities of groundwater annually. In addition, another drinking water well has been permitted by the state (system No. 4000223), and is operated by Skyline Flower Growers (http://www.skylineflowers.com/nipomo--ca.html), located at 2425 Bonita School Road, in Santa Maria. Therefore, it is possible that there is important unaccounted-for groundwater pumping in this portion of the model domain. Please assess whether this pumping should be included as part of the model calibration process.	GEOSCIENCE appreciates the input and will investigate these fluxes in subsequent versions of the model. For the purpose of the current model, the impact of these fluxes will be negligible on the goal of this phase of the model, whcih is to optimize recycled water injection wells to prevent seawater intrusion in the coastal NCMA.
23	NMMA TG	2.7.2.3	17	The allocation of agricultural well pumping to various model layers is described in this section of the TM, but no basis for the assumed allocations for each management area is presented. Most models, including even some regional-scale groundwater models (e.g., see Faunt, C.C., ed., 2009, Groundwater Availability of the Central Valley Aquifer, California: U.S. Geological Survey Professional Paper 1766, 225 p., https://pubs.usgs.gov/pp/1766/), use well construction information, such as that available from DWR (https://dwr.maps.arcgis.com/apps/webappviewer/index.html?id=181078580a214c0986e2da28f8623b37), to allocate pumping to appropriate model layers for wells screened over multiple aquifers. Therefore, it is not clear why the allocation to model layers of pumping from agricultural wells was not based on construction information, as was presumably done for municipal wells. The TM should consequently include a brief explanation justifying the assumed layer allocations. In addition, the current allocations for each management area are different than those employed during the previous calibration efforts (see Section 2.7.2.2 of the May 11, 2018 TM), but no explanation is provided to support changing the allocations. For example, the basis for assigning 50 percent of the pumping from a well to the Paso Robles Formation in the SMVMA portion of the model domain in the current version of the model, compared to 70 percent in the previous version, is not clear. Please describe the basis for such changes in the TM.	This allocation process was discussed and vetted by the TAC. It was based on a sample of wells with screen intervals provided by Steve Bachman (NMMA-TG) and GSI (NCMA-TG). A more detailed analysis was conducted in the NCMA where previous work helped locate and identify most of the agricultural wells. Even when wells were identified, the process of assigning them to specific field being irrigated would still introduce uncertainty, in light of this and the time and resources necessary to identify agricultural wells and assign pumping, it was determined that for the purpose of this phase the current approach was reasonable.
24	NMMA TG	2.7.2.3	17	The average amount of annual agricultural pumping listed in Figure 33 appears to have increased by about 3 percent, from 31,452 af to 32,563 af, during the most recent calibration efforts. It is not clear why this increase would have occurred, which raises questions about the accuracy and/or validity of model inputs. Please provide an explanation for the increased agricultural pumping, particularly in light of apparent changes in hydraulic conductivity values in layers 4 and 6 of the model (see Figure 16 compared to Figure 16 of the May 11, 2018 TM), to allow assessment of the validity of the estimates used to calibrate the model and of the model's representation of actual conditions.	Rounding errors, model mass balance errors, and dry and rewetting cell for various calibration parameters and water levels would explain these minor discrepancies.

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25	NMMA TG	2.7.2.4	17	Whereas pumping of between 85-130 af/year for golf course irrigation in the NCMA was simulated over the model calibration period, significantly greater amounts of groundwater pumping for golf course irrigation in the NMMA were apparently not simulated (see Figure 34). For comparison, on the order of roughly 1,000 af of groundwater was actually pumped for golf course irrigation in the NMMA in 2017, or roughly 10 times the amount pumped in the NCMA. In addition, the amount of groundwater pumping for golf course irrigation in the NMMA has increased over time, given that each of the 3 major golf courses began operating at different times: Blacklake in the 1960s, Cypress Ridge in 1999, and Monarch Dunes in about 2006. As noted during review of the February 2018 conceptual model technical memorandum, the presence of unaccounted-for groundwater pumping within the model domain could lead to propagating errors. For example, model layer hydraulic conductivities might need to be unjustifiably lowered during the calibration process to match simulated groundwater elevations with actual groundwater elevations that are lower due to the unaccounted-for pumping. These lower hydraulic conductivities could then reduce the amounts of horizontal groundwater flow in those portions of the model where unaccounted-for pumping is occurring, rendering certain internal groundwater balance components in Tables 1, 2, and 3 inaccurate. Please therefore revise the groundwater pumping inputs to the model accordingly during additional calibration efforts and indicate the locations of golf course wells on the appropriate figure, either Figure 3 or Figure 30. It is also worth noting that like golf course returns flows listed in Table 1, inclusion of golf course pumping in the NMMA during the model calibration process should be accompanied by return flows from golf course pumping for consistency. Alternatively, to be consistent with estimates by the NMMA Technical Group, return flows from golf course pumping and irrigation could be set to 0 throughout the model domain (i.e., the NMMA TG annually assumes that all water used for golf course irrigation is consumptively used and that none infiltrates past the turf root zone to replenish aquifers). Please consider during additional model calibration efforts.	GEOSCIENCE received pumping information for all golf courses in the NMMA and these were incorporated in the model. What GEOSCIENCE requested but was never provided was the breakdown of these fluxes between golf and municipal use. Therefore, golf pumping in the NMMA was lumped with municipal pumping. If this information is provided on a well by well basis to allow flux separation, then these fluxes can be separated. Return flows for golf courses in the NMMA and NCMA were estimated using an approach approved by the TAC.
26	NMMA TG	2.7.2.5	18	The simulated average amount of annual outflow to the ocean and offshore aquifers, which is listed in Figures 35 and 36, respectively, as output by the model, appears to have decreased by about 43 percent, from 20,182 af to 11,437 af (i.e., a difference of 8,745 af), during the most recent calibration efforts. It is possible that this is related to reduced hydraulic conductivities in the southwestern portion of layer 4 of the model (see Figure 16 compared to Figure 16 of the May 11, 2018 TM). Please provide an explanation for the decreased outflow to the ocean and offshore aquifers to explain how changes in the model's properties influence fluxes throughout the model domain.	This a direct result of recalibrating the model with a lower recharge as recommended by the TAC.

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27	NMMA TG	2.8.1	18	Because the final version of the TM will be a stand-alone document that may be referenced by future model users (i.e., model users won't have earlier drafts), it will be important for users of the model to completely understand the calibration process and hence the reliability of model simulation results. Consequently, it is important that future model users know that model calibration was not a single effort, but that it was at least a 2-step process involving external review of the initial calibration results and implementation of revisions to the model as part of subsequent calibration efforts. Therefore, please add some text to the end of this section letting the reader know of this process, to lay the foundation for subsequent conclusions in the TM in Section 2.8 as to improvements in the model's calibration statistics (i.e., the aforementioned review and revision step is also an important part of the model parameter adjustment process currently described in Section 2.8.1).	This suggestion was taken into account and incorporated into the model.
28	NMMA TG	2.8.1	18	Section 2.7.1.6 of the TM indicates that agricultural "return flows were adjusted during model calibration." If agricultural return flows were adjusted to help achieve acceptable calibration of the model, agricultural return flows should be listed in Section 2.8.1 of the TM, along with the other parameters that are currently listed. In addition, because agricultural pumping increased by about 3 percent compared to the previous calibration efforts (see comment above linked to page 17 in Section 2.7.2.3 of the TM), it is not clear if agricultural pumping was also adjusted to help achieve acceptable calibration of the model, either during the previous (see May 11, 2018 TM) or current calibration efforts. If this in fact occurred, it is a significant step in the calibration process that should be documented, at a minimum by including it in the list in Section 2.8.1 of the TM, given the implications with respect to the model's representativeness, or lack thereof, of observed conditions throughout the model domain as a result of varying of agricultural pumping during the calibration process.	Agricultural pumping and return flows were not adjusted during calibration. This was clarified in the text. Discrepancies are due to minor rounding errors, model mass balance error, and due to the high number of wells - some ending up in dry cells.

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29	NMMA TG	2.8.2	18	Whereas the simulated steady state groundwater elevation contours for 1977 (Figure 40), which are used as the initial condition for transient calibration efforts, are intended to be an "acceptable water level distribution based on observed water levels," it is not clear if this is the case, particularly in the northern NMMA. This is important, because it has implications for the representativeness of the conceptual model, model properties, and calibrated transient model in this area. Alternative interpretations highlight the challenges associated with the need to accurately represent groundwater conditions and model layer properties throughout the model domain. These concepts should be evaluated during additional calibration efforts. The following examples illustrate how observed conditions can influence the conceptual model, which in turn affects the numerical model. Groundwater contours prepared by DWR, representing a single aquifer system, have been cited as evidence that the Santa Maria River fault impedes groundwater flow in the NMMA (see comment associated with Section 2.6.4, pg. 10). In fact, the simulated 1977 groundwater elevation contours can be compared to DWR's Spring 1975 groundwater elevation contours, which have been drawn and interpreted by DWR in a manner that suggests that the Santa Maria River fault impedes groundwater flow. Based on this comparison, it appears that there is reasonable agreement between the simulated (1977) and observed (1975) groundwater elevation contours south of the Santa Maria River fault trace, as interpreted by DWR. On the other hand, north of the Santa Maria River fault trace, for example along Los Berros Creek, the simulated groundwater elevations representing the initial condition in layers 4 to 6 for the transient calibration efforts are about 30 feet (near Nipomo Hill) to 60 feet (near Highway 101) lower than the interpreted/observed groundwater elevations, which likely influences the transient calibration results.	Ultimately, a decision was made by the TAC not to focus on water levels north of the Santa Maria Fault as it is not clear how continuous these aquifers are (they are not contoured by the NMMA-TG in their annual report). Subsequent phases of the project will address these areas and more time and resources will be dedicated to better characterize them.
29 (cont)	NMMA TG	2.8.2	18	It is worth noting, however, that a very similar groundwater elevation dataset representing Fall 1976 conditions, and yielding similar groundwater elevation contours in places to DWR's Spring 1975 contours, appears to have been interpreted by SLO County's Department of Public Works (unpublished map) to reflect a two-aquifer system throughout the NCMA and NMMA, with a downward hydraulic gradient from a shallower/upper to deeper/lower aquifer (note that correlation of these 2 aquifers to model layers may not be possible).	See response above
30	NMMA TG	2.8.2	19	Another construction element of concern is the lack of including Black Lake Canyon as an area of outflow for shallow groundwater. Dr. David H Chipping reports his evaluation of the geology and hydrology of the Black Lake Canyon in his paper titled, “Black Lake Canyon Geologic and Hydrologic Studies” dated November 4, 1994. He documents evidence of persistent seepage from the shallow aquifer system above a substantial clay layer acting as a barrier to downward flow, and he asserts that groundwater seepage is the cause of the erosion producing and evolving the canyon to its current condition. Please evaluate the effect this observation would have on model construction and calibration.	See response to NMMA-TG comment #12

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31	NMMA TG	2.8.2	19	Figure 38 shows that higher groundwater elevations, observed between 125 feet – 200 feet elevation, are under-predicted by the model by as much as 75 feet. Lower groundwater elevations, observed near 0 feet elevation, are over predicted by the model by as much as 25 feet. Therefore, at the coast in the NCMA, where water levels are often at or below sea level, the model shows water levels are "safely" above sea level. These are critical observations both for injection projects near the coast and for overall basin management. We believe that these discrepancies should be addressed.	High water levels north of the Santa Maria Fault were recognized as problematic and will be addressed in future phases. The model was recalibrated since these comments were issued and these locations have improved. Also, spikes of low water levels in some wells that are not sustained would have limited impact on seawater intrusion.
32	NMMA TG	2.8.2	19	The absolute value of the mean residual, the maximum residual, and the standard deviation of the residual displayed on Figure 38 (steady state calibration statistics listed in Table 2-3) indicate a deterioration in the model's representativeness compared to the previous calibration efforts (see Table 2-3 and Figure 34 in the May 11, 2018 TM). This lack of expected improvement, as evidenced by the calibration statistics, should be discussed in the final TM. See for example Figure 8.11 in Anderson and Woessner, 2002, Applied Groundwater Modeling, Simulation of Flow and Advective Transport, Academic Press.	The model calibration has been updated.
33	NMMA TG	2.8.2	19	Please include calibration residuals associated with one or more Woodlands MWC wells pumping from Layer 2 (i.e., on Figure 39) in accordance with previous comment pertaining to Section 2.7.2.1. In addition, there is a noticeable lack of steady state calibration residual data in the SMVMA portion of the model domain (i.e., south of the NMMA and north of the Santa Maria River) that is not close to the general head boundary coinciding with the Santa Maria River, for layers 4 to 6 (Figure 39). This contrasts with the significant quantities of groundwater pumping from these layers. Unless this deficiency can be remedied, the final TM should describe how this lack of calibration data will influence any uncertainty associated with model simulation results.	These can be provided. However, in accordance with the TAC recommendation, the calibration process was focused on key wells provided by NMMA and NCMA and wells vetted by both management areas. The Woodland wells were not included. They appear to be fairly local to the mesa and located in a dune sand aquifer which was not modeled as a separate aquifer but rather lumped together with the alluvium. Even though a significant amount of water is pumped from them, the aquifer they are located in appears to be isolated from the deeper aquifer as it maintains 50 to 100 ft head difference. Hence its impact on the layers being modeled is assumed to be negligible.

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34	NMMA TG	2.8.2	19	The simulated steady-state groundwater elevation contours for model layer 2 (Figure 40) for 1977 are similar to the observed levels of the Pismo dune lakes, from Pipeline Lake in the north to Oso Flaco Lake in the south. The notable exception is Black Lake, which has an elevation of about 31 feet amsl. The steady state groundwater elevation contours suggest that groundwater would be encountered at about 14 feet below the surface of the lake, or at an elevation of about 17 feet amsl. In addition, the simulated steady-state groundwater elevation of about 19 feet amsl, is about 21 feet lower in elevation than the spring depicted on the USGS Oceano 7.5' Quadrangle topographic map (1965, revised 1994) at the base of the Nipomo Mesa, about 3,000 feet east of Pipeline Lake (35°04'27.80", -120°35'44.22"). Finally, the simulated groundwater elevation of about 13 feet amsl in layer 2 at the end of the transient calibration period in the Fall of 2016, in the vicinity of GSWC's Cypress Ridge system on the Nipomo Mesa, is about 10 feet lower in elevation than the water level measured in well 12N/35W-32R04. The model tends to simulate groundwater elevations near the western edge of the Nipomo Mesa that are about 10-20 feet below observed groundwater elevations, and it is worth noting that the entire offshore portion of layer 2 now has a hydraulic conductivity of 60-80 feet/day, compared to the previous value of 20-40 feet/day (see Figure 16 in the May 11, 2018 TM), which could cause lower groundwater elevations within landward portions of layer 2. One possibility for the low groundwater elevations in the model is that there might be insufficient recharge to the shallow aquifer beneath the Nipomo Mesa. This recharge could be in the form of recharge (beyond the root zone) of water applied to irrigate crops on the Nipomo Mesa or possibly septic system discharges.	Some of these observations no longer apply as the model was recalibrated following TAC comments and input. However, it is worth emphasizing that the steady state was devised solely to help establish initial heads and was not intended to be a fully standalone predictive tool. After the transient calibration was set, the initial run was adjusted by using various transient run timesteps as initial heads. Based on the size of the NMMA and the dune sand area, a significantly greater amount of recharge would be needed to raise the water level as suggested. Septic return wouldn't be enough unless they amount to a similar order as the areal recharge. It should be noted that implementing the small system pumping had negligible impact on calibration. It is believed that septic fluxes would have even less of an impact as they tend to be small and distributed across the model domain.
34 (cont)	NMMA TG	2.8.2	19	It was previously suggested that roughly 70 acre-feet of wastewater could have been discharged to septic systems in GSWC's Cypress Ridge system service area in 2009. But, it is not clear from the TM whether recharge from septic systems has been simulated, despite GSWC providing septic system information. Given the estimate provided previously, assuming that some fraction of this might reach the shallow aquifer, and considering the number of homes on the Nipomo Mesa not served by one of the four major wastewater treatment facilities, it seems reasonable to conclude that in recent times several tens to a couple hundred af/year of septic system flows might recharge the shallow aquifer beneath the Nipomo Mesa. Such amounts would be similar to return flows from small systems in the NMMA, as tabulated in Table 2 of the TM. Therefore, it is worth noting that improved calibration of the model, along with estimates of water balance components, might be achieved by simulating recharge from septic systems.	See response above.
35	NMMA TG	2.8.3	20	Figure 42 shows structure in the scatter plot of observed vs. modeled groundwater elevations. Ideally these residuals would be random. For instance, for observed groundwater elevations from 25 feet to 50 feet, the model in some cases predicts elevations from 50 feet to 110 feet. Likewise, for observed groundwater elevations from 110 feet to 175 feet, the model predicts elevations at a constant elevation of approximately 185 feet. Please determine the source of the data structure, and evaluate such correlations with respect to their spatial occurrence.	The model calibration has been updated.

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No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
36	NMMA TG	2.8.3	20	Figure 42 shows that at lower groundwater elevations, observed groundwater elevations from 25 feet to 60 feet are under-predicted by the model (i.e., observed groundwater elevations of 50 feet to 60 feet are predicted as 25 feet to 30 feet); and for observations from -30 feet to 15 feet the model over-predicts (i.e., observations of below sea level are predicted at 15 feet to 25 feet above sea level. Therefore, in the NMMA where water levels in the main portion of the basin are 50 feet, the model shows 15 feet to 25 feet, making water levels look significantly lower than they are; and at the coast in the NCMA where water levels are often at or below sea level, the model shows water levels are well above sea level when they are observed to be much lower. These are critical observations both for injection projects near the coast and for overall basin management. We believe that these discrepancies should be addressed.	The model calibration has been updated.
37	NMMA TG	2.8.3	20	The overall model calibration is systematically biased (Figure 42). If a linear trend line of the modeled groundwater elevation were plotted, the slope of the line would be less than the slope of the 1:1 line shown. This is to say that high elevation groundwater is understated by the model, up to 50% understated at the highest elevations. The geography where high-elevation water occurs is on the east side of the NMMA. This may be a result of including the Santa Maria River fault as a barrier to southwestward flow. The modeled groundwater elevations are also of concern at the lower elevation range. Observed groundwater levels that are below sea level are modeled as being above sea level. Clearly, modeled groundwater elevations at the coast would indicate no issue of concern when in reality observed groundwater elevations would be below sea level and of the utmost concern. Observed groundwater elevations between 25 ft msl and 75 ft msl are modeled as water elevations between 0 ft msl and 50 ft msl.	The updated TM includes a model run without the Santa Maria River Fault as a barrier to flow.
38	NMMA TG	2.8.3	20	In contrast to the expected improvement (see Figure 8.11 in Anderson and Woessner, 2002, Applied Groundwater Modeling, Simulation of Flow and Advective Transport, Academic Press), and despite a slight improvement in the mean residual, the transient calibration statistics listed in Table 2-4 (i.e., the minimum residual, the maximum residual, and the standard deviation of the residual) and displayed on Figure 42 indicate a noticeable deterioration in the model's representativeness compared to the previous calibration efforts (see Table 2-4 and Figure 38 in the May 11, 2018 TM). This lack of expected improvement, as evidenced by the calibration statistics, should be discussed in the final TM. An example of the apparent deterioration in the calibration statistics pertains to a number of observed groundwater elevations exceeding about 170 feet which were significantly underestimated by the current version of the calibrated model based on comparison of data in Figure 38 from the May 11, 2018 TM with data in Figure 42. It is not clear if, and how, these under-predicted groundwater elevations may be related to an increase in the hydraulic conductivity in layer 6 (Figure 16) north of the Santa Maria River fault trace compared to the initial calibration efforts (see Figure 16 in the May 11, 2018 TM). But, the deterioration in the transient calibration statistics indicates additional calibration efforts are needed to instead improve the calibration statistics. In addition, an explanation for the superscript 1 associated with the relative error value should be added to Figure 42.	The model was modified and recalibrated based on TAC recommendations. From a purely calibration quality perspective, GEOSCIENCE and the TAC were pursuing a model which would reflect local understanding of the system rather than matching most water levels. Therefore, input from the TAC was valued over absolute reduction in groundwater level residuals. It is important to remember that the quality of the recorded water levels also included a degree of uncertainty, as various versions of about 100 to 150 wells or so were provided for calibration with water levels varying by as much as 30 feet for the same well, same date, same measurement. Trusting vetted and indexed wells is a safer route even if it is done at the expense of a few others or perfect statistics.
39	NMMA TG	2.8.3	20	The Y-axis scale is too large in Figure 43, perhaps use -25 to 200.	The axis was reduced to 250 ft

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No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
40	NMMA TG	2.8.3	20	The residuals in 1977 fall within a band that ranges from about -75 to 100 feet (Figure 45). On the other hand, the residuals in 2016 fall within a band that ranges from about -50 to 150 feet. These ranges, which are consistent with a visual review of the data displayed on Figure 45, suggest that the value of the residuals over the model calibration period becomes increasingly positive from 1977 to 2016. In other words, simulated groundwater elevations in some parts of the model domain seem to be larger than actual groundwater elevations early in the model calibration period. But, this pattern seems to have reversed late in the calibration period, leading to simulated groundwater elevations in some parts of the model domain being lower than actual groundwater elevations. Note that the opposite trend seems to be apparent when the equivalent residual data (i.e., Figure 41 in the May 11, 2018 TM) from previous calibration efforts are reviewed (i.e., the value of the residuals over the model calibration period subtly becomes increasingly negative from 1977 to 2016). Please address this possible 'drift' in the groundwater elevation residuals and make corrections to the model properties and/or inputs to eliminate this 'drift,' if appropriate. Please also check the x-axis labels on this chart (i.e., Figure 45) and all other charts, as the tick marks are assumed to represent yearly increments, but the labels are not consistent with yearly tick mark increments.	These slight drifts are fairly common because some wells go offline while other come online. In addition, density and frequency of data measurements tend to increase over time. Because of this variability, a bit of drift can be expected. Obvious increases or decreases and divergence would be of concern but no such obvious bias is observed here.
41	NMMA TG	2.8.3	20	Model layer 2 wells 12N/35W-30P02 and 11N/34W-29R01 (Figure 46) were previously assigned to model layers 4-6 (see Figure 43 in the May 11, 2018 TM). Please explain or reconcile this apparent discrepancy. In addition, in contrast to the evaluation of certain calibration residuals at several wells assigned to model layer 2 (see Figure 44), there are no hydrographs available to enable further assessment of calibration efforts in roughly one half of the model domain for layer 2, primarily in the SMVMA portion of the model and the southern NMMA (see Figure 46). The impact of this significant data gap should be explained or the data gap should be filled during additional calibration efforts.	Some wells are screened in more than one layer. Because the model cannot compute mixed water levels, a choice had to be made when wells were screened in multiple layers. In TM-3 the well screen(s) were added. A discussion will be added to address the distribution of the calibration targets
42	NMMA TG	2.8.3	20	Please explain the significance of the calibration wells in model layers 4-6, whose state well numbers have been augmented with the "_mult" notation (Figure 47). In contrast to the evaluation of certain calibration residuals at several wells assigned to model layers 4-6 (see Figure 44), there are no hydrographs available to enable further assessment of calibration efforts in roughly one third of the model domain for layers 4-6, primarily in the SMVMA portion of the model (see Figure 47). For example, well 11N/35W-33G01 appears to coincide with a calibration well where residuals were evaluated (see Figures 41 and 44), has an extensive groundwater elevation dataset over the model calibration period. The impact of this significant data gap should be explained or the data gap should be filled during additional calibration efforts.	More hydrographs were provided. _mult means that the well is screened in more than one layer. The updated TM-3 added the actual screened layer when available.

Comments Received and GEOSCIENCE Responses for Draft TM No. 3: Model Calibration

No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
43	NMMA TG	2.8.3	20	There are no hydrographs available to enable further assessment of calibration efforts in roughly three quarters of the model domain for layers 8 to 10, primarily in the SMVMA portion of the model and the NMMA (see Figure 48). For example, well 11N/35W-28M01 and may be completed in model layers 8-10, has an extensive groundwater elevation dataset over the model calibration period. In addition, well 11N/35W-24J01, which is operated by GSWC, and may be completed in model layers 8-10, has an extensive groundwater elevation dataset over much of the model calibration period (i.e., from 1980 to 2016). The impact of this significant data gap should be explained or the data gap should be filled during additional calibration efforts.	Multi-screened wells have limited use in calibration as they tend to have mixed water levels that are not computed by the model. The data gap can only be filled with installation of additional monitoring wells in the future.
44	NMMA TG	2.8.3	21	The simulated groundwater elevations in layer 2 of the model, as shown in Figures 49 and 50, appear to be higher than those simulated for layer 2 during earlier calibration efforts, as shown in Figure 45 of the May 11, 2018 TM. However, it is not clear if layer 2 hydraulic conductivities, as shown in Figures 16 and 17, were reduced or changed compared to earlier calibration efforts. In addition, as previously noted, there seem to be reduced amounts of groundwater recharge to layer 2 during the most recent calibration efforts, for example in the form of return flows and artificial recharge, which would seem to lead to reduced groundwater elevations in layer 2. Please provide an explanation for these apparently contradictory observations (i.e., reduced recharge and no apparent change in hydraulic conductivity, but increased groundwater elevations), in the possible absence of other changes to the model, to allow assessment of the model's representation of actual conditions.	The model was recalibrated, which would explain changes in water levels and fluxes in various places in the model.

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No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
45	NMMA TG	2.8.3	21	Possible spring discharge has been identified at a ground surface elevation about 135 feet just west of Los Berros Creek and Los Berros Road in the northern NMMA (i.e., at 35°05'16.15", -120°33'38.62"), potentially since 1953 (pre-dating development and landscape irrigation) to the present, as indicated on the attached figure 6 of 13. In comparison, the simulated 1977 groundwater elevation contours at this location for layers 4 to 6 are about 50 feet lower in elevation (Figure 40), while the simulated 2016 groundwater elevation contours are about 110 feet lower in elevation (Figures 49 and 50). An adequately calibrated model should be able to simulate a long-term perched aquifer in the area if one exists, as suggested in Section 2.8.2 of the TM, and if it is the reason for the persistent spring discharge. It is not clear if the spring discharge and historically high groundwater elevations in this area are related to the contact between relatively permeable Dune Sand deposits and relatively low permeability geologic materials associated with the underlying Paso Robles or Franciscan Formation. However, it is worth noting that simulated groundwater elevations in 2016 near Los Berros Creek and Highway 101 (Figure 49) declined about 90 feet compared to steady state groundwater elevations nearly 40 years earlier in 1977 (Figure 40), while simulated groundwater elevations in 2016 near Los Berros Creek and El Campo Road (Figure 49) declined about 60 feet compared to steady state groundwater elevations in 1977 (Figure 40). This artificial decline in groundwater elevations, which does not match observed conditions, indicates that additional calibration efforts are needed to adequately represent the model in this area, particularly if it affects the model calibration in other areas. These concepts should be evaluated during additional calibration efforts.	The TAC has determined that future phases would focus on these area. A detailed review of the geology and an additional cross-section should help refine shallow layers and capture the complex layering in this area. However, this will not be addressed during this phase of the work.
46	NMMA TG	2.8.3	21	Most of the large residuals arising from the transient calibration process reportedly occurred north of the Santa Maria River fault. However, review of Figure 44 shows an equal number of large residuals, where simulated groundwater elevations are less than observed groundwater elevations, are also found south of the Santa Maria River fault, in the central portion of the NMMA. Large residuals also noted north of the Santa Maria River fault during the steady-state calibration process were potentially attributed to relatively shallow perched groundwater (see Section 2.8.2 of the TM), possibly occurring above some deeper regional water table reflected in the simulation results associated with model layer 2. However, groundwater elevations reportedly not contoured by the NMMA Technical Group seem to consistently, season to season and year to year, reflect groundwater flow in the alluvium along Los Berros Creek, from Highway 101 in the east to at least roughly El Campo Road in west. This sort of pattern might be more difficult to attribute to one or more perched groundwater aquifers, and seems to reflect a water table that was roughly 30 to 50 feet below ground surface along Los Berros Creek in the Spring of 2018. One or more changes to model properties or inputs might alleviate the large residuals, including decreased hydraulic conductivities (i.e., compared to Figure 16 in the May 11, 2018 TM, hydraulic conductivities in layer 6 seem to have been increased, based on review of current Figure 16), reduced groundwater pumping, or increased groundwater recharge.	See response to NMMA-TG comment 45.

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No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
46 (cont)	NMMA TG	2.8.3	21	Given the aforementioned need to include rural groundwater pumping in the NMMA portion of the model, it might be more plausible to decrease hydraulic conductivities in the area or possibly reevaluate the amount of groundwater recharge that occurs along Los Berros Creek. Given the length of Los Berros Creek and the size of the associated watershed, it is possible that the modeled recharge along Los Berros Creek, which is noticeably less than the modeled recharge along Arroyo Grande Creek and the estimated mountain front recharge, might be greater than currently modeled. Based on the foregoing discussion, it is not clear why, as described in Sections 2.8.2 and 2.8.3 of the technical memorandum, attempts to better calibrate this portion of the model would be de-prioritized. For example, a conceptual project to complete a 2.5-mile-long pipeline to convey recycled water from the SSLOCSD WWTP to the Phillips 66 refinery in the southwest portion of the NMMA was previously considered, as described in the November 2014 San Luis Obispo County Regional Recycled Water Strategic Plan. Coincidentally, this is about the same distance that would be required to convey recycled water from the SSLOCSD WWTP to be discharged into Los Berros Creek where it crosses under Highway 101 along the northern border of the NMMA. Therefore, to improve the model in these areas, please re-evaluate model parameters and inputs during additional calibration efforts.	See response above.
47	NMMA TG	2.8.3	21	The observed groundwater elevation in the Spring of 2016 in one of GSWC's Cypress Ridge system wells (i.e., T11N/R35W-04D01), which is located between the Santa Maria River fault and Black Lake Canyon to the south, and is completed across the lower portion of the Dune Sands and upper portion of the Paso Robles Formation, was about 90 feet amsl. This is significantly higher than the simulated groundwater elevations of about 22 feet amsl in model layer 2, or 14 feet model layer 4, at the same location (Figure 49). Information about this well, including historical groundwater level measurements from 1998 to 2018, was provided by GSWC in May of 2018, but it is not clear if this information was utilized during model development and calibration. The discrepancy between observed and simulated groundwater elevations of about 70 or 75 feet suggests that the model does not adequately represent conditions in this portion of the NMMA and that adjustments should be made during additional calibration efforts to improve the model's representation of observed conditions.	From a regional groundwater modeling perspective, it is expected that some wells will not be matched perfectly due to various local variability and uncertainty in water level measurements. The goal of model calibration was to match key wells with regional trends and improve the model over time as more details are obtained through subsequent phases.

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No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
48	NMMA TG	2.8.3	21	Tables 1, 2, and 3 provide an excellent opportunity to assess the conceptual validity of the calibrated model. For example, water balance components in Table 2 indicates that there was a net outflow of groundwater from the NMMA into surrounding areas for 13 out of the first 18 years of the model calibration period. If this is correct, please discuss how this might have occurred, such as through greater amounts of groundwater pumping in the adjacent NCMA and the SMVMA portion of the model domain from the late 1970s to mid-1990s. Such a discussion can help to reconcile the behavior of the groundwater model with our conceptual understanding of changes in the groundwater system over time. One observation from review of Tables 1, 2, and 3 is that they do not contain all of the same water balance components. For example, no mountain front recharge is assigned to the NCMA, despite the present of adjacent bedrock hills and the fact that DWR (2002; Table 25) suggests it. This highlights the need to either include mountain front recharge in the NCMA or to provide a basis for excluding it.	This detailed discussion is beyond the scope of this phase and can be investigated as a separate task in the next phase. Various discussions with the TAC and local expert (Tim Cleath) suggested that very little water was coming from mountain front recharge in NCMA
49	NMMA TG	2.8.3	21	Pumping from domestic wells for rural residences and landowners was assumed in the model to be negligible. However, roughly 600 af of groundwater was estimated to have been pumped from aquifers beneath the NMMA in 2017 via rural residential wells. The amount of rural pumping in the NCMA is unknown, and there are several homes in the SMVMA portion of the model domain where small wells may be pumped for domestic water supply. In contrast to the roughly 600 af of rural residential groundwater pumped from NMMA aquifers in 2017, which is not accounted for in the model, lesser amounts of small system pumping, of about 200-450 af/year in the NMMA and about 20-50 af/year in the NCMA, are accounted for. Therefore, it is not clear why rural pumping in the NMMA is considered to be negligible. By excluding this pumping from the model, hydraulic conductivity and other model parameters in the NMMA may be inaccurate. As noted during review of the February 2018 conceptual model technical memorandum, the presence of unaccounted-for groundwater pumping within the model domain could lead to unintended consequences. For example, model layer hydraulic conductivities might need to be unjustifiably lowered during the calibration process to match simulated groundwater elevations with actual groundwater elevations that are lower due to the unaccounted-for pumping. These lower hydraulic conductivities could then reduce the amounts of modeled horizontal groundwater flow in those portions of the model where unaccounted-for pumping is occurring, rendering certain internal groundwater balance components in Tables 1, 2, and 3 inaccurate. Indeed, the combined rural and golf course pumping in 2017 of roughly 1,600 af is essentially equivalent to the net amount of groundwater that reportedly flowed into the NCMA from surrounding areas, as output by the model and summarized in Table 1 of the TM.	Pumping from both rural and small systems was assumed negligible. However, pumping from small systems was included because the data was obtained in a timely manner before most of the model was completed. This was not the case for the rural pumping, which lacked spatial distribution for the longest time. In addition, while 1,000 af/yr of pumping would be important if the pumping was localized in a specific area, this same amount distributed over the entire NMMA would not impact calibration or hydraulic conductivity in any significant way. Even though incorporating this information would help make the model more complete by capturing all fluxes, it is unlikely that it would improve or deteriorate the calibration.

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No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
49 (cont)	NMMA TG	2.8.3	21	For comparison, the combined rural and golf course pumping in 2017 of roughly 1,600 af is essentially equivalent to the net amount of groundwater that reportedly flowed into the ocean or seafloor aquifers adjacent to the NCMA, as output by the model and summarized in Table 1 of the TM. These comparisons suggest that unaccounted-for groundwater pumping from rural and golf course wells, while likely small compared to say the error associated with estimated amounts of agricultural pumping in the model domain, may be important and introduce significant uncertainly in certain water balance components. Please consider during additional model calibration efforts. It is also worth noting that like municipal returns flows listed in Tables 1, 2, and 3, inclusion of rural pumping during the model calibration process could be accompanied by return flows from rural pumping. Please consider during additional model calibration efforts.	See response above
50	NMMA TG	2.8.3	21	A critical analysis of the model calibration process and results, which is important to subsequent calibration efforts and future model users, seems to be limited to the last two paragraphs of this section. For a groundwater model of this size and complexity, a lengthier discussion is warranted. For example, differences in stream flow calibration efforts between the current version of the model and the version described in the May 11, 2018 TM, are alluded to in Section 2.8.4, but warrant further documentation. Documentation of these calibration updates would be helpful as a guide to improvements in the model during future calibration efforts. While the TM duly notes where certain water budget components are assumed to be negligible (see Sections 2.7.1.5, 2.7.1.9, and 2.8.3), there are other water budget components that were apparently neglected and not simulated (i.e., septic system return flows and agricultural pumping for non-crop or non-orchard uses), even though information pertaining to these components was provided by GSWC for portions of the NMMA and these components might be larger than some of those accounted for in Tables 1, 2 and 3 in the TM. For example, model layer hydraulic conductivities might need to be unjustifiably lowered during the calibration process to match simulated groundwater elevations with actual groundwater elevations that are lower due to the unaccounted-for pumping. But, the influence of such decisions on the calibrated model, particularly at the sub-management area scale, where recharge projects are planned, is not described. The eventual removal of the Nipomo Valley fringe area from the active model domain during the calibration process should be documented, given that the Santa Maria River Valley Groundwater Basin, Basin Boundary Modification Request Technical Report (Final Draft), dated May 30, 2018, which was prepared for San Luis Obispo County, suggests that the amount of groundwater applied to irrigate crops in the Nipomo Valley fringe area, adjoining the eastern boundary of the NMMA, is significant, at about 4,000 acre-feet/year.	The model calibration discussion was augmented with these recommendations.

Comments Received and GEOSCIENCE Responses for Draft TM No. 3: Model Calibration

No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
50 (cont)	NMMA TG	2.8.3	21	It is also worth noting that both versions of the TM (i.e., the May 11, 2018 and current version) state that the model was successfully calibrated. While this claim is the ultimate goal of this phase of the model, the fact that two noticeably different versions of the model are reportedly calibrated highlights the fact that neither model may present a non-unique solution to the actual conditions found throughout the model domain. In other words, there remains some uncertainty regarding the model's ability to represent and replicate actual conditions and observations. Based in part on these examples, please consider expanding the discussion and critical analysis of the model calibration results.	See response above.
51	NMMA TG	2.8.3	21	The model water balance shows no golf course pumping (Figure 52), which is contrary to production records.	See response to NMMA-TG comment 25
52	NMMA TG	2.8.3	21	Separate the Municipal and Golf Course Pumping in the Water Balance table. Provide table in excel format.	See response to NMMA-TG comment 25
53	NMMA TG	2.8.5	21	The main purpose of the solute transport model was to determine whether seawater intrusion might occur along the coastline under different scenarios. However, as the modelers acknowledged, not much is known about the hydrogeology in the offshore area of the aquifers to determine potential travel paths of any seawater intrusion. Without knowing travel paths, the model cannot be accurately constructed to simulate the movement of seawater. As suggested by the modelers, the model may not be able to accurately predict whether seawater intrusion may occur except by examining groundwater gradients near the coastline.	Comment noted.

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No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
54	NMMA TG	2.9	24	The conclusion that a 20 percent reduction in agricultural pumping does not have a great impact on the calibrated model is unfortunately not meaningful for a few reasons, including the fact that it does not necessarily reveal whether or not the model adequately represents the observed conditions, including hydraulic properties and the locations of pumping, both horizontally and vertically. In particular, assuming that this conclusion is based on a review of bulk calibration statistics, it should be noted that roughly about 75 percent of the model's simulated average annual agricultural pumping of 31,272 af/year occurs in the SMVMA portion of the model domain (Figure 33), suggesting that the largest impacts to changes in the amount of simulated agricultural pumping should be observed there. In addition, only about roughly 13 percent of the model's calibration targets occur in the SMVMA (Figure 41), including several targets where groundwater elevations are likely to be influenced primarily by boundary conditions more than other recharge or discharge components. This means that there are groundwater elevation data from only a handful of wells that could influence the bulk calibration statistics (6,065 groundwater elevations from 119 wells, see Figure 42) in the portion of the model domain with by far the greatest amount of agricultural pumping. This may likely explain why the bulk calibration statistics might not reflect such a significant reduction in agricultural pumping. In addition, a cursory review suggests that the model simulates agricultural pumping in the SMVMA portion of the model domain using roughly 7 times more wells than may exist (see attached figure with well locations – figure 8 of 13) and does so using MODFLOW's Well Package rather than the Multi-Node Well (MNW) Package, which might be expected for agricultural pumping wells. Moreover, the model appears to simulate agricultural pumping over about 5 percent of the SMVMA for roughly one half of the calibration period, where no water use and pumping actually occurred (see attached figures 9-12 of 13). These deficiencies in the model should be remedied during additional calibration efforts.	GEOSCIENCE respectfully disagrees, because the applied reduction is relative. In the NCMA and NMMA, where more calibration targets are available, agricultural pumping is a significant portion of the water budget. Regardless of what happens in the SMVMA, if the model were sensitive to agricultural pumping, a reduction of 20% would alter water levels in these areas which have a lot of monitoring wells - therefore having a significant impact on calibration. According to the USGS (Central Valley modeling report), error attached to agricultural pumping estimates can be as high as 20%, so 5% is within the expected margin of error.
55	NMMA TG	Fig 3	-	The somewhat homogeneous hydraulic conductivity depicted on layer 7 (see Figure 16) suggests that it is an aquitard, in contrast to layer 8, which appears to look more like an aquifer, with more variable hydraulic conductivity (see Figure 16). Please reconcile/clarify here and on Figures 16-19. Figure 10 depicts layer 8 as an aquitard, which is not consistent with the inset here showing wells assigned to layer 8. On the other hand, layer 7 is here is not assigned wells, which suggests that it is an aquitard. Please reconcile/clarify.	The aquifers in the area exhibit tremedous variability. Aquitards are not continuous across the whole model domain. Even though these layers were labeled aquitard for conceptual reasons, they can exhibit high hydraulic conductivity in some localized areas. Wells screened in multiple aquifers are sometime screened in thin aquitards or an aquitard with higher than average hydraulic conductivity.
56	NMMA TG	Fig 10	-	Figure 14 suggests that there is a 10th layer of finite thickness in the model. However, this layer is not shown here, or on Figures 11 or 12. Please reconcile. See comments on Figure 3 and revise labels if necessary.	The figure was not updated to reflect ongoing editing and adjustments in response to comments from the TAC. The updated TM3 shows the actual nine layers. The 10th layer is a virtual 1-ft thick layer used to represent the contact with the ocean and is set to inactive inland (layer 1).
57	NMMA TG	Fig 12	-	Please move label for Bottom of Recent Alluvium/ Young and Old Dune Sand down on page so that it is right above the bottom of layer 2. Please move the solid black line from bottom of 7 to the bottom of layer 6 if appropriate. Please move label for Bottom of Paso Robles Formation up on page so that it is right below the bottom of layer 6, if appropriate.	Figure was revised.

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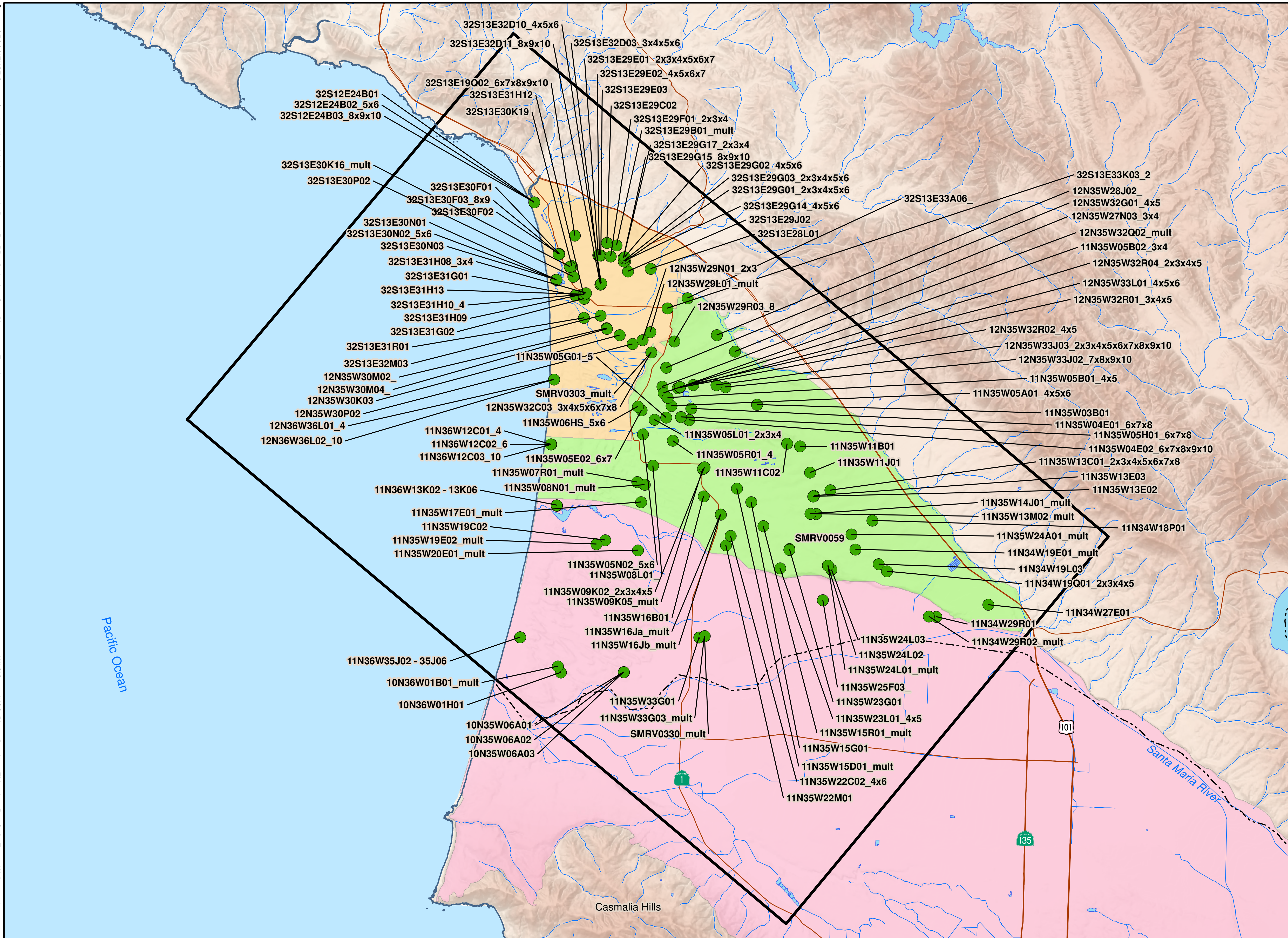
No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
58	NMMA TG	Fig 60	-	What are the maximum and minimum possible values for normalized sensitivity? Please clarify and possibly include such an explanation as a footnote to the table. Please consider adding the appropriate equation to this figure so that the reader knows how the sensitivity is calculated. Specific Yield x 0.5 may be missing. Please clarify.	Figure was revised.
59	NMMA TG	2.9	24	This figure is an attempt to depict the actual location of wells (roughly 130, in yellow) versus the simulated location of wells (roughly 950, or 7x the actual number, in red) in the Santa Maria Valley, south of the Nipomo Mesa and north of the Santa Maria River. The actual well locations, some of which are preliminary in nature, may include roughly 90 percent of historical wells, and were derived from review of Google Earth images, USGS topographic maps, and maps available in reports possessed by the modeling team (e.g., Worts, 1951; Cleath and Associates, 1996; LSCE, 2000; and LSCE, 2017). This review took about 16 hours. Crops were planted and irrigated in this area, which represents roughly 5 percent of the SMVMA portion of the model domain, sometime between 1994 and 2003 (see subsequent pages). This suggests there was no water use or return flow in this area from 1976 to at least 1994 (i.e., almost 50 percent or more of the model calibration period), and possibly no groundwater pumping there during the same time period.	This is included in the uncertainty associated with agricultural pumping estimates, as discussed in the revised TM 3.
1	TAC Meeting	-	-	Add contour map from DWR 2002 to TM3 to illustrate the effect of the SMR faults.	We believe this figure would better belong in one of the previous TMs that discuss the development of the hydrogeological conceptual model (TM1) or calibration plan (TM2). This figure can be incorporated in the final report.

APPENDIX B

Supplemental Calibration Hydrographs



EXPLANATION

CCB Phase 1B Model Boundary

Transient Calibration Target Well

Management Areas

Nipomo Mesa

Northern Cities

Santa Maria Valley

County Boundary

Note:
1). "_multi" indicates that the well is screened in more than one layer, and may be representative of a combined water level.
2). Numbers following well names indicate specific layer(s) that the well is screened in, if known.

N

0 2 4
Miles

GROUNDWATER FLOW MODEL CALIBRATION TARGET WELLS - TRANSIENT CALIBRATION

W:\GIS_proj\WSC_Pismo_Beach\41_TM-3_App_B-1_Calib_Target_Wells_transient_5-19.mxd

14-May-19

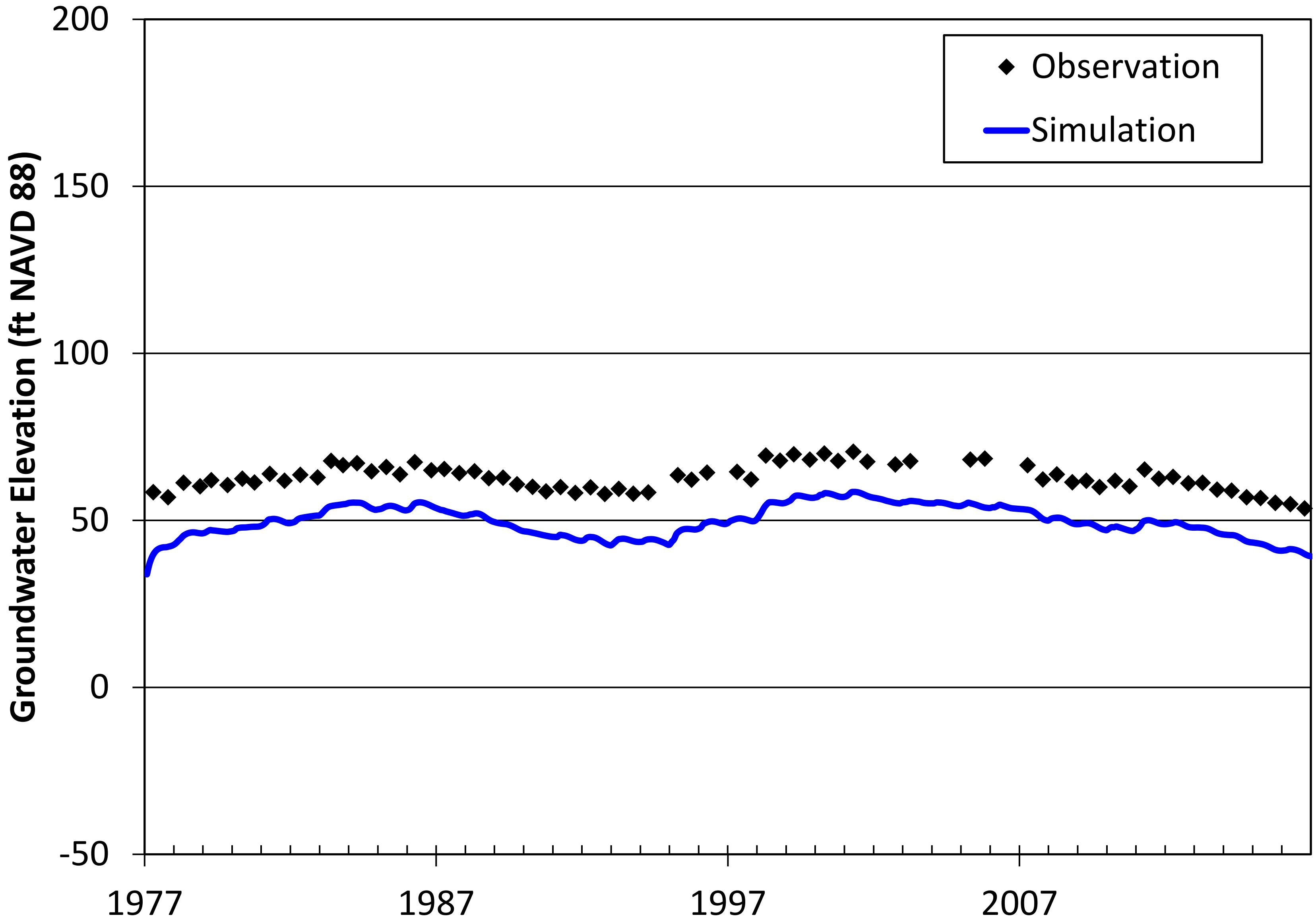
WATER SYSTEMS CONSULTING, INC.

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 3: MODEL CALIBRATION

FIGURE B-1

GEOSCIENCE

10N35W06A01



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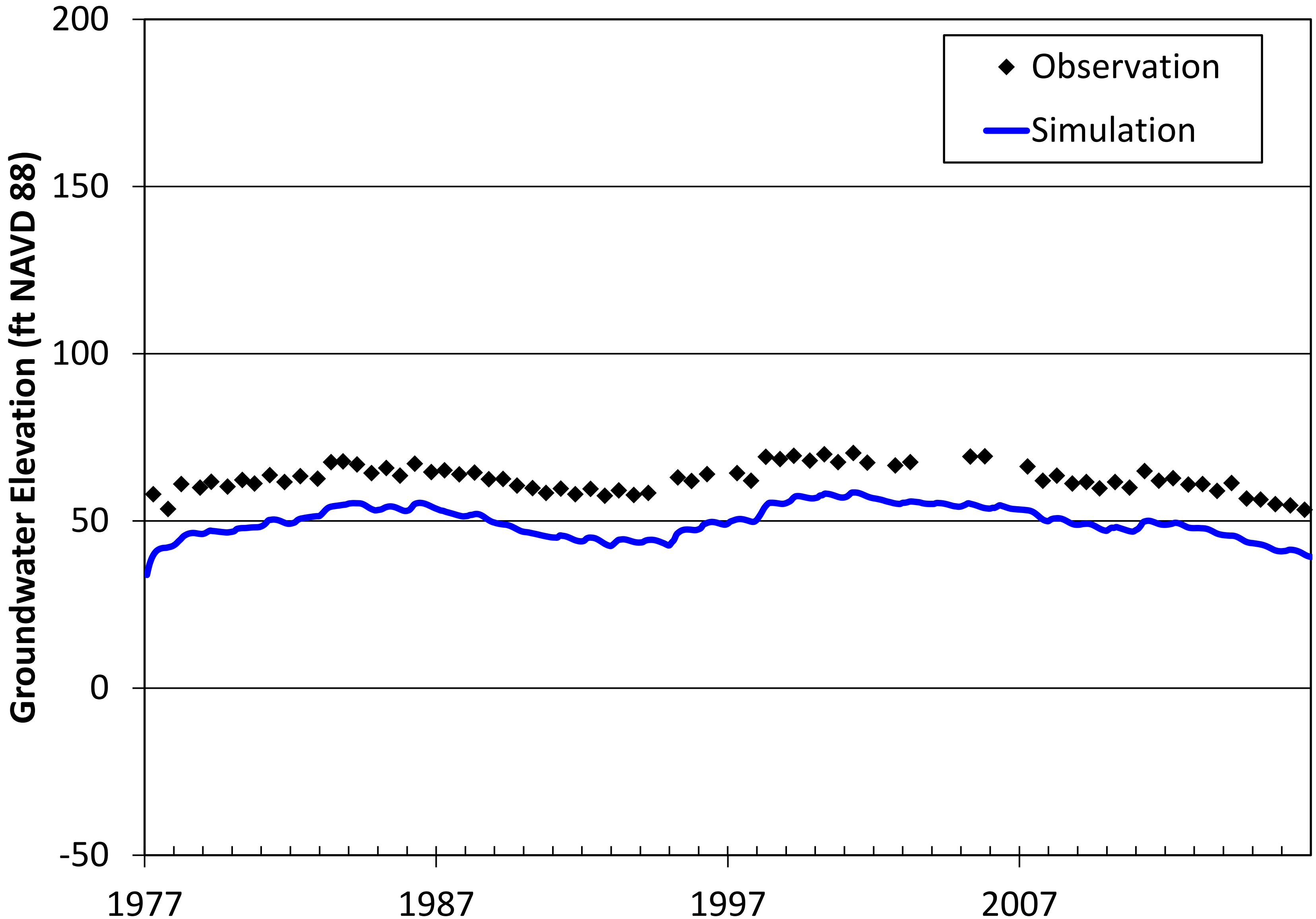

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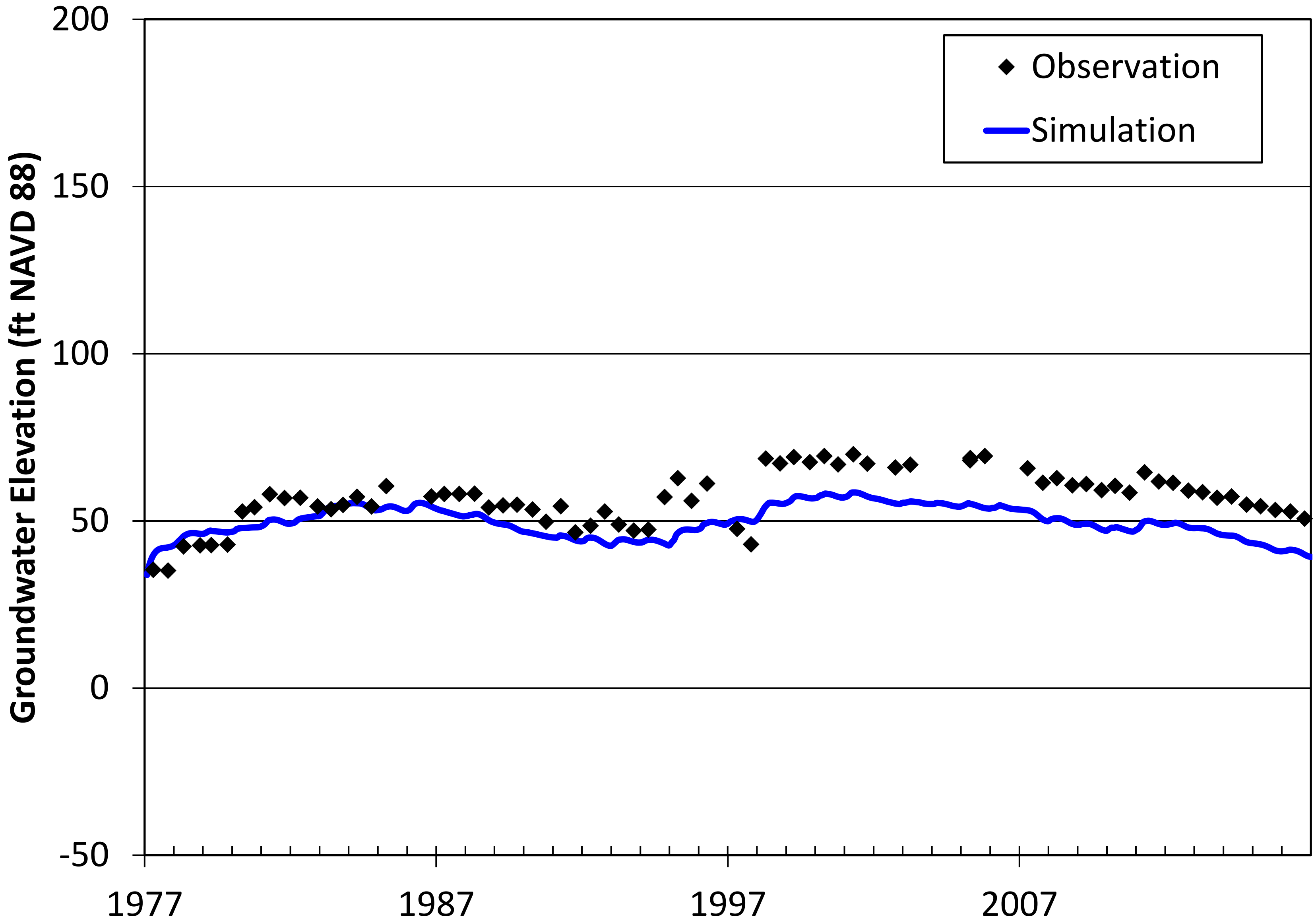

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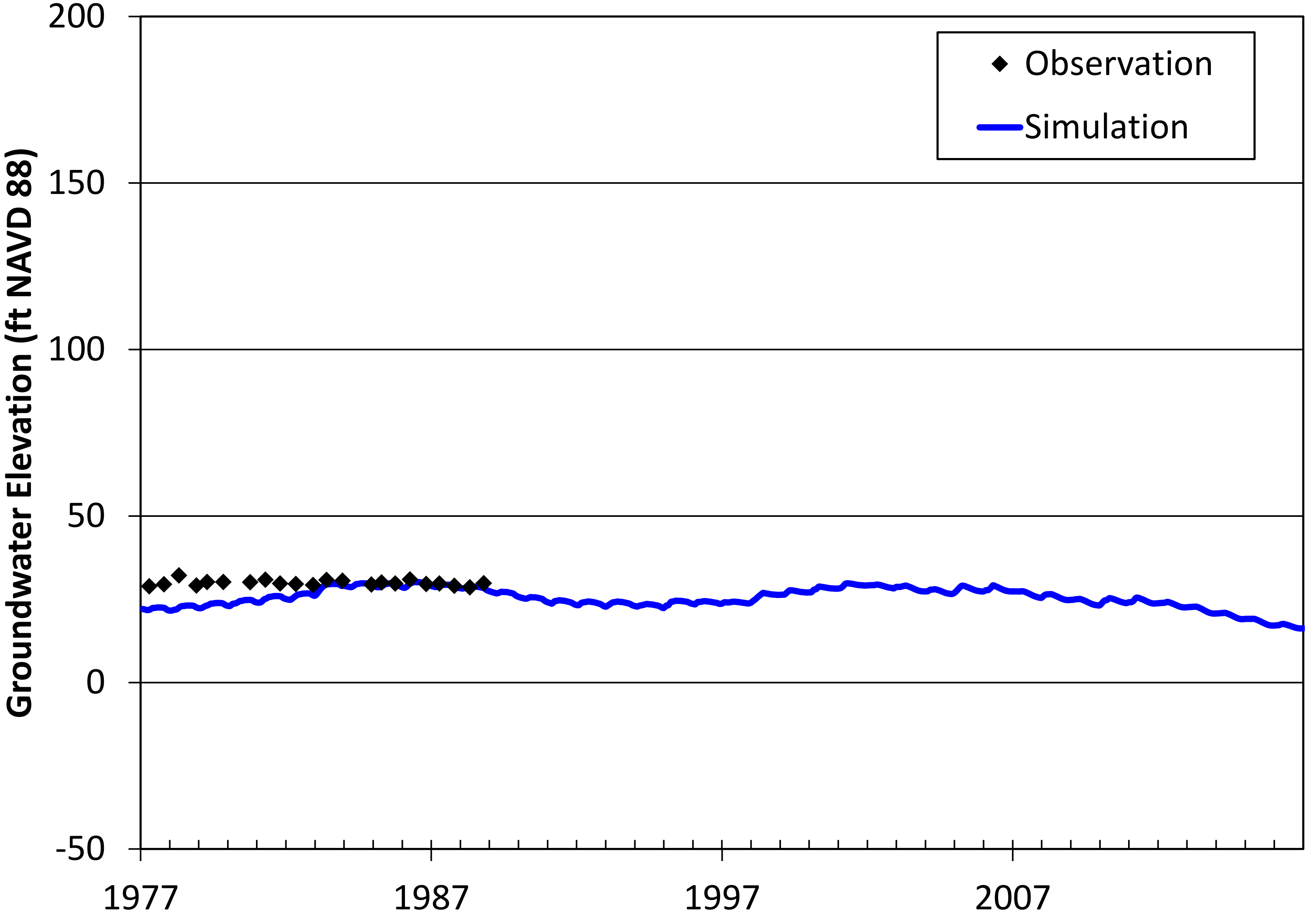
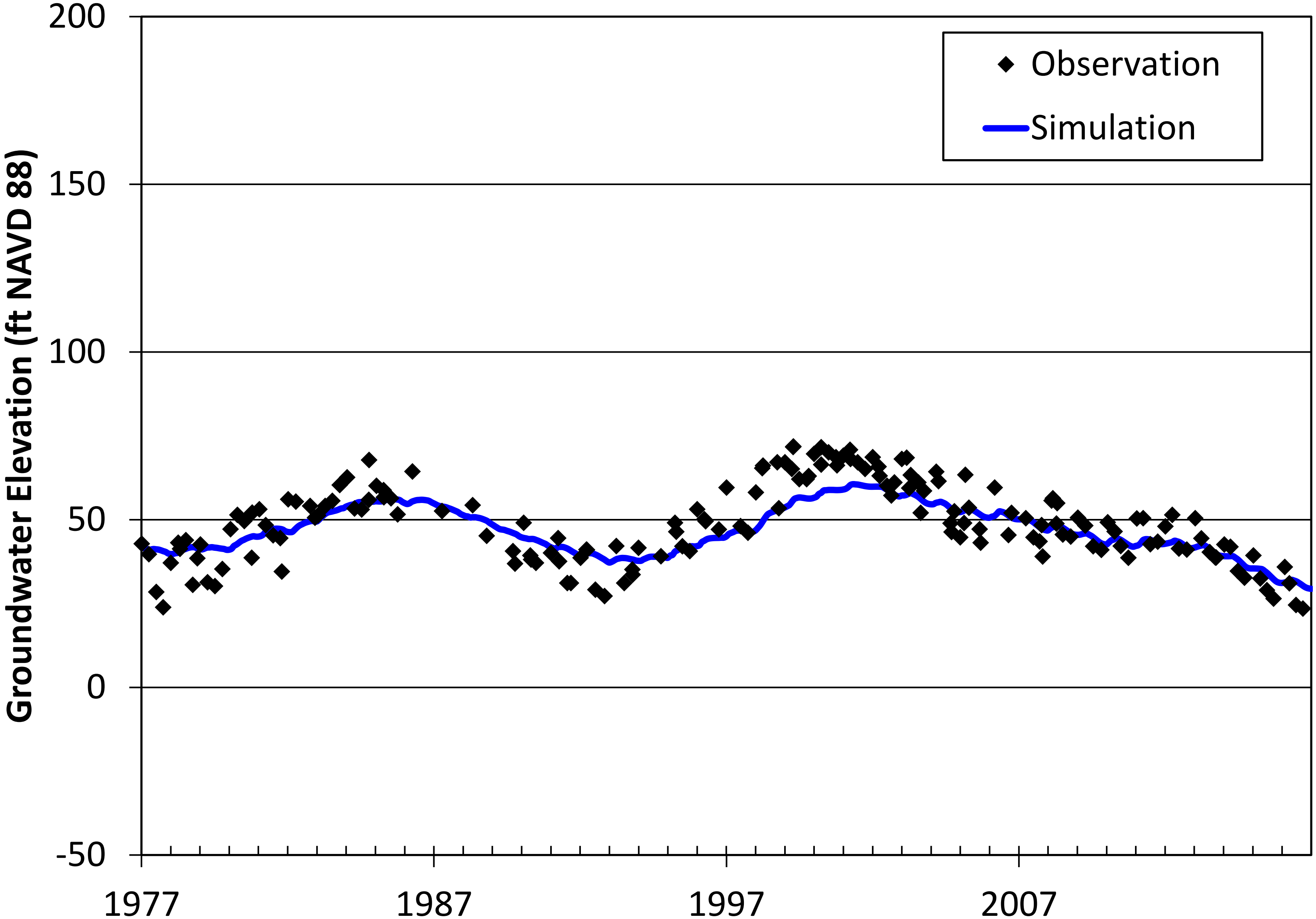
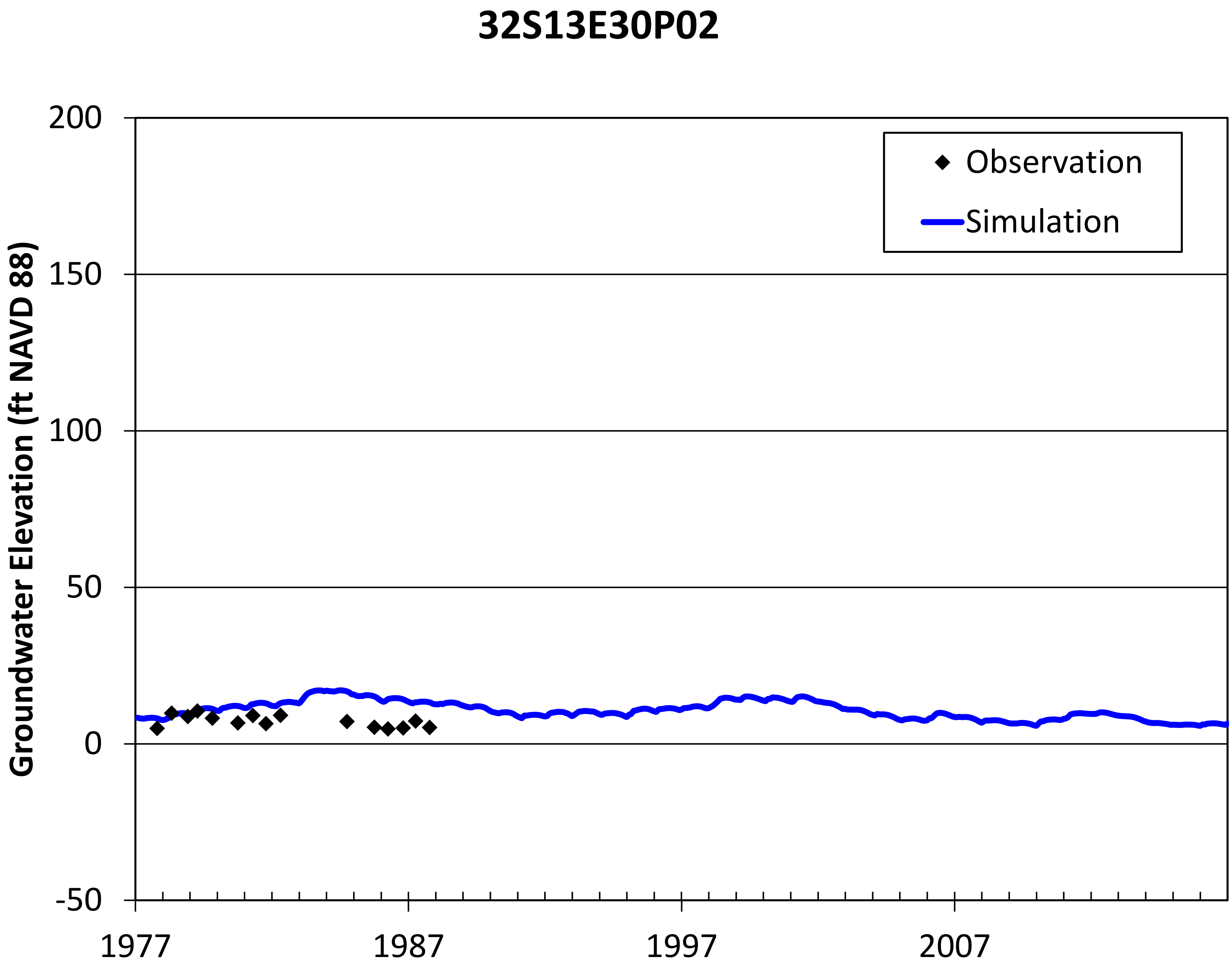
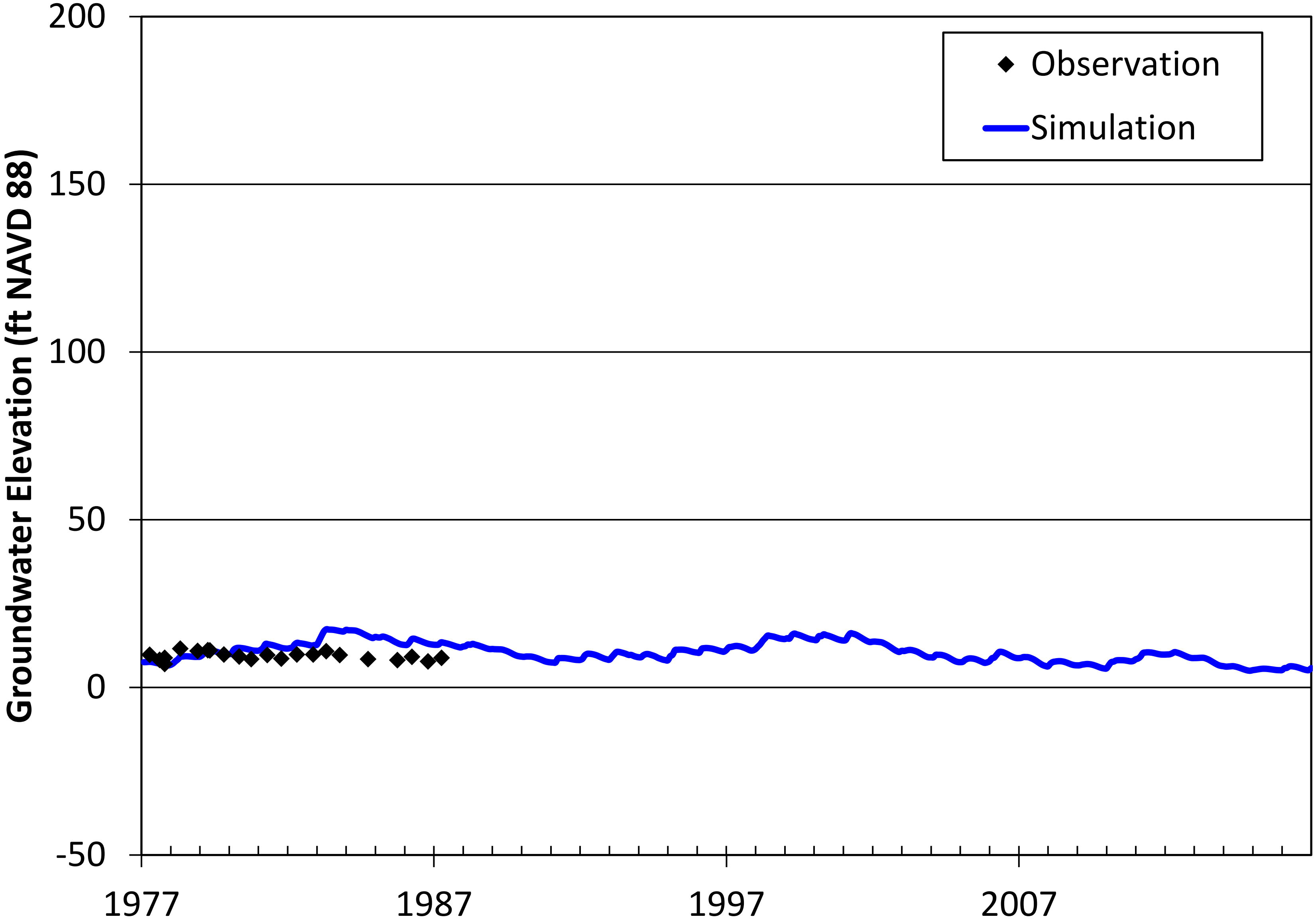


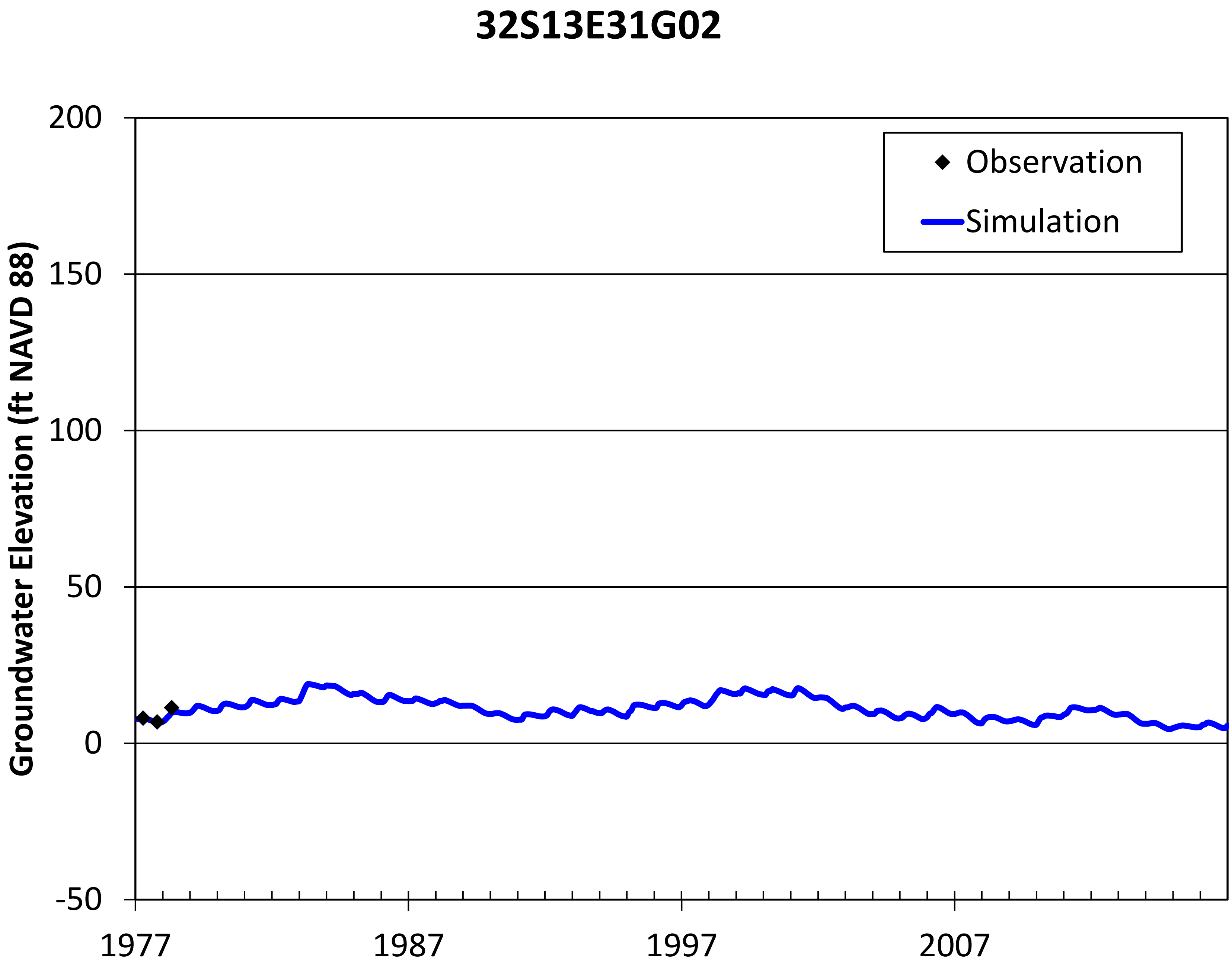
11N35W33G01




32S13E30P02
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007
Observation
Simulation

32S13E31G01




32S13E31G02
Groundwater Elevation (ft NAVD 88)
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150
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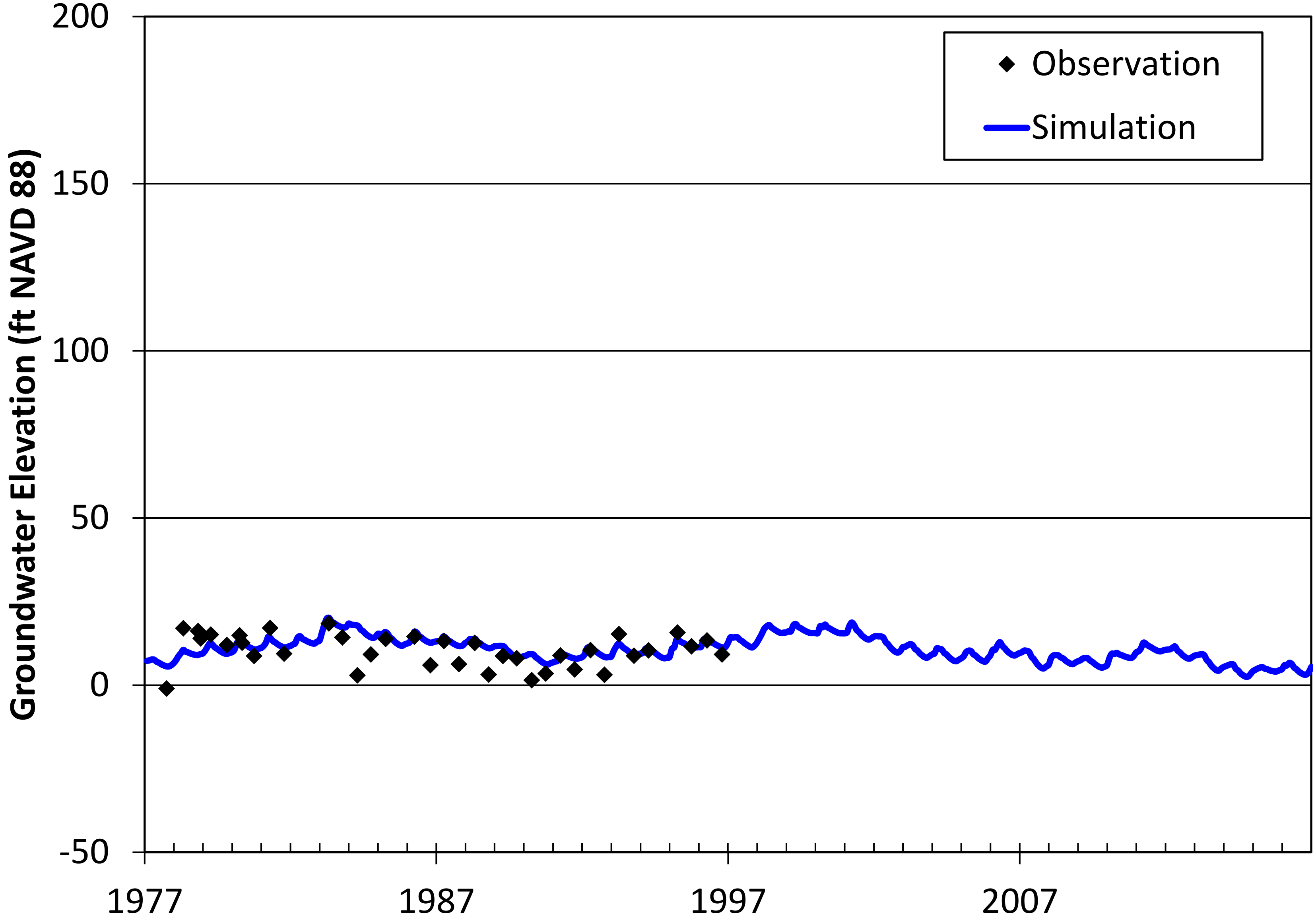
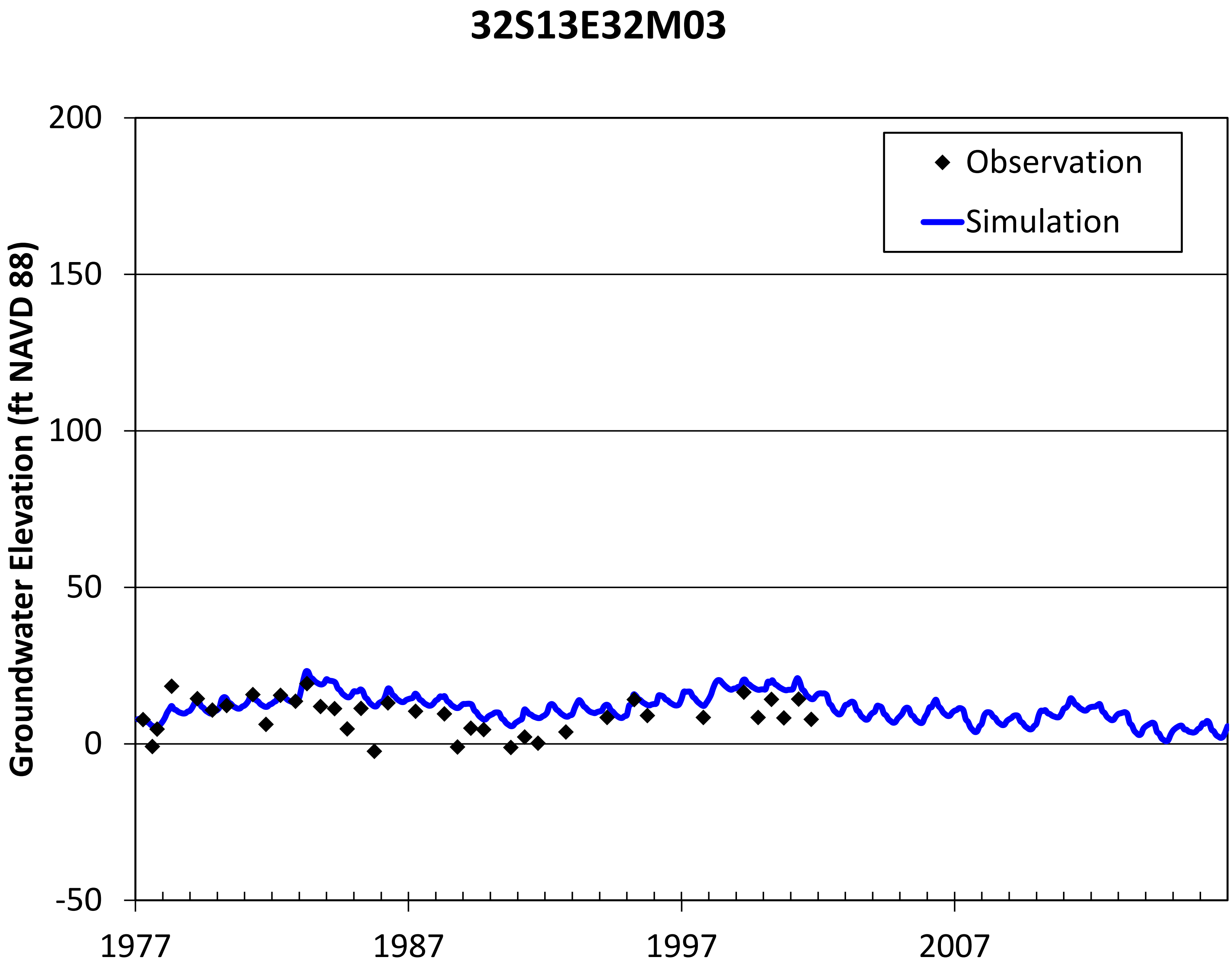
50
0
-50
1977
1987
1997
2007
Observation
Simulation

32S13E31R01




32S13E32M03
Groundwater Elevation (ft NAVD 88)
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150
100
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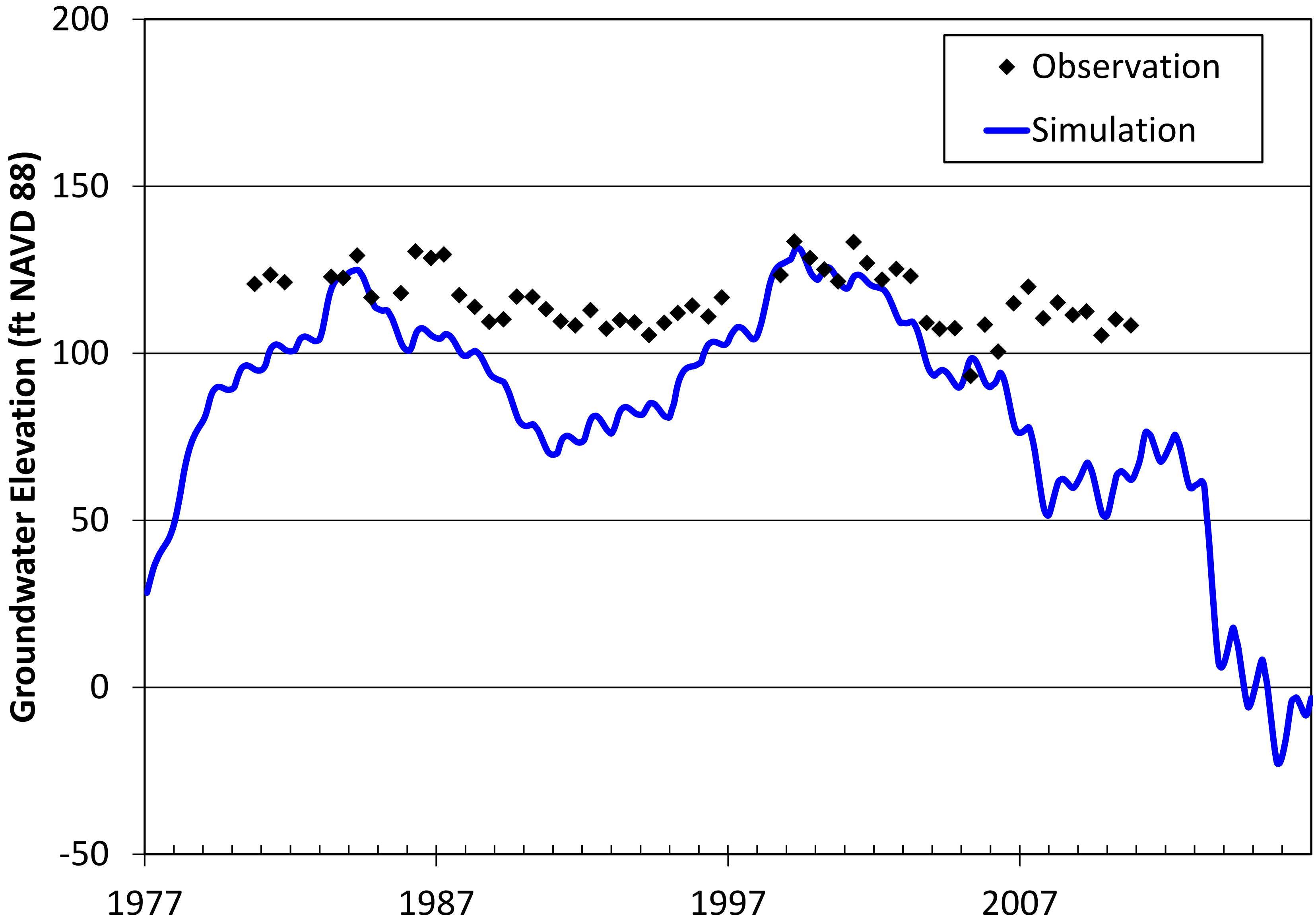
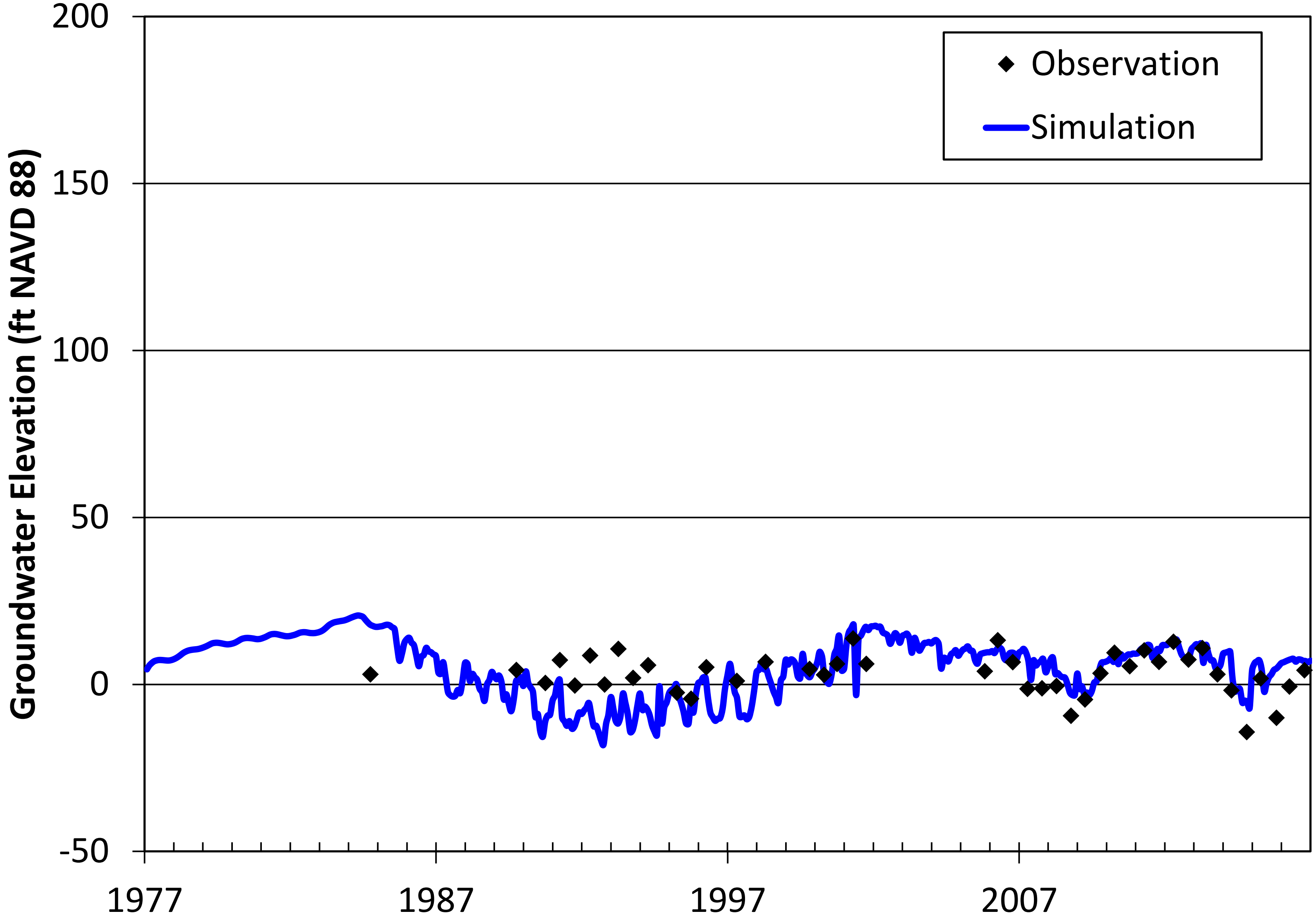
0
-50
1977
1987
1997
2007
Observation
Simulation

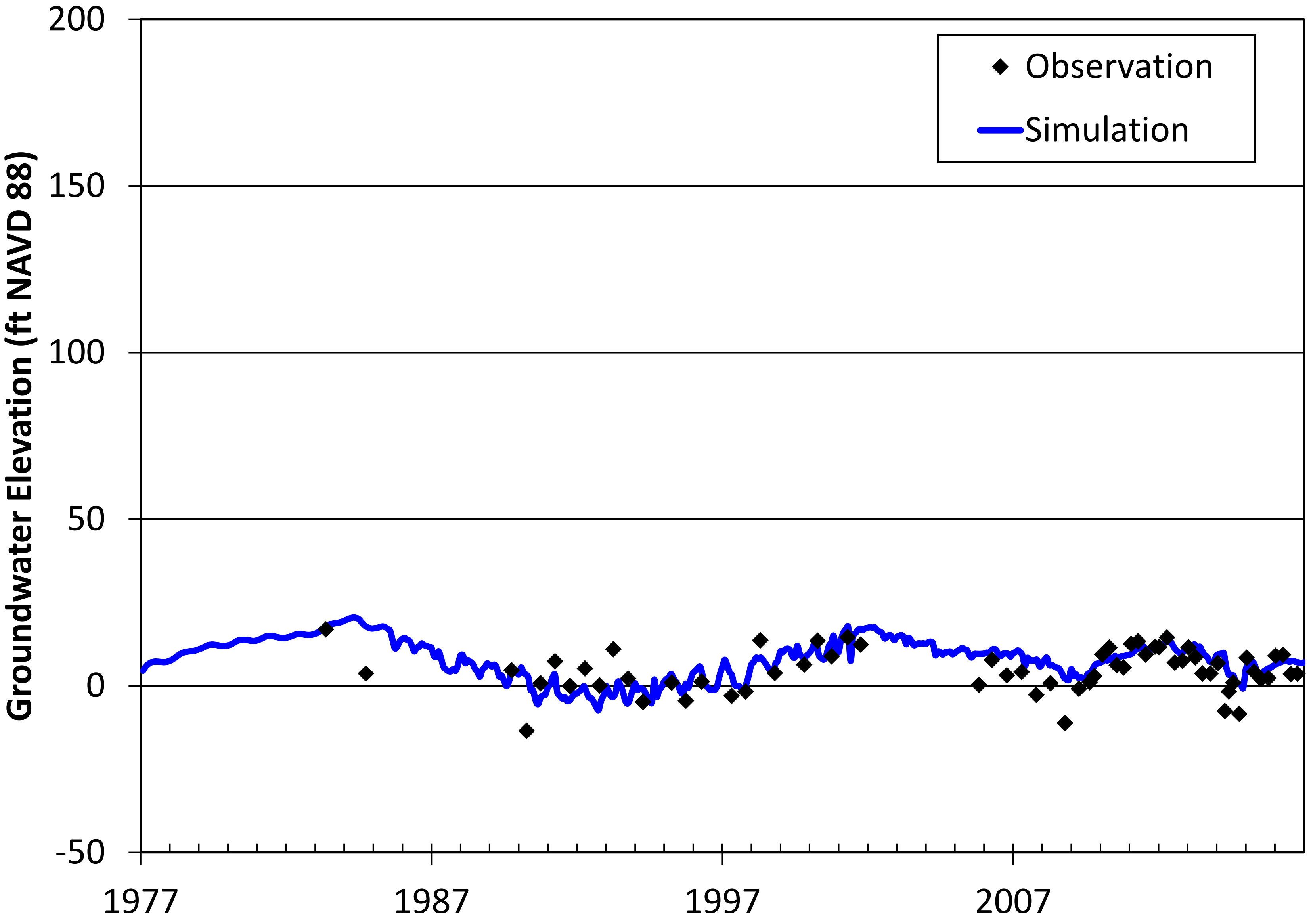
11N34W27E01



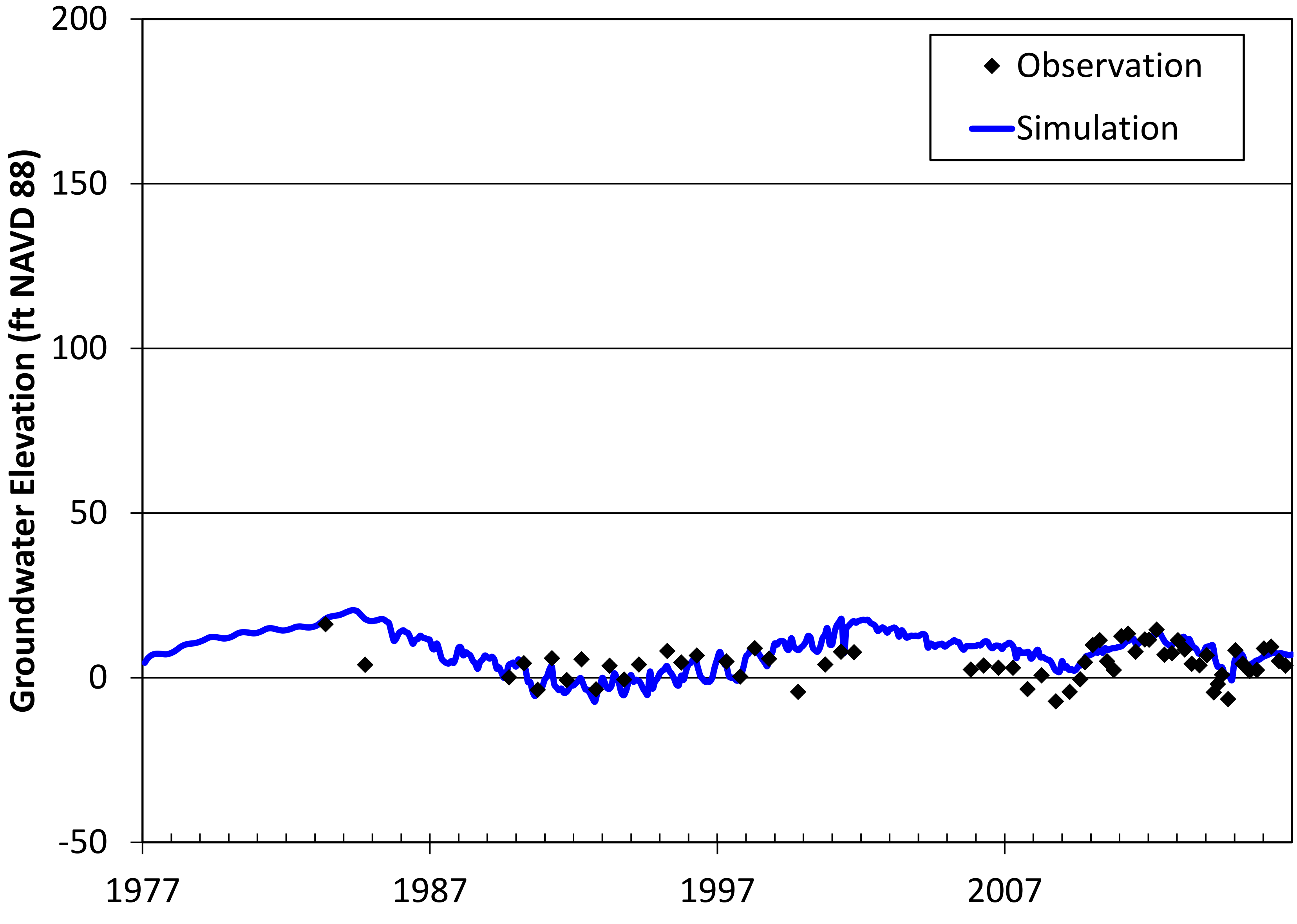
32S13E31H09



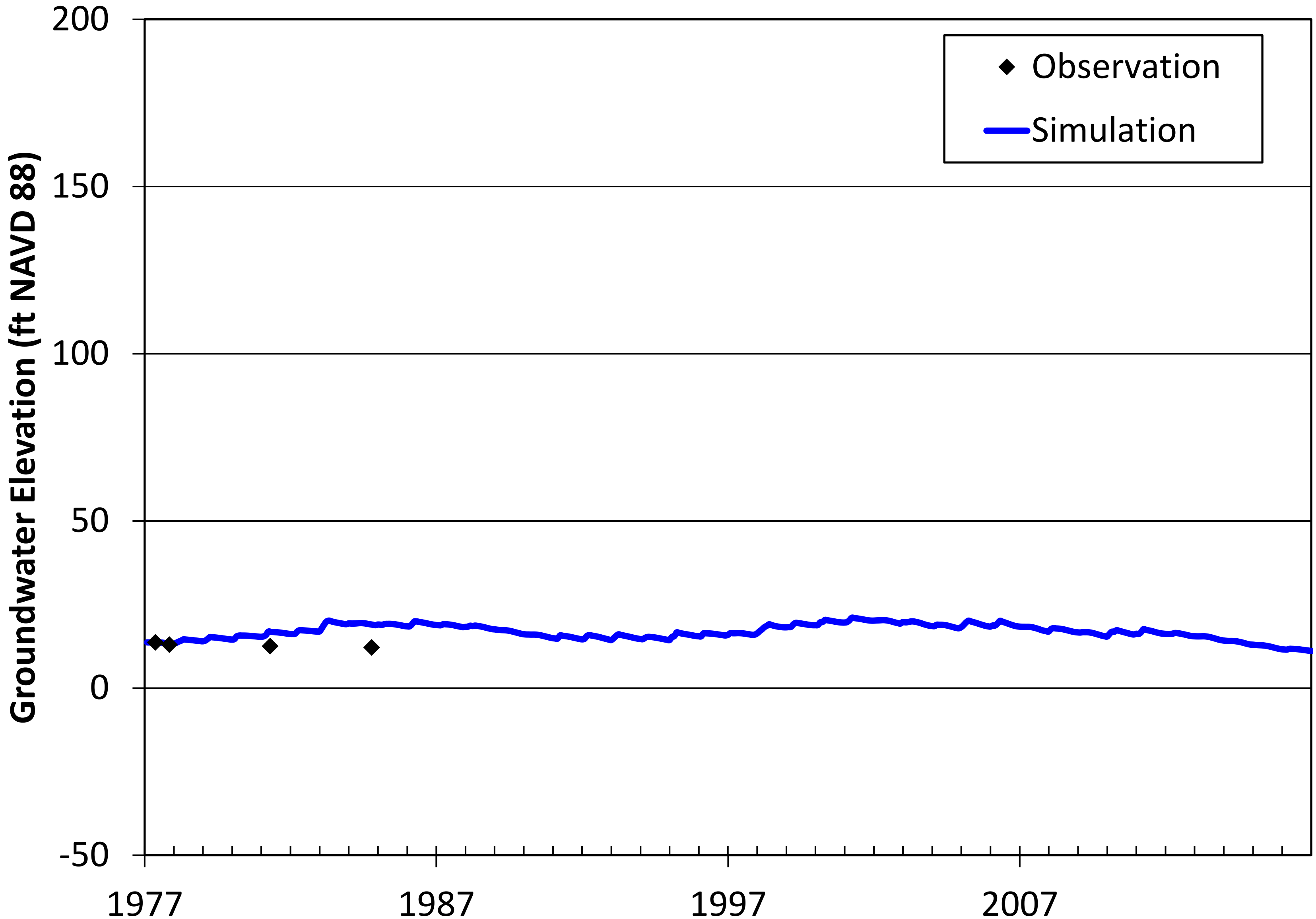
32S13E31H12



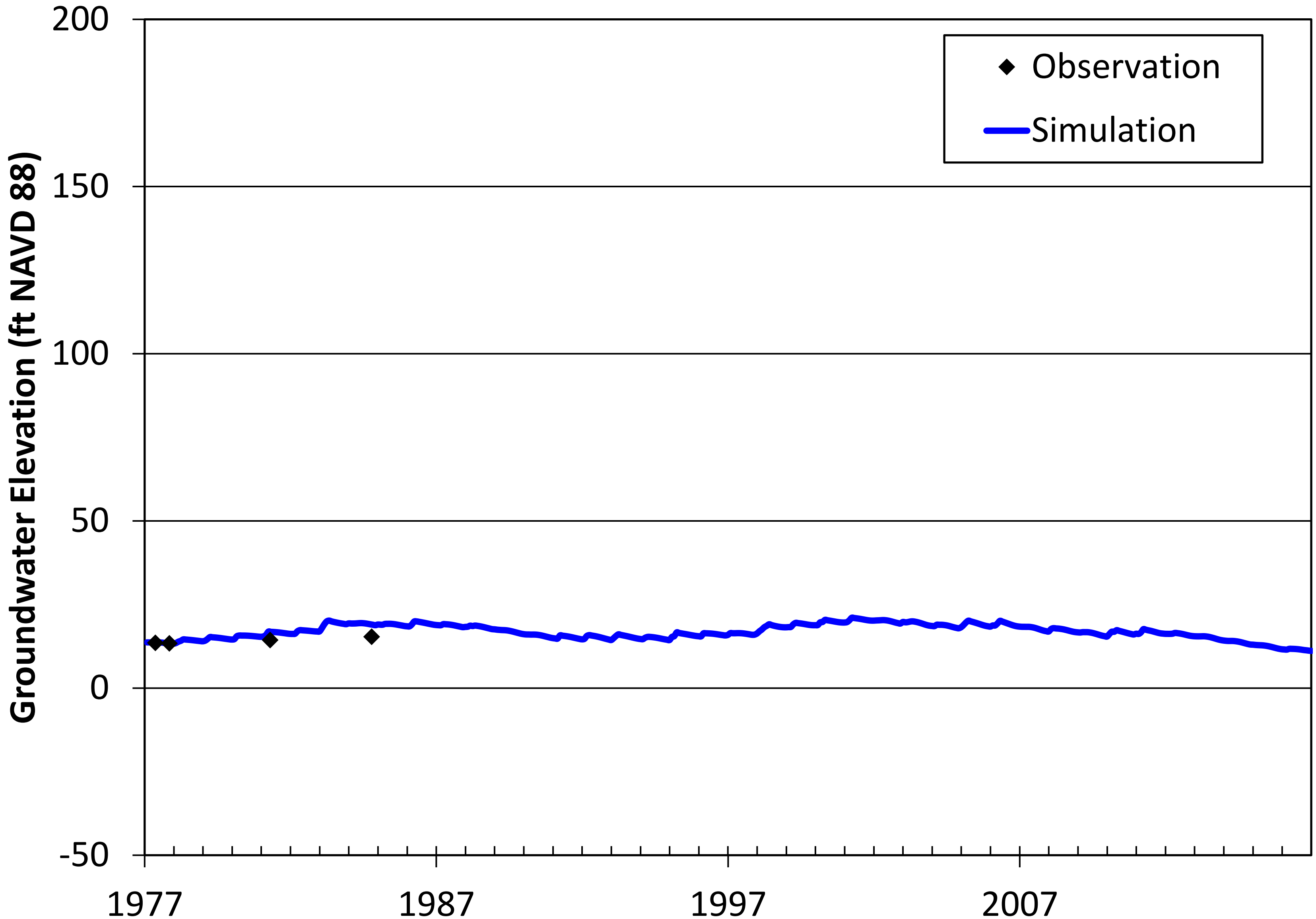
32S13E31H13



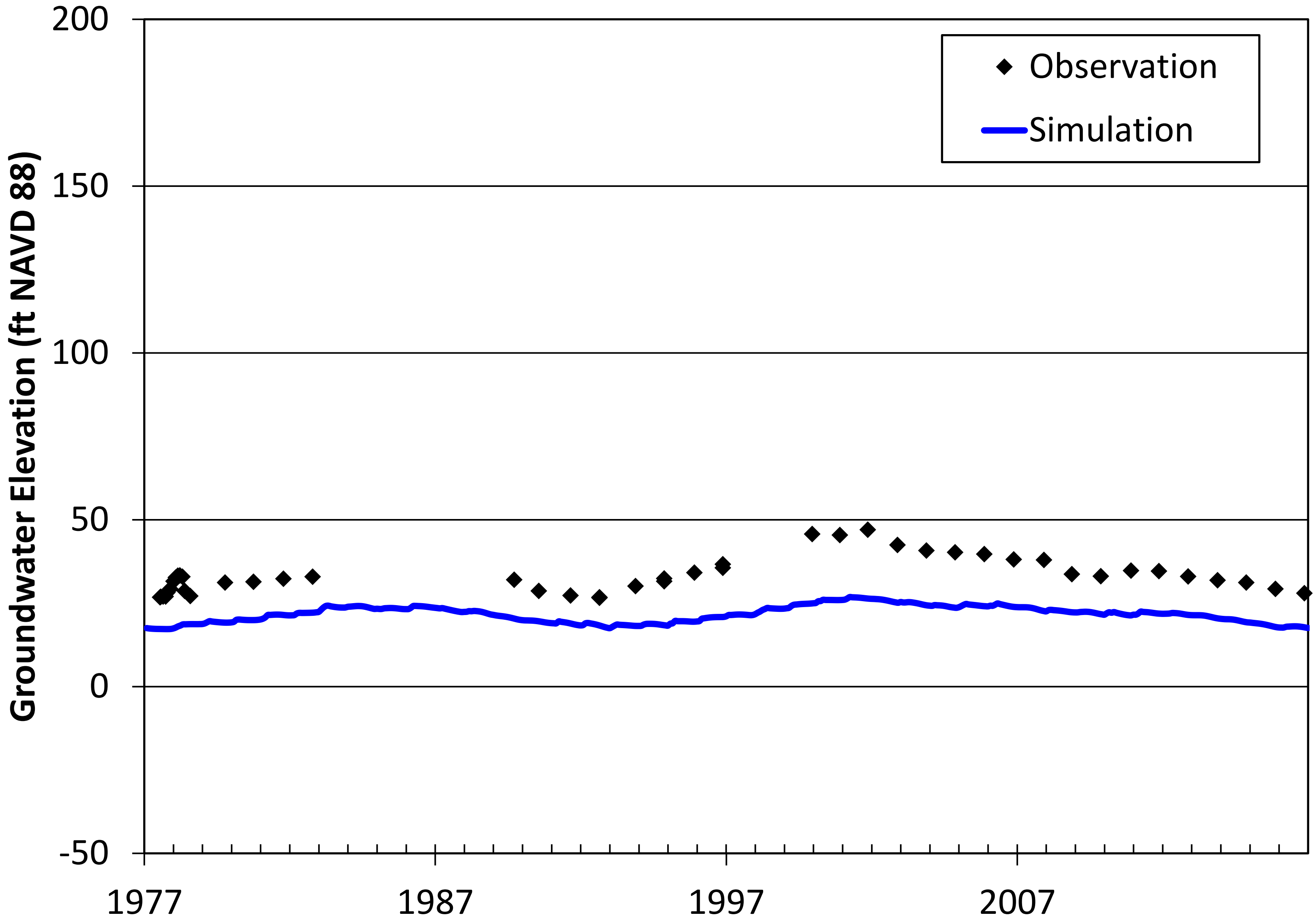
11N36W13K02



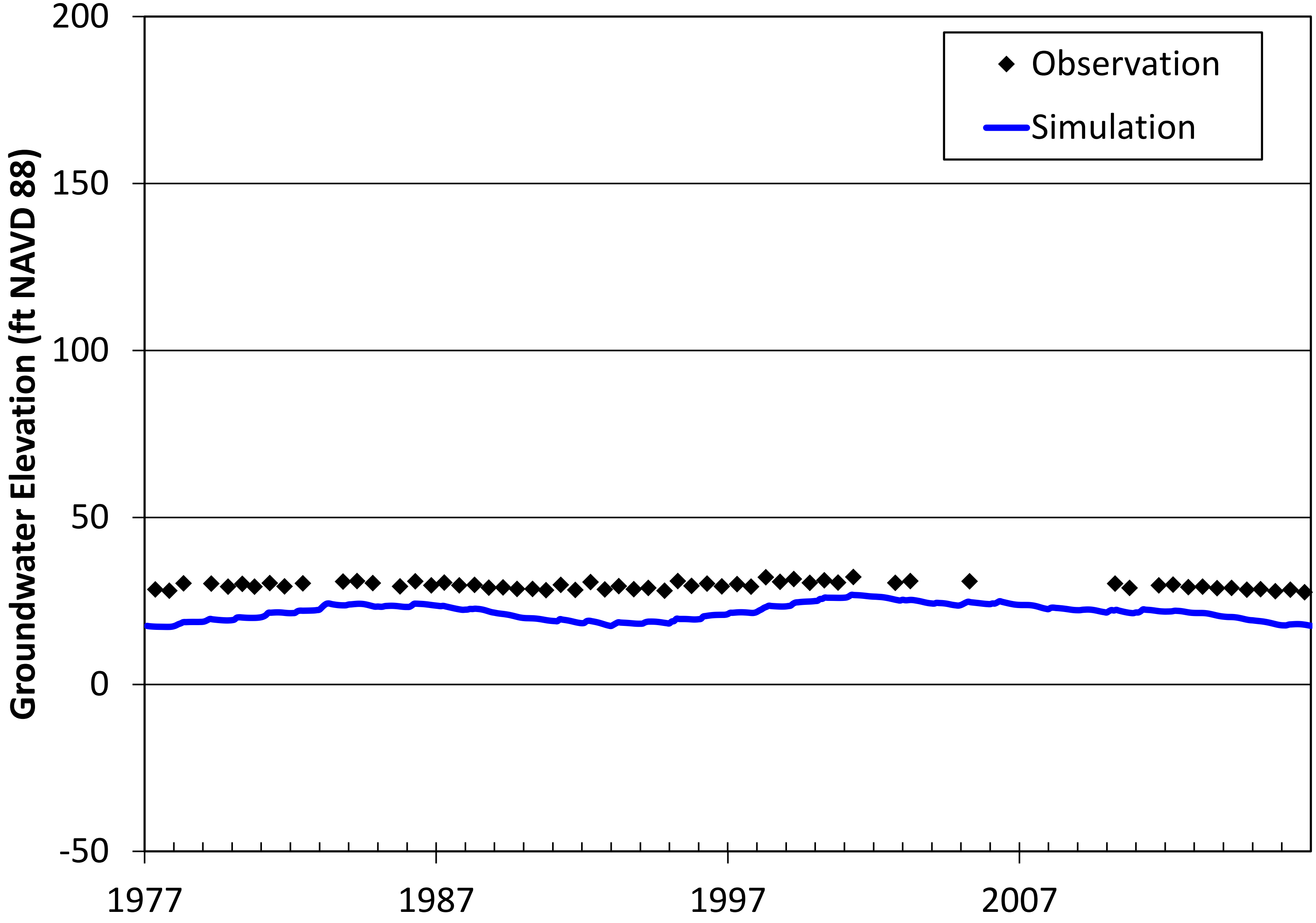
11N36W13K03



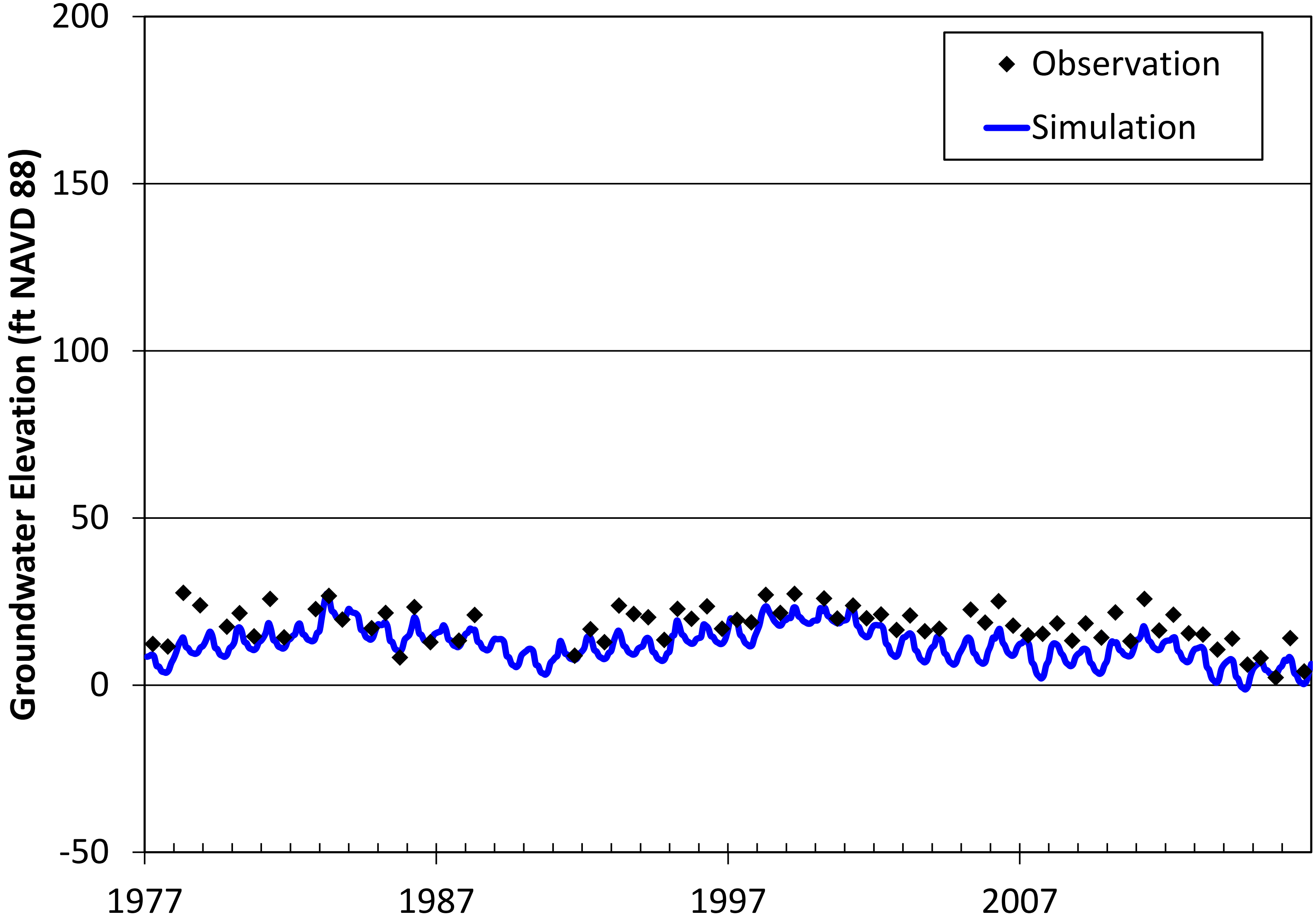
11N36W35J05



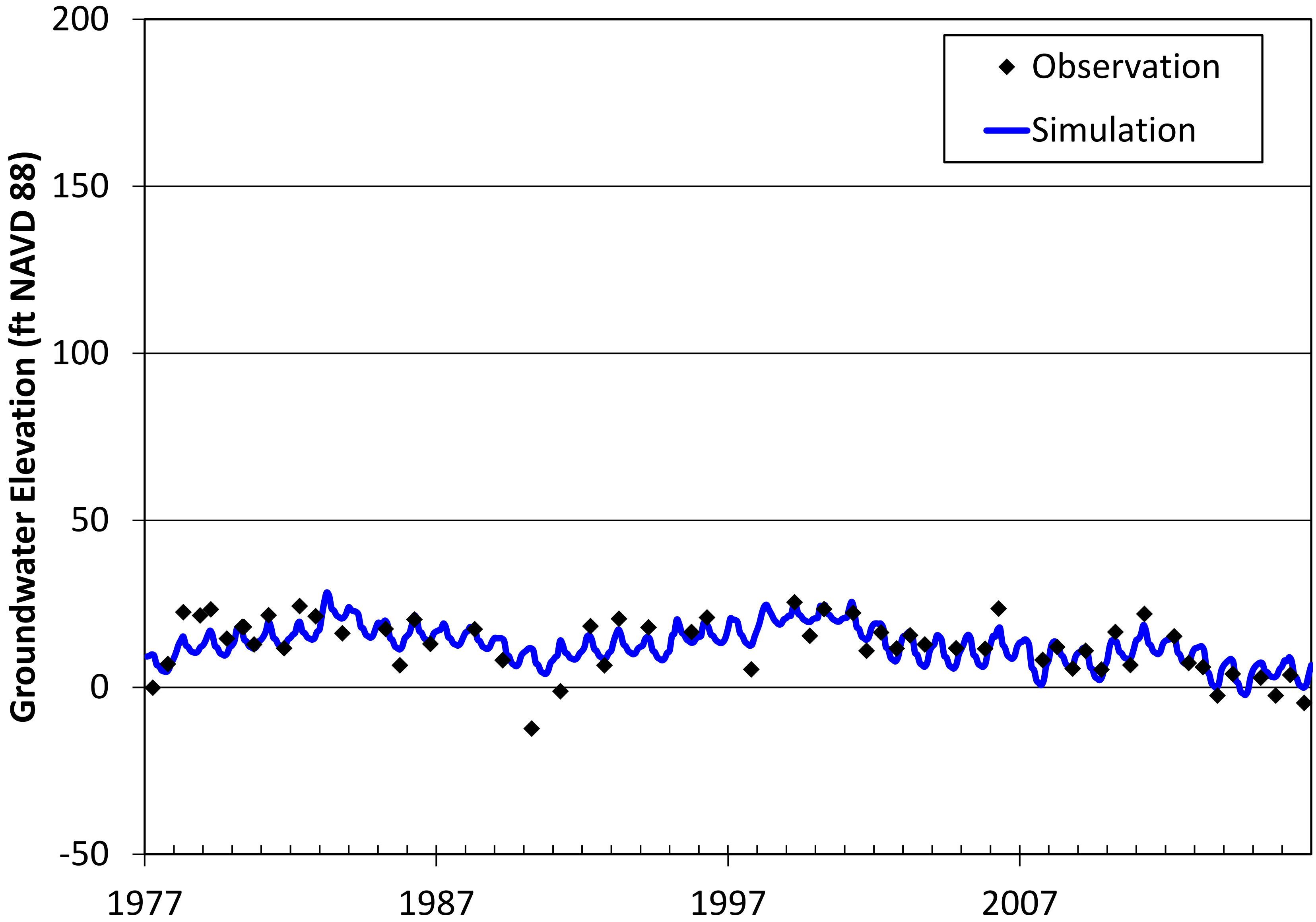
11N36W35J06



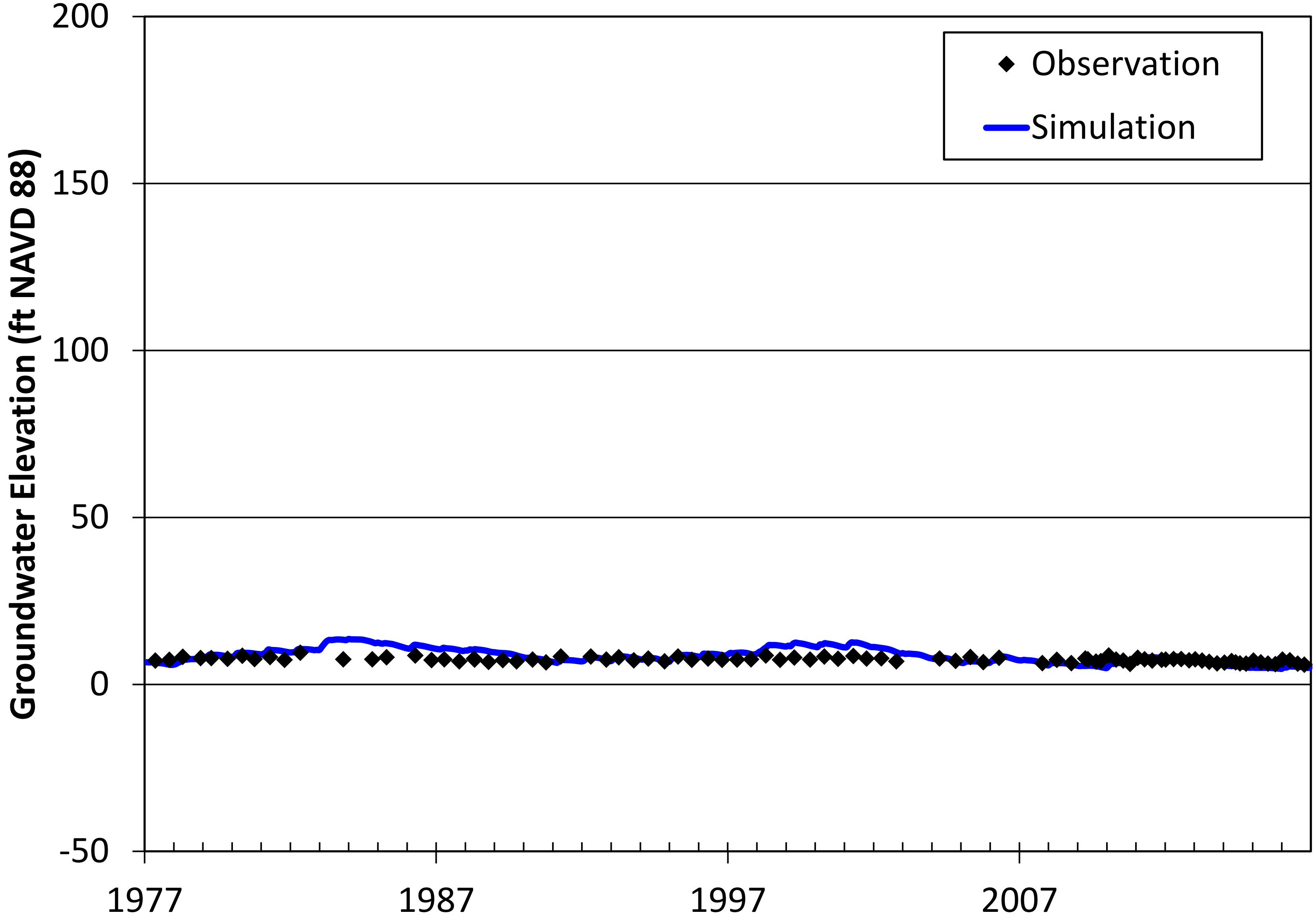
12N35W30K03



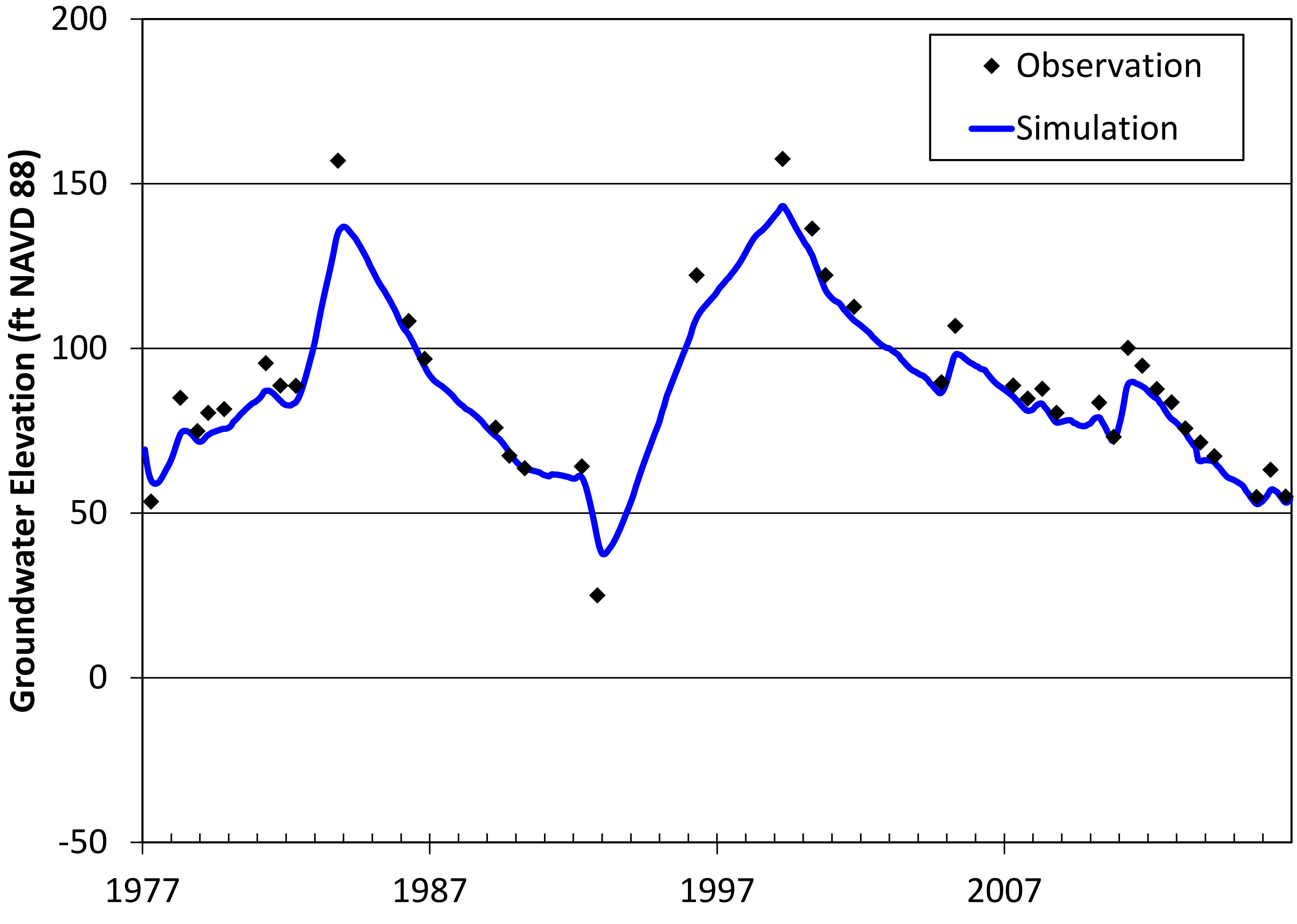
12N35W30P02



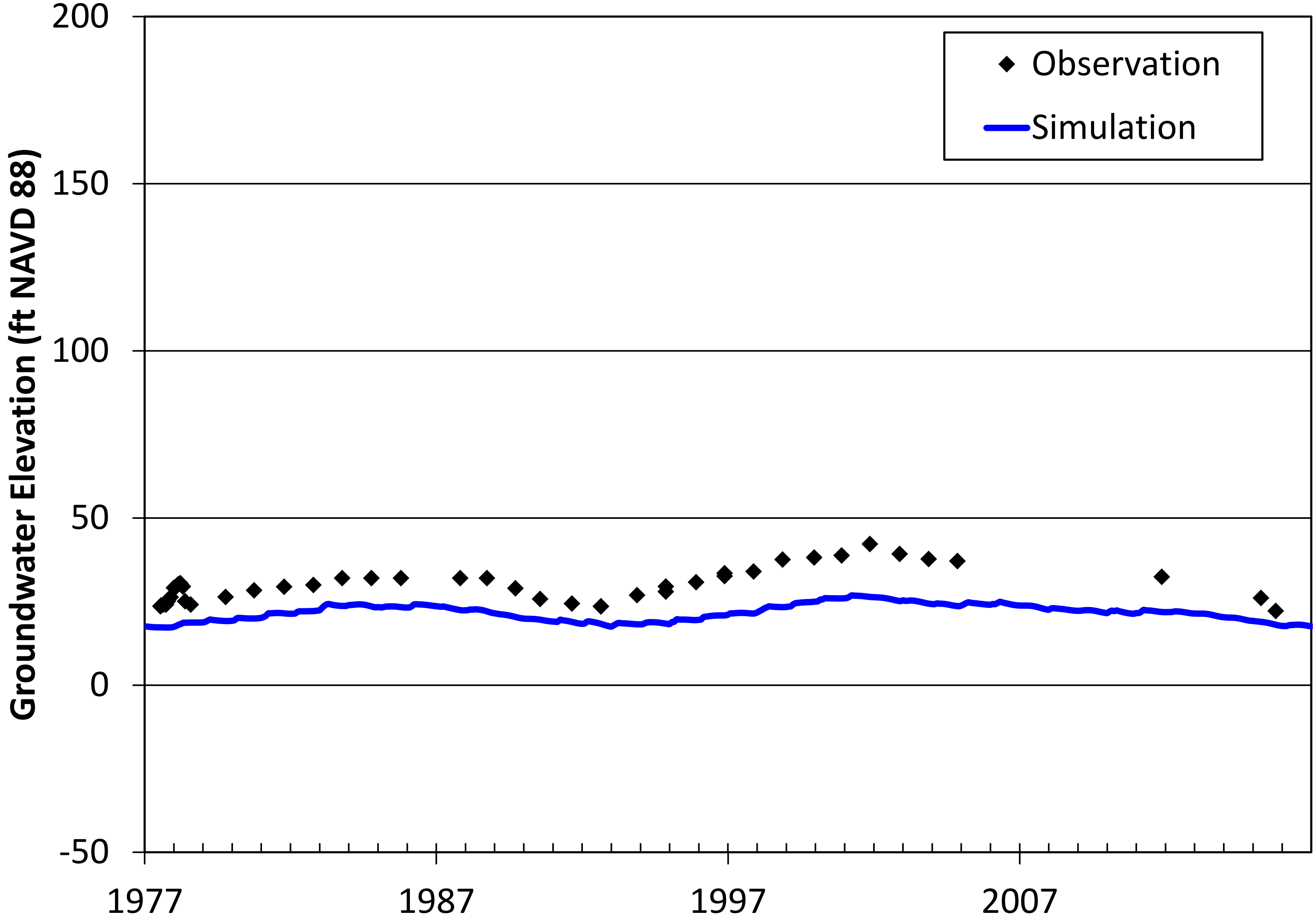
32S13E30N01



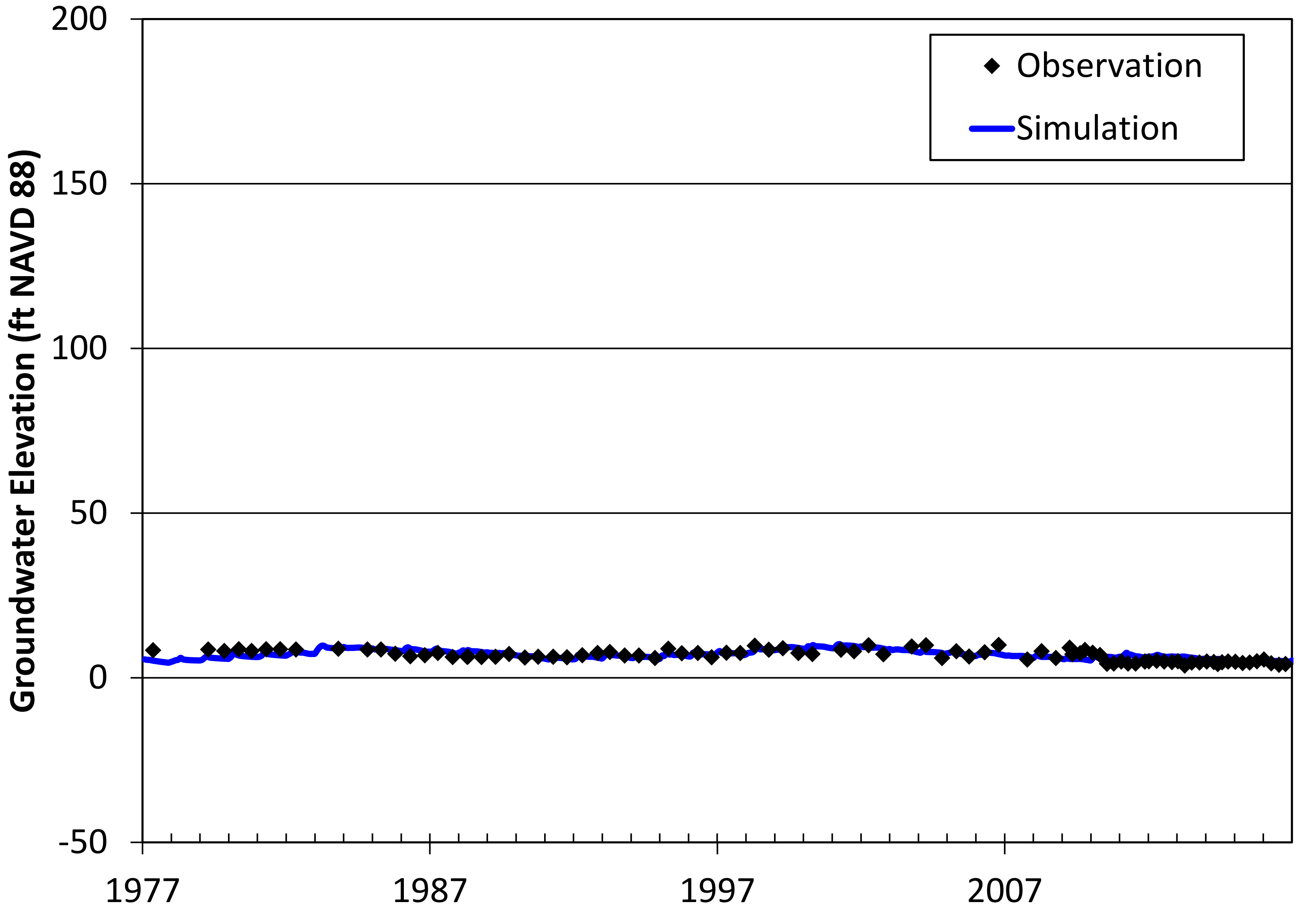
11N34W29R01

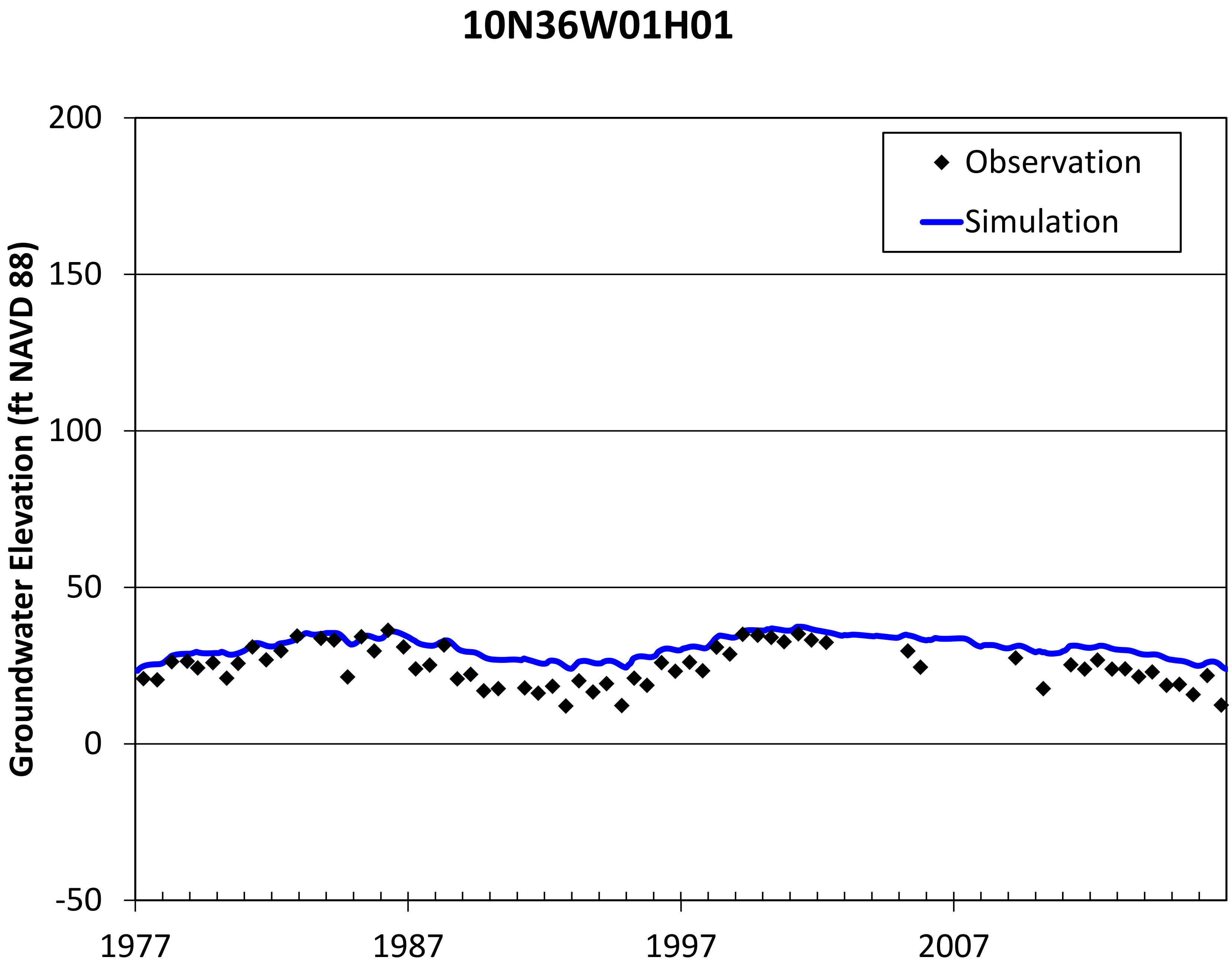


11N36W35J04

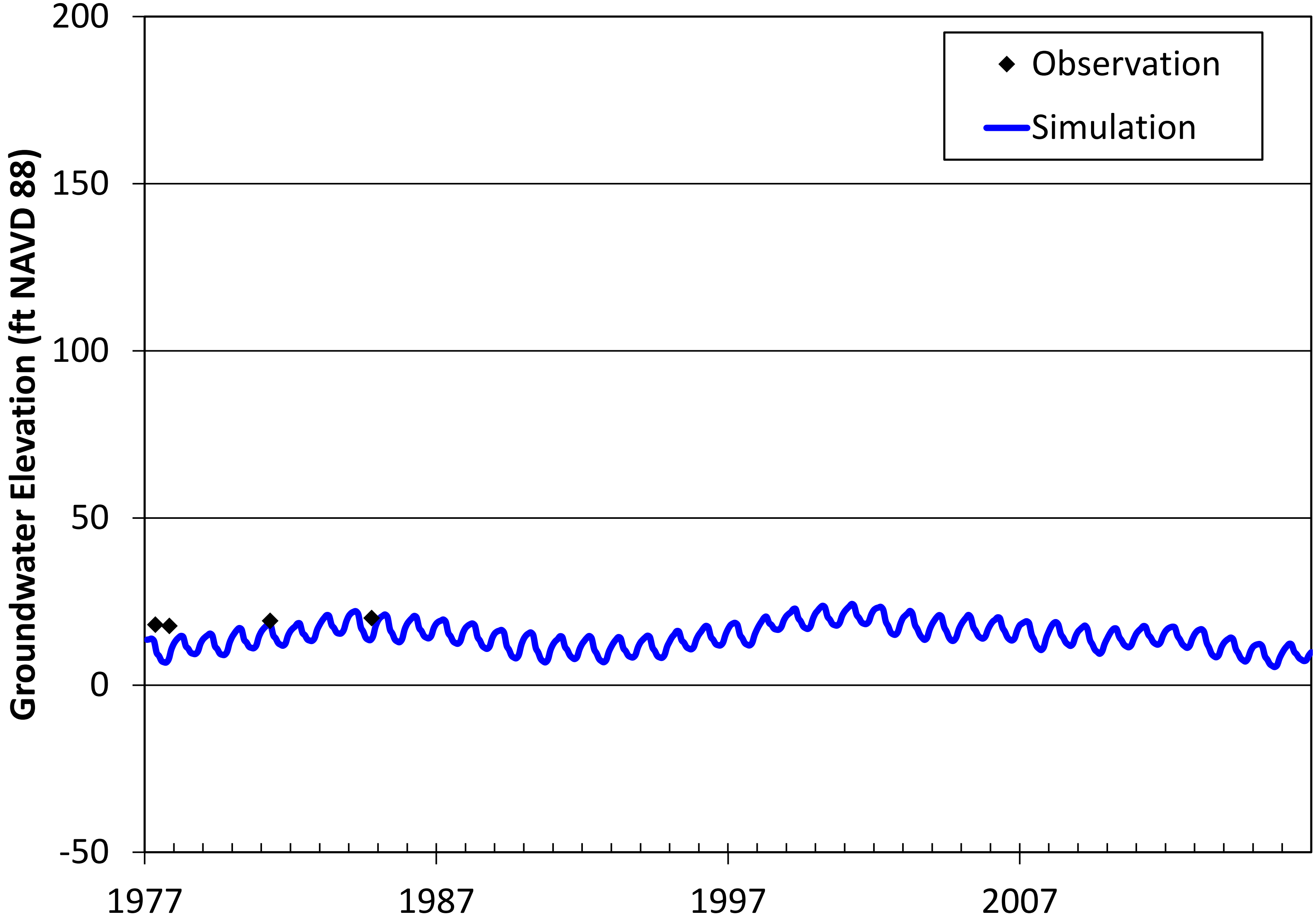


32S12E24B01

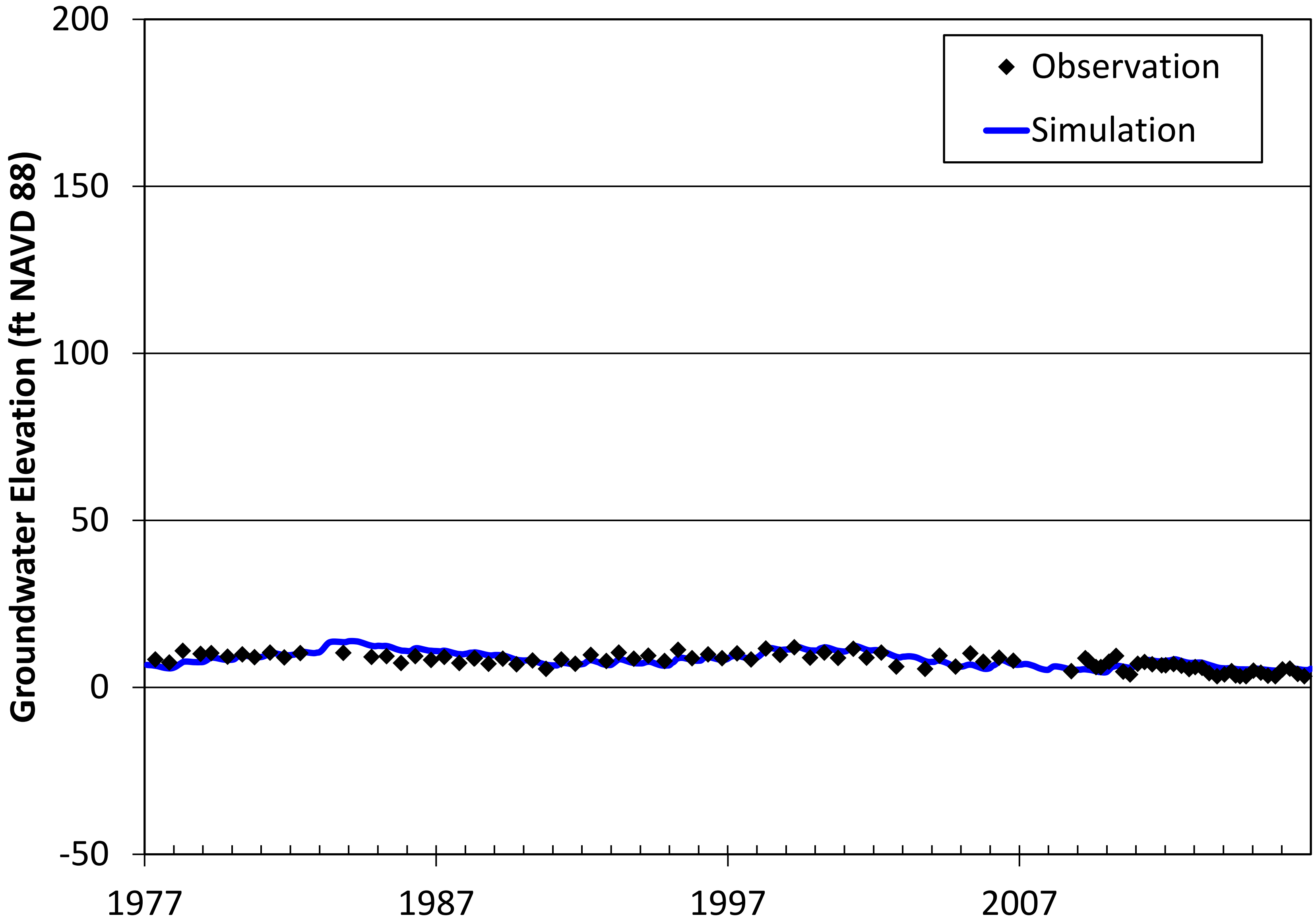



10N36W01H01
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007

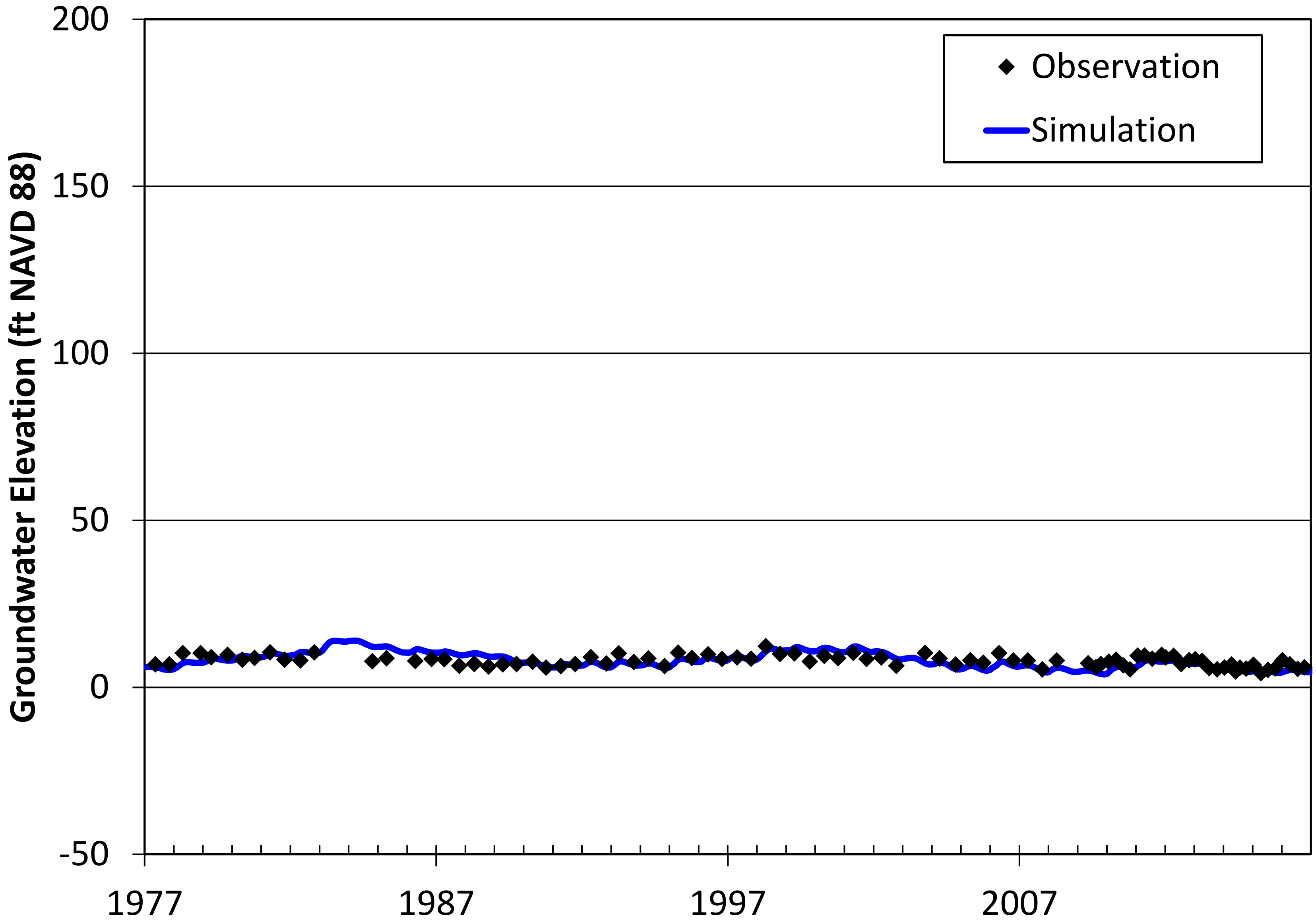
11N36W13K04



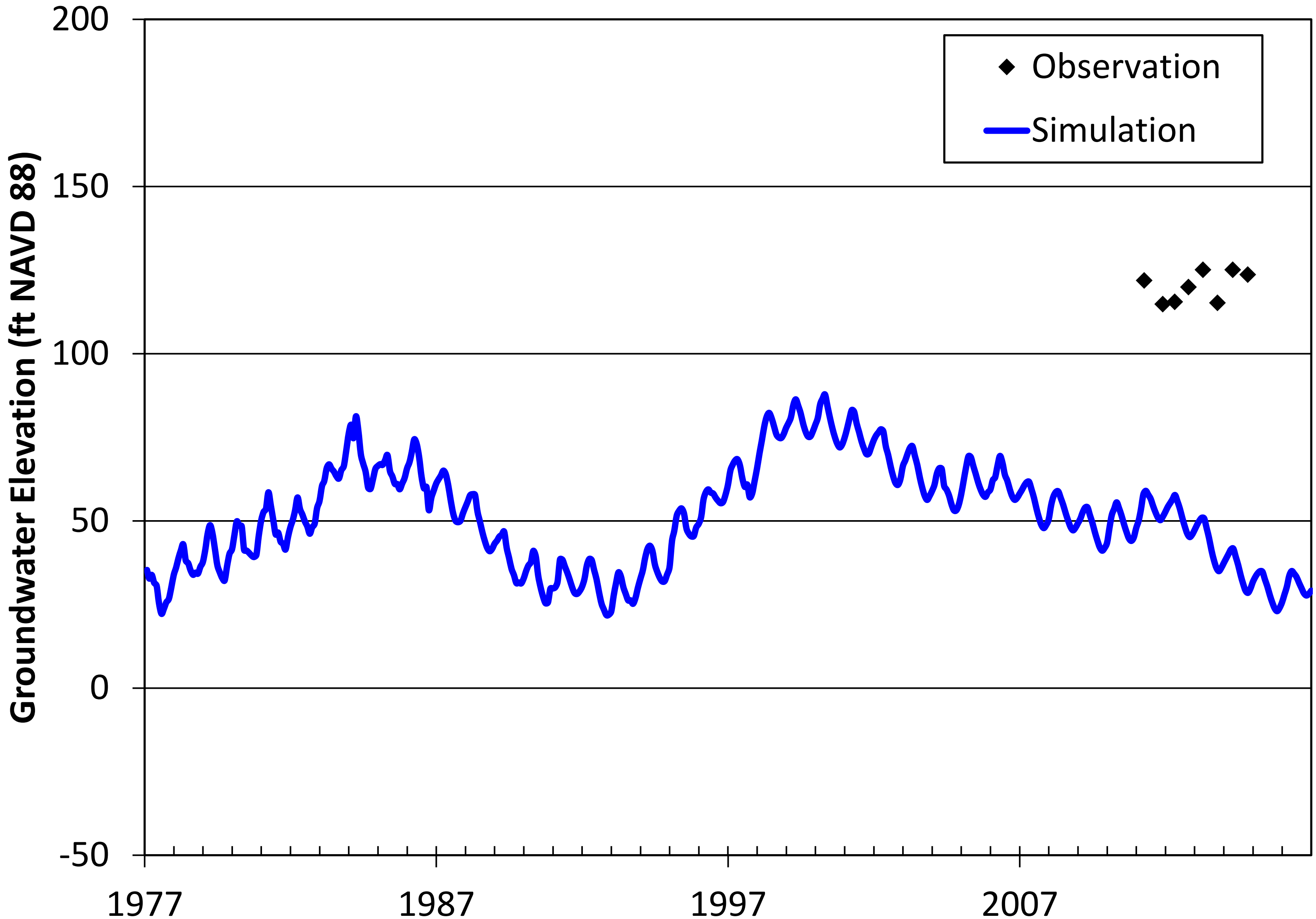
32S13E30F01



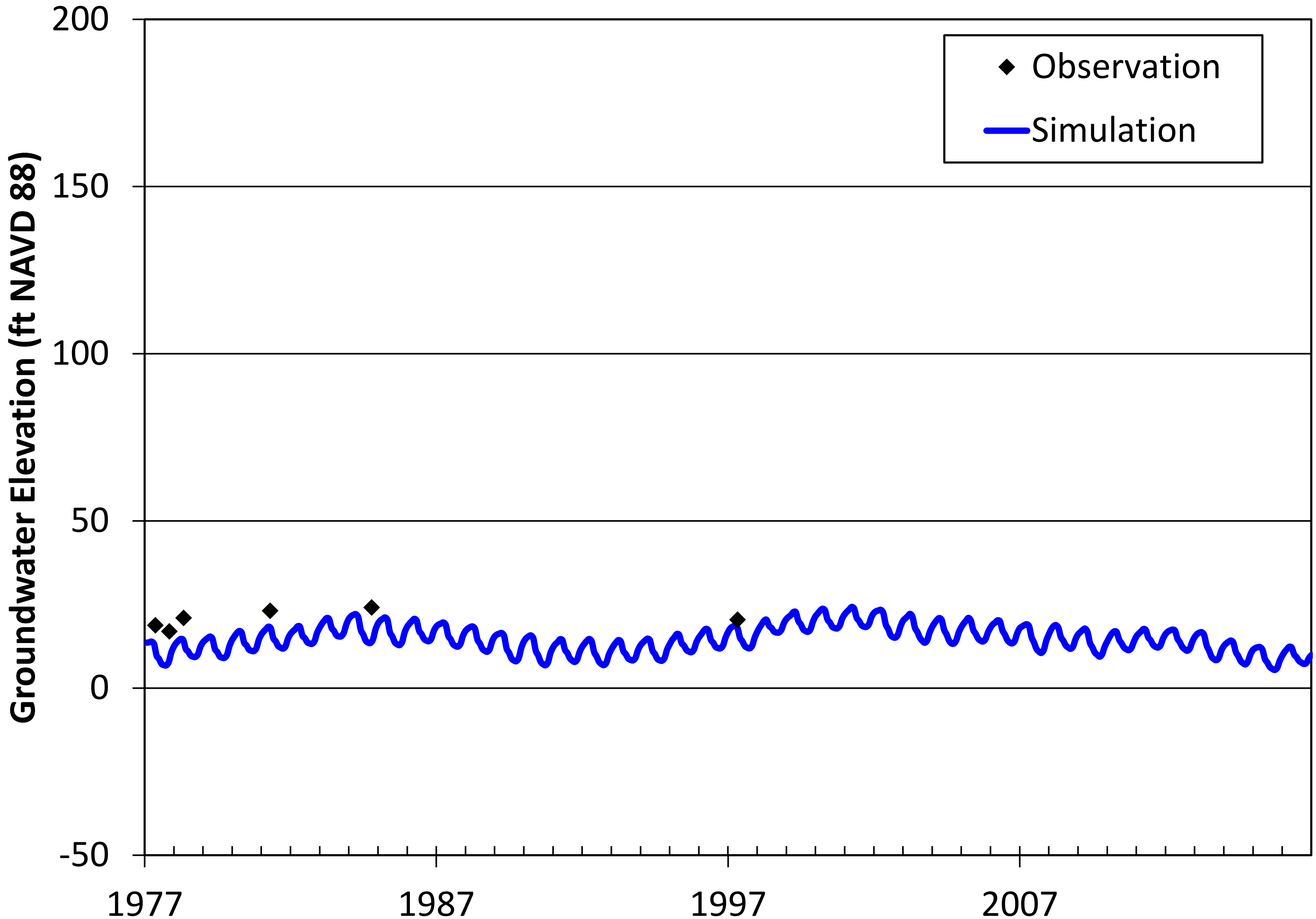
32S13E30N03



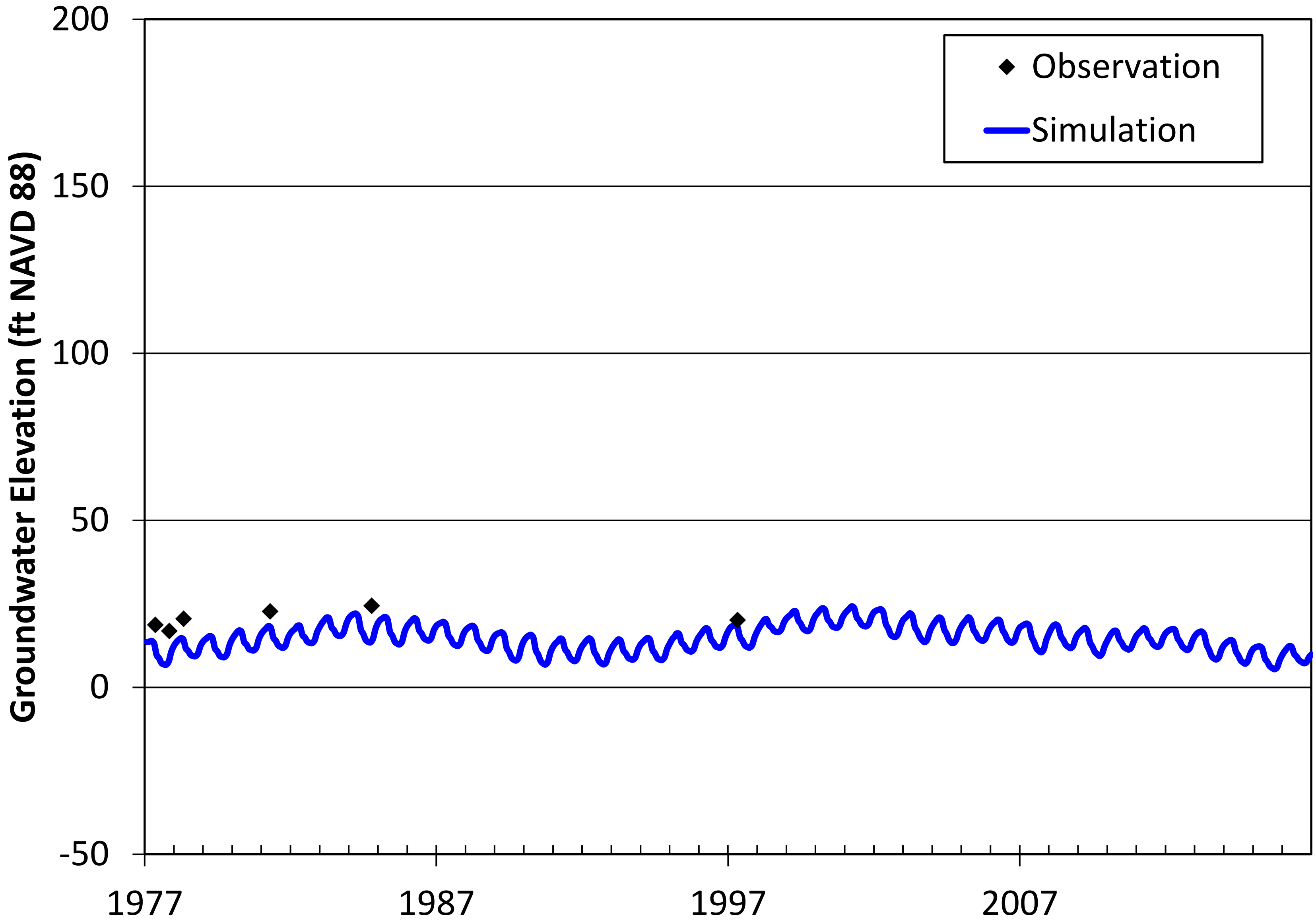
11N34W19L03



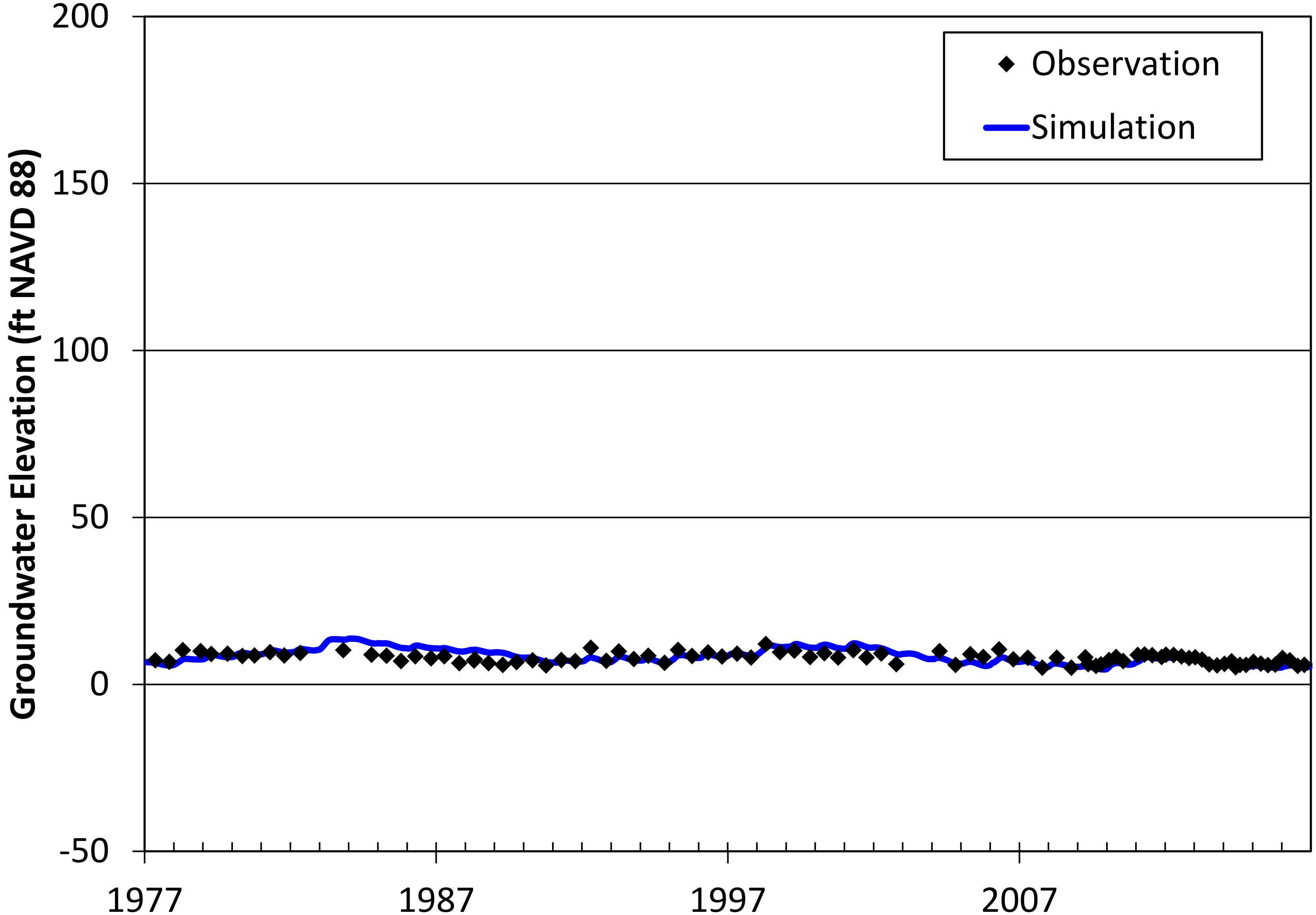
11N36W13K05

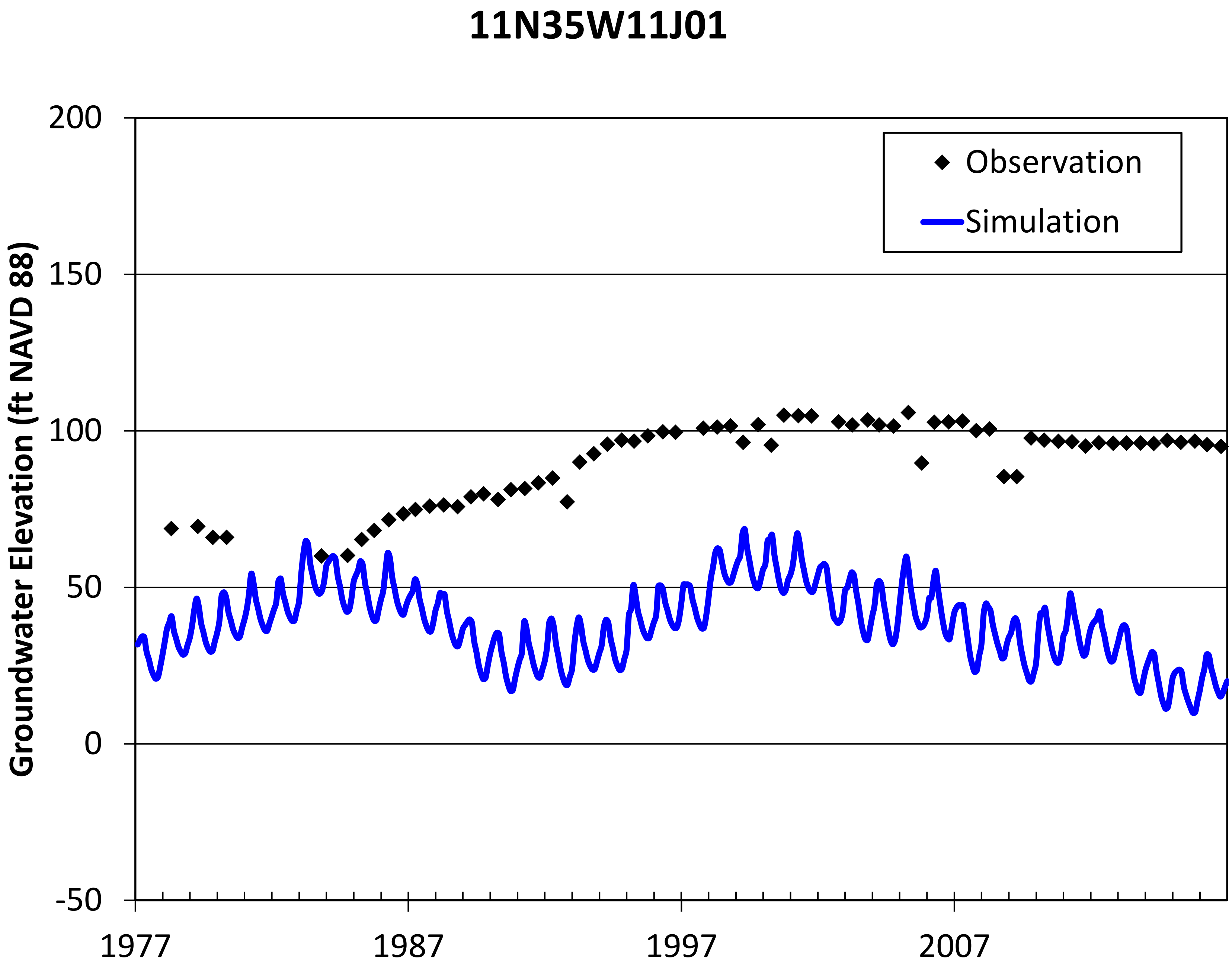


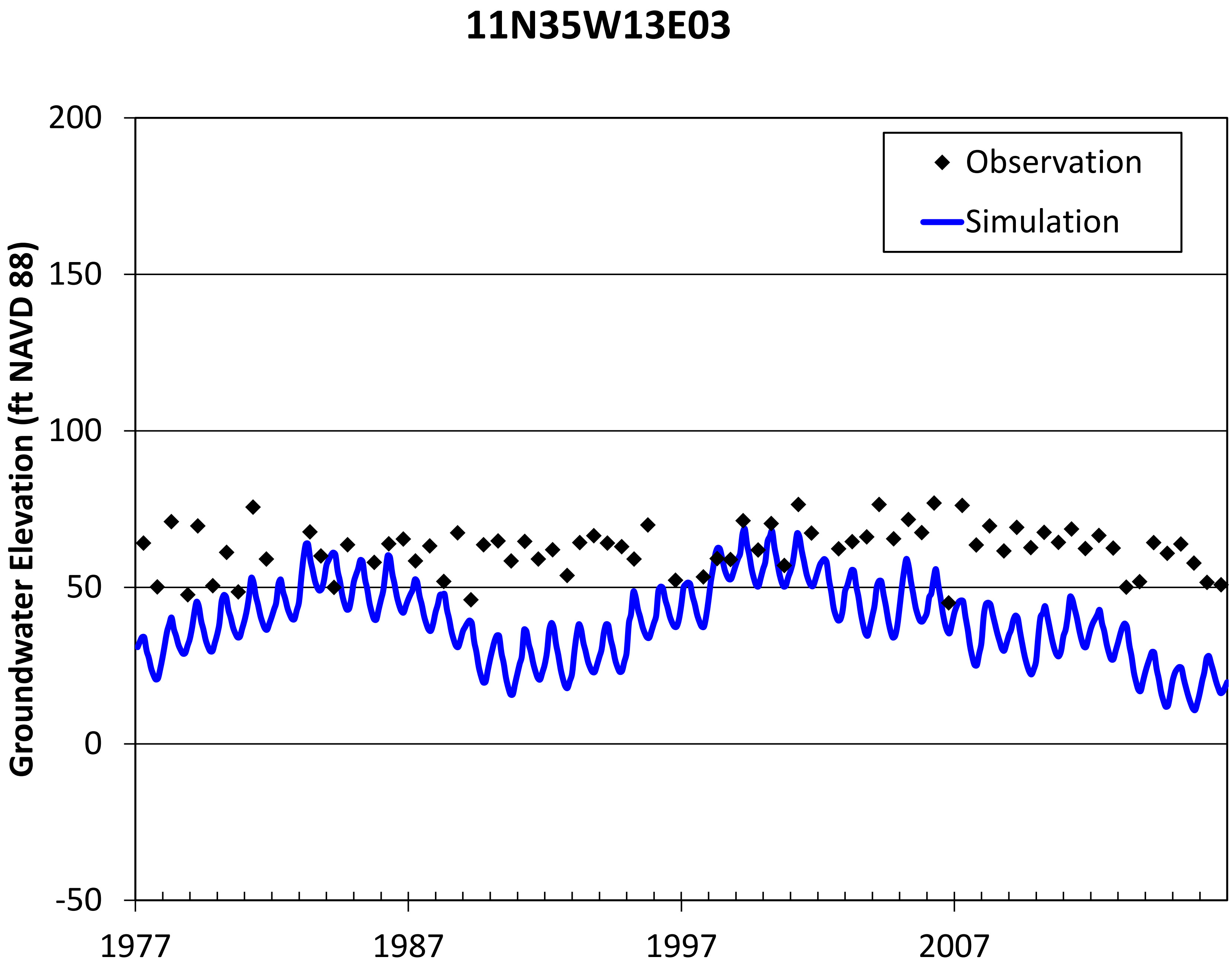
11N36W13K06



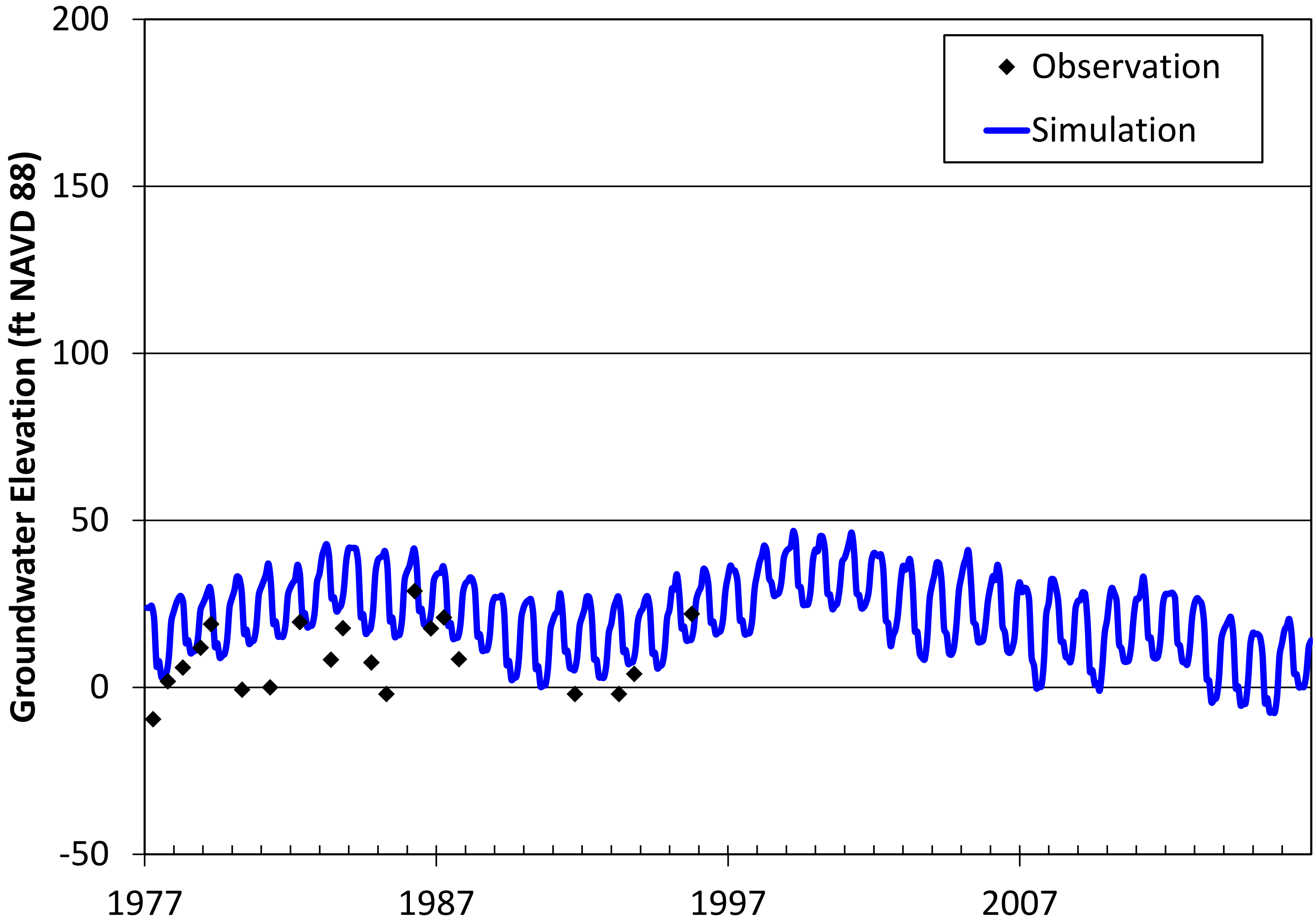
32S13E30F02



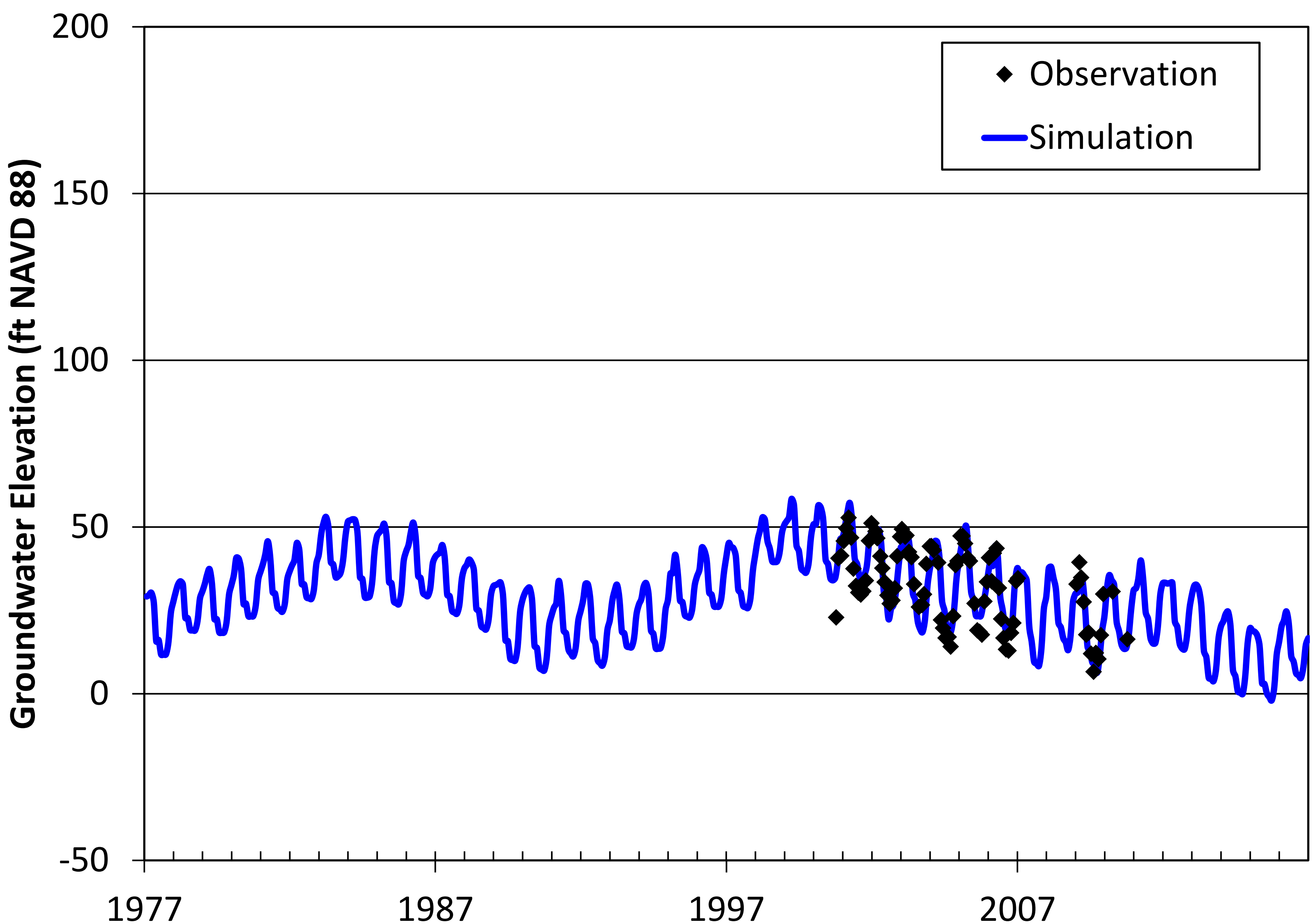

11N35W11J01
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007


11N35W13E03
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007
Observation
Simulation

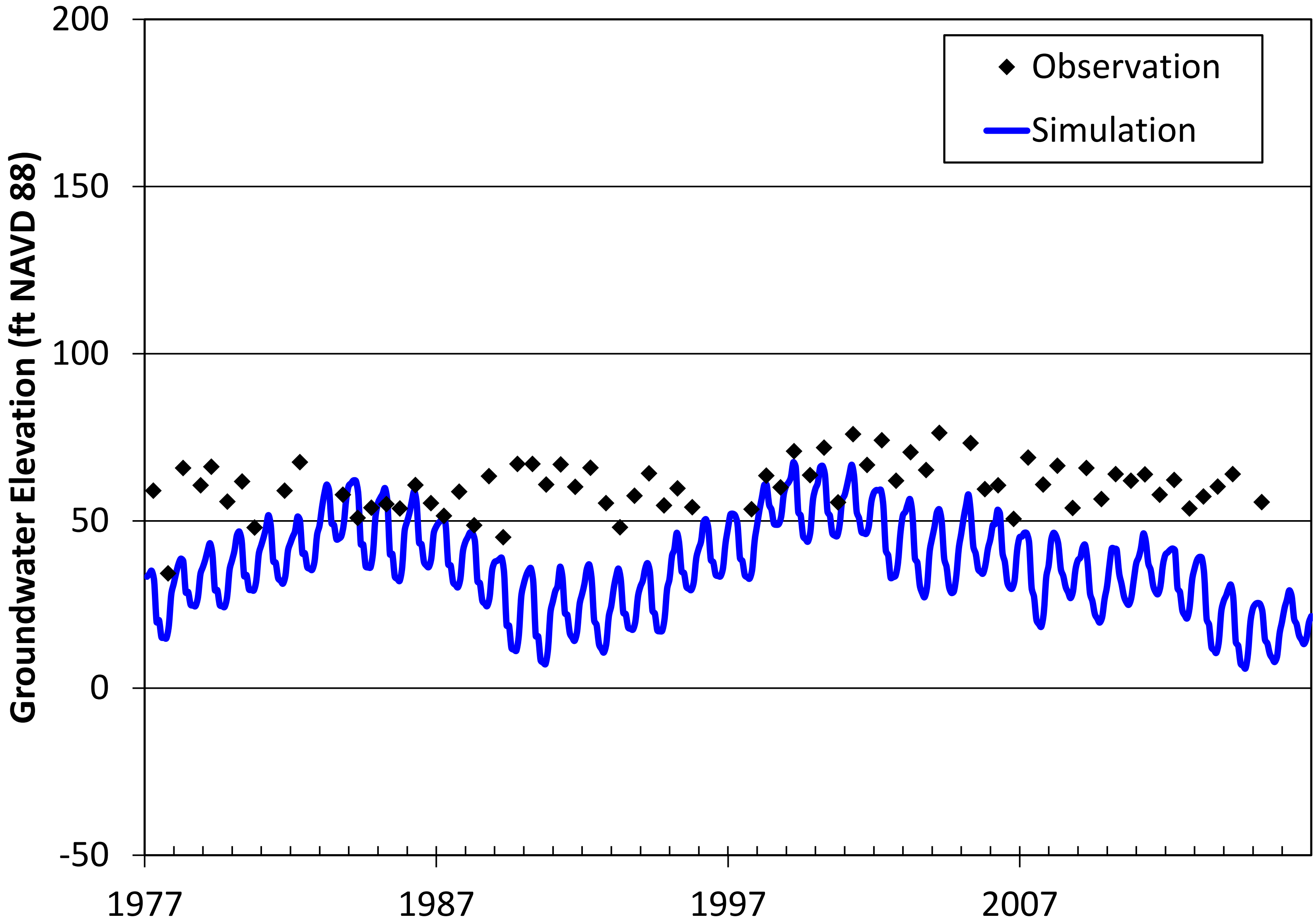
11N35W16B01



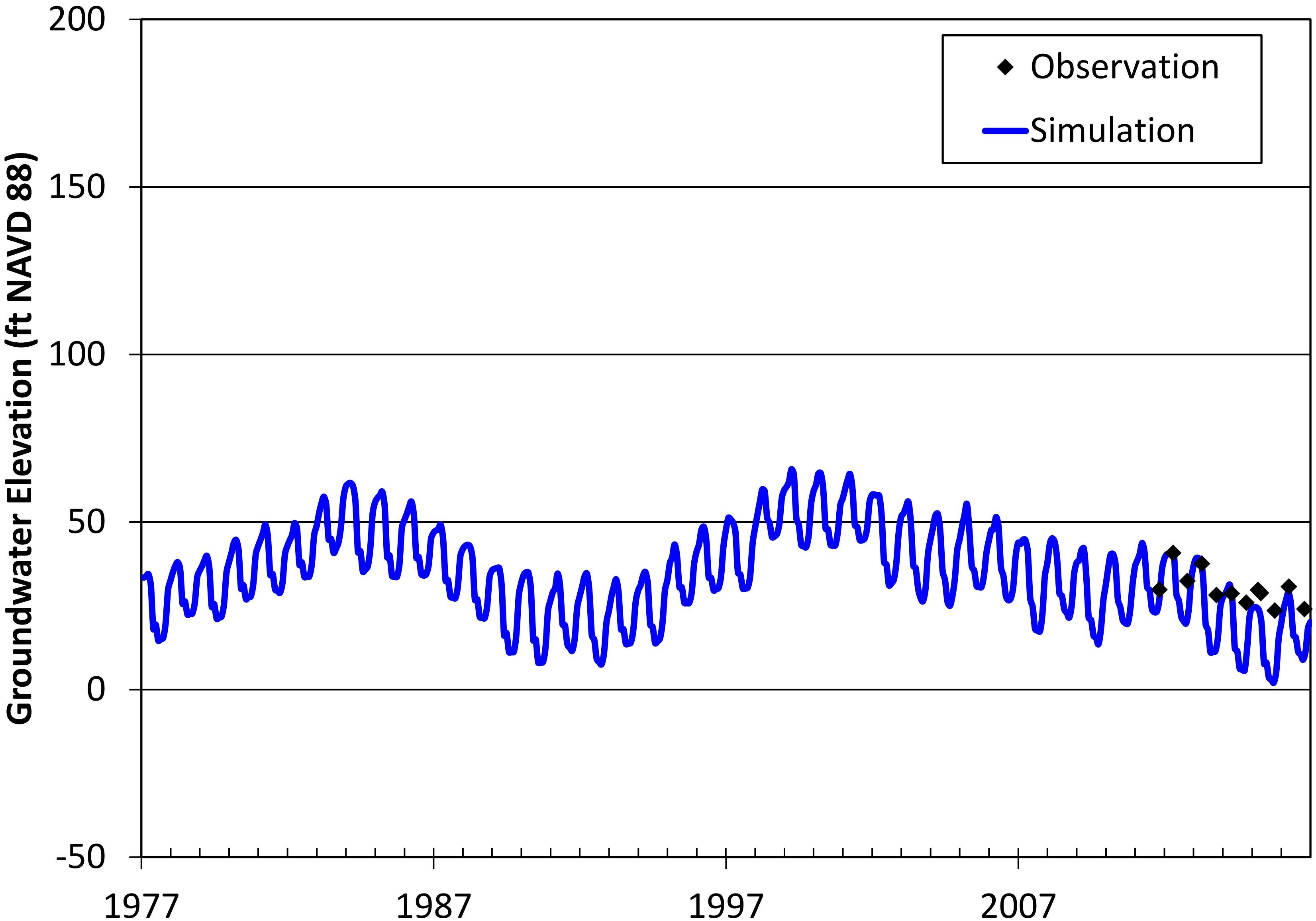
11N35W15G01



11N35W13E02



11N35W23G01



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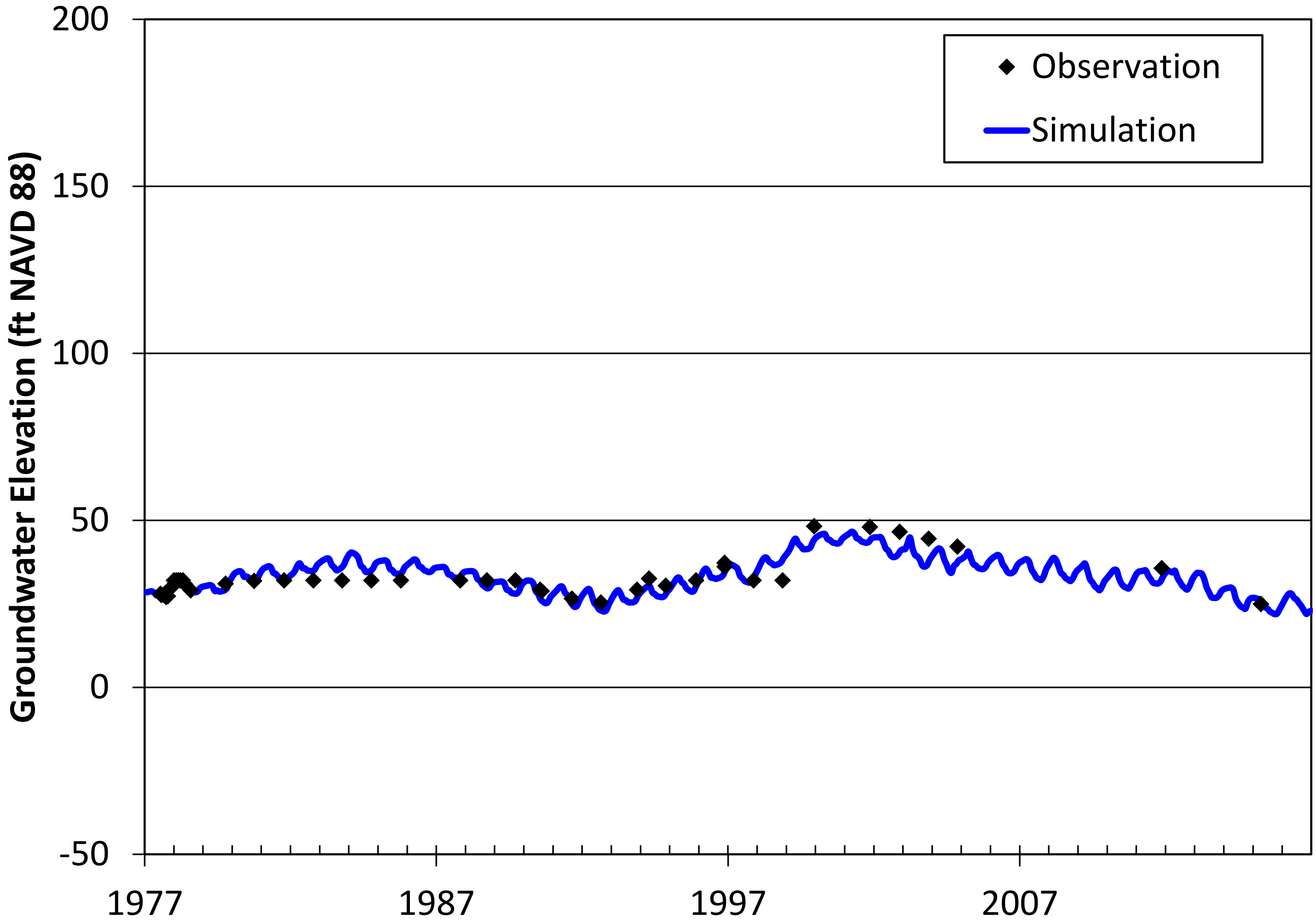

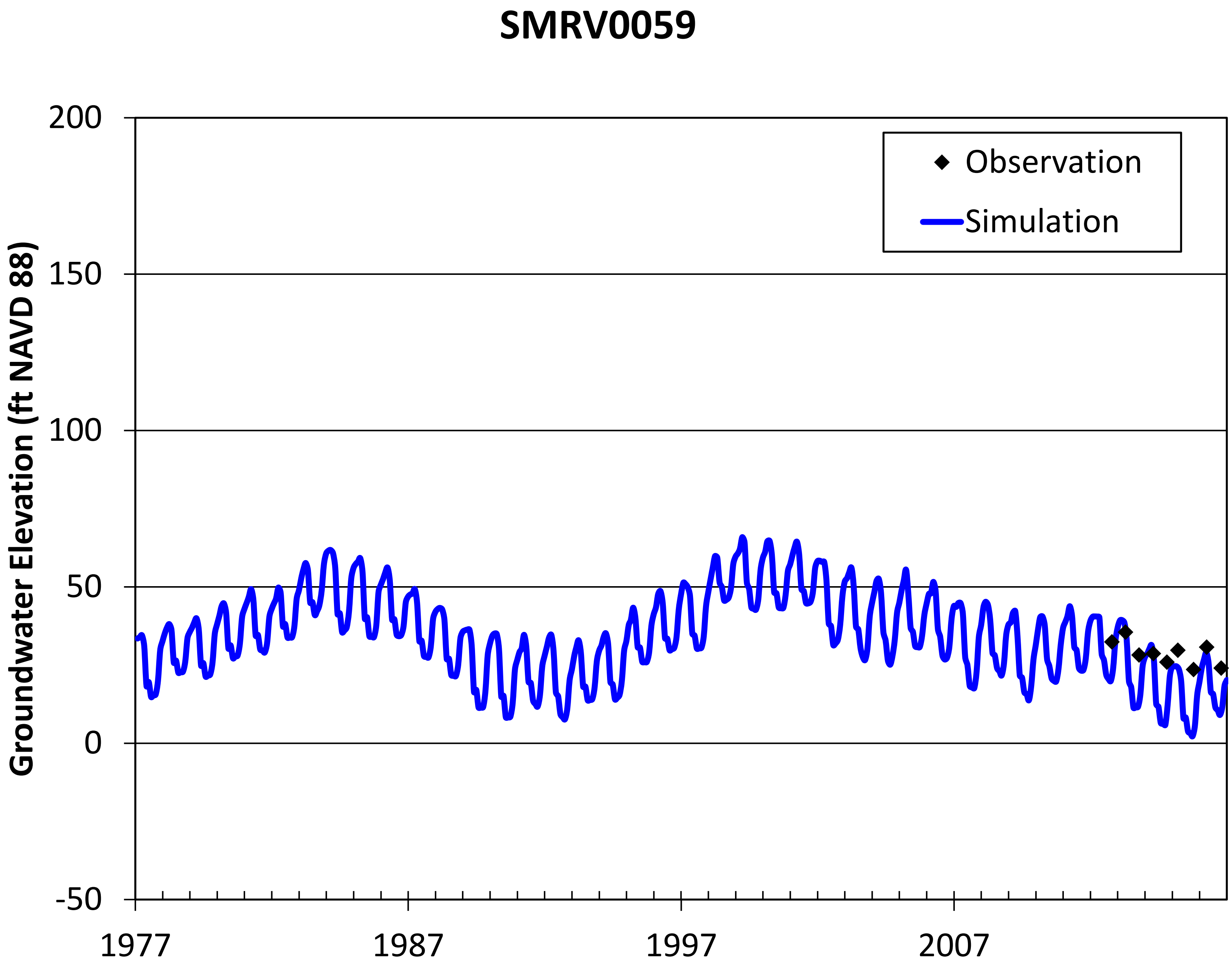
SMRV0059
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
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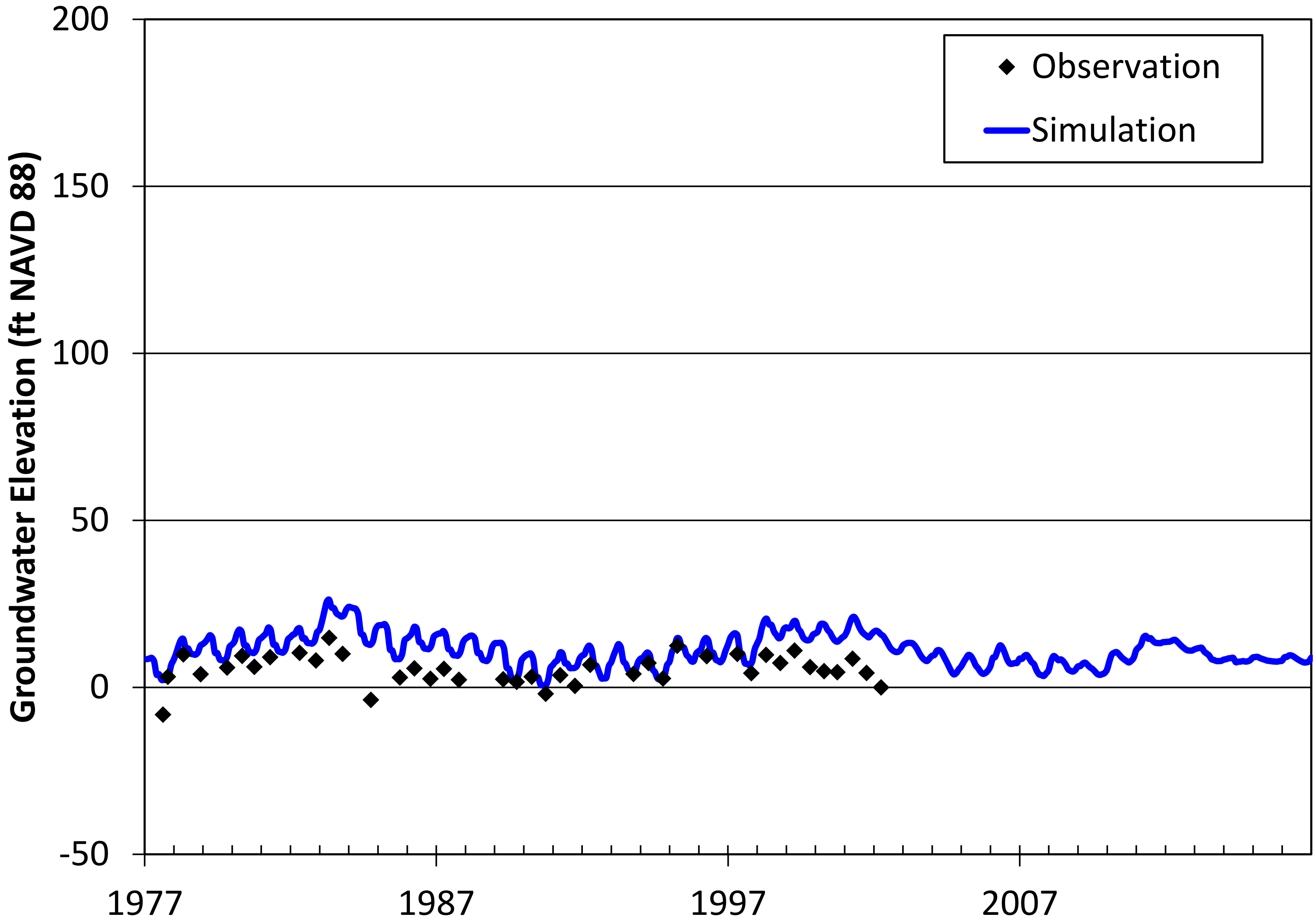
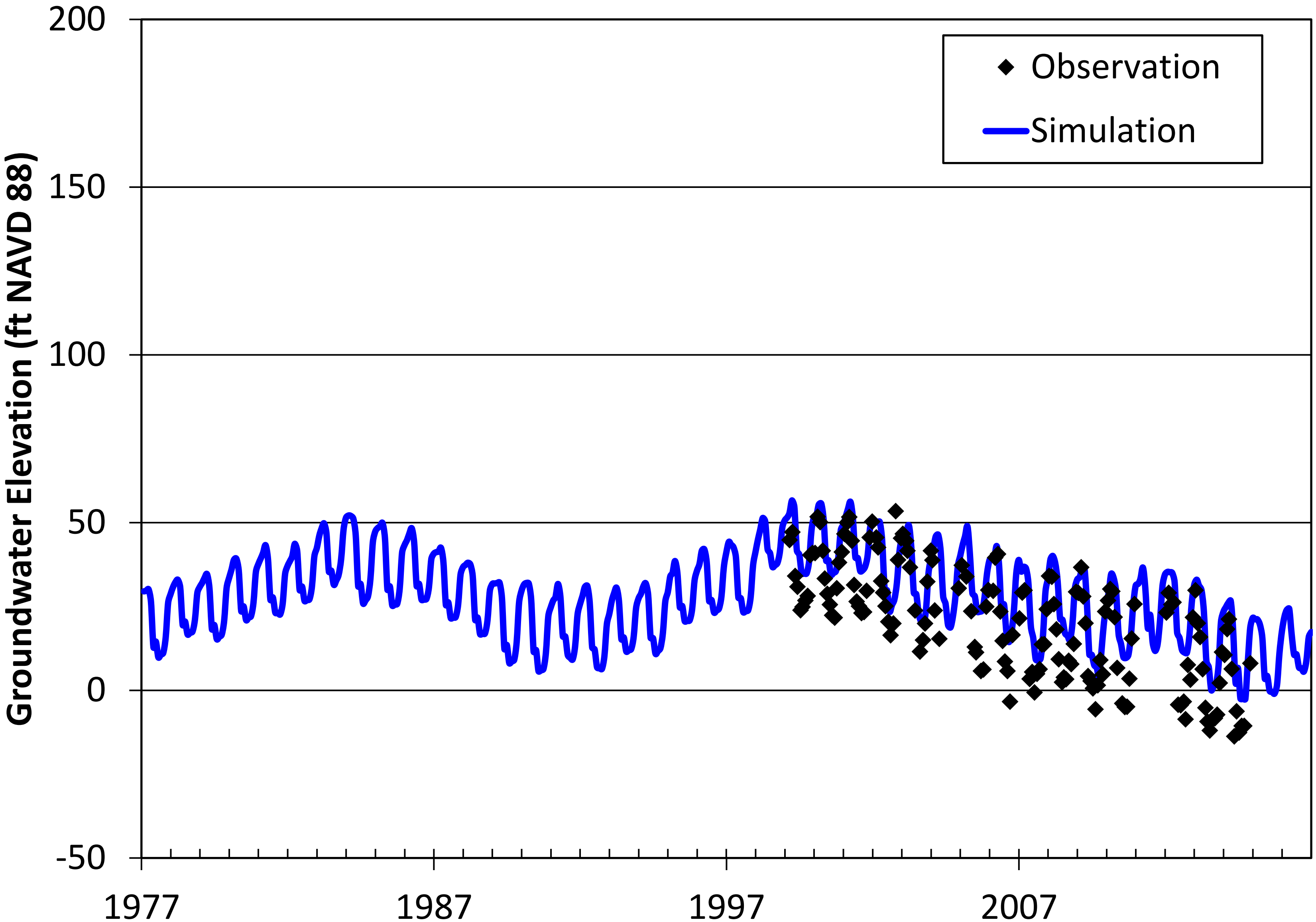
150
100
50
0
-50
1977
1987
1997
2007

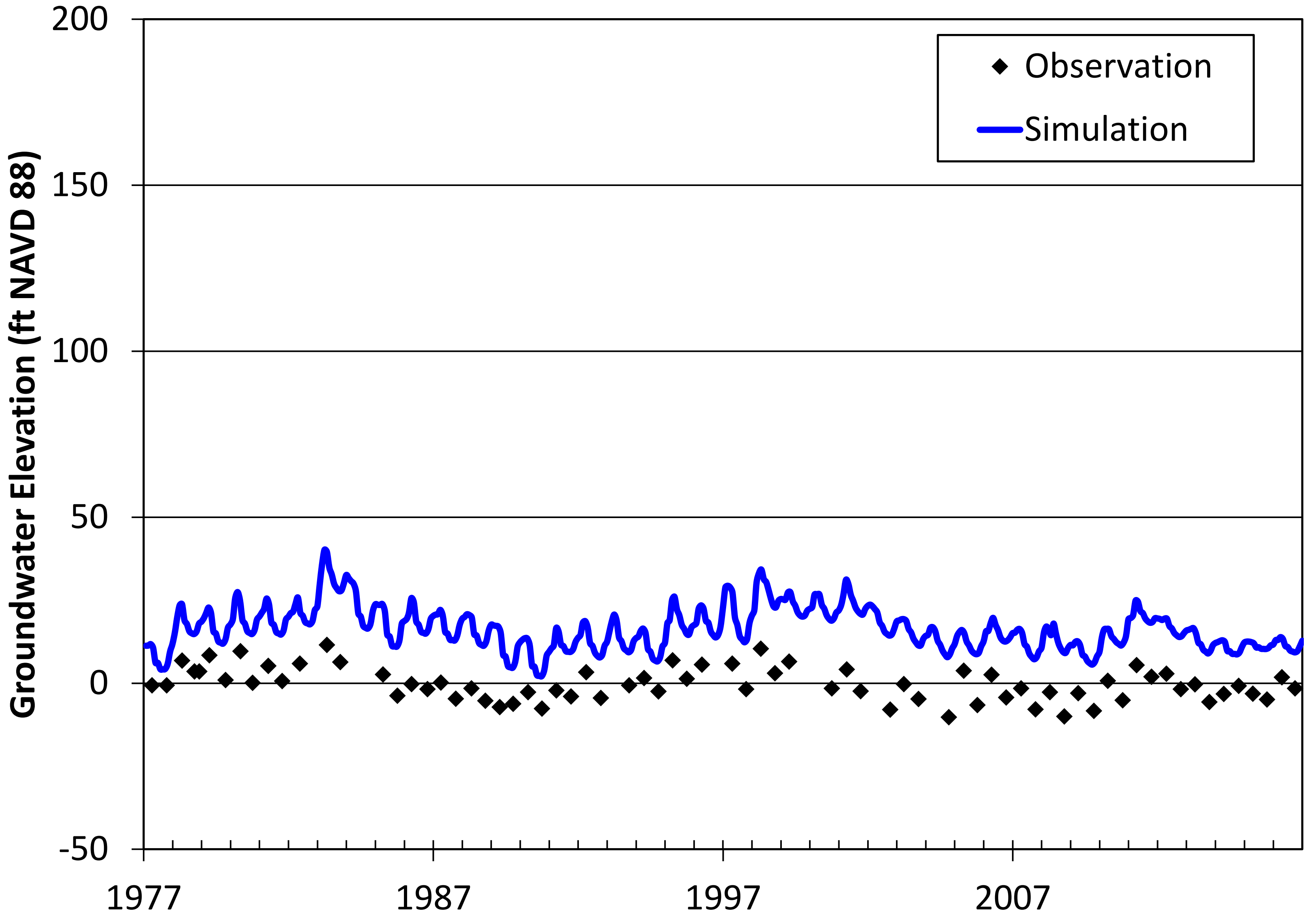
32S13E29C02



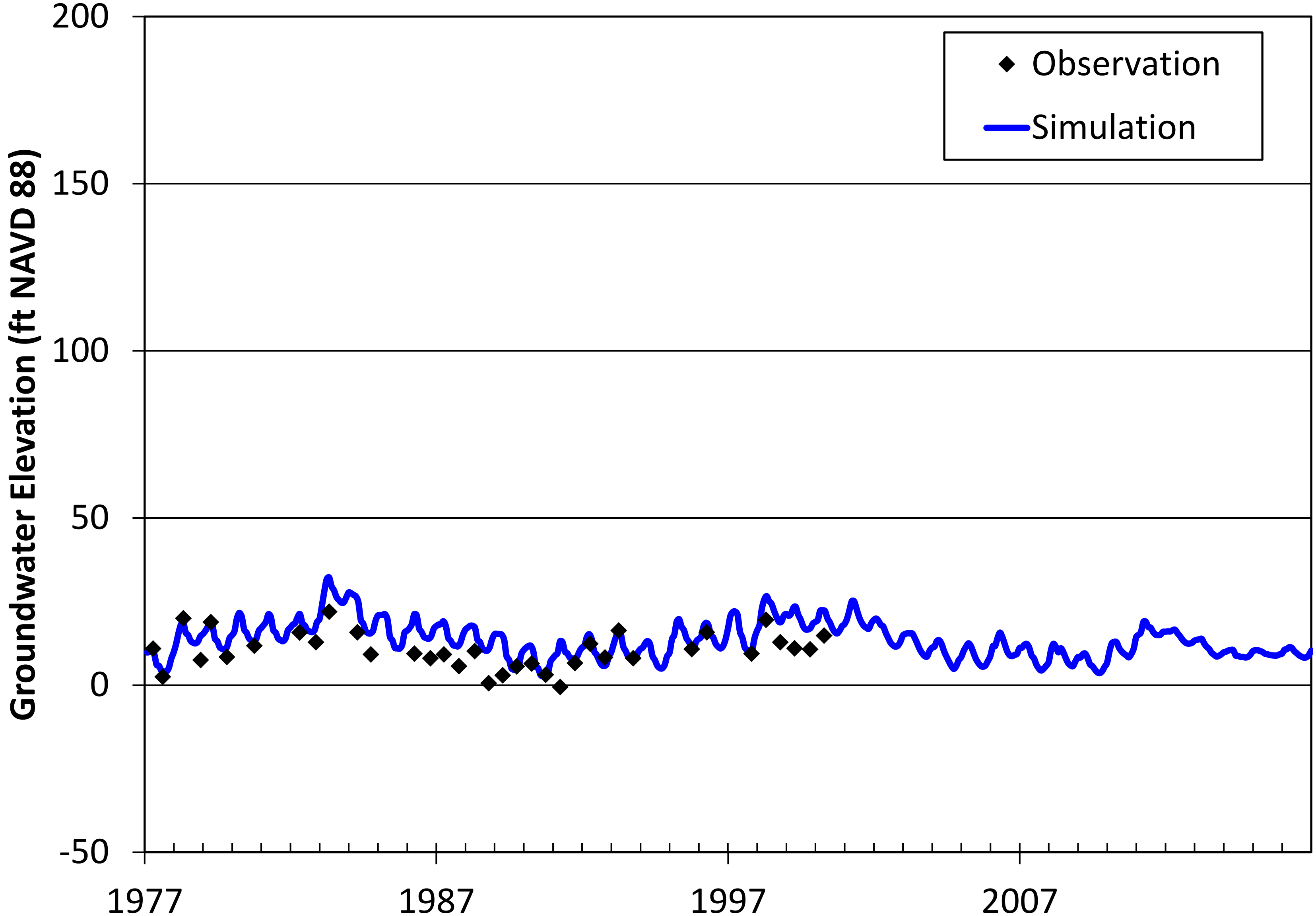
11N35W22M01



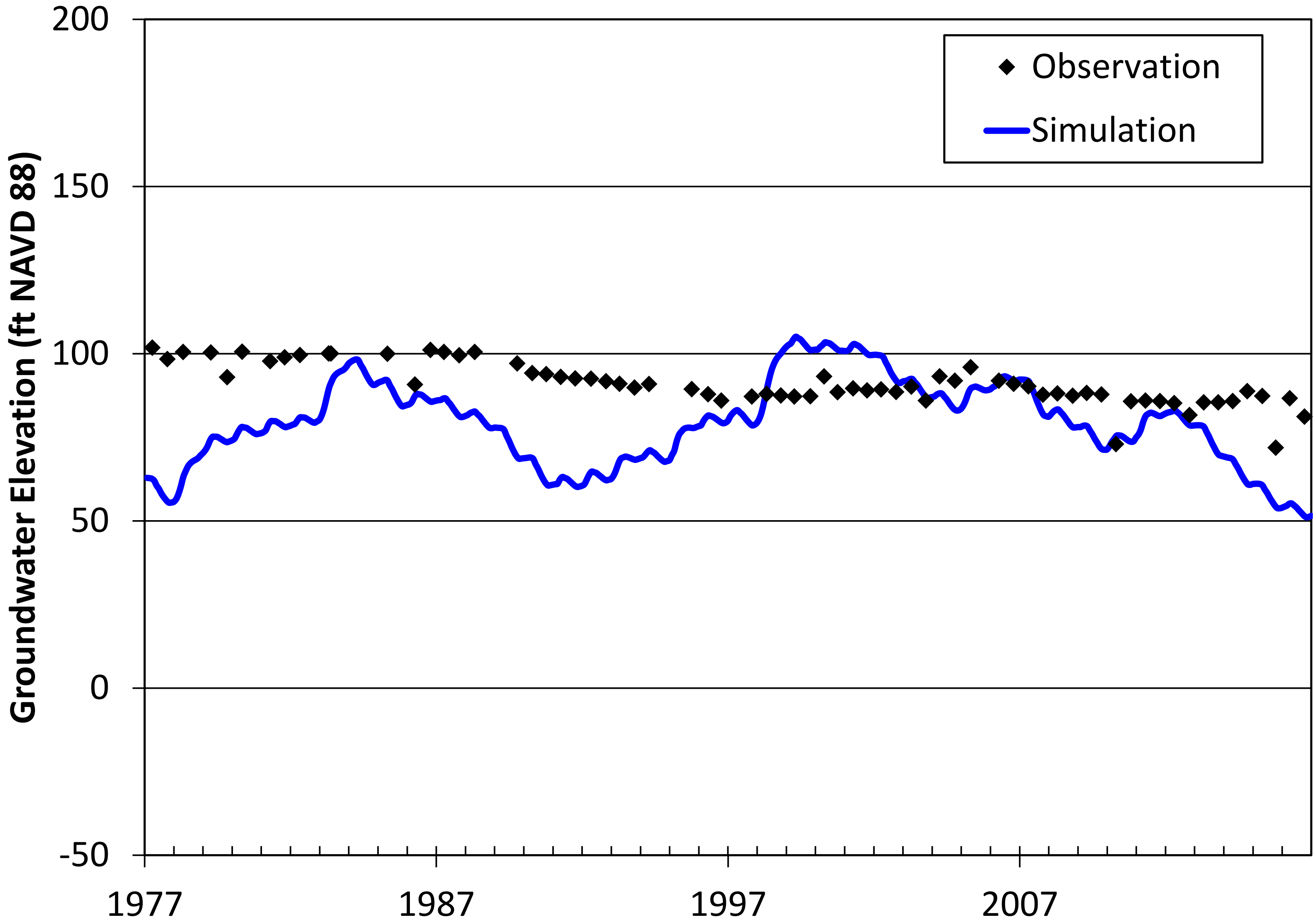
32S13E28L01



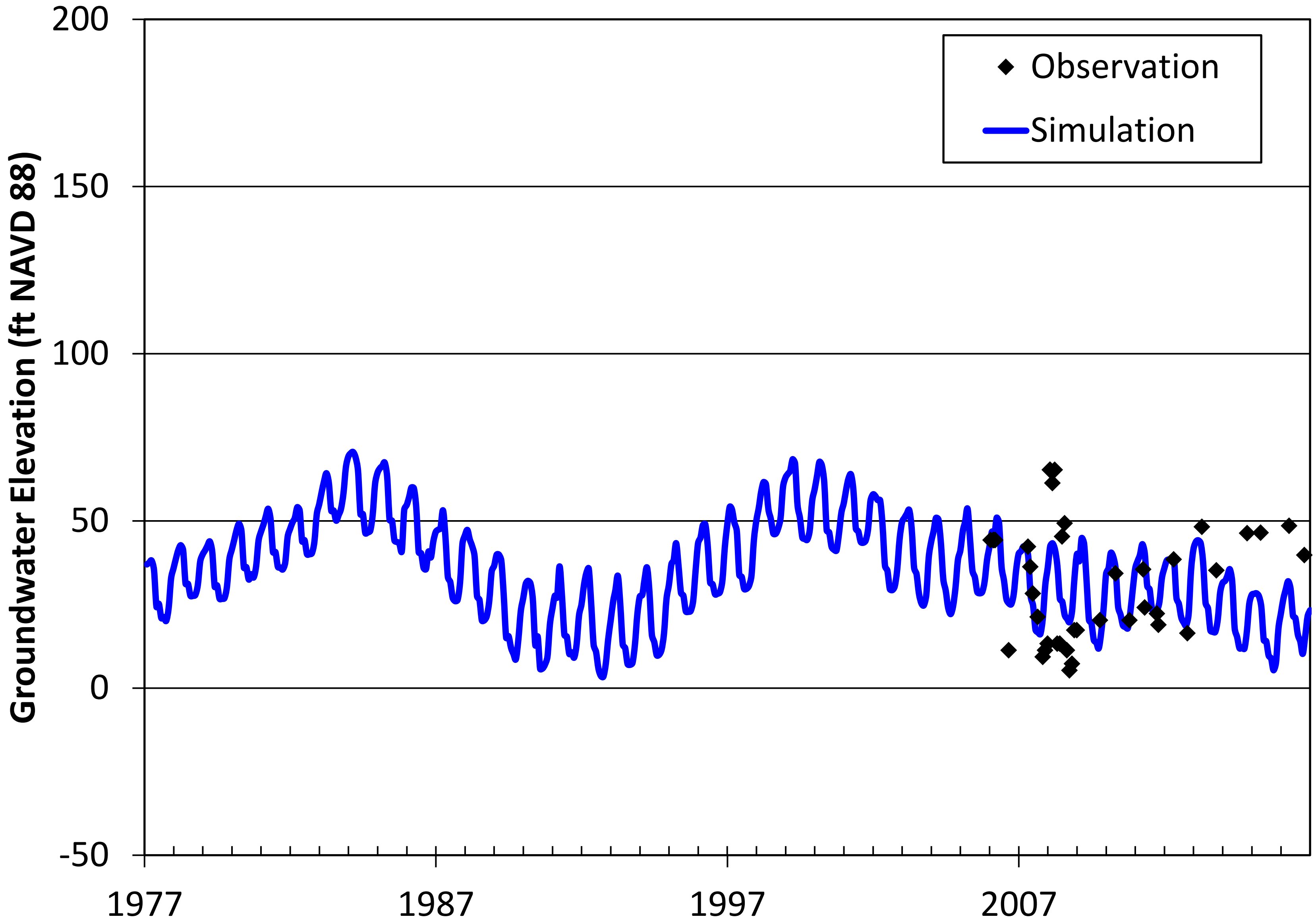
32S13E29J02

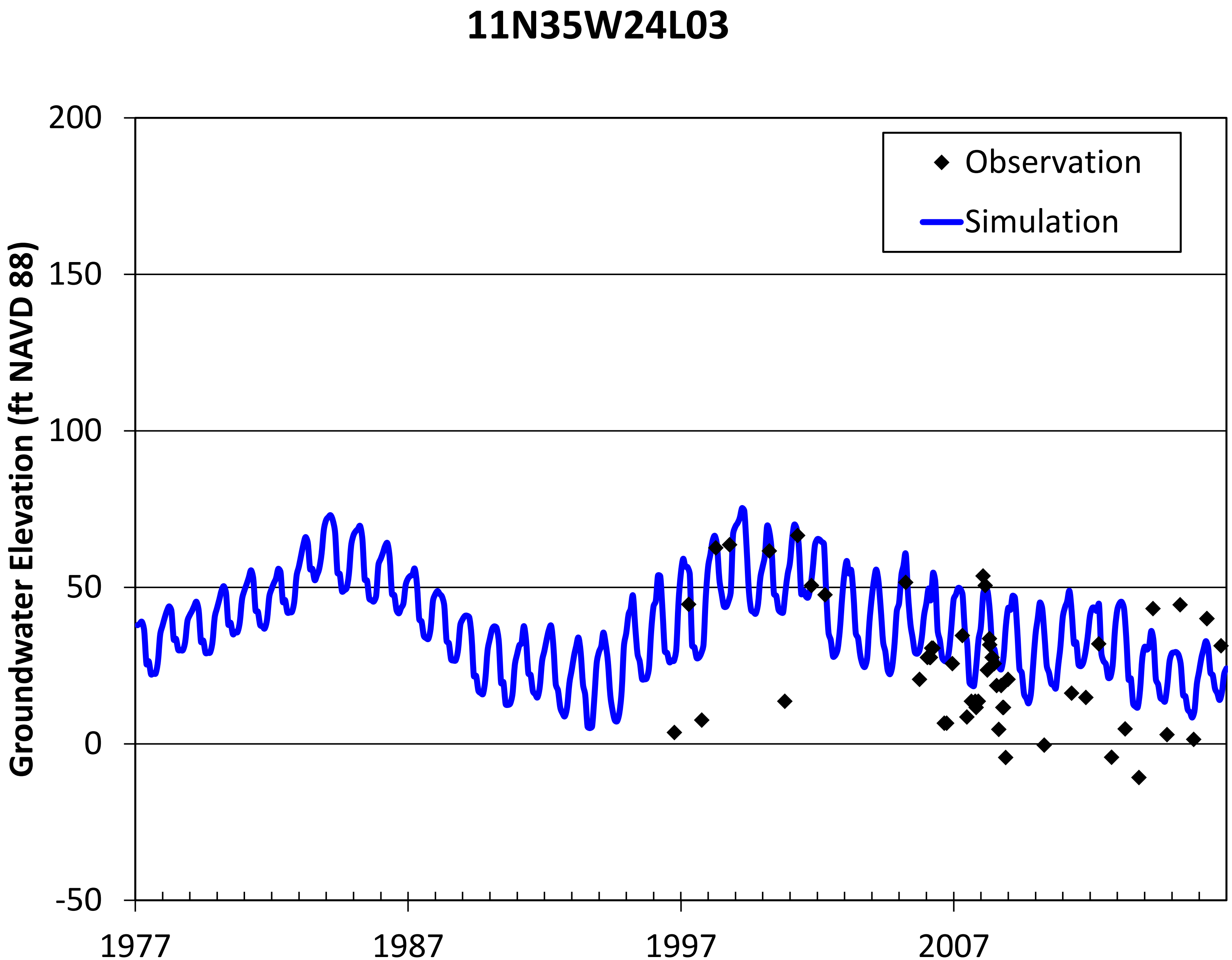


11N35W03B01

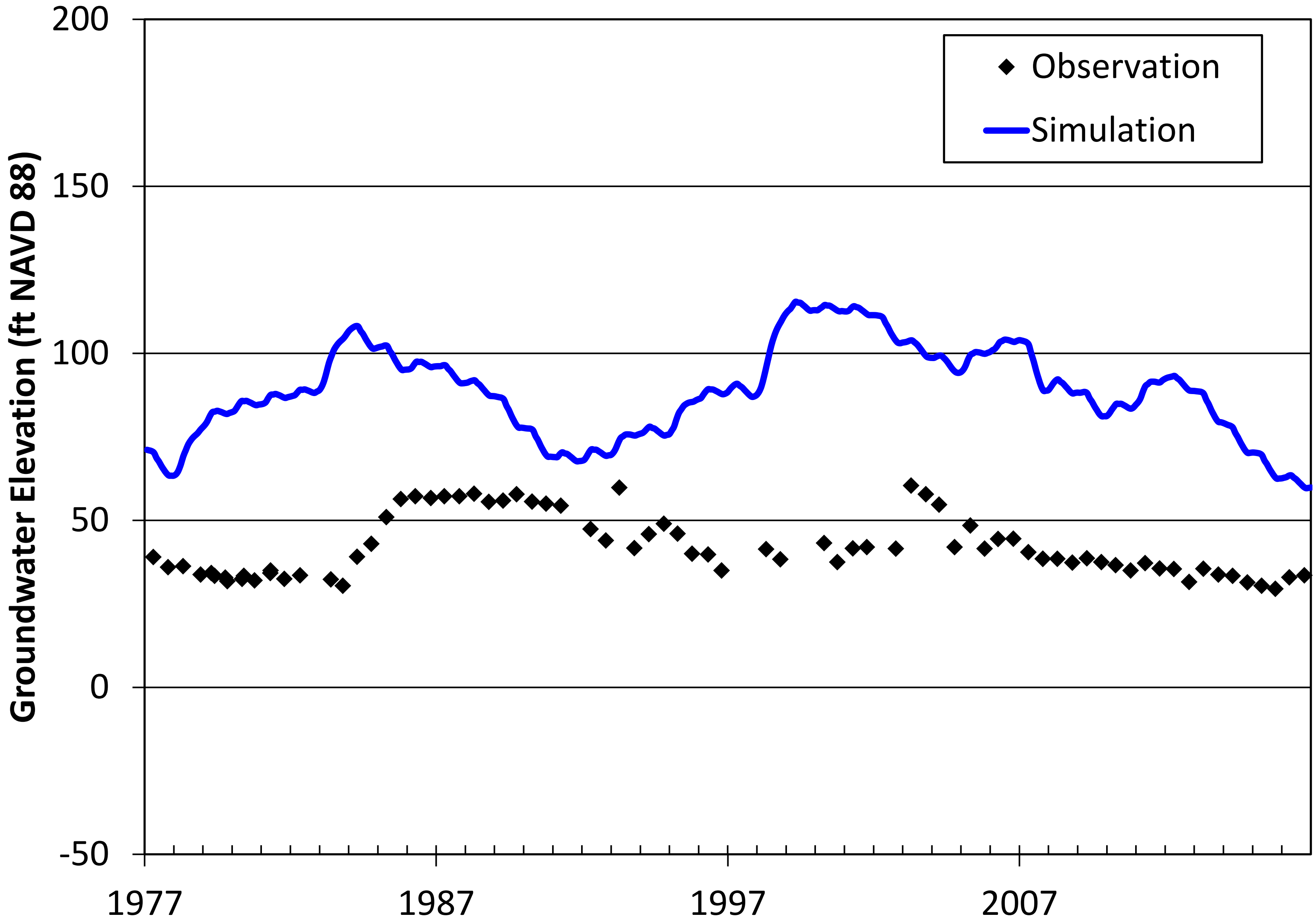


11N35W24L02

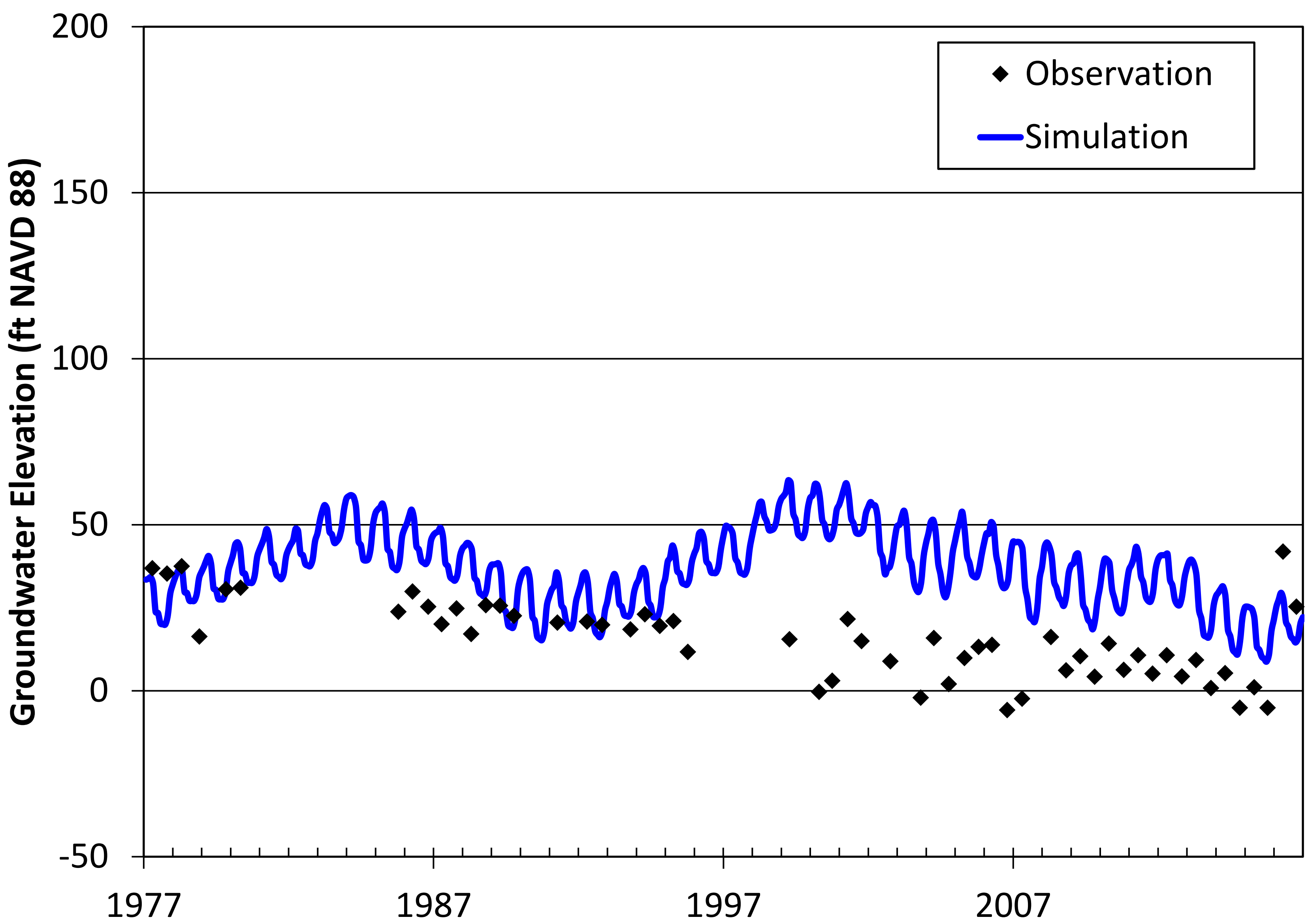



11N35W24L03
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007

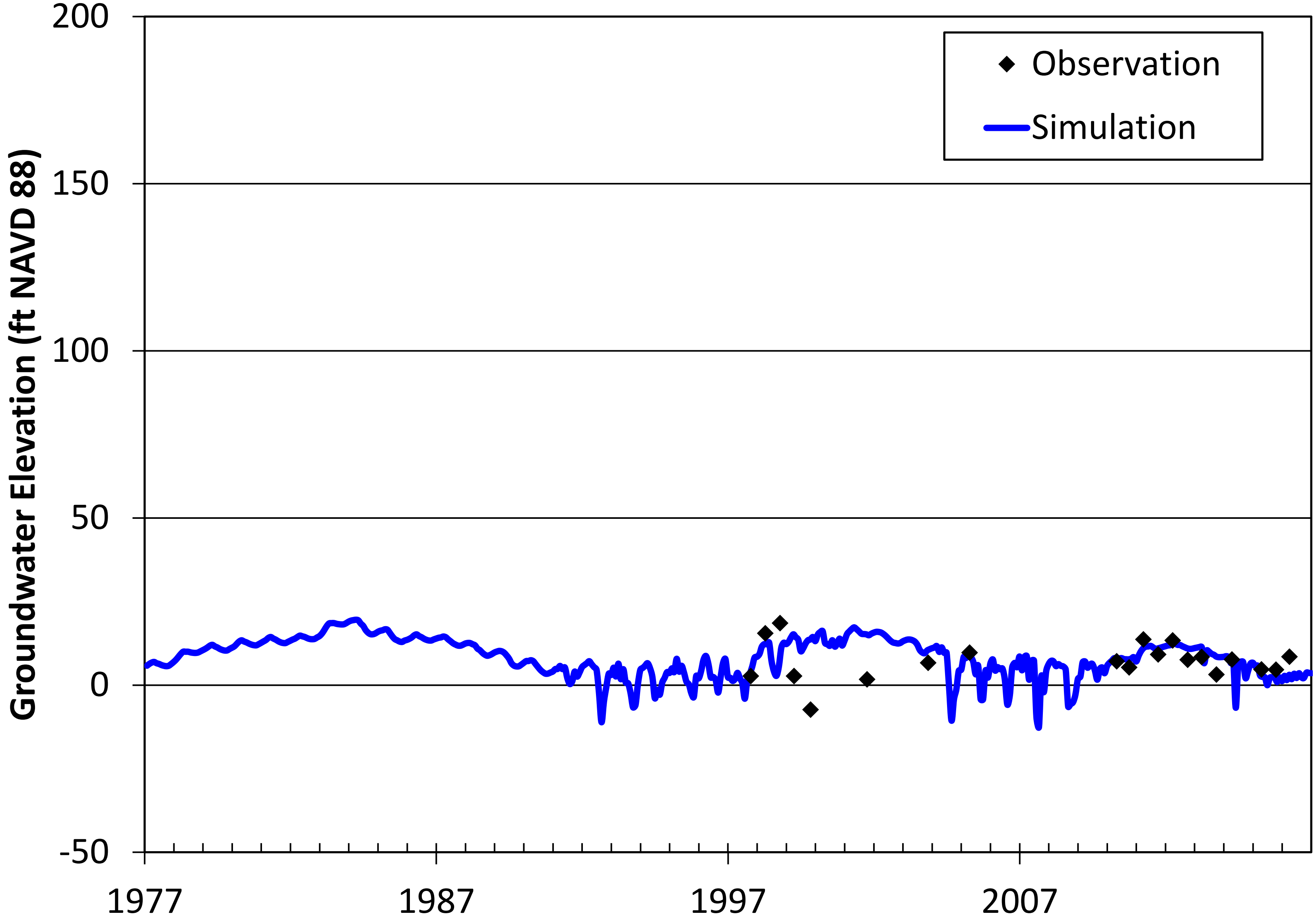
11N35W11B01



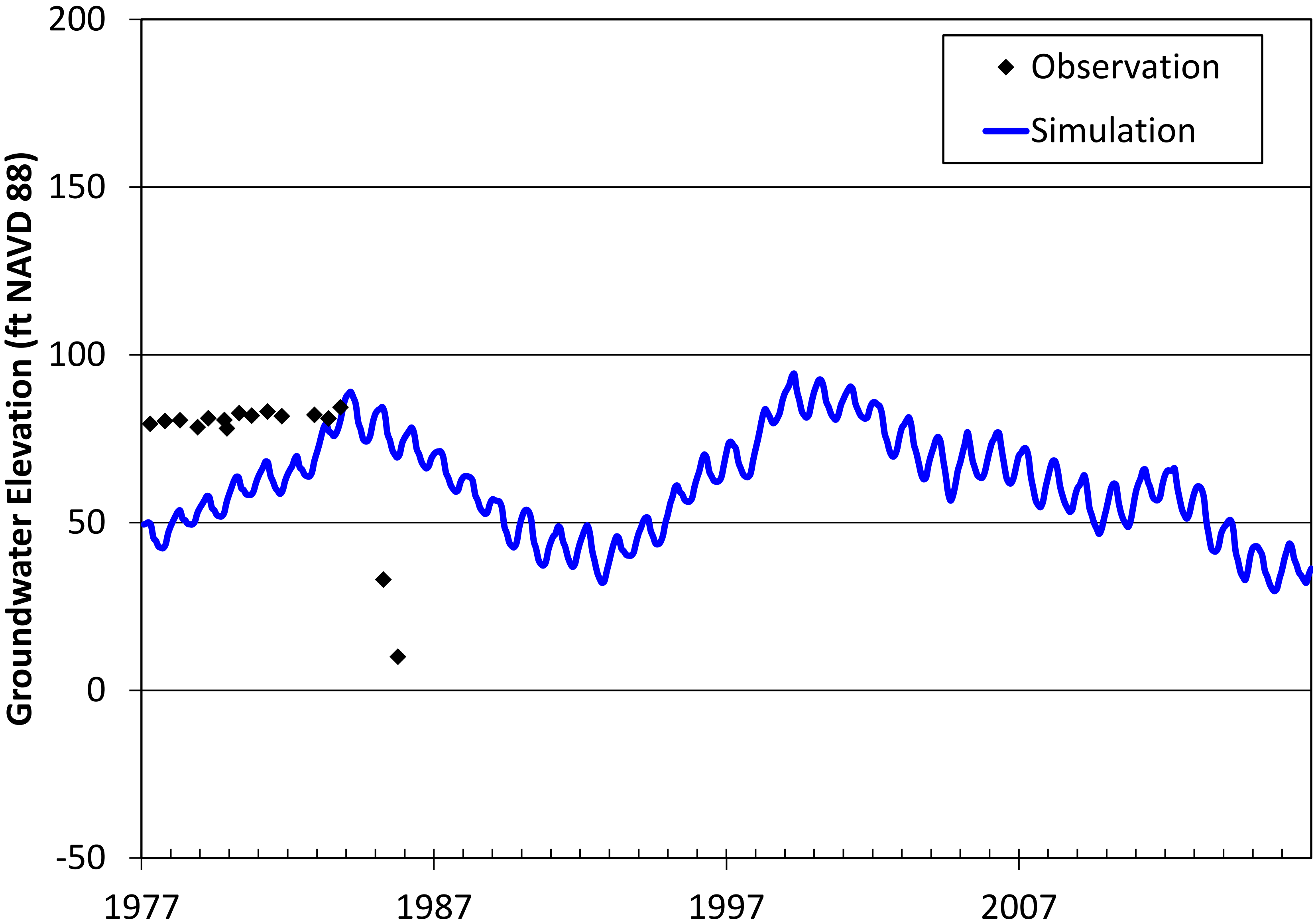
11N35W11C02



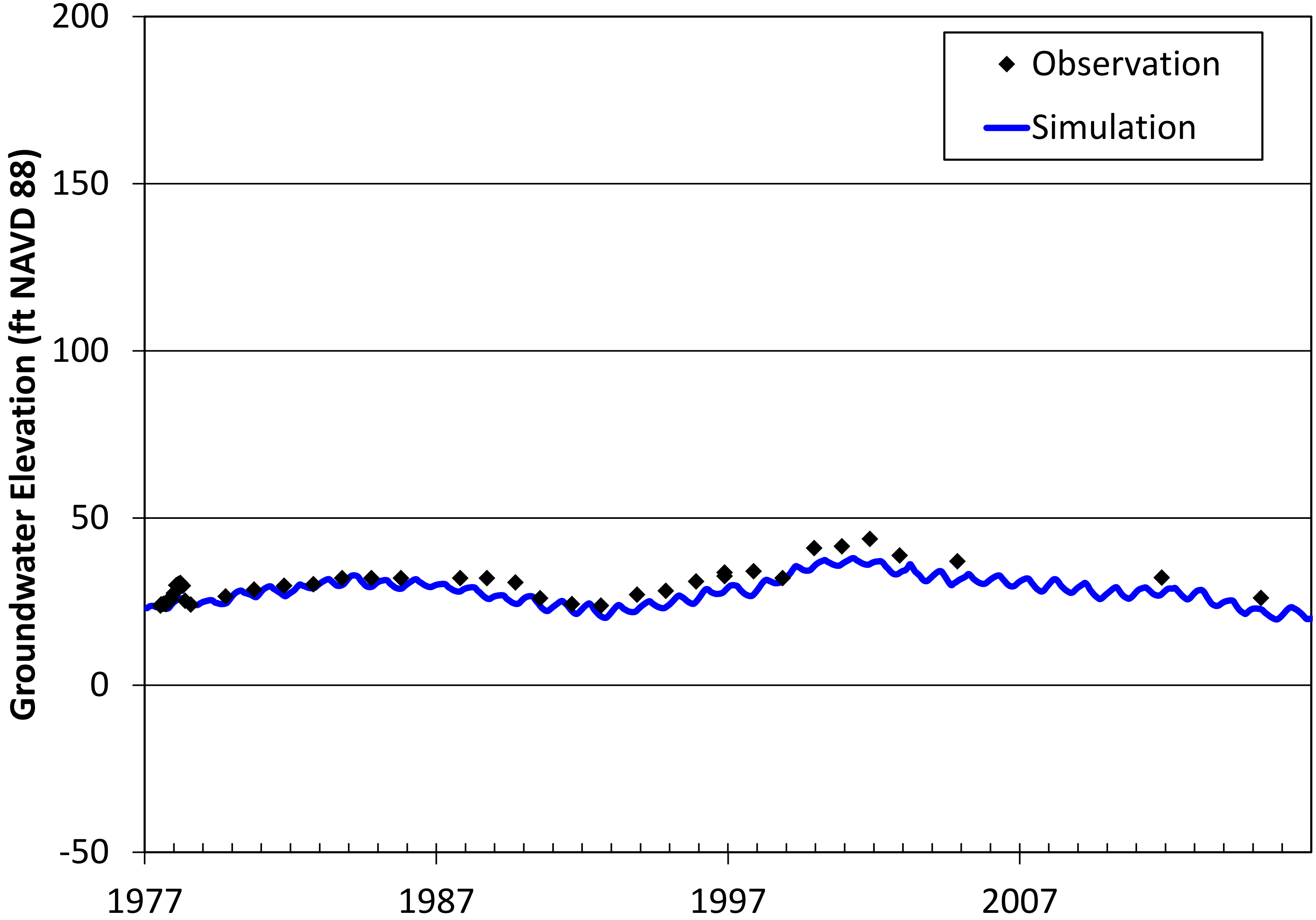
32S13E30K19



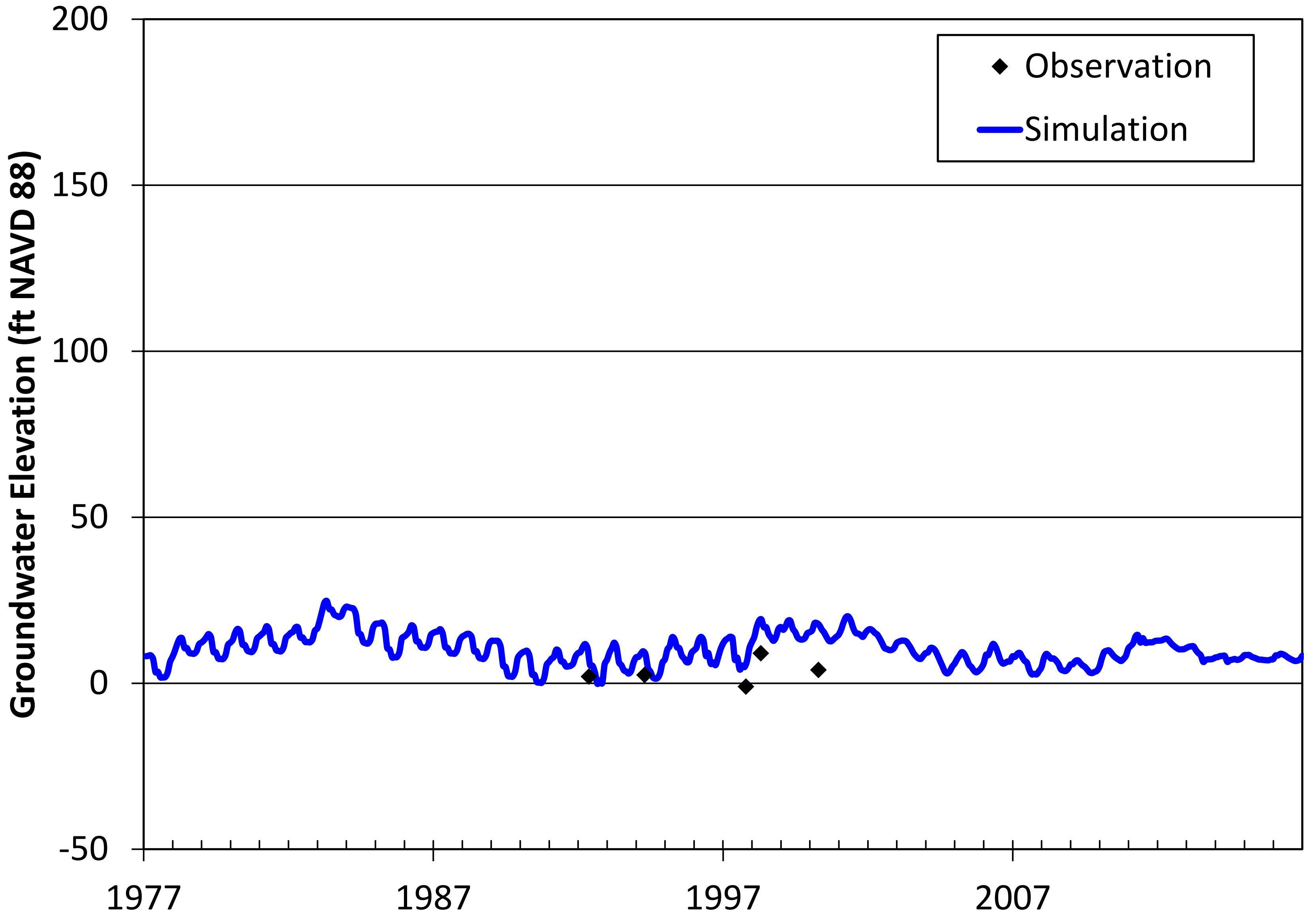
11N34W18P01

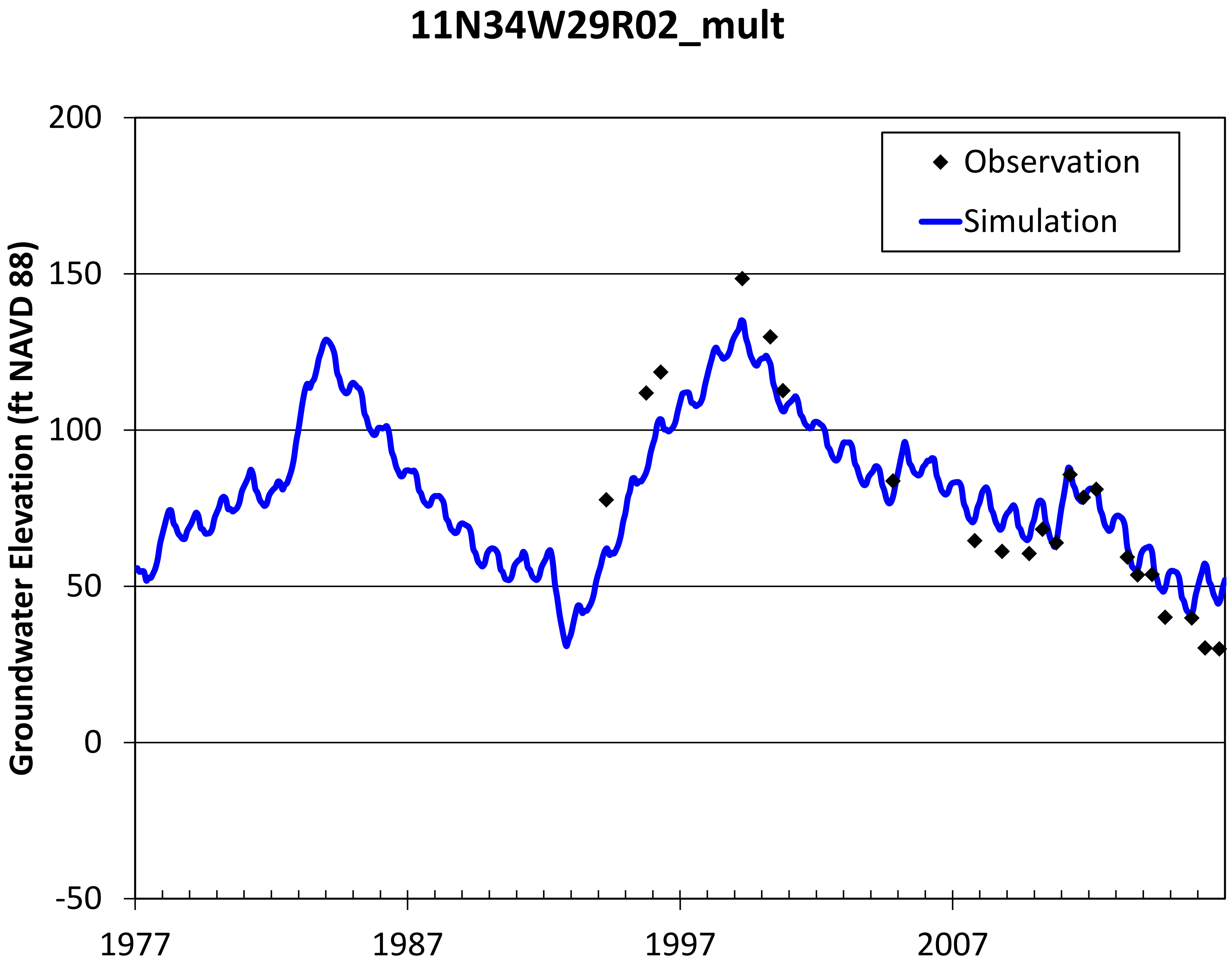


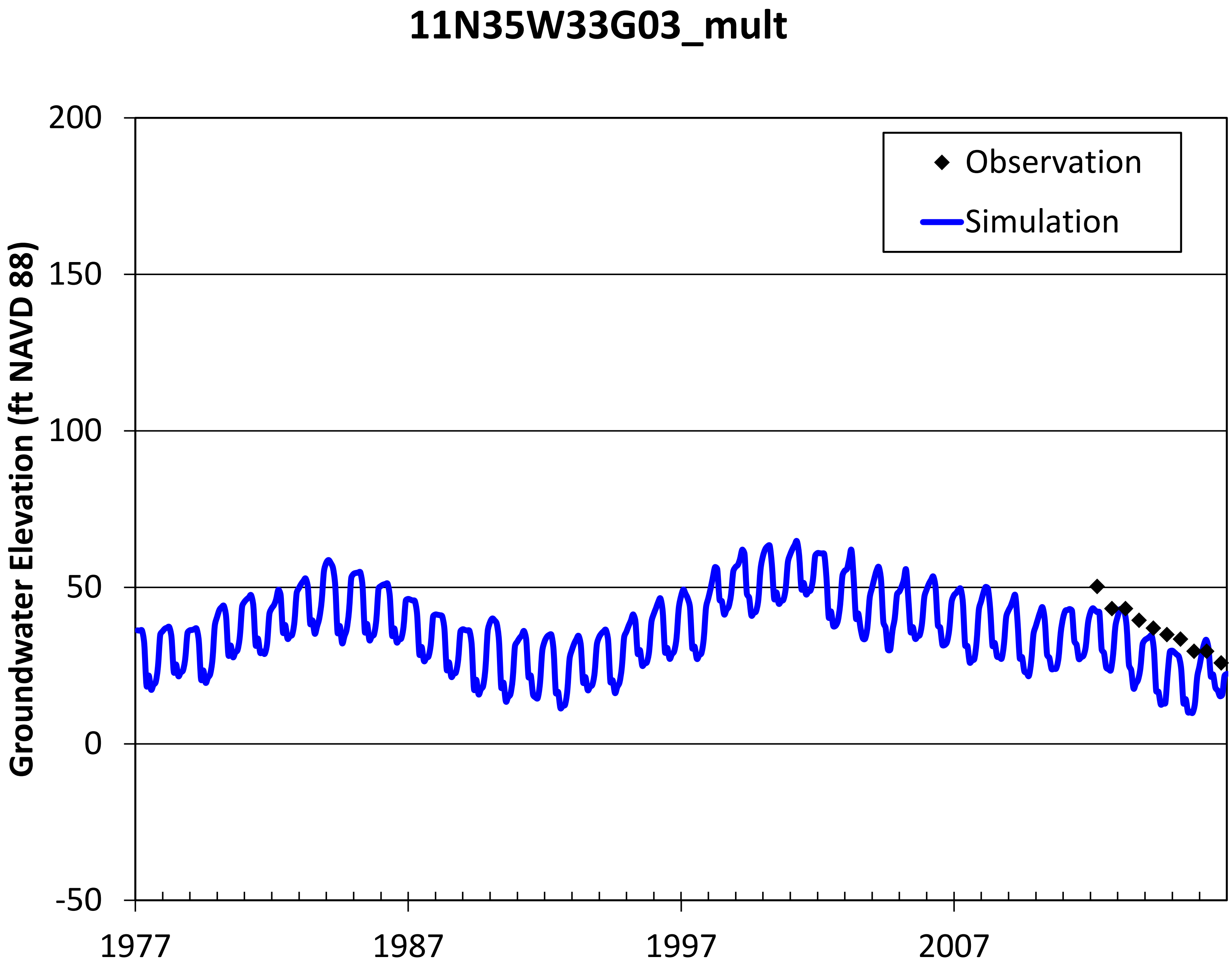
11N36W35J03



32S13E29E03




11N34W29R02_mult
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007


11N35W33G03_mult
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
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100
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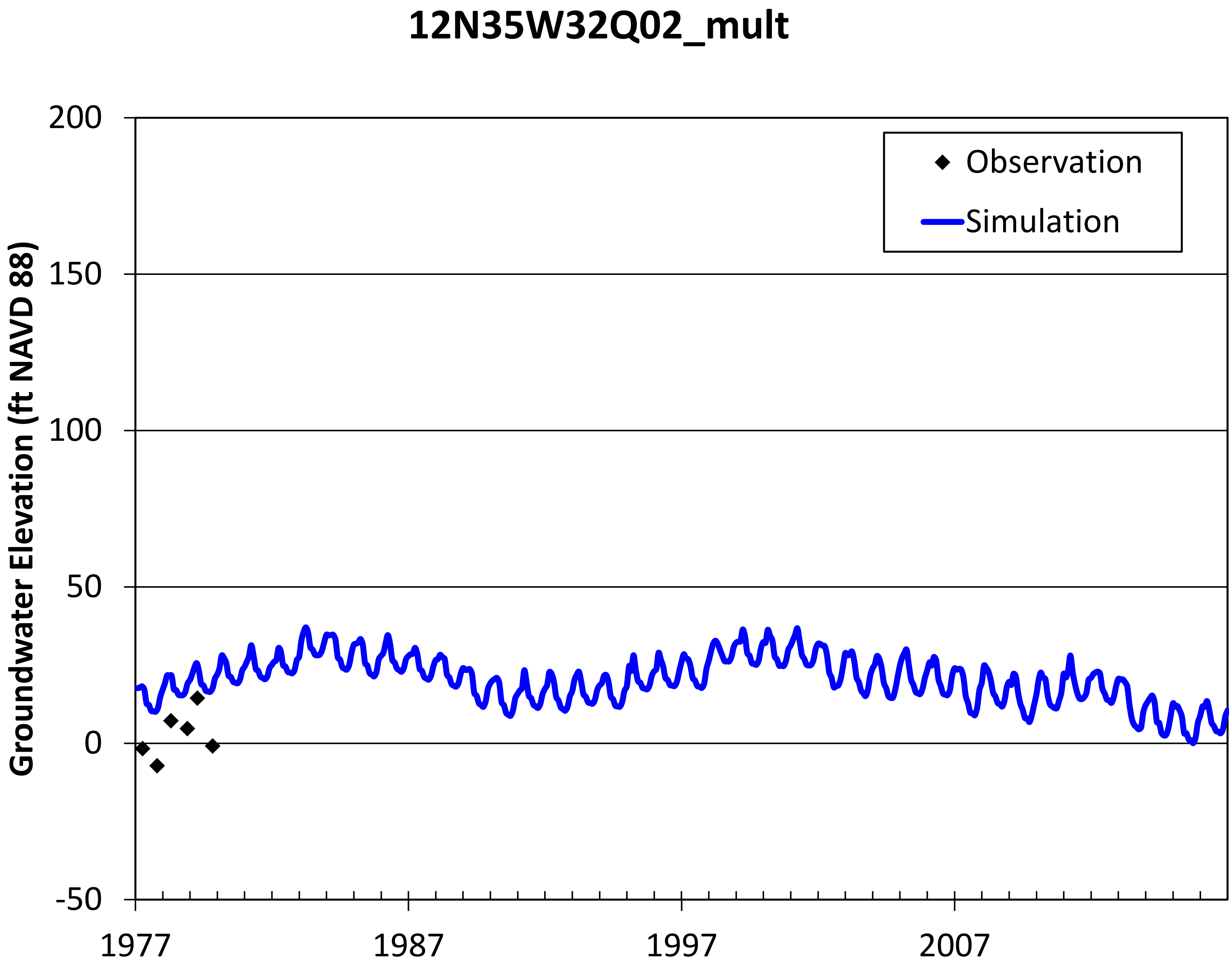
-50
1977
1987
1997
2007


12N35W32Q02_mult
Groundwater Elevation (ft NAVD 88)
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150
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50
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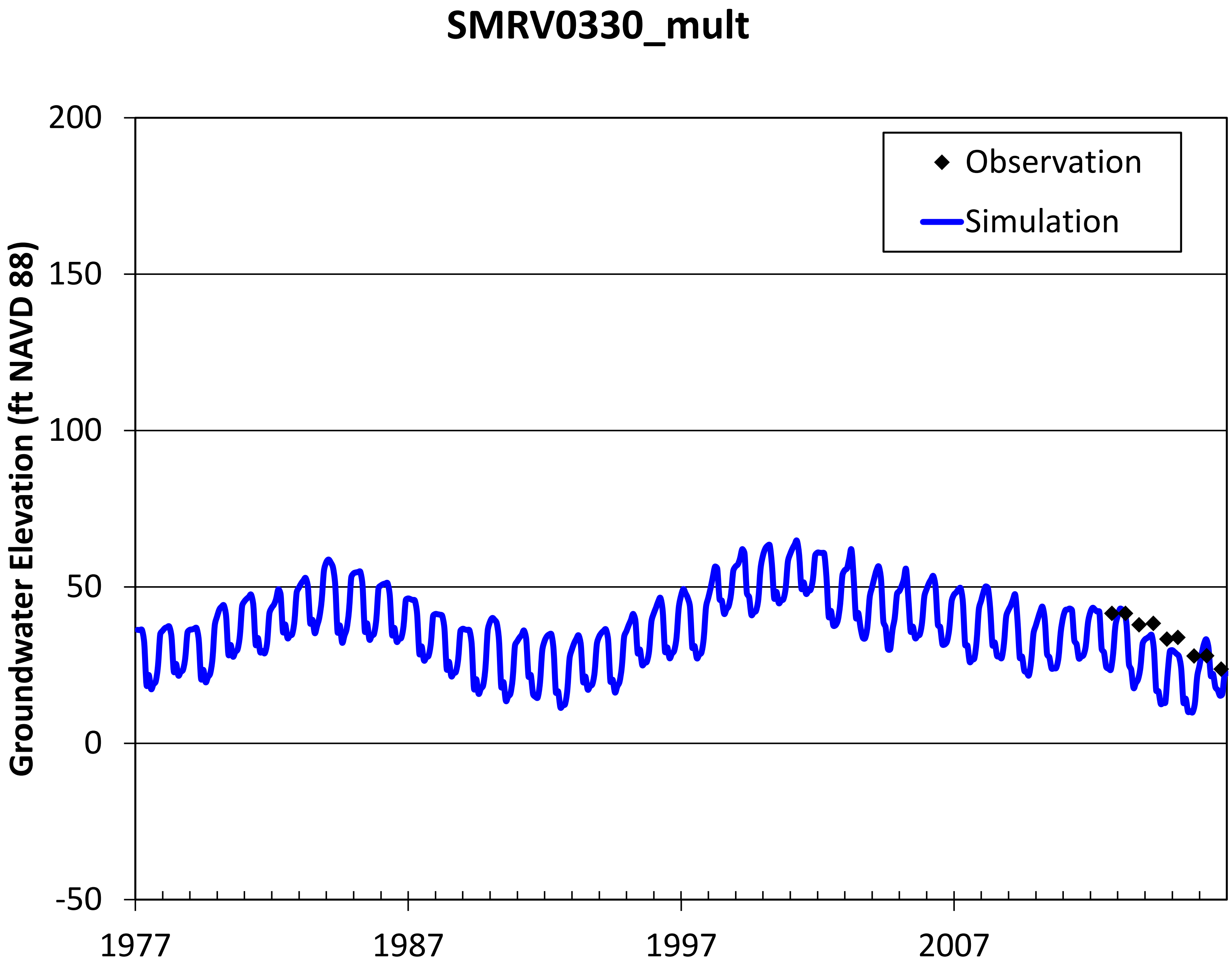
-50
1977
1987
1997
2007
Observation
Simulation


SMRV0330_mult
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
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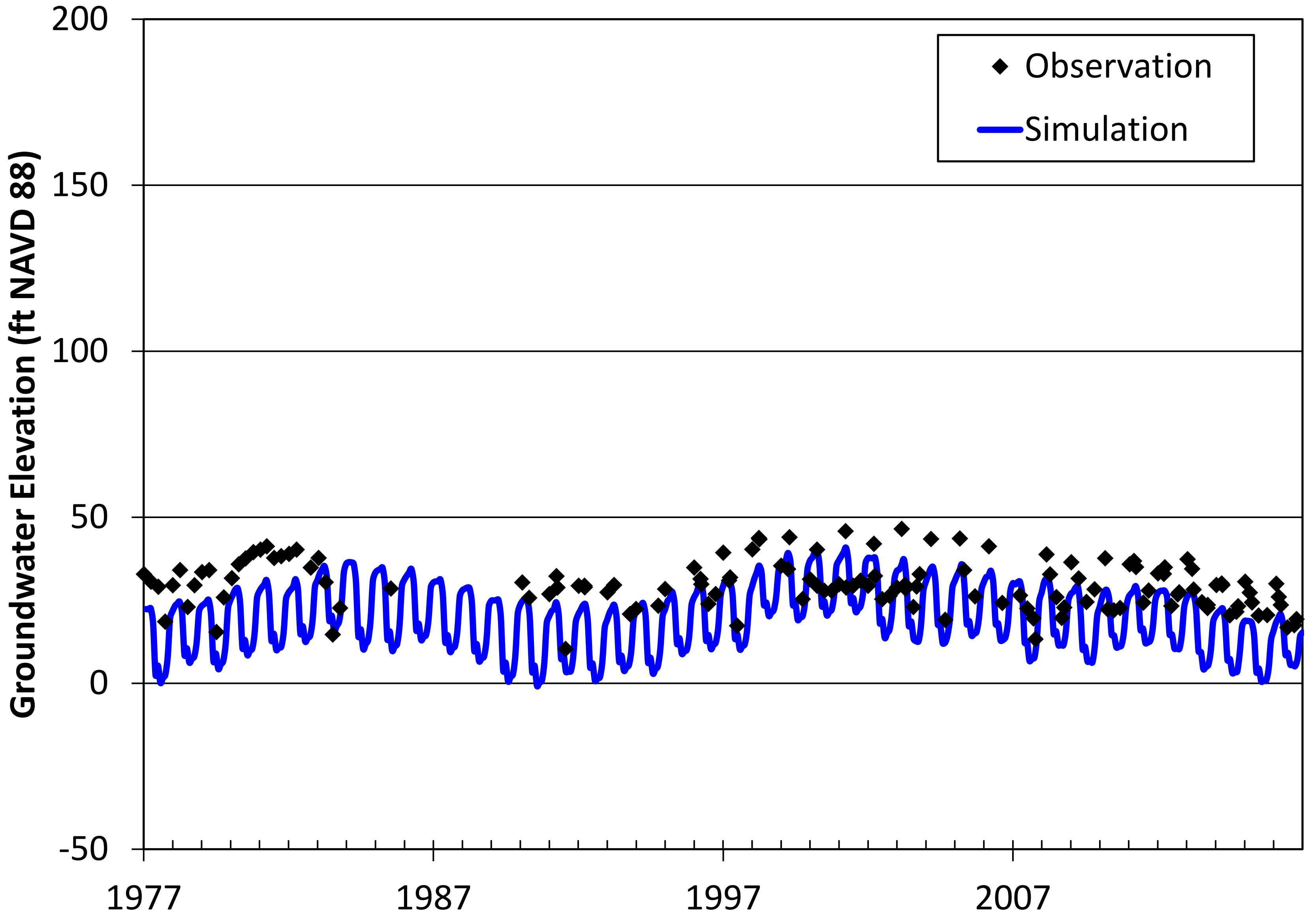
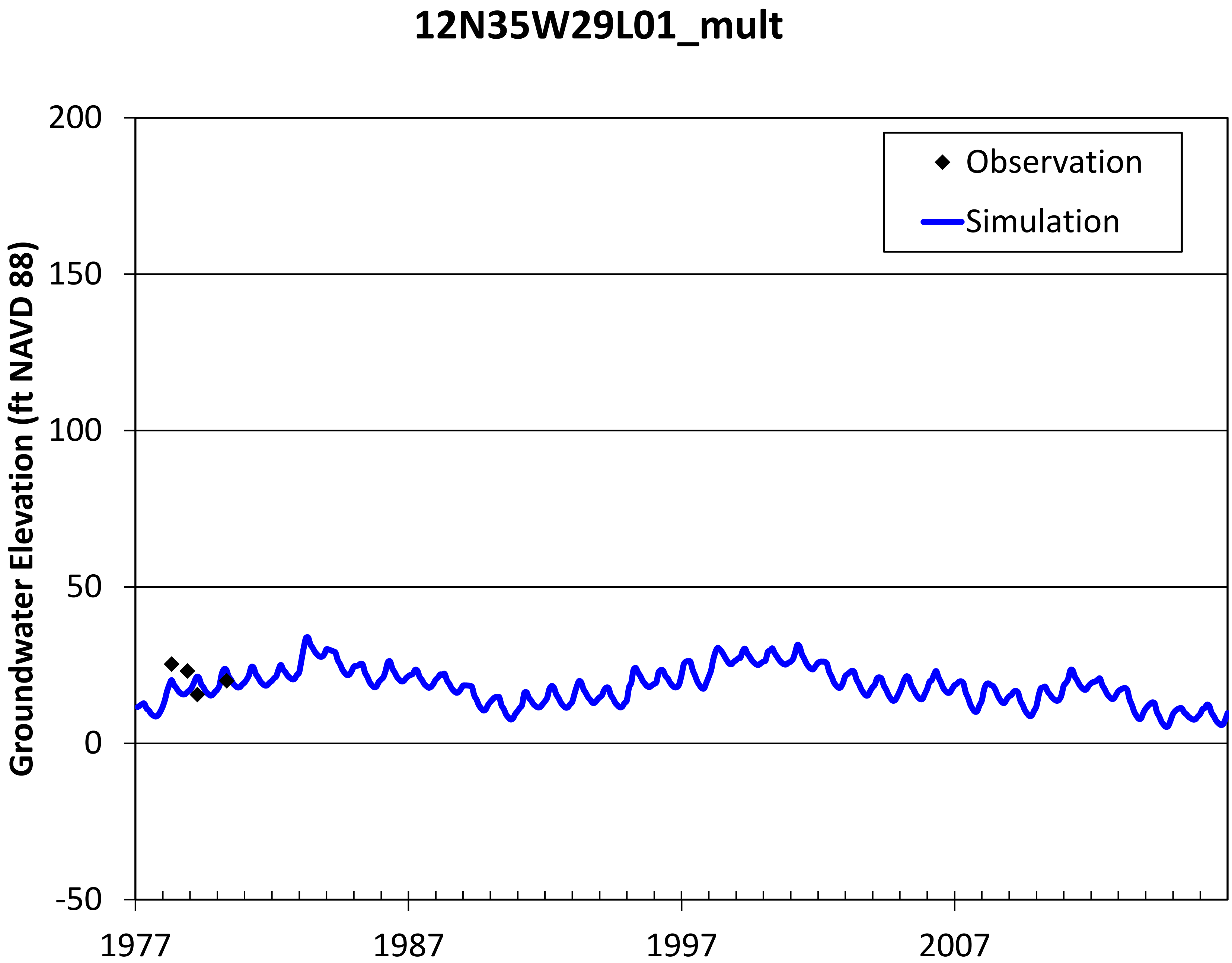
1977
1987
1997
2007

11N35W20E01_mult




12N35W29L01_mult
Groundwater Elevation (ft NAVD 88)
200
150
100
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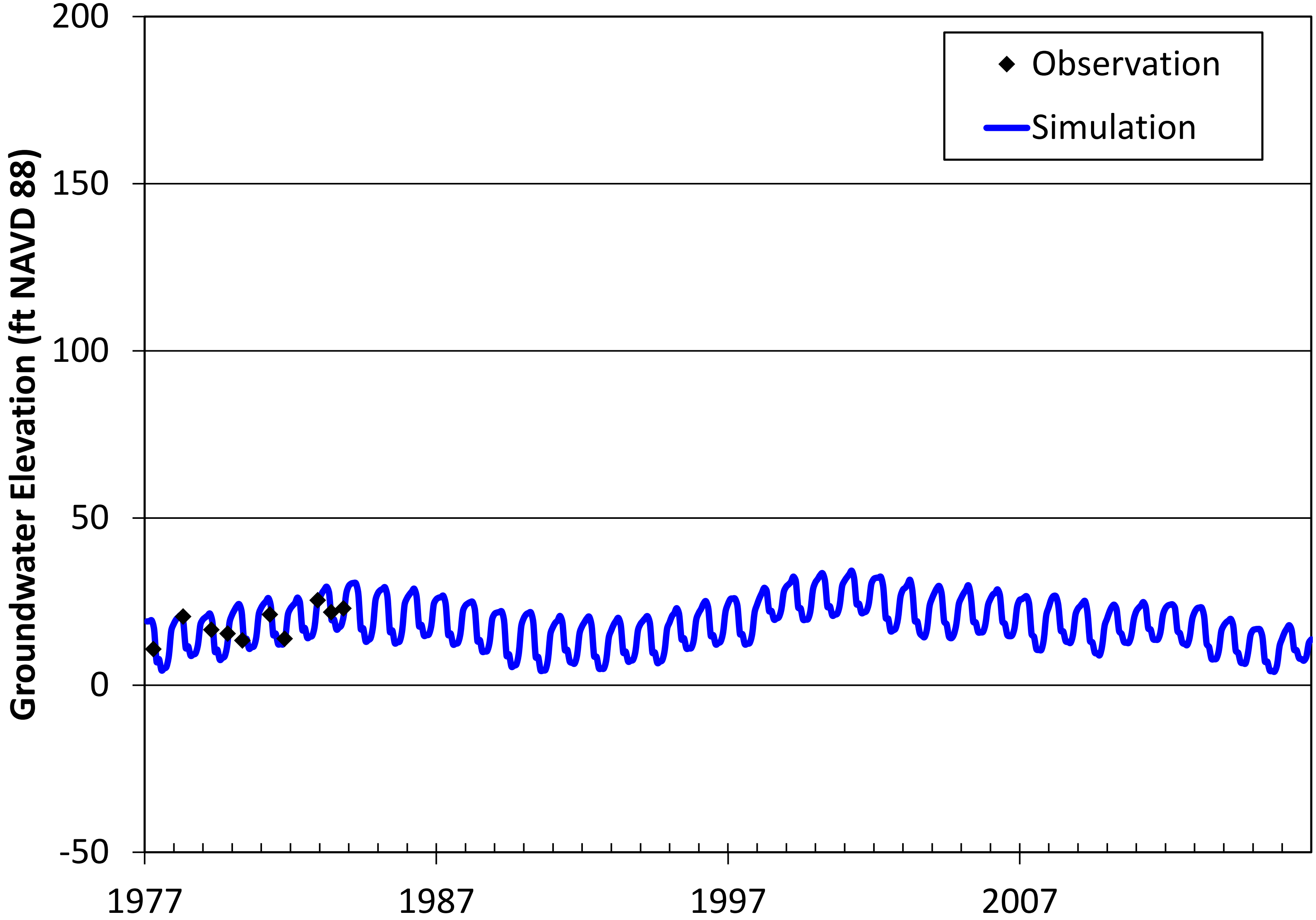
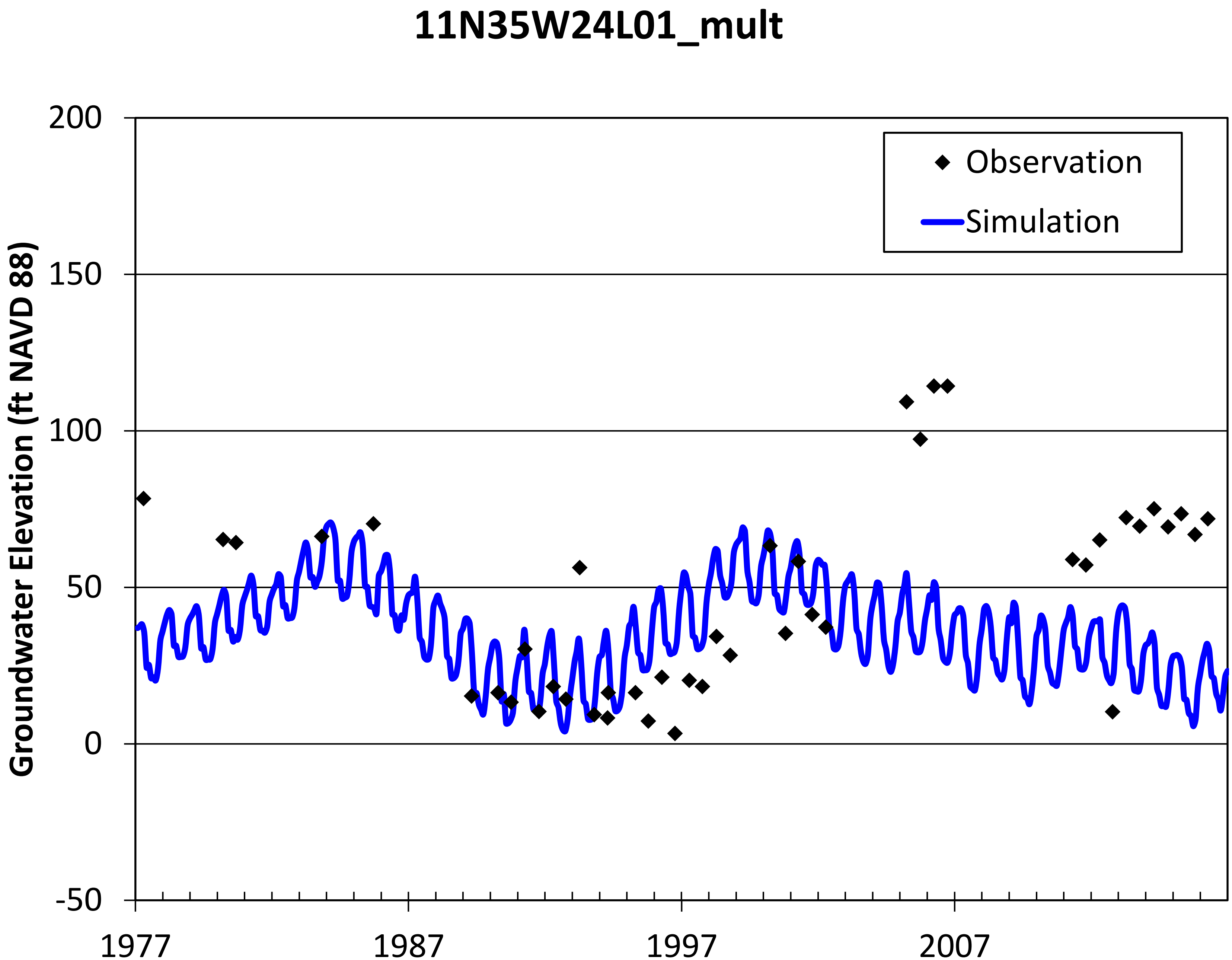
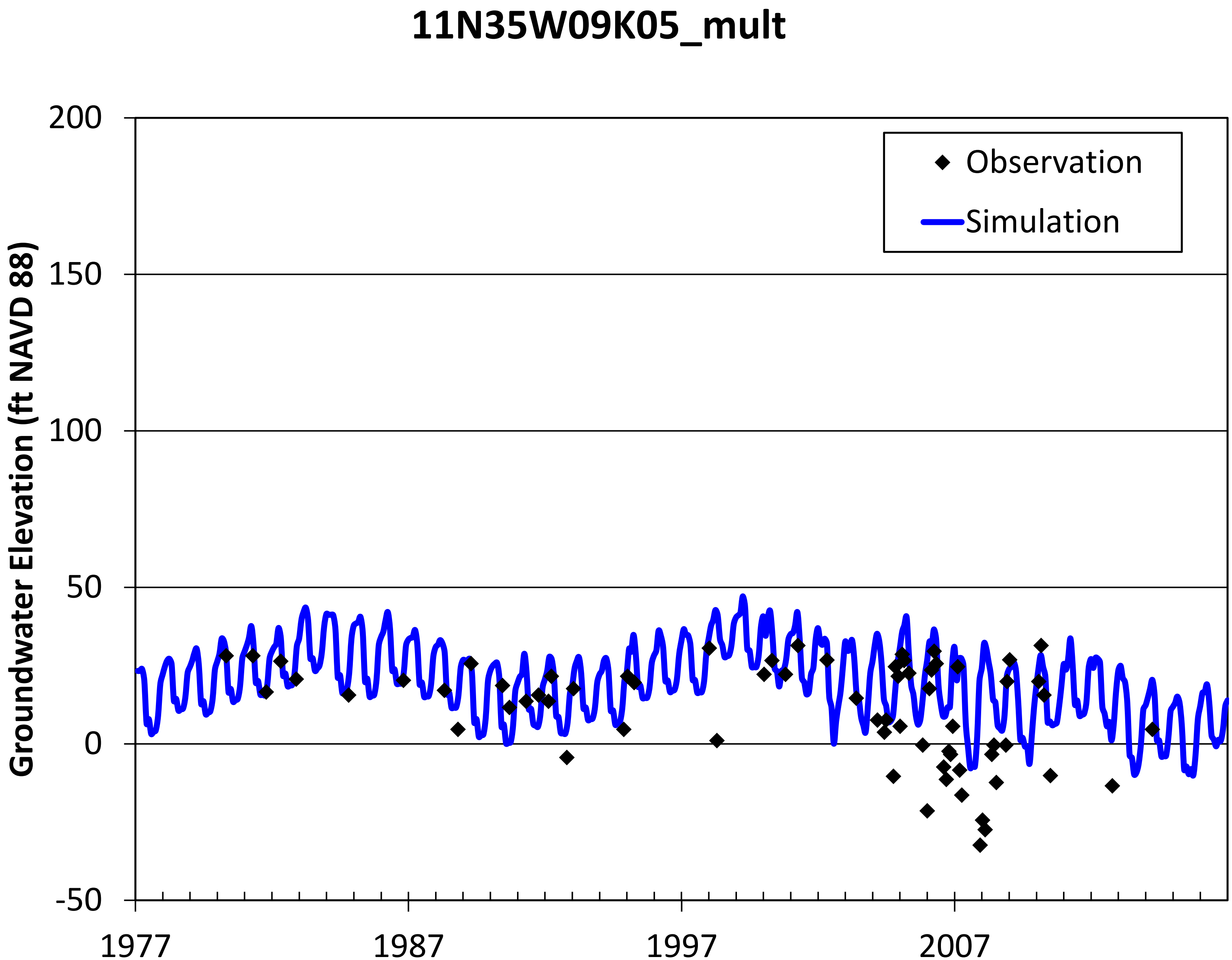
0
-50
1977
1987
1997
2007
Observation
Simulation

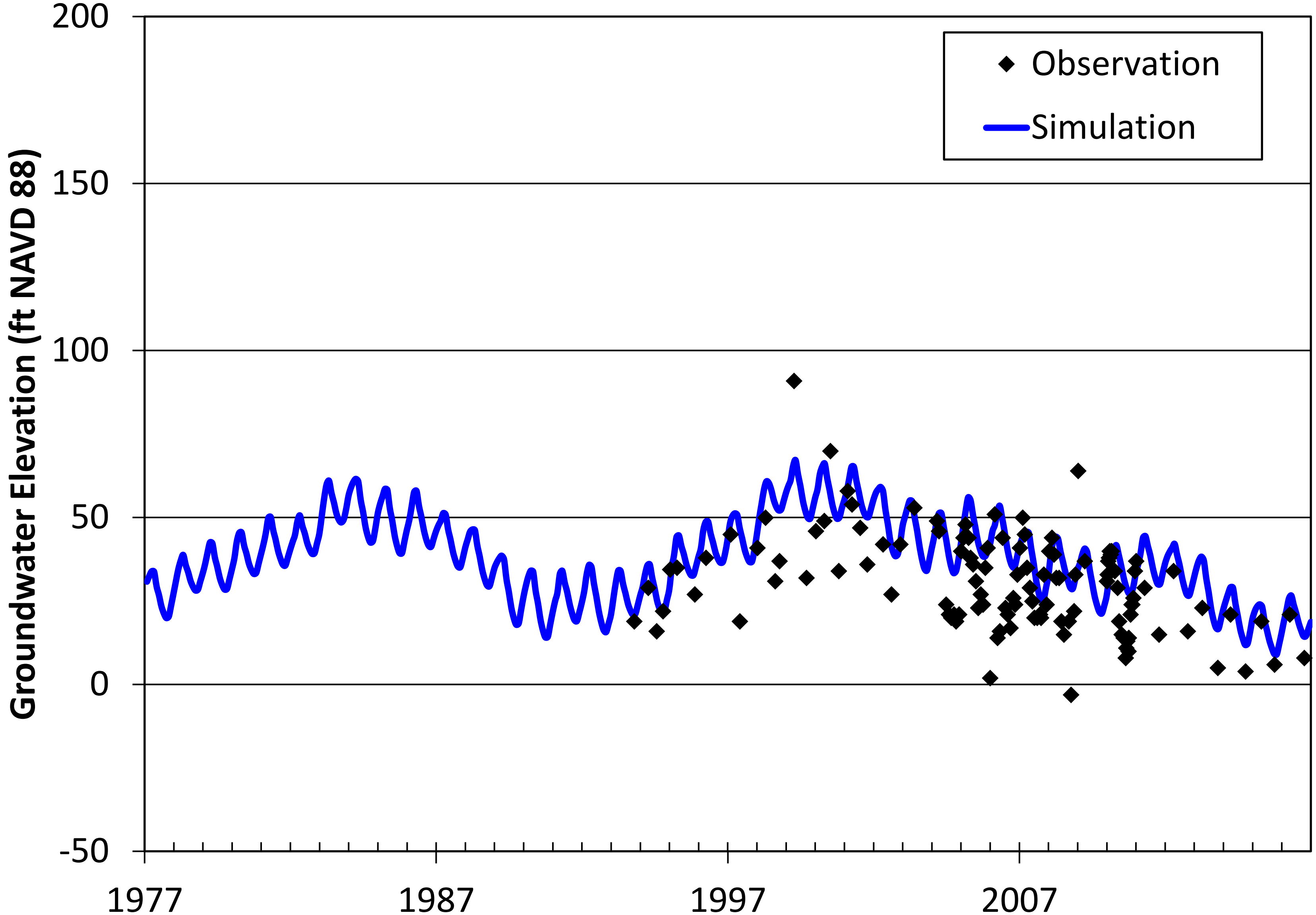
11N35W19E02_mult



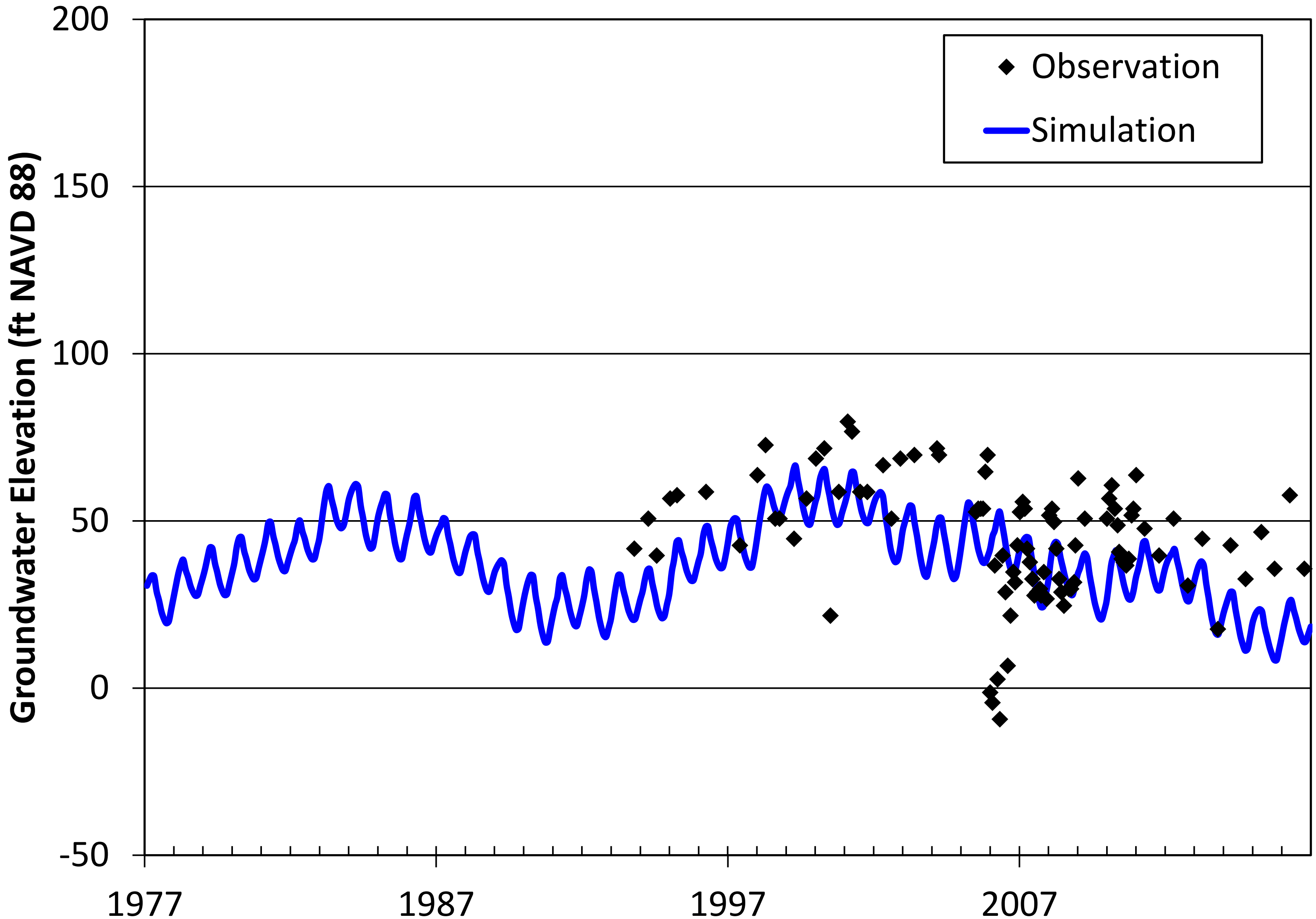

11N35W24L01_mult
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007

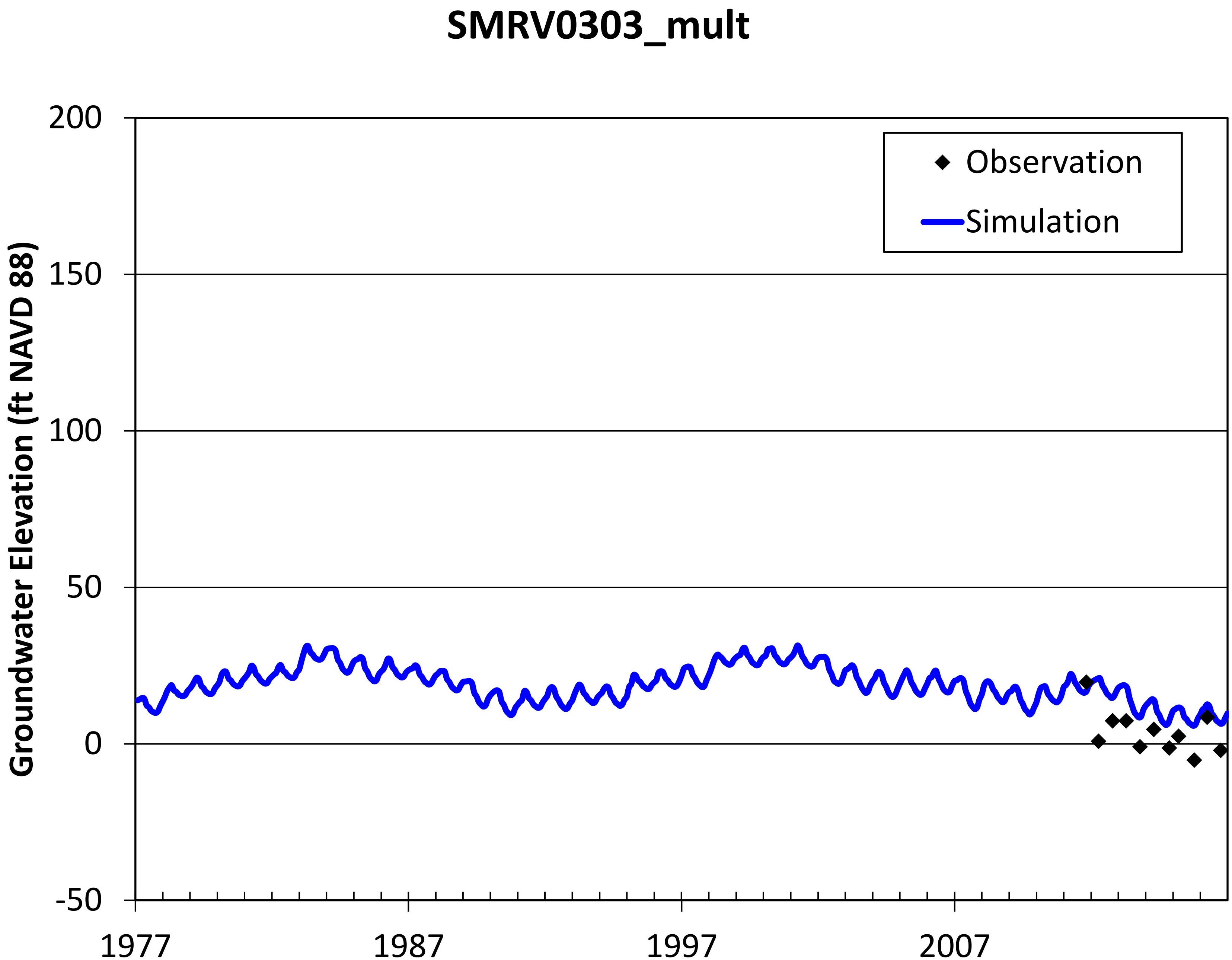

11N35W09K05_mult
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007

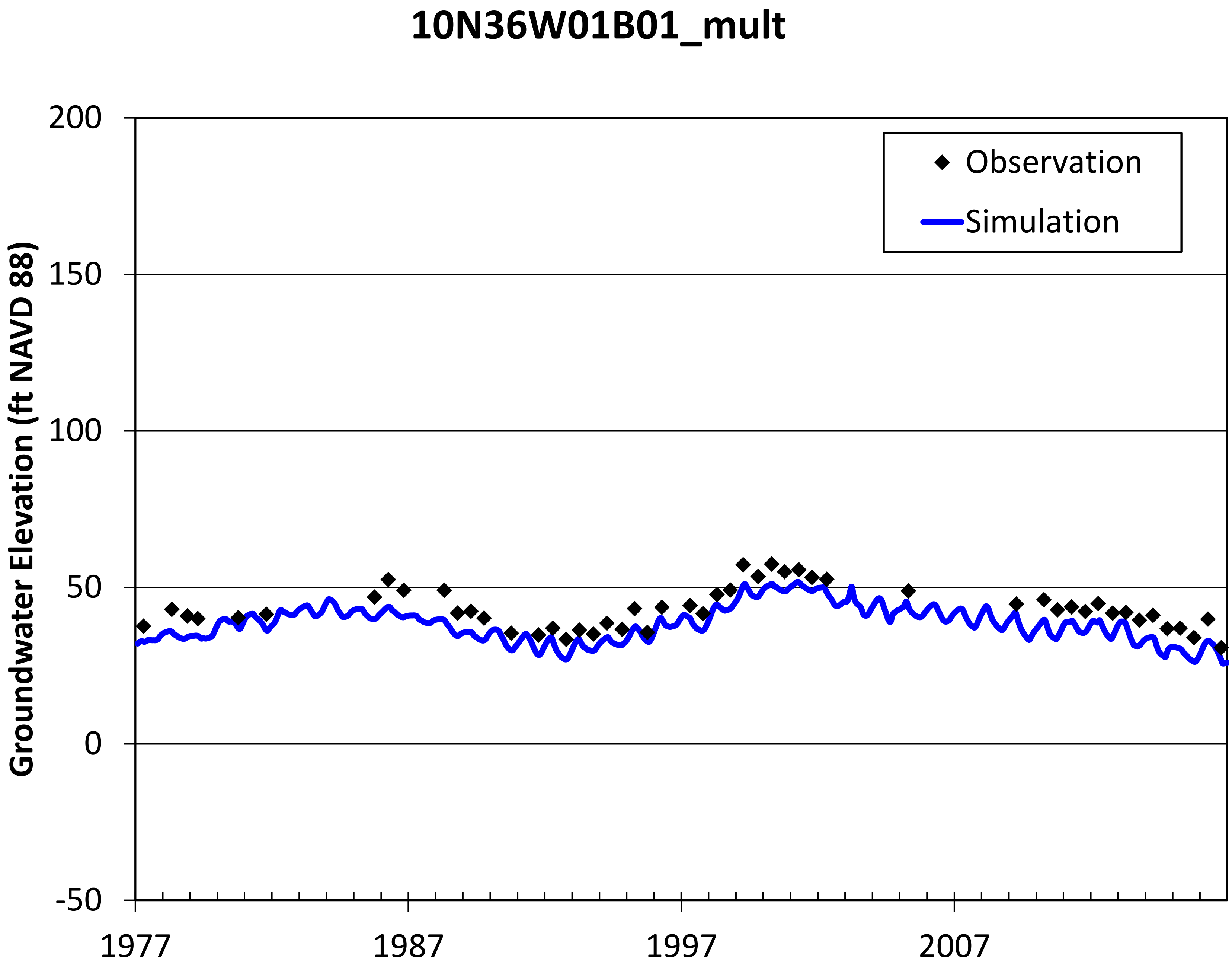
11N35W13M02_mult



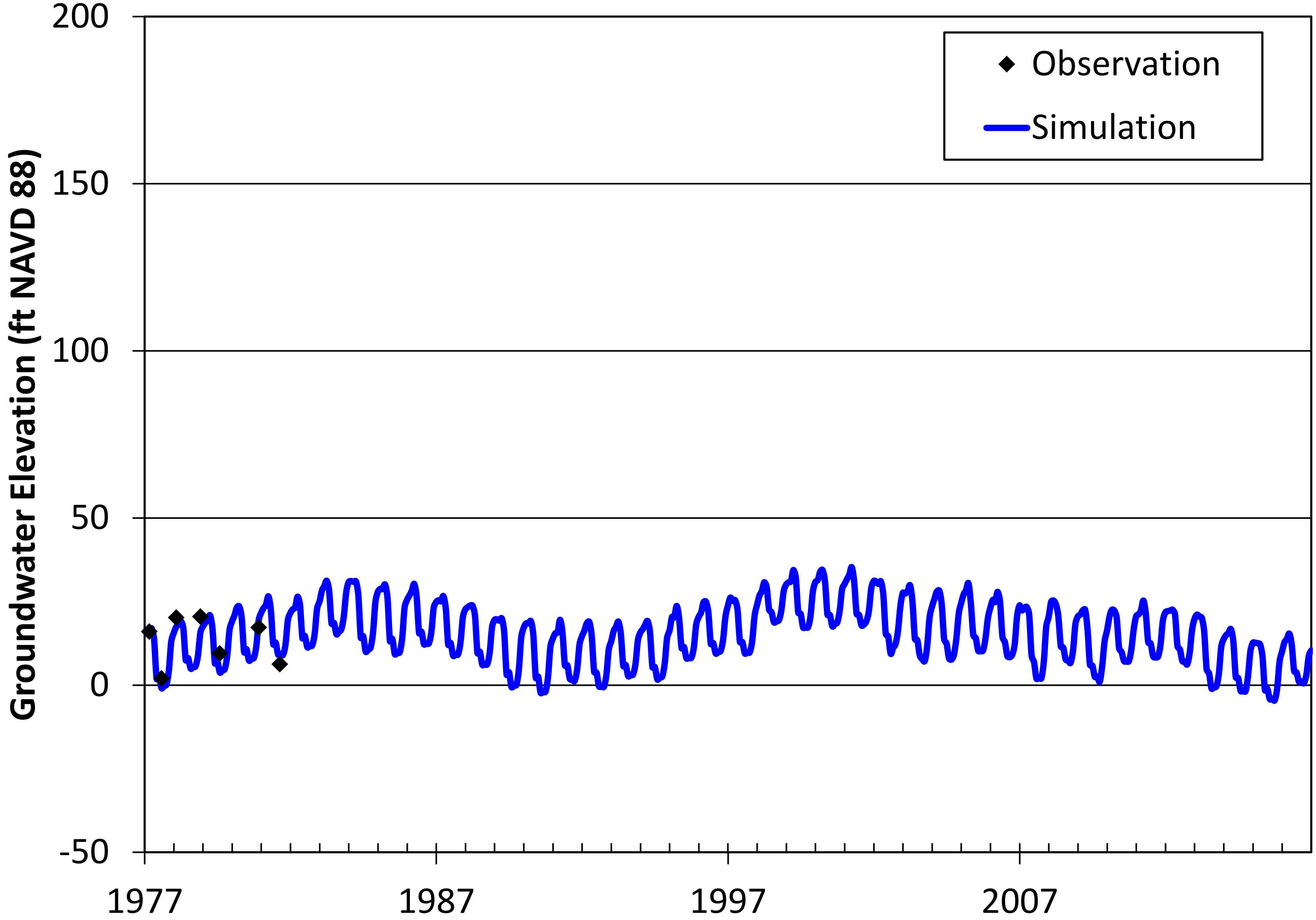
11N35W14J01_mult

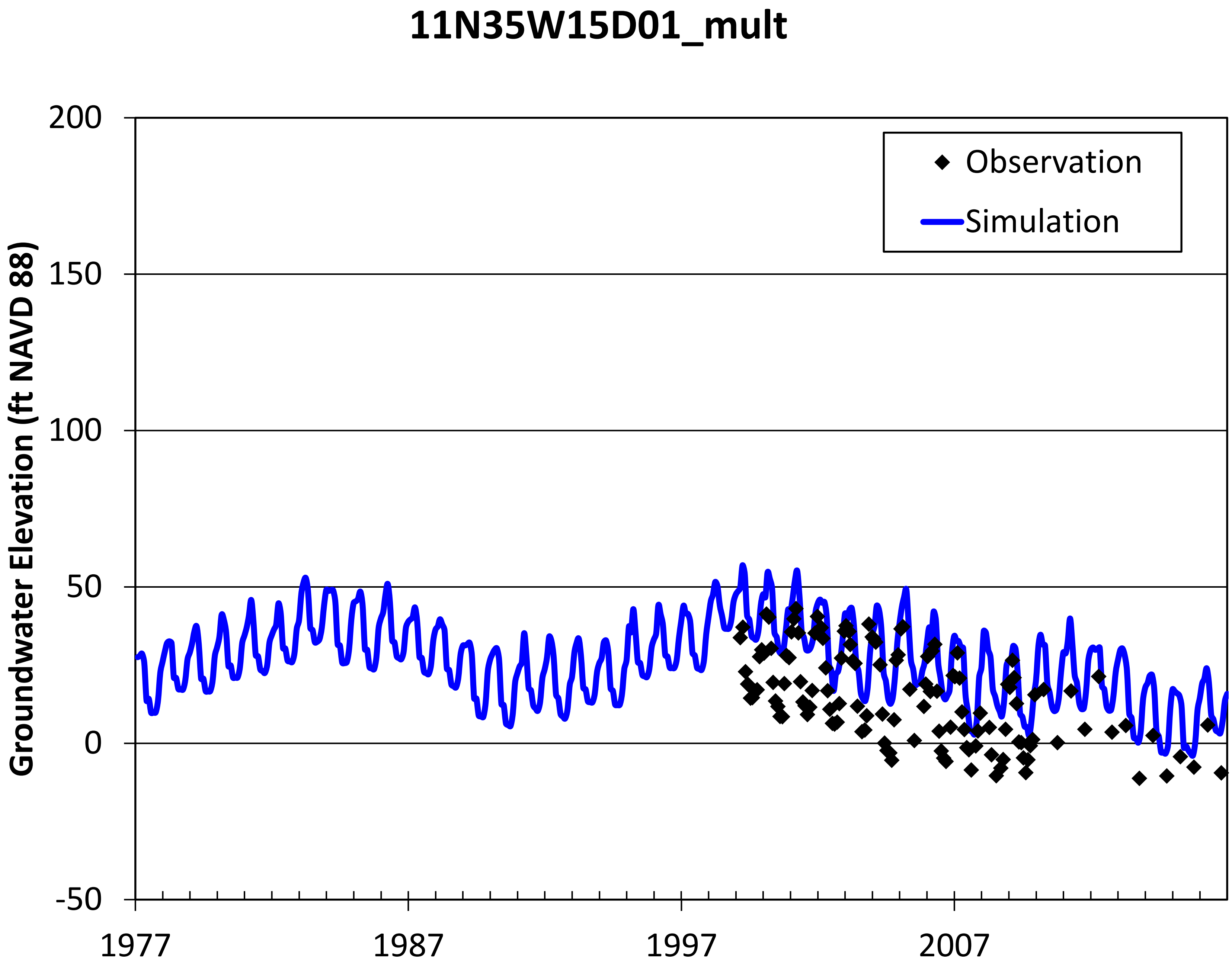


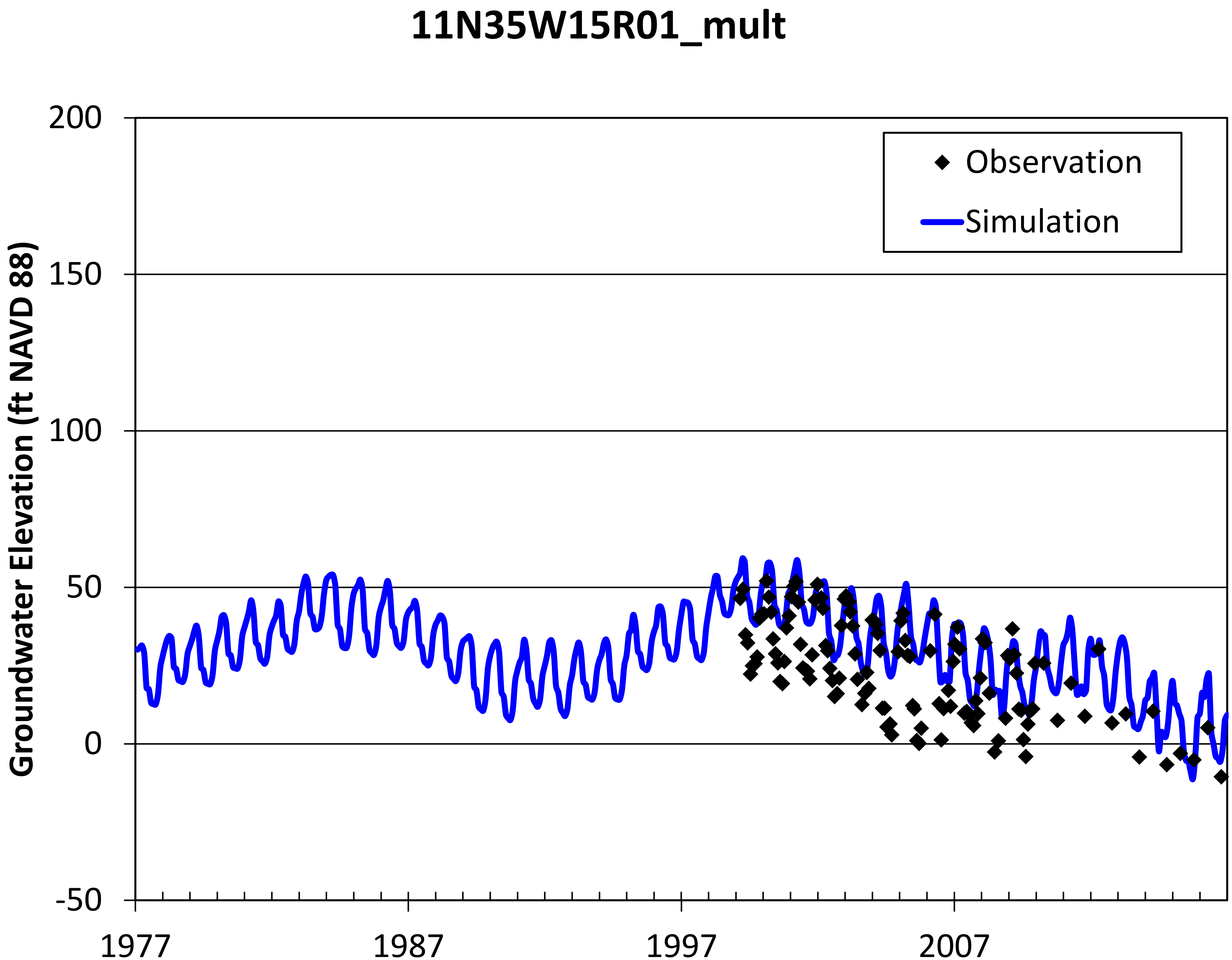

SMRV0303_mult
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007
Observation
Simulation


10N36W01B01_mult
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007

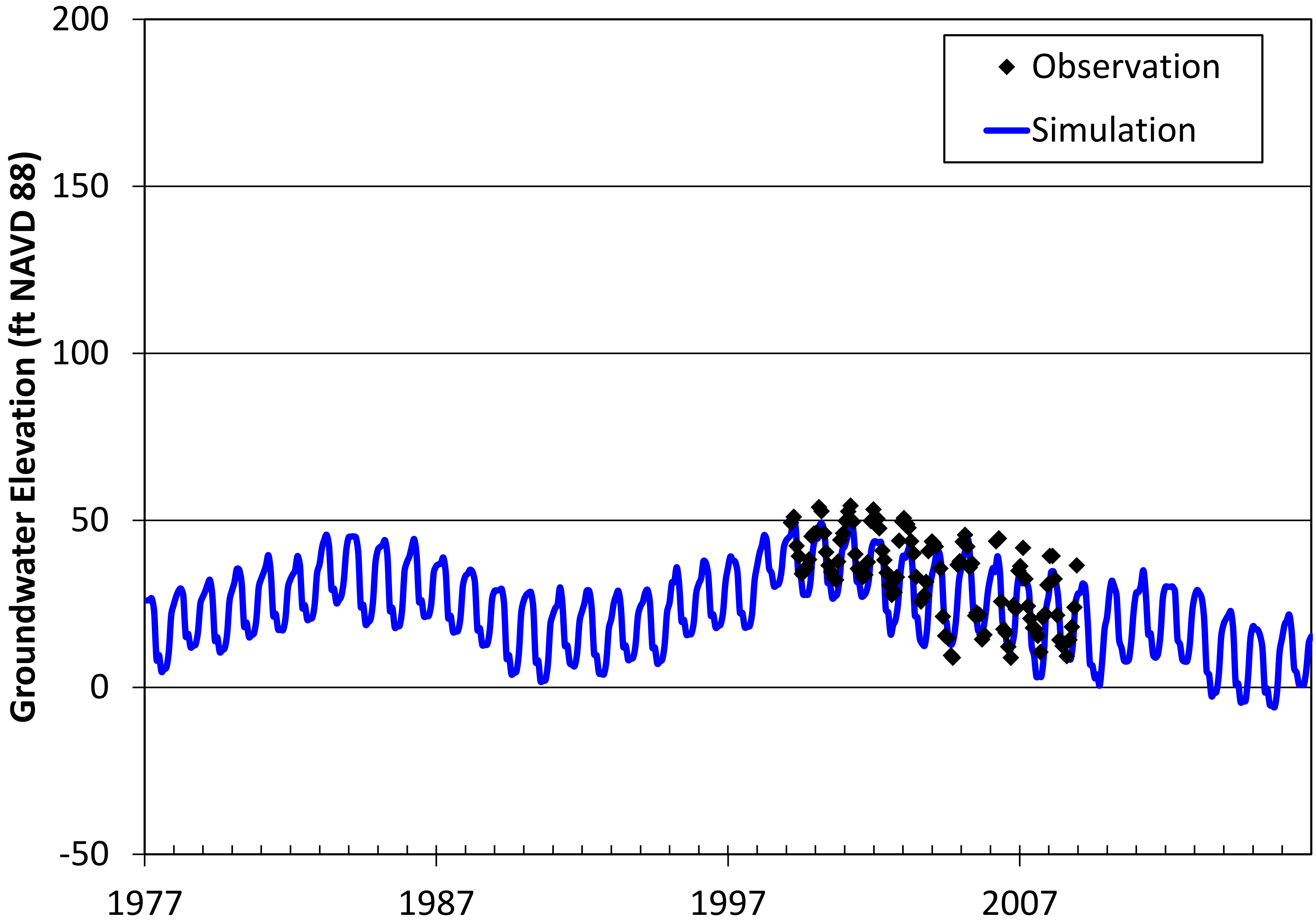
11N35W08N01_mult



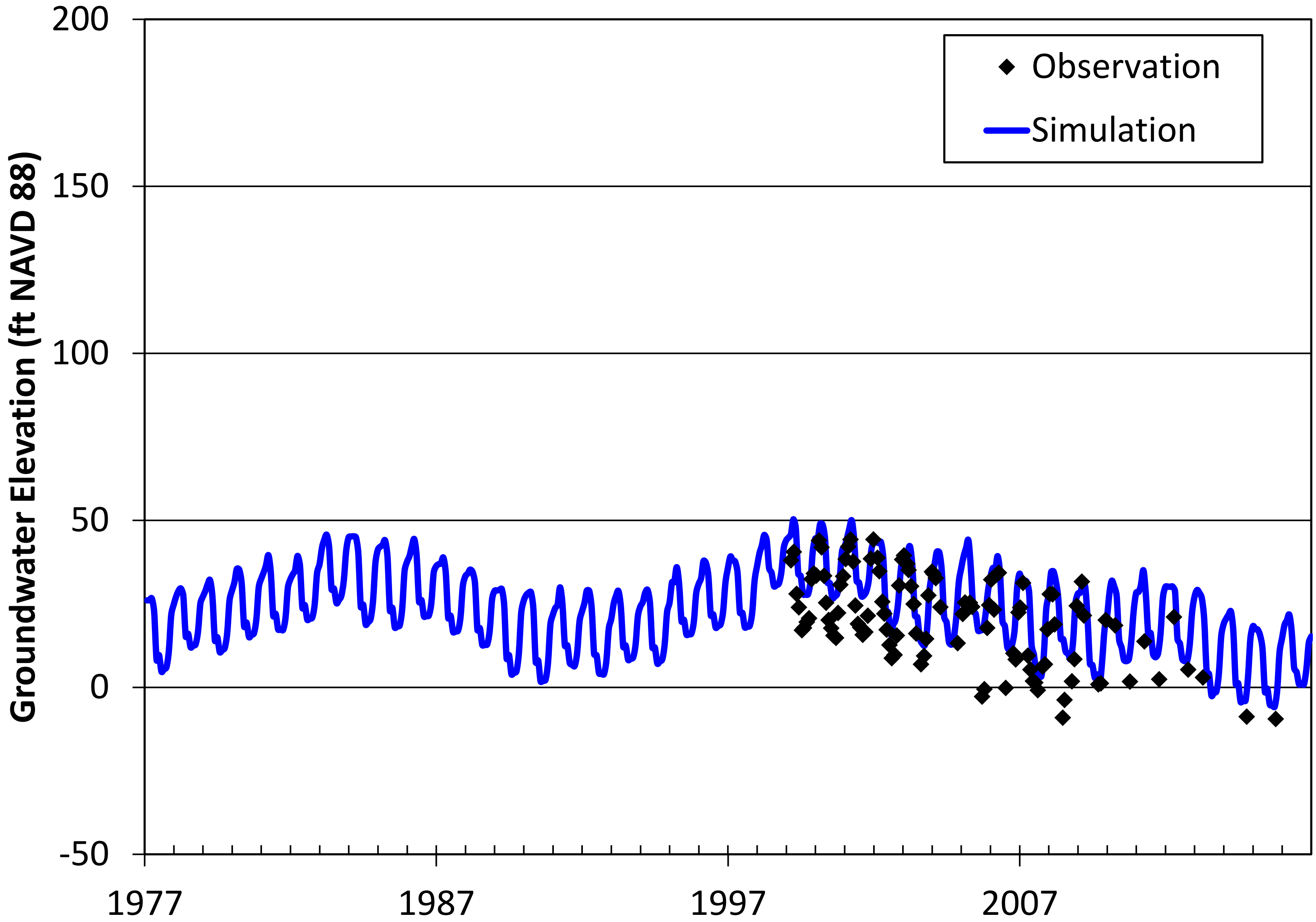

11N35W15D01_mult
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007

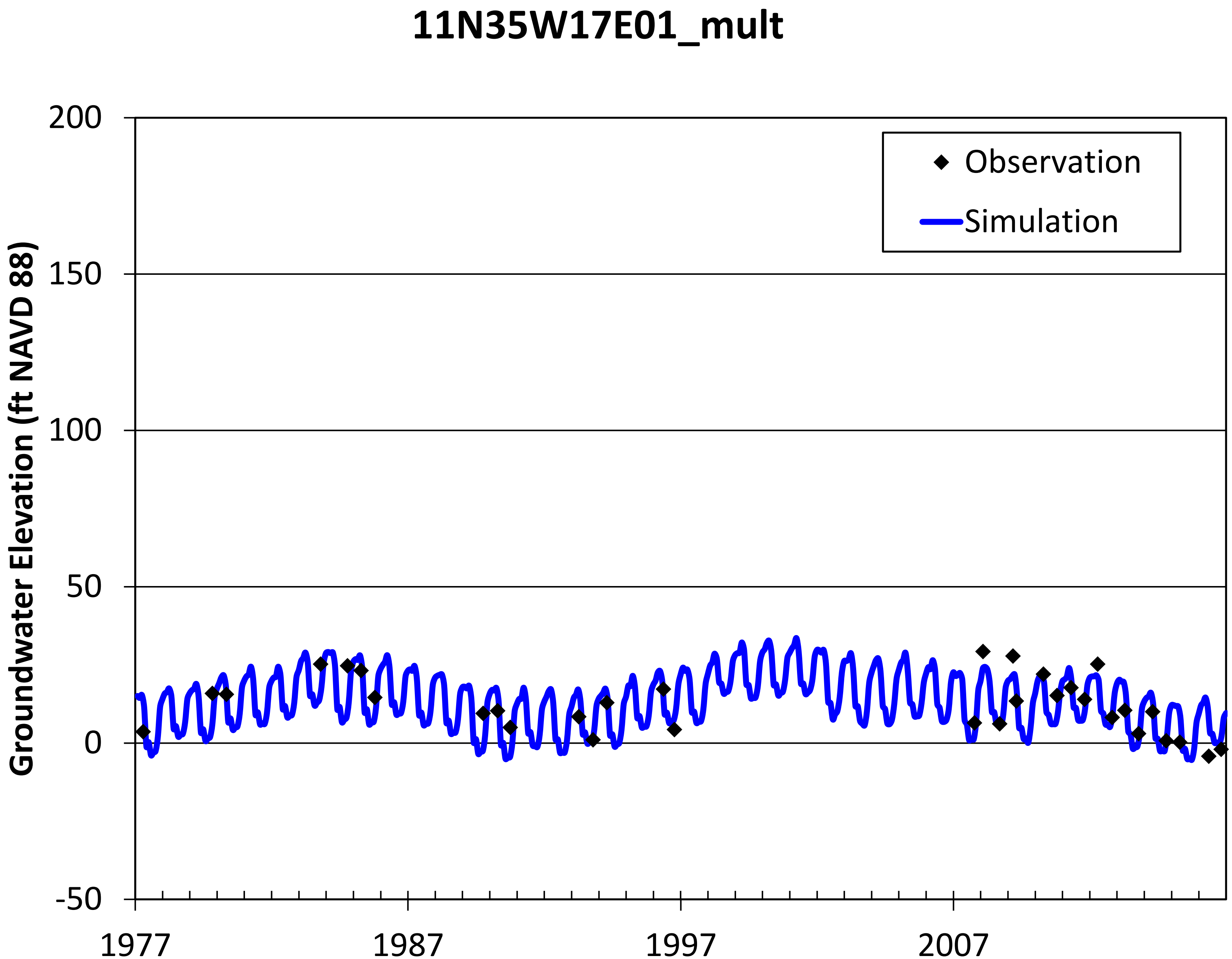

11N35W15R01_mult
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007

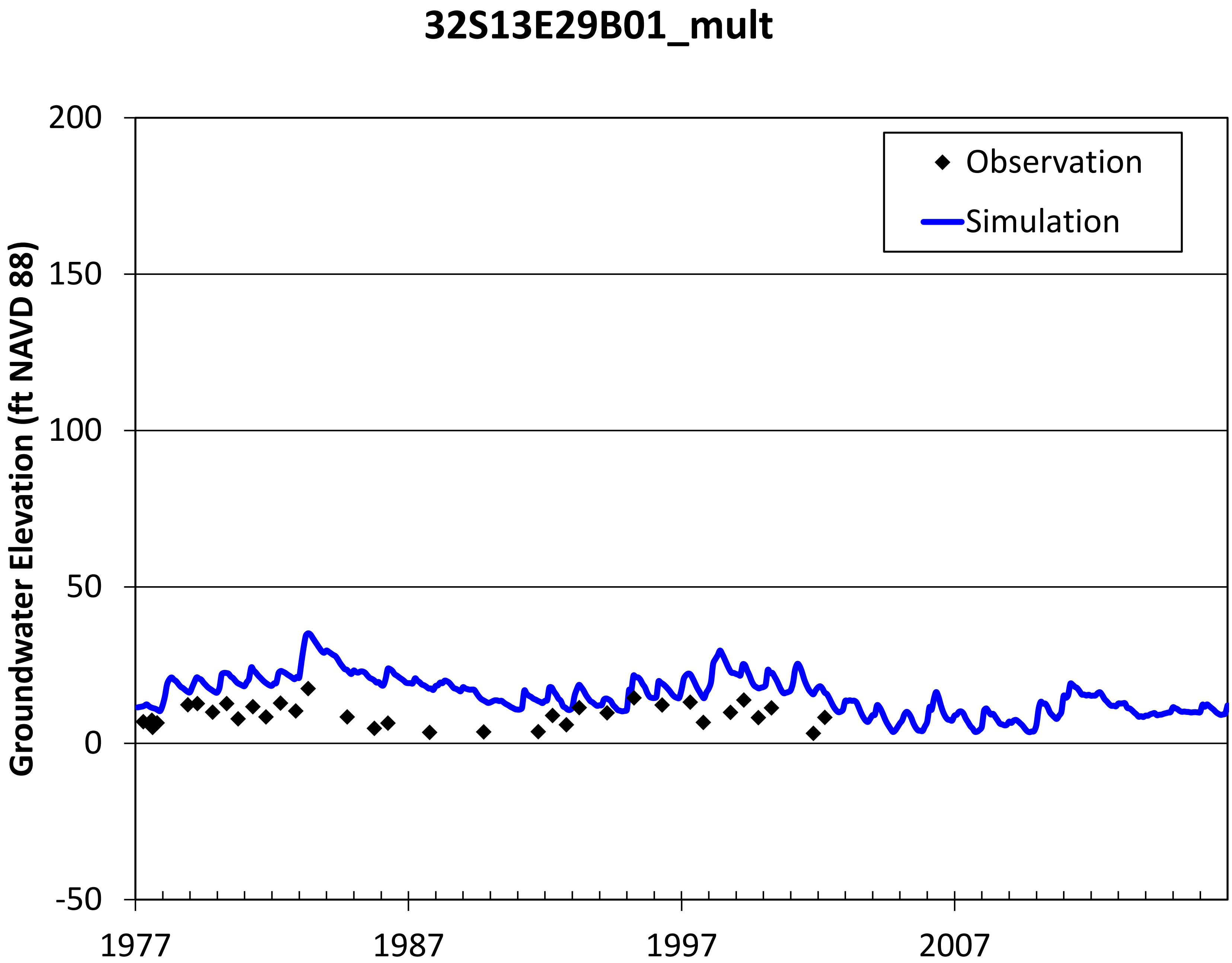
11N35W16Ja_mult

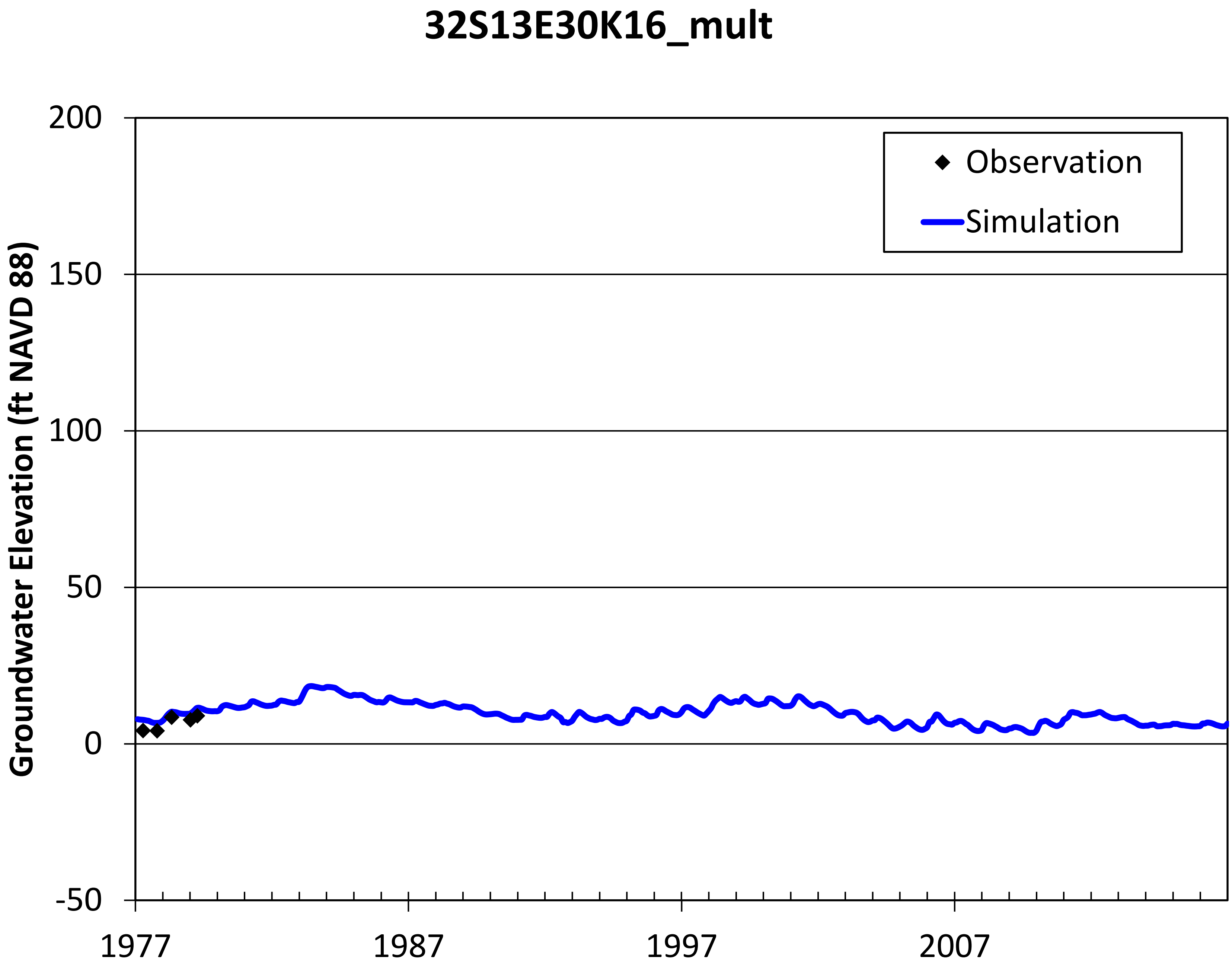


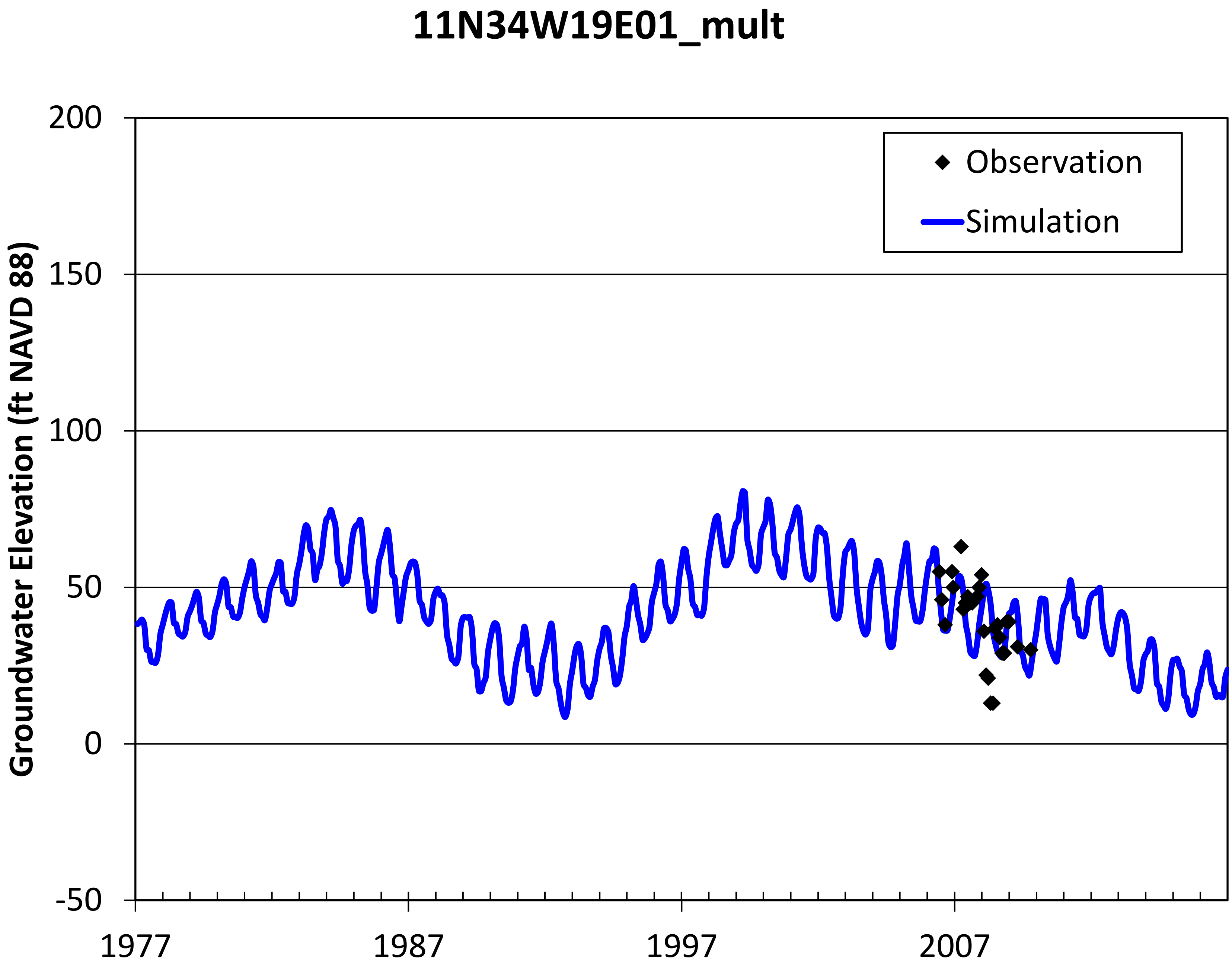
11N35W16Jb_mult




11N35W17E01_mult
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007


32S13E29B01_mult
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007
Observation
Simulation


32S13E30K16_mult
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007


11N34W19E01_mult
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
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150
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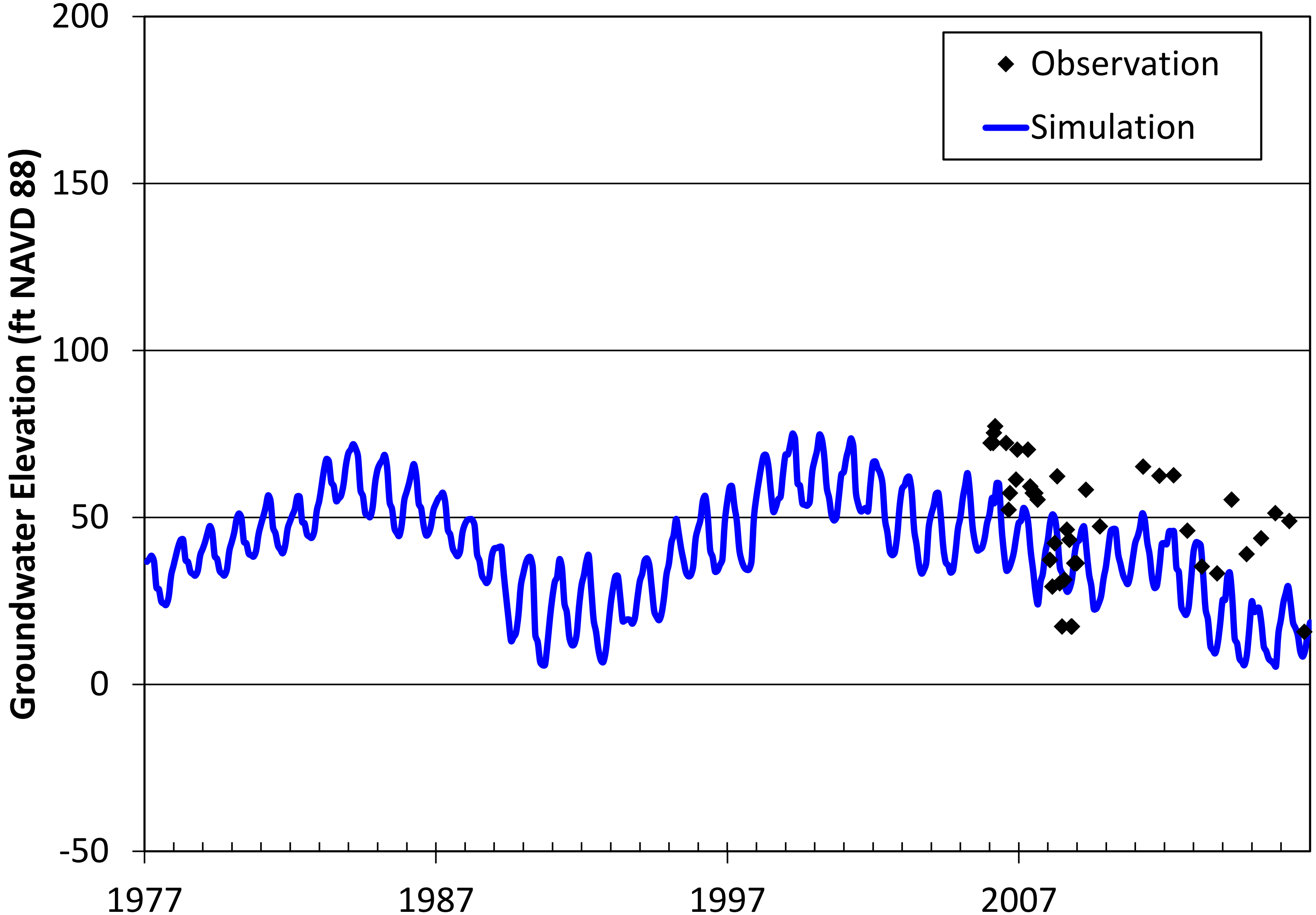
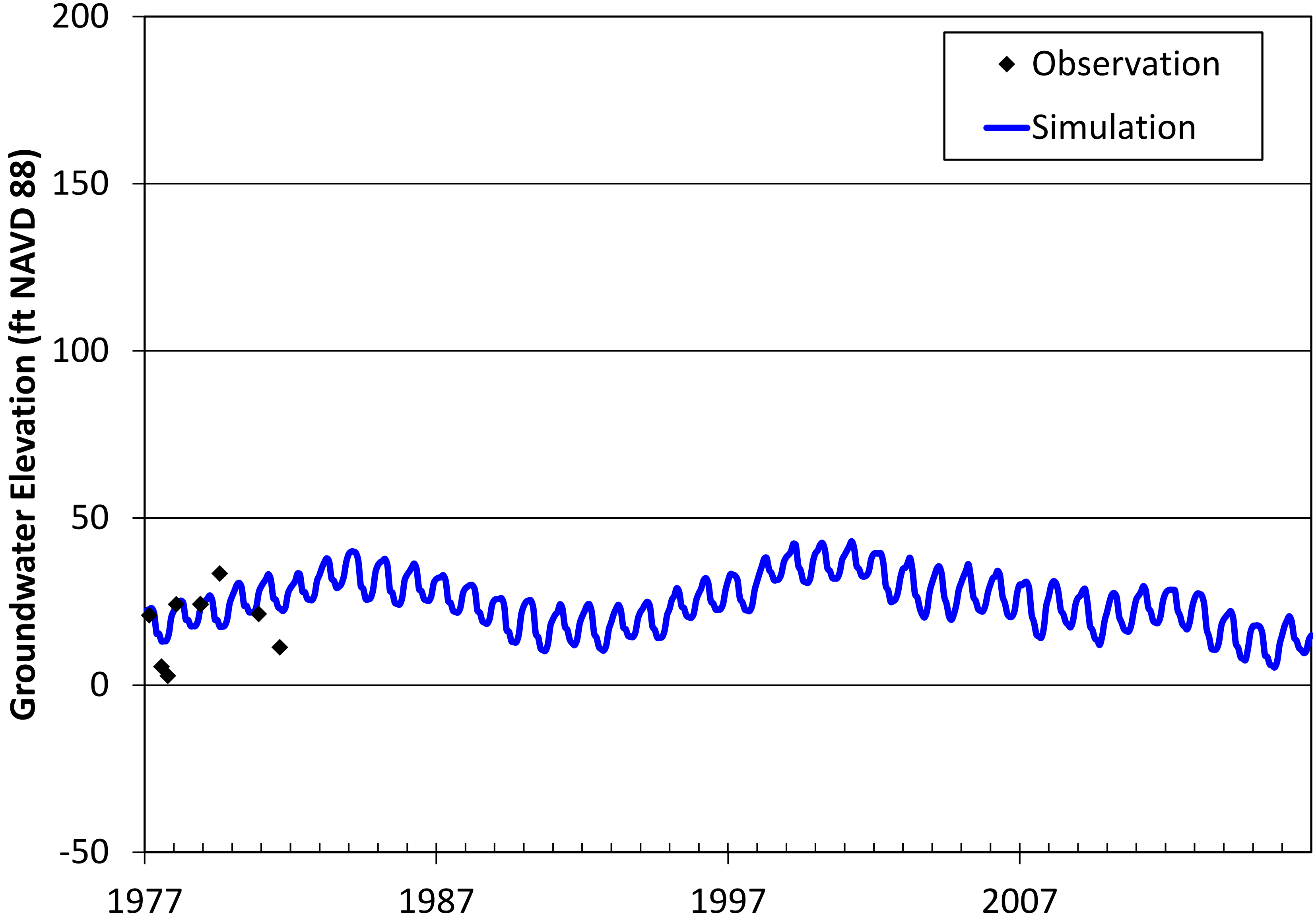
0
-50
1977
1987
1997
2007

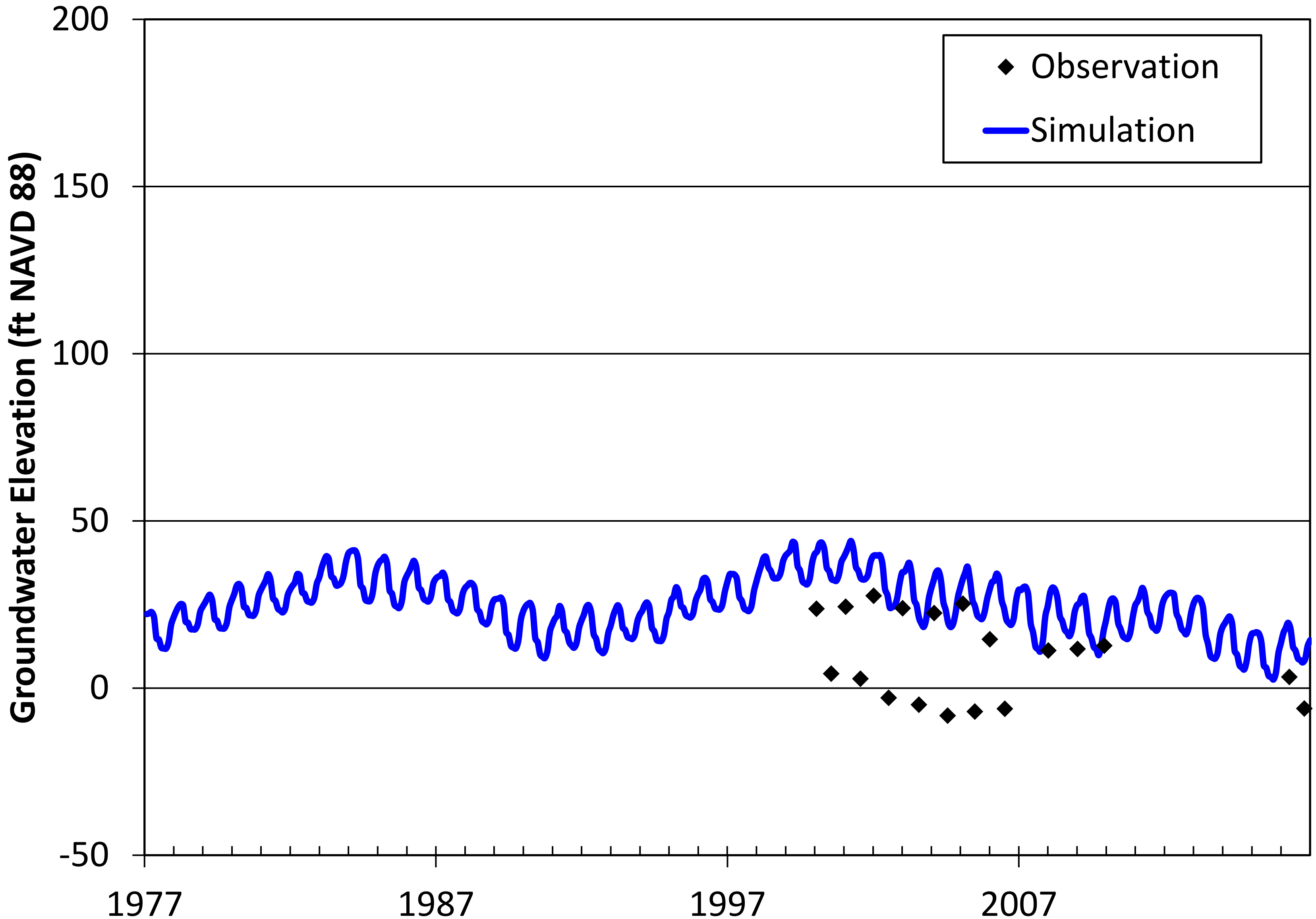
11N35W24A01_mult

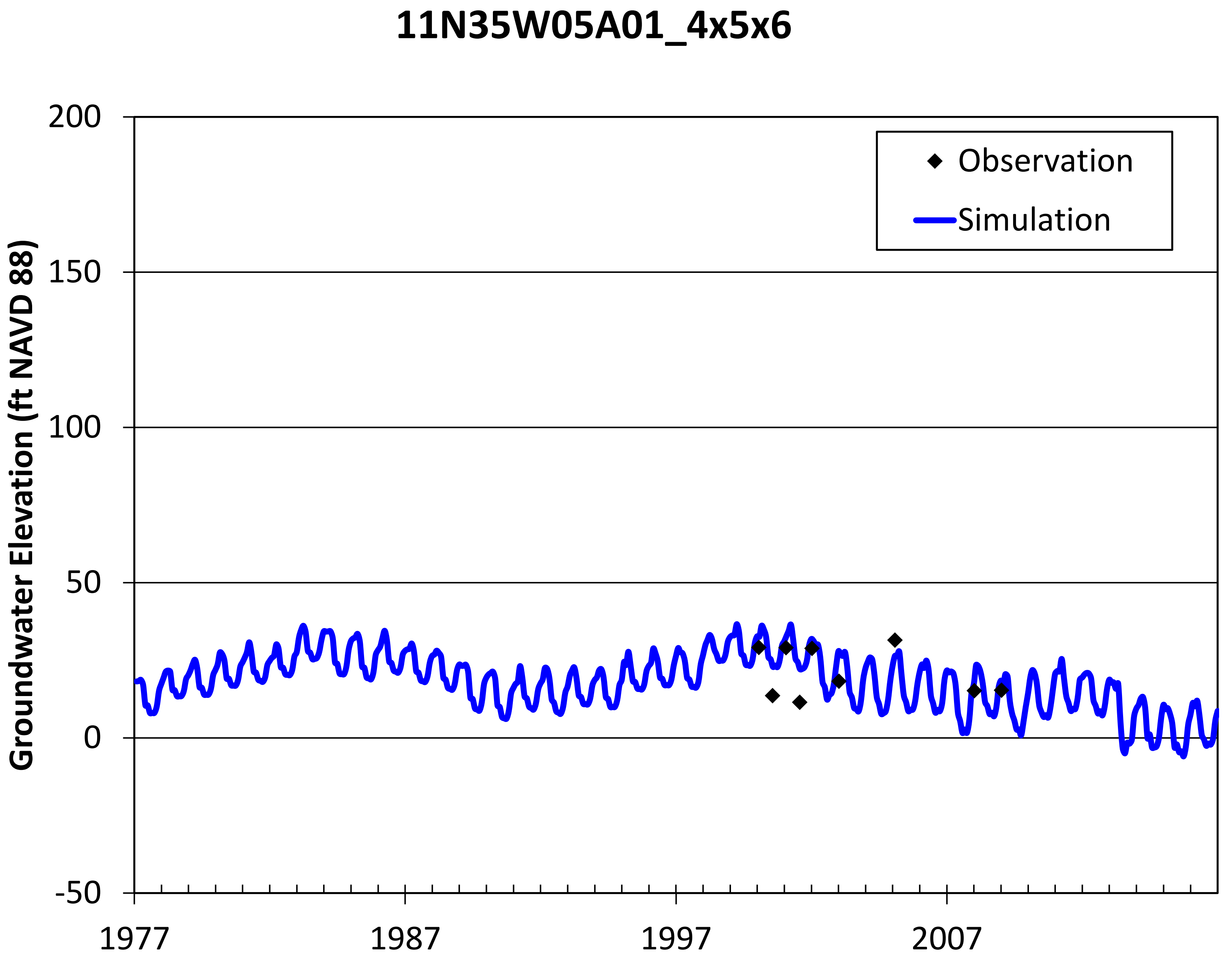


11N35W07R01_mult

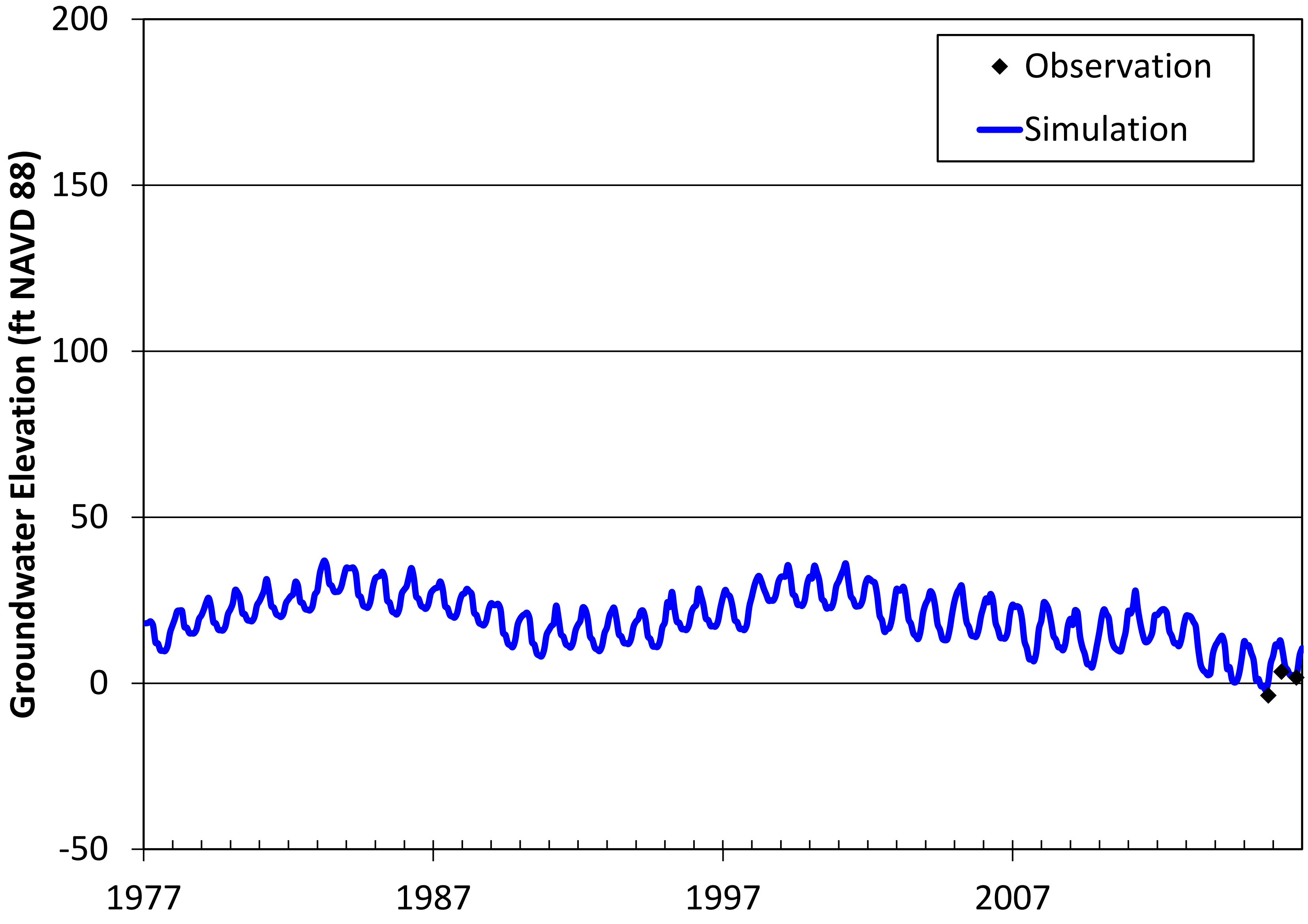


11N35W04E02_6x7x8x9x10

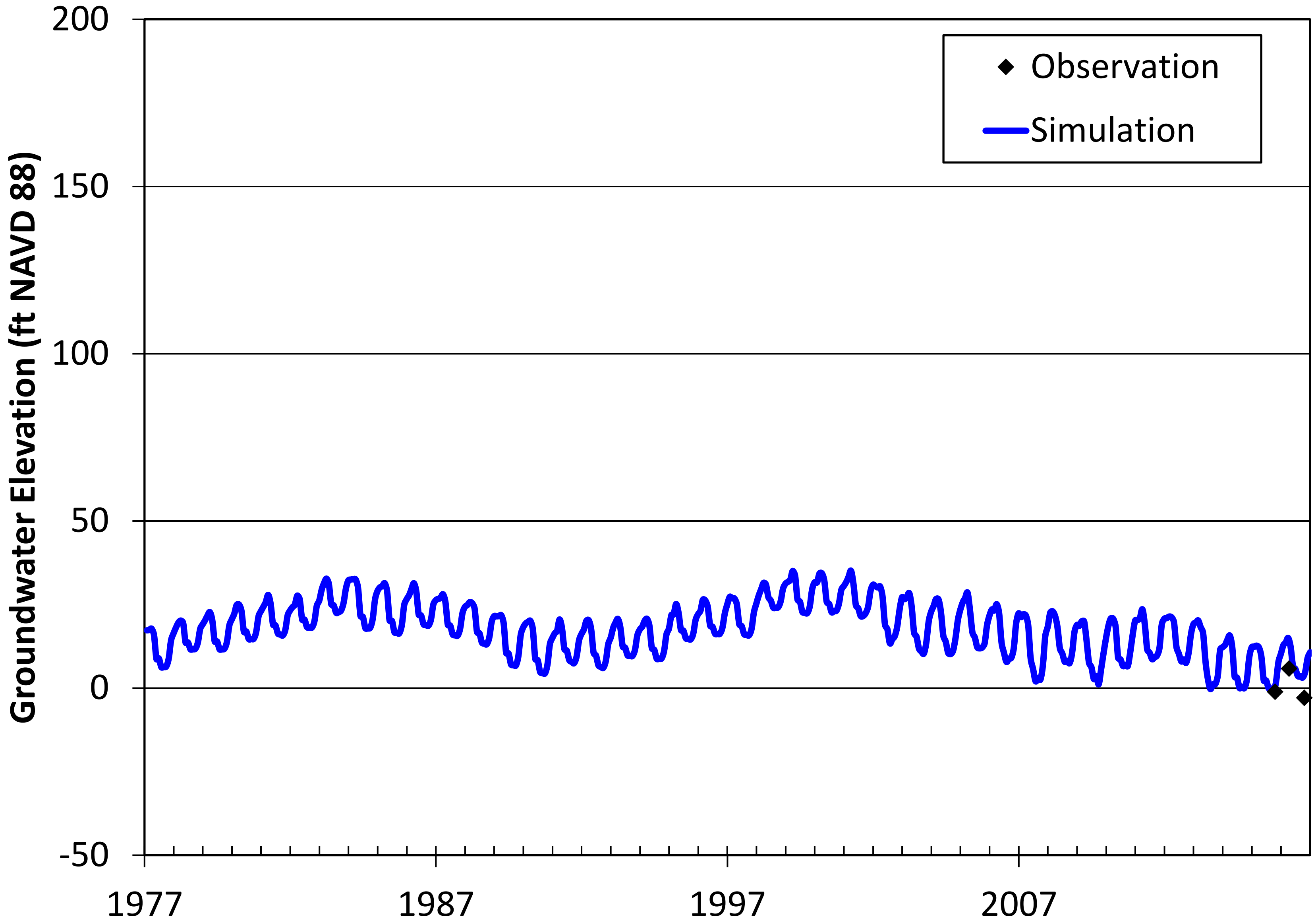



11N35W05A01_4x5x6
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007

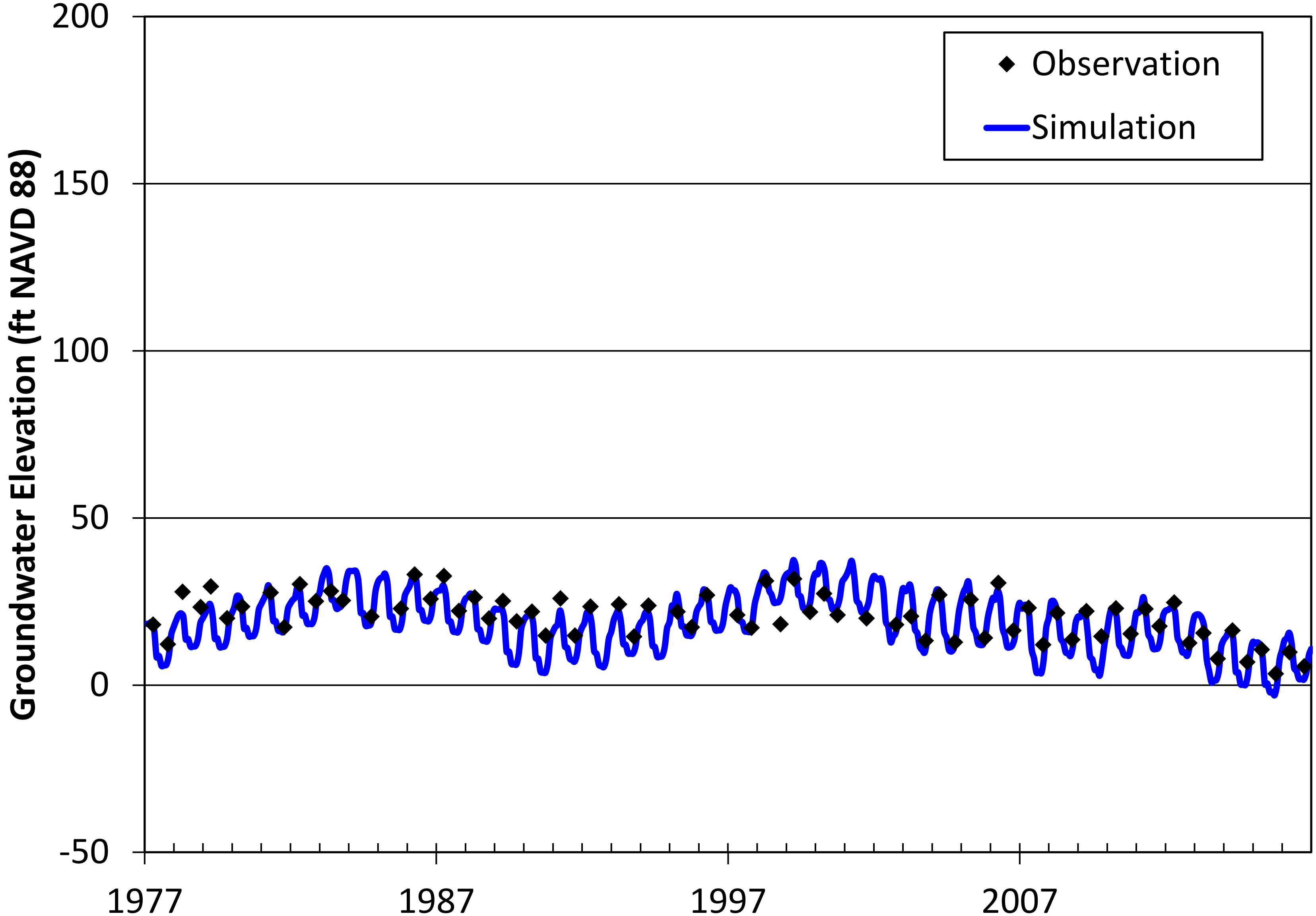
11N35W05B02_3x4

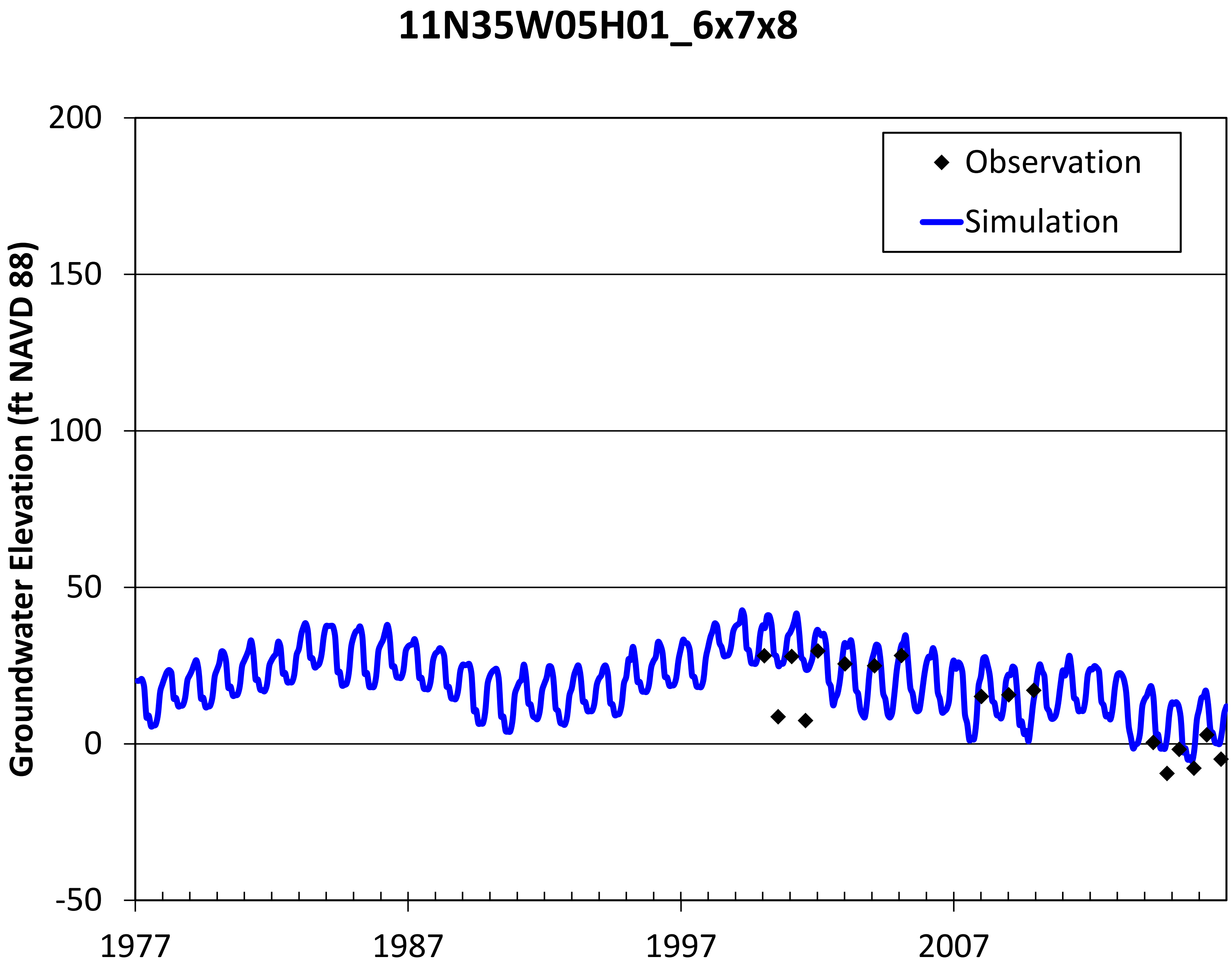


11N35W05E02_6x7

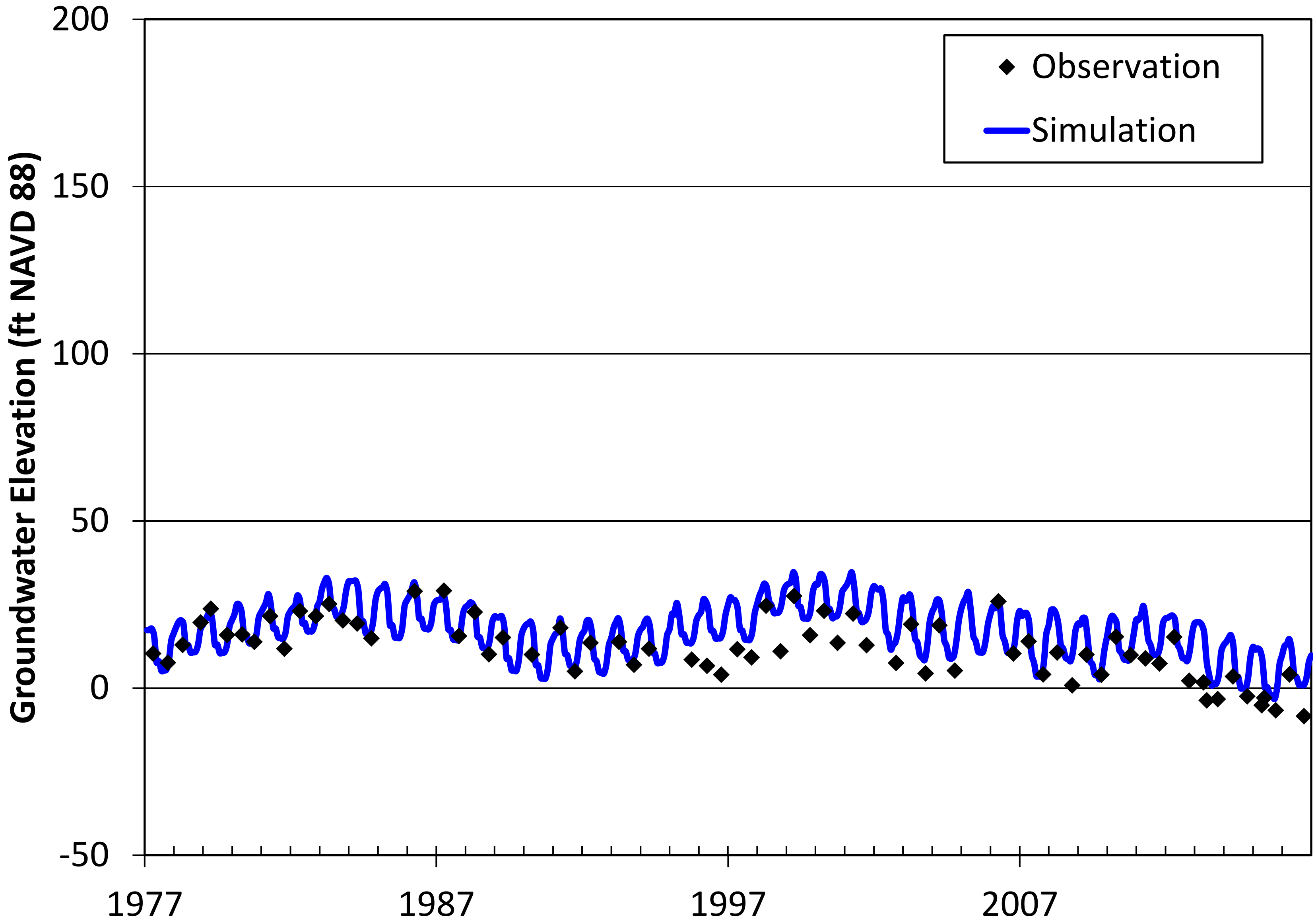


11N35W05G01_5

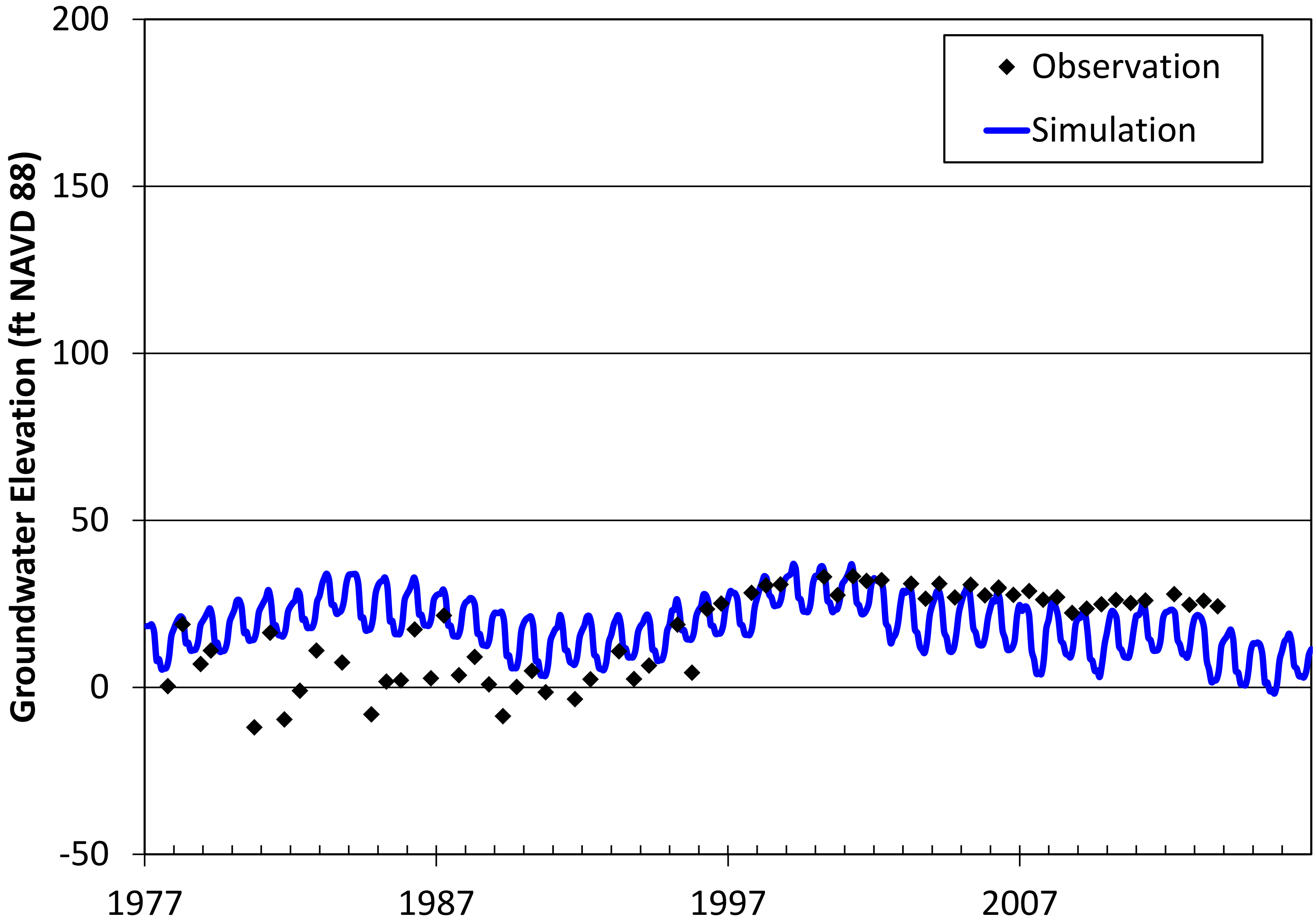



11N35W05H01_6x7x8
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007

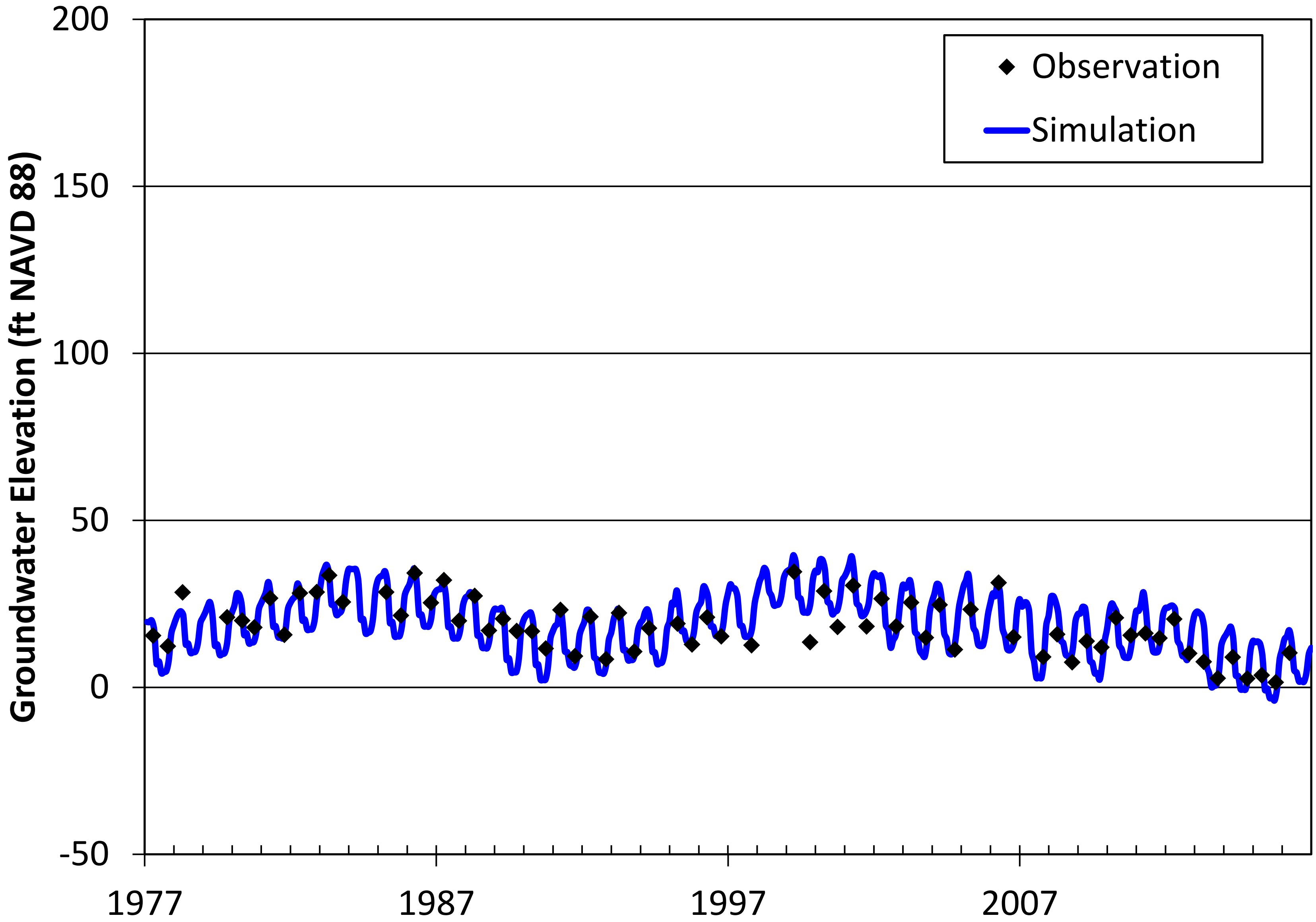
11N35W05L01_2x3x4



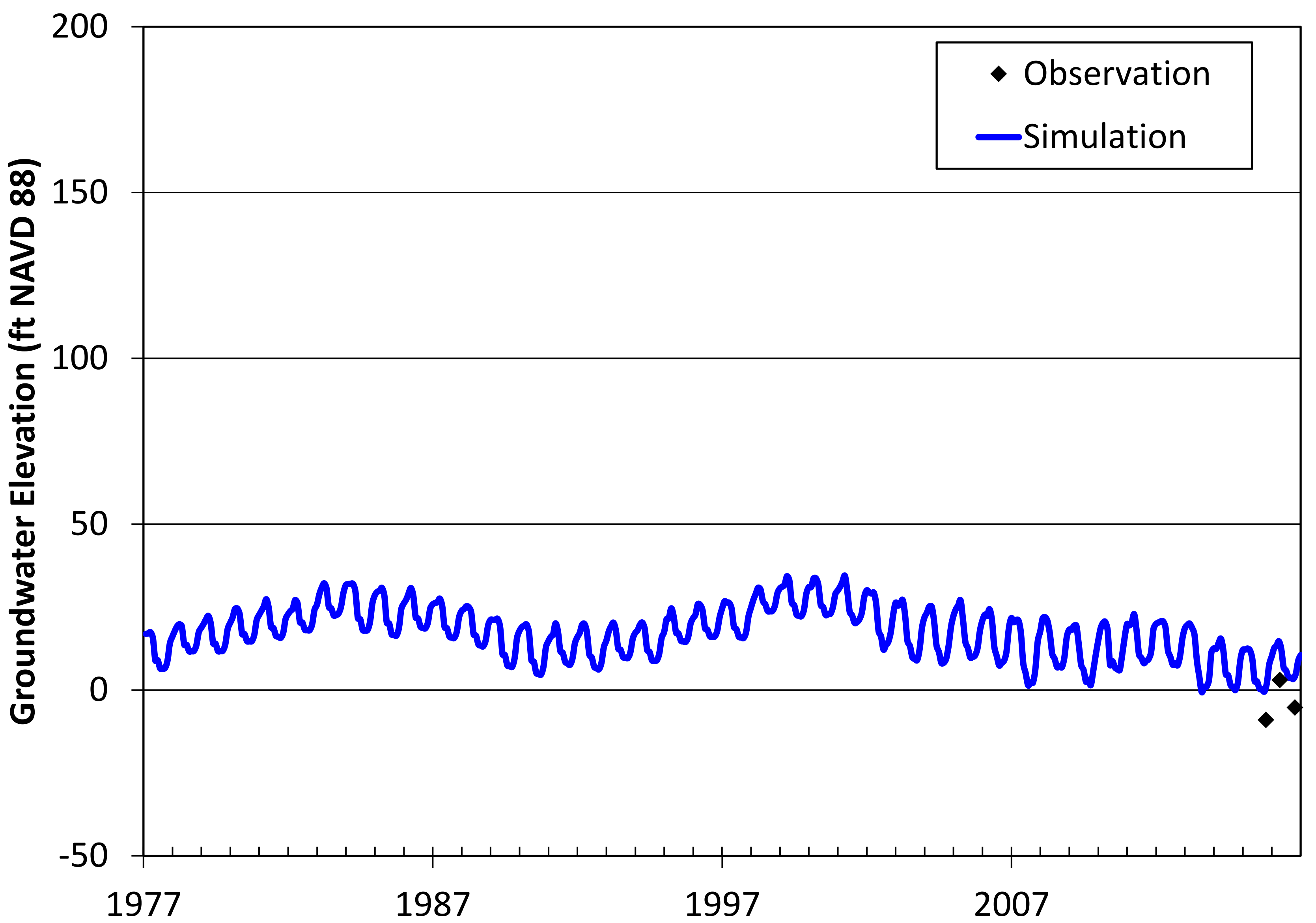
11N35W05N02_5x6



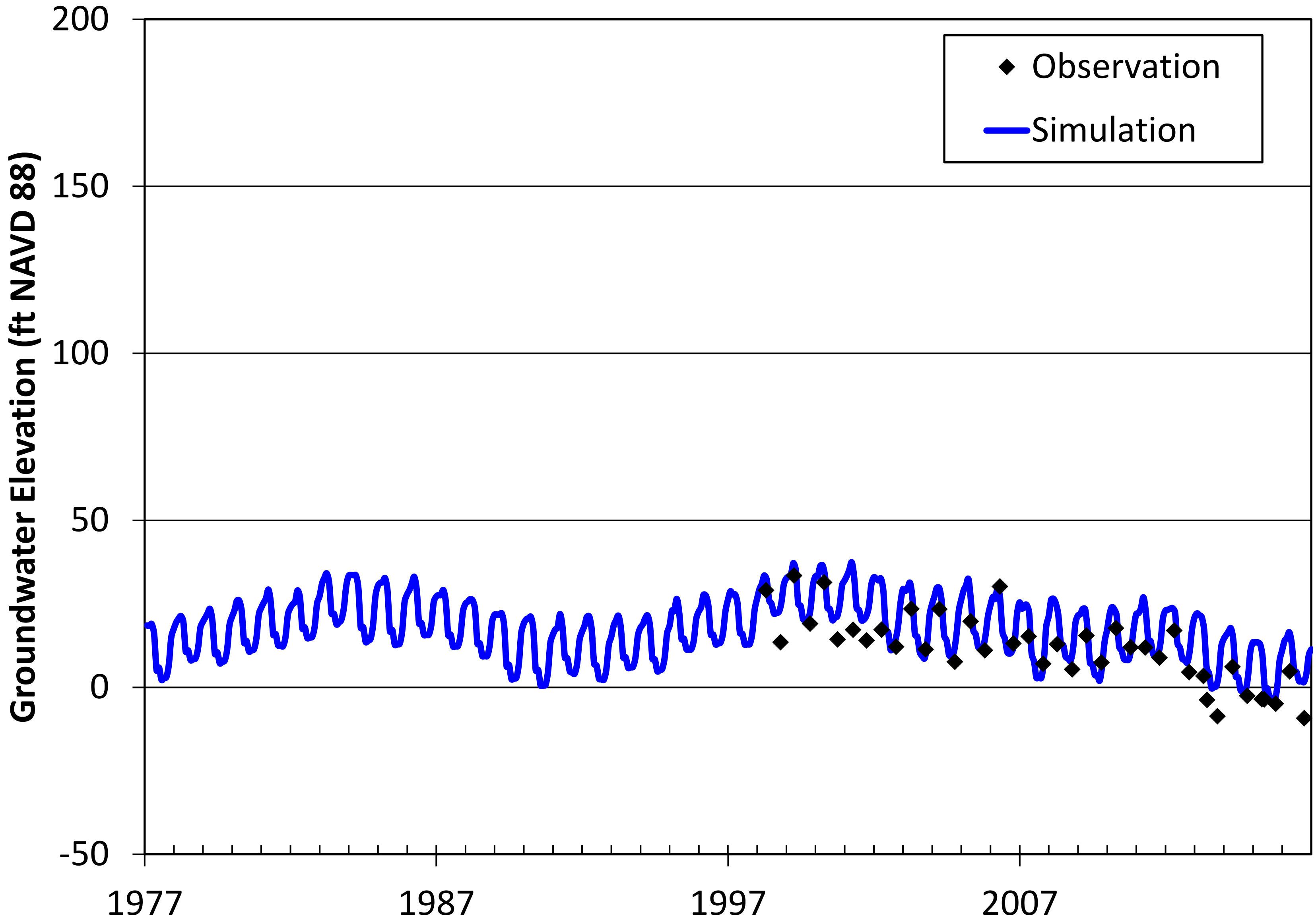
11N35W05R01_4



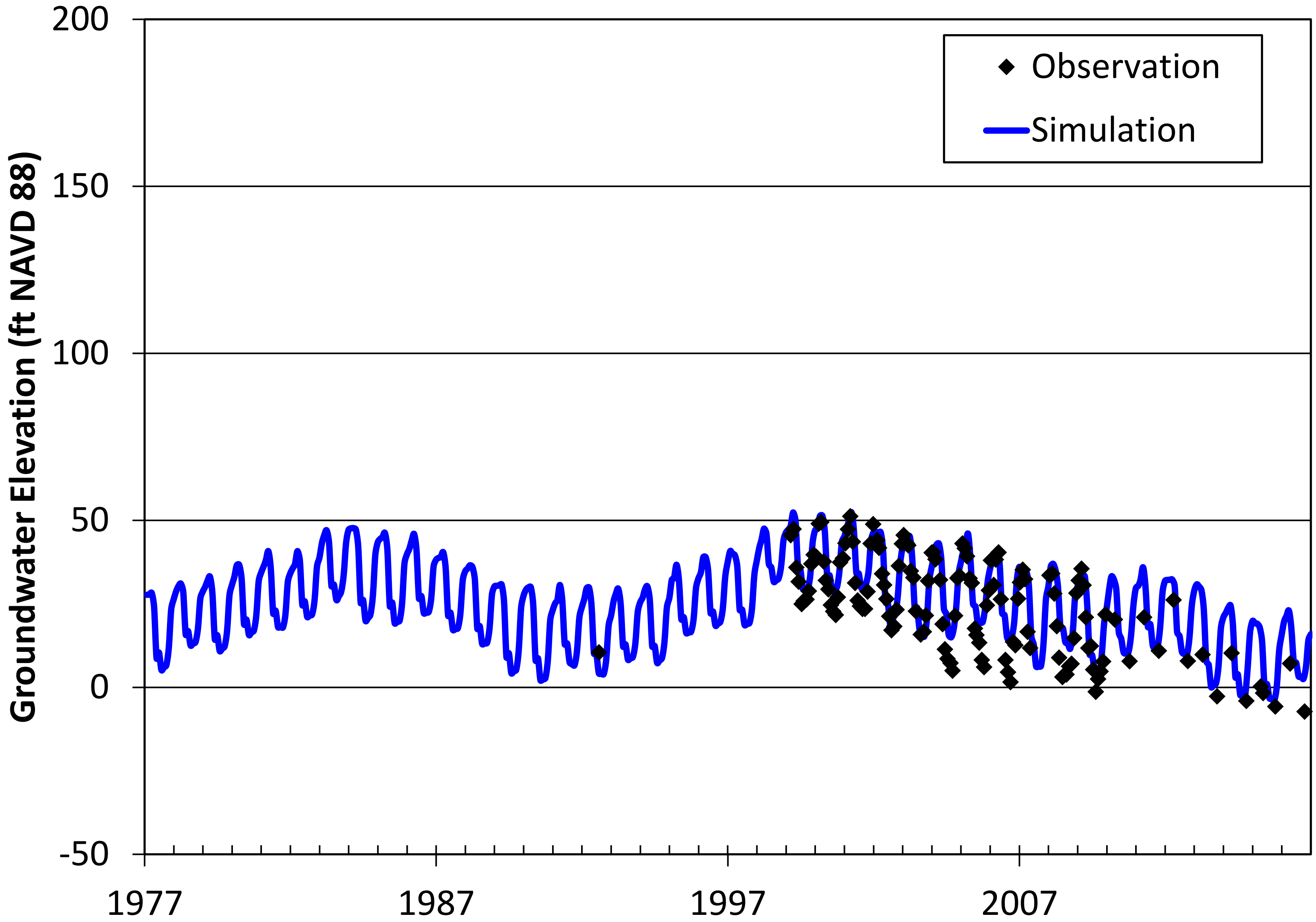
11N35W06HS_5x6



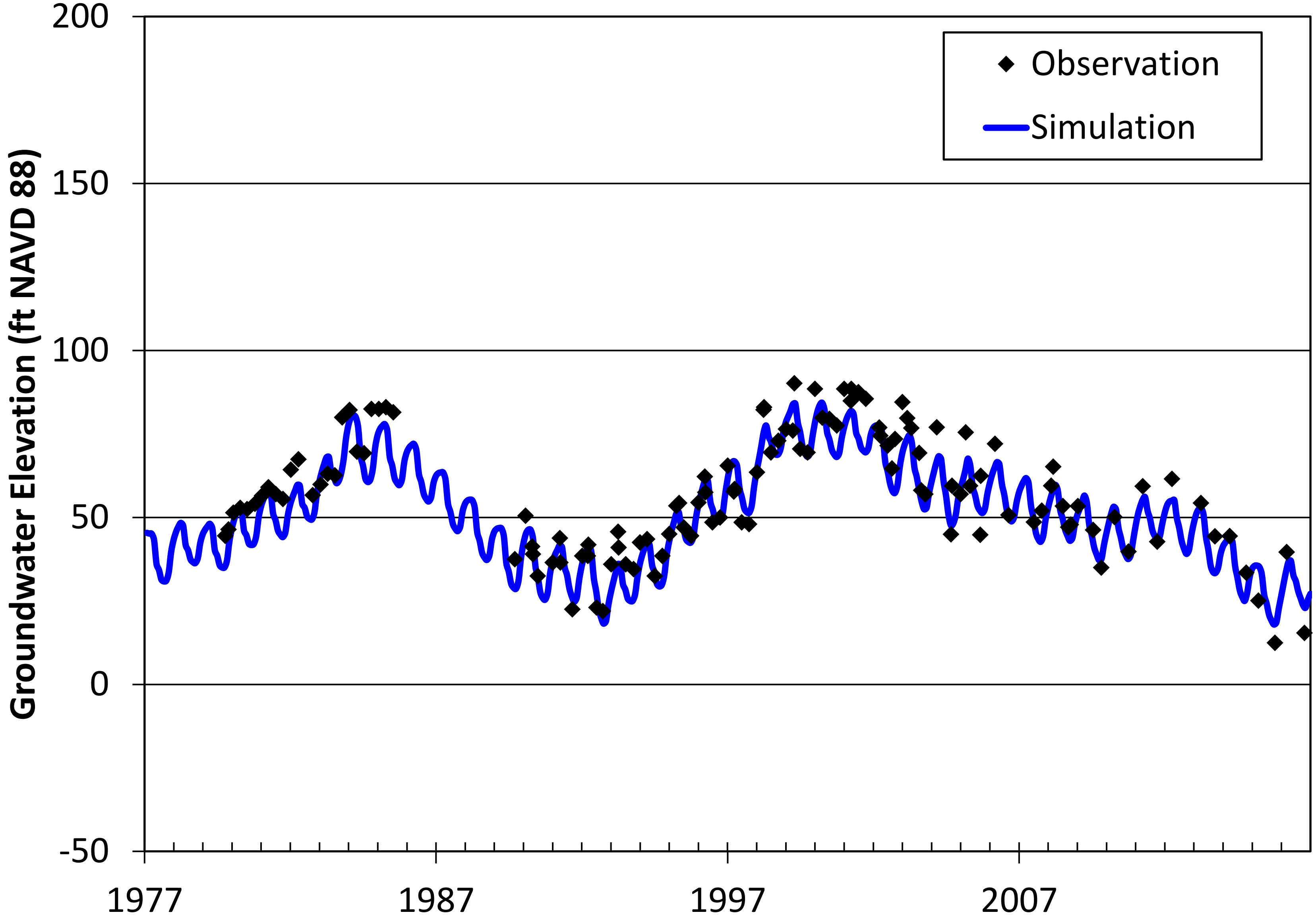
11N35W08L01_



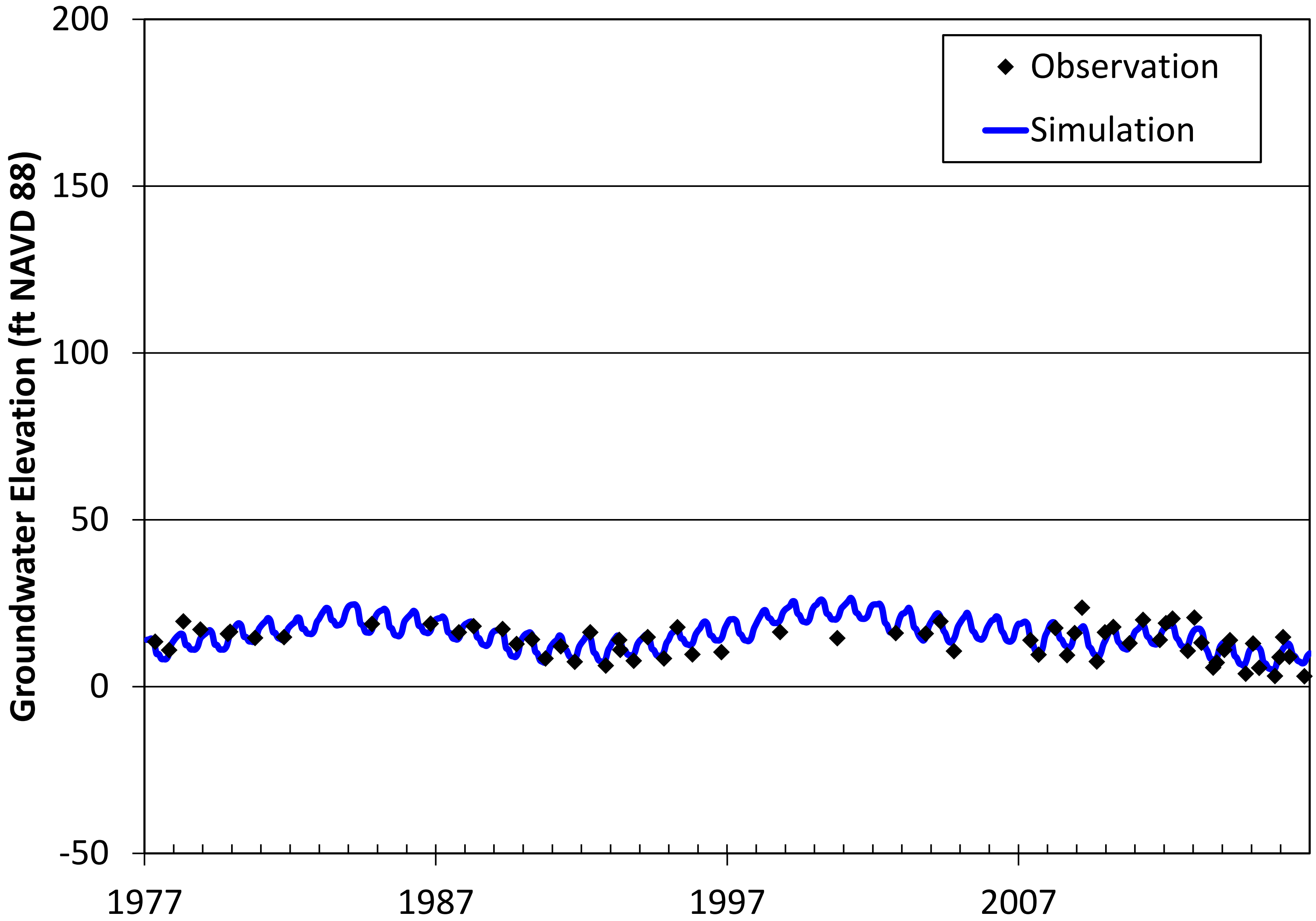
11N35W22C02_4x6



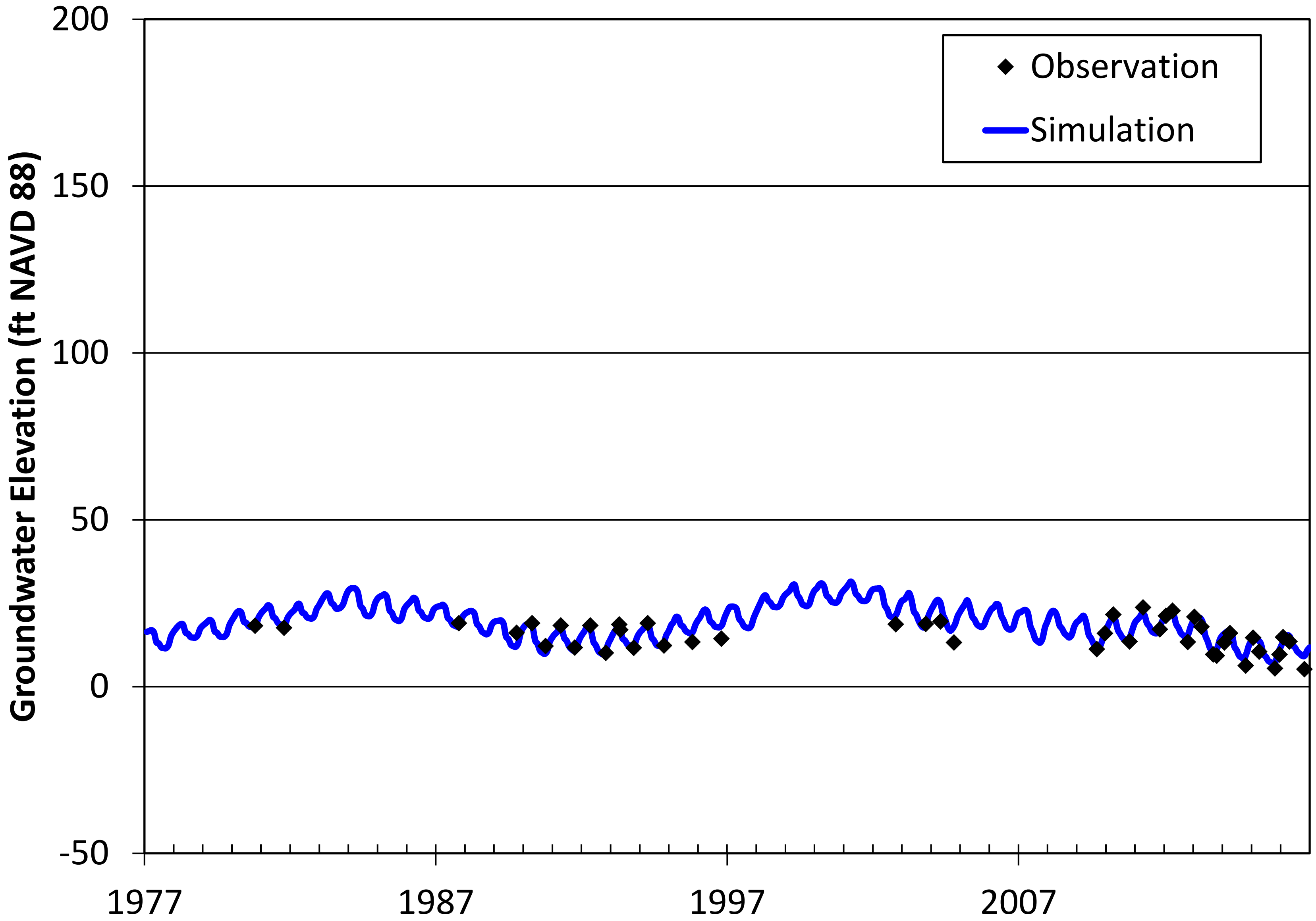
11N35W25F03_



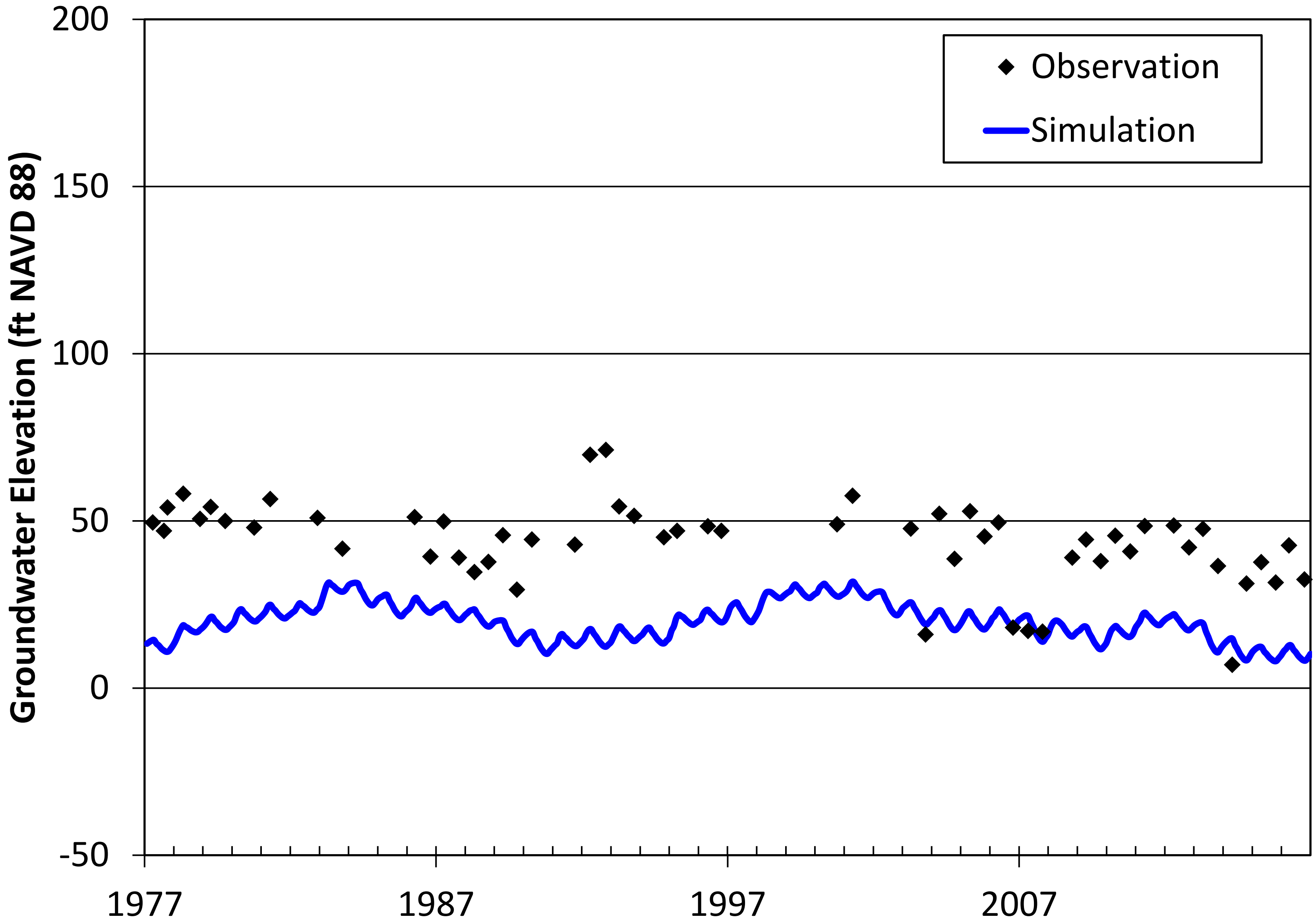
11N36W12C02_6



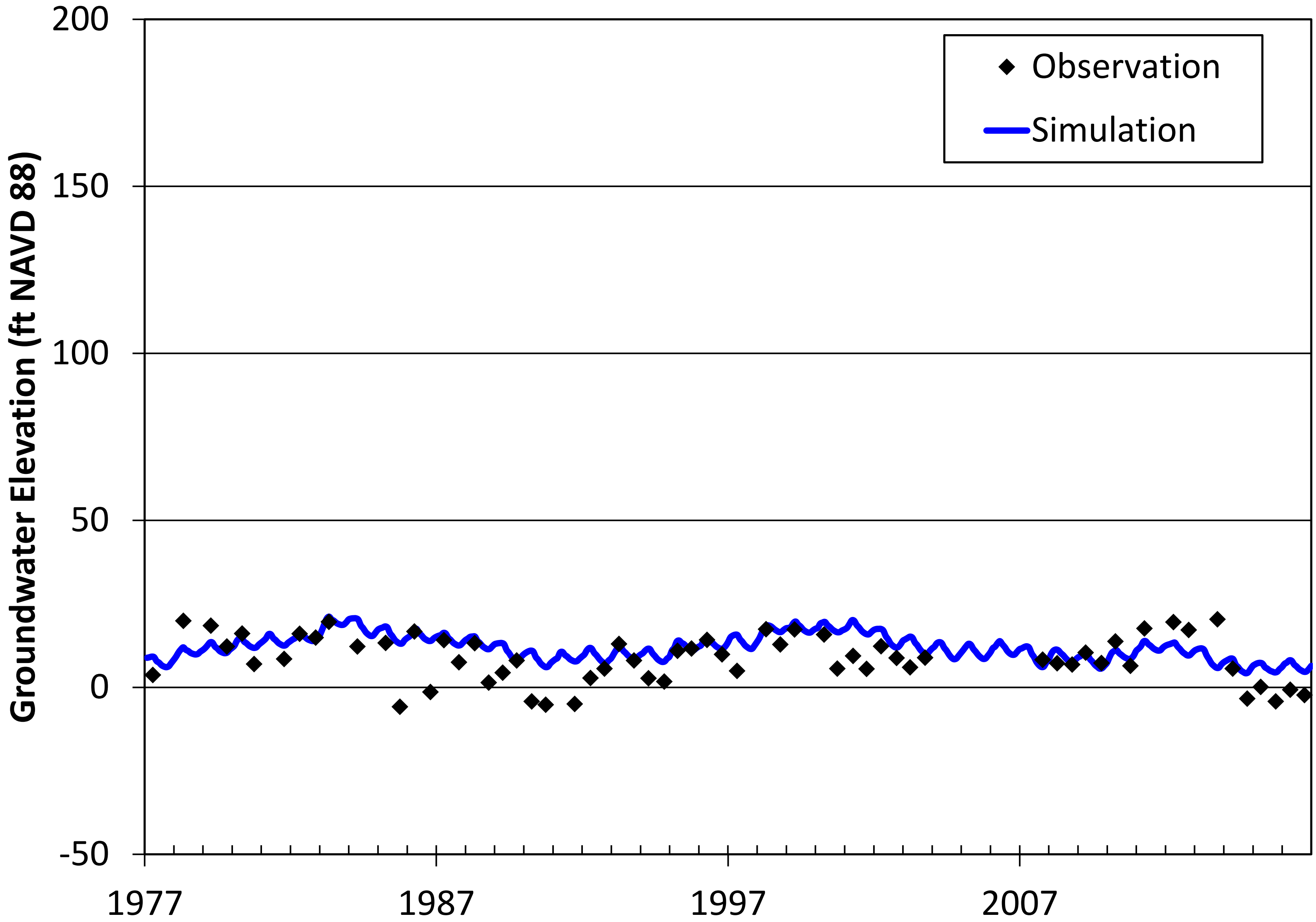
11N36W12C03_10



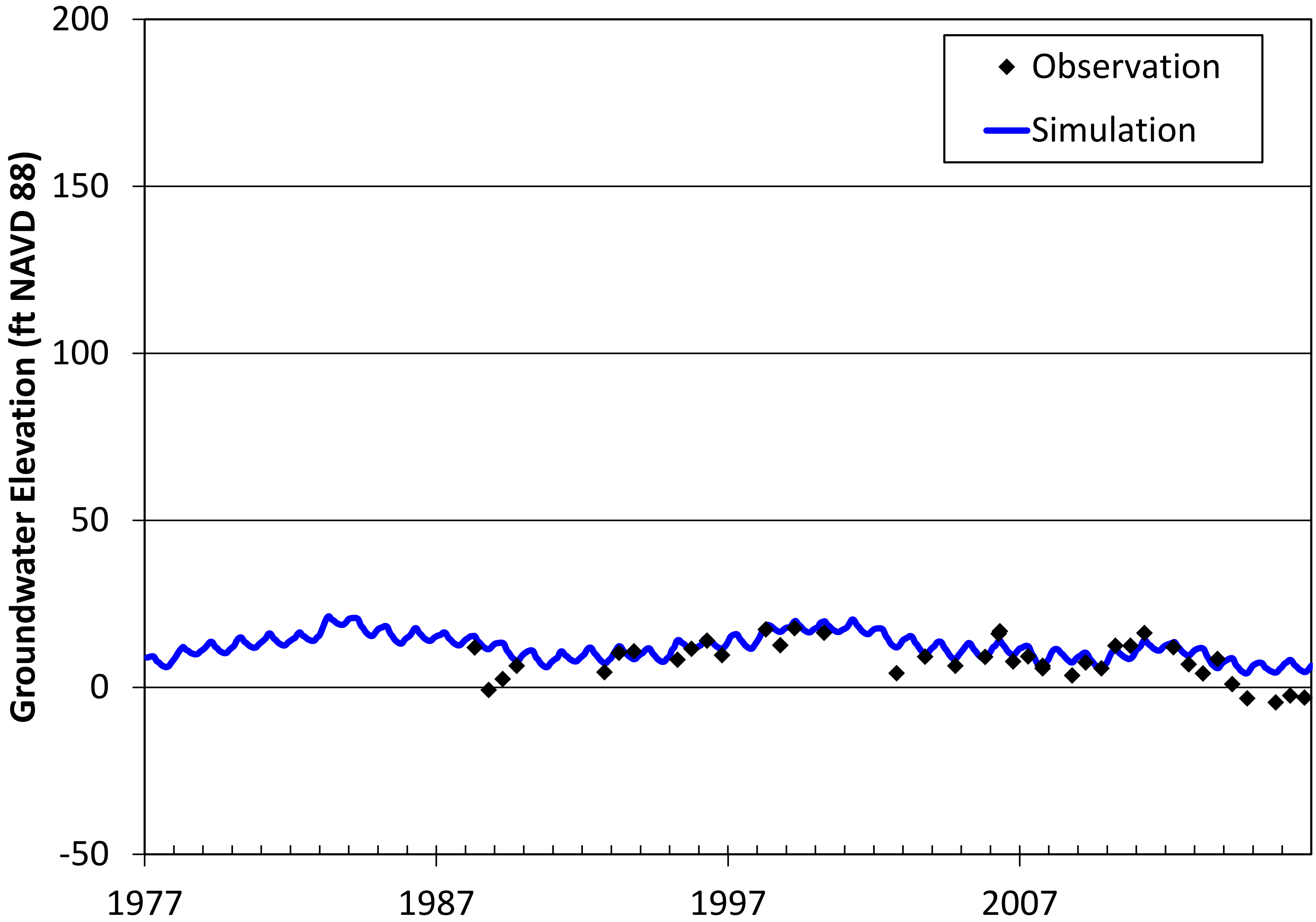
12N35W29R03_8

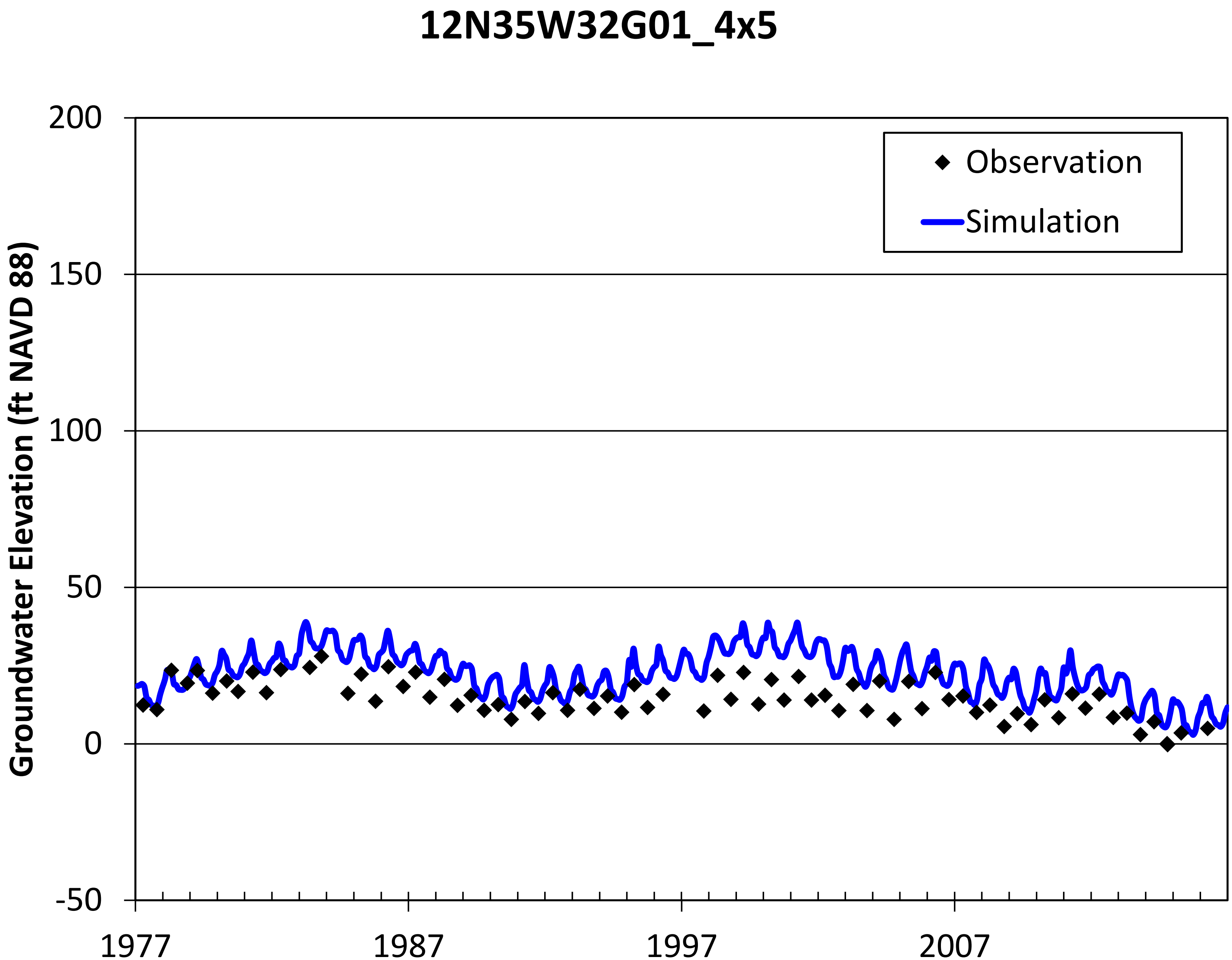


12N35W30M02_

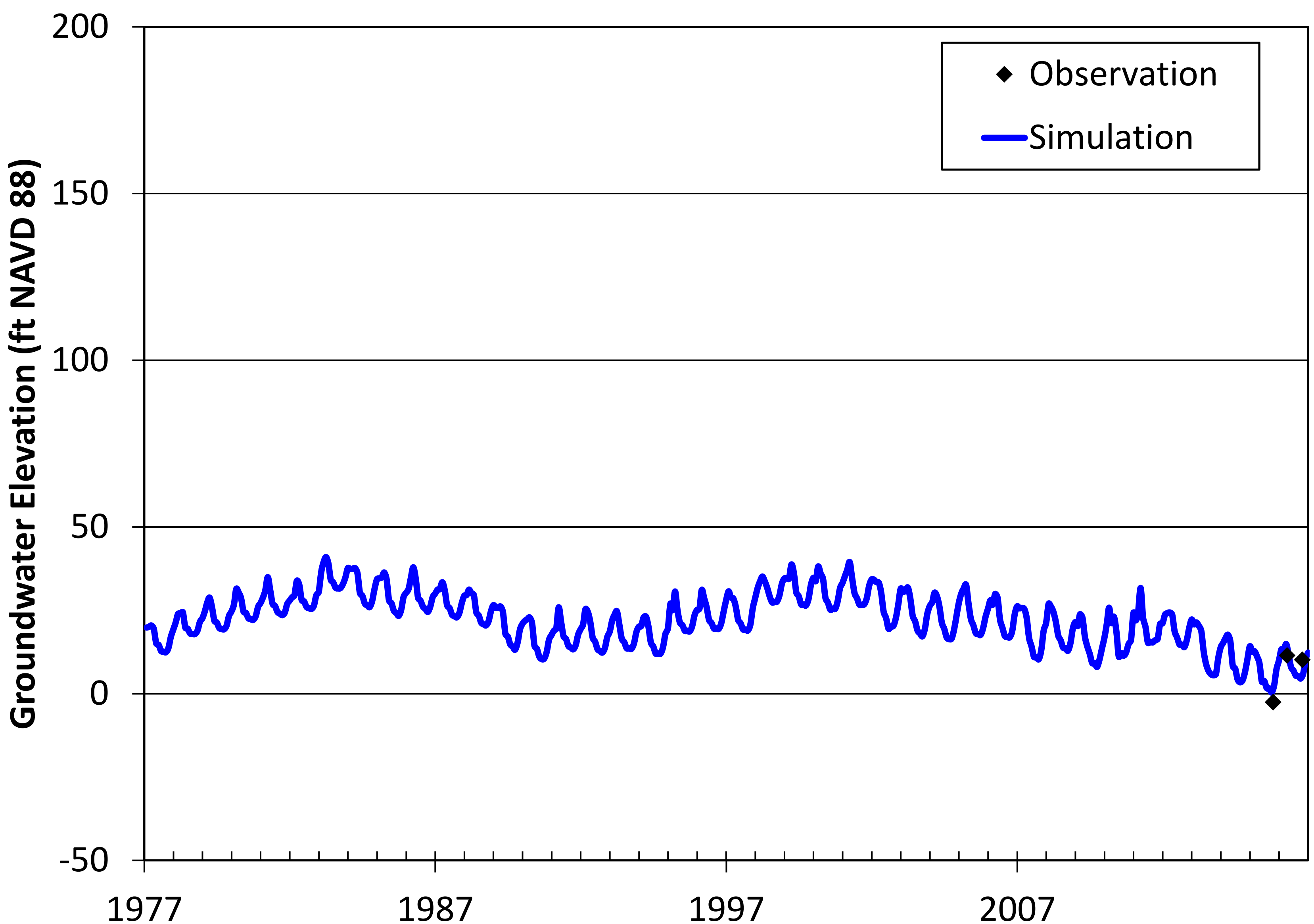


12N35W30M04_

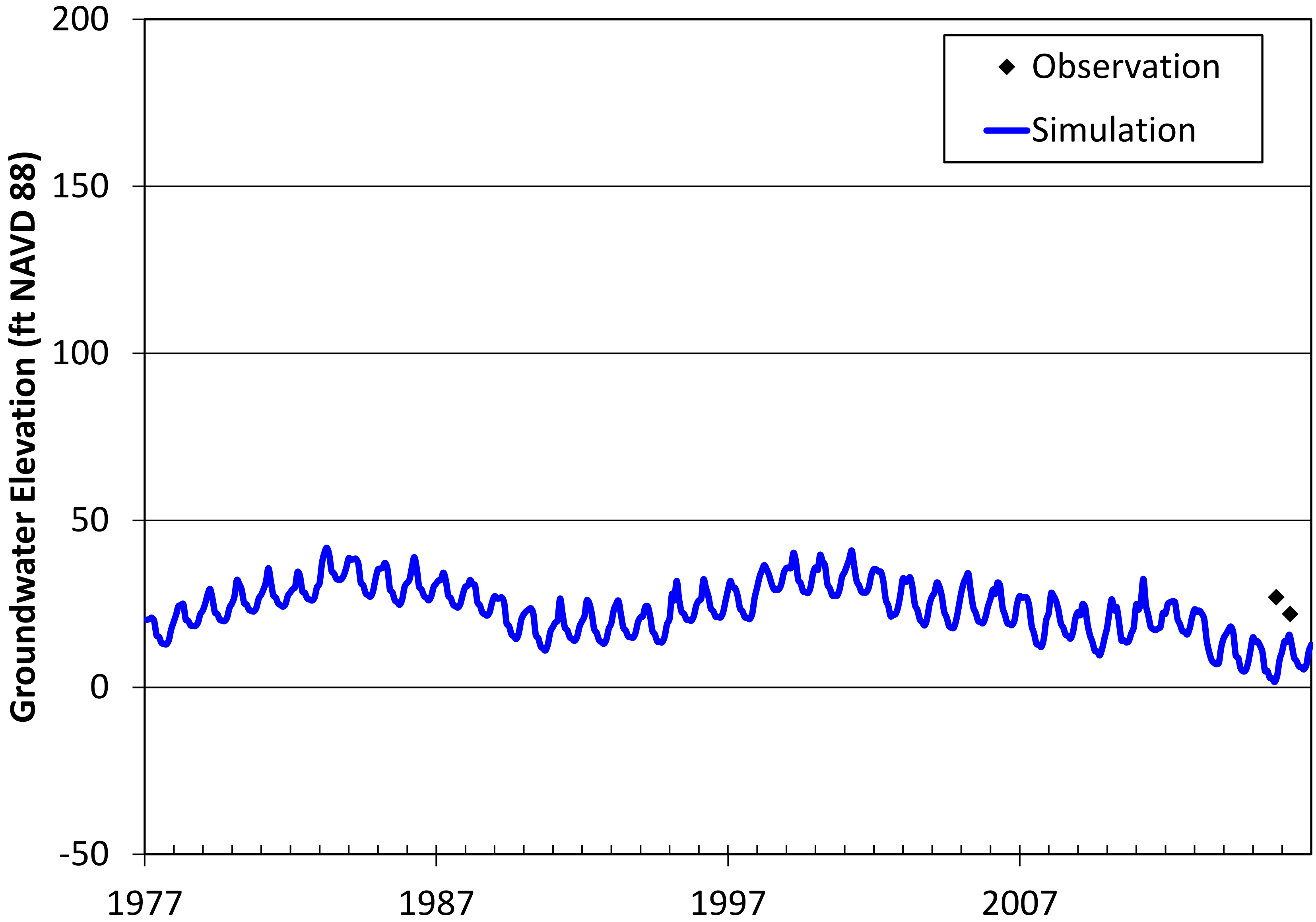



12N35W32G01_4x5
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007

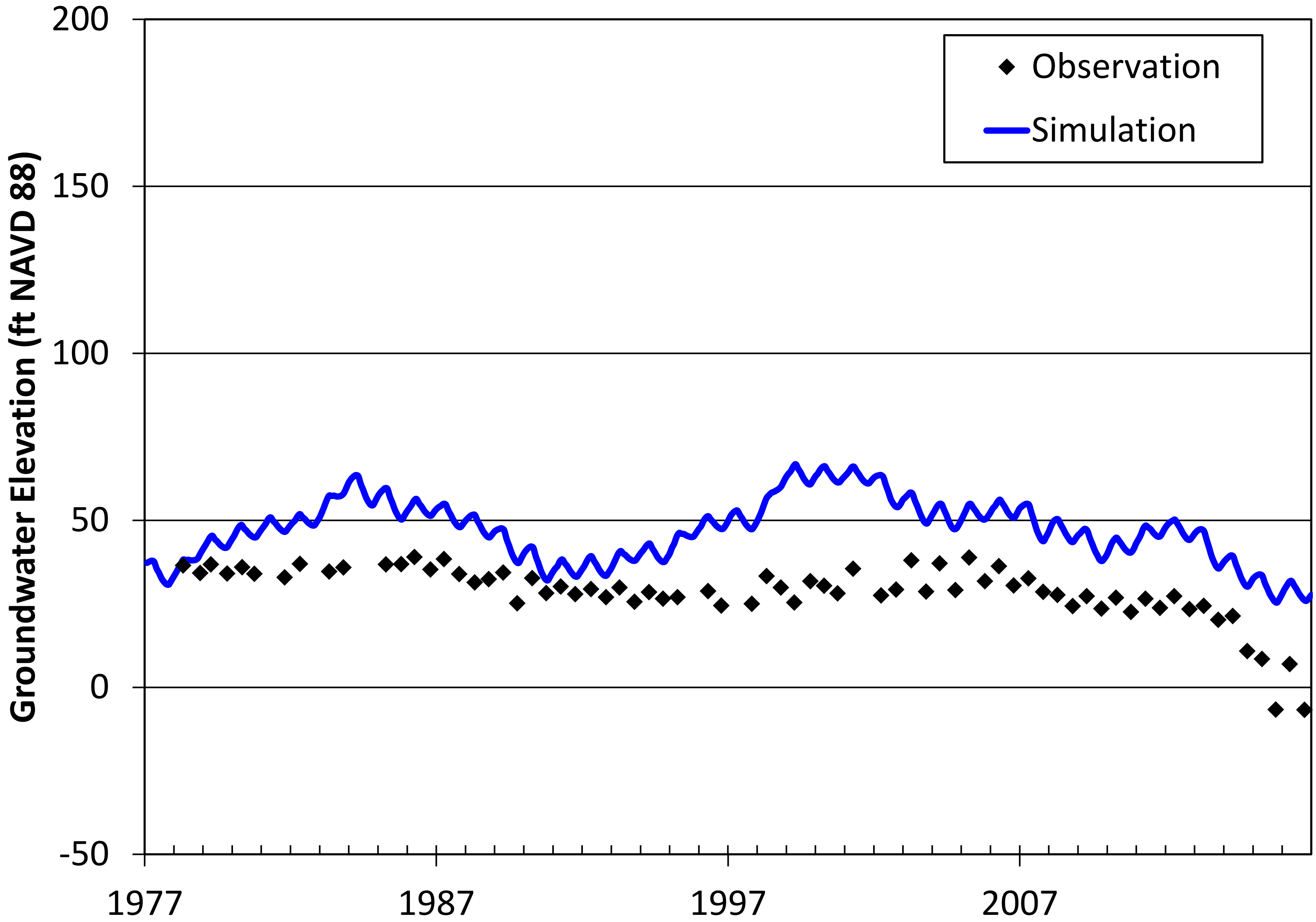
12N35W32R02_4x5



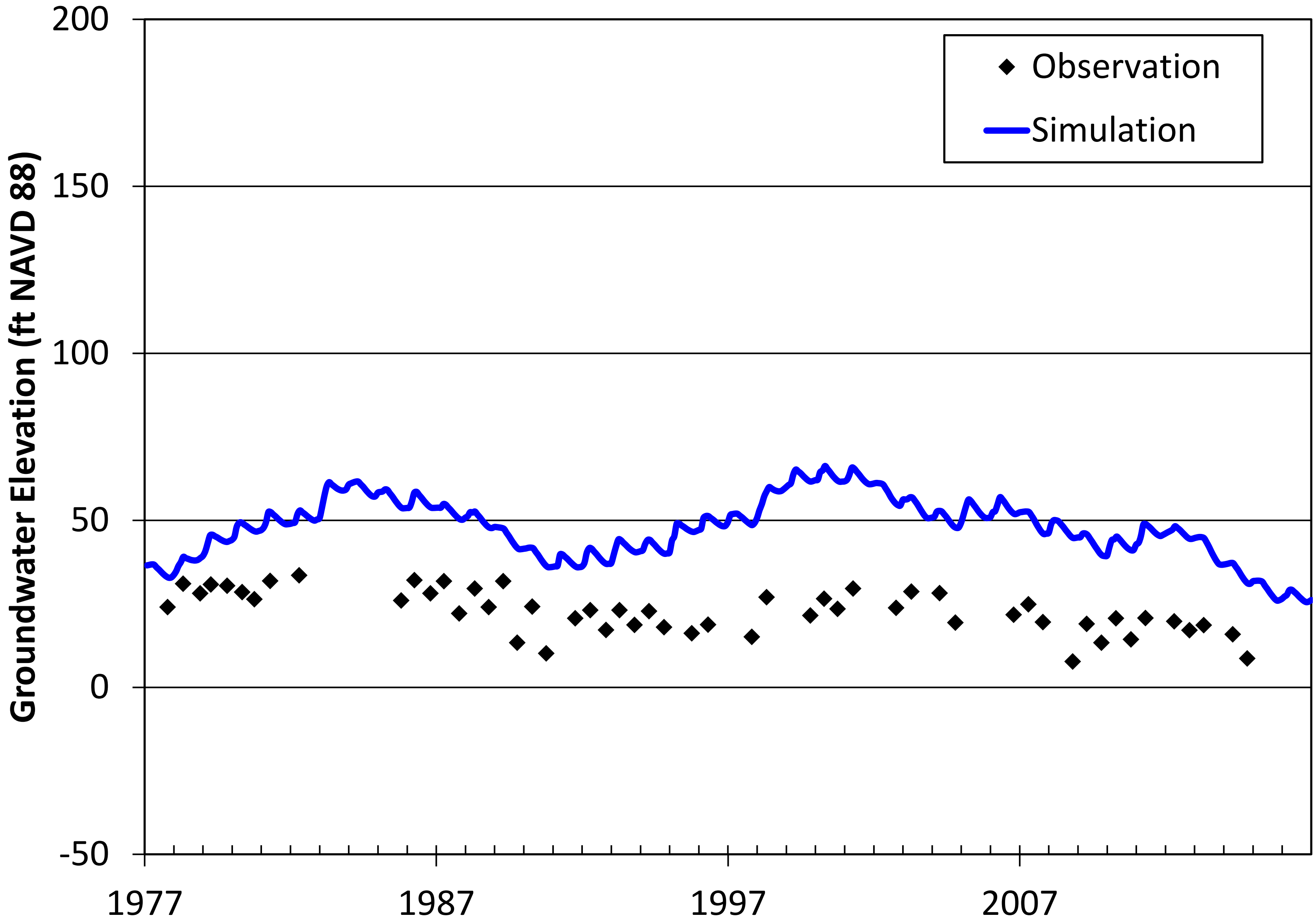
12N35W32R04_2x3x4x5



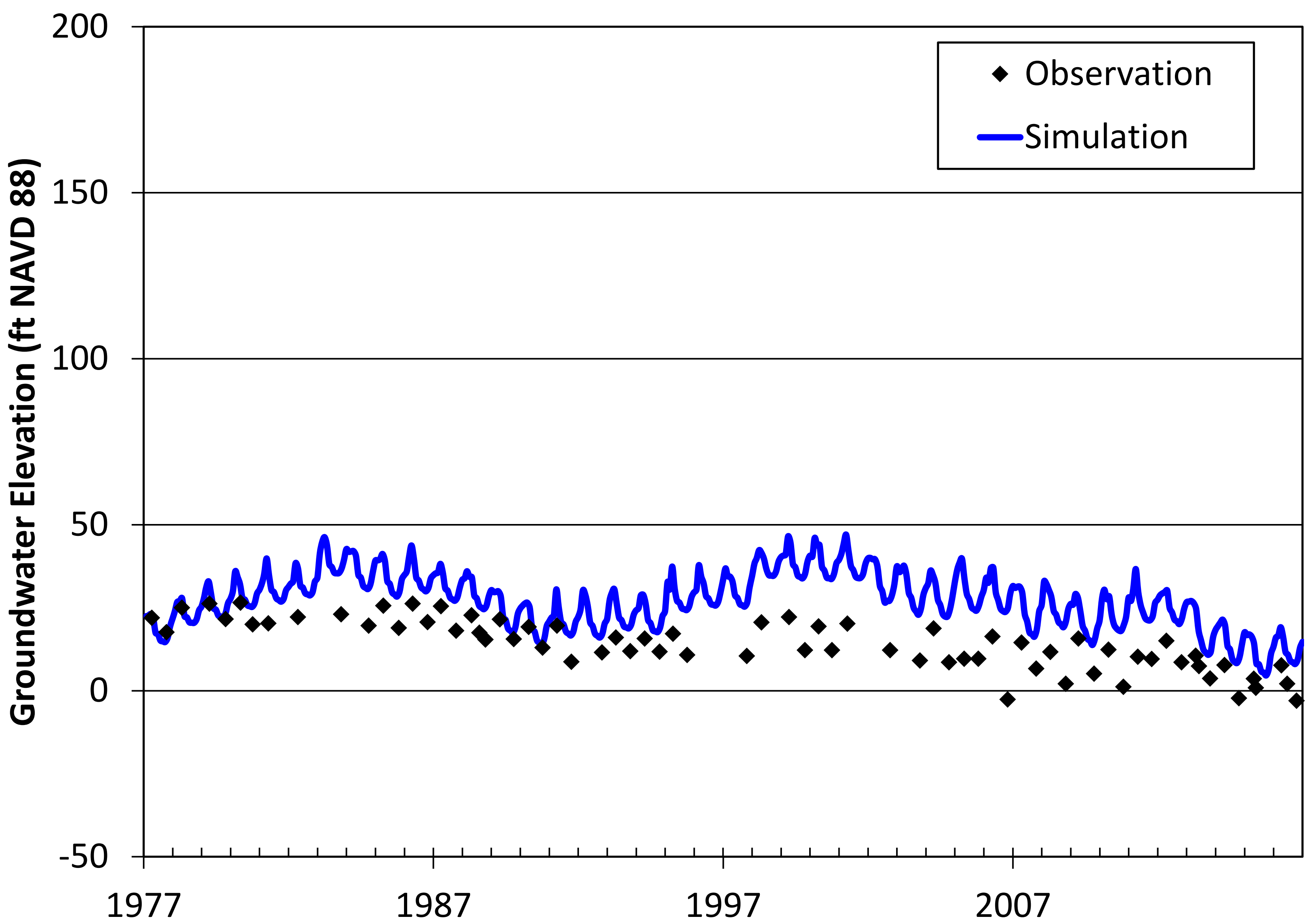
12N35W33J02_7x8x9x10



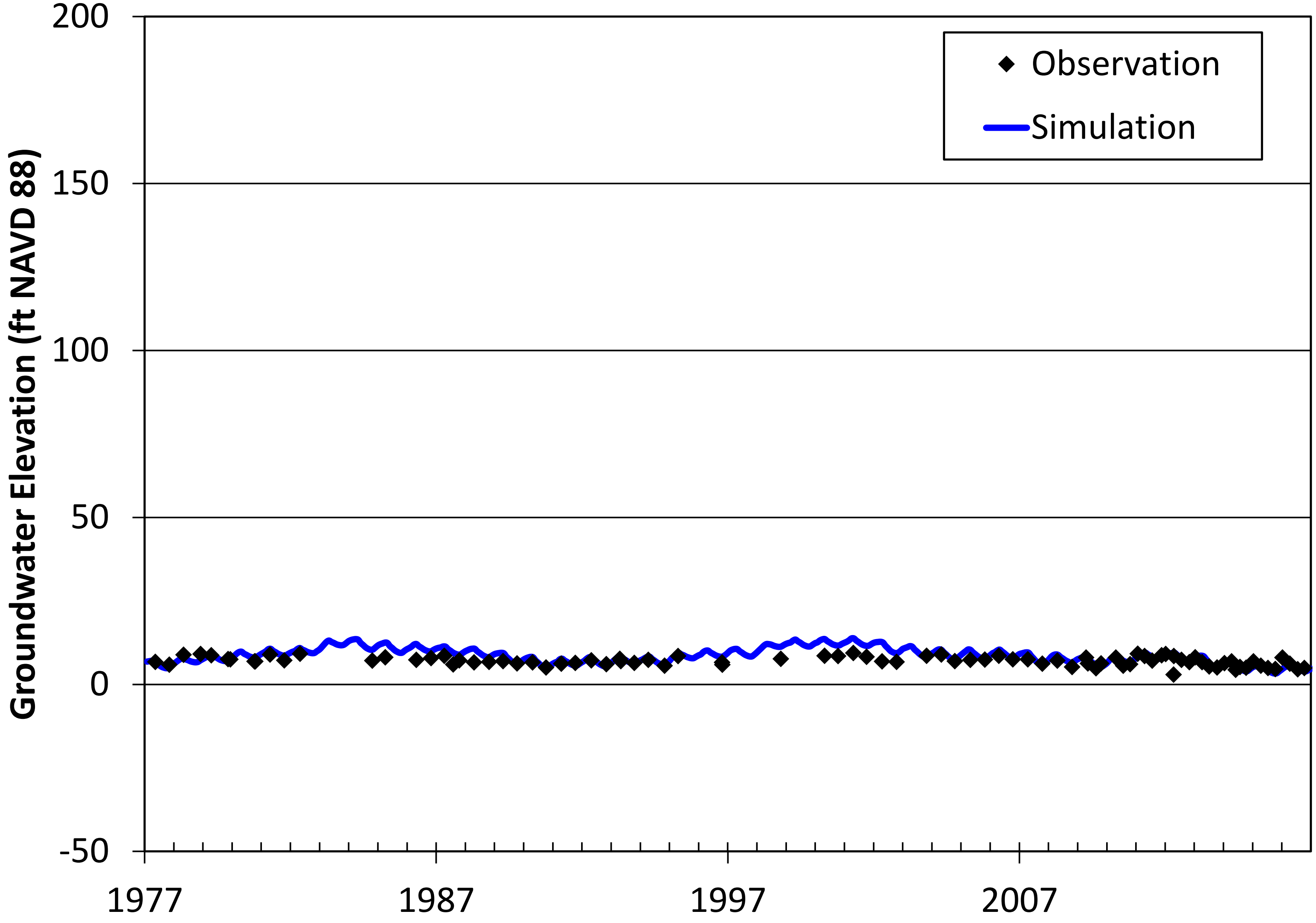
12N35W33J03_2x3x4x5x6x7x8x9x10

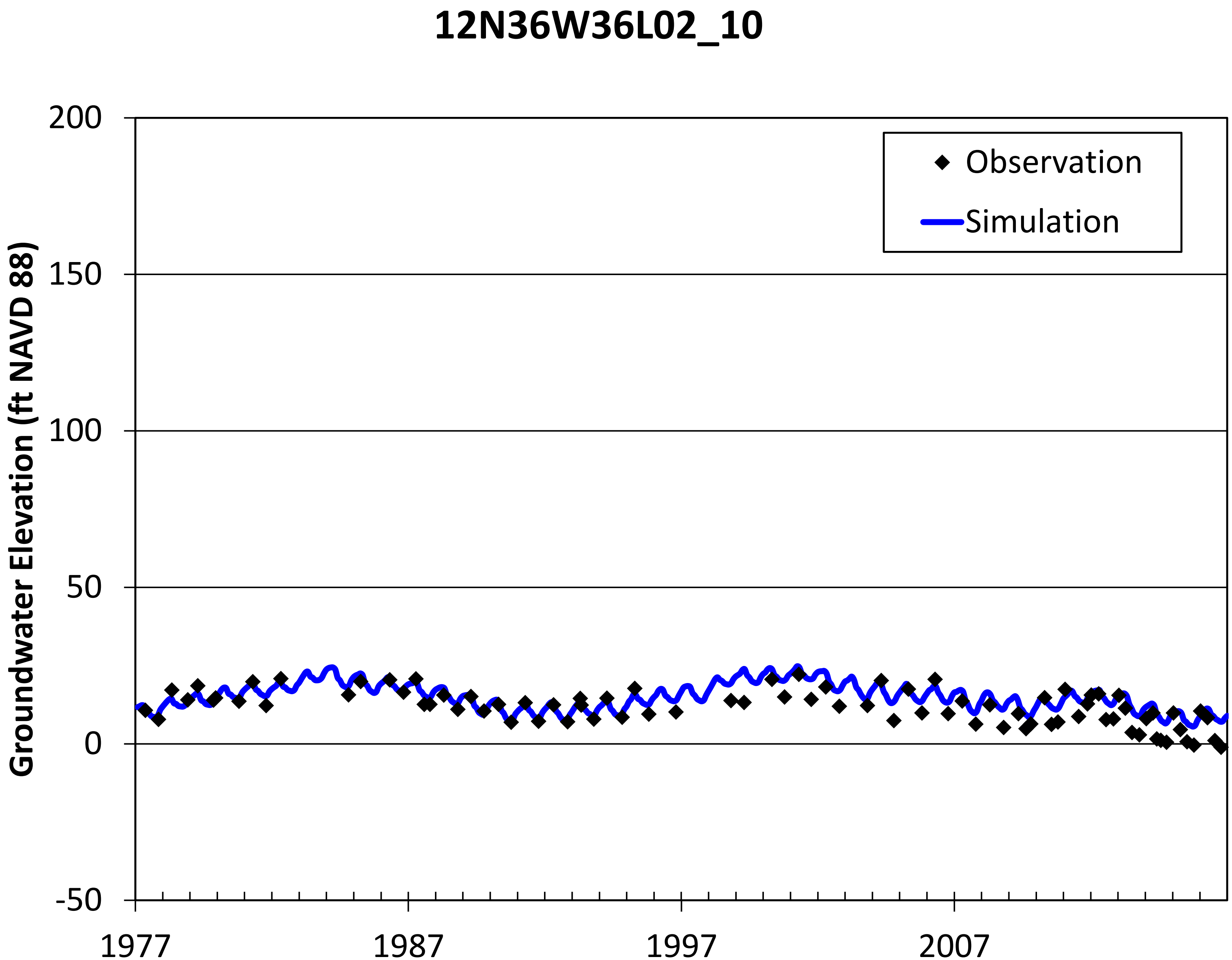


12N35W33L01_4x5x6

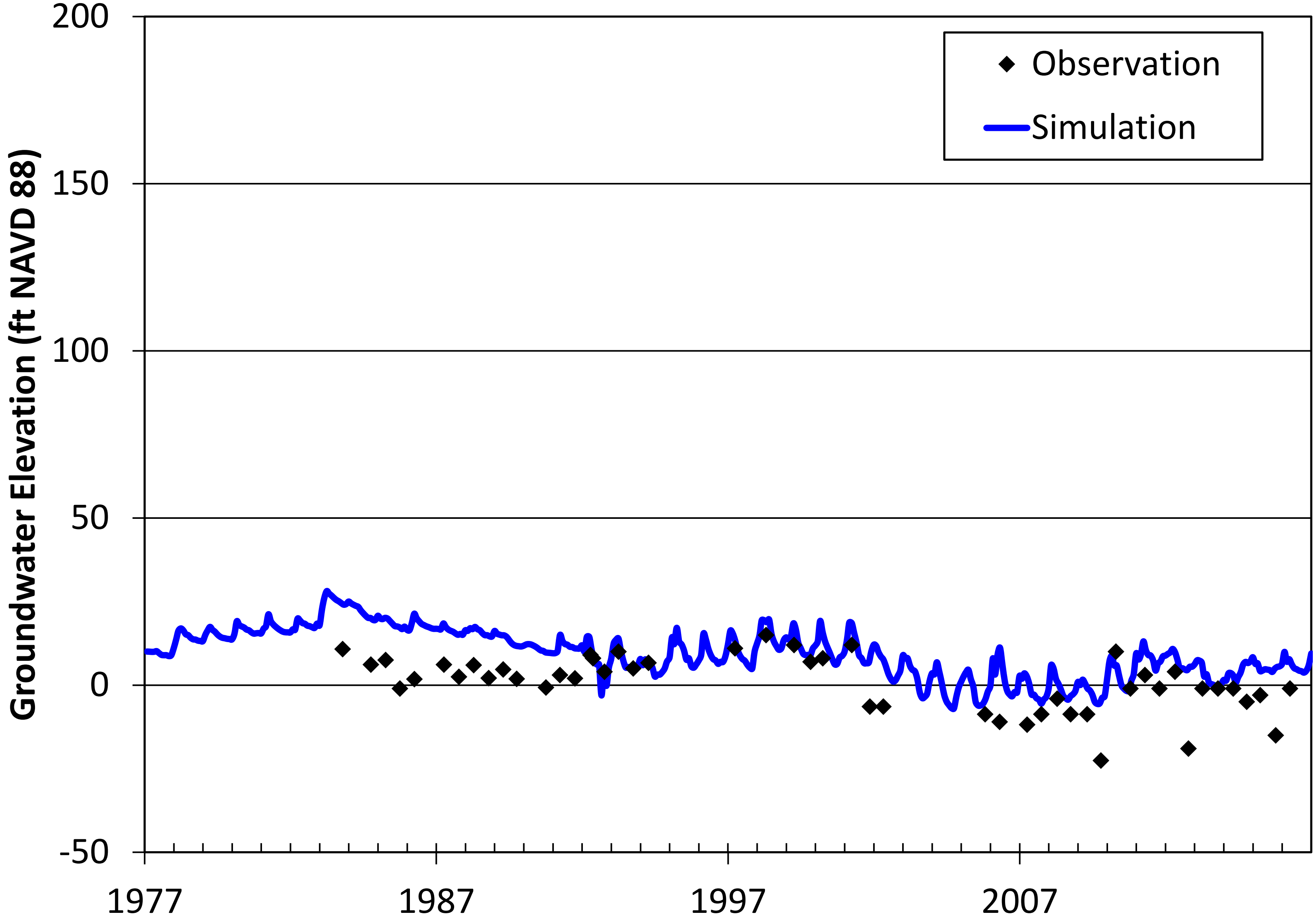


12N36W36L01_4

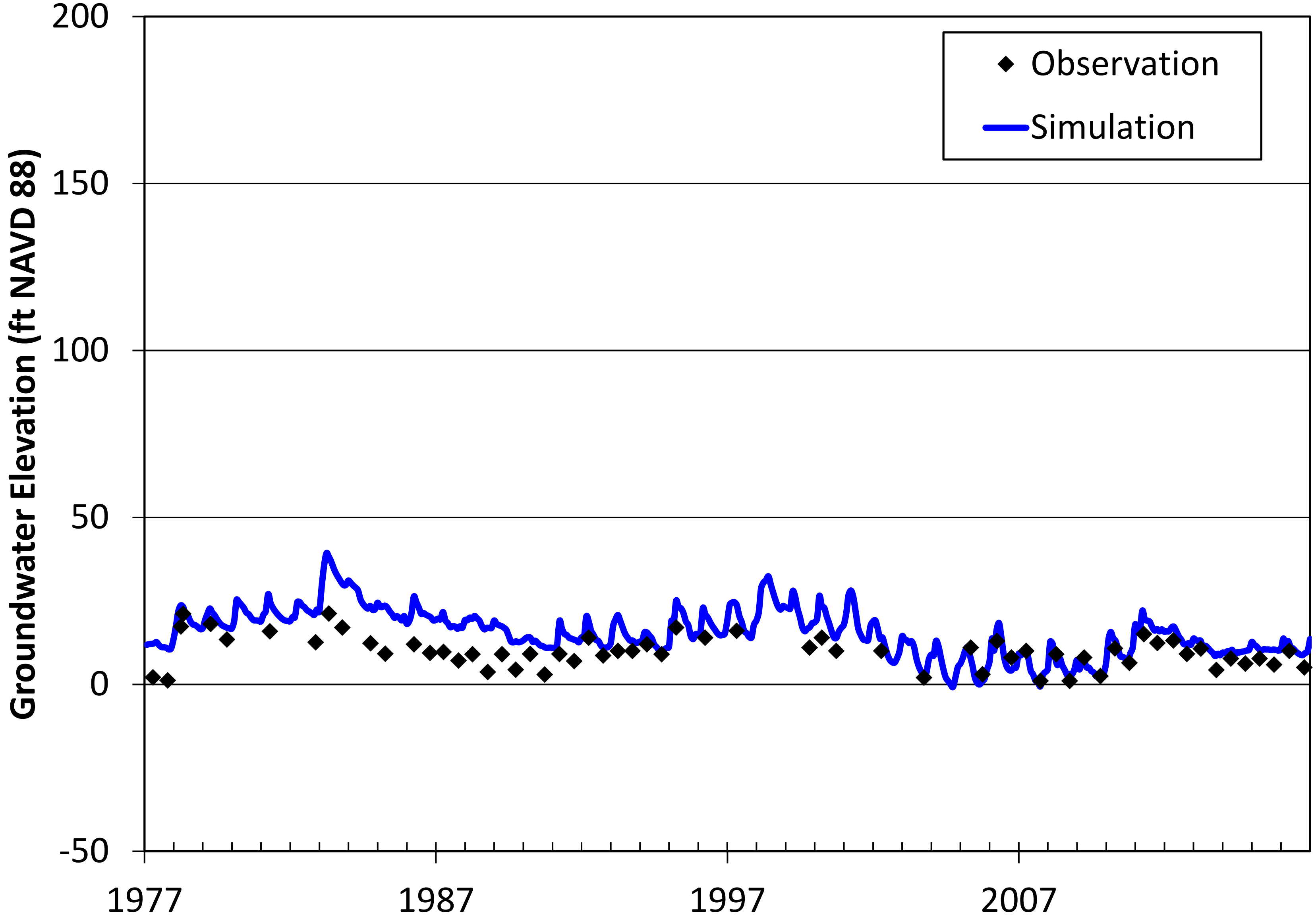



12N36W36L02_10
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007
Observation
Simulation

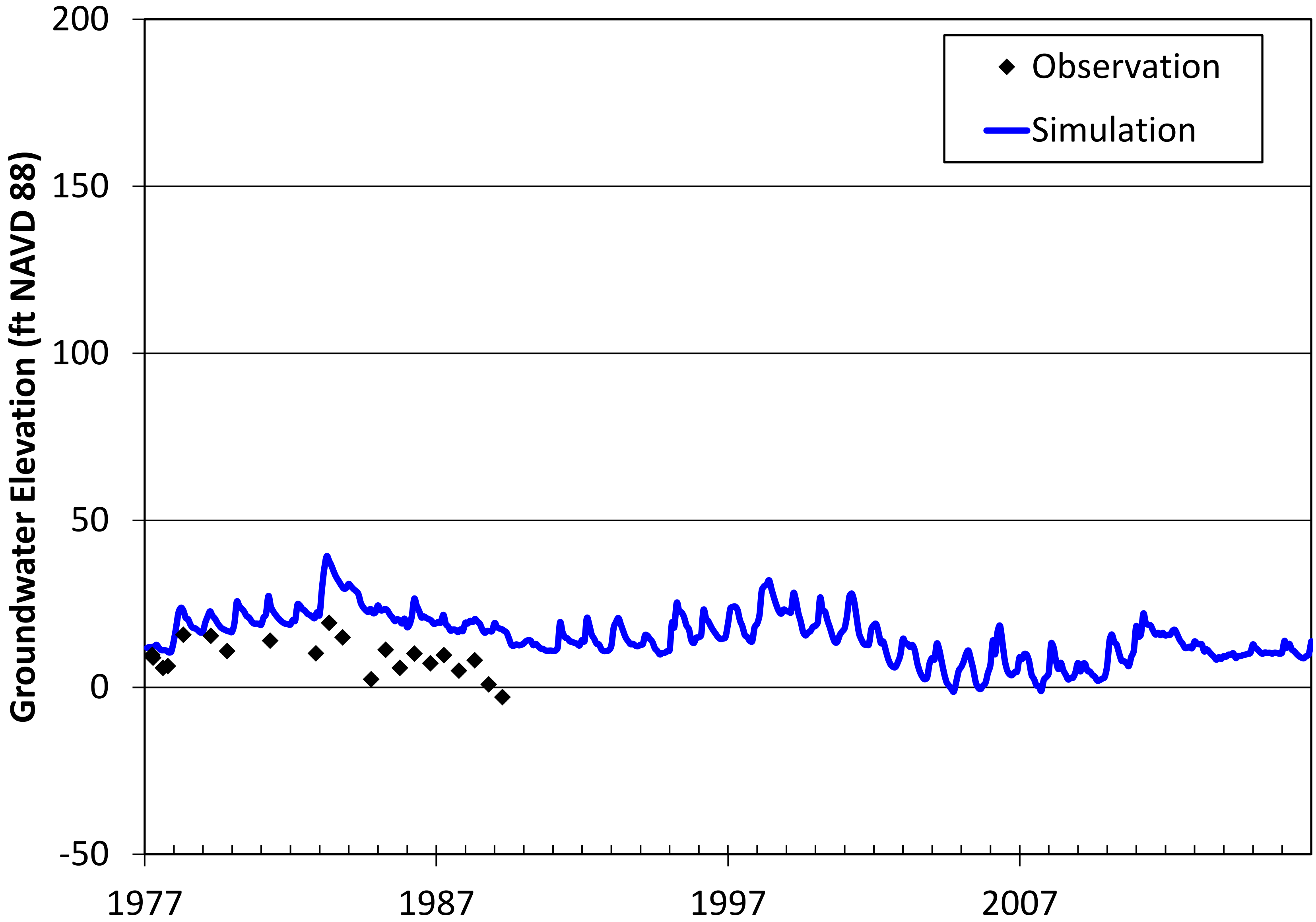
32S13E29E01_2x3x4x5x6x7



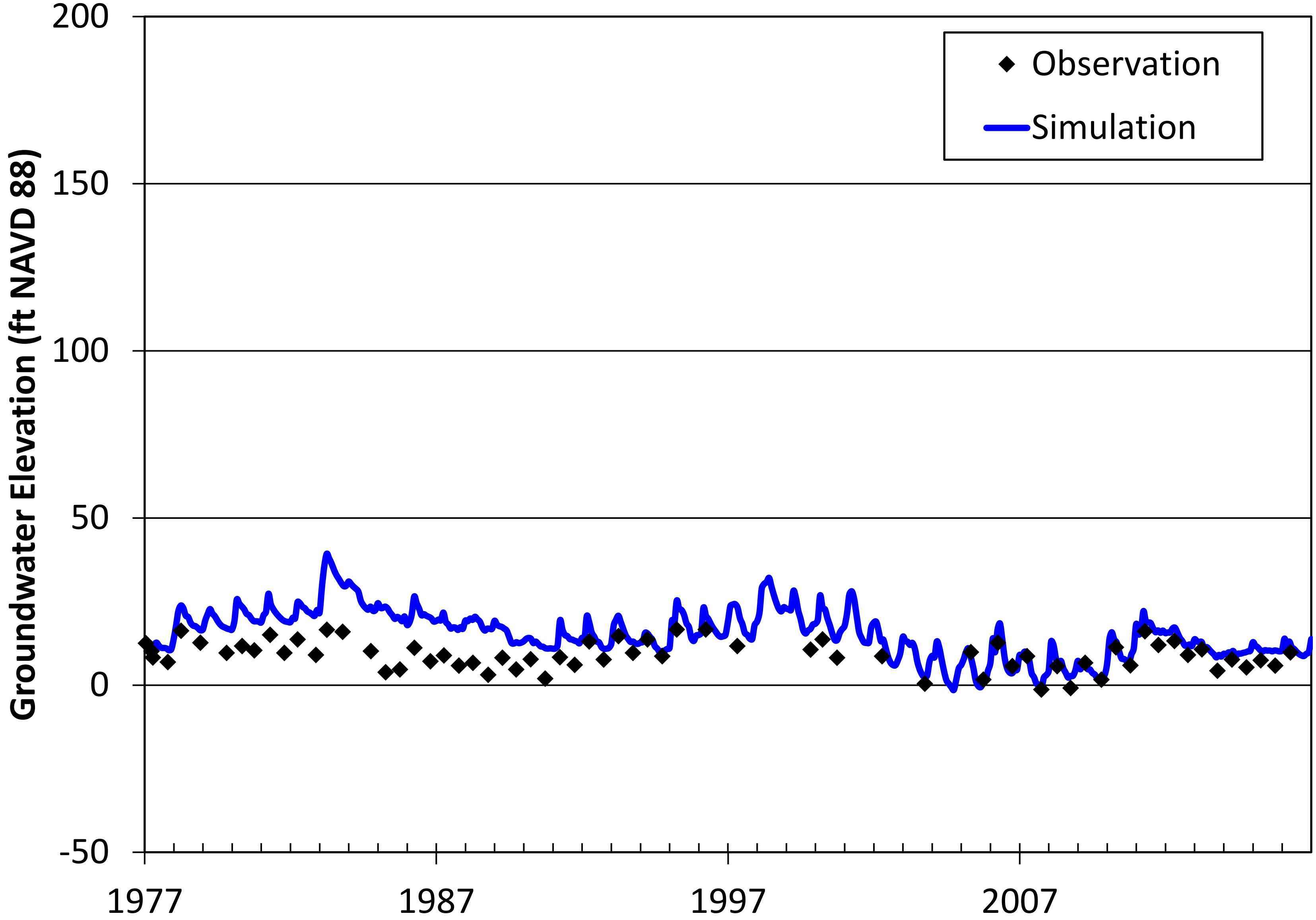
32S13E29G01_2x3x4x5x6



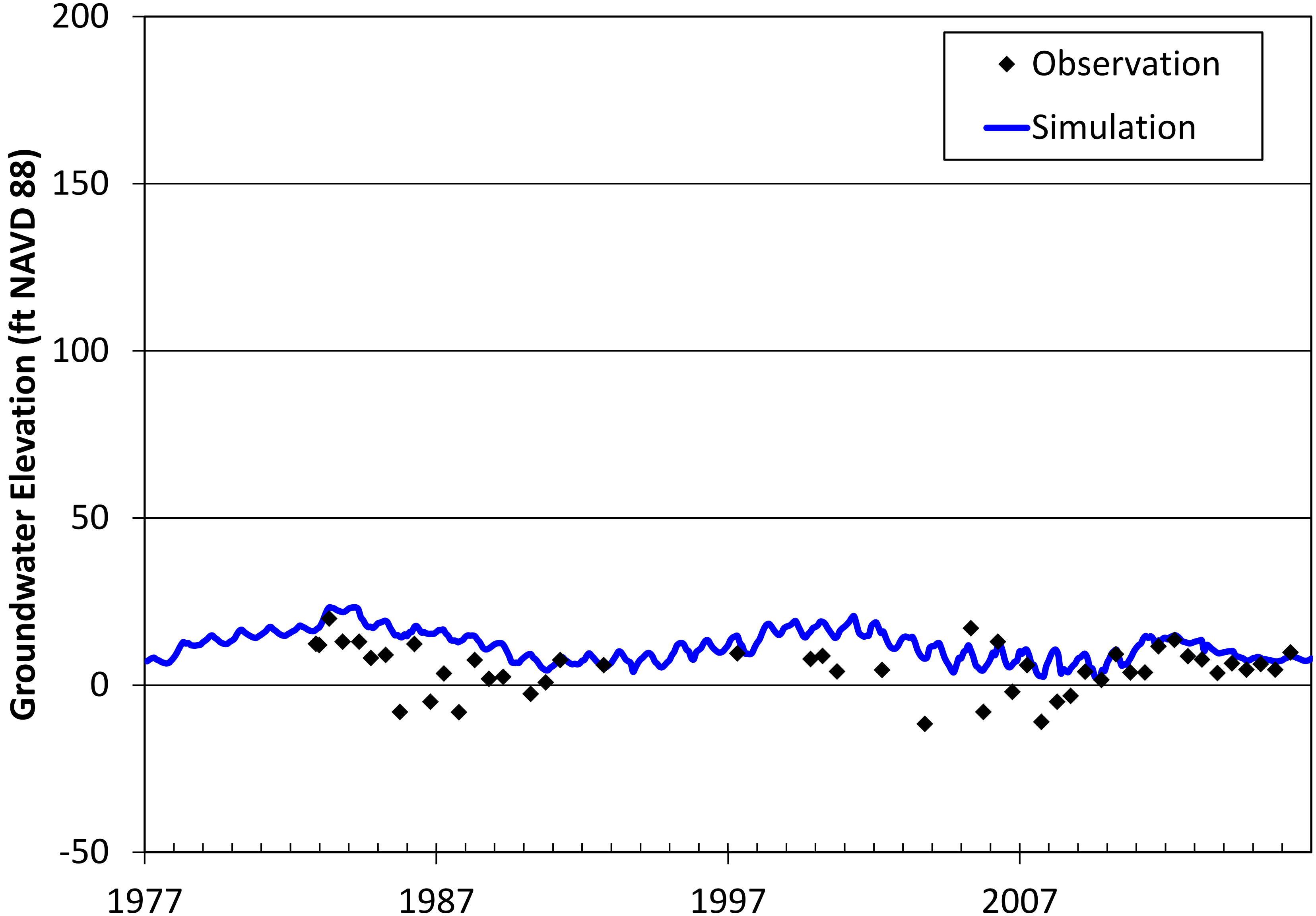
32S13E29G03_2x3x4x5x6



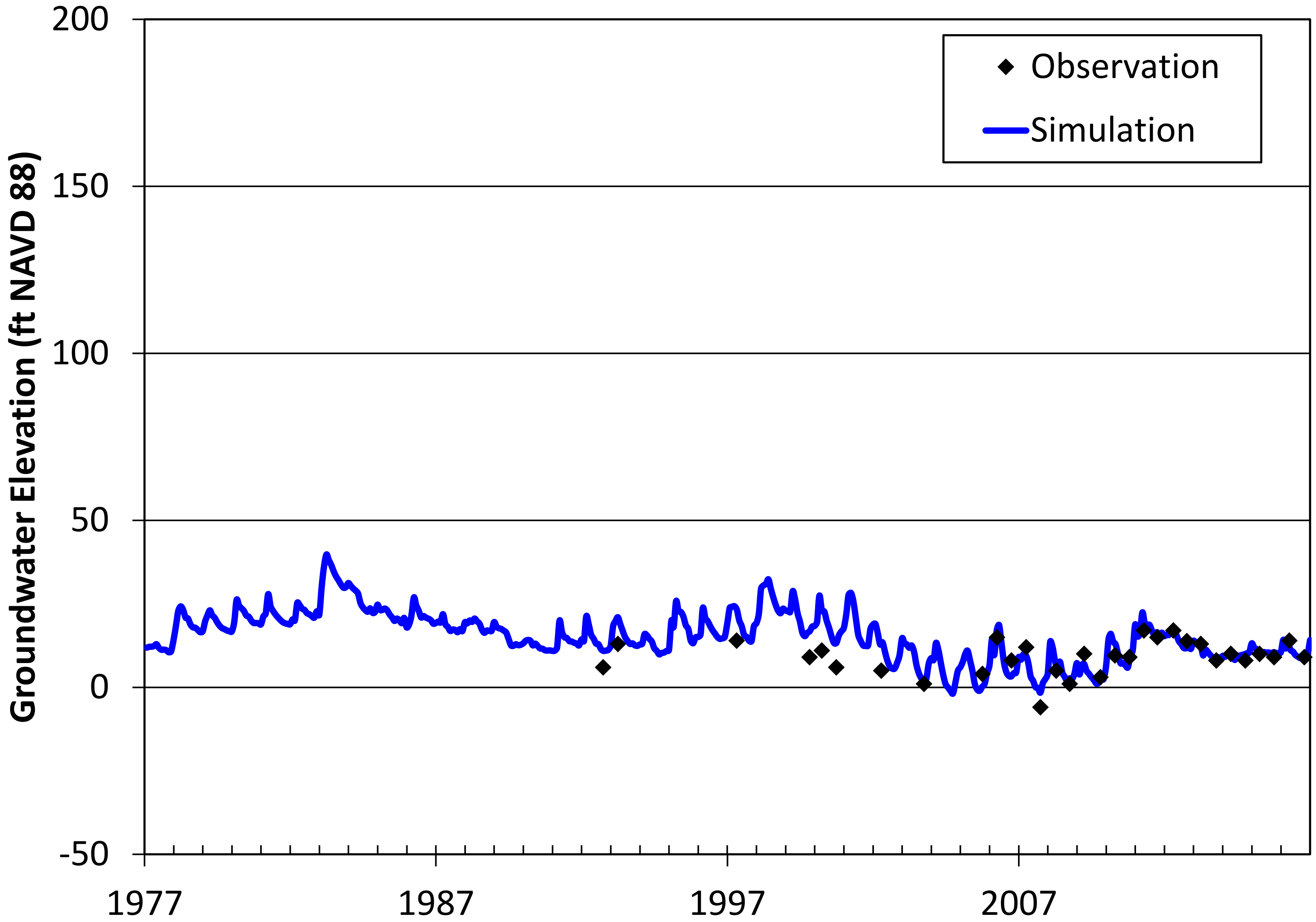
32S13E29G14_4x5x6



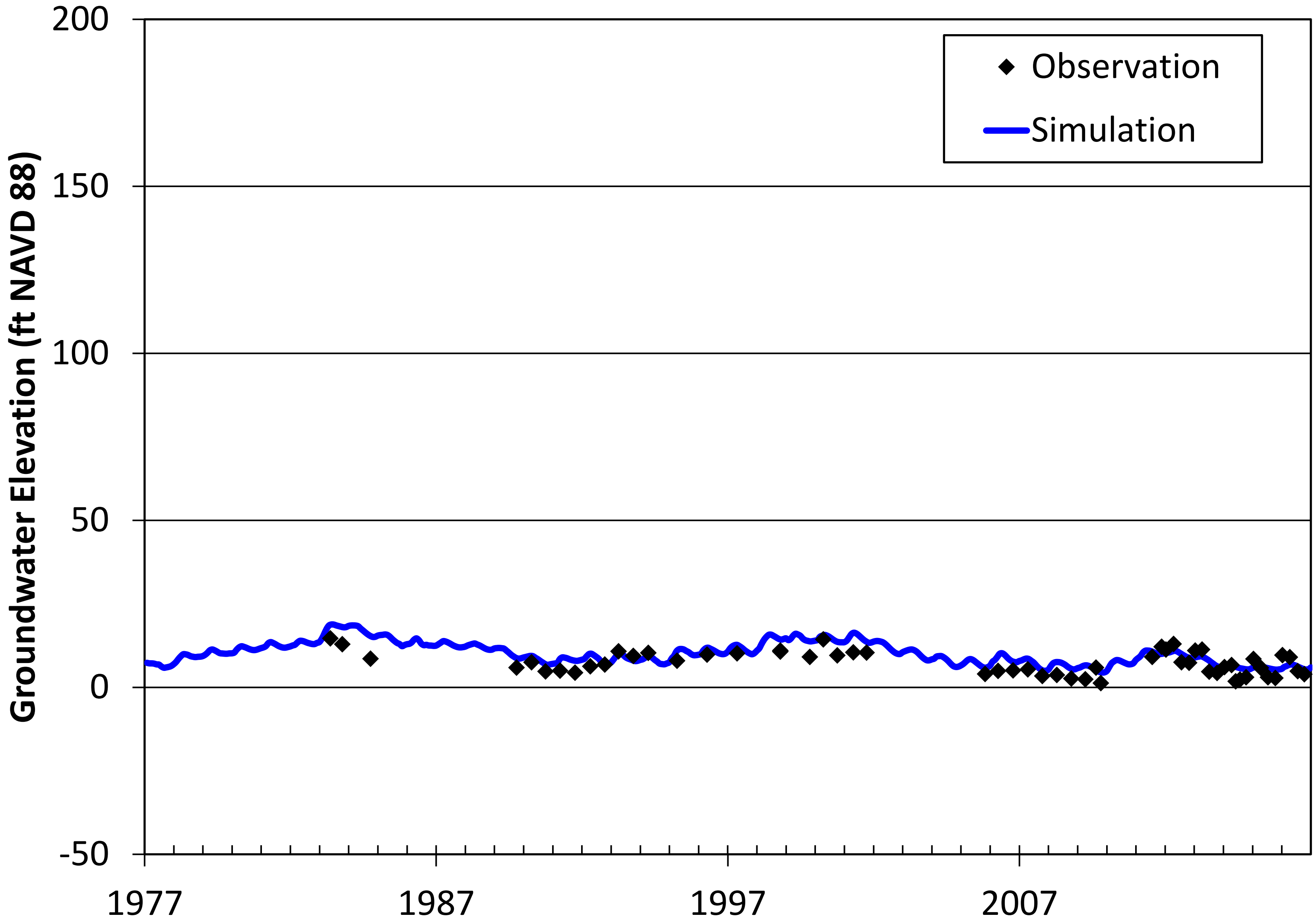
32S13E29G15_8x9x10



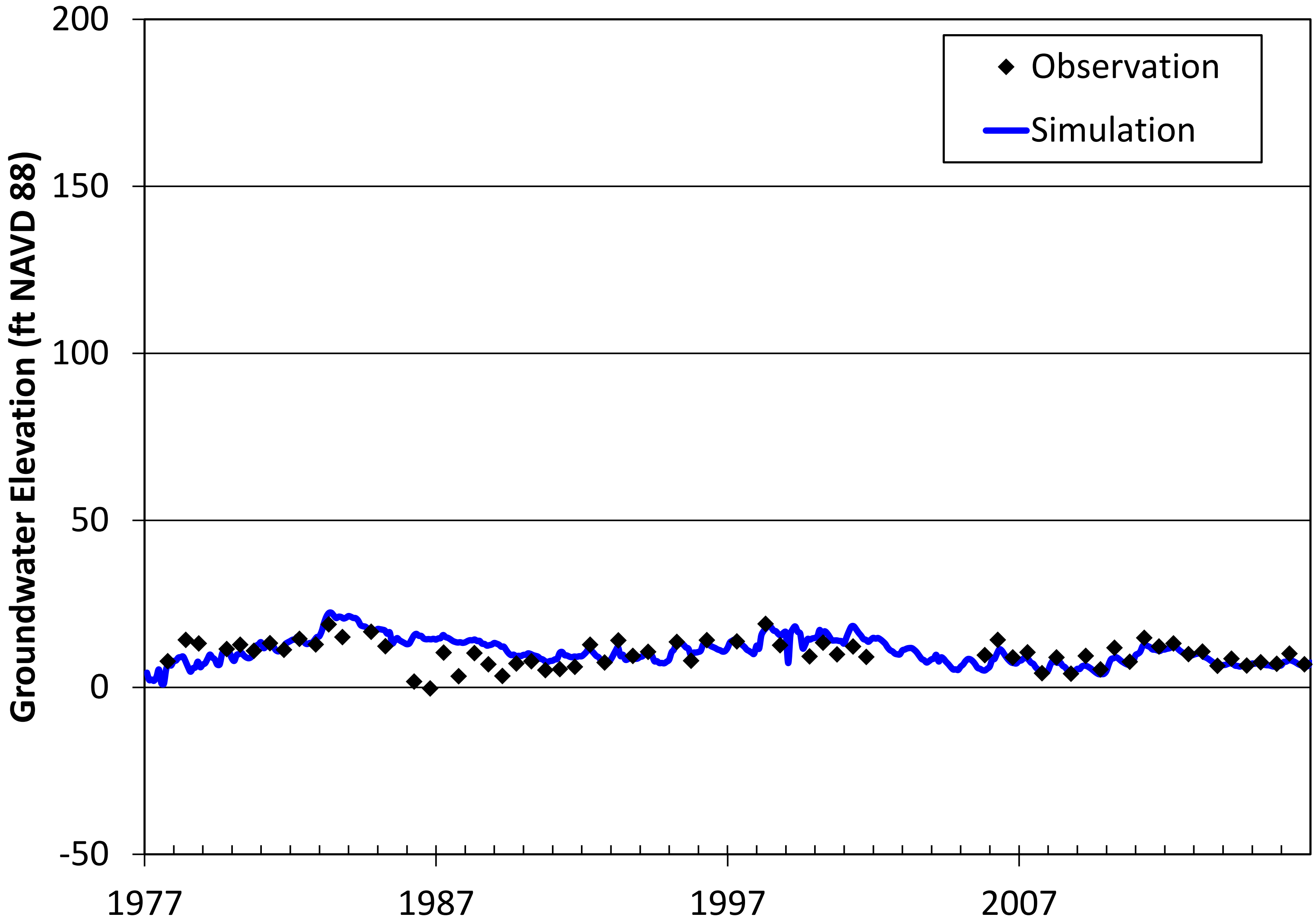
32S13E29G17_2x3x4



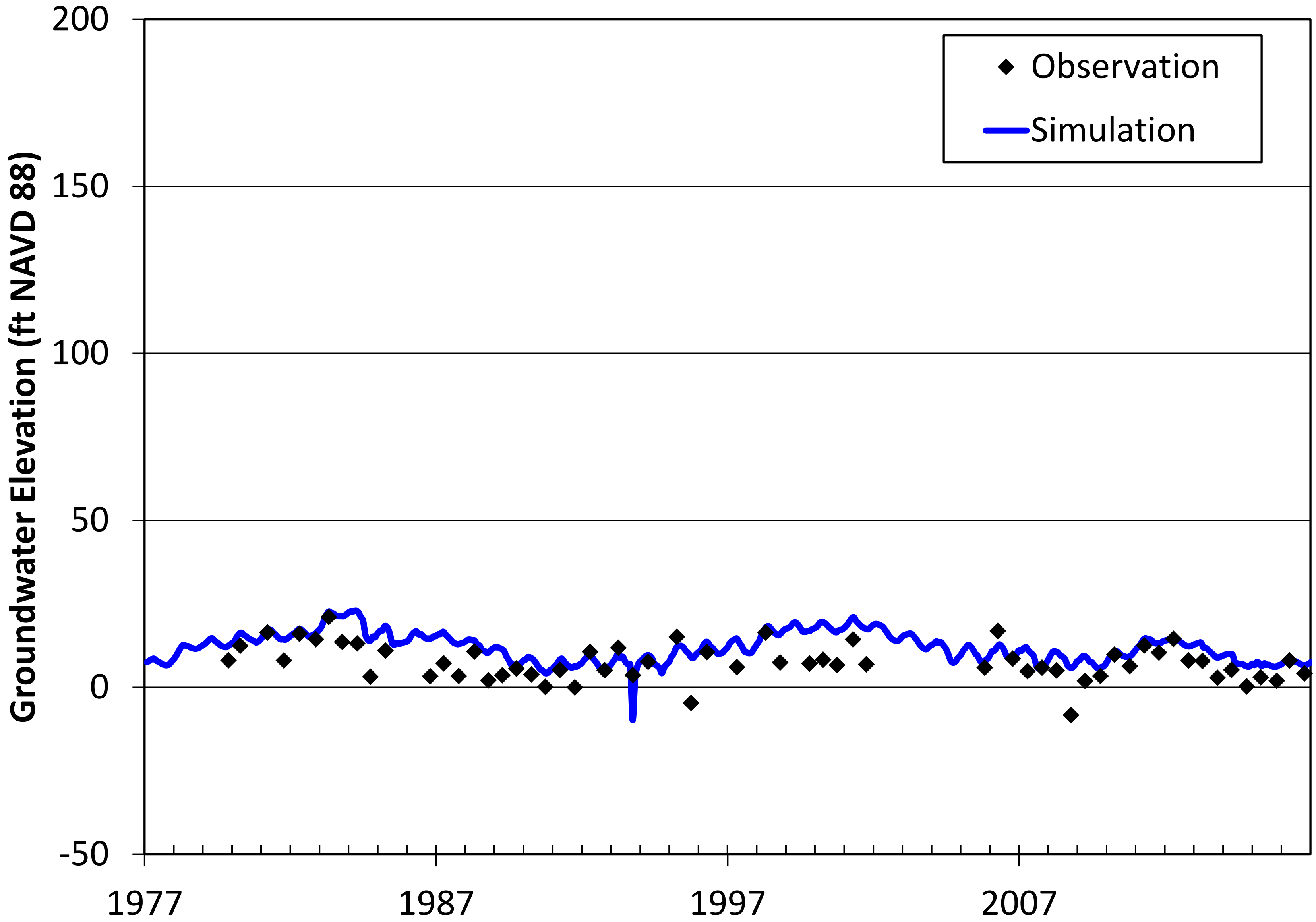
32S13E31H10_4



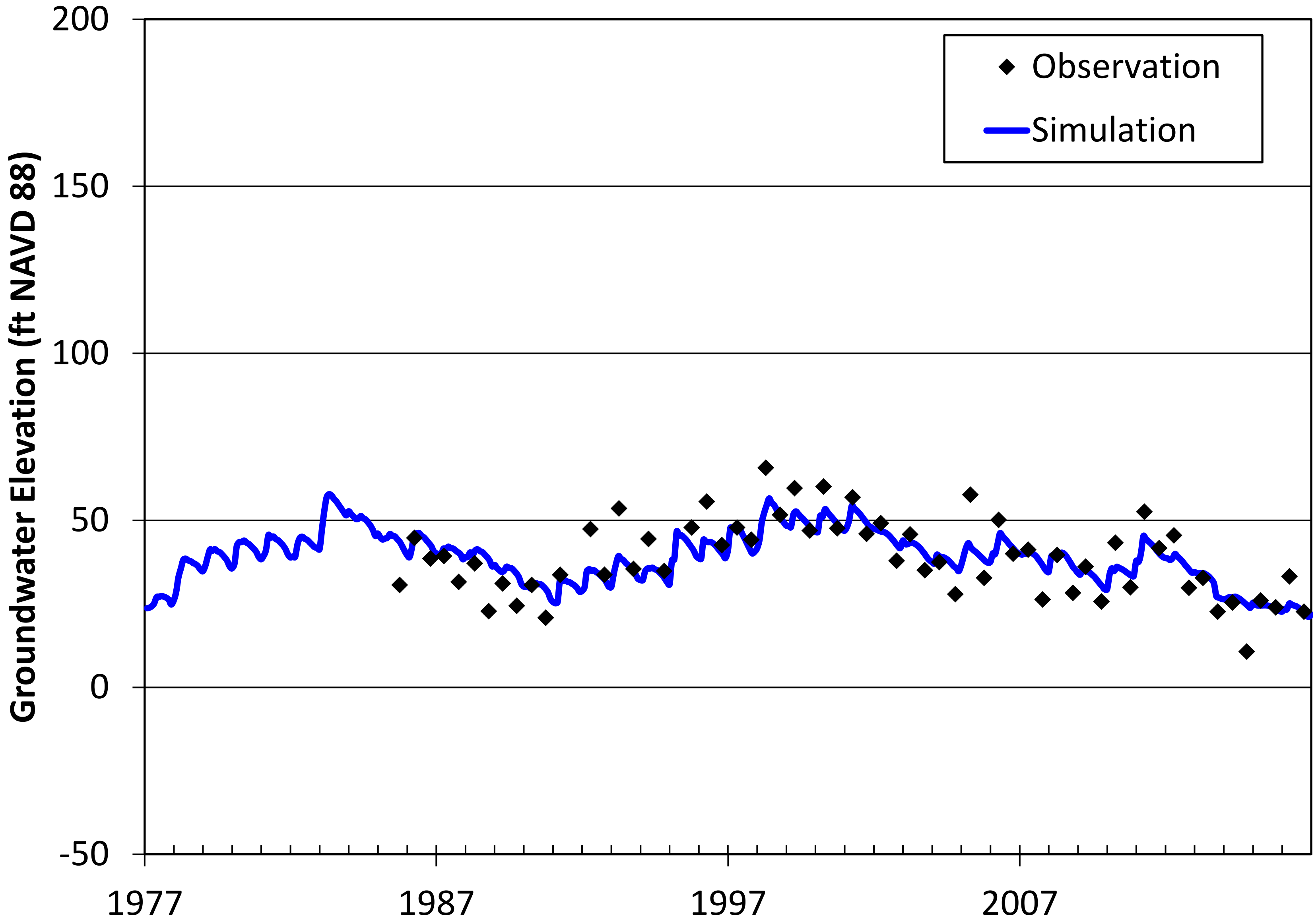
32S13E32D03_3x4x5x6



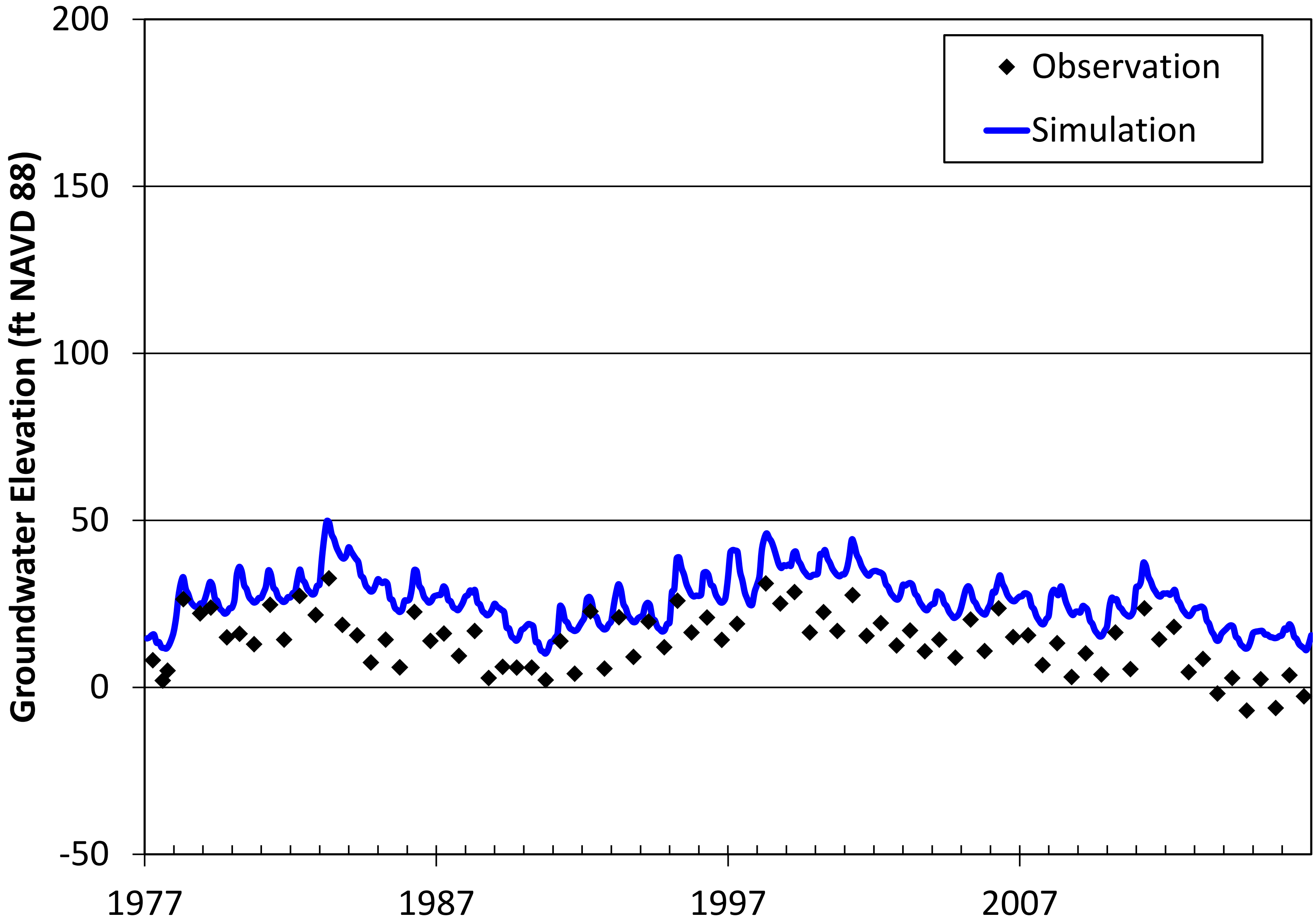
32S13E32D11_8x9x10



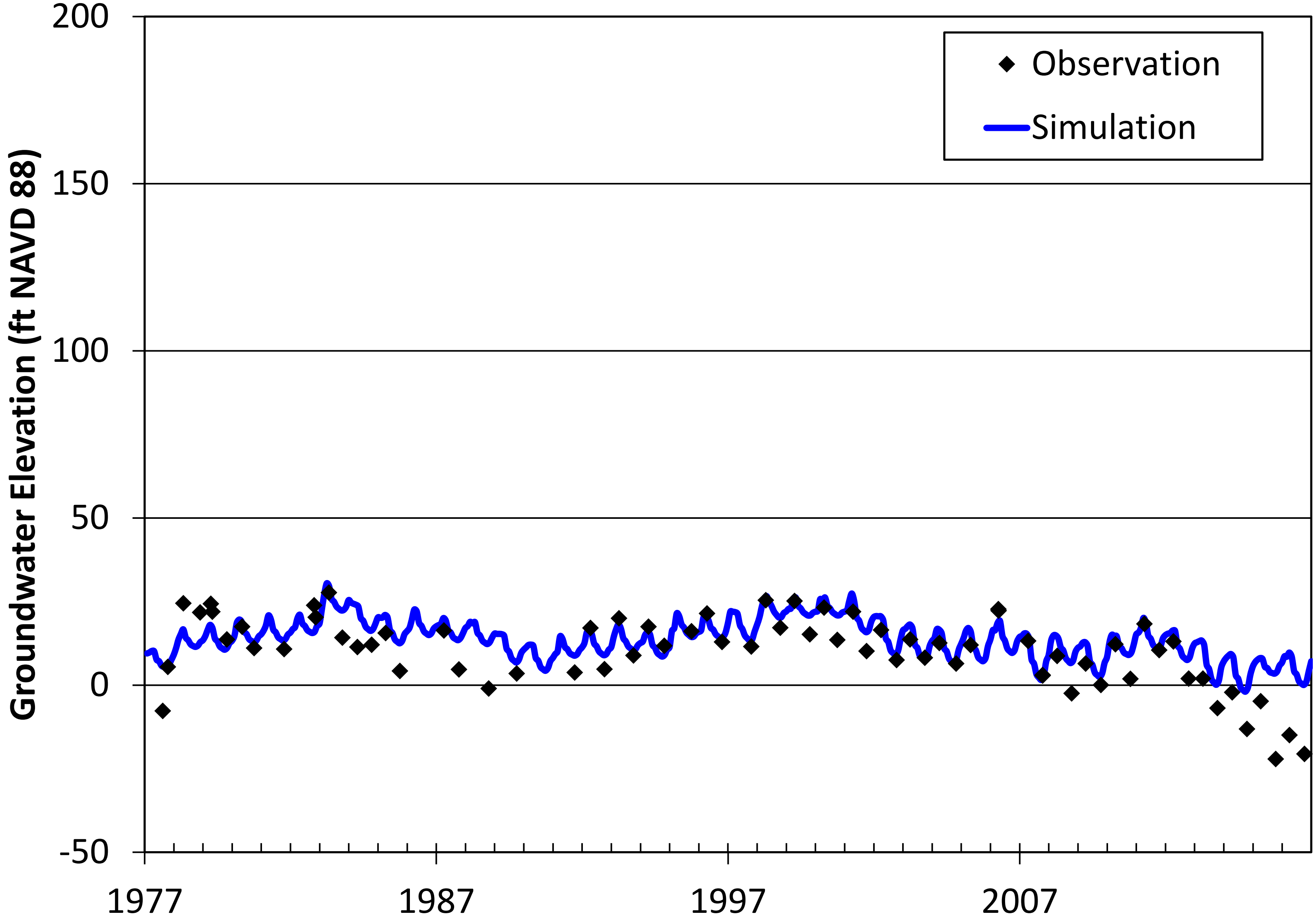
32S13E33A06_



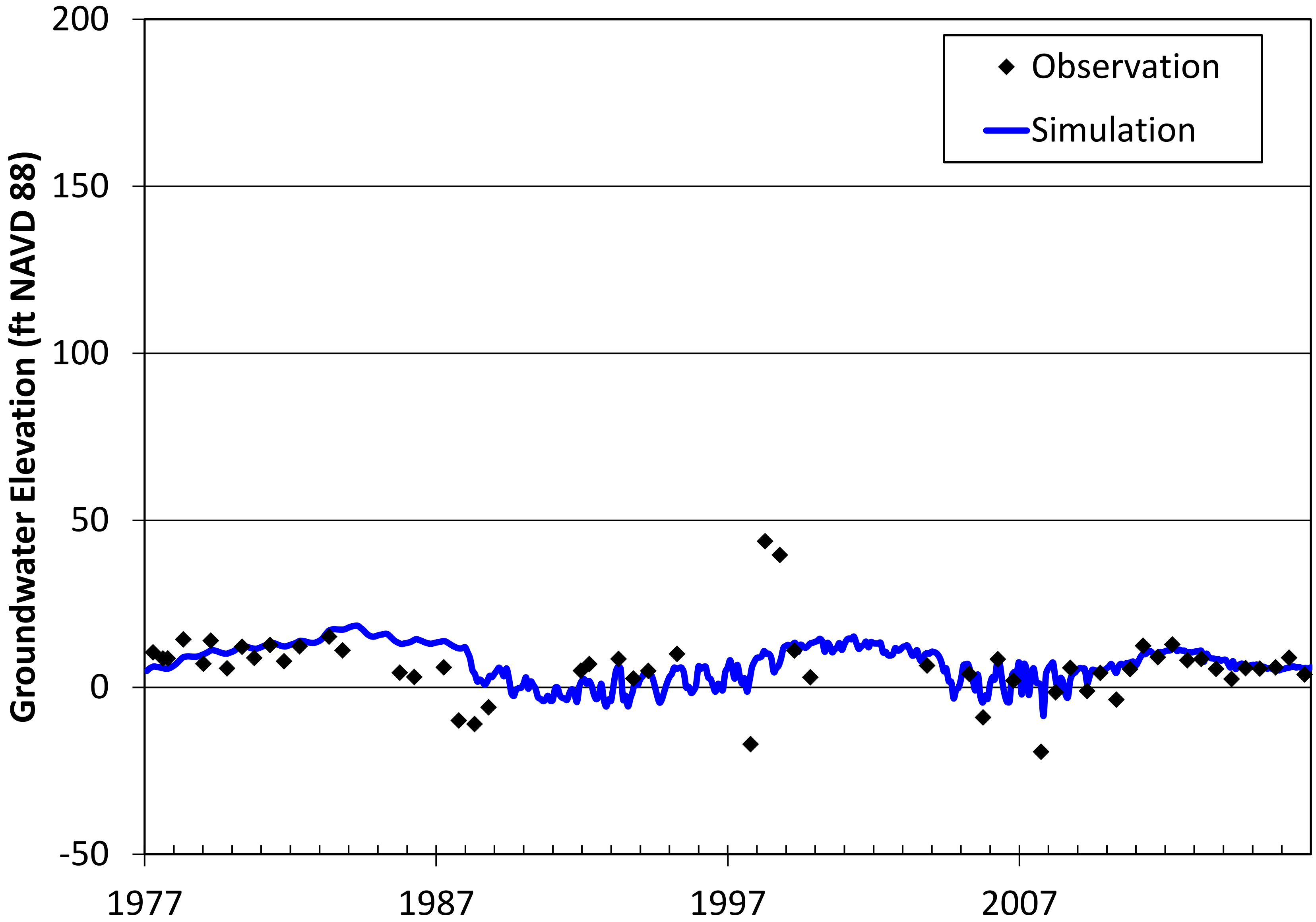
32S13E33K03_2

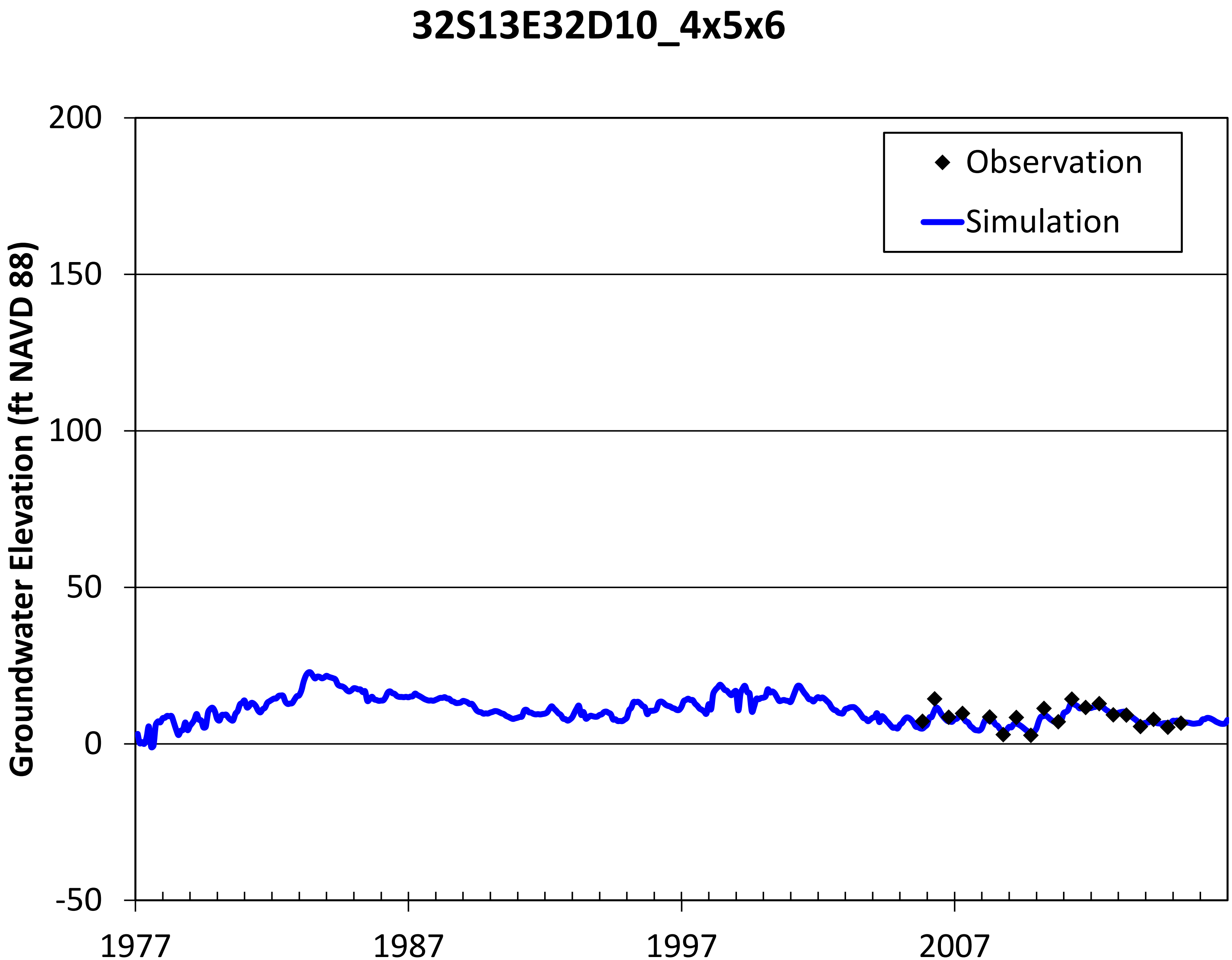


12N35W29N01_2x3

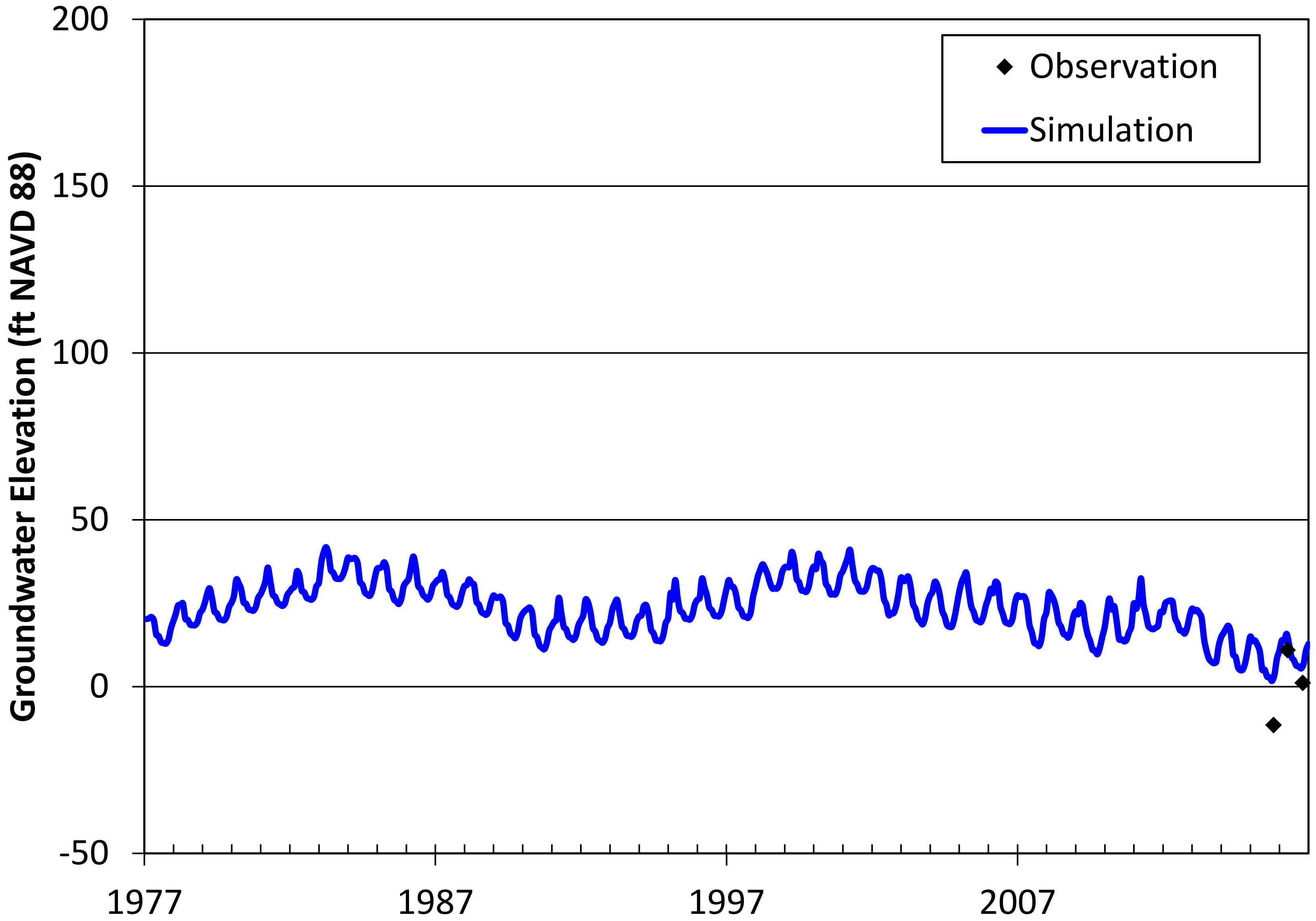


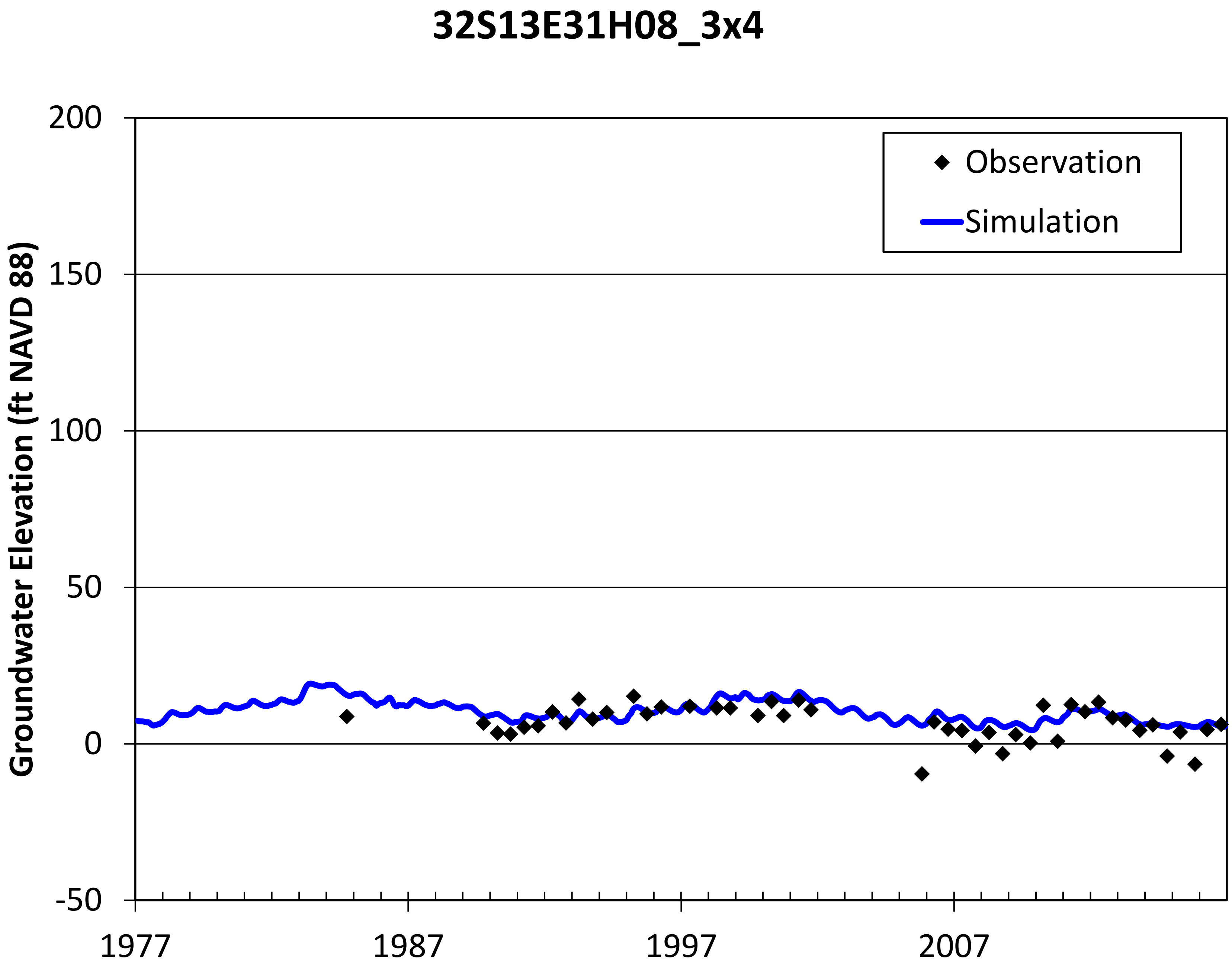
32S13E19Q02_6x7x8x9x10

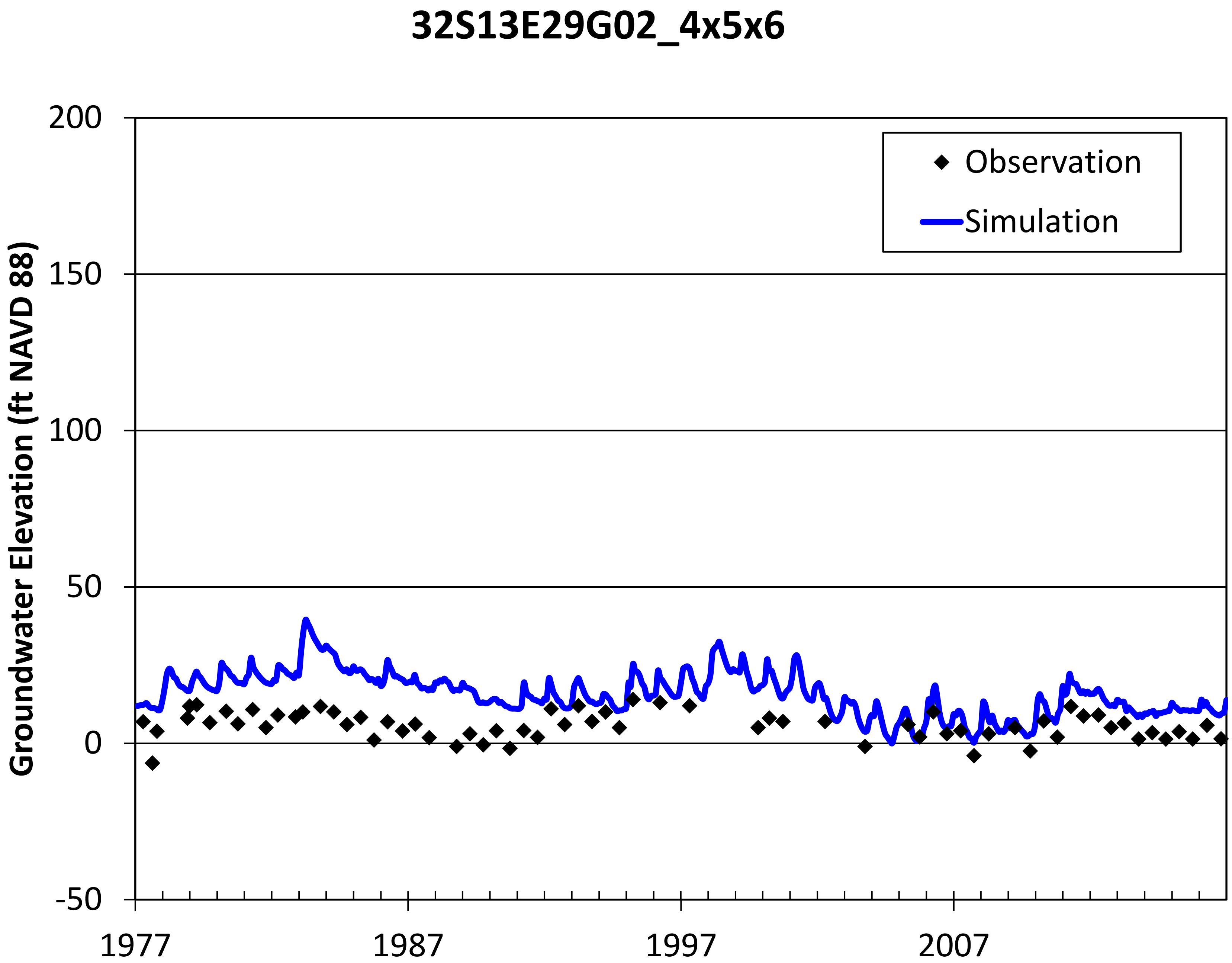



32S13E32D10_4x5x6
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007
Observation
Simulation

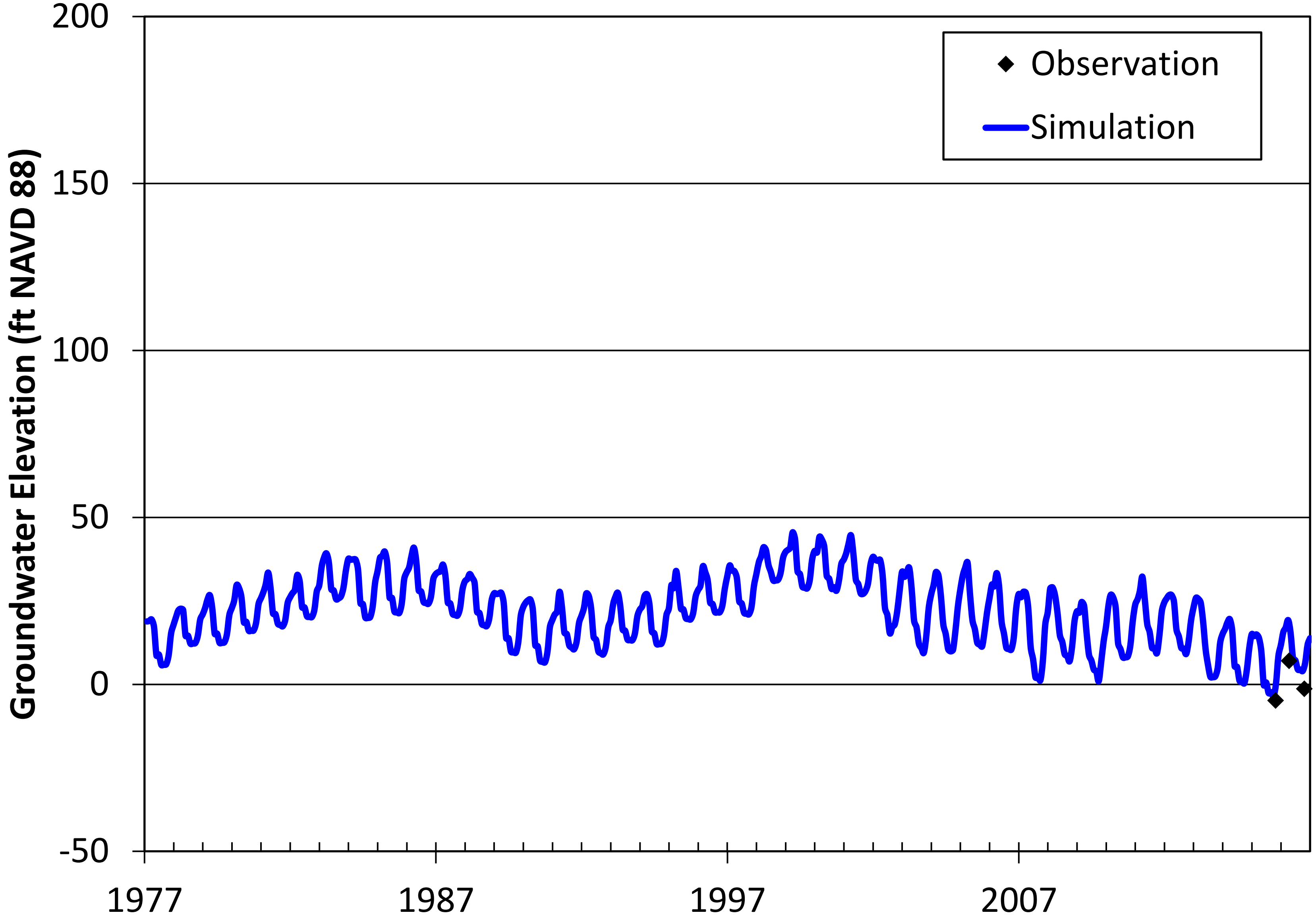
12N35W32R01_3x4x5



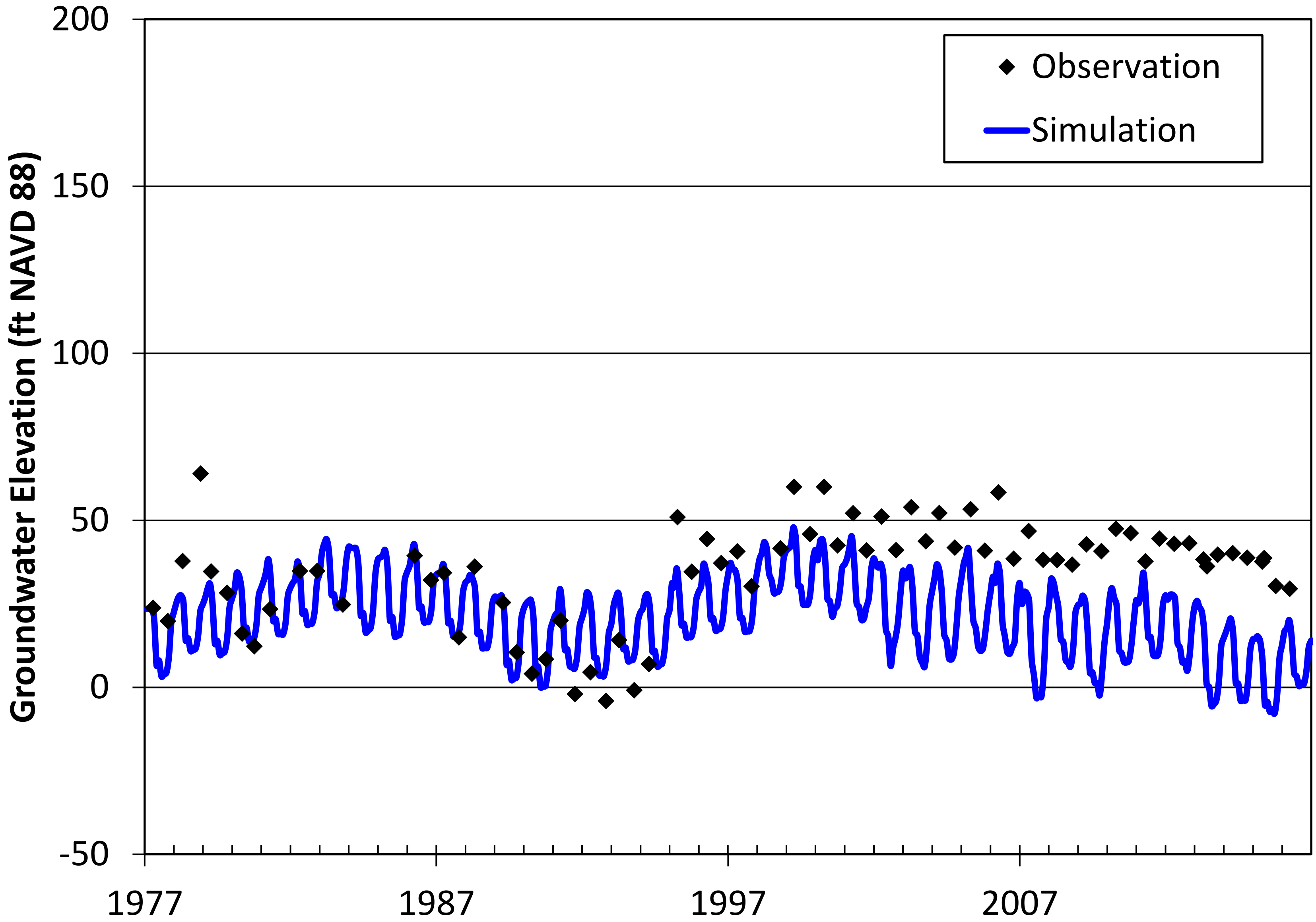

32S13E31H08_3x4
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007
Observation
Simulation

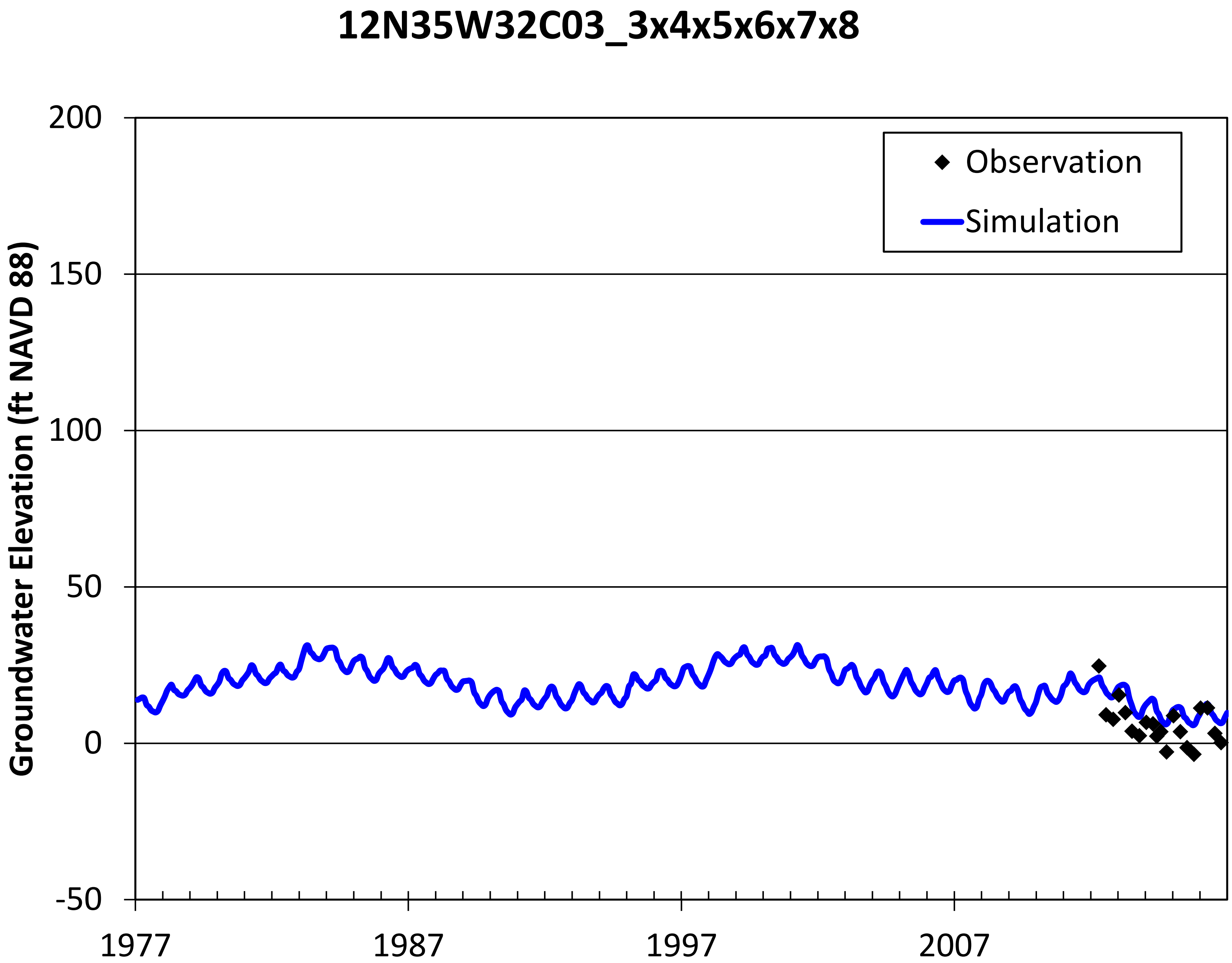

32S13E29G02_4x5x6
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007

11N35W04E01_6x7x8

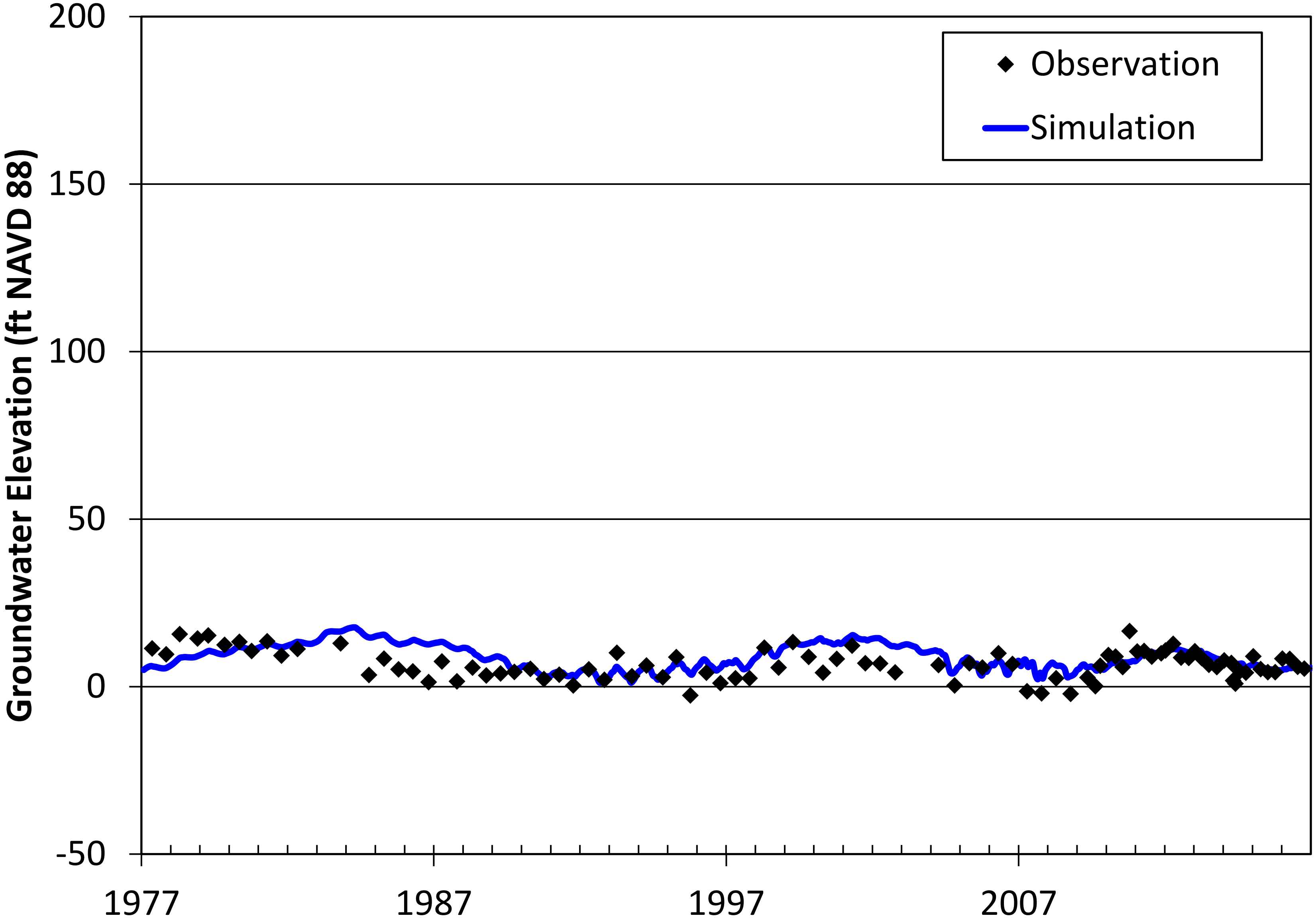


11N35W09K02_2x3x4x5

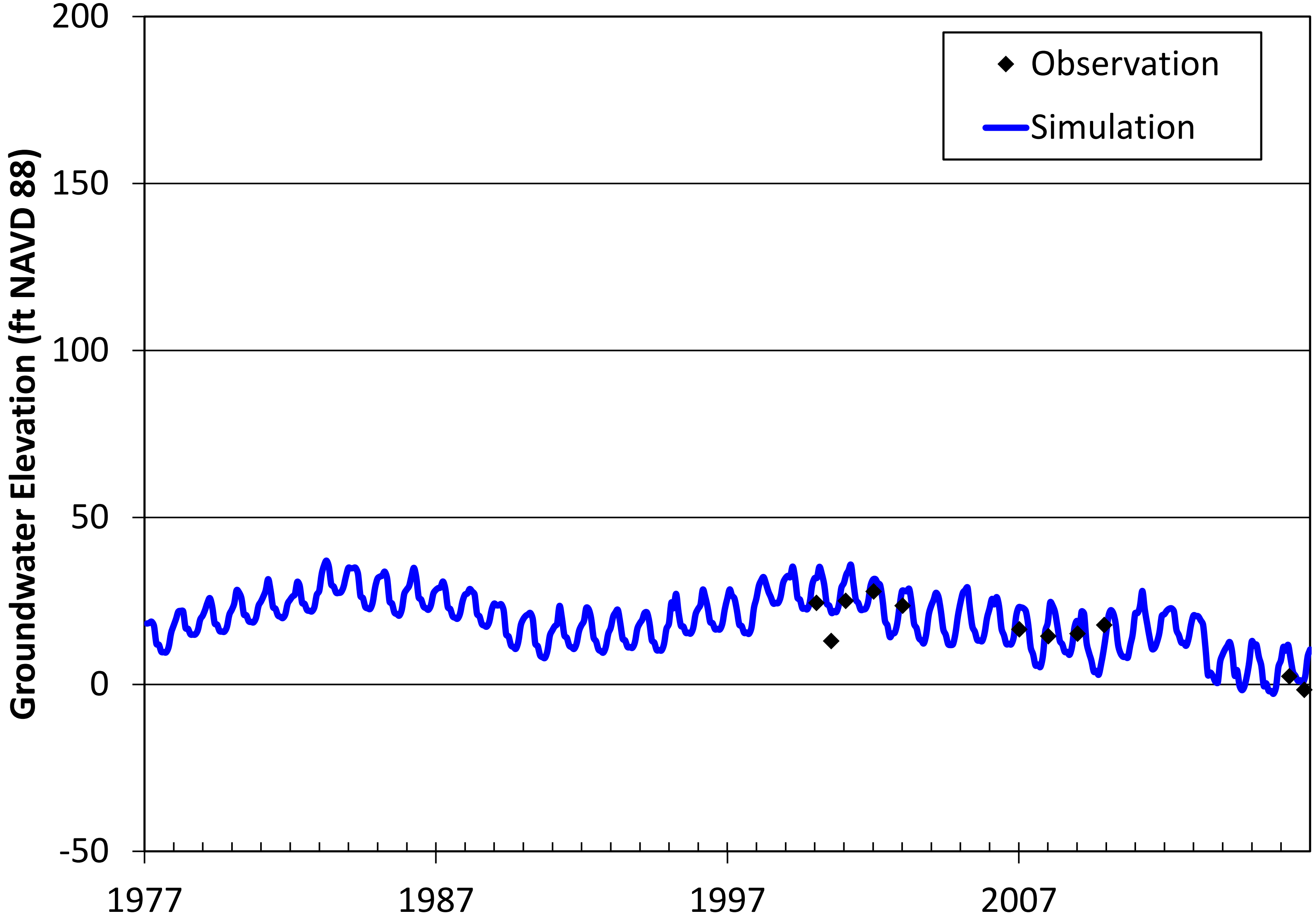


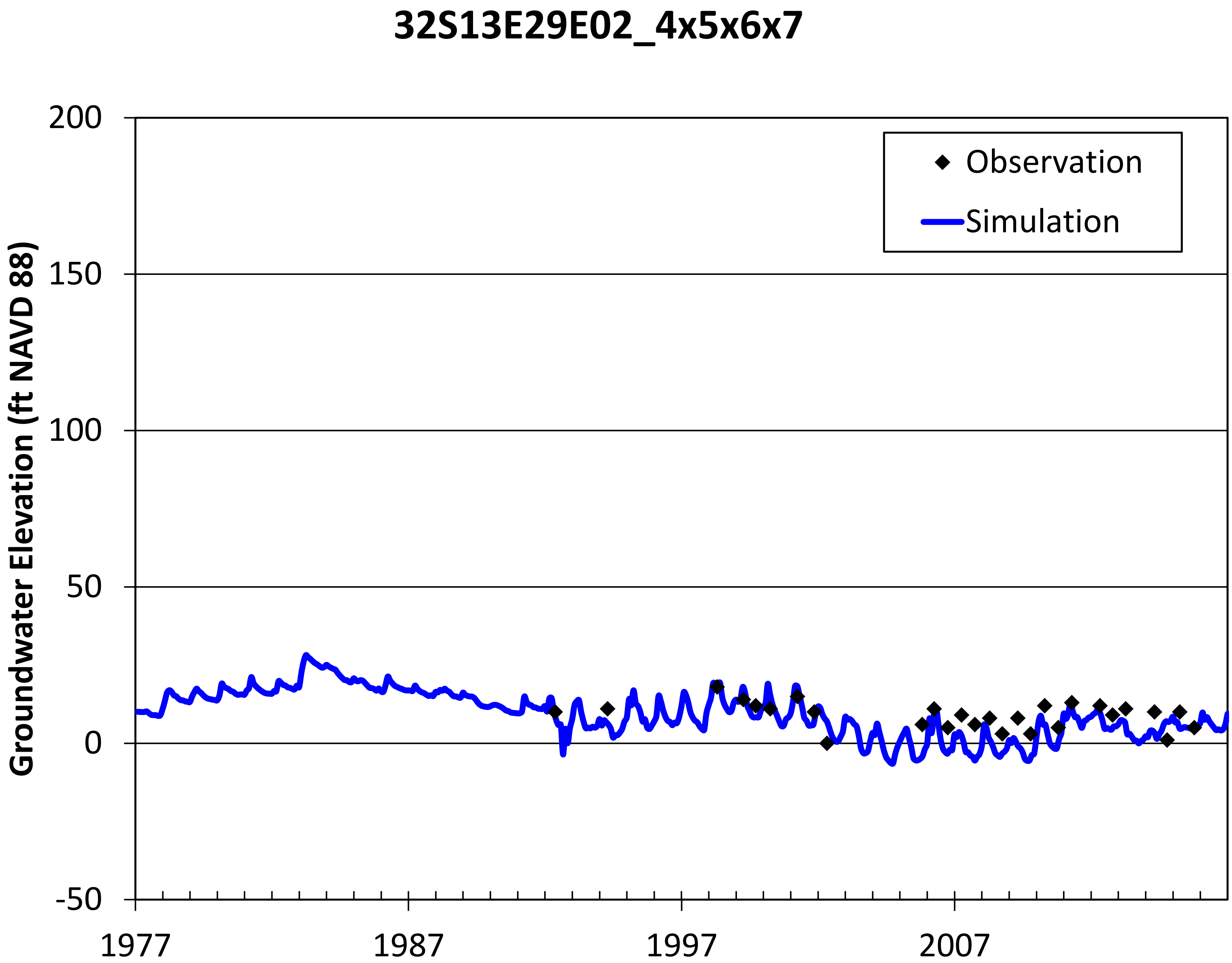

12N35W32C03_3x4x5x6x7x8
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007

32S13E30F03_8x9

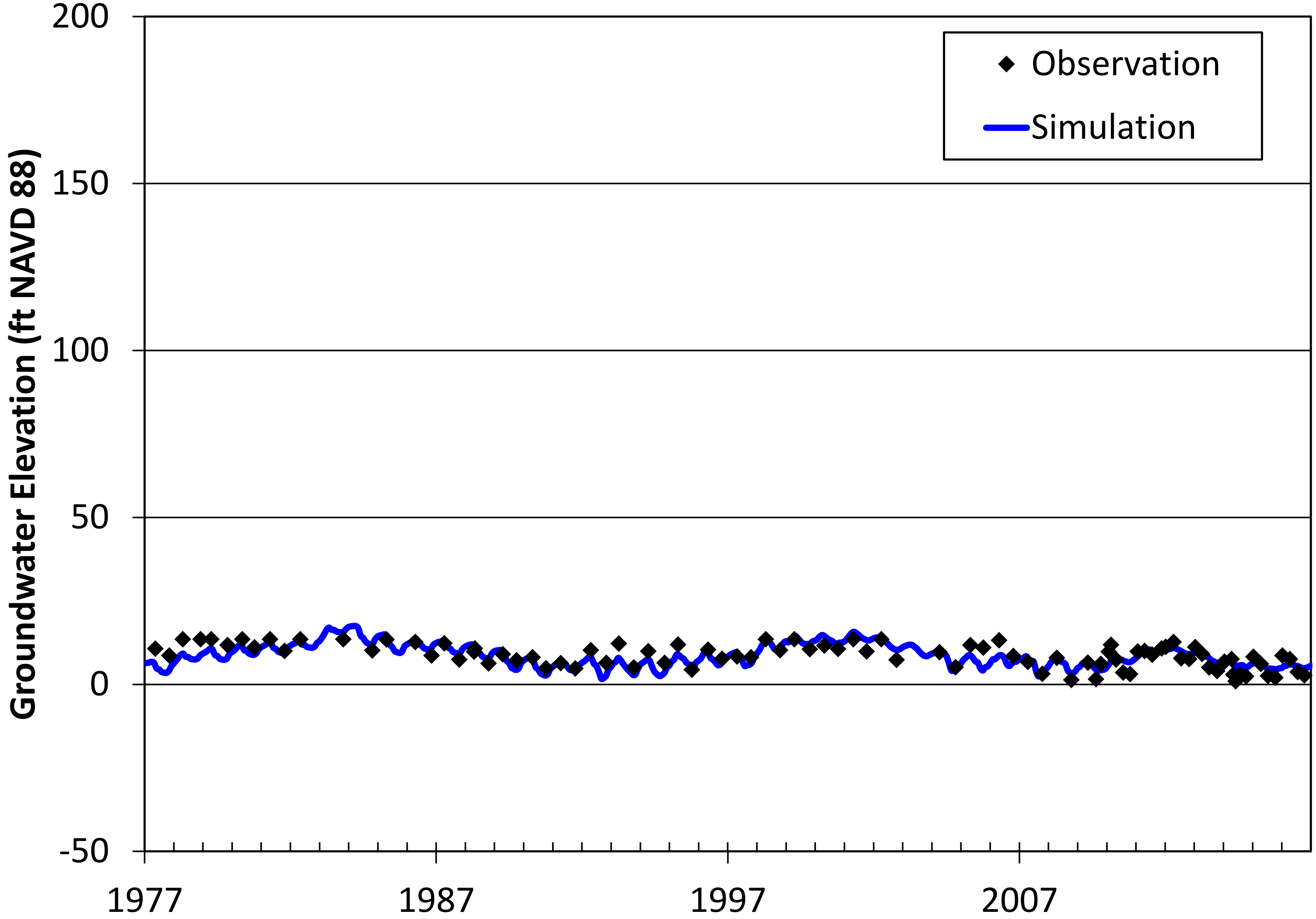


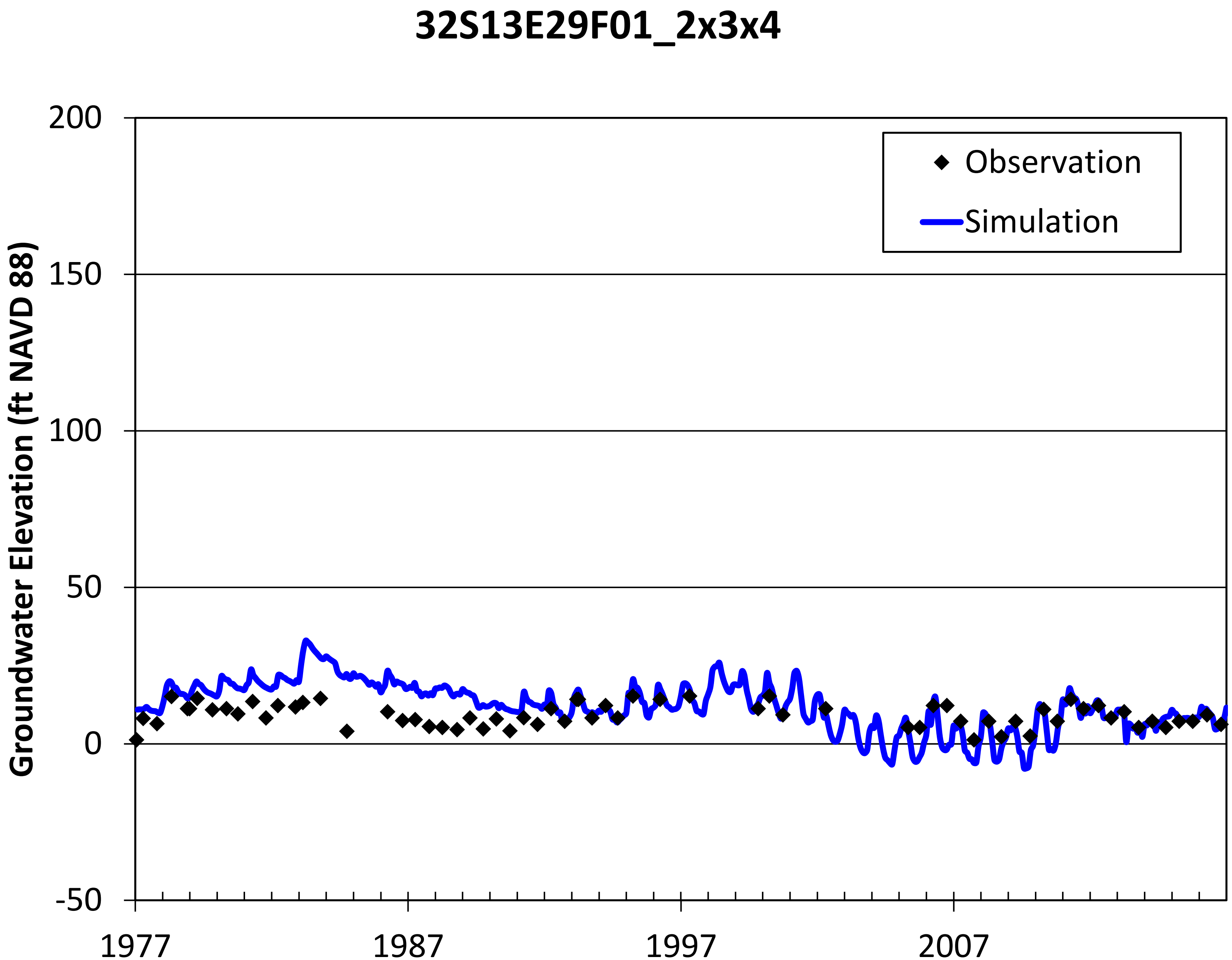
11N35W05B01_4x5



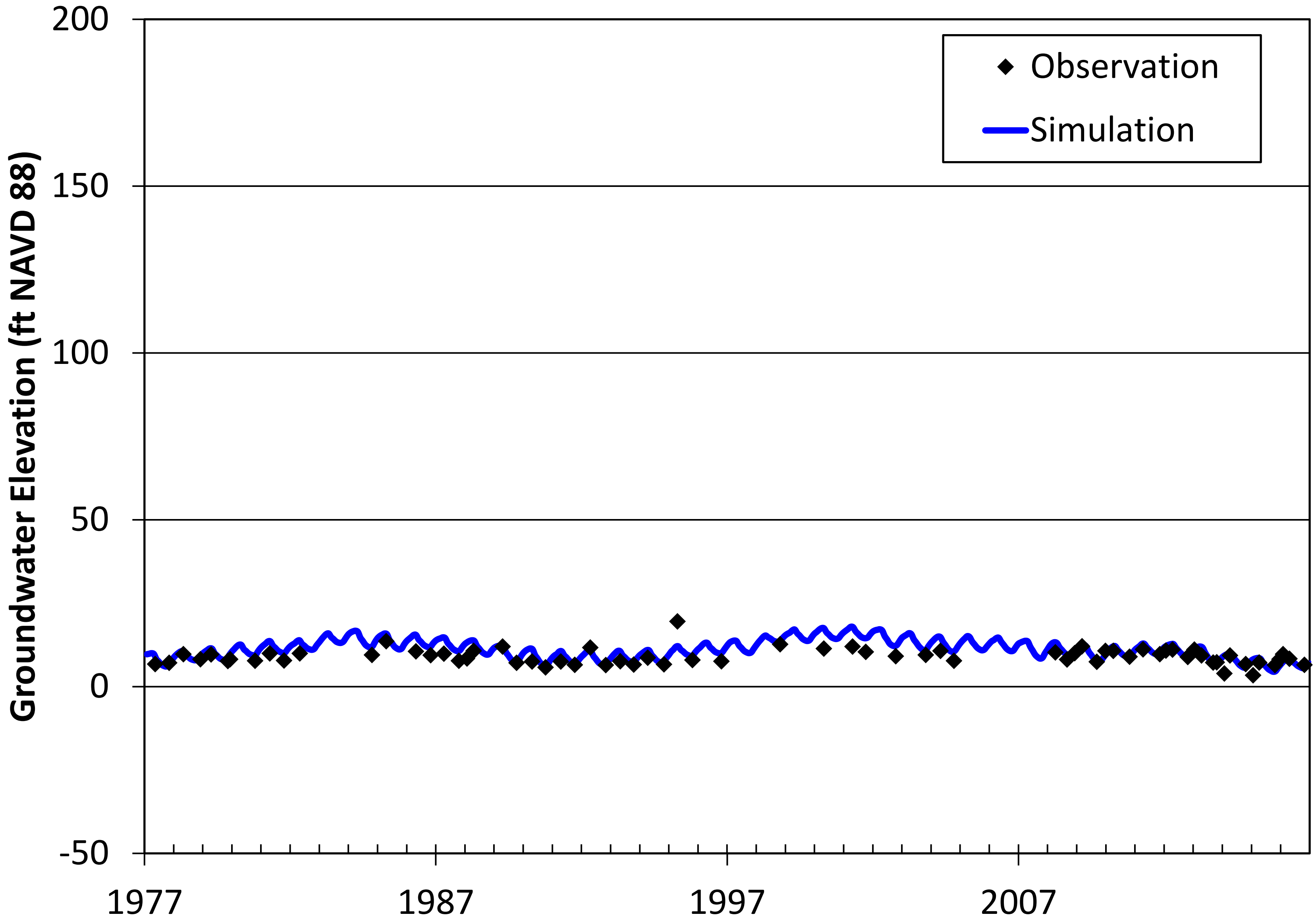

32S13E29E02_4x5x6x7
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007

32S13E30N02_5x6

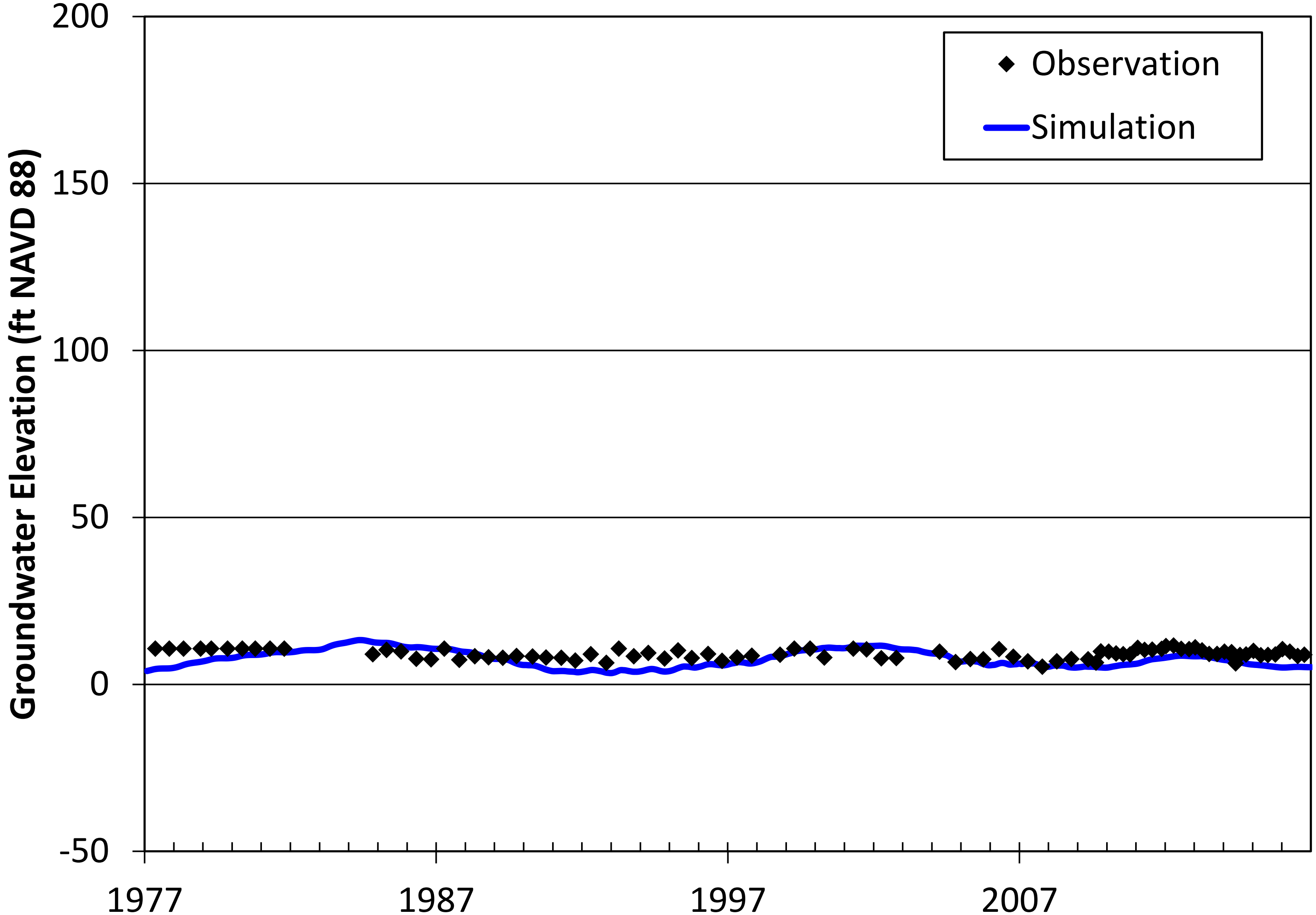



32S13E29F01_2x3x4
Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007

11N36W12C01_4



32S12E24B03_8x9x10



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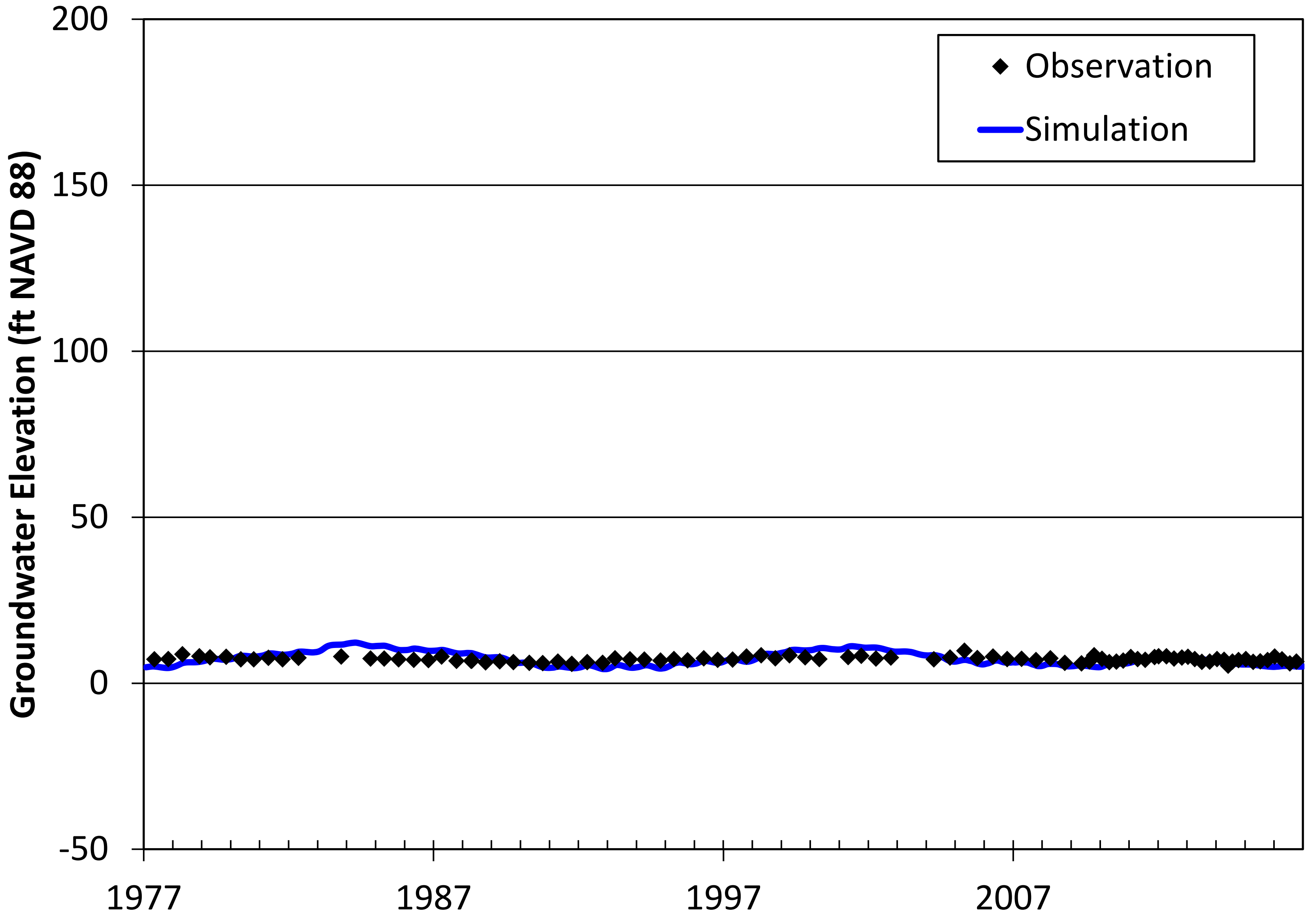

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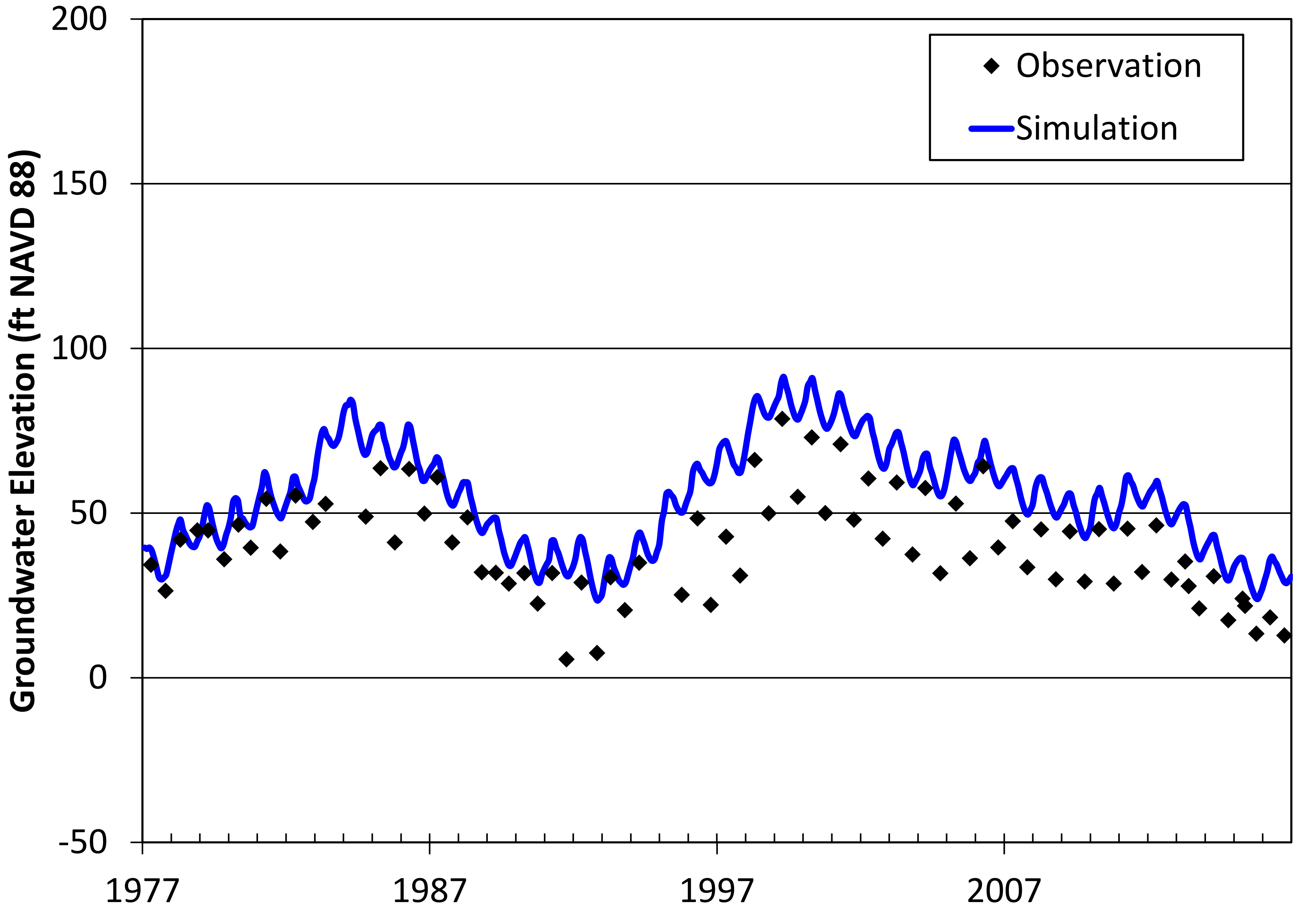

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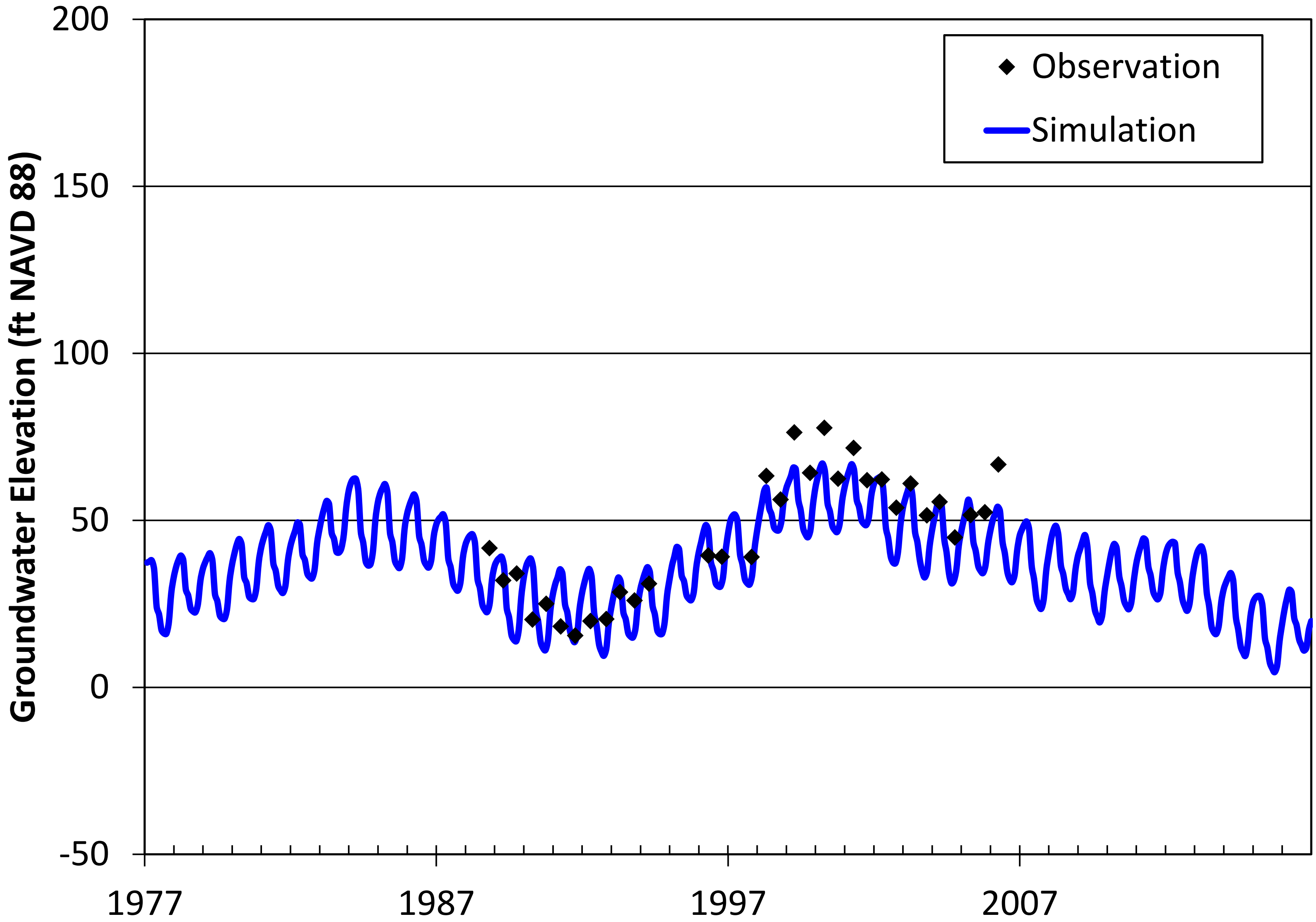

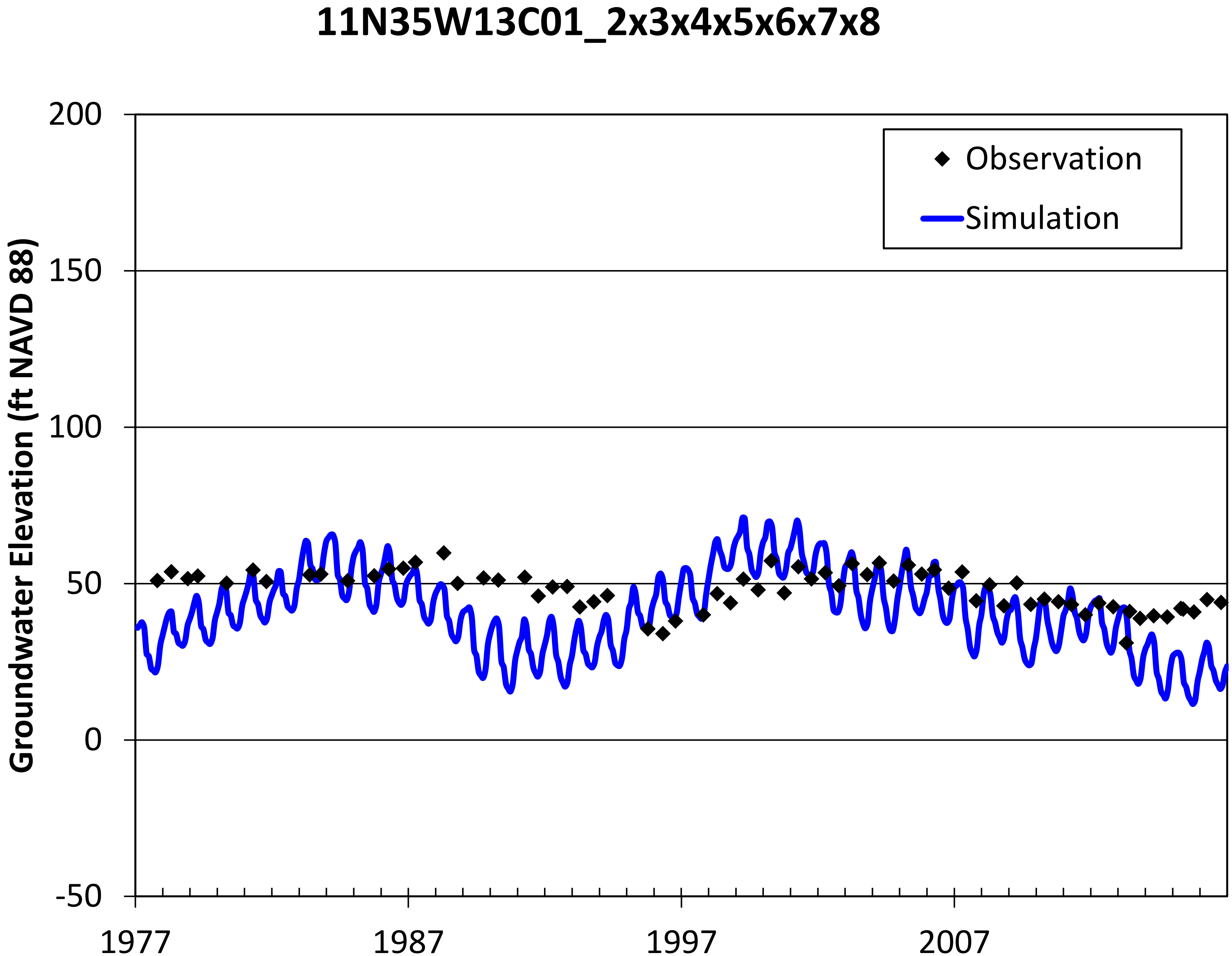
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Observation
Simulation
Groundwater Elevation (ft NAVD 88)
200
150
100
50
0
-50
1977
1987
1997
2007

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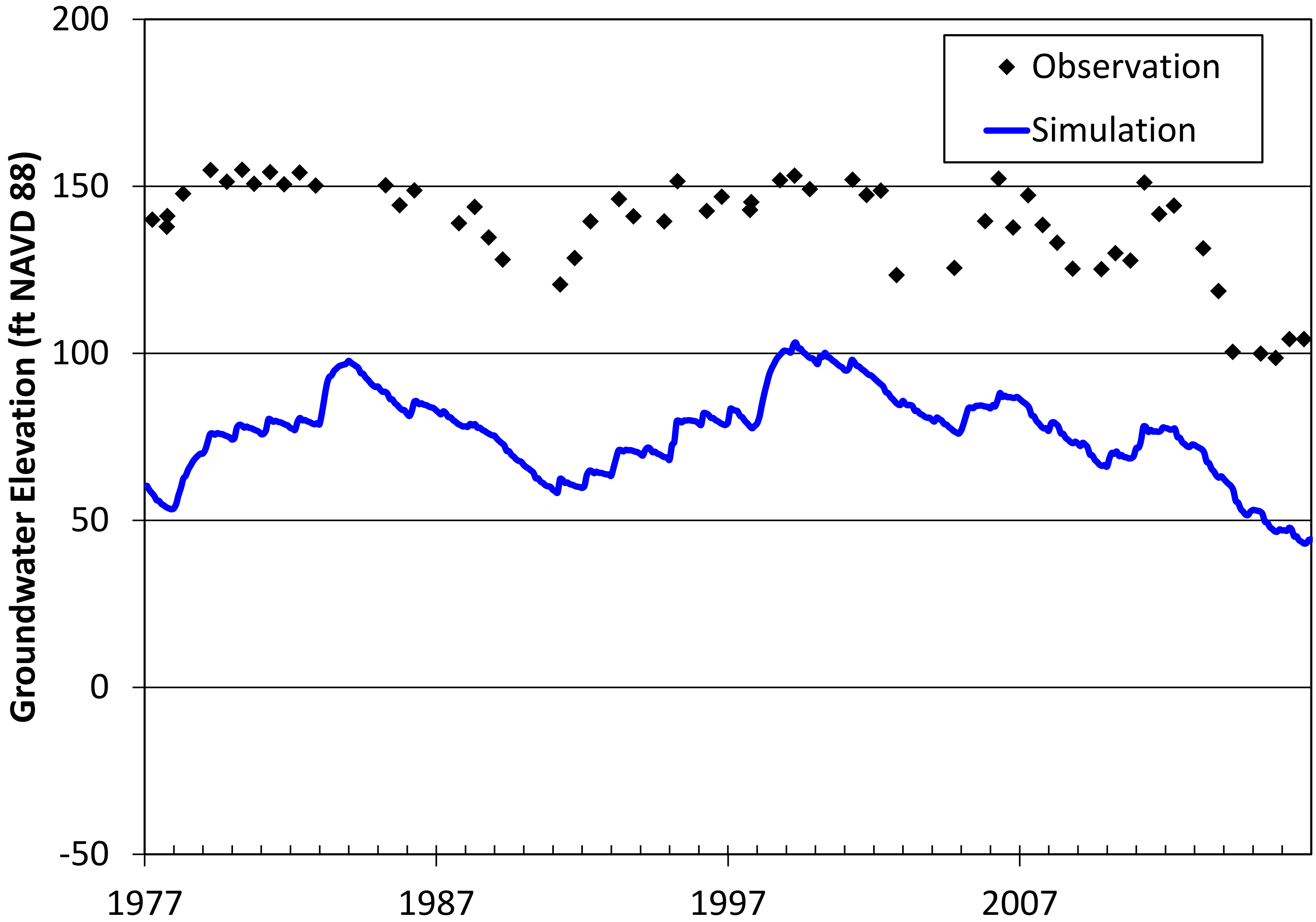

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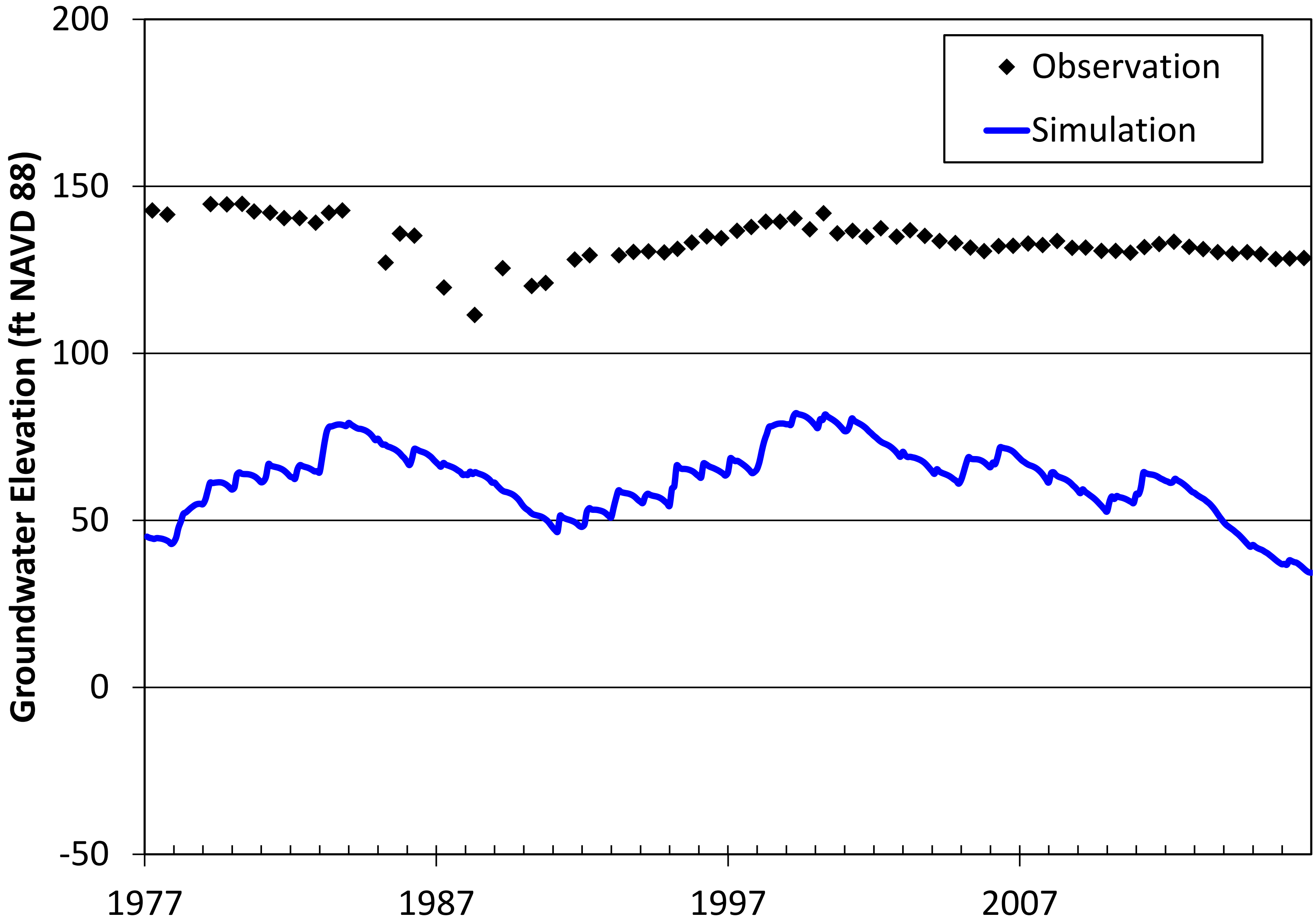

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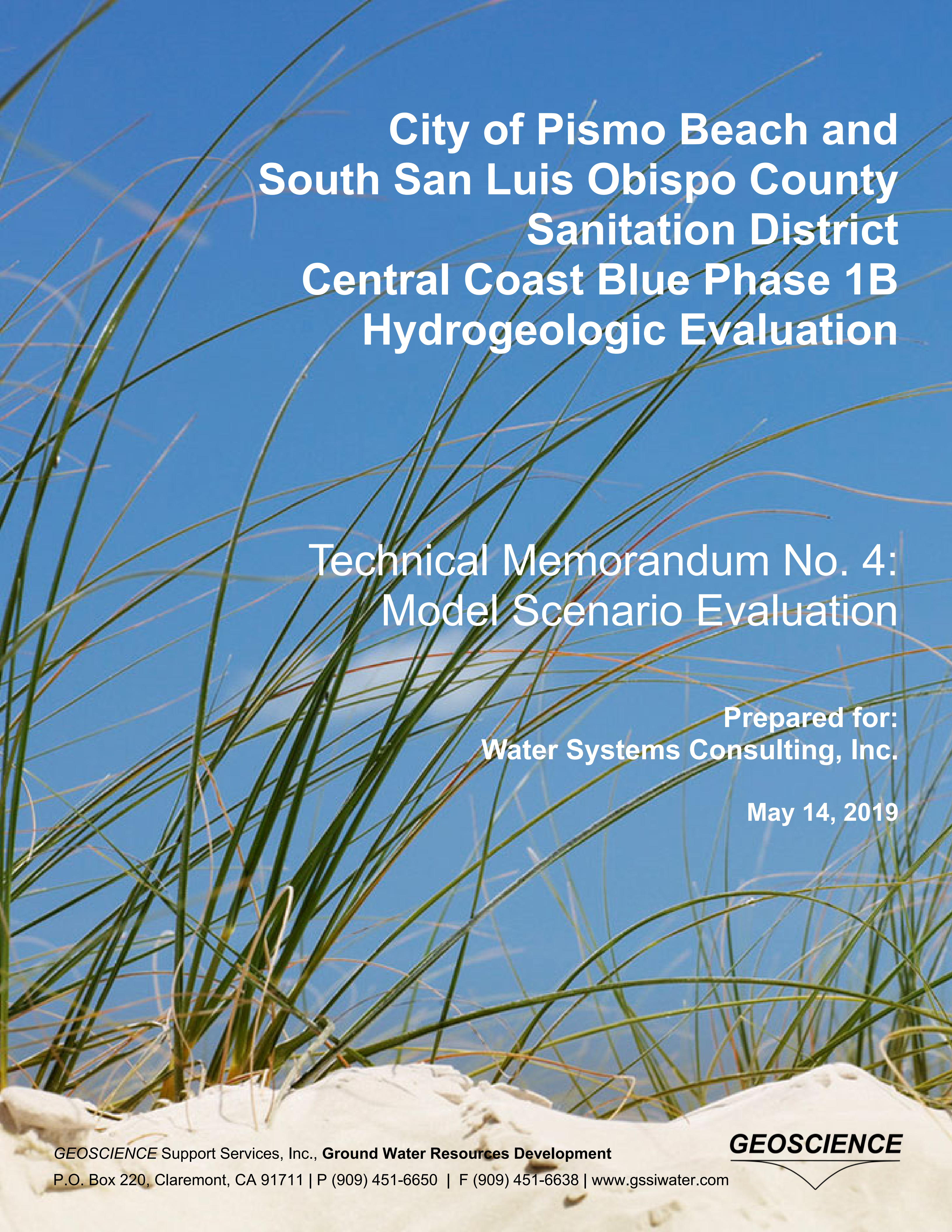

City of Pismo Beach and South San Luis Obispo County Sanitation District Central Coast Blue Phase 1B Hydrogeologic Evaluation

Technical Memorandum No. 4: Model Scenario Evaluation

Prepared for:
Water Systems Consulting, Inc.

May 14, 2019

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CITY OF PISMO BEACH AND SOUTH SAN LUIS OBISPO COUNTY SANITATION DISTRICT
CENTRAL COAST BLUE
PHASE 1B HYDROGEOLOGIC EVALUATION

TECHNICAL MEMORANDUM 4: MODEL SCENARIO EVALUATION

CONTENTS

FIGURES

FIGURES (continued)

FIGURES (continued)

TABLES

TABLES

APPENDIX

Ltr.	Description
(Attached)	
A	Comments Received and GEOSCIENCE Responses for Draft TM No. 4: Model Scenario Evaluation

CITY OF PISMO BEACH AND SOUTH SAN LUIS OBISPO COUNTY SANITATION DISTRICT
CENTRAL COAST BLUE
PHASE 1B HYDROGEOLOGIC EVALUATION

TECHNICAL MEMORANDUM 4: MODEL SCENARIO EVALUATION

1.0 INTRODUCTION

Central Coast Blue (CCB) is a regional recycled water project that will reduce the risk of seawater intrusion and improve water supply sustainability in northwestern Santa Maria River Valley Groundwater Basin (Basin; see Figure 1). The project will use advanced-treated recycled water from the City of Pismo Beach and the South San Luis Obispo County Sanitation District (SSLOCSD) Wastewater Treatment Plants (WWTPs) as an injection water source. This water will then be injected in the Arroyo Grande-Tri-Cities Mesa portion of the Basin to establish a seawater barrier and improve the reliability of groundwater supplies in the region.

1.1 Purpose and Scope

As part of the Phase 1B Hydrogeologic Evaluation, GEOSCIENCE Support Services, Inc. (GEOSCIENCE) has been tasked with expanding the previous Regional Groundwater Sustainability Project (RGSP) Phase 1A Model (CHG, 2017) to include an evaluation of injection and extraction scenarios with flows from the SSLOCSD and City of Pismo Beach WWTPs. The following tasks are included in the development of the CCB Phase 1B groundwater flow and solute transport model (Phase 1B Model) and evaluation of Project scenarios:

- Task 0 – Project Management
- Task 1 – Data Assessment
- Task 2 – Conceptual Model
- Task 3 – Model Construction
- Task 4 – Model Calibration and Sensitivity Analysis
- Task 5 – Scenario Evaluation
- Task 6 – Model Report
- Task 7 – Anti-Degradation Analysis (optional)

This technical memorandum (TM) presents a summary of the development and evaluation of model scenarios (Task 5). Comments received on the draft TM No. 4, along with responses, are provided in Appendix A.

1.2 Phase 1B Model

The Phase 1B Model was developed for the unconsolidated to semi-consolidated water-bearing sediments of the Northern Cities Management Area (NCMA), Nipomo Mesa Management Area (NMMA), and portion of the Santa Maria Valley Management Area (SMVMA) in the northwestern Santa Maria Groundwater Basin (see Figure 1). The Phase 1B Model domain covers an area of approximately 197 square miles (125,857 acres) with a finite-difference grid consisting of 600 rows in the northeast-to-southwest direction and 932 columns in the northwest-to-southeast direction. Each model cell of the Phase 1B Model represents an area of 100 ft x 100 ft and the stress period (i.e., time period) used to vary model fluxes, such as pumping and recharge, occurred monthly.

The main water-bearing formations are the Paso Robles Formation and the Careaga Sand, which constitute the deeper aquifer, and the dune sand, terrace deposits, and quaternary alluvium, which constitute the shallow aquifer (LSCE, 2017). The low-yield formations which underlie and also generally flank the main groundwater basin are considered impermeable and are not part of the modeled groundwater flow system. The Phase 1B Model consists of ten model layers:

- Layer 1 – Ocean floor (allows for vertical leakage from the ocean to the underlying aquifer (i.e., model layer 2), and inflow and outflow between Layer 2 and the ocean)
- Layer 2 – Recent alluvium/young and old dune sand
- Layers 3 through 7 – Paso Robles Formation
- Layer 8 through 10 – Careaga Sand

The development of and subsequent calibration of the Phase 1B Model is presented in TM Nos. 1 through 3 (GEOSCIENCE 2018a, 2018b, and 2019).

2.0 ASSUMPTIONS FOR PREDICTIVE MODEL SCENARIOS

Seven (7) predictive scenario runs were made using the calibrated Phase 1B Model to evaluate and predict how future pumping and recycled water injection activities will affect potential seawater intrusion and the reliability of groundwater supplies in the region. The main assumptions for these scenario runs are summarized in the table below. Each model scenario was run for a period of 40 years. It is important to note that these scenarios focused on the NCMA, so this is the location where the greatest variation in flux terms occurred; fluxes in the NMMA and SMVMA remained fairly constant.

Table 2-1. Model Scenario Assumptions

Model Scenario	Hydrology	Groundwater Pumping			CCB Implementation
		Agricultural	NMMA	NCMA	
Baseline	Historical (1977-2016)	Based on 2016 Crop Distribution and Historical Rainfall	Average of Last 5 Years (2012-2016) (5,663 AFY)	Average of Last 5 Years for Municipal (1,080 AFY) and Small Purveyors	None
1	Historical (1977-2016)	Based on 2016 Crop Distribution and Historical Rainfall	Average of Last 5 Years (5,663 AFY)	Municipal Extraction of 2,500 AFY	None
2	Historical (1977-2016)	Based on 2016 Crop Distribution and Historical Rainfall	Average of Last 5 Years (5,663 AFY)	Municipal Extraction of 2,500 AFY	Phase 1 (900 AFY)
3	Historical (1977-2016)	Based on 2016 Crop Distribution and Historical Rainfall	Average of Last 5 Years (5,663 AFY)	Maximum NCMA Allocation (4,330 AFY)	None
4	Historical (1977-2016)	Based on 2016 Crop Distribution and Historical Rainfall	Average of Last 5 Years (5,663 AFY)	Maximum NCMA Allocation (4,330 AFY)	Phase 2 (3,500 AFY)
5	Climate Change (2030 and 2070 Projections)	Based on Climate Change Predictions of Rainfall	Average of Last 5 Years (5,663 AFY)	Average of Last 5 Years for Municipal (1,080 AFY) and Small Purveyors	None
6	Historical Hydrology with Predicted Sea Level Rise	Based on 2016 Crop Distribution and Historical Rainfall	Average of Last 5 Years (5,663 AFY)	Average of Last 5 Years for Municipal (1,080 AFY) and Small Purveyors	None

The scenarios summarized above in Table 2-1 were developed with specific purposes in mind. The Baseline scenario was used as a point of reference for comparing other scenario runs with altered fluxes to the status quo. Scenarios 1 and 2 represent predicted effects without and with implementation of Phase 1 of the CCB, while Scenarios 3 and 4 represent predicted effects without and with Phase 2 of the CCB. The purpose of Scenario 5 is to identify potential impacts of climate change (compared to Baseline) and Scenario 6 helps identify potential impacts of sea level rise. Specific details associated with these scenario runs are discussed in the following sections.

2.1 Baseline Scenario and General Assumptions

Most scenarios are based on the baseline scenario, hence the assumptions used for the baseline are common to most of the subsequent scenarios presented below. Specific deviations from the assumptions used for the baseline scenario run are specified for each scenario. The baseline scenario is meant to represent a stable state of the NCMA where the groundwater resources can be utilized at a rate that would minimize the risk of seawater intrusion and excessive depletion of the groundwater resource.

2.1.1 Hydrologic Base Period

A hydrologic base period is used as a basis for the amount of precipitation that falls on the model area and surrounding watersheds during the simulation period. This in turn affects those recharge and discharge terms dependent on precipitation (e.g., areal recharge from precipitation, mountain front recharge, agricultural pumping, etc.). Therefore, selection of a forecast period that represents long-term hydrologic conditions is necessary prior to running future model scenarios. The majority of the Phase 1B scenarios rely on the historical hydrology from 1977 through 2016 for the hydrologic base period, which also represents the calibration period. As shown on Figure 2, this period includes wet, dry, and average hydrological conditions.

2.1.2 Initial Water Levels

Initial water levels for the predictive model scenarios represent the water levels at the end of the calibration period (December 2016). These heads are shown on Figure 3.

2.1.3 General Head Boundaries (GHBs)

General head boundaries (GHBs) exist in the Phase 1B Model along the Pacific Ocean, Arroyo Grande Valley, and at the edge of the model extent in the SMVMA. In the calibrated model, the GHBs along the Arroyo Grande Valley and in the SMVMA relied on existing measured water levels. For the predictive model scenarios, the general trend of these GHBs were maintained but the heads at the end of the calibration period were used as the beginning head for the scenario GHBs (Figure 4). Basically, the same cycles of wet and dry (or highs and lows) were maintained with a starting point for the predictive period that corresponded to the end point levels from the calibration period. GHBs along the Arroyo Grande Valley and the SMVMA were modified in the predictive scenarios; the boundary at the ocean was kept unchanged from model calibration (except under sea level rise conditions, as discussed in Section 2.5).

2.1.4 Areal Recharge from Precipitation

In the calibrated Phase 1B Model, areal recharge from precipitation is based on the amount of rainfall (hydrology), soil type, and land use. For the purpose of the predictive runs, it is assumed that future land use will remain similar to current land use. Therefore, for scenarios that rely on the calibrated hydrology for the predictive hydrologic base period, areal recharge from precipitation is the same as that used for model calibration.

2.1.5 Artificial Recharge

Two types of artificial recharges were represented in the model: wastewater infiltration and stormwater infiltration. For the predictive scenarios, wastewater infiltration was assumed to be the average of the last five years (i.e., 2012 through 2016). Stormwater infiltration rates are dependent on the hydrology. Therefore, for scenarios that rely on the calibrated hydrology for the predictive hydrologic base period, recharge from stormwater spreading is the same as that used for the model calibration – with one exception. The Vista Del Mar stormwater spreading basin was constructed in 2003. While this basin was not active throughout the entire calibration period, it was assumed to be active throughout the predictive simulation period.

2.1.6 Municipal and Small Purveyor Pumping

Municipal pumping and small system extraction rates were averaged for the last five years (2012-2016) to represent baseline conditions. The averages were calculated on a monthly basis (e.g., average of pumping for January, February, etc.). The monthly municipal pumping distribution is shown in Table 1. This approach yielded an average year of extraction which was then repeated every year of the predictive simulation period.

2.1.7 Agricultural Pumping

For the development and calibration of the Phase 1B Model, agricultural pumping was estimated using crop type distributions, crop demand, and rainfall. The County of San Luis Obispo provided crop distribution maps from 1996 through 2016. Crop distributions for the remaining years were obtained from the Farmland Mapping and Monitoring Program (FMMP). The same approach taken for model calibration was used for the predictive scenarios, but the 2016 crop distribution was assumed to extend into the future.

2.2 CCB Phase 1 – Scenarios 1 & 2

Scenarios 1 and 2 represent predicted effects without and with implementation of Phase 1 of the CCB (injection of 900 AFY), respectively. During the Phase 1B modeling process, multiple injection scenarios were run to optimize CCB injection well locations, which were initially identified with the Phase 1A Model. However, the locations determined through the iterative Phase 1B modeling to provide the most yield with the least potential for seawater intrusion were used for the active CCB scenarios (i.e., Scenarios 2 and 4).

The implementation of Phase 1 of the CCB in Scenario 2 consisted of five coastal wells (IW-1, IW-2A, IW-3, IW-4, and IW-5A) injecting a total of 900 AFY evenly distributed across all five wells. The location of these wells is shown on Figure 5. All five wells are screened in model layers 6, 7, and 8, which represent the Lower Paso Robles and the Upper Careaga Sand.

Municipal pumping in the NCMA under Scenario 1 and 2 conditions increased from 1,080 AFY under Baseline conditions to 2,500 AFY. This pumping was distributed based on well capacity and prior pumping record ratios.

2.3 CCB Phase 2 – Scenarios 3 & 4

Scenarios 3 and 4 represent predicted effects without and with implementation of Phase 2 of the CCB (injection of 3,500 AFY), respectively. The implementation of Phase 2 of the CCB in Scenario 4 consisted of seven coastal wells injecting a total of 3,500 AFY evenly distributed across all seven wells. The location of these wells is shown on Figure 5. The five wells used for Phase 1 are screened in model layers 6, 8, and 8 (Lower Paso Robles and the Upper Careaga Sand) while two wells (IW-2B and IW-5B) are screened in model layer 10 (Lower Careaga Sand).

Municipal pumping in the NCMA under Scenario 3 and 4 conditions increased from 1,080 AFY under Baseline conditions to maximum allotted pumping for the municipal agencies – totaling 4,330 AFY. Pumping was distributed based on well capacity and prior pumping record ratios. This maximum allotted pumping is summarized in the following table by service area.

Table 2-2. NCMA Maximum Allotted Municipal Pumping and Projected Imported Water by Service Area

Service Area	Arroyo Grande	Grover Beach	Oceano	Pismo Beach	TOTAL
	[AFY]				
Maximum Pumping Allocation	1,323	1,407	900	700	4,330
Average Demand (2012-2016)	2,614	1,474	781	1,902	6,771
Imported Water	1,291	67	0	1,202	2,560

Average demand for the last five years (2012 through 2016) was assumed to represent future demand. The portion of the demand not met by the maximum allocated pumping was assumed to come from imported water.

2.4 Climate Change – Scenario 5

Scenario 5 identifies potential impacts of climate change, compared to baseline conditions, to evaluate whether climate change would yield significant differences compared to approaches using historical hydrology. Climate change assumptions were based on the approach presented in the California Department of Water Resources (DWR) Guidance Document for Climate Change Data Use During Groundwater Sustainability Plan Development (2018).

Using this approach, annual and monthly DWR change factors for rainfall, potential evapotranspiration, and stream flow were applied to historical hydrology. Four sets of change factors were available: 2030 (near future) central tendency (average conditions), 2070 central tendency, 2070 Drier with Extreme Warming (DEW), and 2070 Wetter with Moderate Warming (WMW). These factors are published from 1915 to 2011. DWR suggests running future scenarios with 2030 and 2070 change factors applied to historical hydrology and aggregating or comparing the results. For historical years not covered by this time span, the user is advised to use the DWR water year classification scheme to choose a similar year within the time span covered. Five classification categories exist: Wet (W), Above Normal (AN), below normal (BN), dry (D), and critical (C). Because such a classification does not exist for the whole state of California (only available for the Central Valley and the San Joaquin Valley), the classification for the San Joaquin Valley was used for proximity reasons. For the CCB Phase 1B Model, 2012 through 2016 represent non-overlapping years. Therefore, the procedure described above was used to obtain change factors for these years. Table 2-3 summarizes the classification and change factor used for each of these non-overlapping years.

Table 2-3. Replacement Climate Change Factors for Non-Overlapping Model Years

CCB Phase 1B Model Non-Overlapping Years (Water Year)	Year Type	Change Factor Replacement Year
2012	Dry (D)	2004
2013	Critical (C)	2008
2014	Critical (C)	2008
2015	Critical (C)	2008
2016	Dry (D)	2004
2017	Wet (W)	2011

DWR change factors (aggregate of 2030 and 2070 projections) were used to modify rainfall and evapotranspiration for Scenario 5 conditions. Change factors for stream flow are only applicable to unimpaired streams and creeks (i.e., without dams). They could therefore not be applied to Arroyo Grande Creek due to the presence of Lopez Dam. As a result, the hydrology of Arroyo Grande Creek was not modified. Recharge and discharge terms, including areal recharge from precipitation, artificial recharge from stormwater infiltration, and agricultural pumping and return flows, were recomputed and updated based on the revised hydrology under climate change conditions. The remaining flux terms were kept the same as those used for the Baseline scenario.

2.5 Sea Level Rise – Scenario 6

Impacts from the potential rise in future sea level were specifically evaluated with Scenario 6. Projections of sea level rise presented in the DWR climate change document (2018) were also used for this analysis. According to sea level rise estimates by the National Research Council (NRC), DWR used sea level rise projections of 15 and 45 centimeters for the 2030 and 2070 climate change datasets. The flux terms used for Scenario 6 are identical to those used for the Baseline scenario, with the exception of the GHB at the ocean. This GHB was modified to match the projected 2030 and 2070 sea levels. Results from scenario runs under 2030 and 2070 sea level conditions were then aggregated and compared to the Baseline scenario.

3.0 PREDICTIVE MODEL SCENARIO RESULTS

After the predictive scenario runs were performed using the calibrated Phase 1B Model, comparisons were made between the results from the Baseline scenario run and Scenarios 1 through 6 in order to evaluate the impacts from pumping, CCB injection, climate change, sea level rise, or combinations thereof. Of particular importance is the impact on groundwater elevations and inflow from the ocean and offshore aquifers (inflow across the shoreline). A detailed discussion of these results is provided in the following sections.

3.1 Scenario Evaluation Criteria

One of the main objectives of future pumping and injection operations in the NCMA is to minimize seawater intrusion, or the net flow from the ocean and offshore aquifers. Underflow outflow/inflow to/from the ocean proper is anticipated to occur only through the interface of model layer 2 with the coast. Underflow across the coastal line in the other model layers is assumed to continue through the aquifer offshore. The initial approach for evaluating scenario results was to use water quality and fluxes across the shoreline to assess each scenario's potential for seawater intrusion. After further discussion with the TAC, it was decided that uncertainty related to the current location of the saltwater-freshwater interface would make relying solely on this approach problematical. Therefore, it was decided to use a multicriteria evaluation approach. This approach includes evaluating changes in groundwater levels, net inflow across the shoreline from offshore, groundwater budgets, and Deep Well Indexes.

The NCMA Deep Well Index, which takes into account three deep wells in the NCMA, can be used as a general indicator for when the possibility of seawater intrusion increases. Wells used for the Deep Well Index are shown on Figure 6. Historically, seawater intrusion has been observed in the area in 2009. By analyzing model results during this time period and looking at the Deep Well Index during that same period, it was established that a Deep Well Index at or below the threshold of 7.5 ft for extended periods of time, coupled with landward flow from layer 6 and 8 (corresponding to well screen where sea water intrusion was detected), correlated well with the observed seawater intrusion of 2009. Therefore, it was decided that a reasonable approach to limit or prevent seawater intrusion was to avoid extended periods with a Deep Well Index below the 7.5 ft threshold and to maintain a generally seaward flux at the coast for most layers, especially layers 6 and 8.

The net inflow across the shoreline was computed for each model layer both north of Arroyo Grande Creek and south of Arroyo Grande Creek. A positive flux indicates inflow from the ocean and offshore aquifers while a negative flux indicates groundwater flow to the ocean from inland areas.

A summary of the water budgets for the NCMA was compiled in order to assess the potential impacts that each predictive scenario may have on underflow inflow from the ocean and offshore aquifers as well as changes in groundwater storage. The inflow terms for the Phase 1B Model include areal recharge from precipitation, mountain front recharge, streambed percolation, return flow (from municipal use, agricultural use, and golf course irrigation), artificial recharge, and underflow inflow from the ocean and offshore aquifers or from upgradient groundwater basins. Discharge terms include groundwater pumping (municipal, small purveyor, agricultural, and golf course), and underflow outflow to the ocean and offshore aquifers. The difference between the total inflow and total outflow equals the change in groundwater storage. Zones for the computation of the water budgets are shown on Figure 7.

3.2 Baseline Scenario

Model-calculated groundwater elevations in the NCMA after 40 years of simulation are shown on Figure 8 for the Baseline scenario. As shown, groundwater gradients are typically towards the coastline for all model layers, with some local reversals near the coast. It is important to note that groundwater elevations are shown in feet relative to the North American Vertical Datum of 1988 (NAVD88), for which mean sea level is approximately 2.7 ft NAVD88 in this area.

The NCMA Deep Well Index for the Baseline scenario shows water levels fluctuating around the threshold of 7.5 ft (Figure 9). This is a similar pattern to the index observed under the calibration (historical) period, and indicates that conditions favorable for seawater intrusion may exist during the simulated period, particularly during drier hydrology.

Figures 10 and 11 show net inflow across the shoreline north and south of Arroyo Grande Creek in the NCMA, respectively, under model calibration and baseline conditions. The figures show that net flow across the shoreline remains largely negative (flow offshore) in all model layers north of Arroyo Grande Creek, but is occasionally reversed (flow inland) south of the creek in model layer 6.

The average annual groundwater budgets for the NCMA under Baseline conditions are presented on Figure 12 and annually in Table 2. As indicated, net groundwater flow is onshore to offshore. Flow to the ocean from layer 2 averages 776 AFY during the simulation period while flow to offshore aquifers averages 1,214 AFY over the same period. Groundwater storage in the NCMA decreases by an average of 53 AFY.

3.3 CCB Phase 1 – Scenarios 1 & 2

Model-calculated groundwater elevations in the NCMA after 40 years of simulation are shown on Figures 13 and 14 for Scenarios 1 and 2, respectively. As shown, groundwater gradients are typically towards the coastline for all model layers, with some reversals near the coast. In particular, groundwater levels are low in the northwest model area under Scenario 1 conditions for Layers 6 and 8 – leaving this area vulnerable to seawater intrusion. Under Scenario 2 conditions, with CCB injection of 900 AFY, groundwater levels in this same area increased compared to those seen with Scenario 1.

The NCMA Deep Well Indexes for Scenarios 1 and 2 are presented as Figures 15 and 16, respectively. Under Scenario 1 conditions, the NCMA Deep Well Index is under the threshold of 7.5 ft for the majority of the simulation period. This indicates a significant risk for seawater intrusion. Scenario 2 conditions show a Deep Well Index that fluctuates above and below the threshold index level, similar to that seen under baseline conditions, with a slight increase over Baseline Deep Well Index levels.

Net inflow across the shoreline north and south of Arroyo Grande Creek in the NCMA is shown on Figures 17 and 18 under Scenario 1 conditions and Figures 19 and 20 under Scenario 2 conditions. Under Scenario 1 conditions, net flow across the shoreline is often inland north of the creek in model layers 6, 8, and 10. Inflow in these same layers is reduced south of the creek. Under Scenario 2 conditions, there is very little inflow across the shoreline north and south of Arroyo Grande Creek. North of Arroyo Grande Creek, net inflow from offshore occurs periodically (about half the time) in Layer 10. South of Arroyo Grande Creek, small amounts of net inflow from offshore is seen periodically in Layers 6 and Layer 10, as well as in Layer 4 towards the end of the simulation period.

The average annual groundwater budgets for the NCMA under Scenario 1 and 2 conditions are presented on Figure 21 and annually in Tables 3 and 4. As indicated, net groundwater flow under both scenarios is onshore to offshore. Flow to the ocean from layer 2 during the simulation period averages 616 AFY for Scenario 1 and 706 AFY for Scenario 2 while flow to offshore aquifers over the same period averages 567 AFY and 1,095 AFY for Scenarios 1 and 2, respectively. Groundwater storage in the NCMA decreases by an average of 93 AFY under Scenario 1 and by an average of 58 AFY under Scenario 2.

3.4 CCB Phase 2 – Scenarios 3 & 4

Model-calculated groundwater elevations in the NCMA after 40 years of simulation are shown on Figures 22 and 23 for Scenarios 3 and 4, respectively. As shown, negative groundwater elevations are present in the northwest model area under Scenario 3 conditions for all model layers, which indicates a high probability of seawater intrusion. Under Scenario 4 conditions, with CCB injection of 3,500 AFY, groundwater levels in this same area increased substantially compared to those seen with Scenario 3. This illustrates the CCB Project's ability to provide a protective buffer along the coast against seawater intrusion, even under maximum allocated pumping conditions.

The NCMA Deep Well Indexes for Scenarios 3 and 4 are presented as Figures 24 and 25, respectively. Under Scenario 3 conditions, the NCMA Deep Well Index is well under the threshold of 7.5 ft for the duration of the simulation period. This indicates a high potential for seawater intrusion. Scenario 4 conditions show a Deep Well Index that remains well above the threshold index level for the duration of the simulation period, indicating that CCB injection operations significantly reduce the potential for seawater intrusion in this area, even under high levels of pumping in the NCMA.

Net inflow across the shoreline north and south of Arroyo Grande Creek in the NCMA is shown on Figures 26 and 27 under Scenario 3 conditions and Figures 28 and 29 under Scenario 4 conditions. Under Scenario 3 conditions, net flow across the shoreline is often inland north of the creek in all model layers except layers 2 and 3. Inland flow south of the creek is less frequent but still affects all layers except layers 2 and 3. Under Scenario 4 conditions, CCB injection is able to mitigate inland flow north of Arroyo Grande Creek. South of the creek, inland flow across the shoreline still occurs periodically – particularly in model layer 6.

The average annual groundwater budgets for the NCMA under Scenario 3 and 4 conditions are presented on Figure 30 and annually in Tables 5 and 6. As indicated, net groundwater flow from offshore aquifers reverses under Scenario 3 conditions such that underflow from these units averages 377 AFY during the simulation period. Net flow to the ocean from layer 2, on the other hand, averages 335 AFY under Scenario 3 conditions. Under Scenario 4, net flow to the ocean from layer 2 during the simulation period averages 740 AFY while flow to offshore aquifers over the same period averages 1,656 AFY. Groundwater storage in the NCMA decreases by an average of 195 AFY under Scenario 3 conditions and by an average of 39 AFY under Scenario 4. The water budget indicates that CCB operations are able to reduce inflow from offshore and reductions in groundwater storage.

3.5 Climate Change – Scenario 5

The change in model-calculated groundwater elevations in the NCMA after 40 years of simulation are shown on Figure 31 for Scenario 5, as compared to the Baseline scenario. The change in groundwater elevations is best illustrated using a hydrograph for the key index wells since predicted changes in climate are anticipated to have the greatest effect on seasonal distributions of precipitation and evapotranspiration.

The NCMA Deep Well Index for Scenario 5 is provided as Figure 32. Under Scenario 5 conditions (representing an aggregate of 2030 and 2070 climate change projections), index levels are slightly lower but still fluctuate around the threshold of 7.5 ft in a similar pattern to the index observed under baseline conditions. This indicates that climate change has minimal effect on conditions favorable for seawater intrusion.

Figures 33 and 34 show net inflow across the shoreline north and south of Arroyo Grande Creek in the NCMA, respectively, under Scenario 5 conditions. The figures show that net flow across the shoreline is very similar to simulated flow under baseline conditions. Flow across the shoreline north of the creek is in the offshore direction but is occasionally reversed south of the creek – particularly in model layer 6. Flow inland increased slightly over baseline conditions south of Arroyo Grande Creek and is particularly noticeable in dry hydrologic periods.

The average annual groundwater budgets for the NCMA under Scenario 5 conditions are presented on Figure 35 and annually in Table 7. As indicated, the Scenario 5 results are similar to those seen under Baseline conditions. Flow to the ocean from layer 2 averages 745 AFY during the simulation period while flow to offshore aquifers averages 1,185 AFY over the same period. Groundwater storage in the NCMA decreases by an average of 71 AFY.

3.6 Sea Level Rise – Scenario 6

The change in model-calculated groundwater elevations in the NCMA after 40 years of simulation are shown on Figure 36 for Scenario 6, as compared to the Baseline scenario.

The NCMA Deep Well Index for Scenario 6 is provided as Figure 37. Under Scenario 6 conditions, index levels are slightly higher but still fluctuate around the threshold of 7.5 ft in a similar pattern to the index observed under baseline conditions. However, due to higher ocean water levels, a higher Deep Well Index may be necessary to prevent seawater intrusion.

Figures 38 and 39 show net inflow across the shoreline north and south of Arroyo Grande Creek in the NCMA, respectively, under Scenario 6 conditions. The figures show that net flow across the shoreline is very similar to simulated flow under baseline conditions. Flow across the shoreline north of the creek is in the offshore direction but is occasionally reversed south of the creek – particularly in model layer 6. Flow inland increased slightly over baseline conditions south of Arroyo Grande Creek and is particularly noticeable in dry hydrologic periods.

The average annual groundwater budgets for the NCMA under Scenario 6 conditions are presented on Figure 40 and annually in Table 8. As indicated, the Scenario 6 results are similar to those seen under Baseline conditions. Flow to the ocean from layer 2 averages 757 AFY during the simulation period while flow to offshore aquifers averages 1,166 AFY over the same period. Therefore, it appears that a rise in sea level slightly reduces outflow to the ocean and offshore aquifers. Groundwater storage in the NCMA decreases by an average of 40 AFY.

3.7 Particle Tracking for CCB Operations

Based on the predictive scenario results, Scenarios 2 and 4 were selected as possible candidates for CCB implementation. To help support the design and impact analysis, a particle tracking model was run to estimate the travel time from the injection sites to the nearest water supply wells. These results are shown on Figures 41 through 42 for Scenario 2 (representing NCMA municipal pumping of 2,500 AFY and CCB Phase 1 injection of 900 AFY) and on Figures 43 through 45 for Scenario 4 (representing NCMA municipal pumping at maximum allocation of 4,330 AFY and CCB Phase 2 injection of 3,500 AFY). All municipal wells are located at least one year of travel time away from the injected recycled water in Scenario 2. For Scenario 4, Pismo Well 23 is within 6-months travel time from the injected recycled water. However, it was communicated to GEOSCIENCE that Well 23 is having performance issues and likely will need to be replaced at a location farther away from IW-3 – within six months to one year of travel time distance from the injected recycled water.

4.0 SUMMARY OF FINDINGS

The calibrated Phase 1B Model was used to run model scenarios to evaluate and predict how future pumping and recycled water injection activities will affect potential seawater intrusion and the reliability of groundwater supplies in the region. In particular, one of the main objectives of future pumping and injection operations in the NCMA is to minimize seawater intrusion. A multicriteria evaluation approach was used, which included evaluating changes in groundwater levels, net inflow/outflow across the shoreline from offshore, groundwater budgets, and Deep Well Indexes. Scenario results are summarized in the following table.

Table 4-1. Summary of Scenario Effects

Scenario	Description	Effect
Baseline	NCMA municipal pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016)	• Minimal seawater intrusion potential. • Deep Well Index fluctuates above and below threshold of 7.5 ft. • Groundwater flow is generally offshore. • Groundwater storage decreases by an average of 53 AFY.
1	NCMA municipal pumping of 2,500 AFY with historical hydrology (1977-2016)	• Significant seawater intrusion potential. • Deep Well Index falls below threshold for majority of simulation period. • Inland flow across the shoreline is seen in model layers 6, 8, and 10. • Groundwater storage decreases by an average of 98 AFY.
2	NCMA municipal pumping of 2,500 AFY with historical hydrology (1977-2016) and CCB Phase 1 injection of 900 AFY in 5 injection wells	• Seawater intrusion potential minimized with CCB operations. • Deep Well Index remains above threshold for the duration of the simulation period. • Very little inflow across the shoreline north and south of Arroyo Grande Creek. • Groundwater storage decreases by an average of 58 AFY.
3	NCMA municipal pumping maximum allocation (4,330 AFY) with historical hydrology (1977-2016)	• High potential for seawater intrusion. • Deep Well Index remains well below the threshold for the duration of the simulation period. • Net underflow to offshore aquifers is reversed. • Groundwater storage decreases by an average of 195 AFY.

Scenario	Description	Effect
4	NCMA municipal pumping maximum allocation (4,330 AFY) with historical hydrology (1977-2016) and CCB Phase 2 injection of 3,500 AFY in 7 injection wells	• Seawater intrusion potential minimized with CCB operations. • Deep Well Index remains above threshold for the duration of the simulation period. • Inland flow mitigated north of Arroyo Grande Creek. • Groundwater storage decreases by an average of 39 AFY.
5	NCMA municipal pumping average of last 5 years (1,080 AFY) with climate change hydrologic conditions (applied to hydrologic years 1977-2016)	• Little difference from baseline conditions. • Deep Well Index fluctuates above and below threshold of 7.5 ft. • Net underflow across the shoreline shows slightly elevated inland flow in model layer 6 south of Arroyo Grande Creek during dry periods. • Groundwater storage decreases by an average of 71 AFY.
6	NCMA municipal pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016) and predicted sea level rise	• Little difference from baseline conditions. • Slight increase in Deep Well Index. • Net underflow across the shoreline shows slightly elevated inland flow in model layer 6 south of Arroyo Grande Creek during dry periods. • Groundwater storage decreases by an average of 40 AFY.

5.0 REFERENCES

DWR (California Department of Water Resources), 2018. Guidance Document for the Sustainable Management of Groundwater: Guidance for Climate Change Data Use During Groundwater Sustainability Plan Development. Draft dated April 2018.

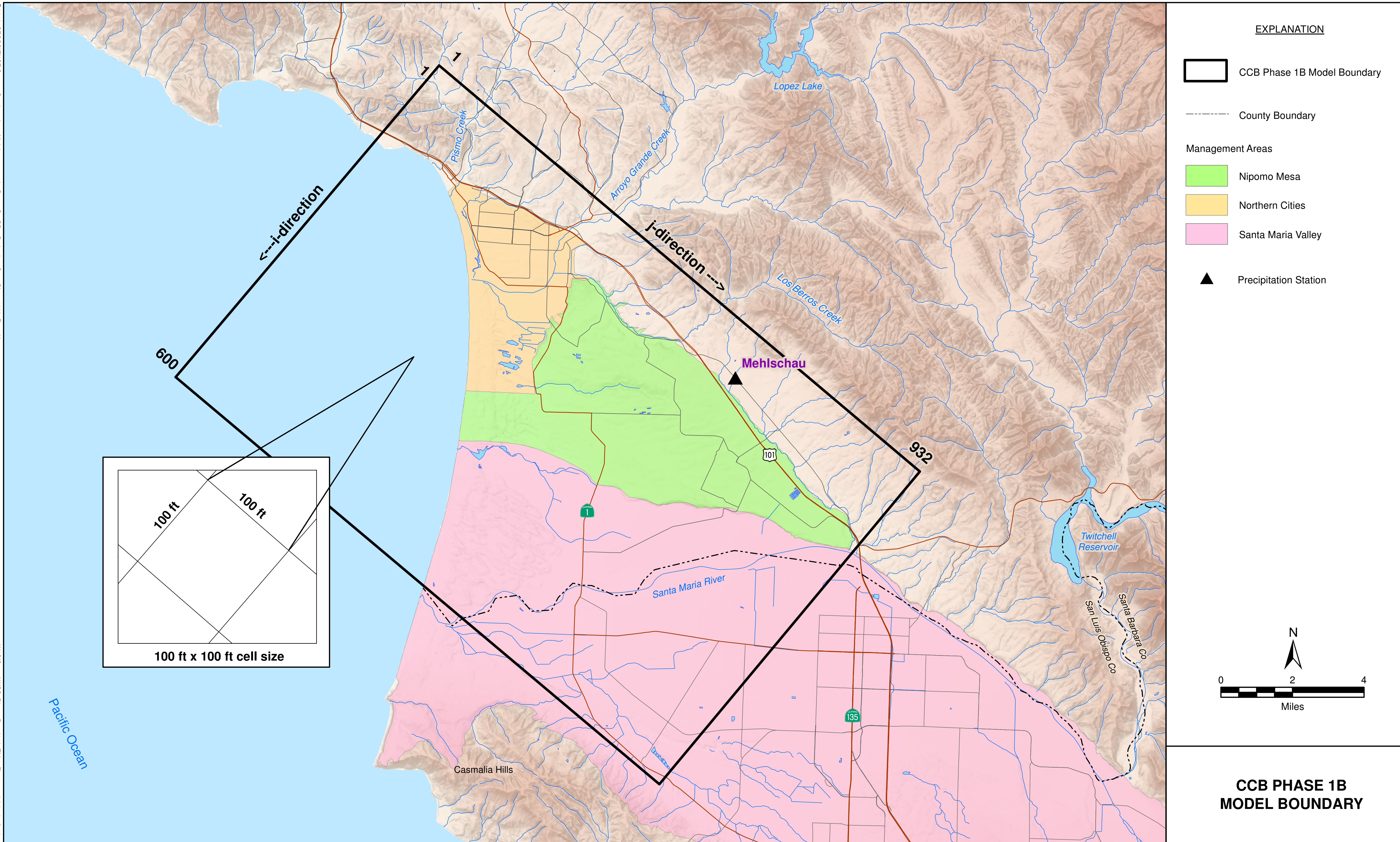
GEOSCIENCE (GEOSCIENCE Support Services, Inc.), 2019. City of Pismo Beach and South San Luis Obispo County Sanitation District Central Coast Blue Phase 1B Hydrogeologic Evaluation – Technical Memorandum No. 3: Model Calibration. Prepared for Water Systems Consulting, Inc. Dated April 18.

GEOSCIENCE, 2018a. City of Pismo Beach and South San Luis Obispo County Sanitation District Regional Groundwater Sustainability Project Phase 1B Hydrogeologic Evaluation – Technical Memorandum No. 1: Conceptual Model. Prepared for Water Systems Consulting, Inc. Dated June 15.

GEOSCIENCE, 2018b. City of Pismo Beach and South San Luis Obispo County Sanitation District Regional Groundwater Sustainability Project Phase 1B Hydrogeologic Evaluation – Technical Memorandum No. 2: Calibration Plan. Prepared for Water Systems Consulting, Inc. Dated June 15.

FIGURES

GEOSCIENCE



CCB PHASE 1B MODEL BOUNDARY

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14-May-19

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FIGURE 1

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 4: MODEL SCENARIO EVALUATION

GEOSCIENCE

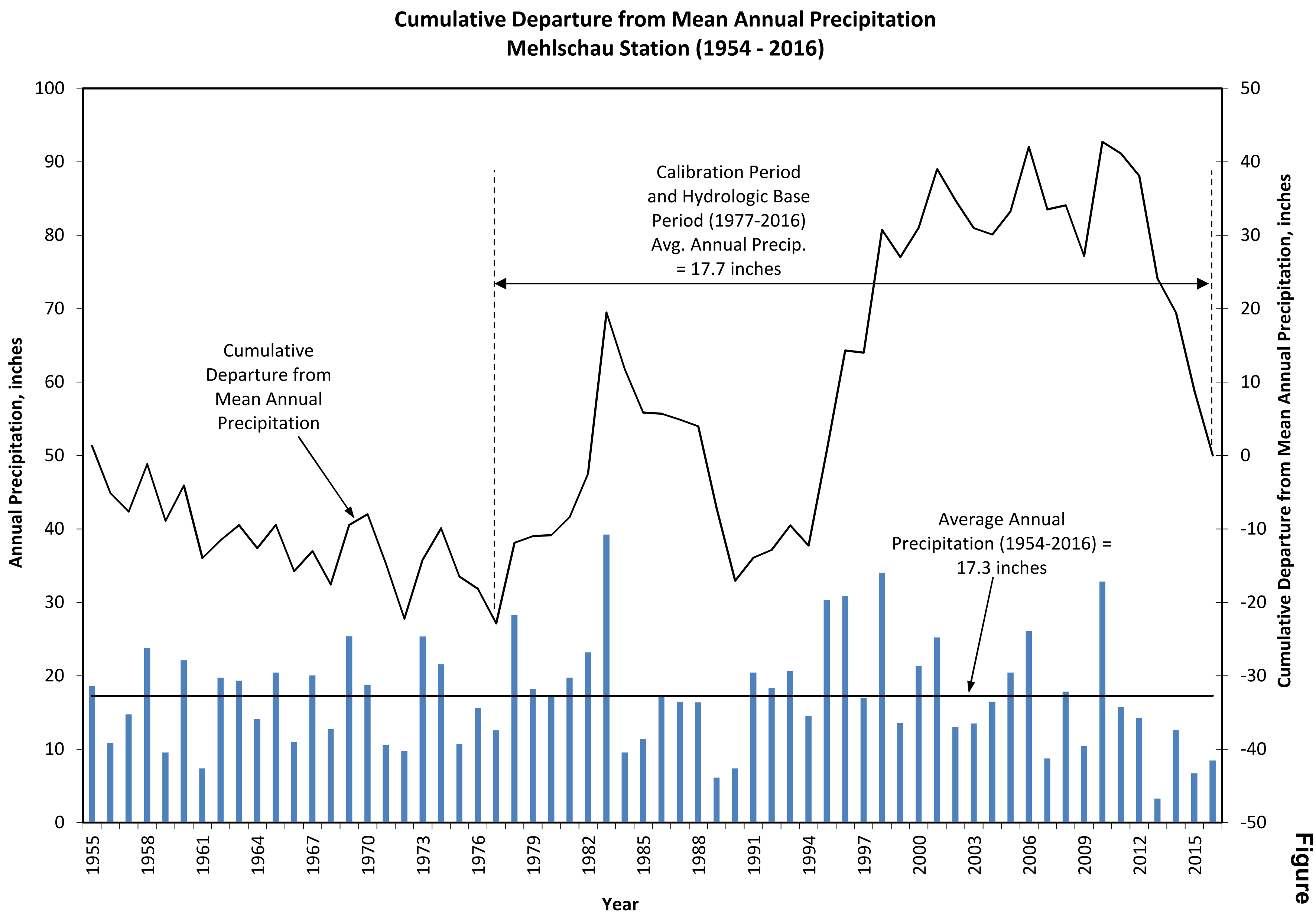
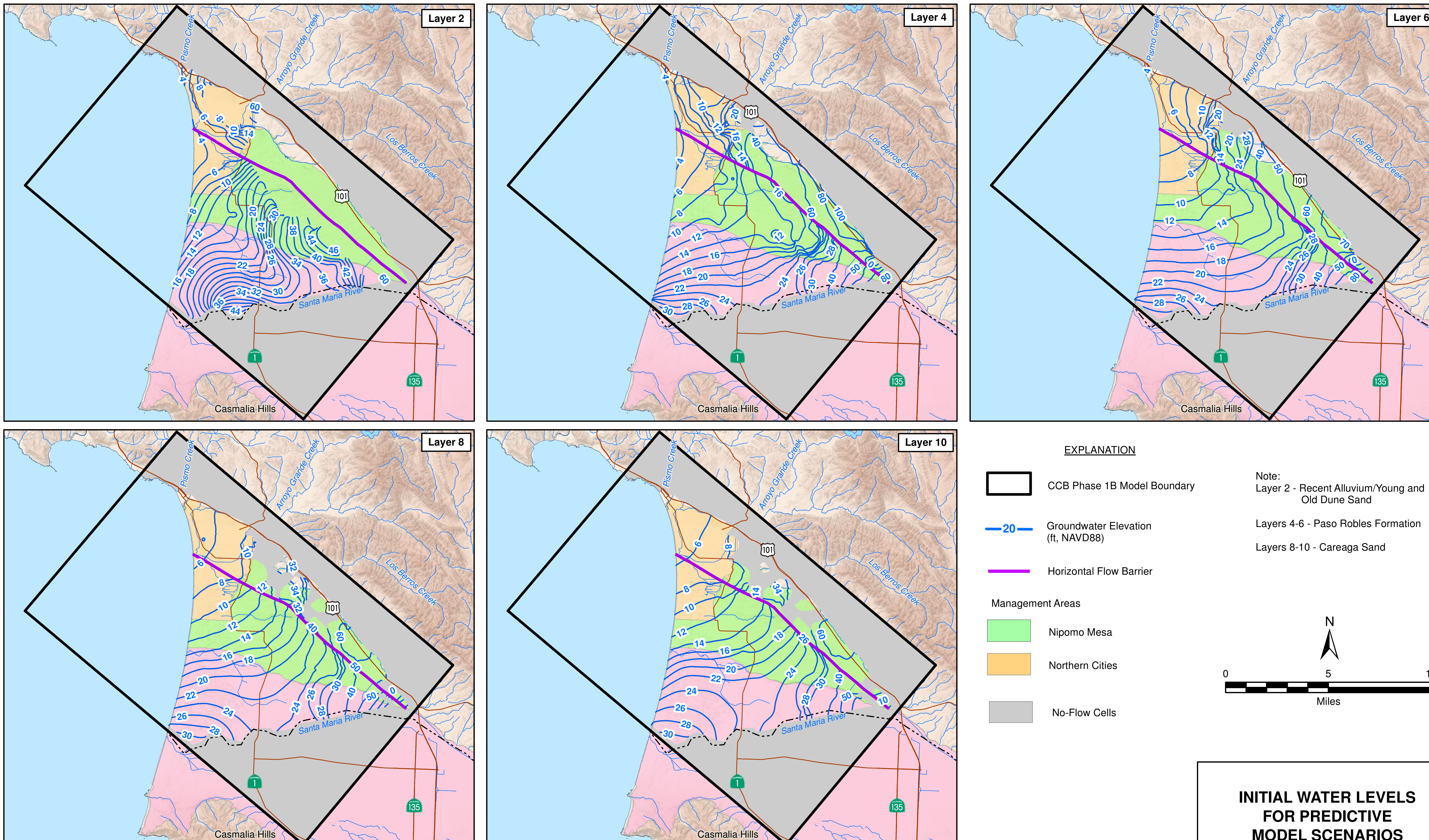

Cumulative Departure from Mean Annual Precipitation
Mehlschau Station (1954 - 2016)
Annual Precipitation, inches
Cumulative Departure from Mean Annual Precipitation, inches
Year
Calibration Period and Hydrologic Base Period (1977-2016) Avg. Annual Precip. = 17.7 inches
Cumulative Departure from Mean Annual Precipitation
Average Annual Precipitation (1954-2016) = 17.3 inches
100
90
80
70
60
50
40
30
20
10
0
50
40
30
20
10
0
-10
-20
-30
-40
-50
1955
1958
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
2015

Figure 2



INITIAL WATER LEVELS FOR PREDICTIVE MODEL SCENARIOS

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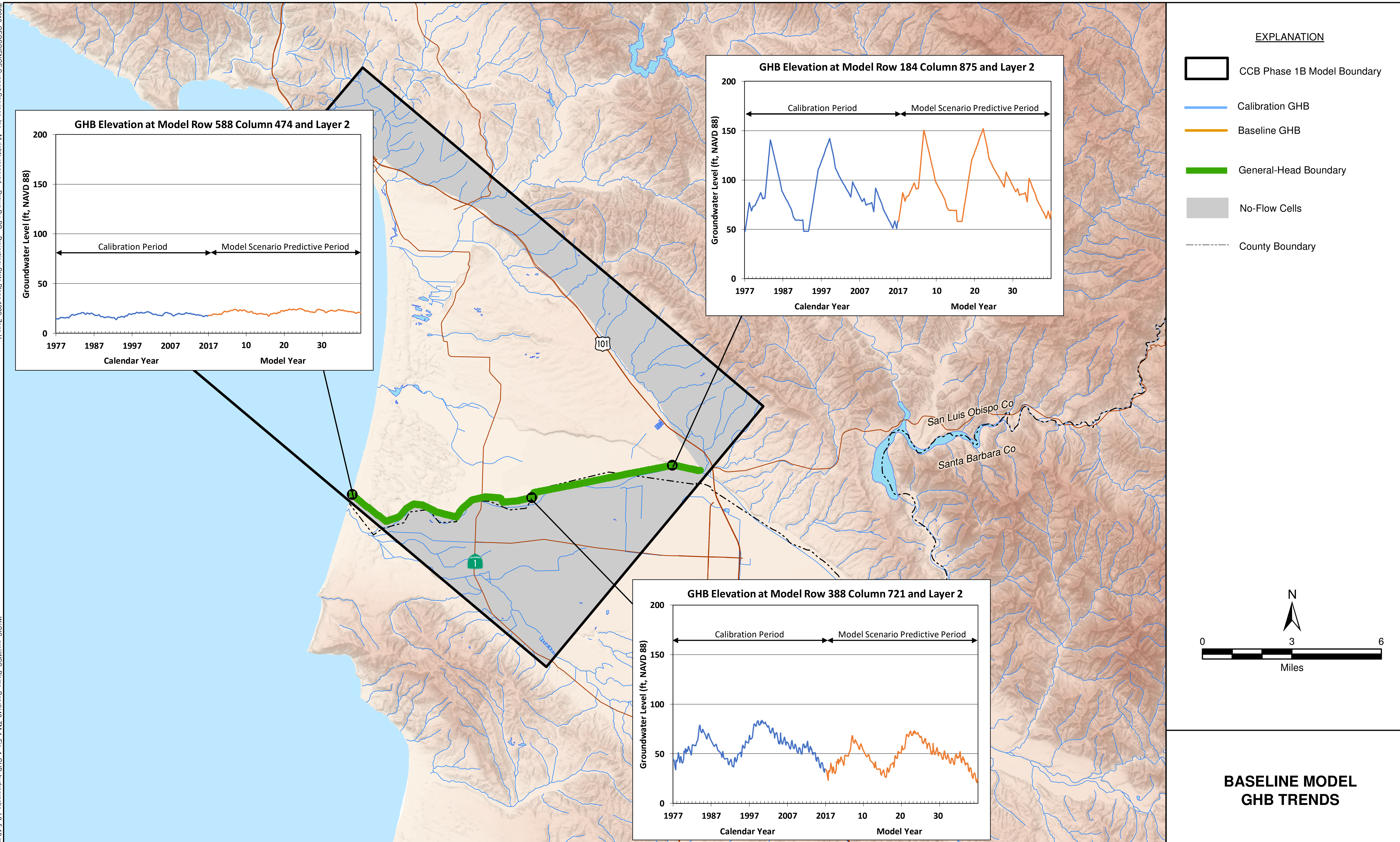
14-May-19



BASELINE MODEL GHB TRENDS

14-May-19

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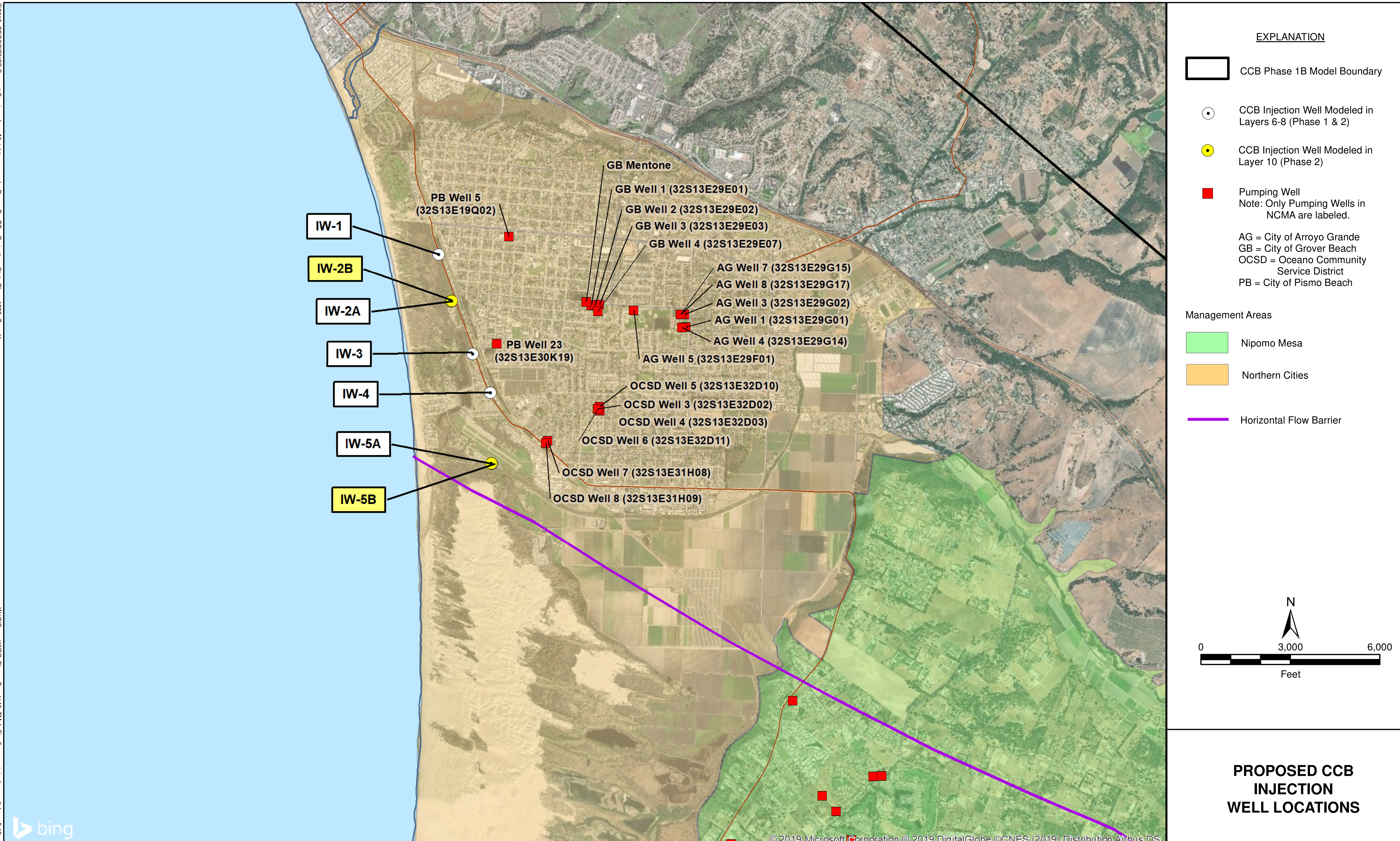
FIGURE 4

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 4: MODEL SCENARIO EVALUATION

GEOSCIENCE



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14-May-19

PROPOSED CCB INJECTION WELL LOCATIONS

FIGURE 5

EXPLANATION

CCB Phase 1B Model Boundary

Location of Well Used for Deep Well Index

Management Areas

Nipomo Mesa

Northern Cities

Horizontal Flow Barrier

N

0 3,000 6,000

Feet

LOCATION OF WELLS USED FOR DEEP WELL INDEX

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14-May-19

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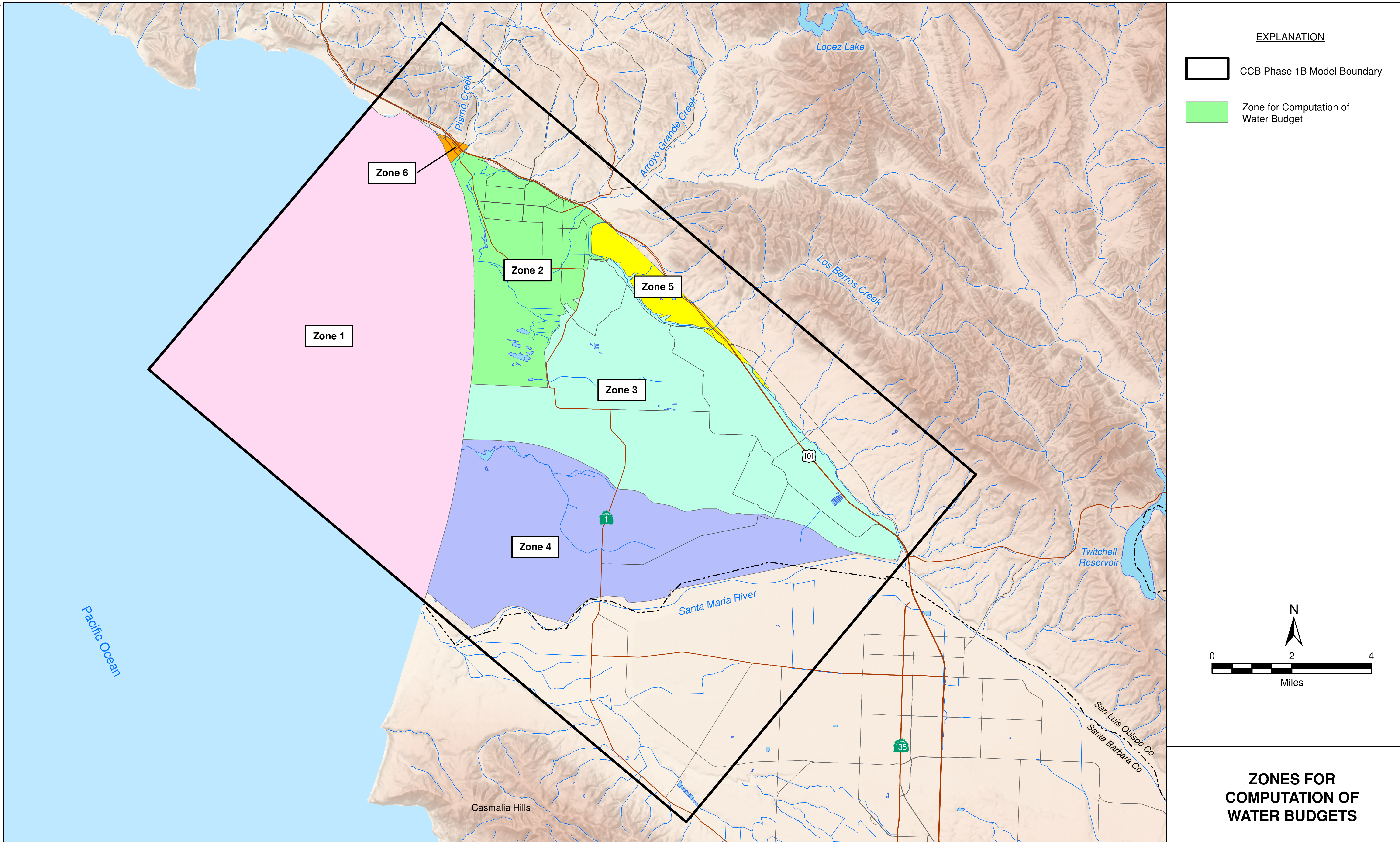
FIGURE 6

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 4: MODEL SCENARIO EVALUATION

GEOSCIENCE



ZONES FOR COMPUTATION OF WATER BUDGETS

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14-May-19

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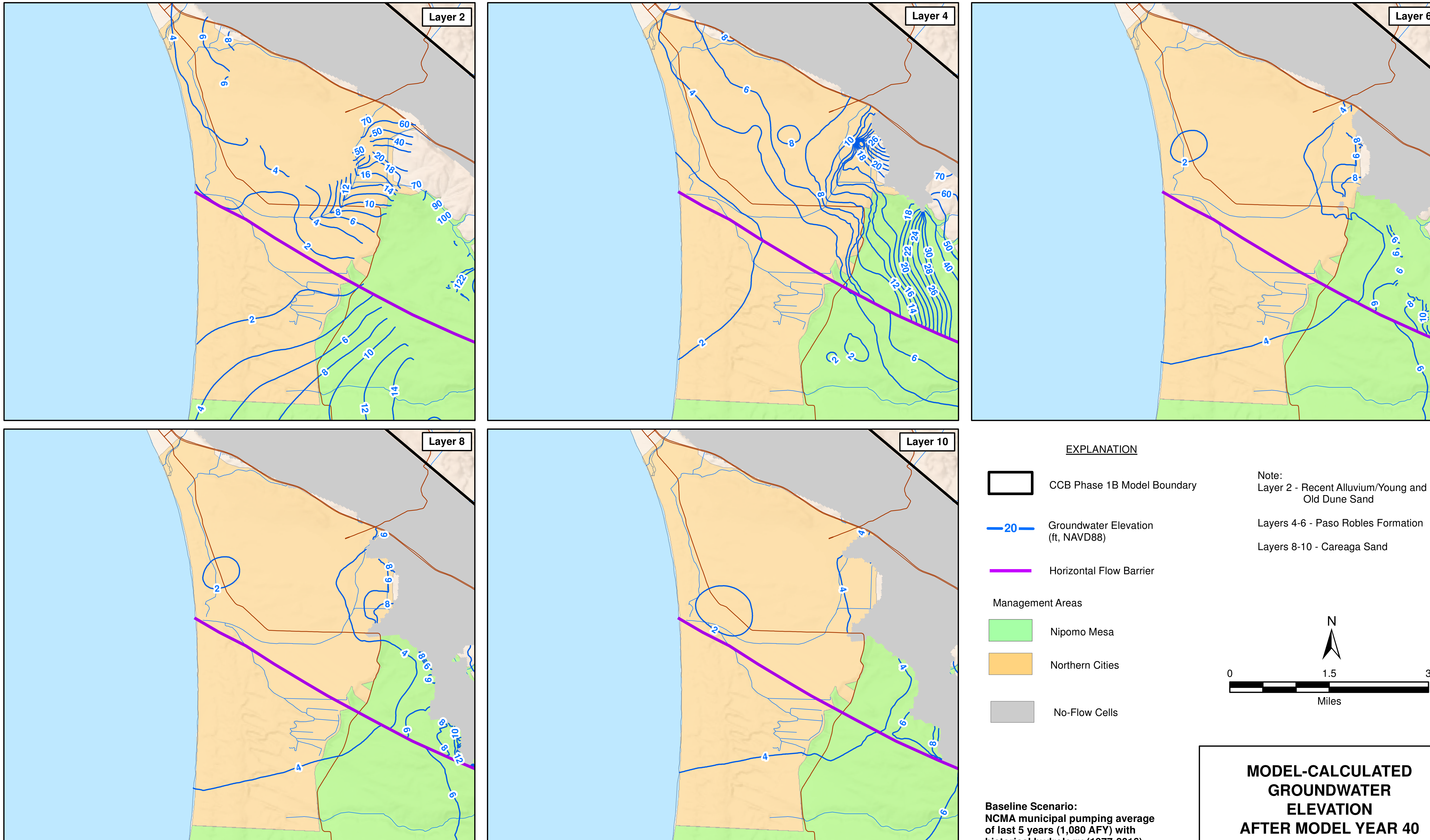
FIGURE 7

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 4: MODEL SCENARIO EVALUATION

GEOSCIENCE



MODEL-CALCULATED GROUNDWATER ELEVATION AFTER MODEL YEAR 40 BASELINE SCENARIO

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FIGURE 8

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 4: MODEL SCENARIO EVALUATION

GEOSCIENCE

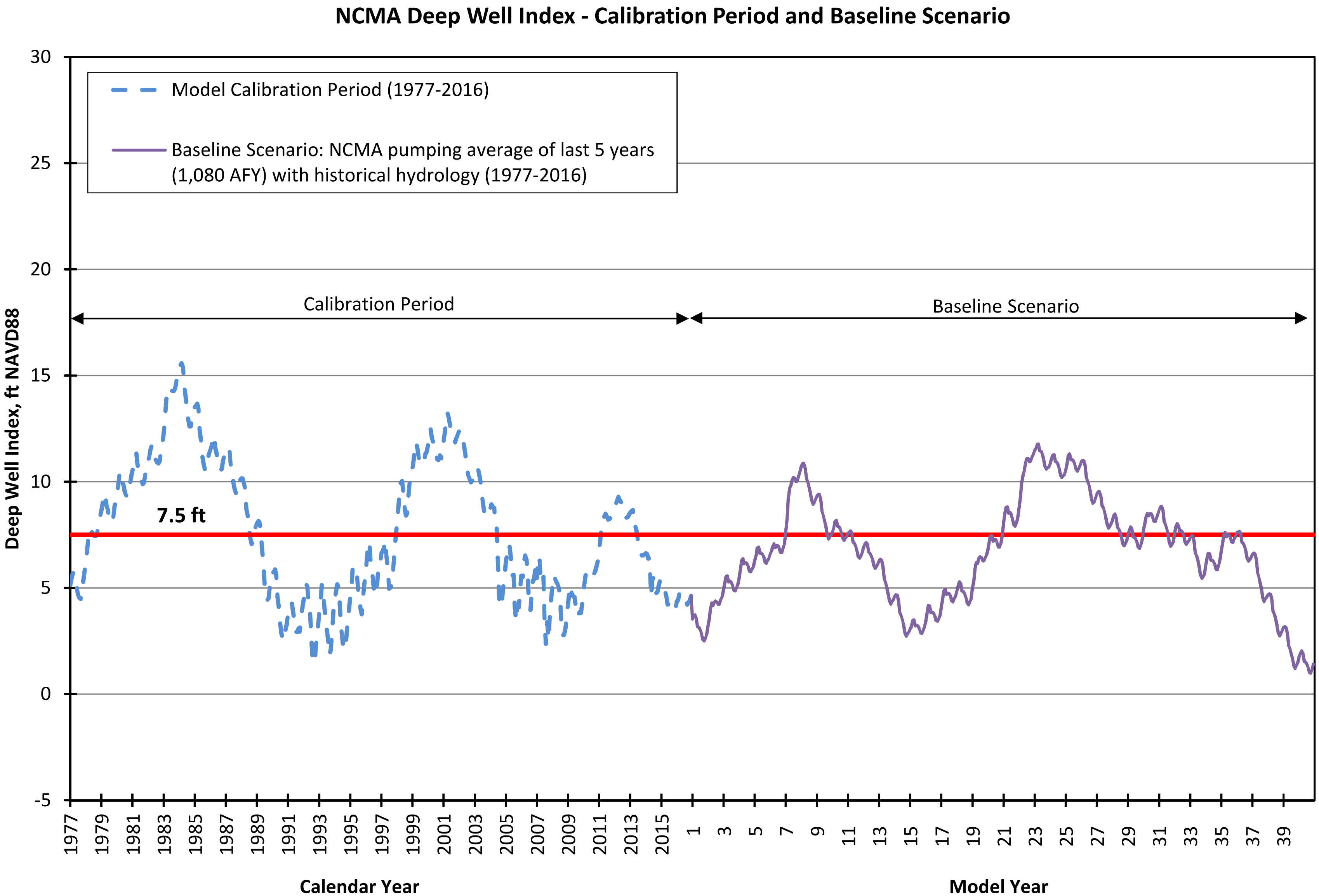

NCMA Deep Well Index - Calibration Period and Baseline Scenario
Model Calibration Period (1977-2016)
Baseline Scenario: NCMA pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016)
Calibration Period
Baseline Scenario
7.5 ft
Deep Well Index, ft NAVD88
30
25
20
15
10
5
0
-5
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
Calendar Year
Model Year

Figure 9

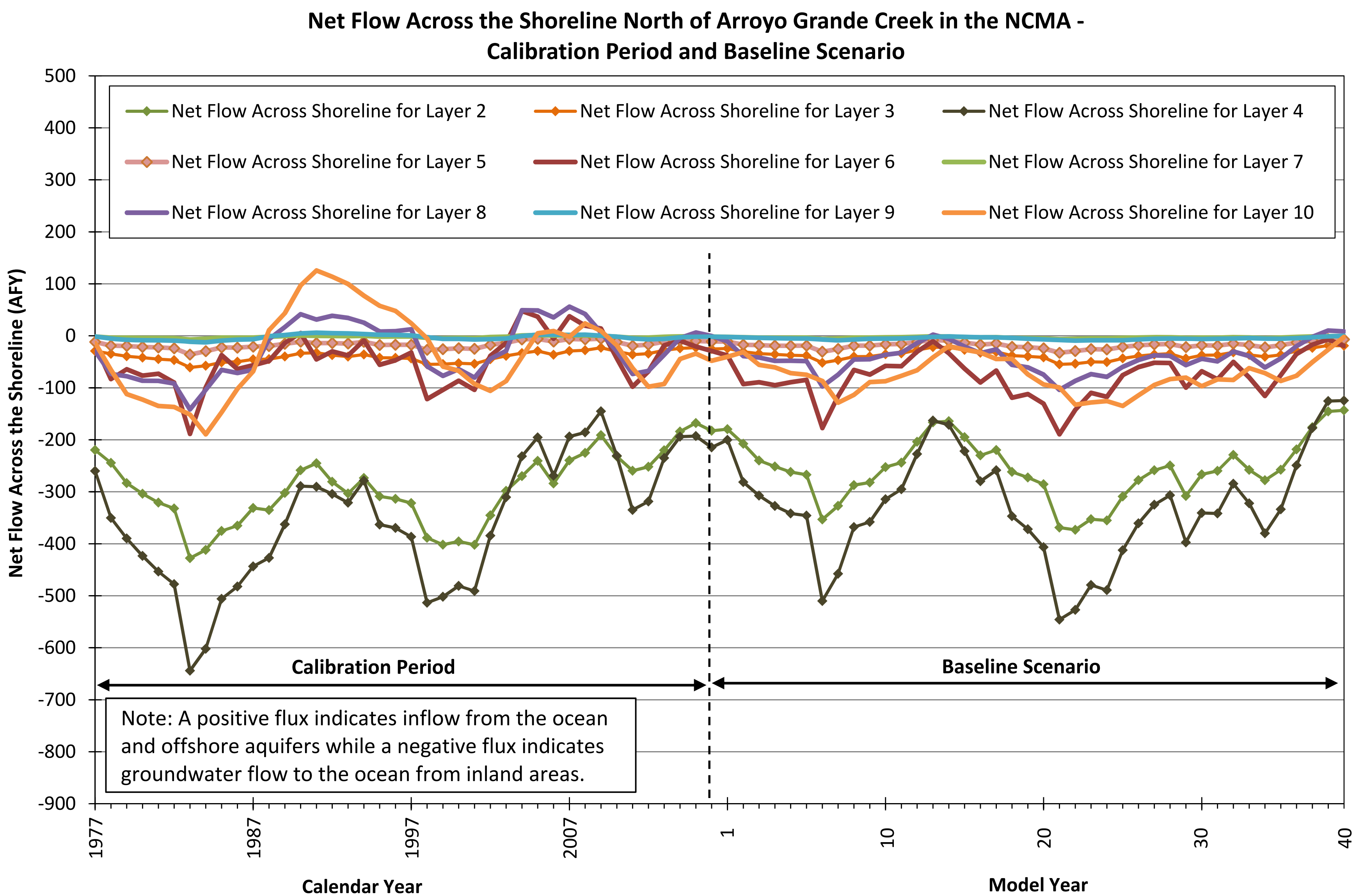

Net Flow Across the Shoreline North of Arroyo Grande Creek in the NCMA - Calibration Period and Baseline Scenario
Net Flow Across Shoreline for Layer 2
Net Flow Across Shoreline for Layer 3
Net Flow Across Shoreline for Layer 4
Net Flow Across Shoreline for Layer 5
Net Flow Across Shoreline for Layer 6
Net Flow Across Shoreline for Layer 7
Net Flow Across Shoreline for Layer 8
Net Flow Across Shoreline for Layer 9
Net Flow Across Shoreline for Layer 10
Net Flow Across the Shoreline (AFY)
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
Calibration Period
Baseline Scenario
Note: A positive flux indicates inflow from the ocean and offshore aquifers while a negative flux indicates groundwater flow to the ocean from inland areas.
1977
1987
1997
2007
1
10
20
30
40
Calendar Year
Model Year

Figure 10

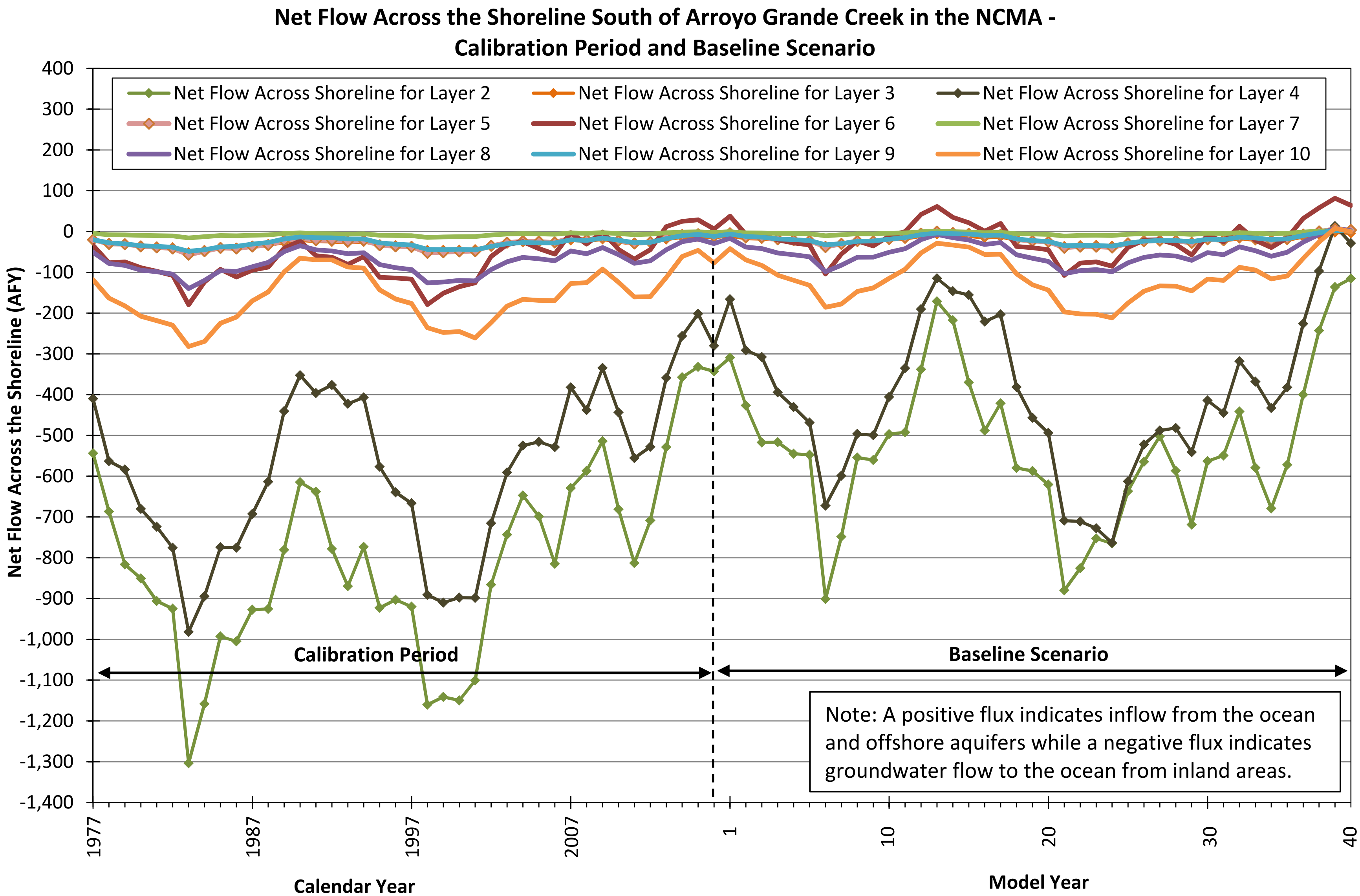
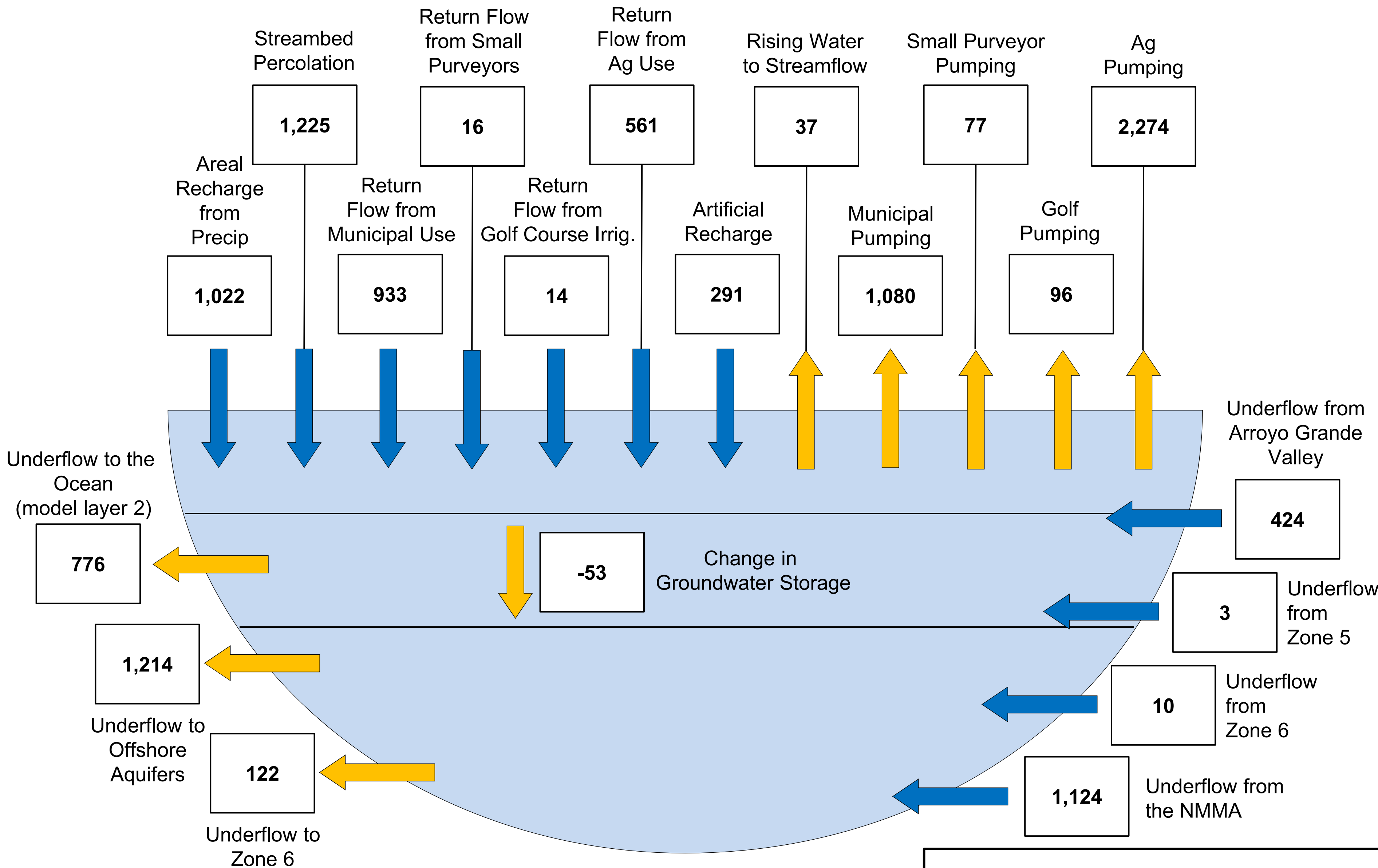

Net Flow Across the Shoreline South of Arroyo Grande Creek in the NCMA - Calibration Period and Baseline Scenario
Net Flow Across Shoreline for Layer 2
Net Flow Across Shoreline for Layer 3
Net Flow Across Shoreline for Layer 4
Net Flow Across Shoreline for Layer 5
Net Flow Across Shoreline for Layer 6
Net Flow Across Shoreline for Layer 7
Net Flow Across Shoreline for Layer 8
Net Flow Across Shoreline for Layer 9
Net Flow Across Shoreline for Layer 10
Net Flow Across the Shoreline (AFY)
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1,000
-1,100
-1,200
-1,300
-1,400
Calibration Period
Baseline Scenario
Note: A positive flux indicates inflow from the ocean and offshore aquifers while a negative flux indicates groundwater flow to the ocean from inland areas.
1977
1987
1997
2007
1
10
20
30
40
Calendar Year
Model Year

Figure 11



All values in acre-ft/yr
Baseline Scenario: NCMA municipal pumping average of last 5 years with historical hydrology (1977-2016)

AVERAGE ANNUAL WATER BUDGETS FOR THE NCMA BASELINE SCENARIO

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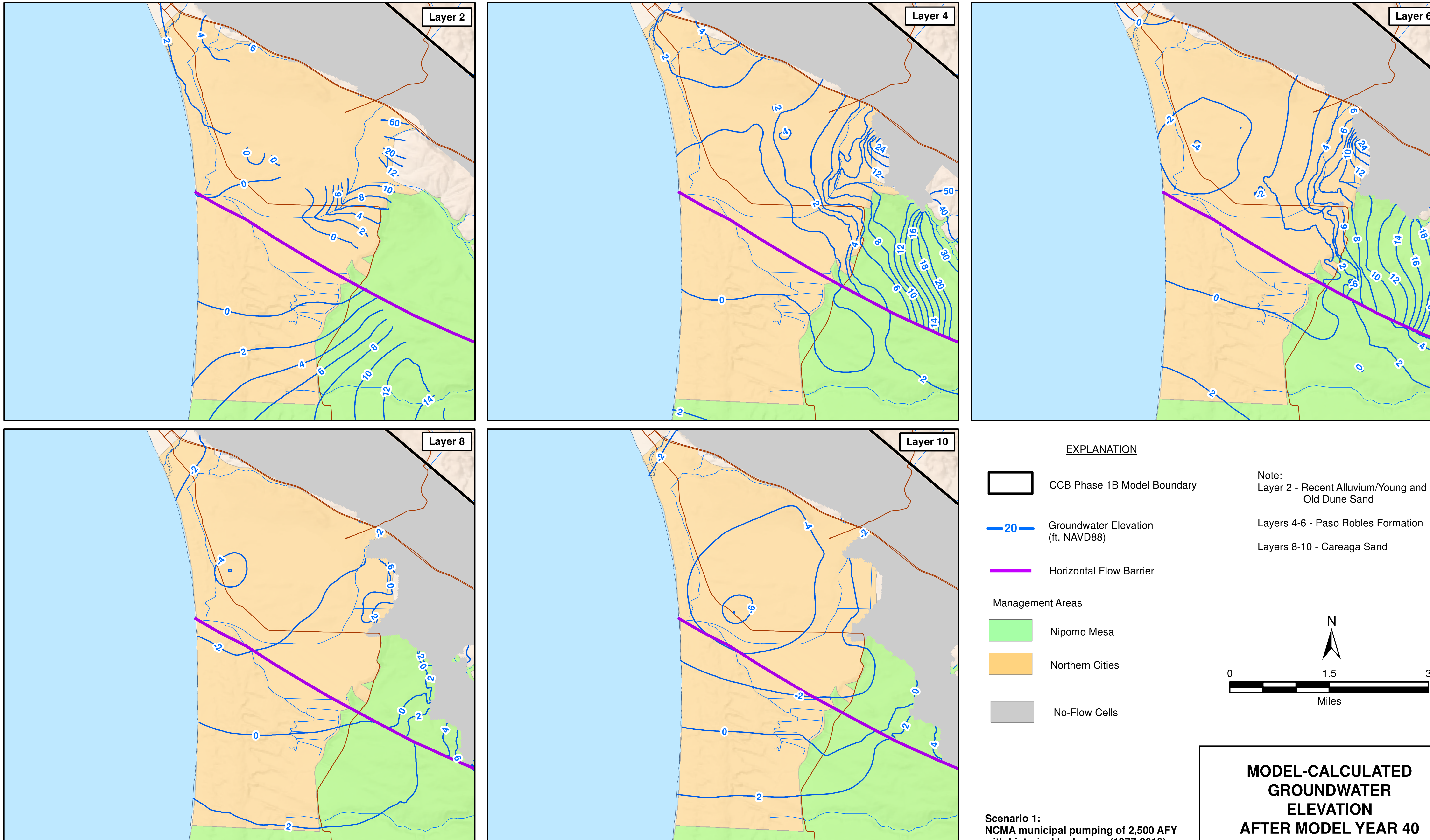
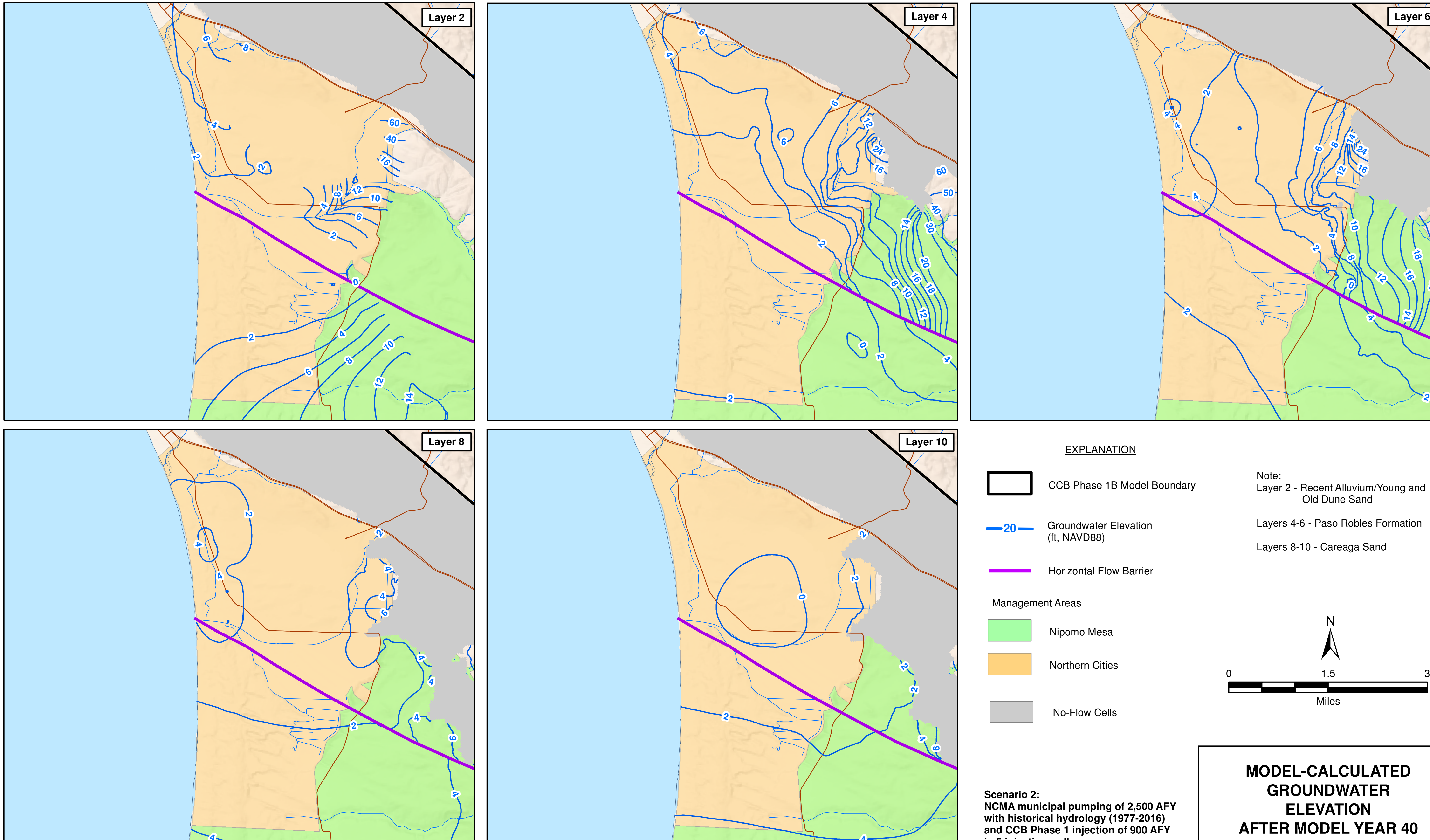


MODEL-CALCULATED GROUNDWATER ELEVATION AFTER MODEL YEAR 40 SCENARIO 1

14-May-19



Scenario 2:
NCMA municipal pumping of 2,500 AFY with historical hydrology (1977-2016) and CCB Phase 1 injection of 900 AFY in 5 injection wells

MODEL-CALCULATED GROUNDWATER ELEVATION AFTER MODEL YEAR 40 SCENARIO 2

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FIGURE 14

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 4: MODEL SCENARIO EVALUATION

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Water Systems Consulting, Inc.
City of Pismo Beach and SSLOCSD CCB Phase 1B Hydrogeologic Evaluation
TM No. 4 - Model Scenario Evaluation

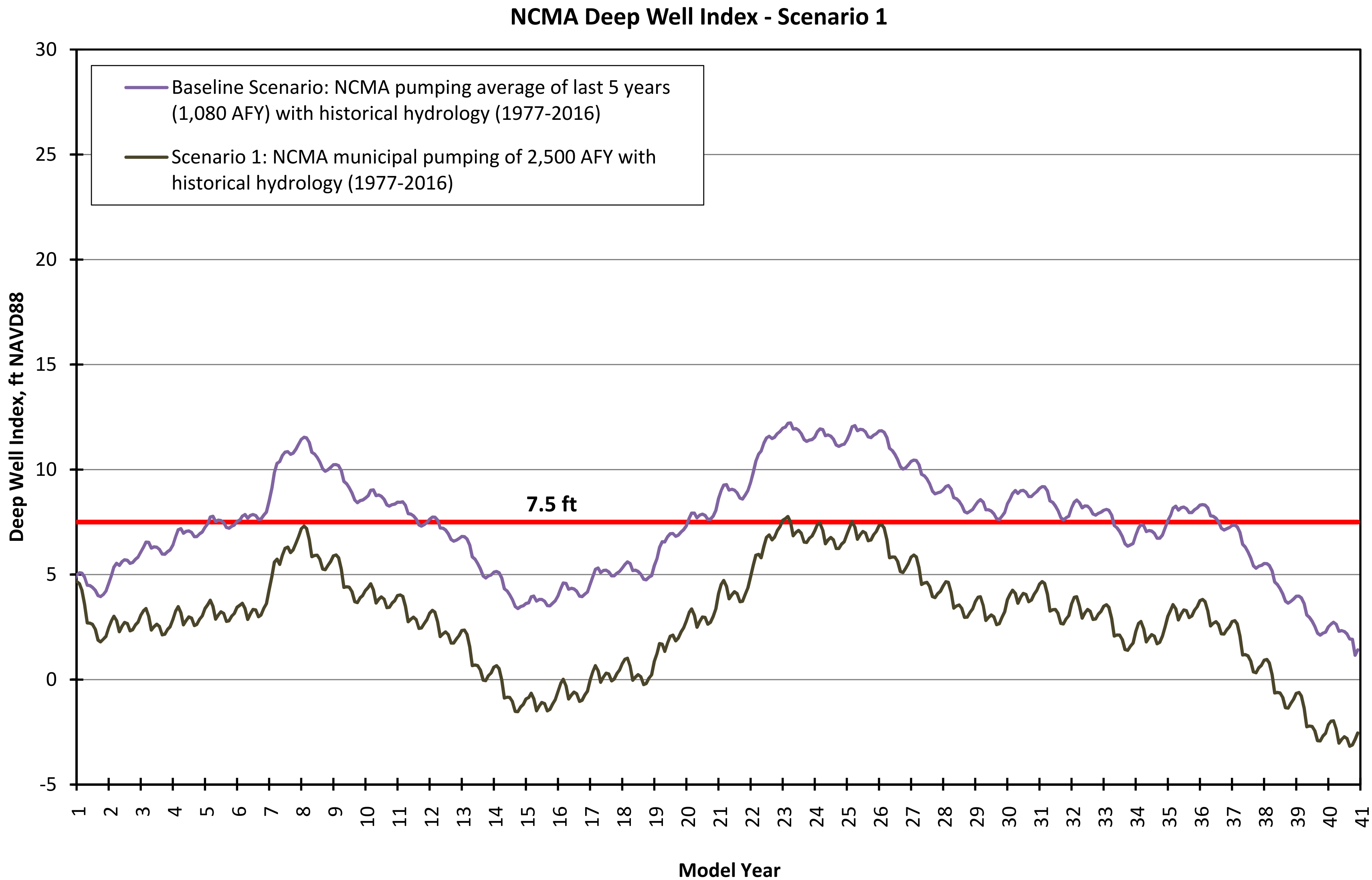


Figure 15

14-May-19

GEOSCIENCE Support Services, Inc.

Water Systems Consulting, Inc.
City of Pismo Beach and SSLOCSD CCB Phase 1B Hydrogeologic Evaluation
TM No. 4 - Model Scenario Evaluation

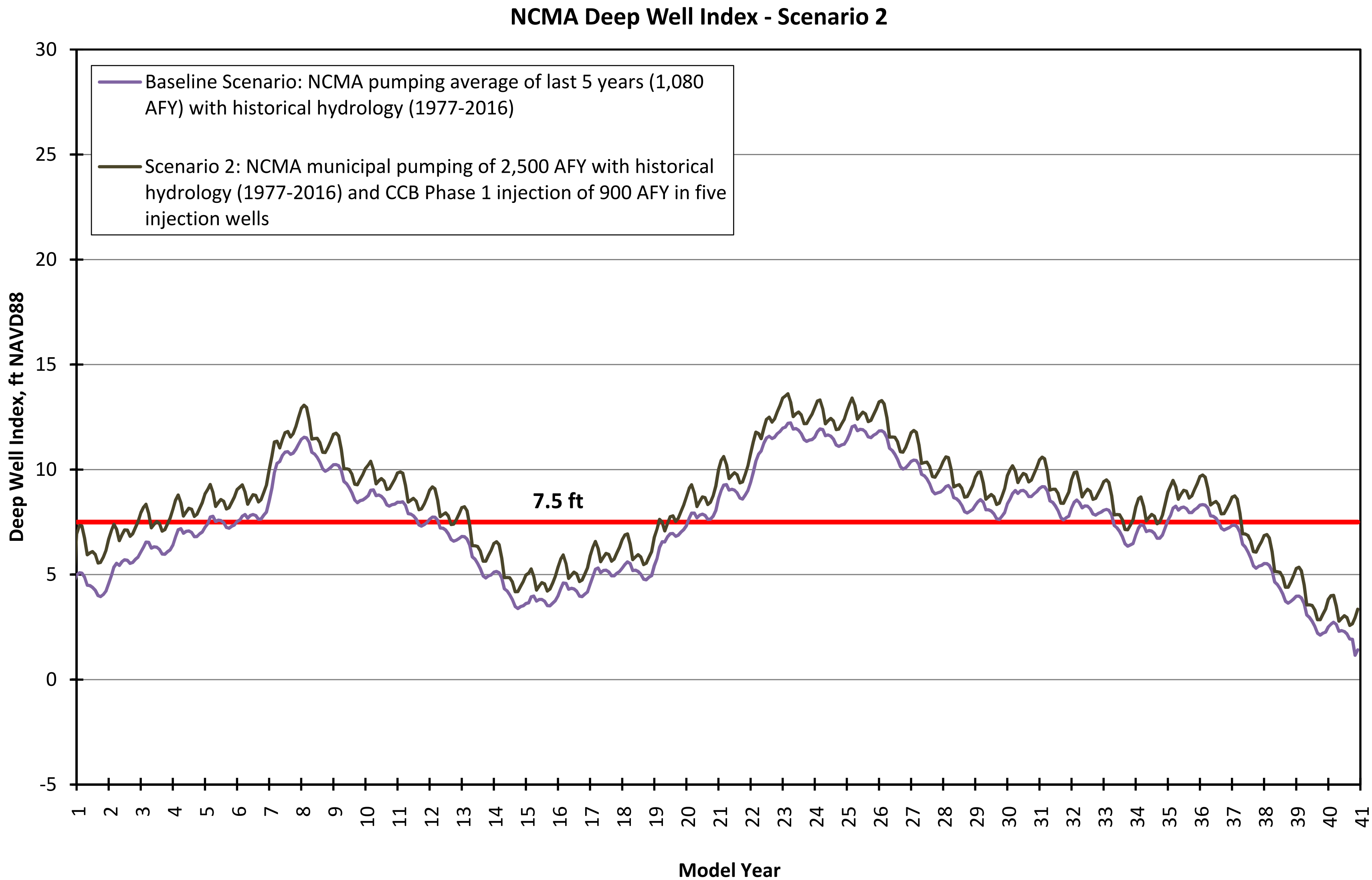


Figure 16

14-May-19

GEOSCIENCE Support Services, Inc.

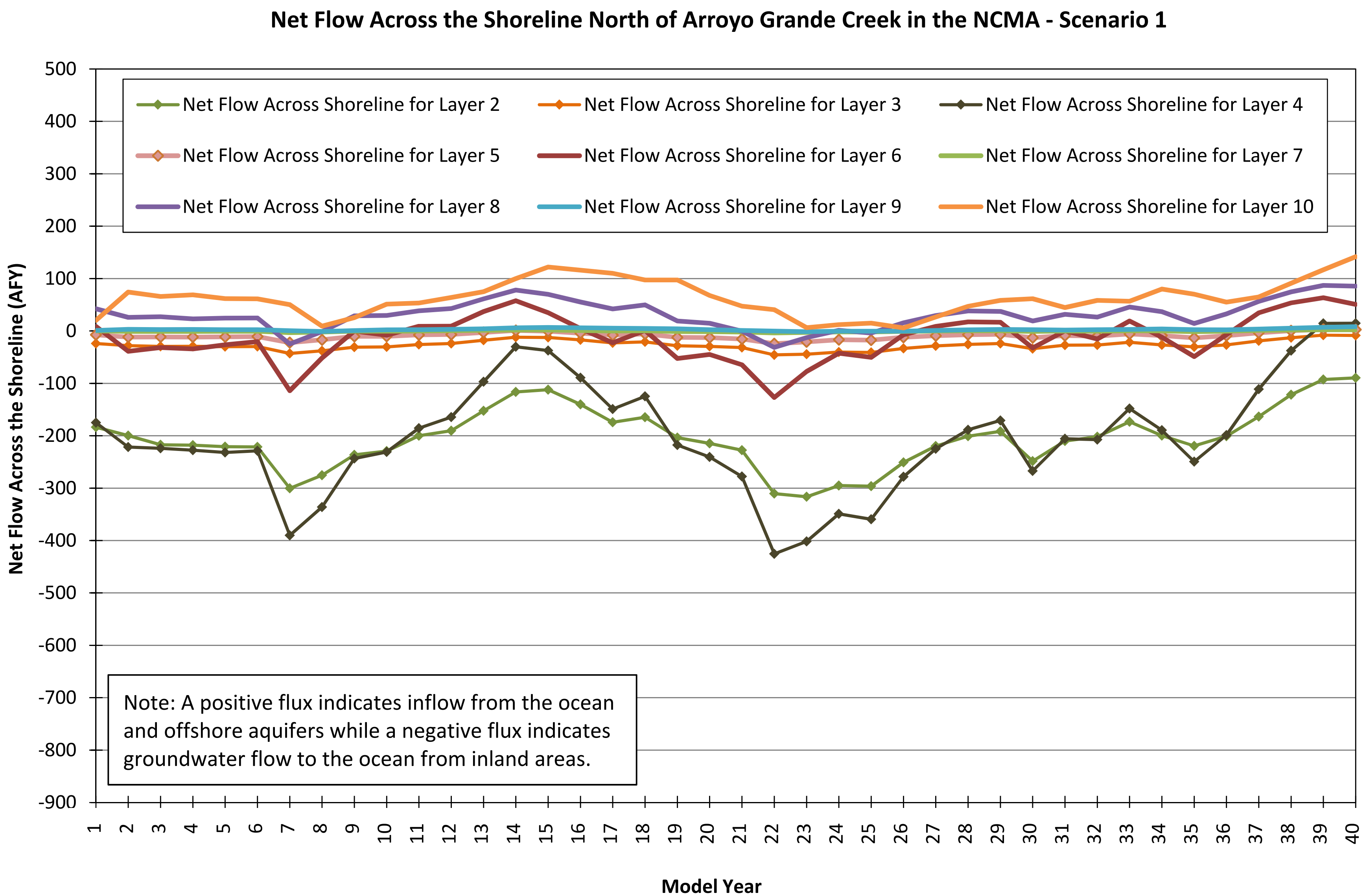

Net Flow Across the Shoreline North of Arroyo Grande Creek in the NCMA - Scenario 1
Net Flow Across Shoreline for Layer 2
Net Flow Across Shoreline for Layer 3
Net Flow Across Shoreline for Layer 4
Net Flow Across Shoreline for Layer 5
Net Flow Across Shoreline for Layer 6
Net Flow Across Shoreline for Layer 7
Net Flow Across Shoreline for Layer 8
Net Flow Across Shoreline for Layer 9
Net Flow Across Shoreline for Layer 10
Note: A positive flux indicates inflow from the ocean and offshore aquifers while a negative flux indicates groundwater flow to the ocean from inland areas.
Net Flow Across the Shoreline (AFY)
Model Year
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900

Figure 17

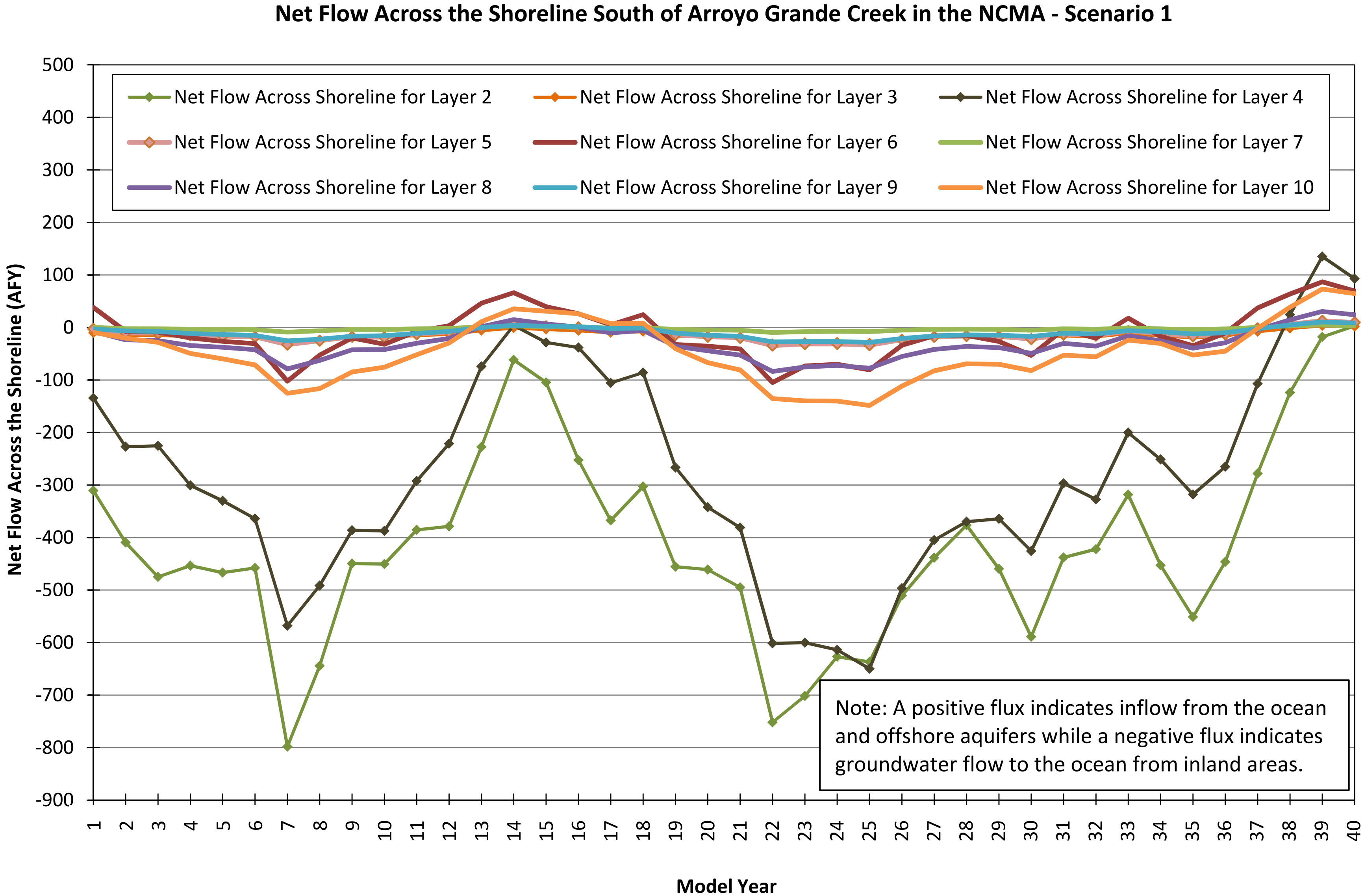

Net Flow Across the Shoreline South of Arroyo Grande Creek in the NCMA - Scenario 1
Net Flow Across Shoreline for Layer 2
Net Flow Across Shoreline for Layer 3
Net Flow Across Shoreline for Layer 4
Net Flow Across Shoreline for Layer 5
Net Flow Across Shoreline for Layer 6
Net Flow Across Shoreline for Layer 7
Net Flow Across Shoreline for Layer 8
Net Flow Across Shoreline for Layer 9
Net Flow Across Shoreline for Layer 10
Net Flow Across the Shoreline (AFY)
Model Year
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
Note: A positive flux indicates inflow from the ocean and offshore aquifers while a negative flux indicates groundwater flow to the ocean from inland areas.

Figure 18

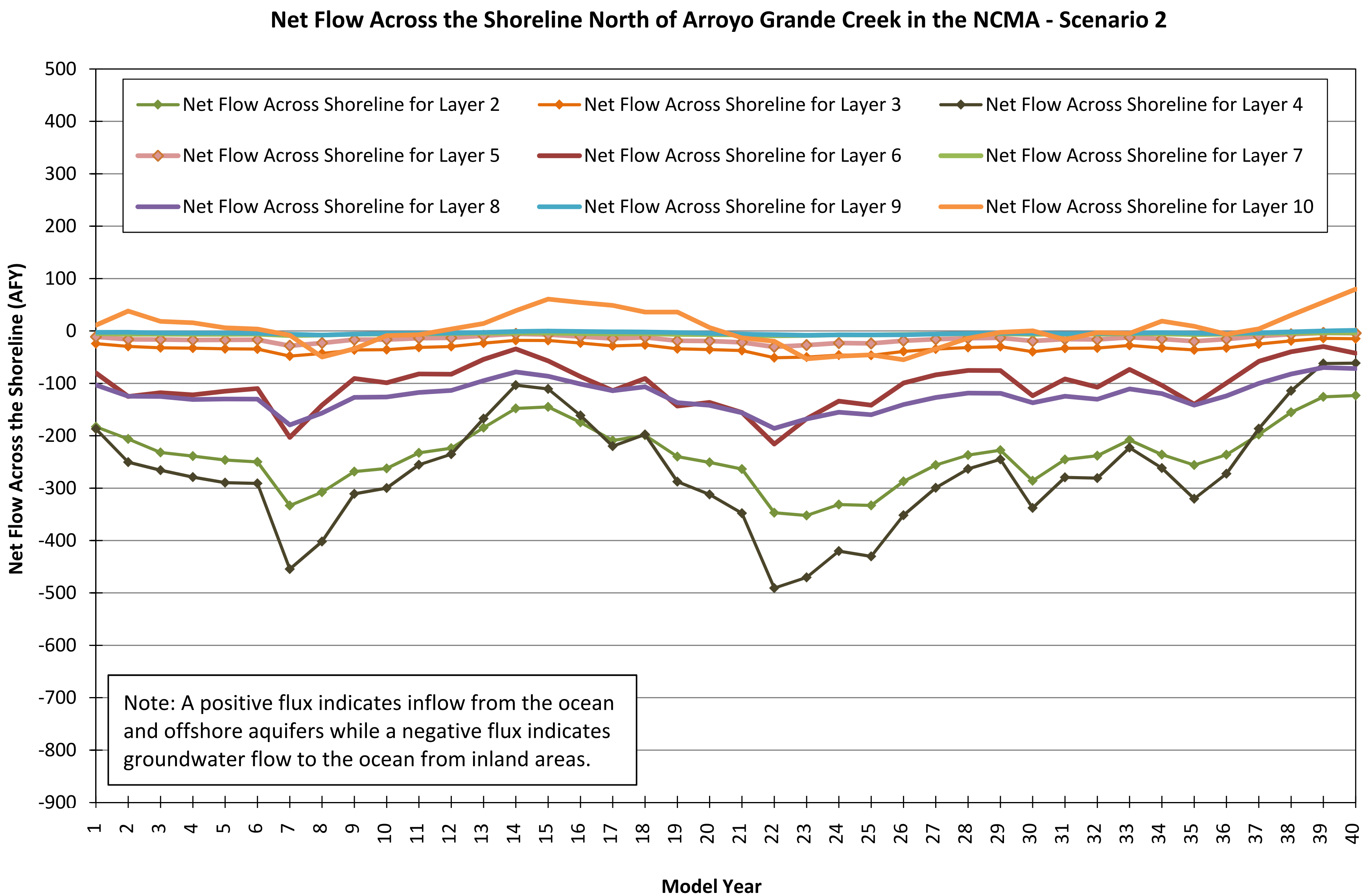

Net Flow Across the Shoreline North of Arroyo Grande Creek in the NCMA - Scenario 2
Net Flow Across Shoreline for Layer 2
Net Flow Across Shoreline for Layer 3
Net Flow Across Shoreline for Layer 4
Net Flow Across Shoreline for Layer 5
Net Flow Across Shoreline for Layer 6
Net Flow Across Shoreline for Layer 7
Net Flow Across Shoreline for Layer 8
Net Flow Across Shoreline for Layer 9
Net Flow Across Shoreline for Layer 10
Net Flow Across the Shoreline (AFY)
Model Year
Note: A positive flux indicates inflow from the ocean and offshore aquifers while a negative flux indicates groundwater flow to the ocean from inland areas.

Figure 19

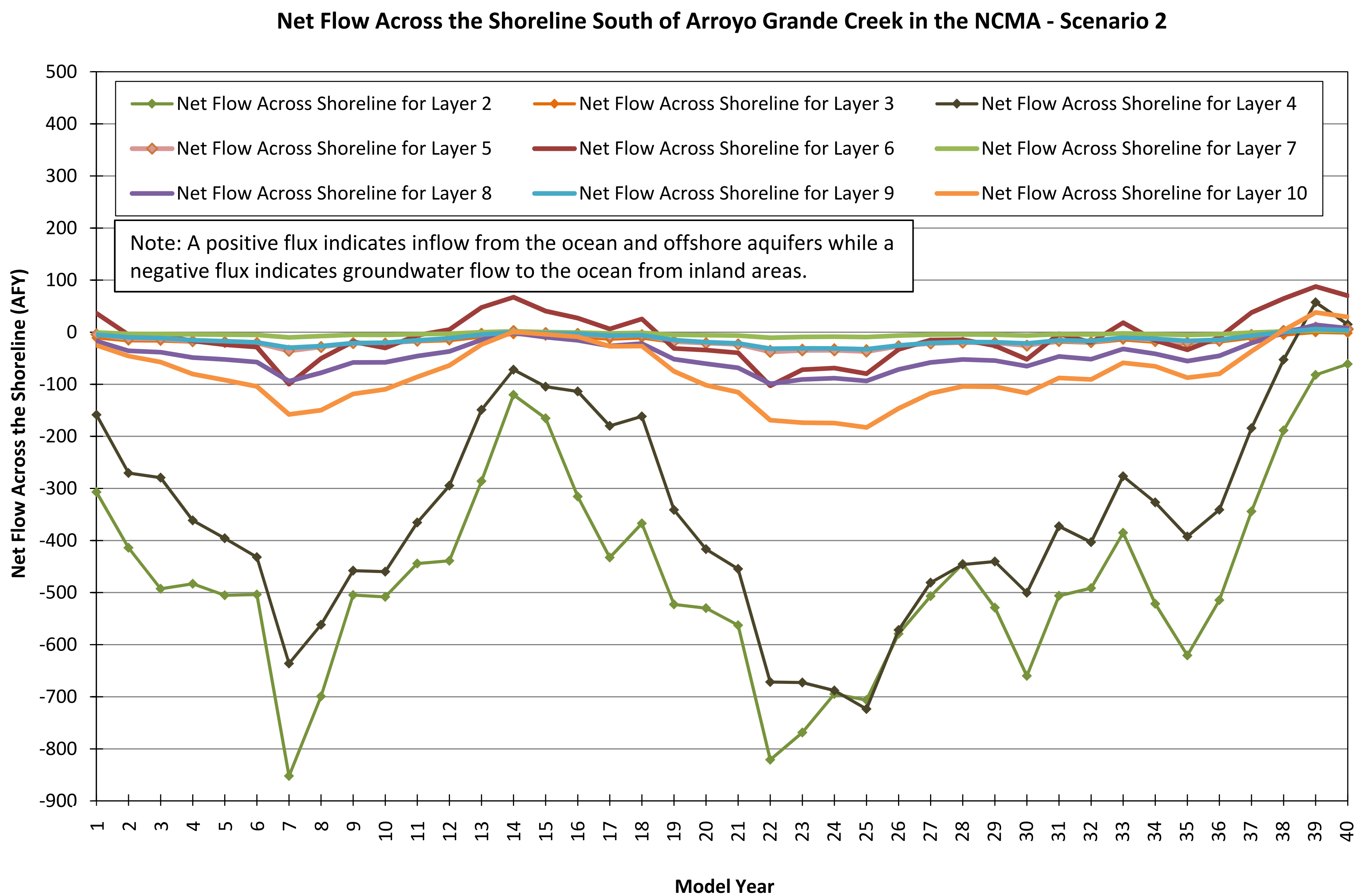
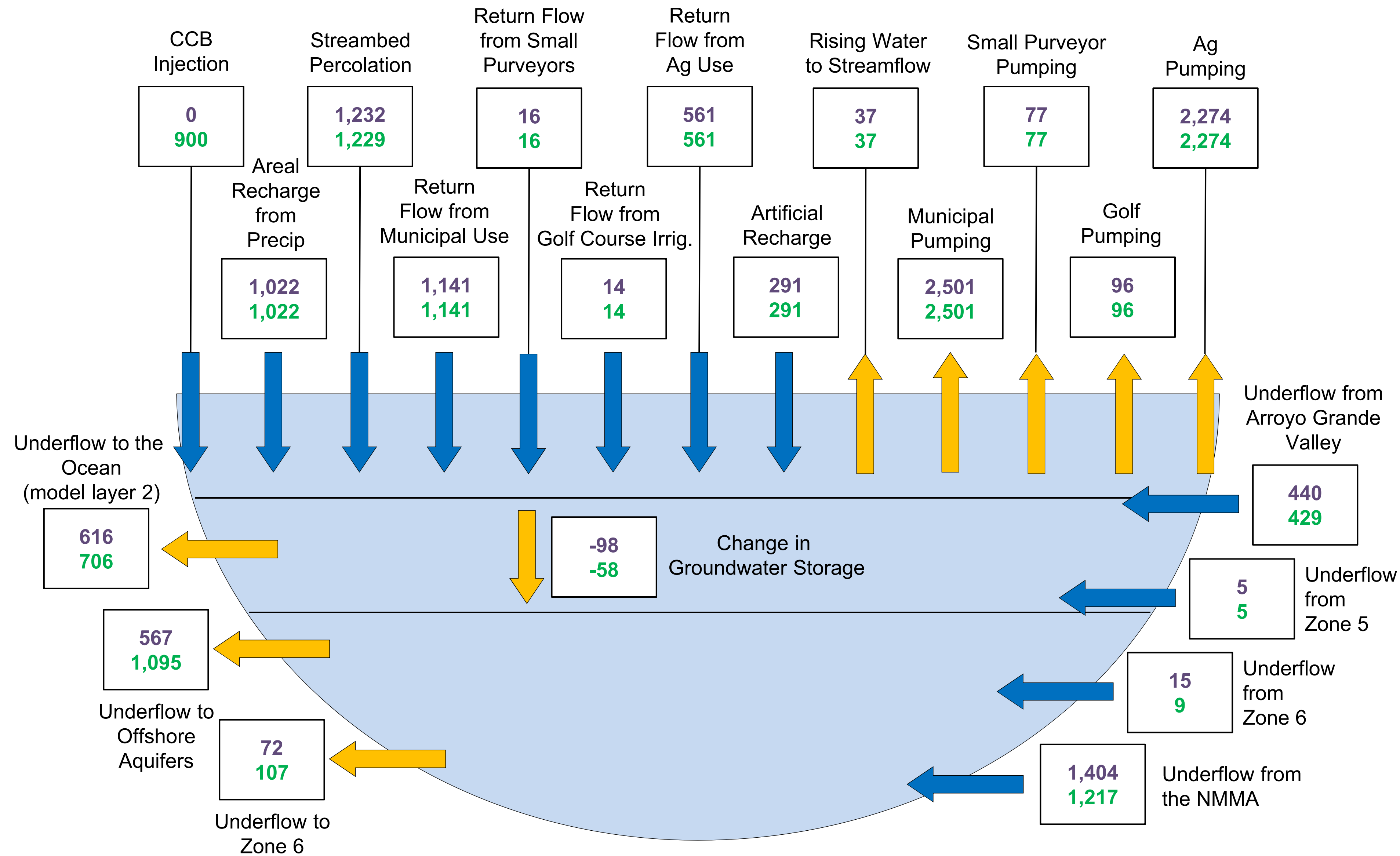

Net Flow Across the Shoreline South of Arroyo Grande Creek in the NCMA - Scenario 2
Net Flow Across Shoreline for Layer 2
Net Flow Across Shoreline for Layer 3
Net Flow Across Shoreline for Layer 4
Net Flow Across Shoreline for Layer 5
Net Flow Across Shoreline for Layer 6
Net Flow Across Shoreline for Layer 7
Net Flow Across Shoreline for Layer 8
Net Flow Across Shoreline for Layer 9
Net Flow Across Shoreline for Layer 10
Note: A positive flux indicates inflow from the ocean and offshore aquifers while a negative flux indicates groundwater flow to the ocean from inland areas.
Net Flow Across the Shoreline (AFY)
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
Model Year

Figure 20



All values in acre-ft/yr
Scenario 1: NCMA municipal pumping of 2,500 AFY with historical hydrology (1977-2016)
Scenario 2: NCMA municipal pumping of 2,500 AFY with historical hydrology and CCB Phase 1 injection of 900 AFY

0 900	Scenario 1 Scenario 2

AVERAGE ANNUAL WATER BUDGETS FOR THE NCMA SCENARIOS 1 & 2

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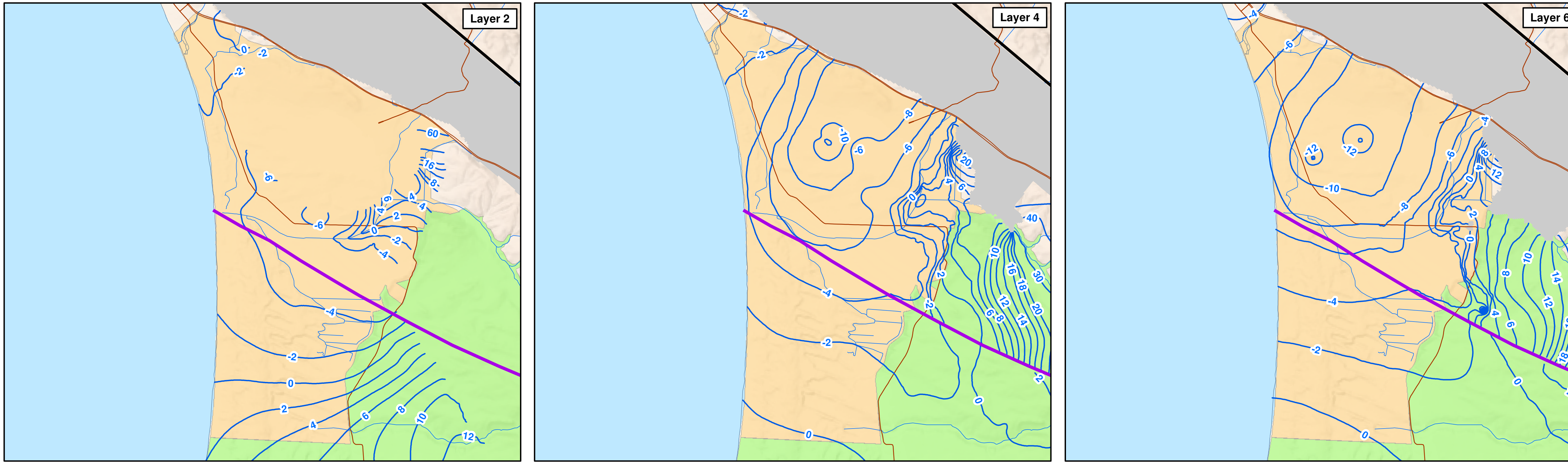

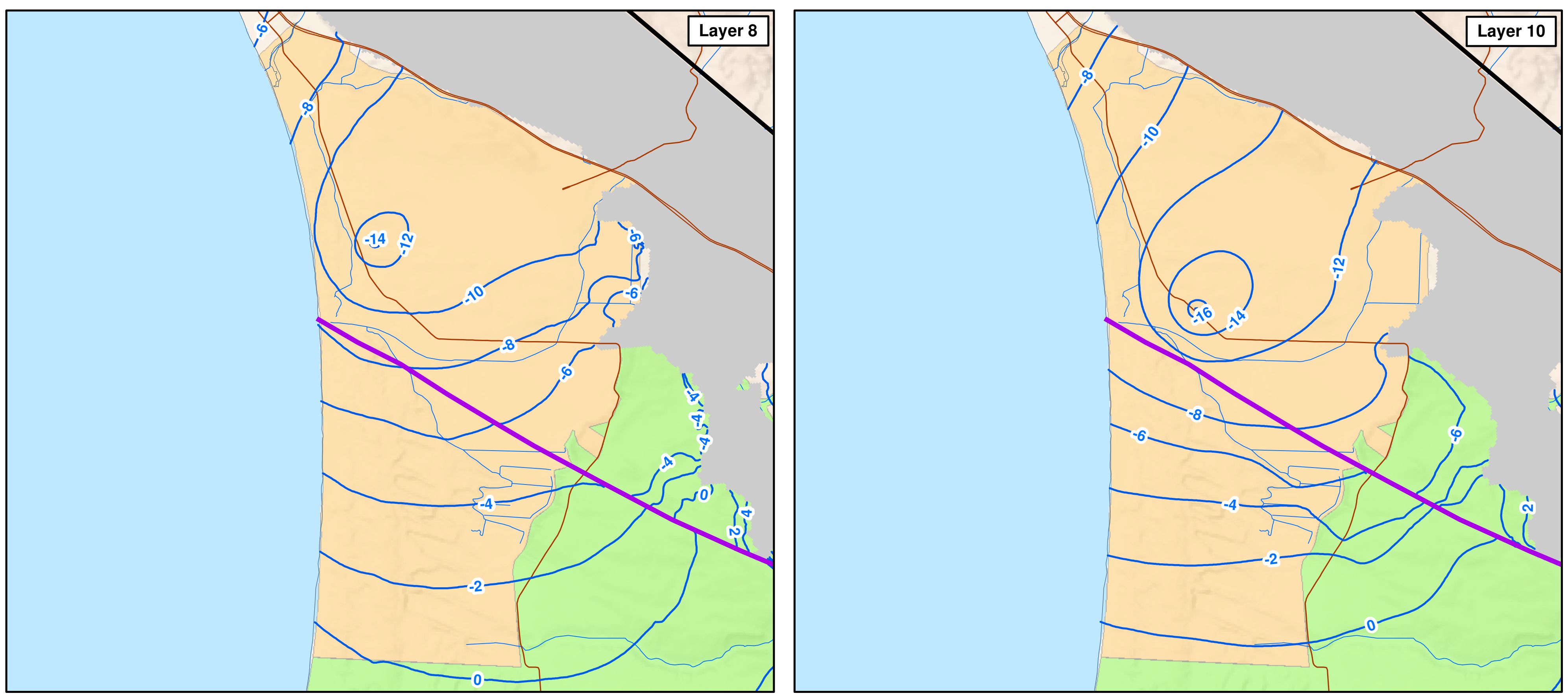

EXPLANATION

CCB Phase 1B Model Boundary

20 Groundwater Elevation (ft, NAVD88)

Horizontal Flow Barrier

Management Areas

Nipomo Mesa

Northern Cities

No-Flow Cells

Note:
Layer 2 - Recent Alluvium/Young and Old Dune Sand

Layers 4-6 - Paso Robles Formation

Layers 8-10 - Careaga Sand

N

0 1.5 3
Miles

Scenario 3:
NCMA municipal pumping maximum allocation (4,330 AFY) with historical hydrology (1977-2016)

MODEL-CALCULATED GROUNDWATER ELEVATION AFTER MODEL YEAR 40 SCENARIO 3

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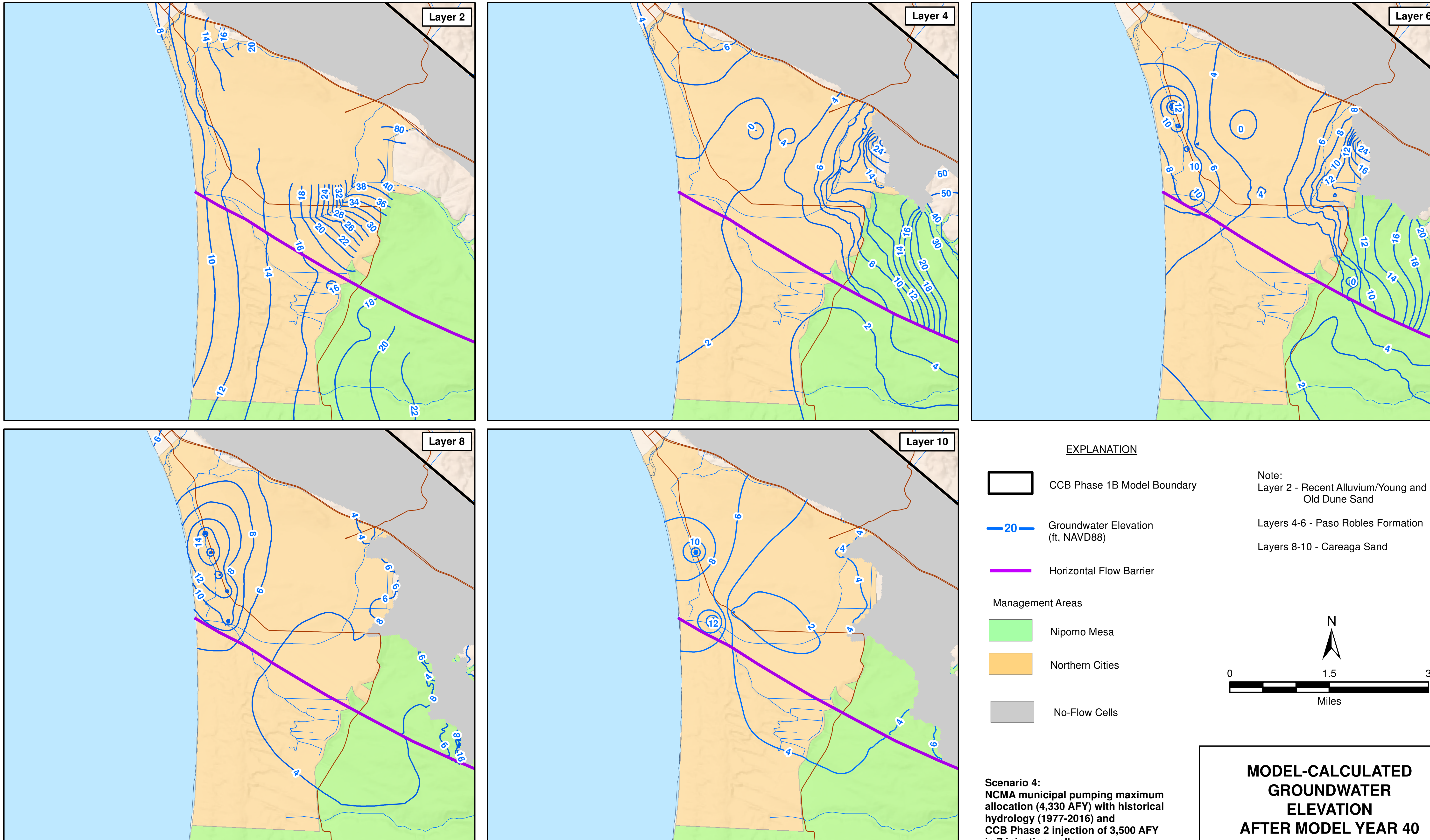
14-May-19

WATER SYSTEMS CONSULTING, INC.

FIGURE 22

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 4: MODEL SCENARIO EVALUATION

GEOSCIENCE



Scenario 4:
NCMA municipal pumping maximum allocation (4,330 AFY) with historical hydrology (1977-2016) and CCB Phase 2 injection of 3,500 AFY in 7 injection wells

MODEL-CALCULATED GROUNDWATER ELEVATION AFTER MODEL YEAR 40 SCENARIO 4

W:\GIS_proj\WSC_Pismo_Beach\42_TM-4_Fig_23_WL_after40yrs_scen4_5panel_5-19.mxd

14-May-19

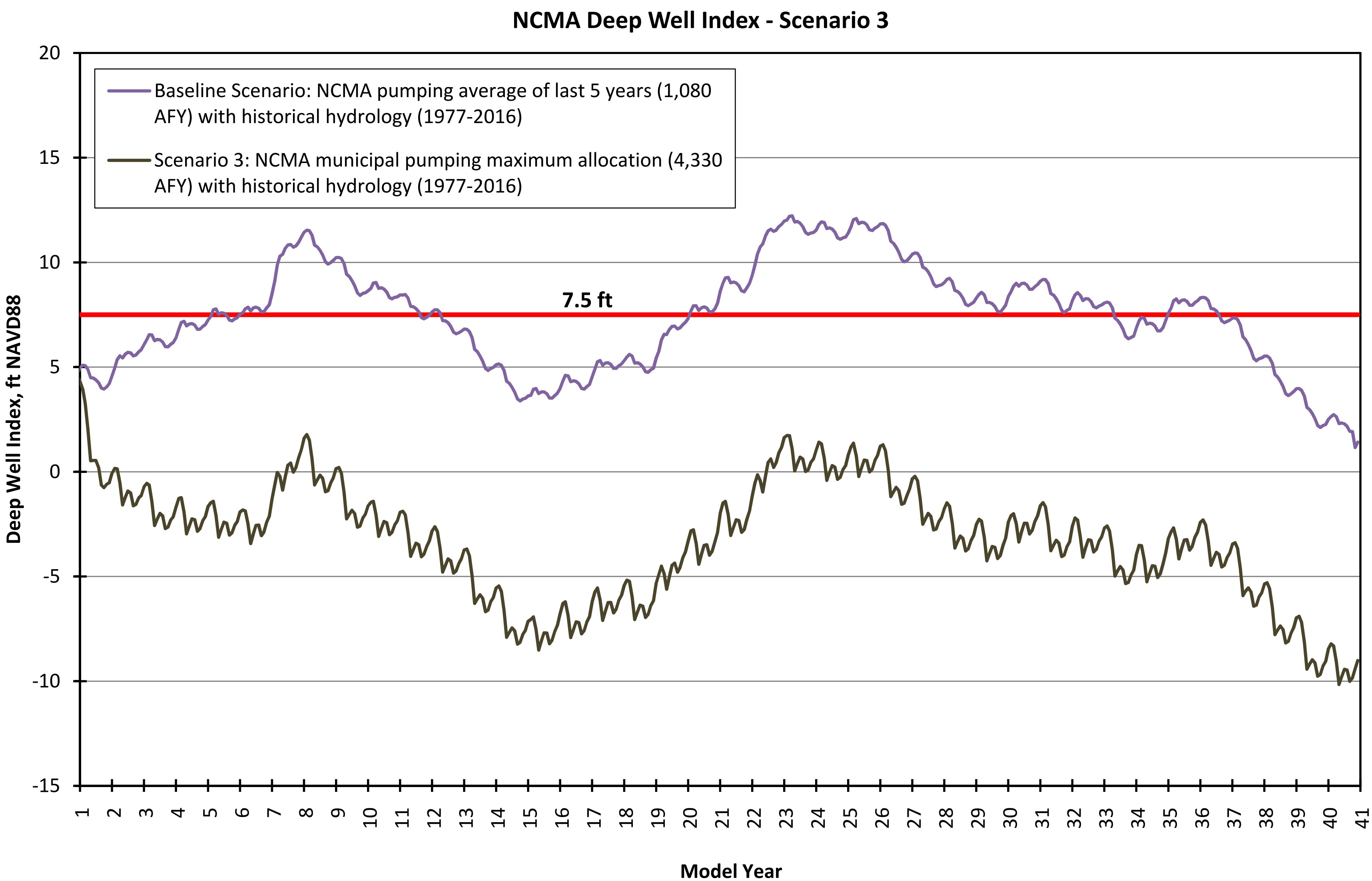

NCMA Deep Well Index - Scenario 3
Baseline Scenario: NCMA pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016)
Scenario 3: NCMA municipal pumping maximum allocation (4,330 AFY) with historical hydrology (1977-2016)
7.5 ft
Deep Well Index, ft NAVD88
Model Year
20
15
10
5
0
-5
-10
-15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41

Figure 24

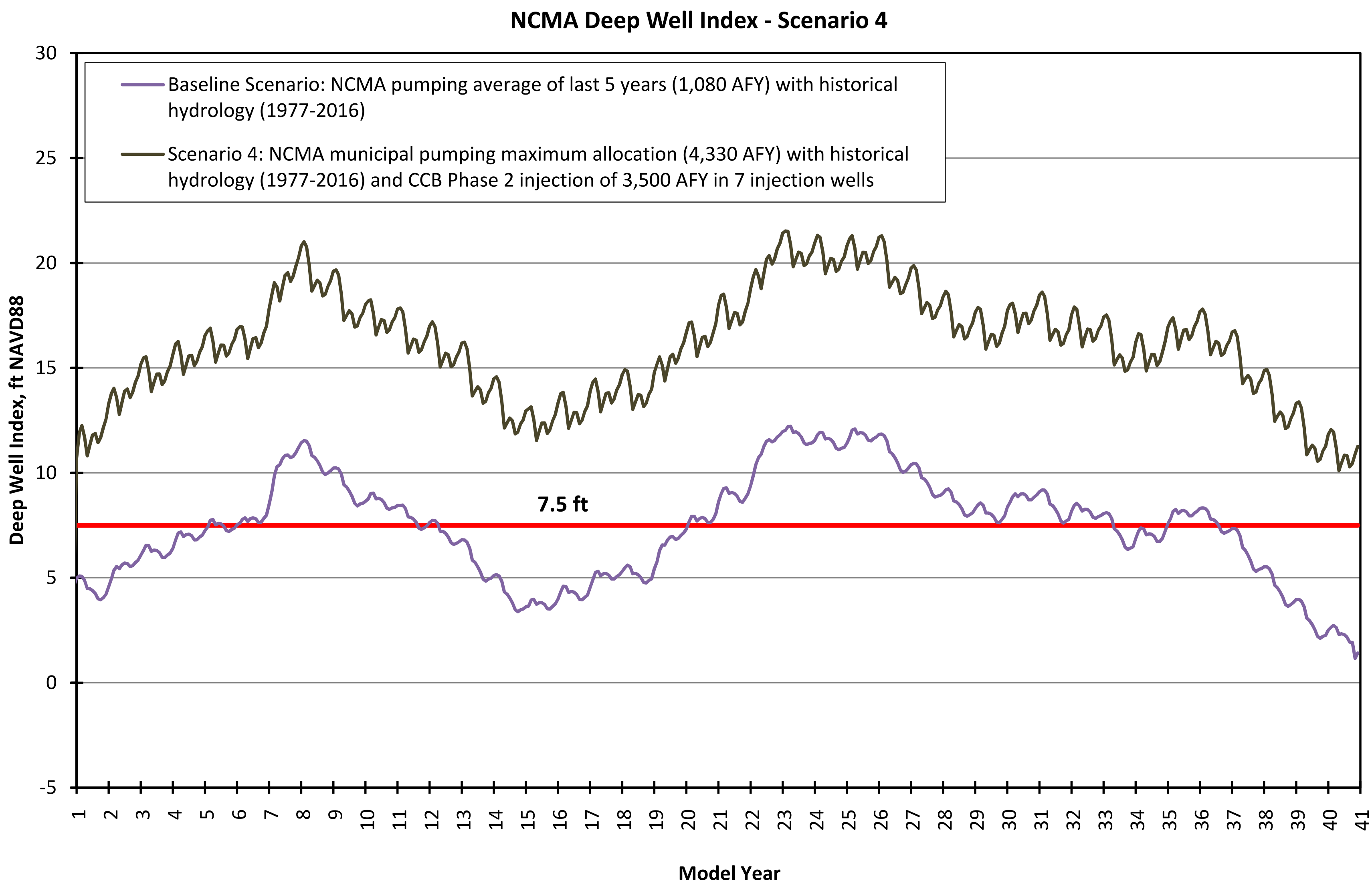

NCMA Deep Well Index - Scenario 4
Baseline Scenario: NCMA pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016)
Scenario 4: NCMA municipal pumping maximum allocation (4,330 AFY) with historical hydrology (1977-2016) and CCB Phase 2 injection of 3,500 AFY in 7 injection wells
7.5 ft
Deep Well Index, ft NAVD88
Model Year
30
25
20
15
10
5
0
-5
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41

Figure 25

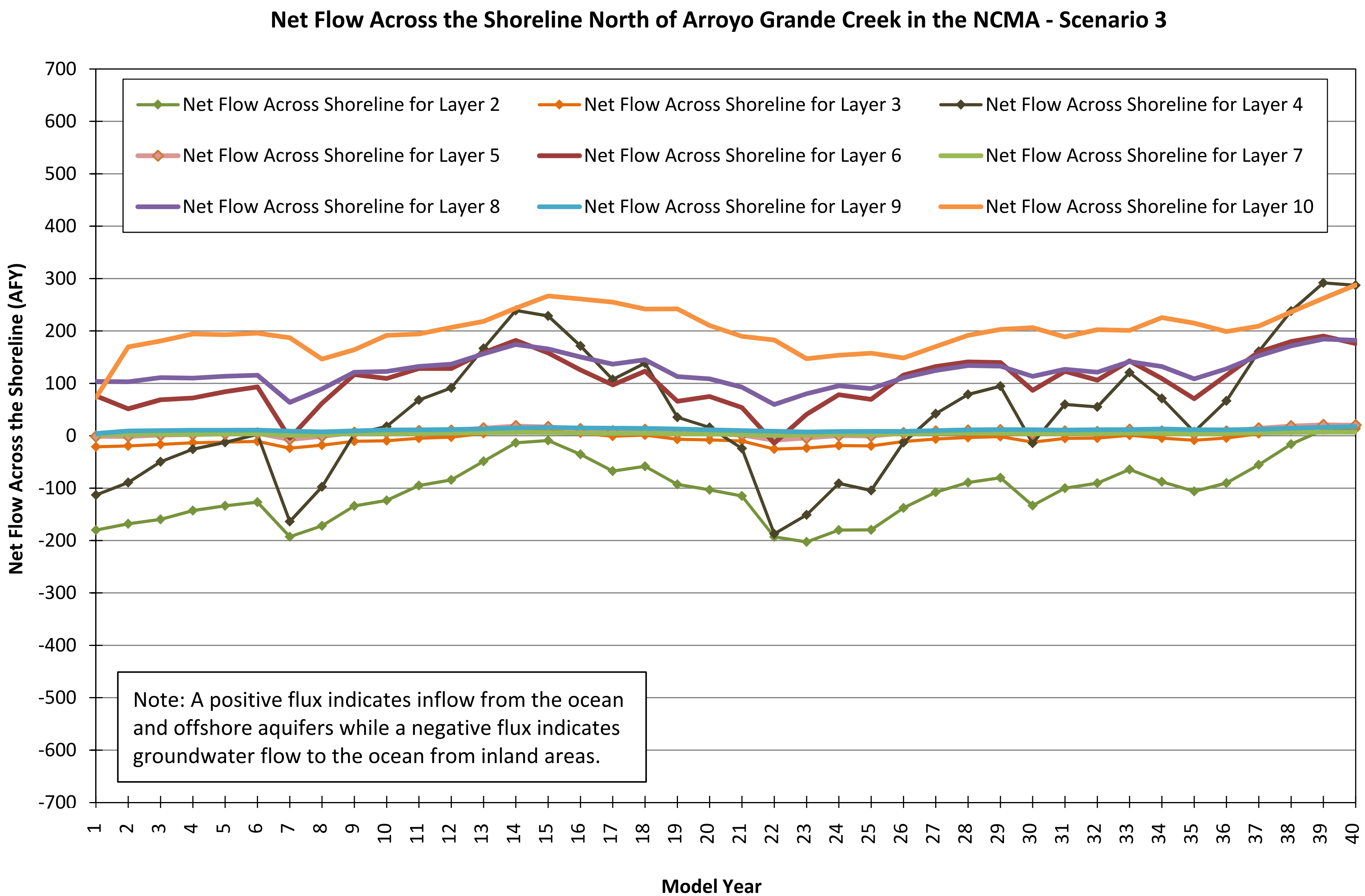

Net Flow Across the Shoreline North of Arroyo Grande Creek in the NCMA - Scenario 3
Net Flow Across Shoreline for Layer 2
Net Flow Across Shoreline for Layer 3
Net Flow Across Shoreline for Layer 4
Net Flow Across Shoreline for Layer 5
Net Flow Across Shoreline for Layer 6
Net Flow Across Shoreline for Layer 7
Net Flow Across Shoreline for Layer 8
Net Flow Across Shoreline for Layer 9
Net Flow Across Shoreline for Layer 10
Net Flow Across the Shoreline (AFY)
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
Note: A positive flux indicates inflow from the ocean and offshore aquifers while a negative flux indicates groundwater flow to the ocean from inland areas.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
Model Year

Figure 26

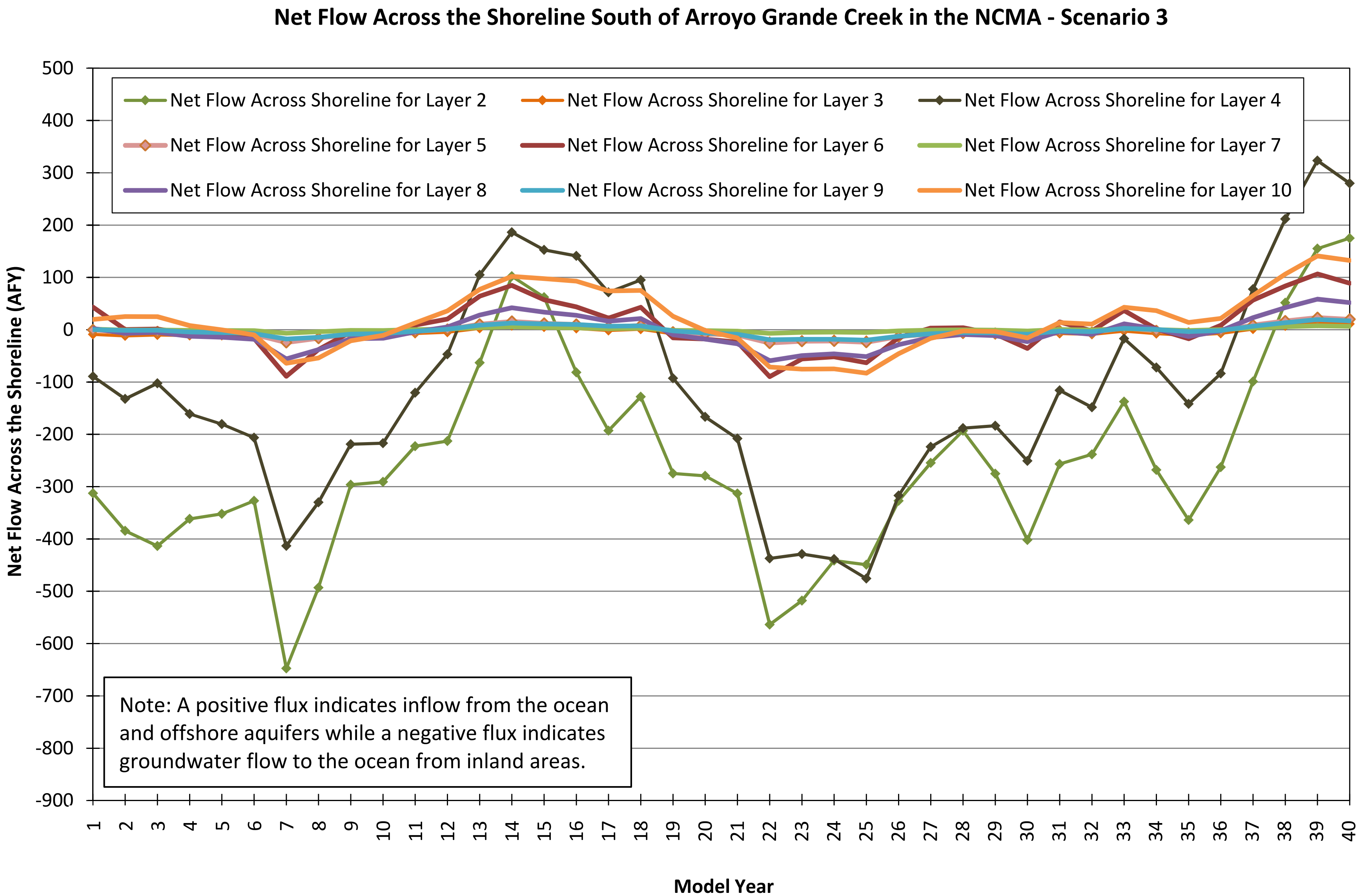

Net Flow Across the Shoreline South of Arroyo Grande Creek in the NCMA - Scenario 3
Net Flow Across Shoreline for Layer 2
Net Flow Across Shoreline for Layer 3
Net Flow Across Shoreline for Layer 4
Net Flow Across Shoreline for Layer 5
Net Flow Across Shoreline for Layer 6
Net Flow Across Shoreline for Layer 7
Net Flow Across Shoreline for Layer 8
Net Flow Across Shoreline for Layer 9
Net Flow Across Shoreline for Layer 10
Net Flow Across the Shoreline (AFY)
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
Note: A positive flux indicates inflow from the ocean and offshore aquifers while a negative flux indicates groundwater flow to the ocean from inland areas.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
Model Year

Figure 27

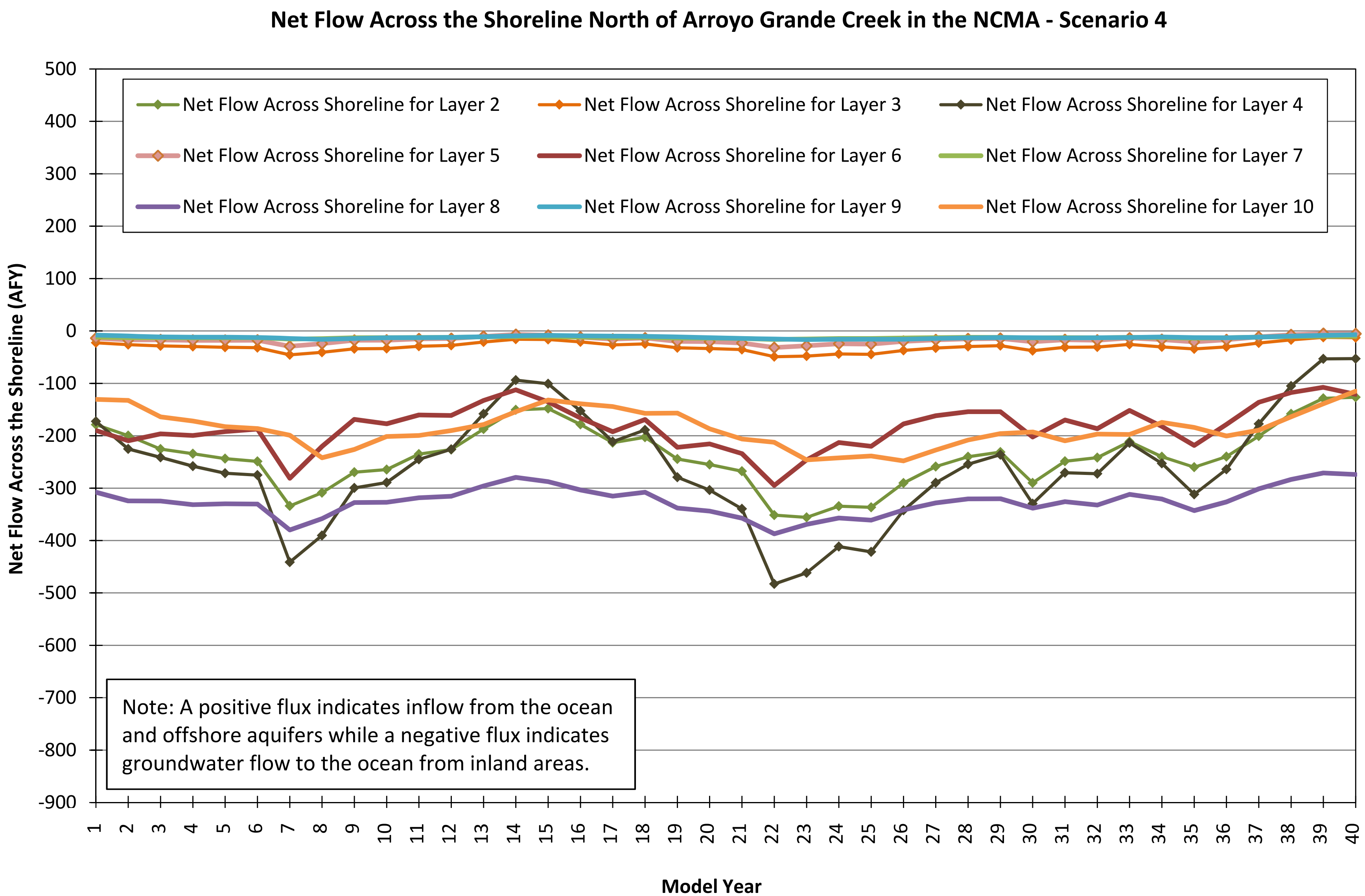

Net Flow Across the Shoreline North of Arroyo Grande Creek in the NCMA - Scenario 4
Net Flow Across Shoreline for Layer 2
Net Flow Across Shoreline for Layer 3
Net Flow Across Shoreline for Layer 4
Net Flow Across Shoreline for Layer 5
Net Flow Across Shoreline for Layer 6
Net Flow Across Shoreline for Layer 7
Net Flow Across Shoreline for Layer 8
Net Flow Across Shoreline for Layer 9
Net Flow Across Shoreline for Layer 10
Net Flow Across the Shoreline (AFY)
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
Model Year
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
Note: A positive flux indicates inflow from the ocean and offshore aquifers while a negative flux indicates groundwater flow to the ocean from inland areas.

Figure 28

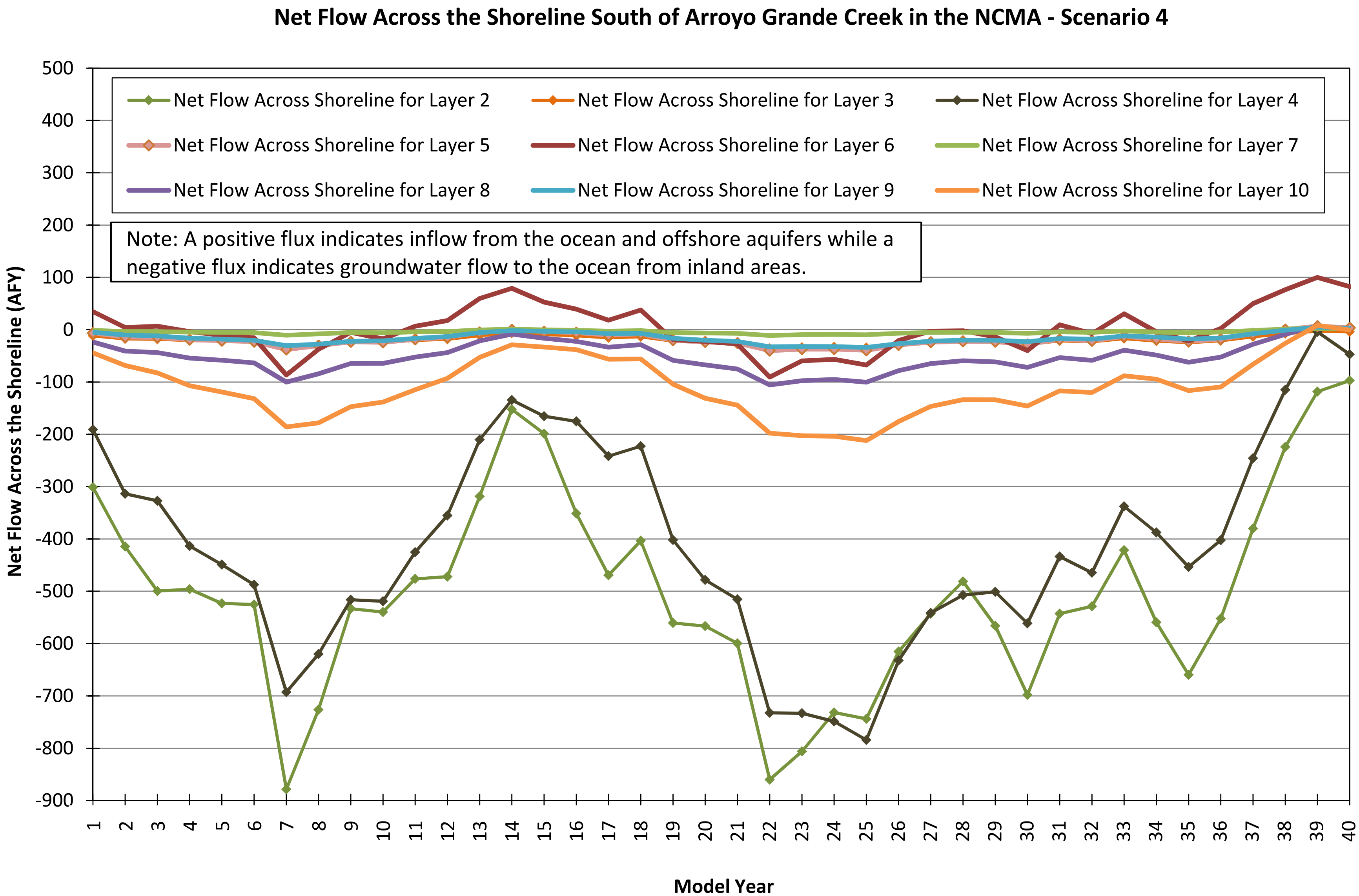
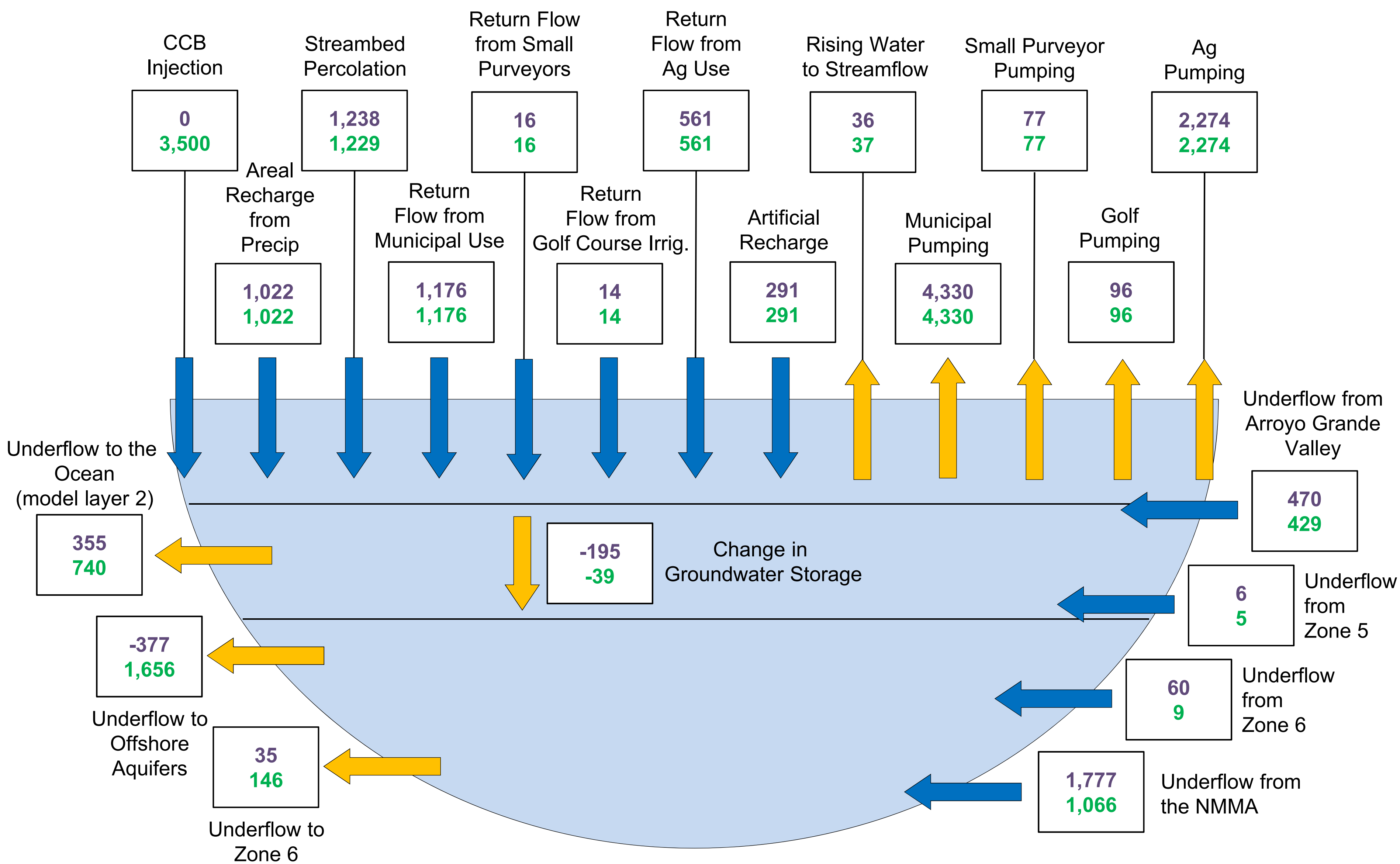

Net Flow Across the Shoreline South of Arroyo Grande Creek in the NCMA - Scenario 4
Net Flow Across Shoreline for Layer 2
Net Flow Across Shoreline for Layer 3
Net Flow Across Shoreline for Layer 4
Net Flow Across Shoreline for Layer 5
Net Flow Across Shoreline for Layer 6
Net Flow Across Shoreline for Layer 7
Net Flow Across Shoreline for Layer 8
Net Flow Across Shoreline for Layer 9
Net Flow Across Shoreline for Layer 10
Note: A positive flux indicates inflow from the ocean and offshore aquifers while a negative flux indicates groundwater flow to the ocean from inland areas.
Net Flow Across the Shoreline (AFY)
Model Year

Figure 29



All values in acre-ft/yr
Scenario 3: NCMA municipal pumping maximum allocation with historical hydrology (1977-2016)
Scenario 4: NCMA municipal pumping of maximum allocation with historical hydrology and CCB Phase 2 injection of 3,500 AFY

0 3,500	Scenario 3 Scenario 4

AVERAGE ANNUAL WATER BUDGETS FOR THE NCMA SCENARIOS 3 & 4

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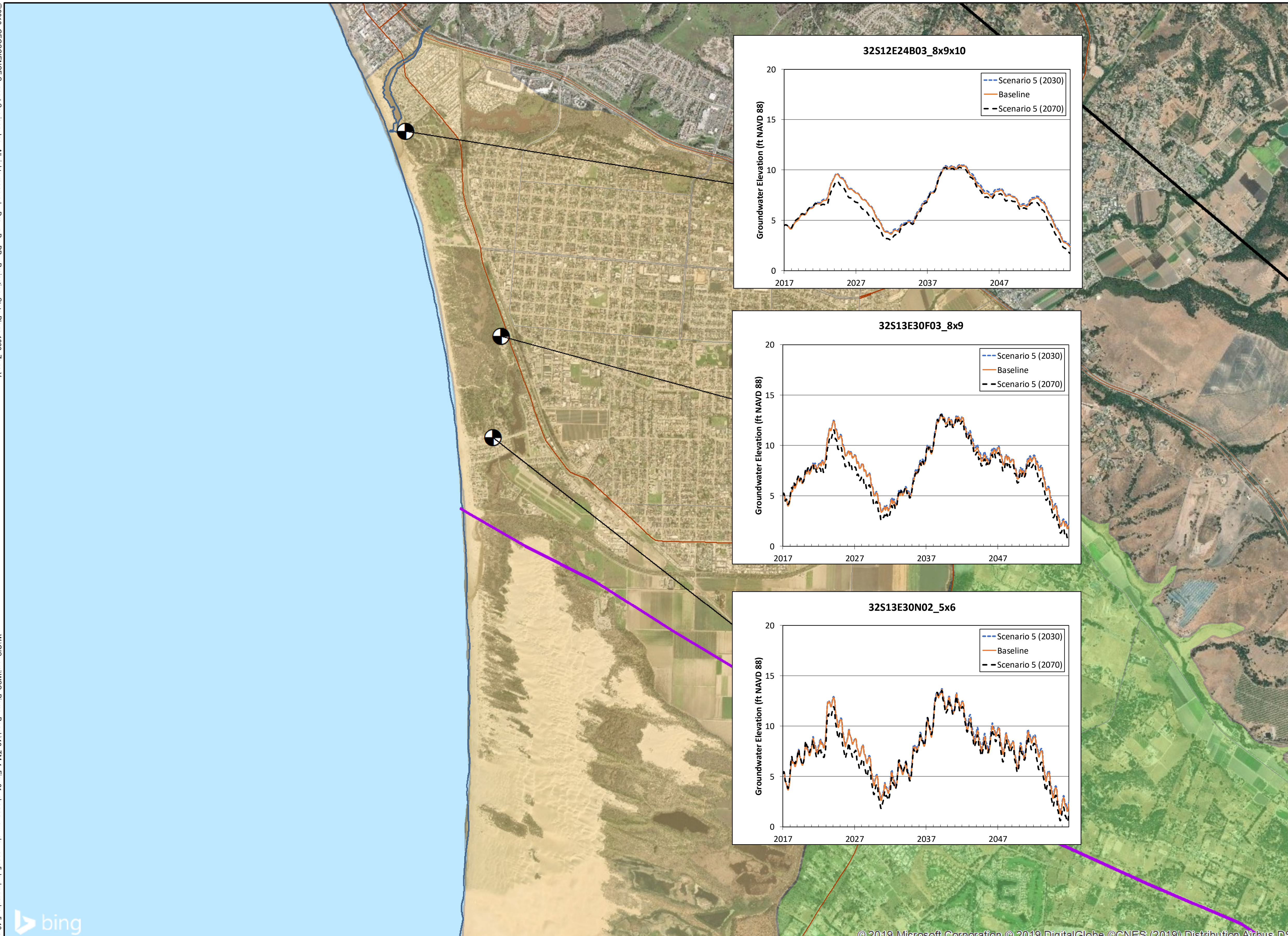

EXPLANATION

CCB Phase 1B Model Boundary

Location of Well Used for Deep Well Index

Management Areas

Nipomo Mesa

Northern Cities

Horizontal Flow Barrier

N

0 3,000 6,000

Feet

CHANGE IN GROUNDWATER ELEVATIONS AFTER MODEL YEAR 40 UNDER 2030 CLIMATE CHANGE CONDITIONS (SCENARIO 5)

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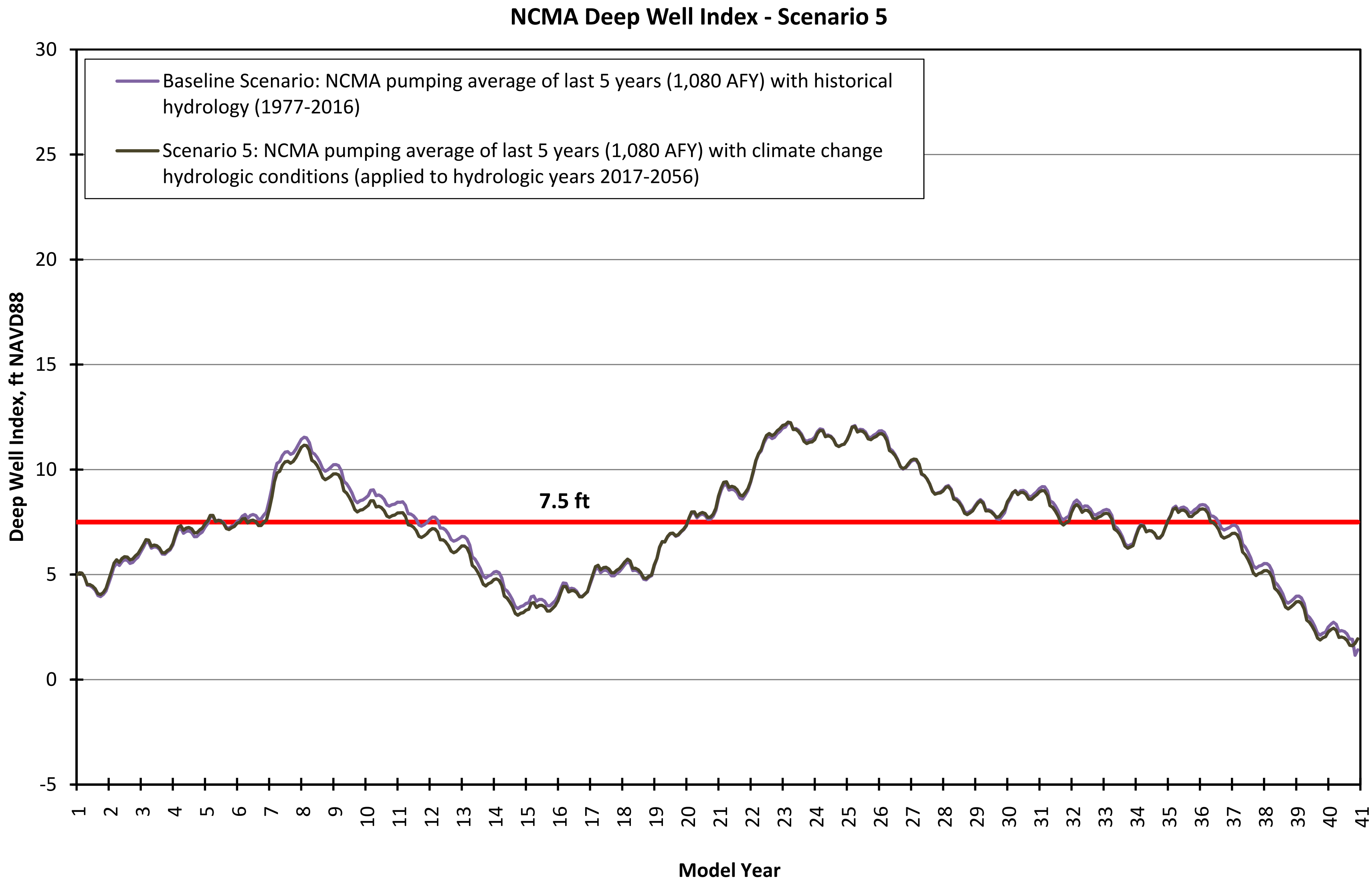
14-May-19


NCMA Deep Well Index - Scenario 5
Baseline Scenario: NCMA pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016)
Scenario 5: NCMA pumping average of last 5 years (1,080 AFY) with climate change hydrologic conditions (applied to hydrologic years 2017-2056)
7.5 ft
Deep Well Index, ft NAVD88
Model Year
30
25
20
15
10
5
0
-5
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
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38
39
40
41

Figure 32

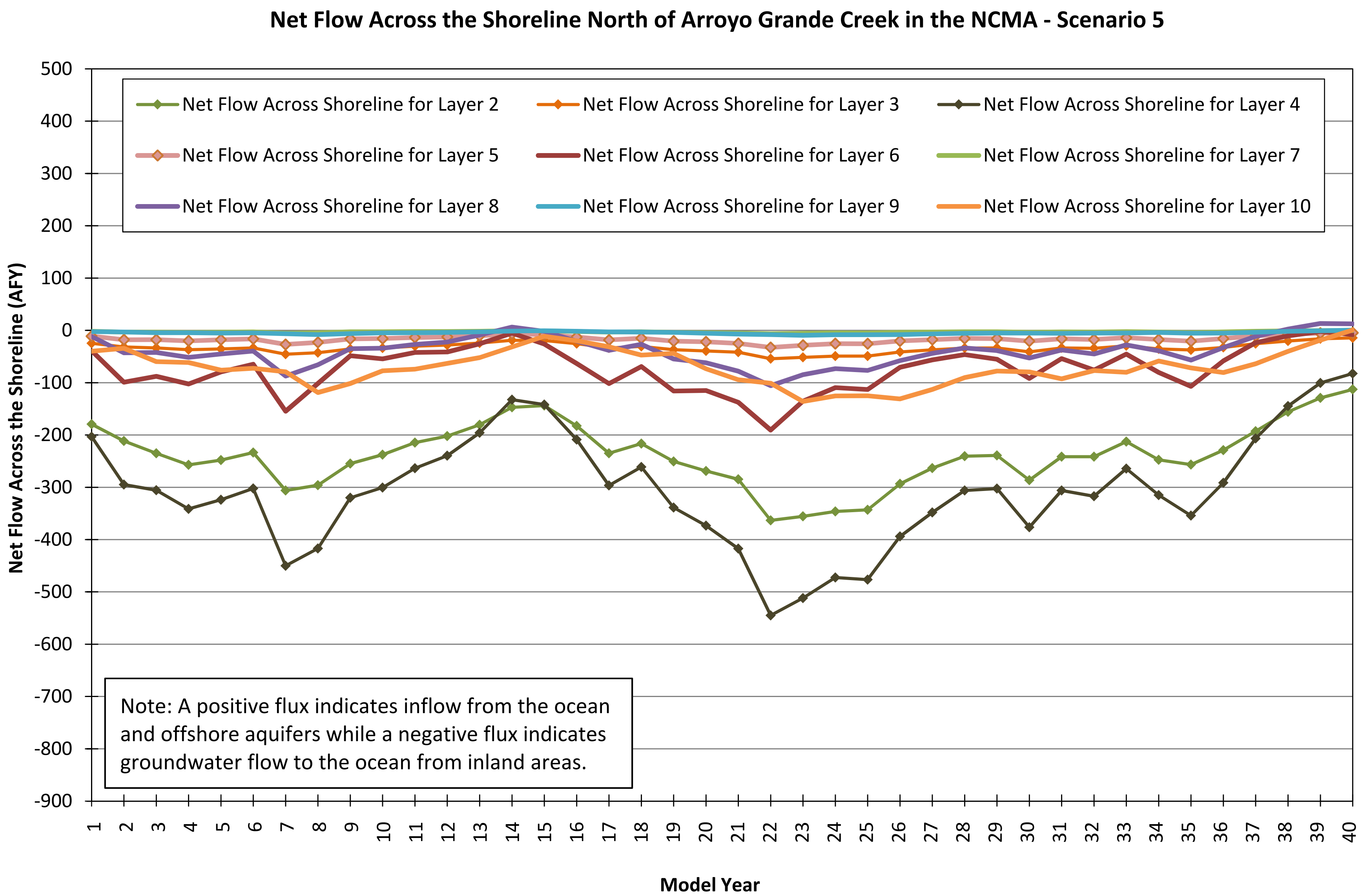

Net Flow Across the Shoreline North of Arroyo Grande Creek in the NCMA - Scenario 5
Net Flow Across Shoreline for Layer 2
Net Flow Across Shoreline for Layer 3
Net Flow Across Shoreline for Layer 4
Net Flow Across Shoreline for Layer 5
Net Flow Across Shoreline for Layer 6
Net Flow Across Shoreline for Layer 7
Net Flow Across Shoreline for Layer 8
Net Flow Across Shoreline for Layer 9
Net Flow Across Shoreline for Layer 10
Net Flow Across the Shoreline (AFY)
Model Year
Note: A positive flux indicates inflow from the ocean and offshore aquifers while a negative flux indicates groundwater flow to the ocean from inland areas.

Figure 33

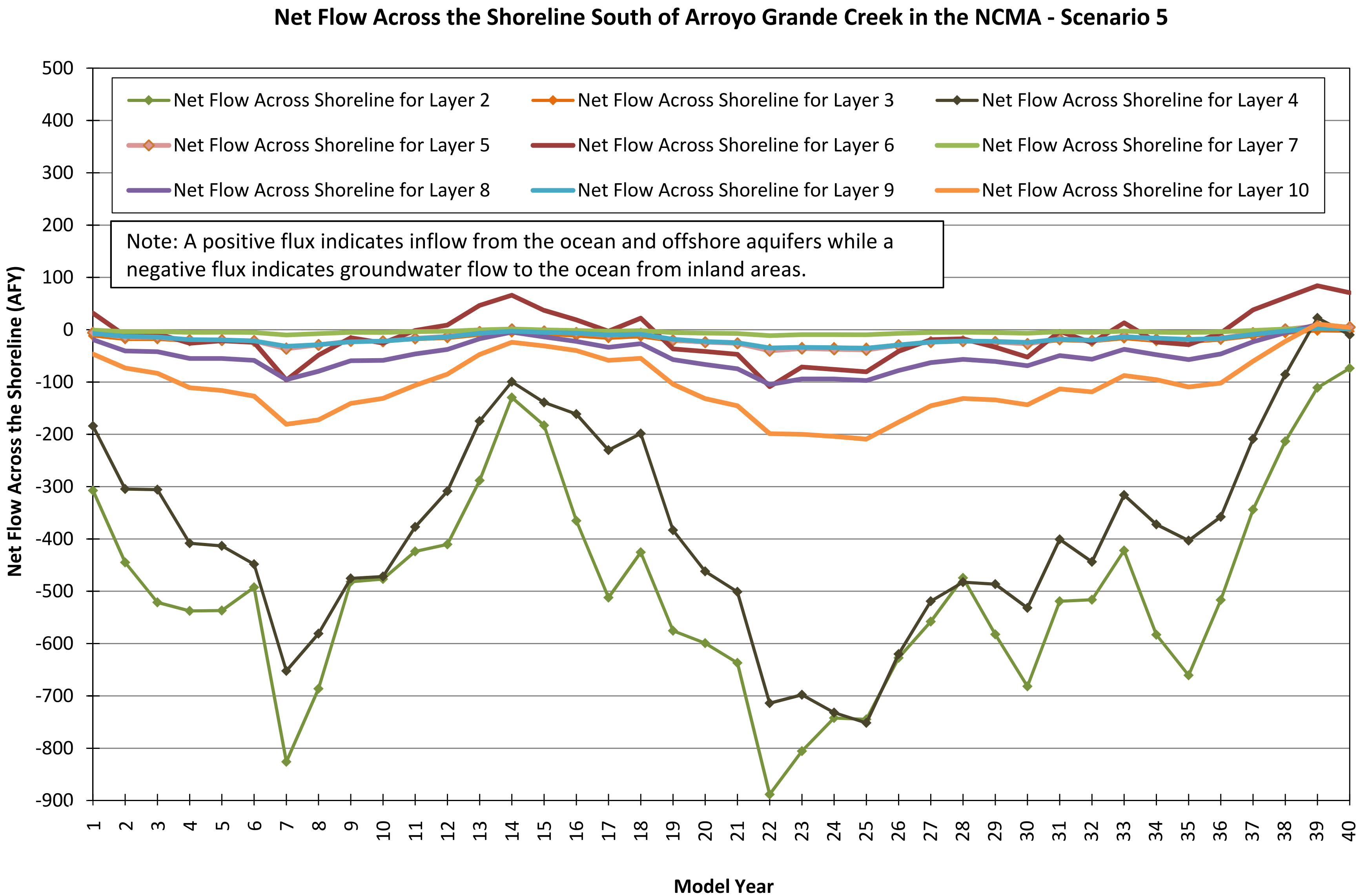
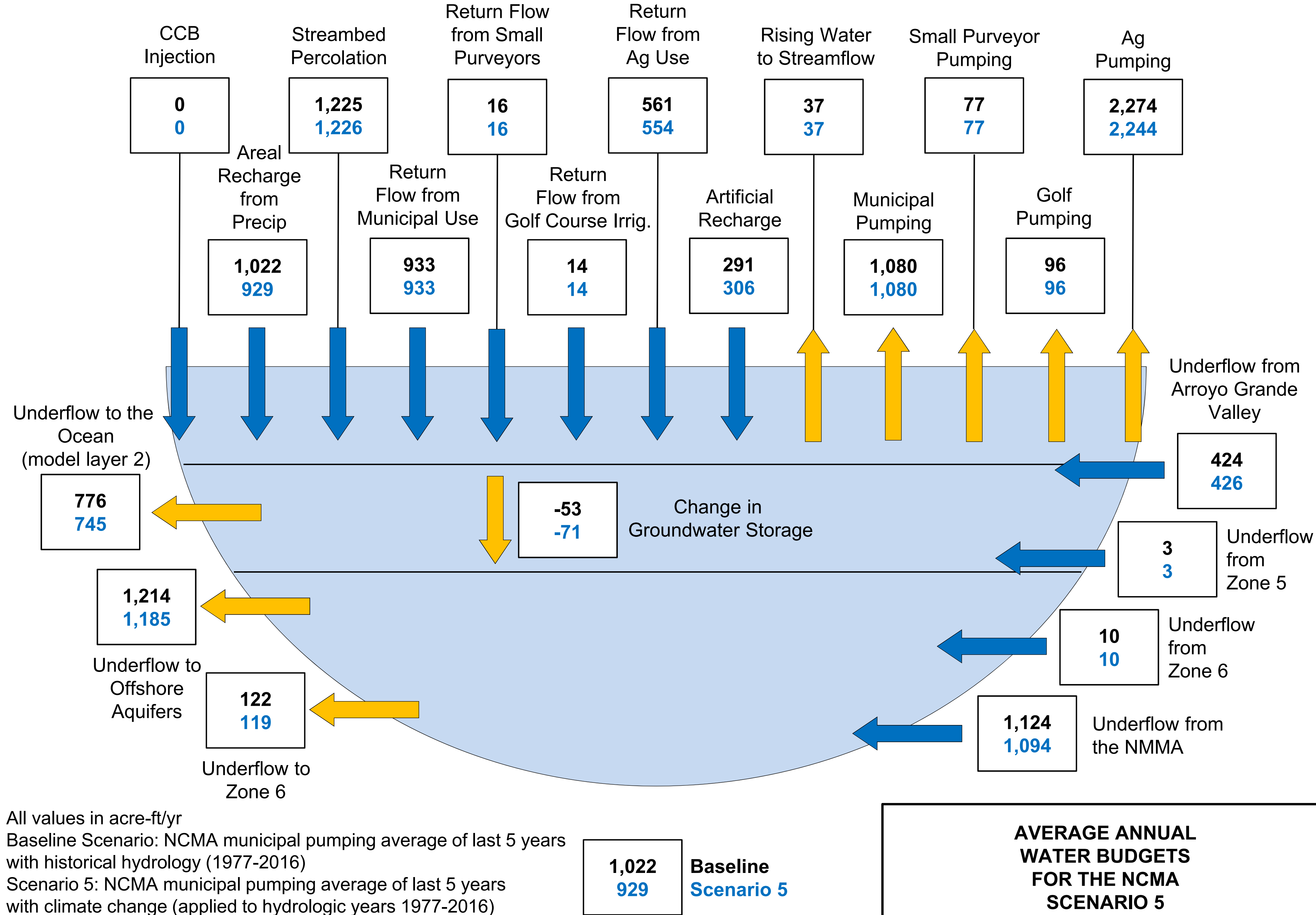

Net Flow Across the Shoreline South of Arroyo Grande Creek in the NCMA - Scenario 5
Net Flow Across Shoreline for Layer 2
Net Flow Across Shoreline for Layer 3
Net Flow Across Shoreline for Layer 4
Net Flow Across Shoreline for Layer 5
Net Flow Across Shoreline for Layer 6
Net Flow Across Shoreline for Layer 7
Net Flow Across Shoreline for Layer 8
Net Flow Across Shoreline for Layer 9
Net Flow Across Shoreline for Layer 10
Note: A positive flux indicates inflow from the ocean and offshore aquifers while a negative flux indicates groundwater flow to the ocean from inland areas.
Net Flow Across the Shoreline (AFY)
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
Model Year

Figure 34



AVERAGE ANNUAL WATER BUDGETS FOR THE NCMA SCENARIO 5

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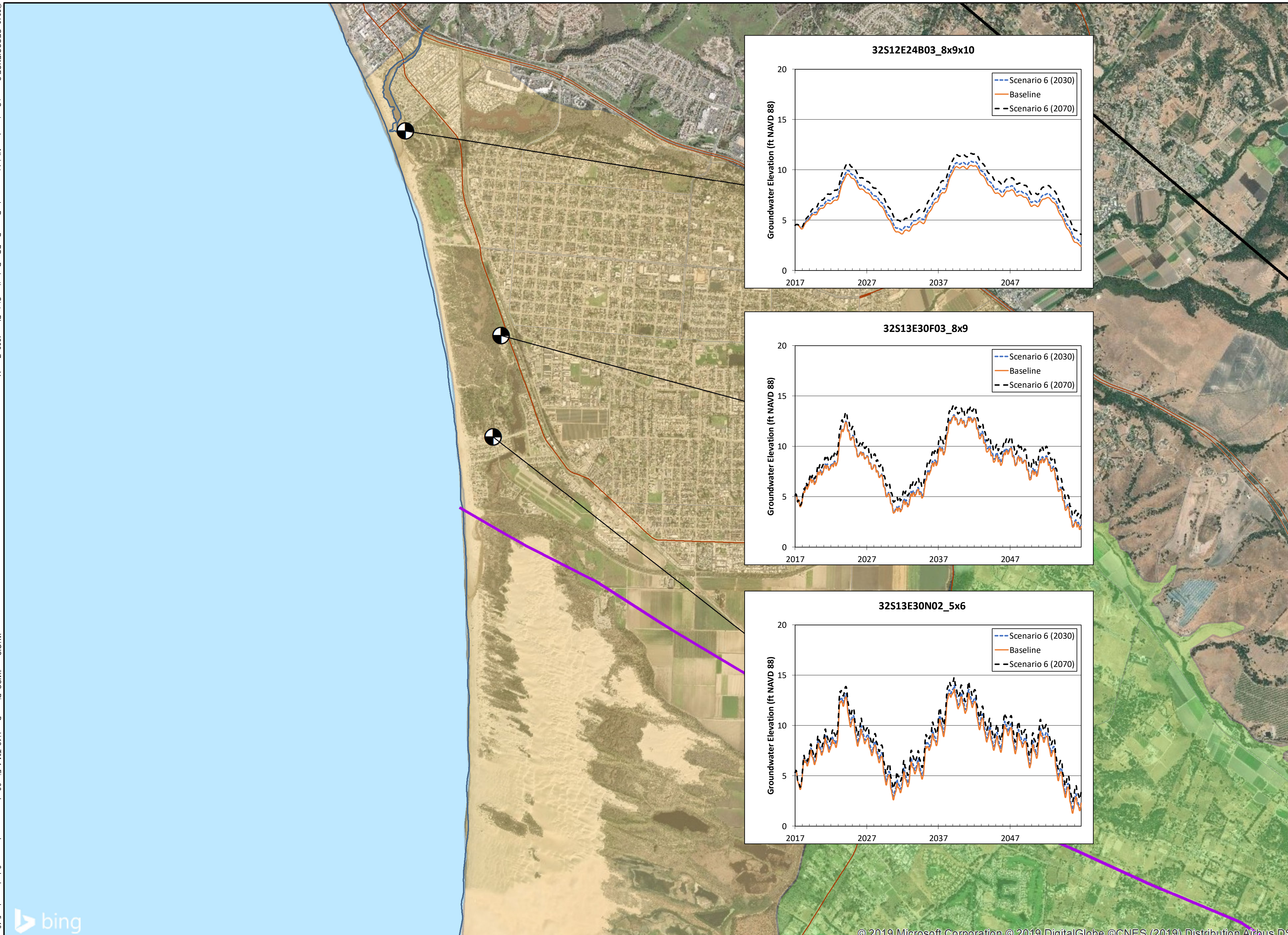


CHANGE IN GROUNDWATER ELEVATIONS AFTER MODEL YEAR 40 UNDER 2040 CLIMATE CHANGE CONDITIONS (SCENARIO 6)

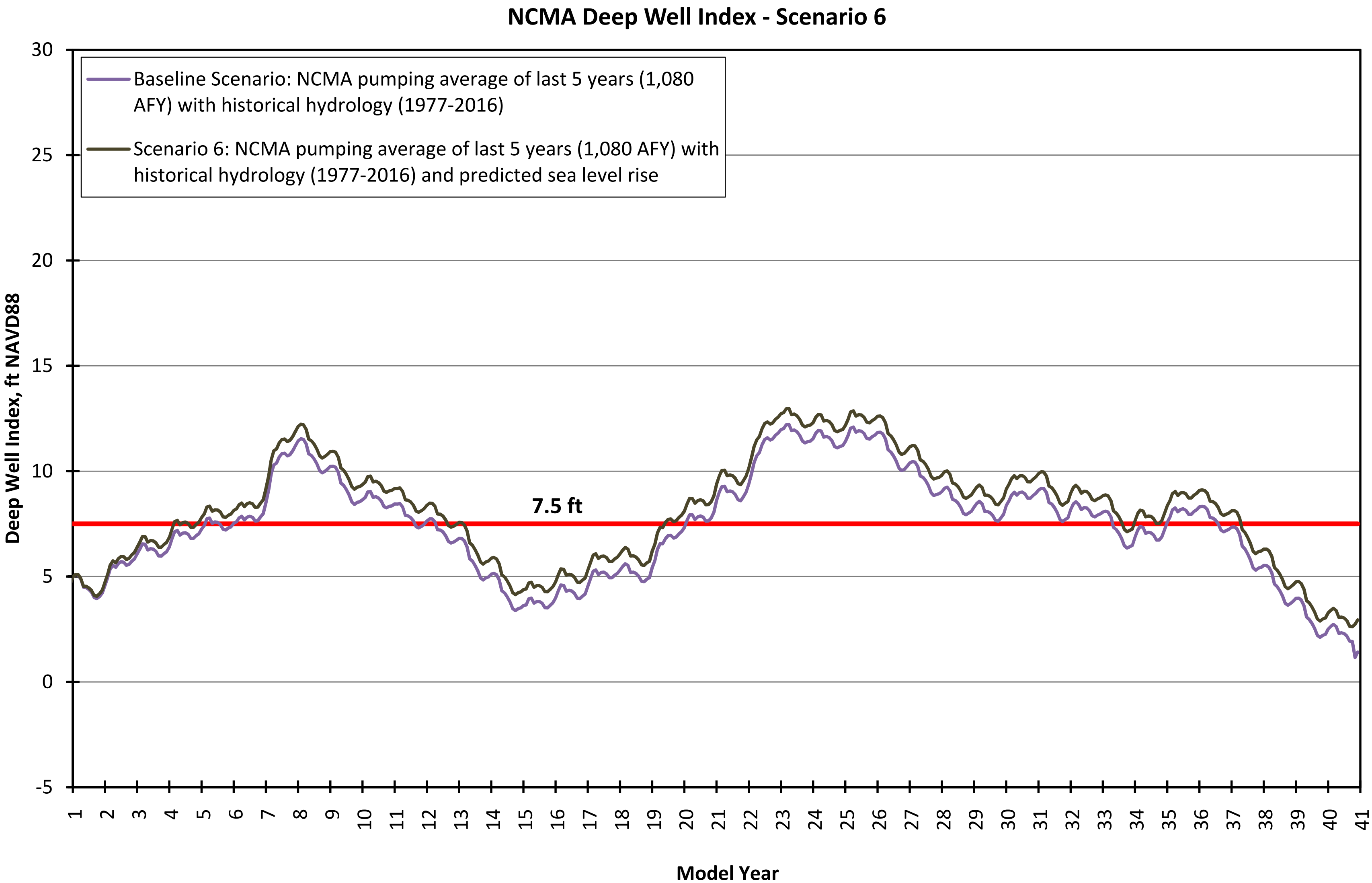
14-May-19

WATER SYSTEMS CONSULTING, INC.

FIGURE 36

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 4: MODEL SCENARIO EVALUATION

GEOSCIENCE


NCMA Deep Well Index - Scenario 6
Baseline Scenario: NCMA pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016)
Scenario 6: NCMA pumping average of last 5 years (1,080 AFY) with historical hydrology (1977-2016) and predicted sea level rise
7.5 ft
Deep Well Index, ft NAVD88
Model Year
30
25
20
15
10
5
0
-5
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
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31
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35
36
37
38
39
40
41

Figure 37

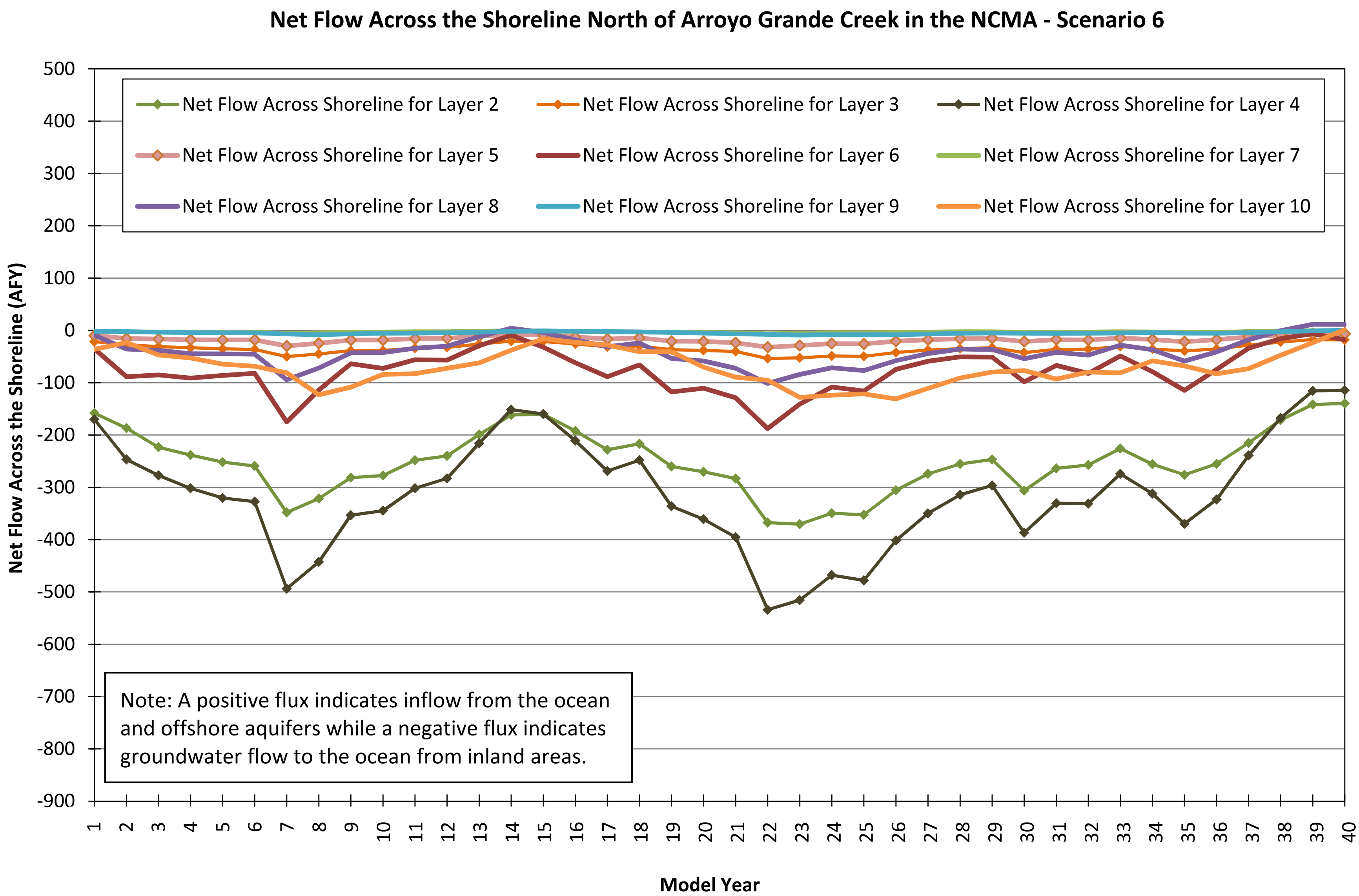

Net Flow Across the Shoreline North of Arroyo Grande Creek in the NCMA - Scenario 6
Net Flow Across Shoreline for Layer 2
Net Flow Across Shoreline for Layer 3
Net Flow Across Shoreline for Layer 4
Net Flow Across Shoreline for Layer 5
Net Flow Across Shoreline for Layer 6
Net Flow Across Shoreline for Layer 7
Net Flow Across Shoreline for Layer 8
Net Flow Across Shoreline for Layer 9
Net Flow Across Shoreline for Layer 10
Net Flow Across the Shoreline (AFY)
Model Year
Note: A positive flux indicates inflow from the ocean and offshore aquifers while a negative flux indicates groundwater flow to the ocean from inland areas.

Figure 38

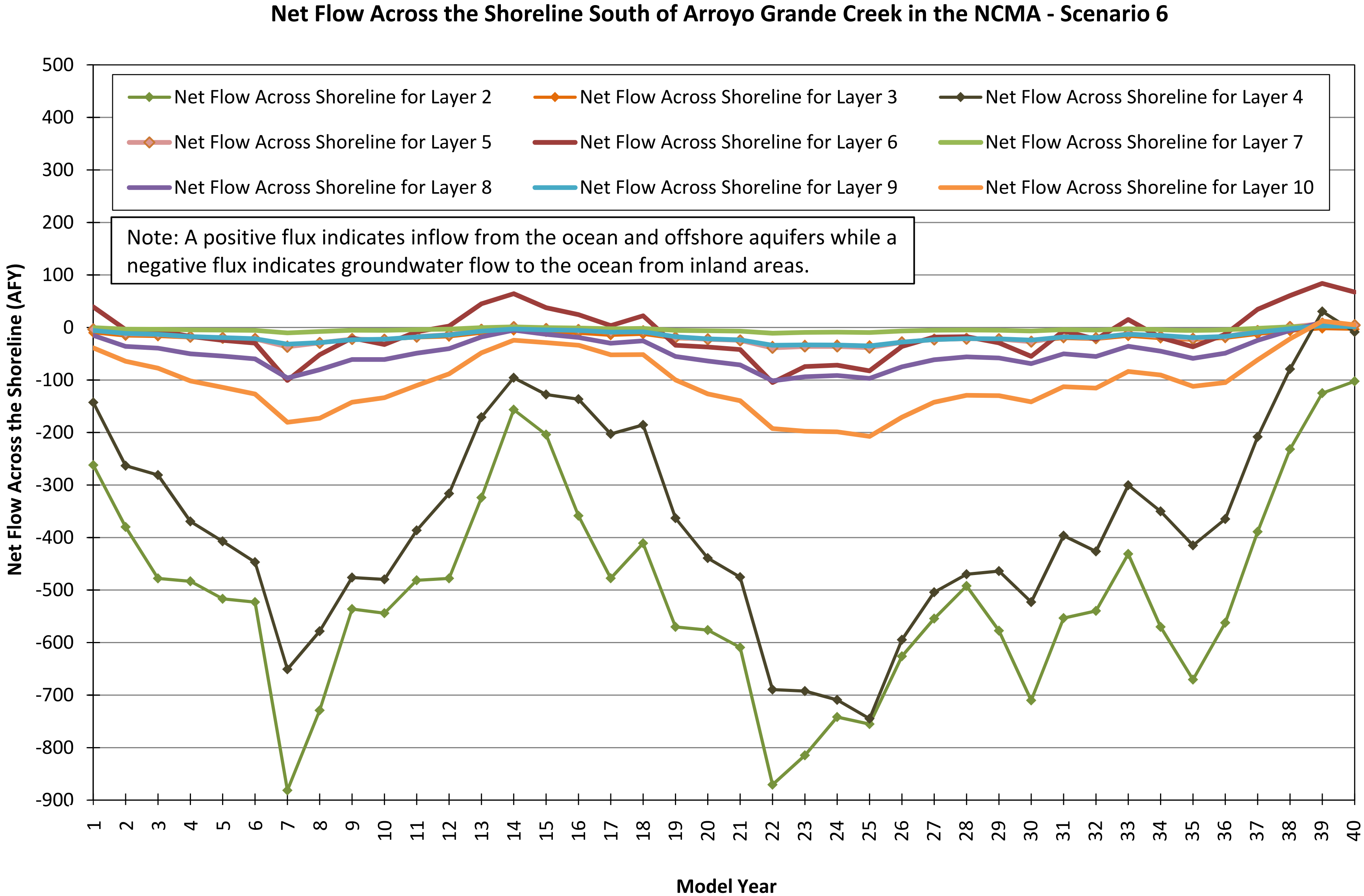
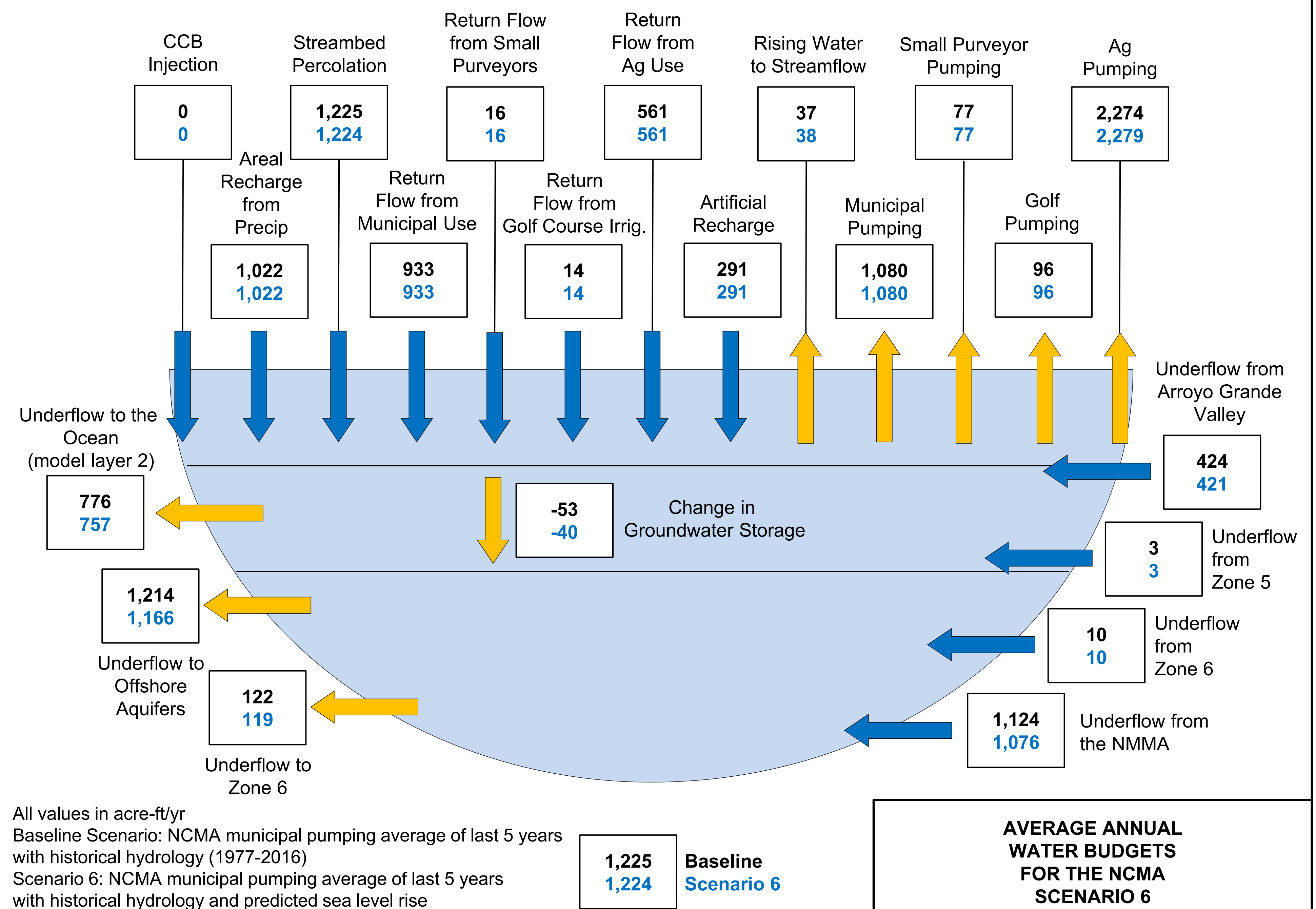

Net Flow Across the Shoreline South of Arroyo Grande Creek in the NCMA - Scenario 6
Net Flow Across Shoreline for Layer 2
Net Flow Across Shoreline for Layer 3
Net Flow Across Shoreline for Layer 4
Net Flow Across Shoreline for Layer 5
Net Flow Across Shoreline for Layer 6
Net Flow Across Shoreline for Layer 7
Net Flow Across Shoreline for Layer 8
Net Flow Across Shoreline for Layer 9
Net Flow Across Shoreline for Layer 10
Note: A positive flux indicates inflow from the ocean and offshore aquifers while a negative flux indicates groundwater flow to the ocean from inland areas.
Net Flow Across the Shoreline (AFY)
Model Year
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40

Figure 39



AVERAGE ANNUAL WATER BUDGETS FOR THE NCMA SCENARIO 6

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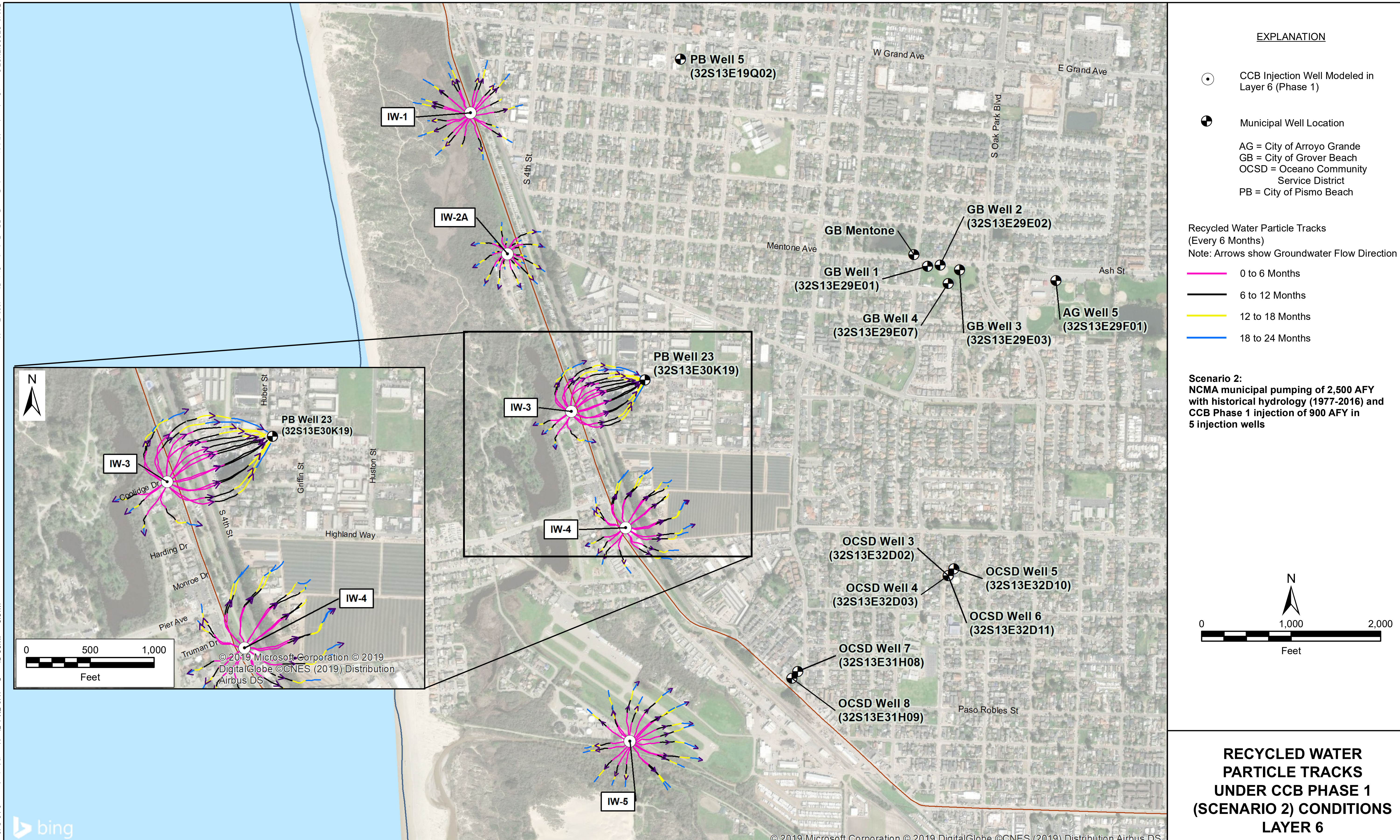

RECYCLED WATER PARTICLE TRACKS UNDER CCB PHASE 1 (SCENARIO 2) CONDITIONS LAYER 6

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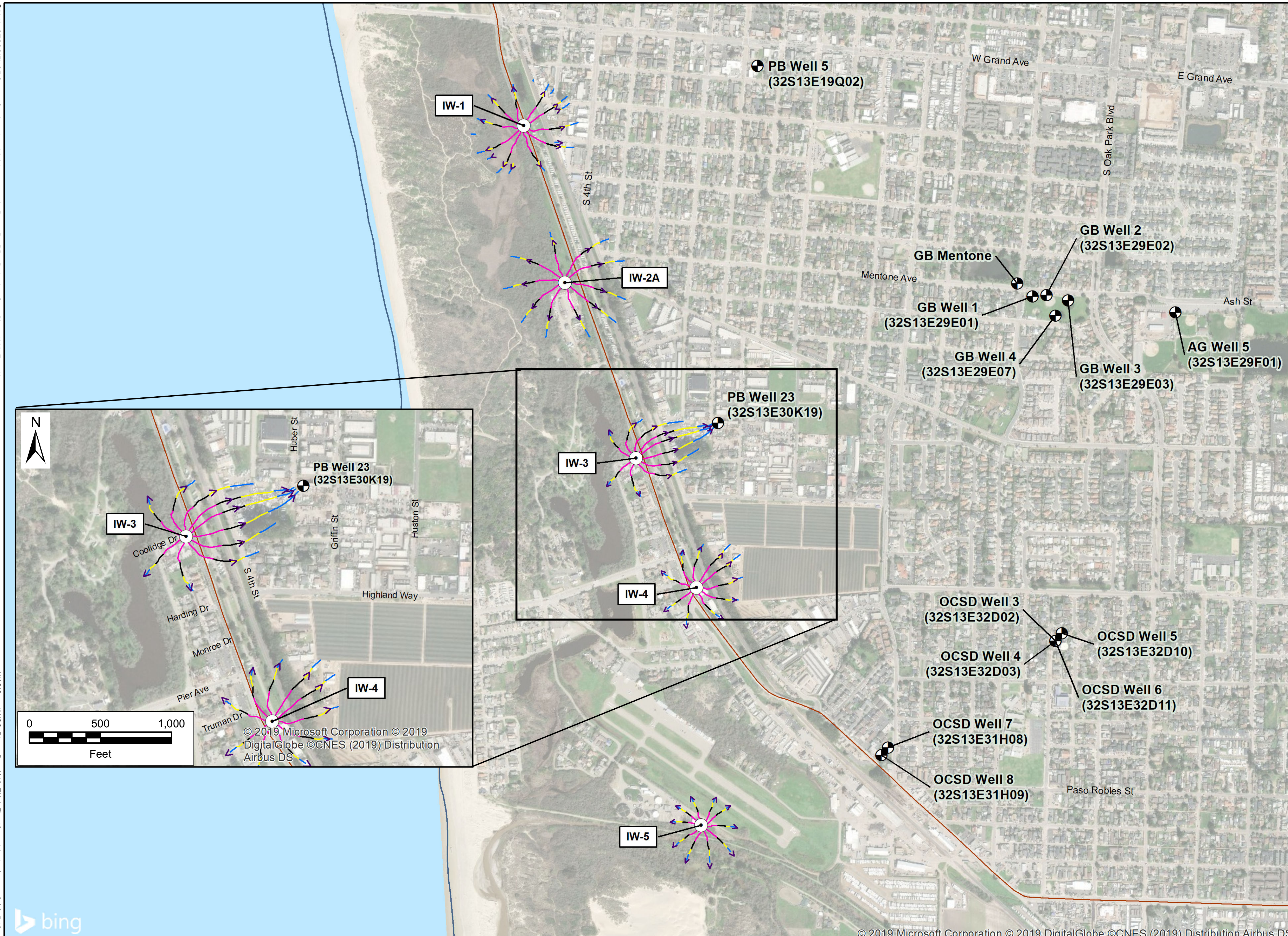
14-May-19

FIGURE 41



EXPLANATION

CCB Injection Well Modeled in Layer 8 (Phase 1)

Municipal Well Location

Recycled Water Particle Tracks
(Every 6 Months)
Note: Arrows show Groundwater Flow Direction

0 to 6 Months

6 to 12 Months

12 to 18 Months

18 to 24 Months

Scenario 2:
NCMA municipal pumping of 2,500 AFY with historical hydrology (1977-2016) and CCB Phase 1 injection of 900 AFY in 5 injection wells

N

0 1,000 2,000

Feet

RECYCLED WATER PARTICLE TRACKS UNDER CCB PHASE 1 (SCENARIO 2) CONDITIONS LAYER 8

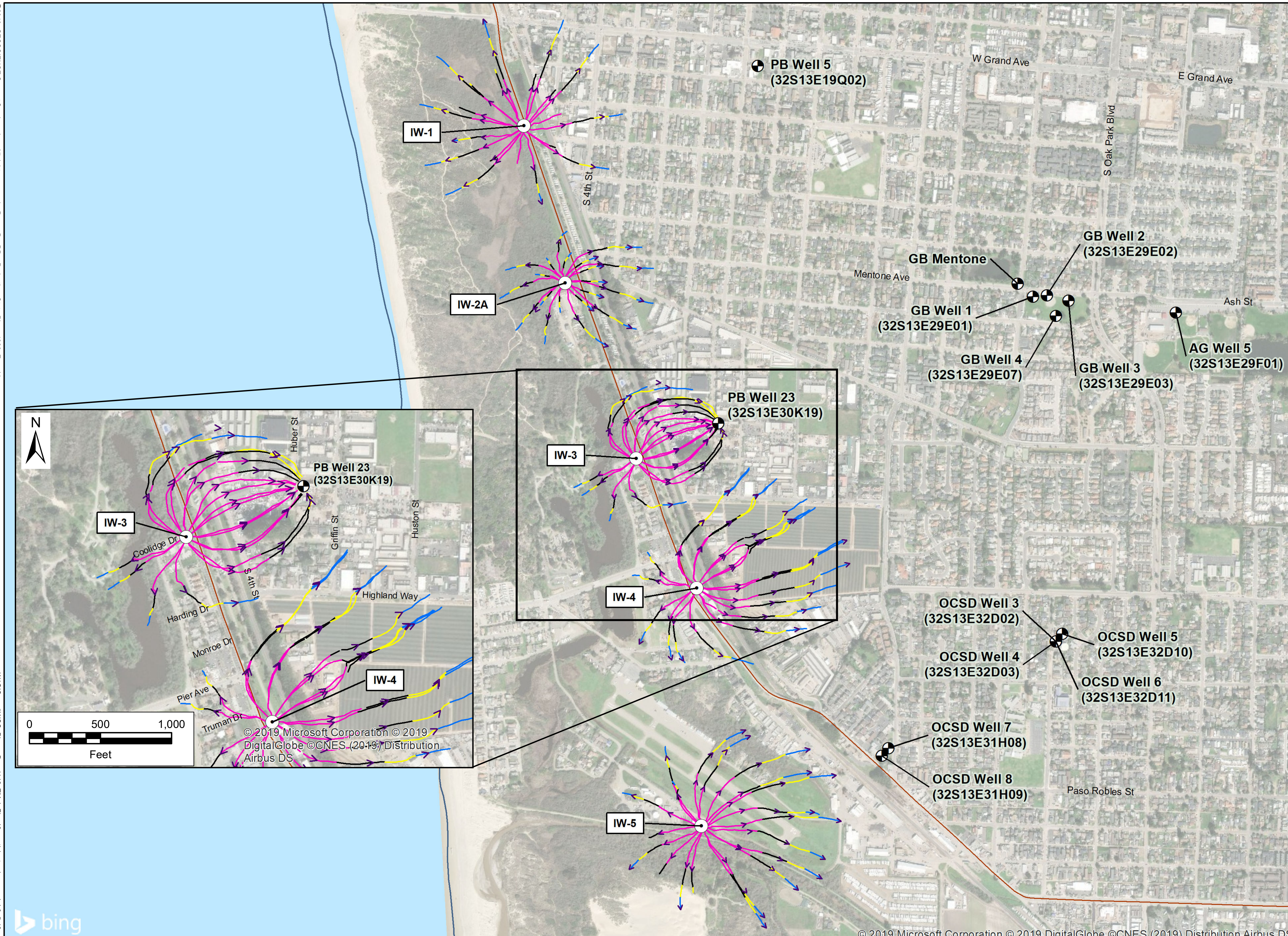
14-May-19

WATER SYSTEMS CONSULTING, INC.

FIGURE 42

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 4: MODEL SCENARIO EVALUATION

GEOSCIENCE



EXPLANATION

CCB Injection Well Modeled in Layer 6 (Phase 2)

Municipal Well Location

Recycled Water Particle Tracks
(Every 6 Months)
Note: Arrows show Groundwater Flow Direction

0 to 6 Months

6 to 12 Months

12 to 18 Months

18 to 24 Months

NOTE: Five Injection Wells in Layers 6-8 and Two Injection Wells in Layer 10

Scenario 4:
NCMA municipal pumping maximum allocation (4,330 AFY) with historical hydrology (1977-2016) and CCB Phase 2 injection of 3,500 AFY in 7 injection wells

N

0 1,000 2,000
Feet

RECYCLED WATER PARTICLE TRACKS UNDER CCB PHASE 2 (SCENARIO 4) CONDITIONS LAYER 6

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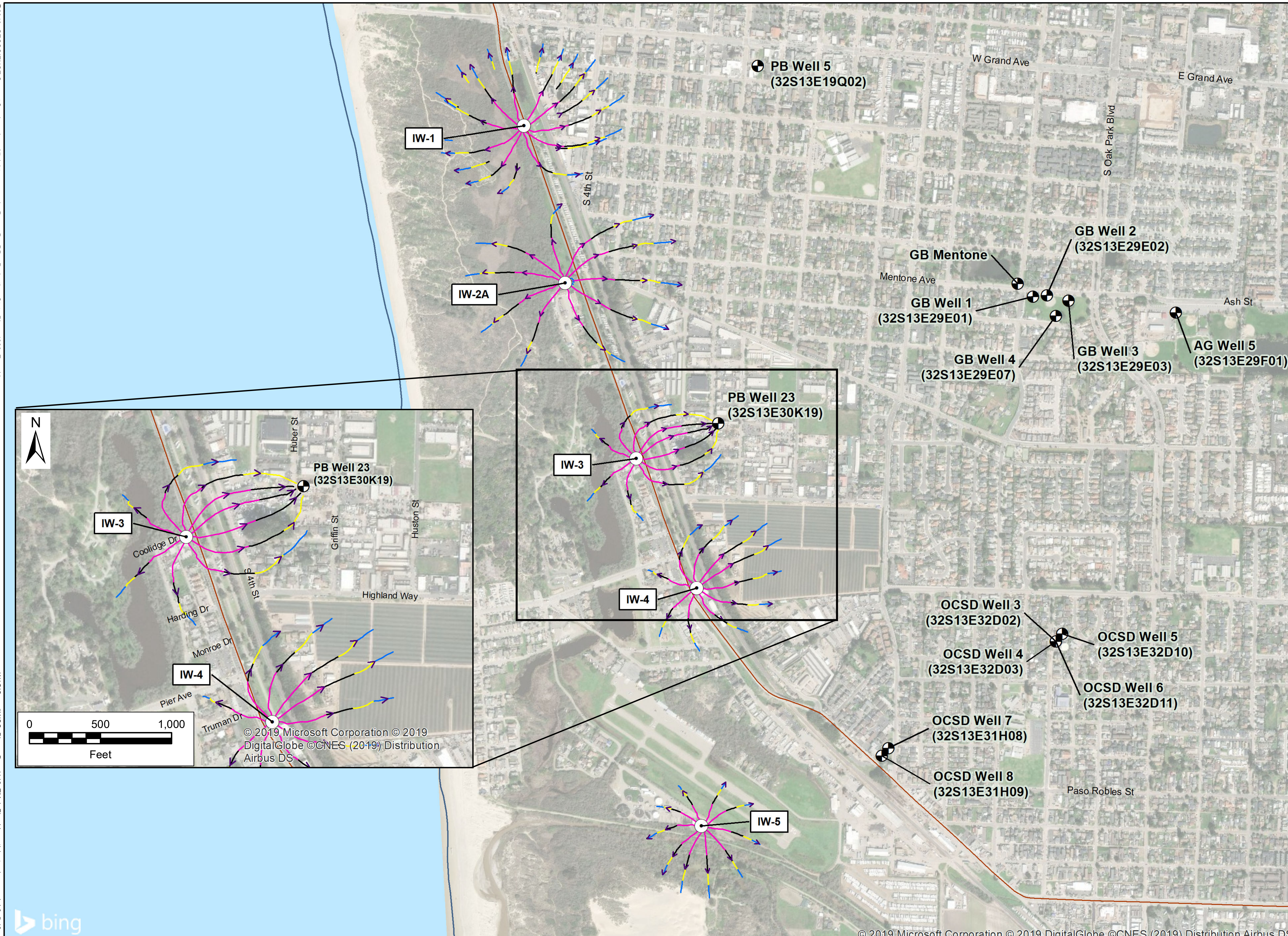
14-May-19



EXPLANATION

CCB Injection Well Modeled in Layer 8 (Phase 2)

Municipal Well Location

Recycled Water Particle Tracks (Every 6 Months)
Note: Arrows show Groundwater Flow Direction

- 0 to 6 Months
- 6 to 12 Months
- 12 to 18 Months
- 18 to 24 Months

NOTE: Five Injection Wells in Layers 6-8 and Two Injection Wells in Layer 10

Scenario 4:
NCMA municipal pumping maximum allocation (4,330 AFY) with historical hydrology (1977-2016) and CCB Phase 2 injection of 3,500 AFY in 7 injection wells

N

0 1,000 2,000
Feet

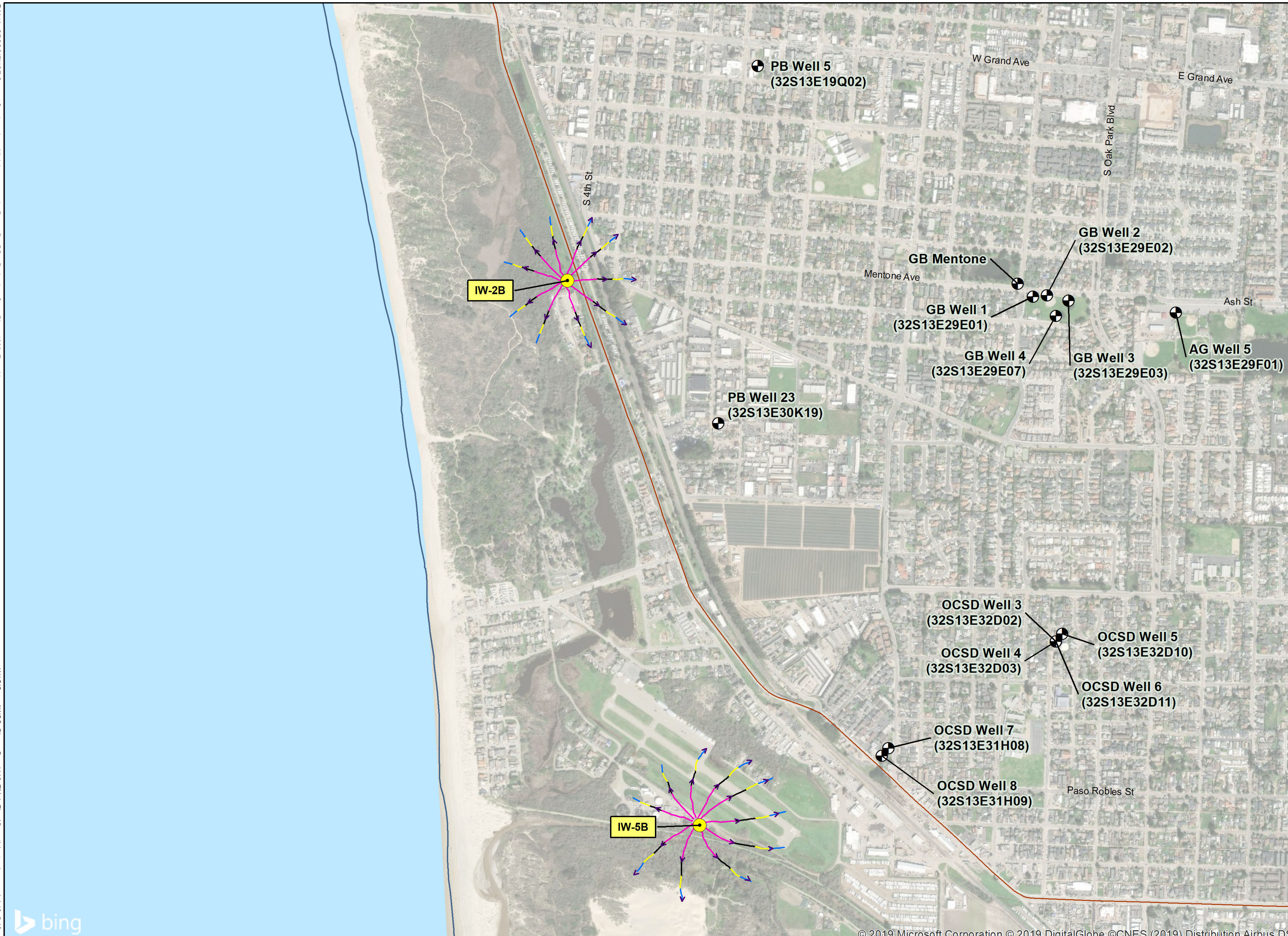
RECYCLED WATER PARTICLE TRACKS UNDER CCB PHASE 2 (SCENARIO 4) CONDITIONS LAYER 8

14-May-19

WATER SYSTEMS CONSULTING, INC.

FIGURE 44

GEOSCIENCE



EXPLANATION

CCB Injection Well Modeled in Layer 10 (Phase 2)

Municipal Well Location

Recycled Water Particle Tracks
(Every 6 Months)
Note: Arrows show Groundwater Flow Direction

- 0 to 6 Months
- 6 to 12 Months
- 12 to 18 Months
- 18 to 24 Months

NOTE: Five Injection Wells in Layers 6-8 and Two Injection Wells in Layer 10

Scenario 4:
NCMA municipal pumping maximum allocation (4,330 AFY) with historical hydrology (1977-2016) and CCB Phase 2 injection of 3,500 AFY in 7 injection wells

N

0 1,000 2,000
Feet

RECYCLED WATER PARTICLE TRACKS UNDER CCB PHASE 2 (SCENARIO 4) CONDITIONS LAYER 10

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14-May-19

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FIGURE 45

CITY OF PISMO BEACH AND SSLOCSD CCB PHASE 1B HYDROGEOLOGIC EVALUATION - TM NO. 4: MODEL SCENARIO EVALUATION

GEOSCIENCE

TABLES

Monthly Municipal Groundwater Pumping Assumptions for Model Scenarios

Month	Monthly Municipal Pumping, AFY						
	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
January	63	123	123	213	213	63	63
February	55	111	111	191	191	55	55
March	78	163	163	282	282	78	78
April	126	323	323	559	559	126	126
May	127	309	309	535	535	127	127
June	112	274	274	475	475	112	112
July	111	267	267	462	462	111	111
August	98	244	244	422	422	98	98
September	96	228	228	395	395	96	96
October	83	194	194	335	335	83	83
November	74	172	172	297	297	74	74
December	57	95	95	164	164	57	57

Table 1

Table 2

NCMA Annual Groundwater Balance - Baseline Scenario

Model Year	Hydrologic Year	INFLOWS [acre-ft]															OUTFLOWS [acre-ft]											
		Areal Recharge from Precip (rch pkg)	Streambed Percolation (model)	Return Flow from Muni Use (rch pkg)	Return Flow from Small Purveyors (rch pkg)	Return Flow from Golf Course Irrig. (rch pkg)	Return Flow from Ag (rch pkg)	Artificial Recharge (wel pkg)	Underflow from NMMA (model)	Underflow from Arroyo Grande Valley (model)	Underflow from Zone 5 (model)	Underflow from Zone 6 (model)	Underflow from Ocean (layer 2) (model)	Underflow from Offshore Aquifers (model)	CCB Injection (wel pkg)	TOTAL INFLOW	Rising Water Discharge to Streamflow (model)	Muni Pumping (wel pkg)	Small Purveyor Pumping (wel pkg)	Golf Pumping (wel pkg)	Ag Pumping (wel pkg)	Underflow to NMMA (model)	Underflow to Zone 5 (model)	Underflow to Zone 6 (model)	Underflow to Ocean (layer 2) (model)	Underflow to Offshore Aquifers (model)	TOTAL OUTFLOW	CHANGE IN STORAGE
1	**1977**	202	844	933	16	15	552	247	1,408	315	122	7	0	136	0	4,796	0	1,080	77	102	2,232	696	125	79	487	674	5,552	-756
2	**1978**	1,265	1,871	933	16	13	392	626	1,245	721	230	9	0	83	0	7,403	117	1,080	77	88	1,585	569	280	100	633	1,034	5,563	1,839
3	**1979**	1,364	975	933	16	14	556	293	1,365	557	254	9	0	66	0	6,402	73	1,080	77	95	2,248	564	238	116	754	1,113	6,358	44
4	**1980**	1,222	1,549	933	16	15	502	350	1,513	614	240	10	0	73	0	7,038	87	1,082	77	102	2,031	500	247	123	766	1,306	6,321	716
5	**1981**	1,370	998	933	16	14	535	322	1,607	558	252	10	0	67	0	6,681	79	1,080	77	92	2,165	445	238	128	804	1,386	6,494	187
6	**1982**	1,295	1,227	933	16	11	411	326	1,650	528	219	11	0	73	0	6,700	48	1,080	77	72	1,662	388	220	129	813	1,464	5,953	747
7	**1983**	3,116	3,123	933	16	12	351	695	1,759	669	238	13	0	58	0	10,981	184	1,080	77	82	1,420	508	256	180	1,252	2,203	7,241	3,740
8	**1984**	284	912	933	16	16	631	145	1,978	349	211	11	0	49	0	5,536	13	1,082	77	107	2,556	517	170	170	1,072	1,924	7,689	-2,153
9	**1985**	252	769	933	16	16	751	150	2,040	284	163	10	0	65	0	5,451	0	1,080	77	110	3,049	465	139	138	838	1,533	7,428	-1,978
10	**1986**	1,411	1,096	933	16	14	544	262	1,900	367	161	11	0	68	0	6,782	0	1,080	77	93	2,198	391	171	132	840	1,516	6,497	285
11	**1987**	588	810	933	16	13	524	216	1,696	420	193	10	0	65	0	5,485	0	1,080	77	88	2,118	437	194	118	747	1,266	6,125	-640
12	**1988**	785	816	933	16	15	548	234	1,542	246	172	10	0	68	0	5,385	1	1,082	77	98	2,216	512	144	111	733	1,109	6,083	-698
13	**1989**	2	685	933	16	17	778	94	1,575	336	147	8	3	138	0	4,733	0	1,080	77	116	3,172	722	143	88	542	767	6,707	-1,973
14	**1990**	68	697	933	16	16	756	137	1,551	167	113	7	29	211	0	4,702	0	1,080	77	108	3,072	760	87	66	364	556	6,169	-1,468
15	**1991**	946	1,071	933	16	14	419	389	1,252	396	142	7	9	130	0	5,726	0	1,080	77	94	1,695	609	171	66	390	574	4,758	969
16	**1992**	1,442	988	933	16	14	474	321	1,173	412	183	8	0	120	0	6,086	8	1,082	77	95	1,919	733	191	85	562	715	5,467	619
17	**1993**	1,883	1,177	933	16	14	466	431	1,164	406	177	9	0	79	0	6,755	2	1,080	77	94	1,886	643	184	103	715	915	5,699	1,056
18	**1994**	917	789	933	16	13	542	177	1,285	421	209	9	0	100	0	5,412	10	1,080	77	90	2,192	705	200	99	638	846	5,936	-524
19	**1995**	2,221	2,380	933	16	13	430	532	1,312	447	182	10	0	62	0	8,538	25	1,080	77	91	1,740	533	201	126	839	1,340	6,052	2,485
20	**1996**	1,301	1,830	933	16	13	393	369	1,461	397	212	10	0	55	0	6,991	47	1,082	77	86	1,593	456	194	138	858	1,514	6,046	945
21	**1997**	1,082	2,617	933	16	16	520	320	1,427	242	135	11	0	48	0	7,365	0	1,080	77	104	2,100	555	130	148	904	1,669	6,768	597
22	**1998**	2,503	3,171	933	16	12	427	585	1,758	390	173	13	0	48	0	10,029	80	1,080	77	79	1,727	489	180	191	1,246	2,328	7,478	2,551
23	**1999**	1,065	1,045	933	16	14	556	284	2,117	354	166	13	0	55	0	6,618	4	1,080	77	95	2,250	476	153	192	1,195	2,242	7,765	-1,147
24	**2000**	1,160	1,125	933	16	14	555	320	2,350	583	219	12	0	73	0	7,361	81	1,082	77	96	2,244	403	229	175	1,102	2,165	7,655	-294
25	**2001**	1,542	1,410	933	16	13	503	465	2,358	682	252	12	0	76	0	8,263	149	1,080	77	89	2,032	373	258	177	1,118	2,256	7,610	653
26	**2002**	465	853	933	16	16	658	164	2,196	540	247	11	0	71	0	6,170	75	1,080	77	105	2,667	440	226	155	943	1,827	7,594	-1,424
27	**2003**	297	832	933	16	15	630	124	2,080	338	193	11	0	80	0	5,549	2	1,080	77	100	2,554	463	170	134	839	1,560	6,979	-1,430
28	**2004**	654	953	933	16	14	560	193	2,008	302	152	10	0	88	0	5,883	0	1,082	77	93	2,269	395	142	122	759	1,429	6,368	-485
29	**2005**	1,398	879	933	16	13	550	189	2,082	679	227	11	0	87	0	7,065	90	1,080	77	89	2,225	415	255	115	833	1,409	6,588	476
30	**2006**	2,149	931	933	16	12	507	446	1,965	678	264	11	0	70	0	7,983	130	1,080	77	81	2,050	388	267	145	1,024	1,681	6,923	1,061
31	**2007**	235	889	933	16	16	761	131	1,943	575	255	10	0	77	0	5,840	80	1,080	77	108	3,094	573	237	129	826	1,347	7,550	-1,709
32	**2008**	985	1,698	933	16	16	557	285	1,778	276	181	10	0	68	0	6,803	5	1,082	77	107	2,253	472	158	126	807	1,408	6,496	307
33	**2009**	176	900	933	16	16	733	161	1,756	308	151	9	0	89	0	5,248	0	1,080	77	105	2,973	603	137	109	668	1,071	6,823	-1,574
34	**2010**	2,184	1,422	933	16	12	418	609	1,563	459	182	10	0	65	0	7,875	19	1,080	77	82	1,694	477	203	117	834	1,222	5,805	2,070
35	**2011**	1,258	1,751	933	16	14	556	223	1,582	574	224	11	0	54	0	7,195	92	1,080	77	92	2,249	529	233	136	954	1,477	6,920	275
36	**2012**	477	667	933	16	14	557	169	1,653	308	186	10	0	56	0	5,045	0	1,082	77	93	2,256	494	153	125	827	1,279	6,386	-1,341
37	**2013**	32	834	933	16	18	790	88	1,697	251	143	9	1	129	0	4,941	0	1,080	77	118	3,227	742	123	97	616	877	6,957	-2,016
38	**2014**	151	863	933	16	15	740	124	1,528	207	122	8	13	205	0	4,924	0	1,080	77	98	3,002	820	106	71	429	571	6,254	-1,330
39	**2015**	0	683	933	16	16	773	115	1,417	262	113	7	45	318	0	4,699	0	1,080	77	111	3,145	972	110	52	325	373	6,245	-1,545
40	**2016**	1,145	887	933	16	13	548	309	1,208	327	130	6	31	226	0	5,779	0	1,082	77	87	2,216	739	146	51	288	352	5,038	741
Average		**1,022**	**1,225**	**933**	**16**	**14**	**561**	**291**	**1,674**	**424**	**188**	**10**	**3**	**94**	**0**	**6,455**	**37**	**1,080**	**77**	**96**	**2,274**	**549**	**185**	**122**	**780**	**1,307**	**6,508**	**-53**

Table 3

NCMA Annual Groundwater Balance - Scenario 1

		INFLOWS [acre-ft]															OUTFLOWS [acre-ft]											
Model Year	Hydrologic Year	Areal Recharge from Precip (rch pkg)	Streambed Percolation (model)	Return Flow from Muni Use (rch pkg)	Return Flow from Small Purveyors (rch pkg)	Return Flow from Golf Course Irrig. (rch pkg)	Return Flow from Ag (rch pkg)	Artificial Recharge (wel pkg)	Underflow from NMMA (model)	Underflow from Arroyo Grande Valley (model)	Underflow from Zone 5 (model)	Underflow from Zone 6 (model)	Underflow from Ocean (layer 2) (model)	Underflow from Offshore Aquifers (model)	CCB Injection (wel pkg)	TOTAL INFLOW	Rising Water Discharge to Streamflow (model)	Muni Pumping (wel pkg)	Small Purveyor Pumping (wel pkg)	Golf Pumping (wel pkg)	Ag Pumping (wel pkg)	Underflow to NMMA (model)	Underflow to Zone 5 (model)	Underflow to Zone 6 (model)	Underflow to Ocean (layer 2) (model)	Underflow to Offshore Aquifers (model)	TOTAL OUTFLOW	CHANGE IN STORAGE
1	**1977**	202	844	1,141	16	15	552	247	1,475	312	125	9	0	311	0	5,251	0	2,500	77	102	2,232	671	124	64	493	574	6,837	-1,586
2	**1978**	1,265	1,871	1,141	16	13	392	626	1,403	726	233	14	0	271	0	7,971	116	2,500	77	88	1,585	536	279	69	608	782	6,640	1,331
3	**1979**	1,364	974	1,141	16	14	556	293	1,565	568	257	11	0	265	0	7,026	72	2,500	77	95	2,248	528	239	73	689	790	7,311	-285
4	**1980**	1,222	1,549	1,141	16	15	502	350	1,757	627	244	11	0	285	0	7,721	86	2,504	77	102	2,031	480	249	74	669	944	7,217	504
5	**1981**	1,370	997	1,141	16	14	535	322	1,872	573	258	9	0	284	0	7,391	78	2,500	77	92	2,165	431	241	75	685	999	7,343	48
6	**1982**	1,295	1,227	1,141	16	11	411	326	1,932	544	226	10	0	300	0	7,437	47	2,500	77	72	1,662	381	224	74	677	1,066	6,780	657
7	**1983**	3,116	3,228	1,141	16	12	351	695	1,998	686	244	11	0	210	0	11,706	181	2,500	77	82	1,420	466	261	123	1,096	1,729	7,934	3,772
8	**1984**	284	912	1,141	16	16	631	145	2,235	366	219	9	0	199	0	6,174	13	2,504	77	107	2,556	483	176	113	917	1,437	8,383	-2,208
9	**1985**	252	769	1,141	16	16	751	150	2,318	301	171	8	0	285	0	6,179	0	2,500	77	110	3,049	451	145	81	683	1,105	8,199	-2,020
10	**1986**	1,411	1,096	1,141	16	14	544	262	2,188	385	169	9	0	301	0	7,537	0	2,500	77	93	2,198	383	177	74	677	1,093	7,272	265
11	**1987**	588	811	1,141	16	13	524	216	1,977	438	199	10	0	323	0	6,256	0	2,500	77	88	2,118	422	199	61	583	862	6,910	-654
12	**1988**	785	817	1,141	16	15	548	234	1,806	263	179	13	0	338	0	6,155	1	2,504	77	98	2,216	476	149	57	566	713	6,858	-703
13	**1989**	2	685	1,141	16	17	778	94	1,811	352	153	21	26	481	0	5,576	0	2,500	77	116	3,172	671	148	43	402	439	7,568	-1,992
14	**1990**	68	697	1,141	16	16	756	137	1,791	180	120	33	91	646	0	5,693	0	2,500	77	108	3,072	717	91	35	267	311	7,177	-1,484
15	**1991**	946	1,071	1,141	16	14	419	389	1,508	412	147	37	51	563	0	6,714	0	2,500	77	94	1,695	572	175	38	266	327	5,745	969
16	**1992**	1,442	989	1,141	16	14	474	321	1,393	430	188	29	4	471	0	6,913	8	2,504	77	95	1,919	658	194	48	394	388	6,285	628
17	**1993**	1,883	1,177	1,141	16	14	466	431	1,389	423	183	24	0	374	0	7,523	2	2,500	77	94	1,886	570	188	61	539	540	6,456	1,067
18	**1994**	917	789	1,141	16	13	542	177	1,512	438	214	21	1	415	0	6,198	9	2,500	77	90	2,192	637	203	54	466	483	6,711	-513
19	**1995**	2,221	2,394	1,141	16	13	430	532	1,553	466	188	17	0	294	0	9,267	24	2,500	77	91	1,740	485	206	75	657	906	6,762	2,504
20	**1996**	1,301	1,832	1,141	16	13	393	369	1,718	416	219	9	0	263	0	7,690	46	2,504	77	86	1,593	418	199	79	674	1,052	6,729	961
21	**1997**	1,082	2,664	1,141	16	16	520	320	1,648	260	142	9	0	206	0	8,024	0	2,500	77	104	2,100	495	136	89	721	1,167	7,390	634
22	**1998**	2,503	3,275	1,141	16	12	427	585	1,981	408	179	11	0	195	0	10,733	79	2,500	77	79	1,727	442	187	134	1,060	1,840	8,125	2,608
23	**1999**	1,065	1,045	1,141	16	14	556	284	2,363	372	176	11	0	198	0	7,242	3	2,500	77	95	2,250	442	160	134	1,015	1,735	8,413	-1,172
24	**2000**	1,160	1,125	1,141	16	14	555	320	2,621	602	228	10	0	246	0	8,039	79	2,504	77	96	2,244	388	237	116	919	1,673	8,334	-294
25	**2001**	1,542	1,411	1,141	16	13	503	465	2,634	702	261	10	0	247	0	8,945	148	2,500	77	89	2,032	362	265	117	931	1,762	8,284	662
26	**2002**	465	853	1,141	16	16	658	164	2,464	559	255	9	0	268	0	6,868	73	2,500	77	105	2,667	421	232	94	759	1,348	8,276	-1,407
27	**2003**	297	832	1,141	16	15	630	124	2,354	356	202	8	0	313	0	6,289	1	2,500	77	100	2,554	448	176	74	655	1,112	7,697	-1,408
28	**2004**	654	953	1,141	16	14	560	193	2,301	320	161	9	1	356	0	6,678	0	2,504	77	93	2,269	396	148	62	576	1,013	7,138	-460
29	**2005**	1,398	879	1,141	16	13	550	189	2,366	699	234	10	1	365	0	7,862	89	2,500	77	89	2,225	406	262	56	649	1,004	7,357	505
30	**2006**	2,149	931	1,141	16	12	507	446	2,238	698	272	9	0	289	0	8,709	128	2,500	77	81	2,050	371	273	85	834	1,231	7,630	1,079
31	**2007**	235	889	1,141	16	16	761	131	2,193	593	262	8	1	316	0	6,562	78	2,500	77	108	3,094	534	242	69	646	905	8,253	-1,691
32	**2008**	985	1,703	1,141	16	16	557	285	2,041	294	189	9	0	299	0	7,535	5	2,504	77	107	2,253	445	164	67	622	959	7,204	331
33	**2009**	176	900	1,141	16	16	733	161	1,998	325	159	11	7	369	0	6,010	0	2,500	77	105	2,973	556	142	52	495	667	7,568	-1,557
34	**2010**	2,184	1,422	1,141	16	12	418	609	1,821	477	189	16	0	333	0	8,640	18	2,500	77	82	1,694	442	208	65	650	812	6,548	2,092
35	**2011**	1,258	1,751	1,141	16	14	556	223	1,822	593	230	11	0	256	0	7,871	90	2,500	77	92	2,249	480	239	78	768	1,009	7,583	289
36	**2012**	477	667	1,141	16	14	557	169	1,907	326	193	9	0	292	0	5,768	0	2,504	77	93	2,256	458	158	66	645	834	7,091	-1,323
37	**2013**	32	834	1,141	16	18	790	88	1,921	267	151	16	16	448	0	5,739	0	2,500	77	118	3,228	676	128	46	454	508	7,734	-1,996
38	**2014**	151	863	1,141	16	15	740	124	1,751	221	129	31	65	619	0	5,865	0	2,500	77	98	3,002	757	111	35	307	289	7,176	-1,311
39	**2015**	0	683	1,141	16	16	773	115	1,627	276	118	44	123	814	0	5,747	0	2,500	77	111	3,145	888	114	30	231	171	7,267	-1,519
40	**2016**	1,145	887	1,141	16	13	548	309	1,444	342	134	49	111	766	0	6,904	0	2,504	77	87	2,216	678	148	34	196	195	6,135	769
Average		**1,022**	**1,232**	**1,141**	**16**	**14**	**561**	**291**	**1,917**	**440**	**195**	**15**	**12**	**352**	**0**	**7,210**	**37**	**2,501**	**77**	**96**	**2,274**	**513**	**190**	**72**	**629**	**919**	**7,308**	**-98**

Table 4

NCMA Annual Groundwater Balance - Scenario 2

Model Year	Hydrologic Year	INFLOWS [acre-ft]															OUTFLOWS [acre-ft]											
		Areal Recharge from Precip (rch pkg)	Streambed Percolation (model)	Return Flow from Muni Use (rch pkg)	Return Flow from Small Purveyors (rch pkg)	Return Flow from Golf Course Irrig. (rch pkg)	Return Flow from Ag (rch pkg)	Artificial Recharge (wel pkg)	Underflow from NMMA (model)	Underflow from Arroyo Grande Valley (model)	Underflow from Zone 5 (model)	Underflow from Zone 6 (model)	Underflow from Ocean (layer 2) (model)	Underflow from Offshore Aquifers (model)	CCB Injection (wel pkg)	TOTAL INFLOW	Rising Water Discharge to Streamflow (model)	Muni Pumping (wel pkg)	Small Purveyor Pumping (wel pkg)	Golf Pumping (wel pkg)	Ag Pumping (wel pkg)	Underflow to NMMA (model)	Underflow to Zone 5 (model)	Underflow to Zone 6 (model)	Underflow to Ocean (layer 2) (model)	Underflow to Offshore Aquifers (model)	TOTAL OUTFLOW	CHANGE IN STORAGE
1	1977	202	844	1,141	16	15	552	247	1,424	311	124	7	0	172	900	5,956	0	2,500	77	102	2,232	686	124	80	488	759	7,049	-1,093
2	1978	1,265	1,871	1,141	16	13	392	626	1,290	722	232	8	0	137	900	8,613	117	2,500	77	88	1,585	553	279	93	619	1,052	6,965	1,648
3	1979	1,364	975	1,141	16	14	556	293	1,427	561	256	8	0	113	900	7,624	73	2,500	77	95	2,248	547	238	105	722	1,087	7,692	-68
4	1980	1,222	1,549	1,141	16	15	502	350	1,591	618	242	9	0	123	900	8,281	86	2,504	77	102	2,031	490	248	110	720	1,263	7,632	649
5	1981	1,370	998	1,141	16	14	535	322	1,694	563	255	9	0	114	900	7,931	79	2,500	77	92	2,165	435	239	114	749	1,329	7,779	152
6	1982	1,295	1,227	1,141	16	11	411	326	1,743	533	223	10	0	123	900	7,958	48	2,500	77	72	1,662	383	222	114	752	1,401	7,230	728
7	1983	3,116	3,176	1,141	16	12	351	695	1,832	674	241	12	0	109	900	12,274	183	2,500	77	82	1,420	489	258	165	1,183	2,143	8,499	3,775
8	1984	284	912	1,141	16	16	631	145	2,059	355	216	11	0	76	900	6,761	13	2,504	77	107	2,556	502	173	155	1,004	1,837	8,928	-2,166
9	1985	252	769	1,141	16	16	751	150	2,131	289	168	10	0	94	900	6,687	0	2,500	77	110	3,049	458	142	123	769	1,442	8,670	-1,983
10	1986	1,411	1,096	1,141	16	14	544	262	1,994	373	166	10	0	107	900	8,035	0	2,500	77	93	2,198	386	174	116	768	1,431	7,743	292
11	1987	588	810	1,141	16	13	524	216	1,786	426	196	9	0	104	900	6,730	0	2,500	77	88	2,118	428	196	102	675	1,178	7,362	-631
12	1988	785	816	1,141	16	15	548	234	1,624	251	176	9	0	111	900	6,627	1	2,504	77	98	2,216	494	146	95	660	1,024	7,316	-689
13	1989	2	685	1,141	16	17	778	94	1,649	341	150	8	11	201	900	5,994	0	2,500	77	116	3,172	701	145	72	479	699	7,960	-1,966
14	1990	68	697	1,141	16	16	756	137	1,627	170	117	7	53	296	900	6,003	0	2,500	77	108	3,072	745	89	50	319	508	7,468	-1,465
15	1991	946	1,071	1,141	16	14	419	389	1,331	401	145	8	21	231	900	7,035	0	2,500	77	94	1,695	591	173	52	330	542	6,055	980
16	1992	1,442	989	1,141	16	14	474	321	1,241	418	186	8	0	210	900	7,361	8	2,504	77	95	1,919	703	192	69	488	672	6,726	634
17	1993	1,883	1,177	1,141	16	14	466	431	1,232	411	181	9	0	155	900	8,017	2	2,500	77	94	1,886	611	185	87	639	862	6,942	1,074
18	1994	917	789	1,141	16	13	542	177	1,356	427	212	8	0	172	900	6,671	9	2,500	77	90	2,192	676	201	83	563	786	7,177	-506
19	1995	2,221	2,388	1,141	16	13	430	532	1,384	453	185	9	0	124	900	9,798	25	2,500	77	91	1,740	508	203	110	760	1,276	7,289	2,509
20	1996	1,301	1,832	1,141	16	13	393	369	1,541	404	215	9	0	106	900	8,241	47	2,504	77	86	1,593	438	196	122	779	1,436	7,279	962
21	1997	1,082	2,645	1,141	16	16	520	320	1,490	247	139	10	0	83	900	8,609	0	2,500	77	104	2,100	526	133	133	825	1,580	7,978	631
22	1998	2,503	3,226	1,141	16	12	427	585	1,822	396	177	12	0	96	900	11,313	80	2,500	77	79	1,727	466	183	176	1,166	2,263	8,718	2,595
23	1999	1,065	1,045	1,141	16	14	556	284	2,194	360	172	12	0	85	900	7,845	3	2,500	77	95	2,250	461	157	177	1,118	2,154	8,992	-1,147
24	2000	1,160	1,125	1,141	16	14	555	320	2,437	590	224	11	0	107	900	8,600	80	2,504	77	96	2,244	395	233	160	1,023	2,073	8,885	-285
25	2001	1,542	1,411	1,141	16	13	503	465	2,447	689	257	11	0	115	900	9,511	149	2,500	77	89	2,032	366	261	161	1,037	2,169	8,843	669
26	2002	465	853	1,141	16	16	658	164	2,283	546	251	10	0	98	900	7,402	74	2,500	77	105	2,667	431	228	138	863	1,723	8,807	-1,405
27	2003	297	832	1,141	16	15	630	124	2,168	344	198	10	0	110	900	6,785	2	2,500	77	100	2,554	454	172	118	760	1,457	8,194	-1,409
28	2004	654	953	1,141	16	14	560	193	2,103	308	157	9	0	127	900	7,135	0	2,504	77	93	2,269	392	145	105	680	1,334	7,600	-465
29	2005	1,398	879	1,141	16	13	550	189	2,174	686	231	10	0	135	900	8,323	90	2,500	77	89	2,225	409	258	98	753	1,322	7,823	500
30	2006	2,149	931	1,141	16	12	507	446	2,052	685	269	10	0	120	900	9,239	129	2,500	77	81	2,050	379	270	129	943	1,602	8,159	1,080
31	2007	235	889	1,141	16	16	761	131	2,022	581	258	9	0	116	900	7,076	79	2,500	77	108	3,094	555	239	112	748	1,253	8,765	-1,689
32	2008	985	1,702	1,141	16	16	557	285	1,859	282	185	9	0	108	900	8,045	5	2,504	77	107	2,253	456	161	110	727	1,316	7,717	328
33	2009	176	900	1,141	16	16	733	161	1,831	313	156	8	1	135	900	6,486	0	2,500	77	105	2,973	581	139	92	591	983	8,041	-1,555
34	2010	2,184	1,422	1,141	16	12	418	609	1,642	465	186	9	0	118	900	9,123	18	2,500	77	82	1,694	458	205	101	755	1,142	7,031	2,092
35	2011	1,258	1,751	1,141	16	14	556	223	1,655	581	227	10	0	101	900	8,433	91	2,500	77	92	2,249	505	235	120	874	1,394	8,138	295
36	2012	477	667	1,141	16	14	557	169	1,732	314	190	9	0	94	900	6,280	0	2,504	77	93	2,256	475	156	109	748	1,185	7,602	-1,322
37	2013	32	834	1,141	16	18	790	88	1,767	256	148	8	5	186	900	6,190	0	2,500	77	118	3,228	713	125	81	543	798	8,183	-1,993
38	2014	151	863	1,141	16	15	740	124	1,600	211	126	7	30	288	900	6,212	0	2,500	77	98	3,002	802	108	54	372	512	7,526	-1,314
39	2015	0	683	1,141	16	16	773	115	1,484	267	116	10	77	430	900	6,030	0	2,500	77	111	3,145	943	112	40	283	343	7,553	-1,523
40	2016	1,145	887	1,141	16	13	548	309	1,282	331	133	14	63	367	900	7,150	0	2,504	77	87	2,216	714	146	42	246	352	6,385	764
Average		1,022	1,229	1,141	16	14	561	291	1,750	429	192	9	7	147	900	7,710	37	2,501	77	96	2,274	533	187	107	713	1,242	7,768	-58

NCMA Annual Groundwater Balance - Scenario 3

		INFLOWS [acre-ft]															OUTFLOWS [acre-ft]											
Model Year	Hydrologic Year	Areal Recharge from Precip (rch pkg)	Streambed Percolation (model)	Return Flow from Muni Use (rch pkg)	Return Flow from Small Purveyors (rch pkg)	Return Flow from Golf Course Irrig. (rch pkg)	Return Flow from Ag (rch pkg)	Artificial Recharge (wel pkg)	Underflow from NMMA (model)	Underflow from Arroyo Grande Valley (model)	Underflow from Zone 5 (model)	Underflow from Zone 6 (model)	Underflow from Ocean (layer 2) (model)	Underflow from Offshore Aquifers (model)	CCB Injection (wel pkg)	TOTAL INFLOW	Rising Water Discharge to Streamflow (model)	Muni Pumping (wel pkg)	Small Purveyor Pumping (wel pkg)	Golf Pumping (wel pkg)	Ag Pumping (wel pkg)	Underflow to NMMA (model)	Underflow to Zone 5 (model)	Underflow to Zone 6 (model)	Underflow to Ocean (layer 2) (model)	Underflow to Offshore Aquifers (model)	TOTAL OUTFLOW	CHANGE IN STORAGE
1	**1977**	202	844	1,176	16	15	552	247	1,558	317	128	23	2	582	0	5,661	0	4,330	77	102	2,232	646	122	55	492	490	8,546	-2,885
2	**1978**	1,265	1,871	1,176	16	13	392	626	1,608	744	234	45	0	644	0	8,634	115	4,330	77	88	1,585	514	277	49	551	552	8,137	497
3	**1979**	1,364	974	1,176	16	14	556	293	1,846	592	260	49	1	727	0	7,868	71	4,330	77	95	2,247	510	239	47	570	516	8,702	-835
4	**1980**	1,222	1,550	1,176	16	15	502	350	2,093	655	248	52	2	787	0	8,669	83	4,330	77	102	2,032	473	251	44	504	631	8,527	142
5	**1981**	1,370	997	1,176	16	14	535	322	2,240	604	262	51	5	820	0	8,413	76	4,330	77	92	2,165	428	245	42	487	671	8,613	-200
6	**1982**	1,295	1,227	1,176	16	11	411	326	2,328	576	231	56	3	863	0	8,518	45	4,330	77	72	1,662	393	229	41	454	729	8,033	485
7	**1983**	3,116	3,359	1,176	16	12	351	695	2,336	720	250	33	0	593	0	12,657	177	4,330	77	82	1,420	434	268	67	838	1,227	8,920	3,737
8	**1984**	284	913	1,176	16	16	631	145	2,596	400	228	26	0	649	0	7,080	12	4,330	77	107	2,556	462	183	50	662	970	9,408	-2,328
9	**1985**	252	769	1,176	16	16	751	150	2,712	334	179	45	22	861	0	7,284	0	4,330	77	110	3,049	455	152	36	449	736	9,394	-2,110
10	**1986**	1,411	1,096	1,176	16	14	544	262	2,603	420	177	56	22	910	0	8,706	0	4,330	77	93	2,198	405	185	38	433	745	8,505	201
11	**1987**	588	811	1,176	16	13	524	216	2,389	472	206	63	35	1,007	0	7,516	0	4,330	77	88	2,118	435	205	31	350	579	8,213	-696
12	**1988**	785	817	1,176	16	15	548	234	2,208	296	187	69	39	1,063	0	7,452	0	4,330	77	98	2,216	482	156	29	333	463	8,185	-733
13	**1989**	2	685	1,176	16	17	778	94	2,183	384	159	81	121	1,331	0	7,026	0	4,330	77	116	3,172	650	153	19	229	293	9,039	-2,013
14	**1990**	68	697	1,176	16	16	756	137	2,171	206	127	97	238	1,593	0	7,299	0	4,330	77	108	3,072	698	97	12	147	246	8,788	-1,489
15	**1991**	946	1,071	1,176	16	14	419	389	1,904	440	151	101	199	1,512	0	8,339	0	4,330	77	94	1,695	573	180	16	145	270	7,381	958
16	**1992**	1,442	989	1,176	16	14	474	321	1,740	460	191	91	93	1,345	0	8,352	8	4,330	77	95	1,919	615	198	25	208	267	7,741	612
17	**1993**	1,883	1,177	1,176	16	14	466	431	1,748	454	188	81	35	1,145	0	8,815	1	4,330	77	94	1,886	543	193	33	293	326	7,776	1,040
18	**1994**	917	789	1,176	16	13	542	177	1,868	468	218	80	59	1,238	0	7,562	8	4,330	77	90	2,192	606	207	27	243	304	8,084	-522
19	**1995**	2,221	2,395	1,176	16	13	430	532	1,913	498	194	66	9	912	0	10,375	23	4,330	77	91	1,740	459	212	40	374	551	7,897	2,479
20	**1996**	1,301	1,833	1,176	16	13	393	369	2,085	448	225	54	2	847	0	8,762	45	4,330	77	86	1,593	401	205	39	383	656	7,816	946
21	**1997**	1,082	2,692	1,176	16	16	520	320	1,978	293	150	43	0	715	0	9,001	0	4,330	77	104	2,100	452	143	39	427	708	8,380	621
22	**1998**	2,503	3,355	1,176	16	12	427	585	2,306	441	187	29	0	573	0	11,610	77	4,330	77	79	1,727	406	196	70	755	1,289	9,006	2,604
23	**1999**	1,065	1,045	1,176	16	14	556	284	2,715	405	187	22	0	626	0	8,112	3	4,330	77	95	2,250	418	169	62	717	1,203	9,325	-1,213
24	**2000**	1,160	1,125	1,176	16	14	555	320	3,006	636	237	30	0	727	0	9,002	77	4,330	77	96	2,244	390	246	50	619	1,173	9,302	-301
25	**2001**	1,542	1,411	1,176	16	13	503	465	3,024	737	269	29	1	716	0	9,902	146	4,330	77	89	2,032	369	274	51	627	1,256	9,252	650
26	**2002**	465	853	1,176	16	16	658	164	2,856	591	263	37	14	826	0	7,934	72	4,330	77	105	2,667	426	239	36	476	906	9,334	-1,400
27	**2003**	297	833	1,176	16	15	630	124	2,758	388	210	52	37	958	0	7,493	1	4,330	77	100	2,554	463	183	30	396	751	8,885	-1,393
28	**2004**	654	953	1,176	16	14	560	193	2,722	351	169	62	54	1,062	0	7,987	0	4,330	77	93	2,269	428	156	28	335	710	8,426	-439
29	**2005**	1,398	879	1,176	16	13	550	189	2,777	732	240	68	50	1,098	0	9,186	87	4,330	77	89	2,225	428	270	27	403	731	8,667	519
30	**2006**	2,149	931	1,176	16	12	507	446	2,635	731	278	55	4	869	0	9,809	127	4,330	77	81	2,050	383	280	45	536	833	8,742	1,067
31	**2007**	235	889	1,176	16	16	761	131	2,574	624	267	56	37	992	0	7,773	77	4,330	77	108	3,094	532	247	30	390	578	9,462	-1,689
32	**2008**	985	1,703	1,176	16	16	557	285	2,433	325	196	59	38	962	0	8,751	4	4,330	77	107	2,253	450	170	31	365	626	8,414	337
33	**2009**	176	900	1,176	16	16	733	161	2,385	355	166	68	82	1,150	0	7,382	0	4,330	77	105	2,973	555	148	23	281	435	8,928	-1,545
34	**2010**	2,184	1,422	1,176	16	12	418	609	2,213	509	195	71	30	1,042	0	9,898	17	4,330	77	82	1,694	442	215	34	383	525	7,799	2,099
35	**2011**	1,258	1,751	1,176	16	14	556	223	2,183	627	235	57	5	844	0	8,946	88	4,330	77	92	2,249	458	245	39	473	614	8,665	280
36	**2012**	477	667	1,176	16	14	557	169	2,287	357	201	59	23	978	0	6,980	0	4,330	77	93	2,256	452	165	30	373	516	8,292	-1,312
37	**2013**	32	834	1,176	16	18	790	88	2,280	296	158	76	103	1,294	0	7,162	0	4,330	77	118	3,227	645	134	20	254	333	9,138	-1,976
38	**2014**	151	863	1,176	16	15	740	124	2,101	247	136	95	209	1,575	0	7,448	0	4,330	77	98	3,002	712	117	12	170	213	8,731	-1,284
39	**2015**	0	683	1,176	16	16	773	115	1,955	301	124	110	295	1,816	0	7,379	0	4,330	77	111	3,145	818	119	9	126	136	8,870	-1,491
40	**2016**	1,145	887	1,176	16	13	548	309	1,824	368	137	114	292	1,768	0	8,595	0	4,330	77	87	2,216	666	151	12	102	168	7,810	785
Average		**1,022**	**1,238**	**1,176**	**16**	**14**	**561**	**291**	**2,278**	**470**	**201**	**60**	**54**	**1,001**	**0**	**8,383**	**36**	**4,330**	**77**	**96**	**2,274**	**502**	**196**	**35**	**409**	**623**	**8,578**	**-195**

Table 6

NCMA Annual Groundwater Balance - Scenario 4

		INFLOWS [acre-ft]															OUTFLOWS [acre-ft]											
Model Year	Hydrologic Year	Areal Recharge from Precip (rch pkg)	Streambed Percolation (model)	Return Flow from Muni Use (rch pkg)	Return Flow from Small Purveyors (rch pkg)	Return Flow from Golf Course Irrig. (rch pkg)	Return Flow from Ag (rch pkg)	Artificial Recharge (wel pkg)	Underflow from NMMA (model)	Underflow from Arroyo Grande Valley (model)	Underflow from Zone 5 (model)	Underflow from Zone 6 (model)	Underflow from Ocean (layer 2) (model)	Underflow from Offshore Aquifers (model)	CCB Injection (wel pkg)	TOTAL INFLOW	Rising Water Discharge to Streamflow (model)	Muni Pumping (wel pkg)	Small Purveyor Pumping (wel pkg)	Golf Pumping (wel pkg)	Ag Pumping (wel pkg)	Underflow to NMMA (model)	Underflow to Zone 5 (model)	Underflow to Zone 6 (model)	Underflow to Ocean (layer 2) (model)	Underflow to Offshore Aquifers (model)	TOTAL OUTFLOW	CHANGE IN STORAGE
1	**1977**	202	844	1,184	16	15	552	247	1,373	312	125	6	0	227	3,500	8,604	0	4,330	77	102	2,232	710	123	111	479	1,331	9,495	-891
2	**1978**	1,265	1,871	1,176	16	13	392	626	1,194	725	230	8	0	153	3,500	11,169	116	4,330	77	88	1,585	572	278	131	613	1,575	9,366	1,803
3	**1979**	1,364	975	1,176	16	14	556	293	1,320	563	254	8	0	149	3,500	10,188	73	4,330	77	95	2,247	573	237	142	722	1,640	10,137	50
4	**1980**	1,222	1,549	1,176	16	15	502	350	1,464	620	240	9	0	131	3,500	10,795	86	4,330	77	102	2,032	509	246	148	728	1,803	10,061	734
5	**1981**	1,370	998	1,176	16	14	535	322	1,558	564	254	9	0	122	3,500	10,437	79	4,330	77	92	2,165	452	238	152	764	1,875	10,224	213
6	**1982**	1,295	1,227	1,176	16	11	411	326	1,600	534	221	10	0	115	3,500	10,441	48	4,330	77	72	1,662	394	220	153	772	1,939	9,667	774
7	**1983**	3,116	3,172	1,176	16	12	351	695	1,701	674	239	12	0	78	3,500	14,742	183	4,330	77	82	1,420	514	256	204	1,210	2,664	10,940	3,803
8	**1984**	284	912	1,176	16	16	631	145	1,929	354	214	11	0	99	3,500	9,287	13	4,330	77	107	2,556	529	171	195	1,032	2,420	11,430	-2,143
9	**1985**	252	769	1,176	16	16	751	150	1,991	289	166	10	0	123	3,500	9,210	0	4,330	77	110	3,049	478	141	163	800	2,030	11,177	-1,967
10	**1986**	1,411	1,096	1,176	16	14	544	262	1,848	373	164	10	0	112	3,500	10,527	0	4,330	77	93	2,198	399	172	157	802	1,998	10,226	301
11	**1987**	588	810	1,176	16	13	524	216	1,648	426	195	10	0	134	3,500	9,256	0	4,330	77	88	2,118	447	194	142	709	1,772	9,878	-622
12	**1988**	785	816	1,176	16	15	548	234	1,494	251	175	9	0	153	3,500	9,174	1	4,330	77	98	2,216	523	145	135	696	1,635	9,857	-683
13	**1989**	2	685	1,176	16	17	778	94	1,533	341	149	8	5	253	3,500	8,558	0	4,330	77	116	3,172	738	144	113	508	1,319	10,517	-1,959
14	**1990**	68	697	1,176	16	16	756	137	1,510	170	116	7	36	324	3,500	8,531	0	4,330	77	108	3,072	778	88	91	336	1,105	9,985	-1,454
15	**1991**	946	1,071	1,176	16	14	419	389	1,208	401	144	7	12	245	3,500	9,548	0	4,330	77	94	1,695	623	171	90	358	1,122	8,561	987
16	**1992**	1,442	989	1,176	16	14	474	321	1,131	418	184	8	0	240	3,500	9,913	8	4,330	77	95	1,919	750	190	109	527	1,274	9,280	633
17	**1993**	1,883	1,177	1,176	16	14	466	431	1,119	411	179	9	0	175	3,500	10,555	2	4,330	77	94	1,886	652	183	128	680	1,452	9,484	1,071
18	**1994**	917	789	1,176	16	13	542	177	1,242	426	210	8	0	210	3,500	9,228	10	4,330	77	90	2,192	720	199	123	603	1,393	9,737	-509
19	**1995**	2,221	2,387	1,176	16	13	430	532	1,257	453	183	9	0	112	3,500	12,290	25	4,330	77	91	1,740	540	201	150	803	1,833	9,789	2,501
20	**1996**	1,301	1,832	1,176	16	13	393	369	1,409	403	213	10	0	107	3,500	10,743	47	4,330	77	86	1,593	462	194	163	820	2,010	9,782	960
21	**1997**	1,082	2,639	1,176	16	16	520	320	1,373	247	137	10	0	104	3,500	11,139	0	4,330	77	104	2,100	564	131	173	866	2,170	10,516	624
22	**1998**	2,503	3,214	1,176	16	12	427	585	1,695	395	175	12	0	71	3,500	13,780	80	4,330	77	79	1,727	495	181	217	1,210	2,807	11,203	2,578
23	**1999**	1,065	1,045	1,176	16	14	556	284	2,063	359	170	12	0	86	3,500	10,346	3	4,330	77	95	2,250	485	155	218	1,159	2,722	11,493	-1,147
24	**2000**	1,160	1,125	1,176	16	14	555	320	2,295	589	223	12	0	96	3,500	11,081	80	4,330	77	96	2,244	409	231	200	1,063	2,634	11,366	-285
25	**2001**	1,542	1,411	1,176	16	13	503	465	2,303	688	255	12	0	96	3,500	11,980	149	4,330	77	89	2,032	378	259	202	1,078	2,718	11,313	667
26	**2002**	465	853	1,176	16	16	658	164	2,147	546	250	11	0	114	3,500	9,915	74	4,330	77	105	2,667	449	227	179	903	2,307	11,317	-1,402
27	**2003**	297	832	1,176	16	15	630	124	2,033	343	196	10	0	132	3,500	9,305	2	4,330	77	100	2,554	473	171	159	799	2,046	10,709	-1,405
28	**2004**	654	953	1,176	16	14	560	193	1,959	307	156	10	0	137	3,500	9,635	0	4,330	77	93	2,269	404	143	146	719	1,916	10,098	-463
29	**2005**	1,398	879	1,176	16	13	550	189	2,032	685	230	10	0	129	3,500	10,807	90	4,330	77	89	2,225	422	256	139	794	1,885	10,308	500
30	**2006**	2,149	931	1,176	16	12	507	446	1,913	685	267	10	0	103	3,500	11,715	129	4,330	77	81	2,050	395	268	169	985	2,155	10,639	1,076
31	**2007**	235	889	1,176	16	16	761	131	1,898	580	257	9	0	150	3,500	9,618	79	4,330	77	108	3,094	585	237	153	788	1,855	11,306	-1,688
32	**2008**	985	1,702	1,176	16	16	557	285	1,728	281	183	10	0	126	3,500	10,565	5	4,330	77	107	2,253	480	159	151	768	1,906	10,237	327
33	**2009**	176	900	1,176	16	16	733	161	1,712	313	154	9	0	184	3,500	9,050	0	4,330	77	105	2,973	616	138	133	630	1,600	10,602	-1,552
34	**2010**	2,184	1,422	1,176	16	12	418	609	1,514	464	185	9	0	131	3,500	11,642	18	4,330	77	82	1,694	486	203	142	797	1,725	9,553	2,089
35	**2011**	1,258	1,751	1,176	16	14	556	223	1,533	580	225	10	0	110	3,500	10,952	91	4,330	77	92	2,249	538	233	160	917	1,974	10,662	290
36	**2012**	477	667	1,176	16	14	557	169	1,606	313	188	9	0	133	3,500	8,825	0	4,330	77	93	2,256	504	154	150	790	1,796	10,149	-1,325
37	**2013**	32	834	1,176	16	18	790	88	1,657	256	147	8	1	240	3,500	8,763	0	4,330	77	118	3,227	754	124	122	579	1,421	10,752	-1,990
38	**2014**	151	863	1,176	16	15	740	124	1,491	211	125	7	17	334	3,500	8,770	0	4,330	77	98	3,002	842	107	95	397	1,129	10,078	-1,308
39	**2015**	0	683	1,176	16	16	773	115	1,387	266	115	6	54	459	3,500	8,568	0	4,330	77	111	3,145	1,001	111	76	299	943	10,092	-1,524
40	**2016**	1,145	887	1,176	16	13	548	309	1,170	331	131	6	40	361	3,500	9,634	0	4,330	77	87	2,216	762	145	75	262	920	8,874	760
Average		**1,022**	**1,229**	**1,176**	**16**	**14**	**561**	**291**	**1,626**	**429**	**191**	**9**	**4**	**164**	**3,500**	**10,232**	**37**	**4,330**	**77**	**96**	**2,274**	**560**	**186**	**146**	**744**	**1,821**	**10,271**	**-39**

Table 7

NCMA Annual Groundwater Balance - Scenario 5

Model Year	Hydrologic Year	INFLOWS [acre-ft]															OUTFLOWS [acre-ft]											CHANGE IN STORAGE
		Areal Recharge from Precip (rch pkg)	Streambed Percolation (model)	Return Flow from Muni Use (rch pkg)	Return Flow from Small Purveyors (rch pkg)	Return Flow from Golf Course Irrig. (rch pkg)	Return Flow from Ag (rch pkg)	Artificial Recharge (wel pkg)	Underflow from NMMA (model)	Underflow from Arroyo Grande Valley (model)	Underflow from Zone 5 (model)	Underflow from Zone 6 (model)	Underflow from Ocean (layer 2) (model)	Underflow from Offshore Aquifers (model)	CCB Injection (wel pkg)	TOTAL INFLOW	Rising Water Discharge to Streamflow (model)	Muni Pumping (wel pkg)	Small Purveyor Pumping (wel pkg)	Golf Pumping (wel pkg)	Ag Pumping (wel pkg)	Underflow to NMMA (model)	Underflow to Zone 5 (model)	Underflow to Zone 6 (model)	Underflow to Ocean (layer 2) (model)	Underflow to Offshore Aquifers (model)	TOTAL OUTFLOW	
1	**1977**	297	844	941	16	15	532	319	1,405	314	121	7	0	122	0	4,935	0	1,080	77	102	2,193	621	125	80	486	697	5,462	-527
2	**1978**	1,197	1,871	933	16	13	388	629	1,238	718	229	9	0	79	0	7,321	117	1,080	77	88	1,477	559	280	102	654	1,073	5,506	1,814
3	**1979**	1,226	974	933	16	14	554	302	1,353	559	254	9	0	66	0	6,260	73	1,080	77	95	2,248	579	238	116	757	1,114	6,379	-119
4	**1980**	1,321	1,548	933	16	15	497	410	1,507	611	239	10	0	70	0	7,178	87	1,082	77	102	1,937	483	246	125	791	1,349	6,279	899
5	**1981**	1,097	997	933	16	14	537	279	1,574	561	253	9	0	67	0	6,337	79	1,080	77	92	2,189	488	239	126	791	1,348	6,509	-172
6	**1982**	830	1,227	933	16	11	411	265	1,652	536	221	10	0	78	0	6,190	48	1,080	77	72	1,792	389	221	122	742	1,388	5,931	258
7	**1983**	2,912	3,163	933	16	12	346	735	1,736	676	239	12	0	63	0	10,844	183	1,080	77	82	1,352	491	259	170	1,153	2,111	6,956	3,888
8	**1984**	151	912	933	16	16	626	140	1,976	355	213	11	0	55	0	5,405	13	1,082	77	107	2,743	508	172	164	996	1,856	7,716	-2,312
9	**1985**	216	769	933	16	16	750	132	2,027	290	163	10	0	74	0	5,397	0	1,080	77	110	3,102	459	141	132	751	1,455	7,305	-1,909
10	**1986**	1,134	1,096	933	16	14	541	270	1,867	376	162	10	0	77	0	6,497	0	1,080	77	93	2,212	385	173	122	735	1,415	6,292	205
11	**1987**	378	810	933	16	13	514	217	1,664	427	194	9	0	77	0	5,253	0	1,080	77	88	2,144	455	195	109	655	1,169	5,973	-720
12	**1988**	726	817	933	16	15	534	295	1,500	252	173	9	0	80	0	5,350	1	1,082	77	98	2,219	512	146	102	632	1,017	5,886	-536
13	**1989**	1	685	933	16	17	777	94	1,535	339	147	8	9	153	0	4,713	0	1,080	77	116	3,187	725	144	84	488	722	6,623	-1,909
14	**1990**	42	697	933	16	16	754	123	1,517	169	113	7	44	230	0	4,663	0	1,080	77	108	3,065	768	87	62	330	518	6,094	-1,431
15	**1991**	930	1,071	933	16	14	411	402	1,223	398	143	7	16	138	0	5,702	0	1,080	77	94	1,650	591	171	62	354	543	4,623	1,079
16	**1992**	1,514	989	933	16	14	465	386	1,107	411	183	8	0	114	0	6,142	8	1,082	77	95	1,625	717	192	84	555	721	5,156	985
17	**1993**	1,966	1,177	933	16	14	469	477	1,125	402	177	9	0	76	0	6,842	2	1,080	77	94	1,859	650	183	107	744	958	5,753	1,089
18	**1994**	817	789	933	16	13	538	197	1,261	421	209	8	0	105	0	5,308	10	1,080	77	90	2,203	741	200	100	643	854	5,997	-689
19	**1995**	2,126	2,380	933	16	13	425	546	1,276	448	182	10	0	61	0	8,418	25	1,080	77	91	1,625	528	202	125	832	1,342	5,927	2,492
20	**1996**	1,288	1,830	933	16	13	390	440	1,420	396	211	10	0	54	0	7,001	47	1,082	77	86	1,473	458	194	139	871	1,533	5,962	1,039
21	**1997**	978	2,612	933	16	16	512	329	1,392	240	134	11	0	46	0	7,220	0	1,080	77	104	1,995	558	130	151	922	1,698	6,716	504
22	**1998**	2,476	3,168	933	16	12	423	619	1,700	390	171	13	0	47	0	9,968	80	1,080	77	79	1,480	494	181	192	1,255	2,345	7,263	2,706
23	**1999**	742	1,045	933	16	14	559	265	2,057	358	166	12	0	54	0	6,221	4	1,080	77	95	2,274	484	153	190	1,167	2,206	7,729	-1,508
24	**2000**	1,216	1,125	933	16	14	543	352	2,315	583	219	12	0	73	0	7,401	81	1,082	77	96	2,112	390	230	175	1,090	2,170	7,503	-102
25	**2001**	1,369	1,410	933	16	13	502	451	2,300	684	253	12	0	76	0	8,021	149	1,080	77	89	2,072	376	259	175	1,093	2,225	7,596	425
26	**2002**	416	853	933	16	16	624	218	2,123	541	246	11	0	71	0	6,068	75	1,080	77	105	2,280	416	227	152	928	1,832	7,172	-1,104
27	**2003**	204	832	933	16	15	628	132	2,042	339	194	10	0	80	0	5,425	2	1,080	77	100	2,654	471	169	134	830	1,557	7,075	-1,651
28	**2004**	594	953	933	16	14	542	242	1,976	304	152	10	0	89	0	5,825	0	1,082	77	93	2,263	390	142	120	726	1,413	6,306	-481
29	**2005**	1,415	879	933	16	13	551	311	2,025	678	226	10	0	87	0	7,145	90	1,080	77	89	2,094	405	256	116	829	1,427	6,463	682
30	**2006**	1,845	931	933	16	12	509	397	1,926	683	266	11	0	70	0	7,599	129	1,080	77	81	2,113	387	267	143	979	1,652	6,908	691
31	**2007**	124	889	933	16	16	760	122	1,923	578	256	9	0	83	0	5,710	79	1,080	77	108	3,118	571	238	124	772	1,295	7,461	-1,751
32	**2008**	981	1,698	933	16	16	546	297	1,777	278	182	10	0	71	0	6,805	5	1,082	77	107	2,252	444	159	123	766	1,386	6,399	406
33	**2009**	134	900	933	16	16	703	170	1,716	309	151	9	0	91	0	5,148	0	1,080	77	105	2,803	596	137	106	642	1,055	6,601	-1,453
34	**2010**	2,131	1,422	933	16	12	418	640	1,526	458	182	10	0	65	0	7,812	19	1,080	77	82	1,582	474	203	117	836	1,234	5,703	2,109
35	**2011**	1,084	1,751	933	16	14	559	203	1,528	576	225	10	0	60	0	6,960	91	1,080	77	92	2,252	616	235	133	929	1,416	6,921	40
36	**2012**	298	667	933	16	14	539	174	1,659	313	188	9	0	65	0	4,876	0	1,082	77	93	2,533	506	154	120	761	1,205	6,530	-1,654
37	**2013**	36	834	933	16	18	786	79	1,683	255	144	8	4	144	0	4,941	0	1,080	77	118	3,220	741	124	92	554	821	6,826	-1,885
38	**2014**	162	863	933	16	15	714	132	1,515	209	123	7	22	220	0	4,930	0	1,080	77	98	2,992	822	107	67	401	537	6,181	-1,251
39	**2015**	0	683	933	16	16	772	111	1,410	264	113	7	58	335	0	4,719	0	1,080	77	111	3,149	972	111	49	306	350	6,205	-1,486
40	**2016**	799	887	933	16	13	521	326	1,213	332	131	7	55	261	0	5,494	0	1,082	77	87	2,219	771	146	46	258	316	5,002	492
Average		**929**	**1,226**	**933**	**16**	**14**	**554**	**306**	**1,644**	**426**	**189**	**10**	**5**	**98**	**0**	**6,351**	**37**	**1,080**	**77**	**96**	**2,244**	**550**	**186**	**119**	**750**	**1,283**	**6,422**	**-71**

NCMA Annual Groundwater Balance - Scenario 6

Model Year	Hydrologic Year	INFLOWS [acre-ft] Areal Recharge from Precip (rch pkg)	Streambed Percolation (model)	Return Flow from Muni Use (rch pkg)	Return Flow from Small Purveyors (rch pkg)	Return Flow from Golf Course Irrig. (rch pkg)	Return Flow from Ag (rch pkg)	Artificial Recharge (wel pkg)	Underflow from NMMA (model)	Underflow from Arroyo Grande Valley (model)	Underflow from Zone 5 (model)	Underflow from Zone 6 (model)	Underflow from Ocean (layer 2) (model)	Underflow from Offshore Aquifers (model)	CCB Injection (wel pkg)	TOTAL INFLOW	OUTFLOWS [acre-ft] Rising Water Discharge to Streamflow (model)	Muni Pumping (wel pkg)	Small Purveyor Pumping (wel pkg)	Golf Pumping (wel pkg)	Ag Pumping (wel pkg)	Underflow to NMMA (model)	Underflow to Zone 5 (model)	Underflow to Zone 6 (model)	Underflow to Ocean (layer 2) (model)	Underflow to Offshore Aquifers (model)	TOTAL OUTFLOW	CHANGE IN STORAGE
1	1977	202	844	941	16	15	552	247	1,401	314	122	7	2	145	0	4,808	0	1,080	77	102	2,232	702	125	78	428	622	5,446	-638
2	1978	1,265	1,871	933	16	13	392	626	1,223	720	229	8	0	89	0	7,386	117	1,080	77	88	1,585	576	280	96	573	960	5,433	1,953
3	1979	1,364	975	933	16	14	556	293	1,333	556	253	8	0	71	0	6,373	73	1,080	77	95	2,248	572	238	112	704	1,040	6,239	134
4	1980	1,222	1,549	933	16	15	502	350	1,474	612	239	9	0	76	0	6,999	87	1,082	77	102	2,031	509	247	119	724	1,237	6,216	783
5	1981	1,370	998	933	16	14	535	322	1,562	556	252	9	0	68	0	6,635	80	1,080	77	92	2,165	452	238	124	769	1,323	6,399	236
6	1982	1,295	1,227	933	16	11	411	326	1,602	526	219	10	0	73	0	6,648	49	1,080	77	72	1,662	393	219	126	783	1,405	5,865	783
7	1983	3,116	3,108	933	16	12	351	695	1,711	666	237	12	0	57	0	10,914	184	1,080	77	82	1,420	514	255	177	1,229	2,147	7,164	3,749
8	1984	284	912	933	16	16	631	145	1,932	346	210	11	0	49	0	5,486	13	1,082	77	107	2,556	525	169	167	1,049	1,871	7,617	-2,131
9	1985	252	769	933	16	16	751	150	1,993	281	162	10	0	65	0	5,399	0	1,080	77	110	3,049	473	138	136	816	1,481	7,360	-1,961
10	1986	1,411	1,096	933	16	14	544	262	1,851	364	160	10	0	66	0	6,728	0	1,080	77	93	2,198	397	170	130	821	1,466	6,431	297
11	1987	588	810	933	16	13	524	216	1,652	417	192	10	0	65	0	5,437	0	1,080	77	88	2,118	447	193	115	729	1,219	6,066	-629
12	1988	785	816	933	16	15	548	234	1,502	243	171	10	0	68	0	5,342	1	1,082	77	98	2,216	525	143	108	716	1,064	6,032	-690
13	1989	2	685	933	16	17	778	94	1,541	334	146	8	5	148	0	4,708	0	1,080	77	116	3,172	745	143	86	526	730	6,674	-1,967
14	1990	68	697	933	16	16	756	137	1,519	164	112	7	33	223	0	4,683	0	1,080	77	108	3,072	781	86	64	350	522	6,140	-1,457
15	1991	946	1,071	933	16	14	419	389	1,219	393	142	7	11	136	0	5,698	0	1,080	77	94	1,695	628	171	64	375	535	4,719	978
16	1992	1,442	988	933	16	14	474	321	1,144	409	183	8	0	128	0	6,062	8	1,082	77	95	1,919	759	190	83	549	678	5,439	623
17	1993	1,883	1,177	933	16	14	466	431	1,131	402	176	9	0	82	0	6,721	2	1,080	77	94	1,886	661	183	101	703	875	5,662	1,058
18	1994	917	789	933	16	13	542	177	1,254	418	208	8	0	104	0	5,381	10	1,080	77	90	2,192	724	199	97	626	809	5,903	-522
19	1995	2,221	2,377	933	16	13	430	532	1,274	444	181	10	0	60	0	8,491	25	1,080	77	91	1,740	547	200	124	829	1,296	6,009	2,482
20	1996	1,301	1,830	933	16	13	393	369	1,421	394	211	10	0	54	0	6,945	47	1,082	77	86	1,593	466	193	136	845	1,470	5,996	949
21	1997	1,082	2,609	933	16	16	520	320	1,391	238	134	11	0	47	0	7,316	0	1,080	77	104	2,100	568	130	146	891	1,624	6,720	596
22	1998	2,503	3,152	933	16	12	427	585	1,714	387	172	13	0	47	0	9,960	80	1,080	77	79	1,727	494	179	189	1,236	2,280	7,422	2,538
23	1999	1,065	1,045	933	16	14	556	284	2,074	351	165	13	0	53	0	6,569	4	1,080	77	95	2,250	483	152	190	1,183	2,195	7,709	-1,141
24	2000	1,160	1,125	933	16	14	555	320	2,303	580	218	12	0	71	0	7,307	81	1,082	77	96	2,244	407	228	173	1,089	2,118	7,596	-290
25	2001	1,542	1,410	933	16	13	503	465	2,309	678	251	12	0	73	0	8,207	150	1,080	77	89	2,032	375	257	175	1,106	2,210	7,552	655
26	2002	465	853	933	16	16	658	164	2,155	537	246	11	0	69	0	6,122	75	1,080	77	105	2,667	448	225	153	930	1,782	7,542	-1,419
27	2003	297	832	933	16	15	630	124	2,040	335	192	10	0	79	0	5,503	2	1,080	77	100	2,554	473	169	132	827	1,516	6,929	-1,426
28	2004	654	953	933	16	14	560	193	1,965	299	151	10	0	86	0	5,834	0	1,082	77	93	2,269	403	141	120	747	1,385	6,317	-483
29	2005	1,398	879	933	16	13	550	189	2,038	676	226	10	0	85	0	7,015	90	1,080	77	89	2,225	422	255	113	822	1,365	6,538	477
30	2006	2,149	931	933	16	12	507	446	1,921	675	263	11	0	67	0	7,932	130	1,080	77	81	2,050	396	266	143	1,014	1,637	6,874	1,059
31	2007	235	889	933	16	16	761	131	1,907	571	254	10	0	77	0	5,800	80	1,080	77	108	3,094	586	236	127	815	1,305	7,507	-1,708
32	2008	985	1,698	933	16	16	557	285	1,739	272	180	10	0	67	0	6,759	5	1,082	77	107	2,253	484	158	124	796	1,365	6,451	308
33	2009	176	900	933	16	16	733	161	1,722	305	150	9	0	91	0	5,213	0	1,080	77	105	2,973	620	136	107	656	1,032	6,786	-1,573
34	2010	2,184	1,422	933	16	12	418	609	1,524	455	182	10	0	64	0	7,830	19	1,080	77	82	1,694	490	202	116	824	1,179	5,762	2,068
35	2011	1,258	1,751	933	16	14	556	223	1,545	571	223	11	0	53	0	7,152	92	1,080	77	92	2,249	543	232	134	944	1,434	6,879	274
36	2012	477	667	933	16	14	557	169	1,616	304	185	10	0	56	0	5,004	0	1,082	77	93	2,256	507	153	123	816	1,237	6,343	-1,339
37	2013	32	834	933	16	18	790	88	1,667	248	143	8	1	136	0	4,915	0	1,080	77	118	3,227	762	122	96	603	843	6,928	-2,013
38	2014	151	863	933	16	15	740	124	1,500	204	122	7	14	217	0	4,907	0	1,080	77	98	3,002	843	106	69	417	542	6,234	-1,327
39	2015	0	683	933	16	16	773	115	1,397	262	112	7	49	336	0	4,699	0	1,080	77	111	3,149	998	112	50	315	351	6,243	-1,545
40	2016	1,145	886	933	16	13	548	309	1,208	345	137	7	41	243	0	5,831	0	1,082	77	87	2,377	754	153	48	275	325	5,178	652
Average		**1,022**	**1,224**	**933**	**16**	**14**	**561**	**291**	**1,637**	**421**	**188**	**10**	**4**	**96**	**0**	**6,418**	**38**	**1,080**	**77**	**96**	**2,279**	**561**	**185**	**119**	**761**	**1,262**	**6,458**	**-40**

APPENDIX A

Comments Received and GEOSCIENCE Responses for

Draft TM No. 4: Model Scenario Evaluation

GEOSCIENCE

Comments Received and GEOSCIENCE Responses for Draft TM No. 4: Model Scenario Evaluation

No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
1	GSI	1	1	"The project uses…". Suggest change to future tense to agree with first sentence ("…will reduce…")	Text was modified.
2	GSI	2	3	Table 2.1: Suggest to make clear either in text or title of table that predictive scenarios run 40 years.	Clarification was added to the text.
3	GSI	2	3	Table 2.1: Suggest to include pumping quantity in AFY for NMMA, as is done for NCMA.	NMMA pumping was added to the table.
4	GSI	2	3	Table 2.1: I recall some discussions that had some pretty aggressive projected population growth estimates for NMMA areas. Why is there no increase in NMMA pumping in predictive scenarios? Suggest explaining in text.	It was agreed upon with WSC that the actual projections used for these scenarios were not officially vetted by NMMA and also that such an endeavor was beyond the scope of Phase 1.
5	GSI	2.1.3	5	"Only GHBs along the Arroyo Grande Valley and the SMVMA were modified in the predictive scenarios." Suggest a sentence or two explaining why may be appropriate here.	There are three sets of GHBs in the model. The Pacific ocean, Arroyo Grande Valley and the SMVMA. The Ocean GHBs were not modified because it was assumed that sea water would stay the same for the baseline scenario. Sea level rise being a separate scenario.
6	GSI	2.1.6	5	editorial suggestion, change "carried out" to "calculated".	Text was modified.
7	GSI	2.2	6	editorial suggestion, change "without and with" to "with and without".	Since text indicates that "without and with" apply to Scenarios 1 and 2, respectively, text was left as-is to avoid confusion.
8	GSI	2.3	7	Table 2-2: This table might be clearer if there were a Total column on the right, and also if the Average Demand Row was at the bottom, instead of the middle, since average demand is dependent on the other two rows.	Table was left as-is. As explained in the text, the portion of the demand not met by the maximum allocated pumping was assumed to come from imported water. Therefore, the amount of imported water necessary to meet projected demand is calculated as the assumed groundwater pumping minus the assumed demand.
9	GSI	3.1	9	suggest changing "…deep well index…several deep wells…" to "…three deep wells…".	Text was modified.
10	GSI	3.1	9	"…a safe approach to limit seawater intrusion…". This sentence sounds overly definite with respect to real world results. Suggest revising to something like "…a reasonable modeling metric for evaluating conditions that may result in sea water intrusion…" or something similar.	Text was modified.
11	GSI	3.1	9	"A positive flux indicates inflow from the ocean and offshore aquifers while a negative flux indicates groundwater flow to the ocean from inland areas." This is a very important point that may not be intuitive to non-modeling readers. Suggest including a text box with a note to this effect be placed on every water budget graph figure in the report, so that if people view the figures without reading the text, this is pointed out.	Text explanation was added to figures showing net flow from the ocean and offshore aquifers.
12	GSI	3.1	10	Suggest changing ""underflow inflow from upgradient groundwater basins" to "underflow inflow from the ocean and offshore aquifers or from upgradient aquifers".	Text was modified.
13	GSI	3.3	11	"…net inflow from offshore occurs periodically in Layer 10." Looks like about half the time to me. The large y-axis scale obscures the details. Just an observation.	Text was clarified.
14	GSI	3.7	14	"For Scenario 4, Pismo Well 23 is within 6-months travel time from the injected recycled water." Pismo Well 23 is not identified by that name on the Figures, so it is not clear on the figures where you are talking about. Suggest identifying Pismo Well 23 on the Figures.	Well names were indicated on Figures 41-45.
15	GSI	4	15	Suggest changing "net inflow across the shoreline…" to "net inflow/outflow across the shoreline..", since it can go both ways.	Text was modified.

Comments Received and GEOSCIENCE Responses for Draft TM No. 4: Model Scenario Evaluation

No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
16	GSI	4	15	General suggestion on presentation of the "Effect" column of this table. Each scenario is evaluated on 4 criteria; sea water intrusion potential, deep well index, flux direction across shore, and groundwater storage decrease. It might make it easier to interpret this table if each cell in the effect column was identically formatted with 4 bullets, with one simple sentence for each criteria. Not suggesting a change in the table text, just with identical bullet format it'd be easier to identify different effects for each scenario.	Table was modified.
17	GSI	-	Fig 4	suggest revising y axis. 75% of graph area is unused.	Figure was modified.
18	GSI	-	Fig 5	and global comment for all figures displaying municipal wells. If there is not a privacy concern, it would be more instructive to label the municipal wells by municipality/owner rather than the state well number.	Figures showing wells were modified to display well names rather than state well numbers.
19	GSI	-	Fig 8	I realize this has been discussed before, but the significant discontinuity in NMMA water levels across the fault displayed in layer 4 seems problematic. There is no such discontinuity displayed in the NCMA area. Why the difference? Be prepared to defend this from NMMA comments.	As discussed in the model update presentation, a DWR 2002 report shows groundwater level contours with this pattern. Given the lack of reliable water levels across the SMR fault, the DWR map was used as a guideline to determine the spatial extent of the fault effectiveness as a barrier.
20	GSI	-	Fig 9	Is there a reason the x-axis isn't just labelled 2017-2056 for the predictive scenario time period? It would be easier and more intuitive to display as such. How would you label the axis the way it is presented now, it mixes two categories (calendar year and year from start of predictive run).	Typically, we refer to years in the predictive simulation period by model year since the hydrology for the scenarios is assumed and likely will not represent actual conditions for a specific future calendar year.
21	GSI	-	-	Global comment for all water budget graphs: Why is the y-axis so big? Positive y axis goes to 1,000 AFY, but graphed values rarely exceed 100 AFY. Similarly, the negative y-axis goes to -1000 or -1300 when graphed values never get close to that. This obscures a lot of the detail in the vicinity of the 0 flux line, which is one of the main criteria for evaluation (positive or negative flux). Suggest using a smaller y-axis to more clearly display the graphed values/lines and make trends easier to see on the graph.	Figure axes were modified.
1	NCMA TG (Jim Garing)	3.4	12	Under Scenario 4, net flow to the ocean from layer 2 during the simulation period averages 740 AFY while flow to offshore aquifers over the same period averages 1,656 AFY. Groundwater storage in the NCMA decreases by an average of 195 AFY under Scenario 3 conditions and by an average of 39 AFY under Scenario 2 (4? Jim). The water budget indicates that CCB operations are able to reduce inflow from offshore Does the 39 AFY above refer to Scenario 4?	Yes, the 39 AFY refers to Scenario 4. Typo was corrected.
2	NCMA TG (Jim Garing)	-	-	I am wondering about use of the Mehlschau rainfall station, which is in NMMA. If this station is the only station used when forecasting future rainfall, it may not represent average rainfall over the study area.	Four stations were used for hydrology but Mehlschau was chosen for illustration putposes because it has the longest uninterupted record of all four stations used.
3	NCMA TG (Jim Garing)	-	Fig 4	I am still troubled by Figure 4, General Head Trend For Predictive Model Scenarios. It is not intuitive to me that this trend would apply to Scenario 4, where injection is 3500 AFY, extraction 4330 AFY and the Deep Well Index jumps up to what would appear to be an average of about 15 over the 40 year model scenario.	Figure 4 is just one example out of about 1,500 GHB cells.The figure was revised to show several GHB trends.
4	NCMA TG (Jim Garing)	-	-	Thinking further about the General Head Boundary comment above, it is time for a discussion on whether the Deep well Index will be the best indicator of potential sea water intrusion when injecting CCB water at high rates. Maybe cumulative flow across the shoreline for critical layers would be better. Also some thought on whether flow across the shoreline could be measured, versus being predicted by the Model.	After discussions with the TAC (05-07-2019), it was agreed that both criteria are useful and should be used. Also, it is not possible to measure the actual flow across the shorelines but the accuracy of the estimates can be imporved with more data collection both off-shore and on shore (water levels, salinity, stratigraphy, geophysics)

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No.	Commenter	Section	Pg.	Comment	GEOSCIENCE Response
5	NCMA TG (Jim Garing)	-	-	Figure 4 indicates a decline of about 10 feet, 1977- 2016 and another 10 feet projected for 2016- 2056. Since the ocean boundary is projected to rise slightly over time because of climate change I infer that the Santa Maria River GWS is, according to Figure 4, projected to have declined 20 feet 1977-2056, 30 feet by 2096 and so on. If the above is true, the whole Santa Maria River Valley GWB would seem to be in overdraft but that was not a conclusion of the adjudication.	Once again, this is just one GHB. See response to Comment 3
1	WSC (Dan Heimel)	-	Cover	Need to remove reference to the RGSP and call project Central Coast Blue in final reports.	Typo in cover was corrected.
2	WSC (Dan Heimel)	-	-	We shoudl talk with the NCMA TG about whether to include SSLOCSD in the title.	We will incorporate any changes into the final report when a decision is reached.
3	WSC (Dan Heimel)	2.2	6	1,080 AFY? I thought we were assuming 1,170 AFY for Baseline NCMA Municipal pumping.	QA/QC revealed a computation error. The average of the last five years is 1,080 AFY
4	WSC (Dan Heimel)	2.4	8	What model was used? Aggregate of 2030 and 2070?	An aggregate was used. This was clarified in the text.
5	WSC (Dan Heimel)	3.1	9	Re deep well indexes: Capitalize or call "well indexes"	Term was capitallized throughout document.
6	WSC (Dan Heimel)	3.2	10	What does underflow from Ocean and from Offshore Aquifers represent? Need to understand and be able to convey to the NCMA TG.	Underflow from Ocean is flow between the Ocean and layer 2. Off-shore aquifers are portions of Paso and Careaga extending in the Ocean. Additional text was added to clarify.
7	WSC (Dan Heimel)	3.4	11	Consider putting all deep well index graphs on the same scale.	Figures were modified.
8	WSC (Dan Heimel)	3.4	12	Do you think there is the potential to increase municipal pumping beyond 4,330 AFY w/o inducing seawater intrusion along the shoreline north of the creek?	Potentially, but it is not possible to tell with certainty until a scenario is run.
9	WSC (Dan Heimel)	3.5	12	Is this the 2030, 2070 or combination of both? Would be helpful to know what impacts (e.g. hotter and wetter) the climate change models are predicting for the region to better understand the modeling results.	Yes, it is a combination of both per DWR guidelines. Though individual scenarios with 2030 and 2070 were run first.
10	WSC (Dan Heimel)	3.6	13	Is this an appropriate statement for this scenario? We are looking a sea level rise not changing precip patterns, correct.	Text was modified.
11	WSC (Dan Heimel)	3.6	13	Do we want to include a statement that higher deep well index levels are likely required to prevent seawater intrusion at higher ocean water levels?	Additional text was added.
12	WSC (Dan Heimel)	3.7	14	Should we say this differently? All municipal wells are at least an estimated one year of travel time away from the injected water in Scenario 2.	Text was revised.
13	WSC (Dan Heimel)	4	16	Re Scenario 6, Table 4-1: Increase in net offshore flux? Average offshore flow shows slight decrease in Figure 40.	Text was modified.
14	WSC (Dan Heimel)	-	Fig 41	IW3 appears to be very close to being less than 1 year away from Pismo Well 23. Hard to tell from the figure. Can you confirm in the model that there is 1 year of travel time between the wells?	Yes, there is a 1 year travel time.
1	TAC Meeting	-	Fig 4	Figure 4 from the scenario runs should be turned into a map showing a few GHB trends and their locations. Similar to the Hydrographs.	Figure was updated.
2	TAC Meeting	3.7	14	Revise the write up on well 23 being within 1 year of travel time of injectate in phase 2 and state that it will have to be moved or phased out.	Text was modified.

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